OCCURRENCES AND IMPACTS OF INVASIVE ALIEN PLANT SPECIES IN THE AGULHAS PLAIN AND LACUSTRINE WETLANDS, WESTERN CAPE, SOUTH AFRICA

GLORIA AFUA APEDO
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SUPERVISORS:
Dr. Ir. C.M.M. Mannaerts
Ir. G.N. Parodi

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THESIS ASSESSMENT BOARD:
Dr. Ir. M.S. Salama (Chair)
Dr. Ir. D.C.M Augustijn, (External Examiner, CTW - University of Twente)
Dr. Ir. C.M.M. Mannaerts
Ir. G.N. Parodi

I dedicate this work to the memory of my late mother who wished to see this day but could not endure long enough to witness it.
May her good soul rest in perfect peace.

ABSTRACT

One important land cover that is being threatened globally are wetlands. The Agulhas coastal plain is located at the Southernmost point (Cape Agulhas) of Africa in the Western Cape province of SA. Due to its biodiversity, it has wetlands considered to be of international importance by the Ramsar convention. There are views that the wetlands are being damaged due to either climate change, land use and land cover (LULC) activities and changes and due to an increase of invasive alien plants (IAPs). The IAPs which were introduced in the late sixties in the area for a wide range of uses (e.g. sand dune fixation), are perceived to have taken over the natural "Fynbos" vegetation which is an important indigenous and unique biome in South Africa. Alien species (e.g. certain Acacia spp.) are also seen as competitors for water resources, and are blamed also for the drying up of the wetlands because of their high evapotranspiration rates. It was postulated that the increase in agricultural activities and the use of fertilizers which runoff into the waterbodies could likewise be a basis for which the invasive plants are thriving or a possible climate change and variations could be a reason, because alien species are also rather drought resistant.

The Support Vector Machine supervised multispectral image classification method (or SVM) was used and tested here to classify the images from different seasons and years in order to perform post classification for change detection analysis.

Field and laboratory analysis of water samples were carried out to determine the concentrations of the mineral and chemical constituents in the water courses and bodies. The results indicated a rather unique Na-Cl hydrochemical signature and water type. This is due to the proximity of the coastal area to the Ocean and the geology in the area.

Linear regression applied to a > 100-year rainfall data series showed a positive slope trend which was concluded as significant since the t-stat of 2.12 was greater than t-critical of 1.98 at 5% level of significance. However, the small positive linear trend in the temperature data records did not test significant; with a t-stat (0.36) < t-critical (2.02). The pattern of the climate (P, T) was found to be a cyclic at multi-decadal time scales. So, persistent years with drier or warmer conditions, seem to be exchanged for sequences of wetter (a/o colder) years. The closest agreement with climate change predictions by other researchers was the reduction in precipitation during the dry season and increase during the wet season.

It was observed from the land cover classification that the areal extent of the waterbodies increased during the wet season. Also a decreasing trend in cultivated land areas was measured from the image classification. This could be explained by the acquisition program of private farmlands by SANParks of the SA Government.

The natural vegetation of the area especially the vegetation class "shrubs" is increasing and this could be attributed to the Working for Water programme. Locations with the occurrences of the alien vegetation were found both upstream (waters with very low EC values) and downstream on the plain in waters with high salinity content, and no relation of aliens spatial distribution with water chemistry was found. In our opinion, the pollen of the IAPs are propagated predominantly by wind and settle (also due to wash off and runoff) in the riparian zones and grow in the drainage network. Regression analysis did not indicate any relation between the IAPs and rainfall even though there was a positive relation between rainfall variation and cultivated land areas. These seasonal trends and agricultural land are however obvious.

The SVM classification method on the 30m Landsat images did not enable us to detect and delineate the IAPs and monitor their spreading. Higher resolution images and more information on the spectral reflectances of the IAPs are recommended for effective detection and monitoring of their spread.

Keywords: Cape Agulhas plain, wetlands, South Africa, invasive alien plants, Remote sensing, land use-land cover change, Support Vector Machine (SVM), climate change

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Last but not the least, sincere thanks goes to my late mother who believed in me and encouraged me to pursue this course despite the difficult times we were in. She saw the beginning but could not see the end. I have come this far because of her prayers, support, advice and encouragement. In my heart, I will always cherish and remember the times we had together. I know you are resting in perfect peace and smiling upon me each day. May you and the angels above watch over me with your watchful eyes each step of my journey in this life.
Mama, I love you. Rest in peace till we meet again.
To all who in diverse ways helped to comfort me in time of sorrow, thought about me and said a prayer for me, may the Lord remember you in your difficult times too.

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LIST OF ACRONYMS

ARC	Agricultural Research Council
ENVI	Exelis Visual Information Solutions
ETM	Enhanced Thematic Mapper
GPS	Global Positioning System
IAPs	Invasive alien plants
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectrometry
Log	Logarithm
LULC	Land use/land cover
Meq/l	Milliequivalent per litre
Mg/l	Milligram per litre
NASA	National Aeronautics and Space Administration
OLI	Operational Land Imager
SAR	Sodium Adsorption Ratio
SAWS	South African Weather Service
SRTM	Shuttle Radar Topography Mission
SVM	Support Vector Machine
TDS	Total Dissolved Solids
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WfW	Working for Water
WGS	World Geodetic System
YSI	Yellow Springs Instruments

LIST OF SYMBOLS

Symbols	Description	Units
Al^{3+}	Aluminium Ion	Mg/l
Ca^{2+}	Calcium Ion	Mg/l
Cl^{-}	Chloride Ion	Mg/l
EC	Electrical Conductivity	μS/cm
F^{-}	Fluoride Ion	Mg/l
Fe^{3+}	Iron Ions	Mg/l
H^{+}	Hydrogen Ion	Mg/l
HCO_3^{-}	Bicarbonate Ion	Mg/l
K^{+}	Potassium Ion	Mg/l
Mg^{2+}	Magnesium Ion	Mg/l
Mn^{2+}	Manganese	Mg/l
Na^{+}	Sodium Ions	Mg/l
NH_4^{+}	Ammonium Ion	Mg/l
NO_3^{-}	Nitrate Ions	Mg/l
pH	Power of Hydrogen	
PO_4^{3-}	Phosphate Ion	Mg/l
SiO_2	Silicate	Mg/l
SO_4^{2-}	Sulphate Ion	Mg/l
TDS	Total Dissolved Solids	Mg/l

1. INTRODUCTION

1.1. Background

Globally, land use and land cover have been identified to be changing fast with space and time. These changes are caused by natural and anthropogenic activities. Natural causes such as climate change are over a long time span, but those from anthropogenic activities have been unprecedented in magnitude, space and time (Turner et al., 1994). Turner found that, even though there has been a general trend for example, in the decreasing of global forest land cover due to an increase in cultivated land, there have been some exceptions. One of such has rather been the expansion of forest land cover in Western Europe and the decline in cultivated lands. This makes the author argue that in monitoring the land use/land cover changes, there has to be an integrated approach of all factors that necessitate these.

A land cover that is fast changing despite its numerous benefits is wetlands. Benefits of wetlands have been identified by the Millennium Ecosystems Assessment (2005) as, but not limited to, purification of water and detoxifying wastes, regulation of climate and mitigation of climate change. Their benefits are both public to a whole community and private to an individual (Sherren & Verstraten, 2012).

Globally, their degradation is moving at a faster rate than other ecosystems. Some causes of this degradation include habitat loss and degradation, invasive alien species, overharvesting and pollution. However, the introduction of invasive alien plants (IAPs) is now considered to be a major cause of local extinction of native freshwater and plant species (Millennium Ecosystems Assessment, 2005).

Even though propagation of these IAPs may have come through a natural process, human action and inactions have exacerbated the rate of their spread and consequently their impacts (Poona, 2005).

The thriving of these species gives an indication that certain favourable conditions in their new environments make it possible for them to outcompete their native counterparts. Conditions such as adaptability to local climate, lack of predators and nutrient rich environments may be some factors (Gao, 2013; Eskelinen & Harrison, 2014). It is common knowledge that a major source of nutrients such as phosphates is the runoff from agricultural farms due to the excessive use of fertilizers.

Some species like the *Australian acacias* are nitrogen-fixers and so are able to increase nitrogen inputs and soil fertility in areas they invade and thus making them propagate at a faster rate than their native species (Chamier et al., 2012). Reasons such as these make it more confusing in deciding ways to eradicate the invasive species. It is therefore prudent to agree with Turner et al., (1994) that deciding to monitor land cover changes such as these need a holistic approach.

Even though some schools of thought have argued out the benefits of the invasive species (Richardson, 2011), their negative impacts have been overwhelming making governments employ all possible ways to eliminate them.

Chamier et al. (2012) confirms that the invasive alien plants (IAPs) are a major environmental problem to tackle. Their high evaporation rates as compared to indigenous species cause them to use more water than the vegetation they replace (Malan & Day, 2002). Their rapid growth which include their higher height, deeper roots and metabolically active cells, compared to the native species (Calder and Dye, 2001) make their potential water reductions 8 times greater (Chamier et al., 2012) .

1.2. Problem Statement

Australian acacias have been identified to be a significant breed of invaders of South African Fynbos areas in the Western Cape. These areas are largely nutrient-poor and as stated earlier, the invasive species spread because of improvement in soil fertility which occurs due to their nitrogen-fixing ability which tends to increase nitrogen inputs.

Also, water quality issues associated with these invasions leave much to be desired. The inhibition of both water flow and diffusion of air into water can be attributed to dense mats of these weeds resulting in lower concentrations of dissolved oxygen. Lower oxygen concentrations, combined with the increased amounts of organic matter can accelerate eutrophication processes (Chamier et al., 2012).

A lot of interventions have been employed to combat the spread and impact of these invasive species especially in the Agulhas plain, South Africa. A national programme like "Working for Water" was established almost some two decades ago to control and reduce their negative impacts (Richardson, 2011).

A number of control methods employed in the project included mechanical and chemical methods, biological control and integrated control (Department of Water and Sanitation, 2014).

Although it has been judged to be successful in some respects especially in the short term, it will be worth it if the success is measured over medium to long-term (Dini, 2004). However, Chamier et al., (2012) asserts that the control operations aimed at reducing the extent of invasive aquatic weed mats have had negative impacts on water quality.

The Agulhas Plain is known for large scale agricultural activities like wheat cultivation and animal husbandry (River Health Programme, 2011). These, some people think are the causes of the spread of the invasive species and thus, the nutrient hypothesis (Gao, 2013). However, the aspect of whether the climate is favouring them than their indigenous species cannot be overlooked. Are these species thriving because the climate is getting drier and the native species are not able to survive? Or are they thriving because the climate is getting wetter and so supporting their propagation?

There is a need therefore to understand their underlying causes in order to stem their negative impacts from there (Richardson, 2011).

1.3. General Objective

To identify impacts of invasive plant species on water quantity and quality of the Agulhas Plain and lacustrine wetlands; to investigate the expansion of the invasion of these species in the riparian areas in relation to land use land cover (LULC) change and climate.

1.3.1. Specific Objectives

- To quantify the land use/land cover (LULC) changes over a period of over seventy years using aerial photos (1938 -..) and satellite images (>1972 onwards) and change detection methods focusing on wetlands, water bodies, agricultural land expansions, invasive species occurrences.

- To verify if invasive species and their spatial distribution can be detected from remote sensing images;
- To analyse the relationship between invasive plant species occurrences and the hydrogeochemistry (including nutrients) of the wetlands and land areas using existing water data, new field survey and laboratory water quality data.

1.4. Research Questions

- What has been the historical trend from 1938 – 2014 in the extent of water bodies, marches, agricultural lands, urban development etc.?
- What has been the historical trend (100 year) in climate (rainfall and temperature) in the area?
- How accurately can we delineate the long term dynamics of the waterbodies (wetlands) from Landsat series of images?
- Can we differentiate IAPs from other vegetation and so monitor and evaluate invasive species eradication programmes from satellite images?
- Are the IAPs occurrences and locations related to agricultural activities (nutrient hypothesis) or changes in hydro climate (local/global) or a combination of the two?

1.5. Structure of the Thesis

The thesis is structured into six major chapters

Chapter 1: This chapter deals with the introduction of the research. This includes the background, research problem, objectives and questions to be answered with the data and methods chosen.

Chapter 2: Literature review related to the subjects of Remote sensing, land cover/ land use change and detection and water quality make up this chapter. Previous works conducted in the study area have also been reviewed in this chapter. It also presents a brief overview of the study area selected for this research describing the climate, vegetation, hydrology, land use and geology of the area.

Chapter 3: This chapter describes the data collection process including both primary and secondary data. That is, water sampling for laboratory analysis and gathering of land use and land cover data.

Chapter 4: Presents the main findings of the study. Results include illustration of the general hydrogeochemistry, calculation of results and analysis using the Aquachem modelling program. Also included are results gotten from the image processing and change detection of LULC changes in the study area.

Chapter 5: After presenting the results from the laboratory analysis, land classification and exploring the climate data, an attempt is made in this chapter to discuss the spatial and temporal distribution of the climate, land cover changes and water quality and their possible interrelations. The discussions in this chapter put this study in the context of other previous researches.

Chapter 6: This last chapter concludes the research by outlining the main issues that emerged and whether there will be a need to improve or continue this research.

2. LITERATURE REVIEW

2.1. Land Cover and Land Use Classification

Land cover has been defined as natural and artificial structures found on the land while, land use has been defined as the activities carried out on the land by humans (Giri, 2012). These two have been inseparable since change in one always affects the other. This makes their distinction very confusing and ground-truthing can be the best way out. Knowledge of both land cover and land use is important to understand processes that relate to managing land and conserving natural habitats.

There is a need to distinctively classify them in order to be able to assess their impacts and also their degradation. Wetlands are changing rapidly as a result of both natural and human induced activities. Digital classification has been identified to be an effective way of monitoring changes occurring in the cover and use of land.

Classification methods that exist have been grouped into broad categories of supervised and unsupervised classifications. Supervised meaning there is control of the process by the human while, unsupervised means the whole process is entirely done without any human interference.

One way to determine how reliable data is, is the quality. Quality may be relative depending on the intended use of the data. However, making it fit for sensitive purposes makes it stand the test of time. One of such ways is the accuracy assessment after classification. A standard method of which has been the use of the confusion matrix.

2.2. Land Cover change detection

Owing to the ripple effects of changes in land cover and land use in an entire ecosystem, there is a need to monitor the changes closely and timely in order to reduce their negative impacts. Some changes can go a long way to affect hydrological processes and thereby, reducing quantity and quality of water available for use. Land cover change detection is for the purpose of identifying the state of the land cover at different times. Over the years, many techniques have been developed to assess these changes; some of which include Change vector analysis, Hybrid change detection, Post-classification comparison, principle component analysis, image ratioing, chi-square, artificial neural networks etc.

Even though Giri (2012) observed that most of these techniques depend on the data available, Alqurashi & Kumar (2013) investigated eleven of these techniques and concluded that the widely used technique is post-classification comparison because it decreases the effects of different sensors and the atmosphere between two dates.

2.3. Remote Sensing

Remote sensing has been identified to be of immense help in the monitoring of land use/land cover changes over decades. With increase in data availability and knowledge, detecting change in objects and phenomena are highly possible. The advantages of remote sensing over the traditional forms of mapping has been the rapid way of getting current data over remote areas and the ability to easily manipulate and analyse. Although freely available, cost of it being high or low can be relative (Giri, 2012).

However, very little has been applied in the Agulhas plain over the years in tackling the menace of the invasive species. Poona (2005) in his paper identified some researches that have been undertaken elsewhere in the world on the use of remote sensing for mapping invasive species and concludes that South Africa must adopt these new strategies if she really wants to effectively and efficiently manage these invasive species. Even though lack of knowledge, skills and data may have been the reason why remote sensing was unexploited in the past, it must not be so now.

Notwithstanding though, more of these researches have focused on using remote sensing to delineate locations, spatial extent, and intensity of the invasion. But more can be done in not only delineating the spatial extents of the invasive species, but also their underlying causes and their relation to other LULC. This is the reason why this research comes in handy in times like this.

Another reason for researches such as this is the integration of wide range of data spanning a period of over seventy years (1938-2014). Most researches carried out on land use/land cover have made use of data over at most three decades. It is understandable since changes in land cover occur gradually and so may be observed at long time scales. However, according Townshend et al. (1991) these changes occur at temporal frequencies from days to millennia and so must be observed frequently in order to understand the onset of certain phenomena that have become problematic (Kayastha et al., 2012). Archived images from 1978 spanning different seasons were downloaded to monitor the different land covers and land uses.

This research sought to do a change detection analysis using aerial photographs from 1938, topographic map of 1997 at a scale of 1:50000 and Landsat images from 1978. The long time-series data available makes this research worth advancing since it sought to monitor changes at the time they began no matter how insignificant they were in order to assess the rate at which they increased.

2.4. Landsat

The Landsat mission has been the longest continuously running program that records the Earth's surface from space.

The detection, monitoring and differentiation of land cover change was the main reason for the launch of the Landsat mission (Giri, 2012). Landsat therefore have moderate spatial resolution enough to capture large man-made objects and to characterize processes such as urban growth, but low temporal resolution (revisit time) of 16 days (NASA, 2014).

The first to be launched was Landsat 1 in July, 1972. It had on board the Return Beam Vidicon (RBV) and the Multispectral scanner (MSS). It lasted till 1978 when it went out of use.

Landsat 2 followed in 1975 with the same instruments on board but was removed from operations in 1982 due to problems associated with yaw control.

Landsat 3 was launched in March, 1978 and had an improved ground resolution of 38m for the RBV with a broad spectral band. It operated till March, 1983.

Landsat 4 which was launched in July, 1982 had the thematic mapper(TM) which had improved spatial and spectral resolutions. This and the MSS were onboard the Landsat 4 until 2001 when it was finally decommissioned. Landsat 5 operated from March, 1984 to December, 2012. It was designed and built at the same time as the Landsat 4 and has been known as the longest operating earth-orbiting satellite. Landsat 6 had an Enhanced Thematic Mapper (ETM) but failed at launch in October, 1993. It had an additional 8th panchromatic band with a spatial resolution of 15m.

Landsat 7, launched in April, 1999 has been described as the most accurately calibrated because measurements are the same when compared to ground measurements. However, its Scan line corrector failed in 2003 and since then, data acquired have had gaps.

Landsat 8 which is the newest addition was launched in February, 2013 and has onboard the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments (NASA, 2014).

2.5. Water Quality

Selecting variables for water quality assessment depends on the purpose of the data and the use of the water. In other words, variables assessed for drinking water are different from that of irrigation, recreation, industry, etc.

For a healthy ecosystem (wetland) to support a lot of aquatic life, temperature, pH, conductivity, major ions, oxygen, suspended solids and the general biodiversity have been identified to be important variables to consider all the time (Chapman, 2002). Sampling these parameters could rather be a daunting task owing to the fact that samples taken should be representative of the study area as much as possible. Interpreting analyses done on water samples could be very sensitive and so the best practices have to be followed to ensure integrity of the data (Hounslow, 1995). Further reliability analysis done also ensures consistency.

2.6. Invasive Alien plants/species (IAPs/Ss)

Invasive alien plants have been defined as plants in a given area introduced deliberately or accidentally from the activities of man. They are said to be naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants and thus have the potential to spread over a considerable area (Richardson et al., 2000).

These IAPs were introduced into South Africa as far back as the seventeenth century for a number of purposes (FAO, 2003). Even though they may have been introduced as ornamentals (Henderson, 2006), for tannin, charcoal, timber and as wind breaks to control erosion of sand into water bodies (Henderson, 2001), their nitrogen fixing ability, drought resistance and other physiological advantages they have over native species make them propagate at faster rates (Crous et al., 2011; Chamier et al., 2012). Their impacts affect water resources due to their high evapotranspiration rates. They occur along many river systems and riparian areas of water bodies (Richardson & Wilgen, 2004).

The Acacias have been identified to be the most dominant (with 13 different species) invasive plants in the Western Cape province of South Africa. The *Acacia mearnsii* (black wattle) is the most abundant and well-known as one of the top ten invaders of the fynbos vegetation in the province (Henderson, 2001).

2.7. Climate Change

The issue of climate change is one that will continuously be discussed for a long time until there is enough understanding of what is really happening in the atmosphere. It has been identified as a major cause of various disasters and land cover changes occurring globally. It has impacted all elements of most ecosystems and hydrology is no exception. Some impacts of climate change have been extreme rainfall events and flooding, droughts, and sea level rise due to high temperatures leading to the melting of glaciers.

Its impact however, may vary from region to region even though comfort of all/some of the elements of the ecosystem may be at risk and wetlands are no exception (Todd et al., 2010). Apart from the fact that they may dry up due to evaporation attributed to high temperatures, both animal and plant species that have their habitation in the wetlands will be threatened.

Some invasive species have been said to establish, grow and increase in populations due to climate change. Some of which have been said to be drought tolerant and have faster growth rates (Crous et al., 2011). On the contrary, if the highest amounts of rates of climate change being projected are anything to go by, it is predicted that native species will not be able to move fast enough to track suitable environments and thus affect their survival rates, consequence of which will be their extinction (Settele et al., 2014).

2.8. Previous Work Done

Owing to the fact that the Agulhas plain inhabits two of the wetlands of importance according to the Ramsar Convention, a lot of researches have been done in different aspects and some are still ongoing.

A review of previous work done in the area have indicated the saline nature of the water bodies due to its proximity to the sea and the presence of the old table mountains.
The River Health Programme gives annual reports on the state of major rivers including those in the Agulhas plain.
Gordon (2012) focused on the limnology of the Soetendalsvlei wetlands and established from the results that the Vlei has become freshwater dominated.

Zenni et al. (2009) evaluated the invasiveness of the alien plants and concluded that dedicated and frequent follow ups are necessary to monitor their propagation.

Four main disturbances were identified by Jones et al. (2000) in their research and it included that of Agricultural activities and the invasion of alien plants.

2.9. Study Area

The Agulhas plain covers a total area of about 2160 km^2 (Rouget & Richardson, 2009). It is located at the southernmost tip of the Western Cape Province and the country of South Africa as a whole. It lies between longitudes 19°16'E and 20°14'E and latitudes 34°22'S and 34°49'S. Figure 2-1 shows the location of the study area in relation to South Africa.

The Plain has a very rich biodiversity because of its vegetation and the large numbers of different species of birds present. This is encouraging authorities to preserve the plain as much as possible. Shrubs, farmlands, wetlands and rivers form the main land cover of the plain. Built-up areas are a minute part of the land cover. It can therefore be said to be largely natural (River Health Programme, 2011).

The main activities carried out in this area are wheat cultivation and animal husbandry (River Health Programme, 2011).

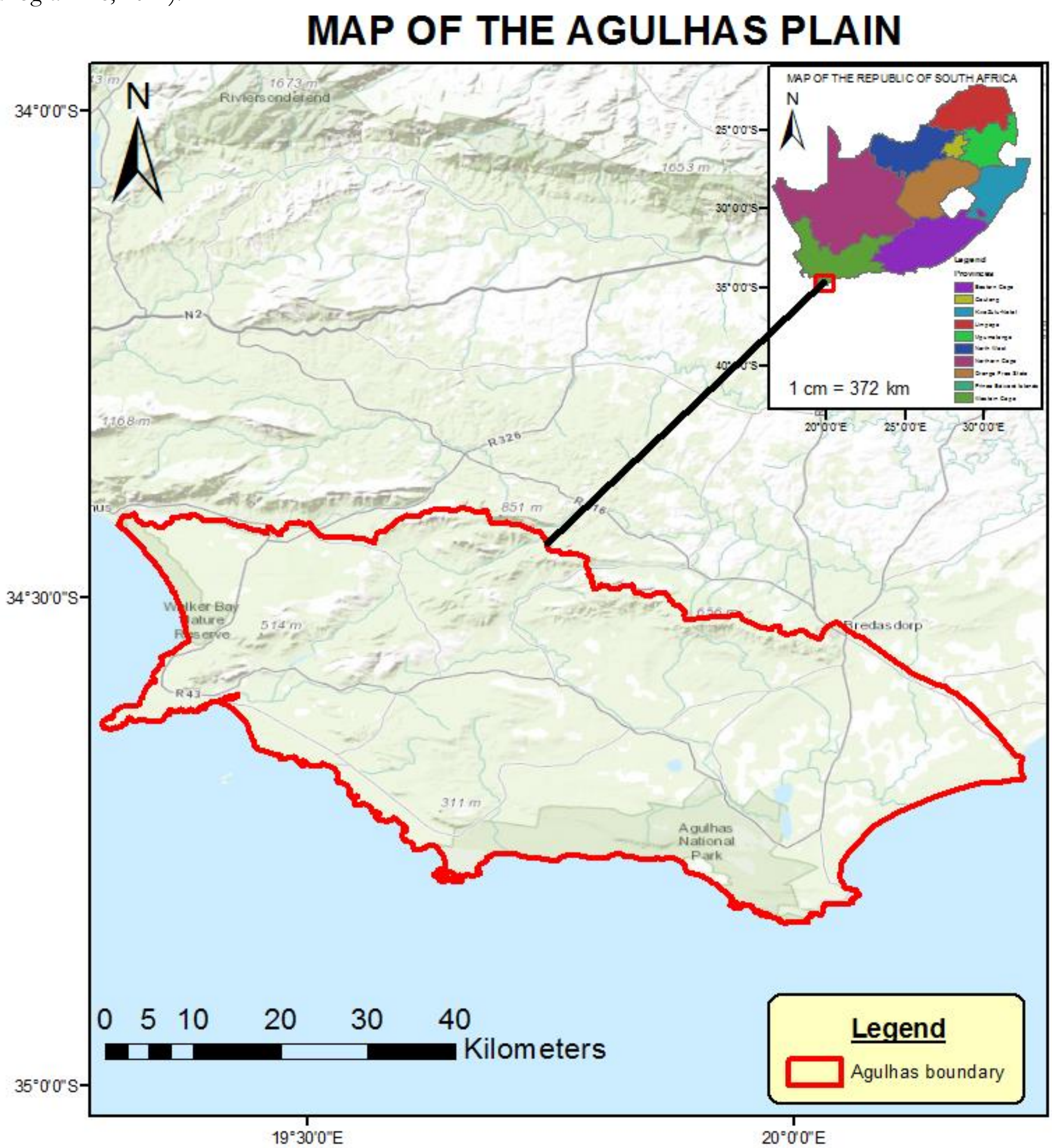

Figure 2-1: Map of the study area on basemap from ArcGIS.

2.9.1. Climate

The climate may be generally described as that akin to the Mediterranean making it have hot dry summers and cold wet winters (Kraaij et al., 2009). The month of January comes with average maximum temperatures of about 28^{o}C and that of minimum temperatures are usually around July and August of about 8^{o}C. Rainfall in winter is between April and late August. Rainfall amounts between 445mm and 540mm per annum have been frequently observed even though relatively low annual rainfall of 350mm has also been recorded over the years (Hoekstra & Waller, 2014).

2.9.2. Topography and Geology

The topography of the area is generally described as low-lying having elevations between 0-500m above m.s.l. as depicted by the SRTM image in Figure 2-2 (River Health Programme, 2011). The main geology is limestone although shales have been identified to be present too. The geology in the area is rather very variable and not that simple to describe. A report by Cleaver & Brown (2005) tried to summarise it in a map shown in Appendix A.

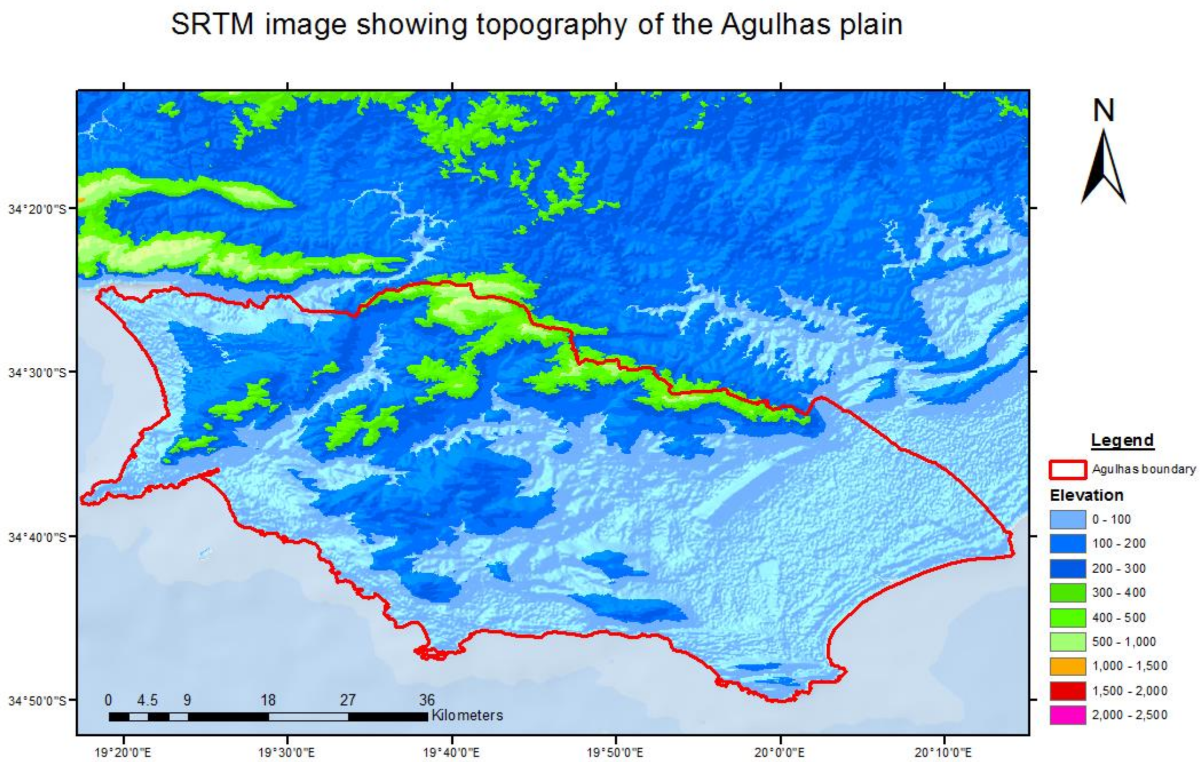

Figure 2-2: Map showing topography of the plain from SRTM image

2.9.3. Vegetation

The plain is largely natural with vegetation such as grass and shrubs. The fynbos vegetation (Limestone and Sand plain) are however very dominant and adds to the bio diversified nature of the plain. Additionally, South/South-West Coast Renosterveld, and Dune Thicket have been identified as being present in the Agulhas plain. The presence of the invasive alien plants (Acacias) nonetheless cannot be overlooked since it forms the core of this research.

2.9.4. Hydrology

The study area is located in the Heuningnes catchment which is a sub-catchment of the bigger Overberg East catchment that stretches from the Nuwejaars River at Elim in the west to the Breede River. Slower flowing, more turbid and saline rivers on the Agulhas Plain are associated with a number of inland water bodies and wetlands (River Health Programme, 2011). The Nuwejaars River flows into Soetendalsvlei, overflow of which creates a confluence with the Kars River. The Soetendalsvlei which has a maximum depth of about 3m is one of the largest freshwater lakes in South Africa (approximately 7.5 km long and 3km wide) and can be found in this plain. It supports the largest numbers of water birds on the Agulhas Plain (Hoekstra & Waller, 2014).

2.10. Data Set

Topographical maps of 1997 and aerial photographs of 1938 and 1962 were obtained from the National Geo-spatial information of South Africa. Rainfall data from 1909 were obtained from a private farmer and that of temperature from 1973 were gotten from the SAWS made available on the webpage of the ARC.
A quick look of Landsat images used in this research are shown in Figure 2-3 while the climate data is presented in Appendix F.
Water quality data obtained cannot be said to contain all the parameters of interest since the objectives of the previous researches done were different from that of this study. However, parameters such as EC, pH and dissolved oxygen were common in all the researches. Moreover, although sampling was done in the study area by previous researchers, sampling locations could not be said to be the same since this study focused more on where the occurrences of the invasive alien plants are. Previous studies were not particularly interested in whether there were occurrences of the alien vegetation or not. A summary of available data is given in Table 2-1 for ease of reference.

Data	Year	Bands	Spatial Resolution	Temporal Resolution
Landsat MSS	1972 – 1994	4 bands(0.50-1.1μm)	79m	18 days
Landsat TM	1982 – 2012	1-5, 7 (0.45-2.35μm) 6 (10.4-12.5μm)	30m 120m	16 days
Landsat ETM+	1999 -	1-5, 7 (0.45-2.35μm) 6 (10.4-12.5μm) Panchromatic (0.52-0.9μm)	30m 150m 15m	16 days
Landsat OLI & TIRS	2013 -	1-6, 7(0.435-2.294 μm) 8, Panchromatic(0.50-0.67 μm) 10,11(10.6-12.51μm) Source: All Landsat images from NASA, USGS, http://glovis.usgs.gov/	30m 15m 100m	16 days
Topographical Map	1997		1:50000	
Aerial Photos	1938, 1960 etc.		1:25000, 1:36000	
Meteorological data	From 1909	Sources: -Private farmer -South African Weather Service (SAWS)		
Water quality data	1989, 2000, 2007, 2014	Sources: -Taken from literature & fieldwork		

Table 2-1: Summary of data available

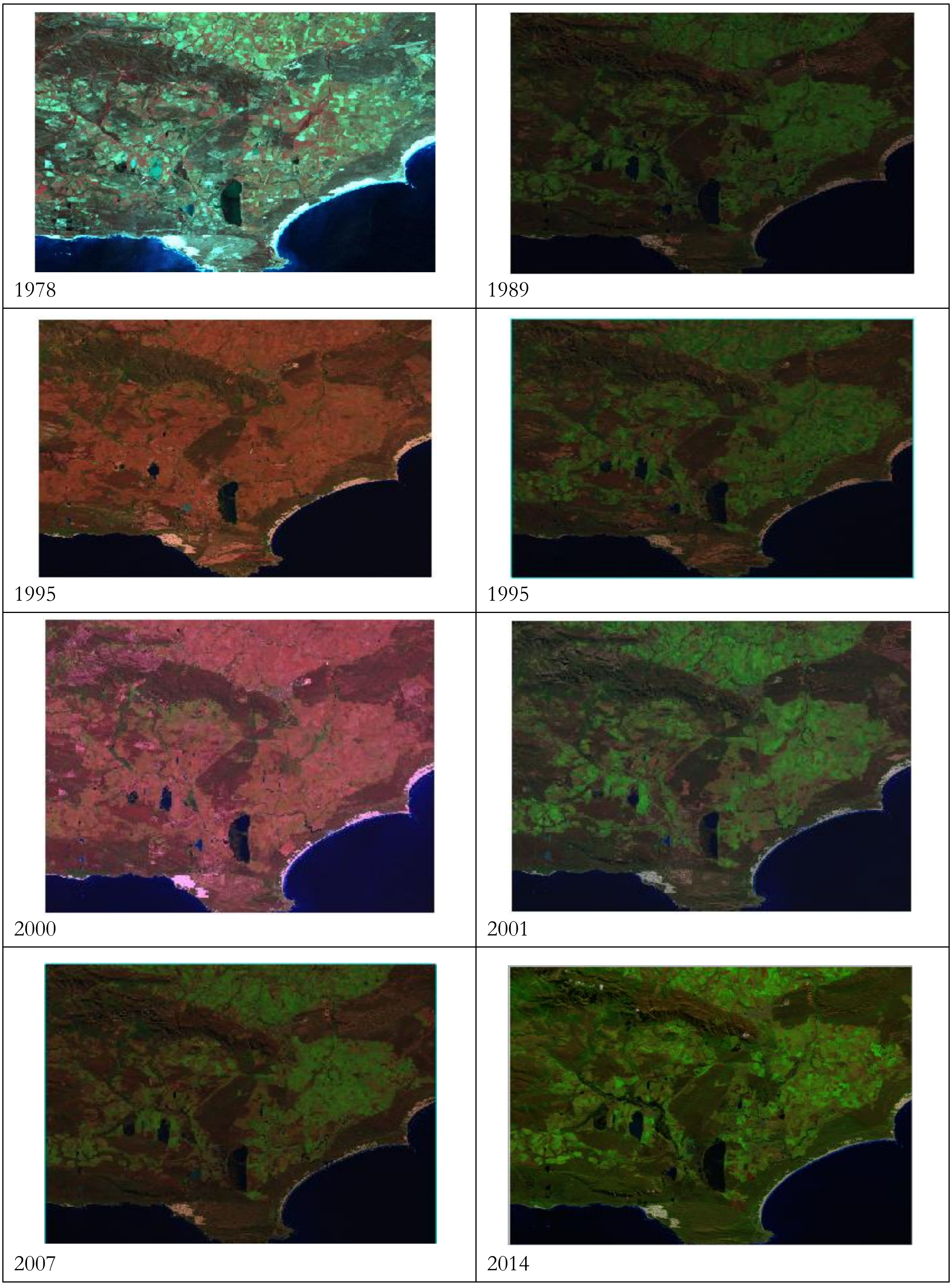

Figure 2-3: A quick look at some Landsat images over the years in different seasons

3. MATERIALS AND METHODS

Below is Figure 3-1 which gives a general overview of the workflow and data to achieve the objectives of this research.

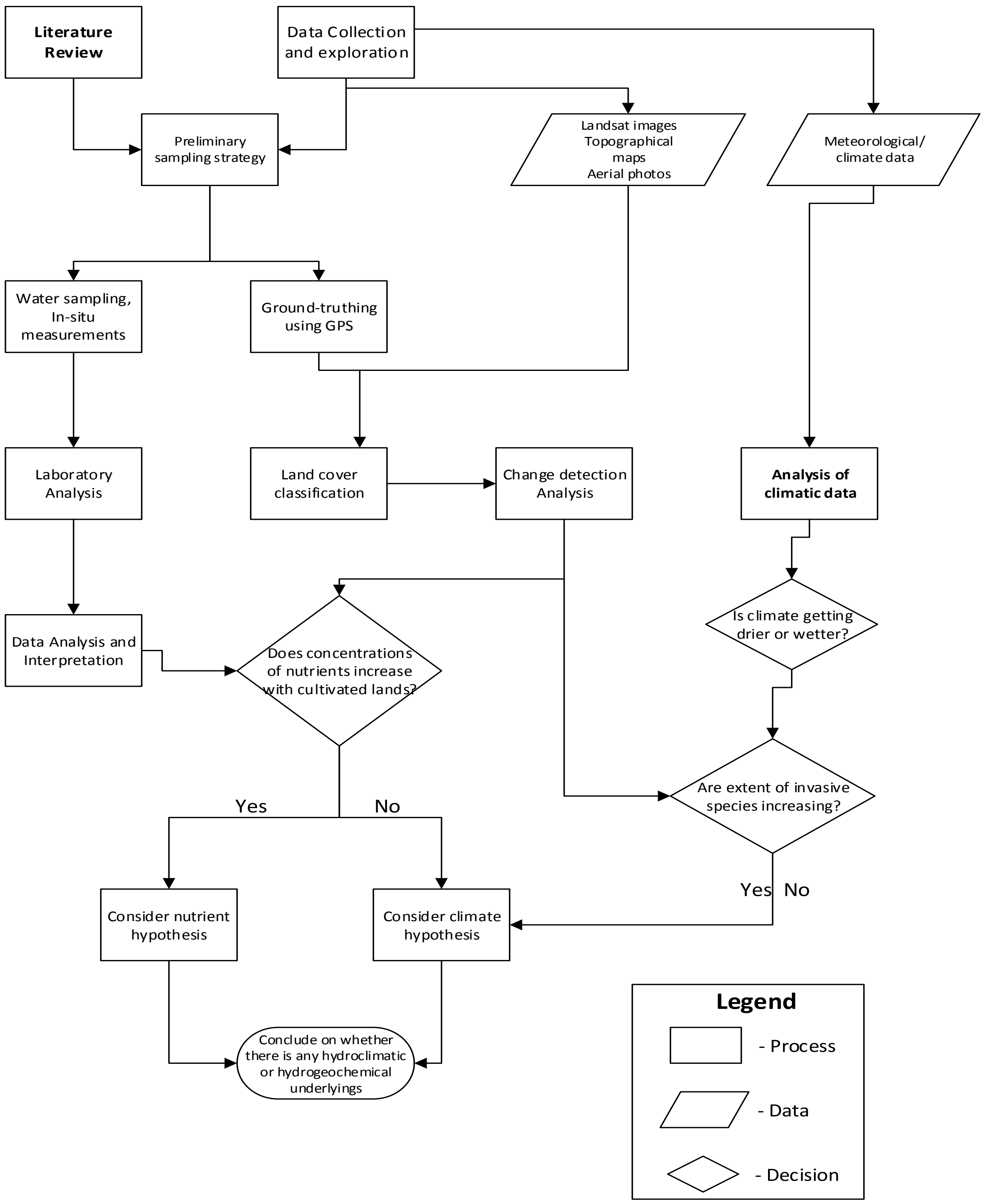

Figure 3-1: Flow chart summarising methodology

3.1.1. Sampling plan

The sampling plan adopted in this research was a judgmental one based on experience and previous knowledge of the study area. This was due to the objective of this research to identify the occurrences of the invasive alien species especially along the riparian areas and other water bodies. Owing to the variability in the geology of the area, the sampling plan was chosen to help capture that variability as much as possible and to avoid redundancies.

A total of 16 locations were sampled, some of which had the occurrences of the invasive plants around them. The sampling locations are shown in Figure 3-2. The field work involved in-situ measurements and sample collection. The parameters measured in-situ were Temperature in degrees celsius, pH, electrical conductivity in µS/cm and dissolved oxygen in mg/l. The HACH multiprobe (HQ40d) was used for these measurements. The samples were then preserved with nitric acid and sent to the ITC Geoscience laboratory for further analysis.

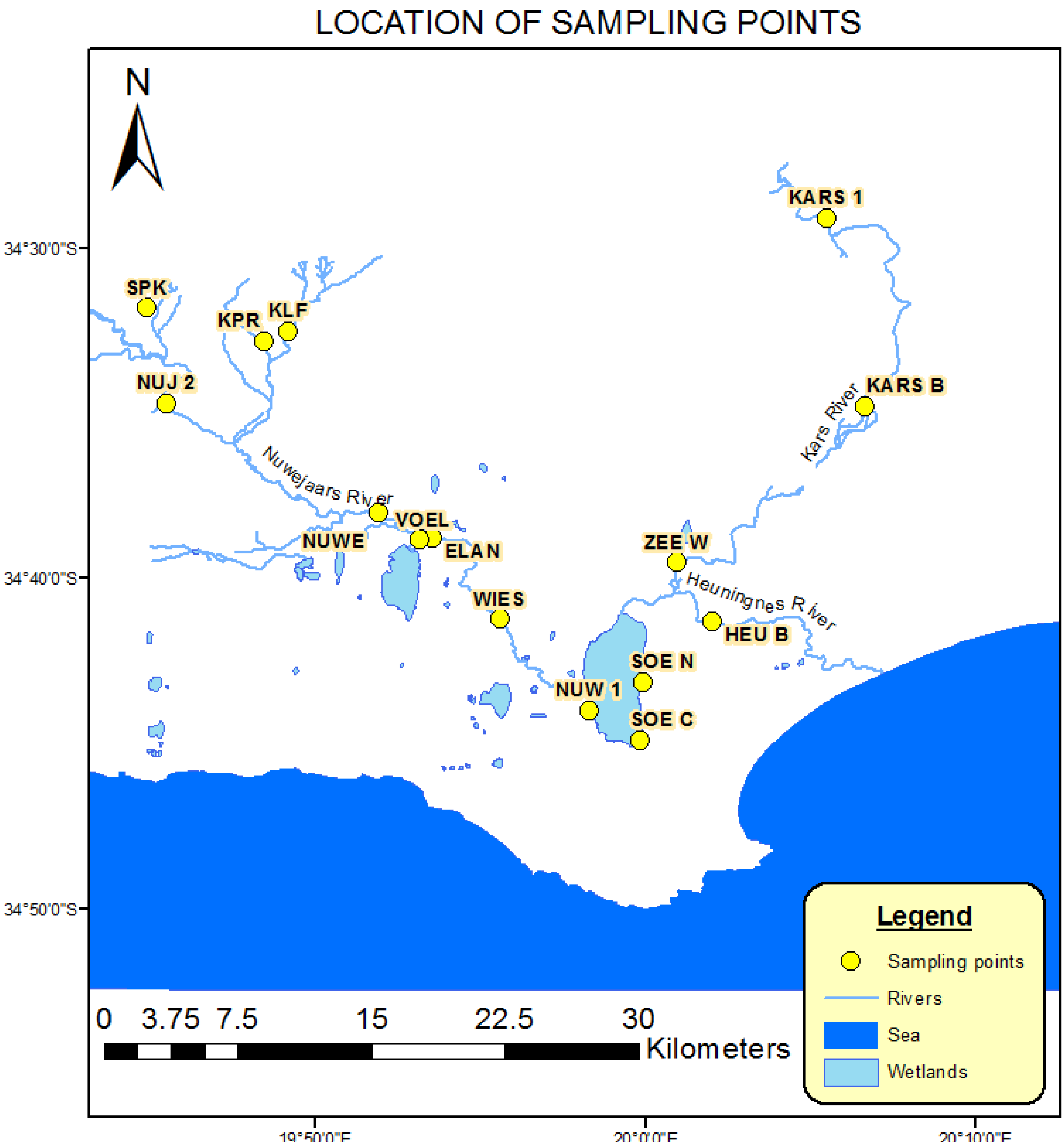

Figure 3-2: Map showing location of sampling points

3.1.2. Laboratory Analysis

Generally, the Standard Method procedures were followed for analysis (APHA, 1999). The major cations were analysed with the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) while the anions, chloride and sulphate were analysed with the HACH spectrometry. Ammonia and phosphates were analysed using the SEAL AQ-1 Discrete Multi-Chemistry Analyzer which uses the principle of discrete analysis where each test occurs in a separate discrete reaction vessel. It ensures lowest detection limits and good reproducibility.

The constituents were measured in mg/l.

To ensure quality control and assessment of laboratory analysis techniques, sample containers and reagents using blank samples, duplicates and standard solutions were checked.

3.1.3. Reliability Analysis determination

With the aid of the Aquachem software, the reliability of the analysis done on the samples were determined.

Aquachem Analysis

The Aquachem analysis was applied to three general approaches which include anion-cation balance, Conductivity/sum meq cations and ratios of the following;

$K^+/Na^+ + K^+$

$Mg^{2+}/Ca^{2+} + Mg^{2+}$

$Ca^{2+}/Ca^{2+} + SO_4^{2-}$

$Na+/Na^+ + Cl^-$

Details of the results are in Chapter 4.

Anion-Cation balance

This reliability check is necessary because it is required that the sample solution must be electrically neutral. Therefore, the sum of the cations in meq/l must be equal to that of the anions in meq/l. the charge balance is then expressed as a percentage.

Balance = $(\sum\text{Cations} - \sum\text{Anions})/ (\sum\text{Cations} + \sum\text{Anions})*100$

For freshwater, the balance is assumed to be good if it is ±10% (Clesceri et al., 1999)

In cases where the balance is greater than ±10%, the results could still be accepted on the basis of one or more of the following assumptions;

- The analysis was poorly done
- Other water constituents present in the samples were not used in the calculation
- The water is very acidic and the H+ ions were not used
- Organic ions were present in significant quantities which are often indicated by coloured water

Ionic Ratios

This approach of determining the accuracy of an analysis by observing unusual ionic ratios is to bring potential inconsistencies to the attention of the investigator. It is rather to be expected in case there are exceptions to these generalizations. It may not mean that one has to discard those result in further analyses (Hounslow, 1995).

Interpretation of Water types and source rock reduction

In order to gain an insight into the origin of the samples and category of water they fall into, piper plots included in the functionality of Aquachem was used. The software also deduced the source rock from the constituents. The results are as presented in chapter 4.

3.2. Image Processing

Landsat Images were used in this research to identify the land use/land cover changes in the Agulhas plain over a 36 year period from 1978-2014. The images were selected based on the availability of water quality data for those years. From literature review, data were gotten for the years 1989, 2000 and 2007; that of 2014 was gotten from fieldwork embarked upon in September. Additionally, images from the dry season of the years 1990, 1995 and 2000 were included in order to observe seasonal changes. The images were selected from both seasons of the year. For the years that did not have cloud free images for a particular season, an image from either the preceding or succeeding year (±1 year) was chosen for the analysis for that season. This was done so as to achieve one of the objectives of this research which was to identify whether the extents of cultivated lands were increasing. This could only be done in the wet season, which was the farming season. The images were cloud free as much as possible in order to obtain much information from them.

All the images obtained had been georeferenced and so did not need much georeferencing operations. The metadata file downloaded from the USGS website was very comprehensive. They had been projected onto the UTM projection, WGS 1984 datum and zone 34S. Although cloud free images were selected as much as possible, those that had some amounts of clouds like the 2014 image were atmospherically corrected using the Dark object subtraction (DOS) algorithm in ENVI 5.1 software.

The DOS is a method which assumes that the darkest parts or very low reflectance values of an image such as clear water in the near-infrared part of the electromagnetic spectrum should be black if not for the effects of atmospheric scattering and absorption. This approach although the simplest method so far, is the most widely used. It assumes that there is a horizontally homogeneous atmosphere in the image (Song et al., 2000; Goslee, 2014).

The 1978 image which had been originally resampled to 60m was again resampled using the 1989 image of 30m resolution.

Below is Table 3.1 showing the acquisition dates, sensor, path/row and resolution of the images used.

Path/Row	Acquisition data	Sensor	Spatial Resolution(m)
186/84	19/09/1978	MSS	79
174/84	03/08/1989	TM	30
174/84	27/02/1990	TM	30
174/84	09/02/1995	TM	30
174/84	05/09/1995	TM	30
174/84	05/08/2007	TM	30
174/84	28/10/2000	ETM+	30
174/84	12/08/2001	ETM+	30
174/84	07/07/2014	OLI/TIRS	30

Table 3-1: Landsat data for the analysis of land cover changes

3.3. Land cover mapping

3.3.1. Land cover classes

Seven different land cover classes were identified after ground truthing in the plain. They are described as follows:

Class	Description
Bare land	Areas that have been ploughed and lying fallow. Also includes cleared land with traces of shrubs.
Cultivated land	Areas for both annual and perennial crop cultivation. This included fields of wheat, grass and other cereals grown in the plain.
Shrubs	Natural vegetation of the area found on the hills and anywhere which is not used for agricultural purposes. They are made up of small trees and bushes mixed with some grasses.
Alien vegetation	Areas identified to be dominant with the invasive alien plant species specifically the *Acacia mearnsii*.
Waterbody	This includes all areas of open water and marshes like wetlands, ponds and rivers.
Sand dune	A hill or gathering of sand built by wind or water flow, estuaries are also included.
Residential	Areas covered by buildings, paved roads and other man-made structures.

3.3.2. Image classification

The ability to effectively classify land cover types, separating into sets of spectral signatures to represent what exists on the ground is very important in remote sensing. The supervised image classification was used to separate the various land cover classes.
Ground control points collected in the field were used as training set for the supervised classification. Additional information were gathered from field observation, interviews with local people, topographic maps and google earth.
The classification was done by assigning pixels to land cover classes they belonged to in the training set, also called regions of interest in ENVI. Even though the maximum likelihood classification is the method most widely used, the accuracies were not as good as the support vector machine method. This confirms what Giri (2012) intimated that the data available will determine the best method to employ.

The supervised classification method, Support Vector Machine (SVM) is derived from statistical learning theory that often yields good classification results from complex and noisy data. Although this method was developed over five decades ago, much attention has not been given it. It has been proven to perform significantly better than other competing methods used over the years (Burges, 1998; Weston, 2011) and also gave better results in this study. Comparative analyses by Szuster et al. (2011), Devadas et al. (2012) and Moughal (2013) of the classification methods available showed that the SVM gave higher overall classification accuracies (around 90%) than the widely used maximum likelihood method.

The algorithm used separates the classes with a decision surface that maximizes the margin between the classes. The surface is called the optimal hyperplane, and the data points closest to the hyperplane are called support vectors as seen in Figure 3-3. The support vectors are the critical elements of the training set (Sarp, Erener, Duzgun, & Sahin, 2014).

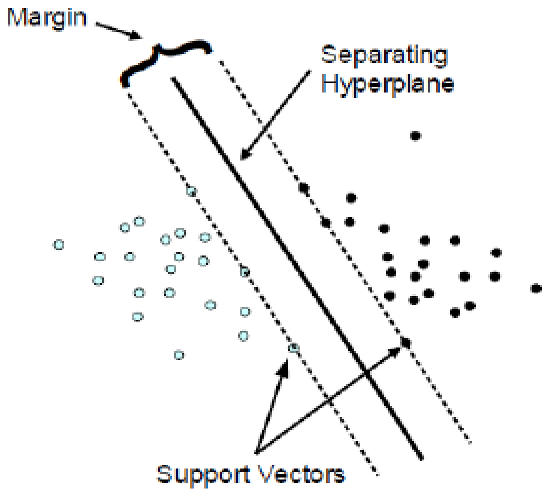

Figure 3-3: An illustration of the SVM algorithm adapted from Devadas et al., 2012

Even though the maximum likelihood method which is widely used and the SVM both use separating planes, the maximum likelihood may make use of a separating plane which may not likely be the best. The SVM gets the best separating hyperplane (http://www.quora.com/Support-Vector-Machines).
The optimum hyperplane is determined using a training dataset and its generalization ability is verified using a validation dataset (Devadas, Denham, Pringle et al., 2012). SVM makes use of kernel functions for the purpose of mapping non-linear data into a higher dimensional space for the generation of the separating hyperplane. A mapping function Φ with input data represented as Φ(x) is utilized in a space of *n* dimensions as in Equation 1 below (Szuster et al., 2011).

$$K(x_i, x_j) = \Phi(x_i) \times \Phi(x_j) \quad \text{…………………… Equation 1}$$

There are four main kernel types available in ENVI 5.1 and depending on the type chosen, parameters will have to be set for the kernel. The kernel types are Linear, Radial basis function, Polynomial and Sigmoid (ENVI, 2013). It is important to note that selecting a kernel type and setting its parameters tends to influence the classification's speed and accuracy (Szuster et al., 2011). For this study, the polynomial kernel with default parameters given by the software gave the best results.

3.3.3. Accuracy Assessment of image classification

Accuracy assessment is a cardinal step in the image classification process. It is to determine how effectively pixels have been grouped into the classes under investigation. One way of doing that is the use of the confusion matrix. The confusion matrix generated from the classified image and the field data was used for accuracy assessment.
The overall accuracy is evaluated as the total number of correctly classified pixels (diagonal elements) divided by the total number of ground truth pixels. User's accuracy and producer's accuracy measured the correctness of each category with respect to errors of commission and omission (non-diagonal elements). The user's accuracy is defined as the probability that a pixel classified on the map represents that class on the ground (Lillesand et al., 2008).
The kappa/khat, *k* statistic was used to determine the extent to which the percentage correct values of the confusion matrix are due to true agreement versus chance agreement. It ranges between 0 and 1, with 1

being best result (complete agreement) and 0 being worst result (no agreement). Negative values may indicate very poor classification performance and agreement worse than classification by chance.

Generally, it is computed as;

$$k = \frac{P(o) - P(c)}{1 - P(c)} \quad \text{…………………… Equation 2}$$

Where: *P (o)* = proportion of observed agreements

P(c) = proportion of agreements expected by chance

3.4. Climate data exploration

Rainfall and temperature data for the area made available from the South African Weather Service (since 1973) and accessed through the Agricultural Research Council (ARC) Agromet web databank together with data from a private farmer (since 1909) were explored to identify the trend (100 year) in the climate. Simple statistical analysis was done in R to check how normally distributed the data is. In addition, analyses such as average, total, minimum and maximum values were applied to the data using Microsoft excel and R. Details of the statistical analysis are presented in Chapter 4.

4. RESULTS

4.1. Water Quality Analysis

With one objective of this research being to analyse the historical trend of chemical compositions, results from instruments used for previous sampling have to be reconciled with that used during fieldwork of this research. Generally, the common instrument used by previous researchers for sampling in the area was the multiprobe from Yellow Springs Instruments (YSI). EC values were estimated from TDS measurements gotten from the YSI by dividing the TDS by a factor of 0.65 (Hounslow, 1995). A plot of the estimations from the YSI against the HACH gave a coefficient of determination (R^2) of 0.99. Differences between the measurements from the two instruments were in ranges between 1 and 16%, with more than half of the difference around 4%. The plots are presented in Appendix D. This check was necessary in order not to underestimate or overestimate the concentrations of constituents being measured, in that case, analysis done will not be flawed. Also, pH and dissolved oxygen results from both instruments were comparable.

4.2. Reliability Analysis

The results of the constituents from the 16 samples were subjected to reliability analysis as explained previously in Chapter 3.1.3. Table 4-1 presents the results of the reliability tests carried out.

No.	Reliability check	Acceptance value	Number of samples passed	Percentage passed (%)
1	Anion-Cation Balance	$0.55 \leq x \leq 0.75$	16	100
2	Measured TDS - Measured EC	$0.55 \leq x \leq 0.75$	16	100
3	Measured TDS - Calculated EC	$1.0 \leq x \leq 1.2$	10	62.5
4	Calculated TDS - Measured EC	$0.55 \leq x \leq 0.75$	3	18.75
5	Measured EC - Ion sums	$0.9 \leq x \leq 1.1$	Cations = 9 Anions= 8	Cations = 56 Anions= 50
6	Measured EC - Calculated EC	$0.9 \leq x \leq 1.1$	3	18.75
7	$K^+/Na^+ + K^+$	< 20%	16	100
8	$Mg^{2+}/Ca^{2+}+Mg^{2+}$	< 40%	0	0
9	$Ca^{2+}/Ca^{2+} + SO_4^{2-}$	> 50%	11	68.75
10	$Na^+/Na^+ + Cl^-$	> 50%	7	43.75

Table 4-1: Summary of reliability checks applied to water samples

All samples passed the $K^+/Na^+ + K^+$ test which means Na^+ was in large quantities than the K^+.

The samples failed the $Mg^{2+}/Ca^{2+}+Mg^{2+}$ test because the concentrations of Mg^{2+} were more than that of the Ca^{2+}.

Five (5) of the samples failed the $Ca^{2+}/Ca^{2+} + SO_4^{2-}$ test, meaning that SO_4^{2-} was more than the Ca^{2+}. The samples were VOEL, ZEE W, HEU B, KARS 1 and KARS B.

Nine (9) samples failed the $Na^+/Na^+ + Cl^-$ test indicating that Cl^- was more than that of the Na^+.

For the samples that failed some of the reliability tests, they were accepted based on one or more of the following assumptions stated earlier which are;

- The analysis was poorly done
- Other water constituents present in the samples were not used in the calculation
- The water is very acidic and the H+ ions were not used
- Organic ions were present in significant quantities which are often indicated by coloured water

Details of results are presented in Appendix C.

4.3. Water Types

Piper plots in Aquachem showed two main water types, Na-Cl and Na-Mg-Cl (See Figure 4-1). Fourteen of the samples were of the type Na-Cl and two of them were Na-Mg-Cl as shown in Table 4-2. An interpretation of this plot as given by Hounslow (1995) describe waters lying on that side of the diamond as saline and typical of marine and deep ancient ground waters.

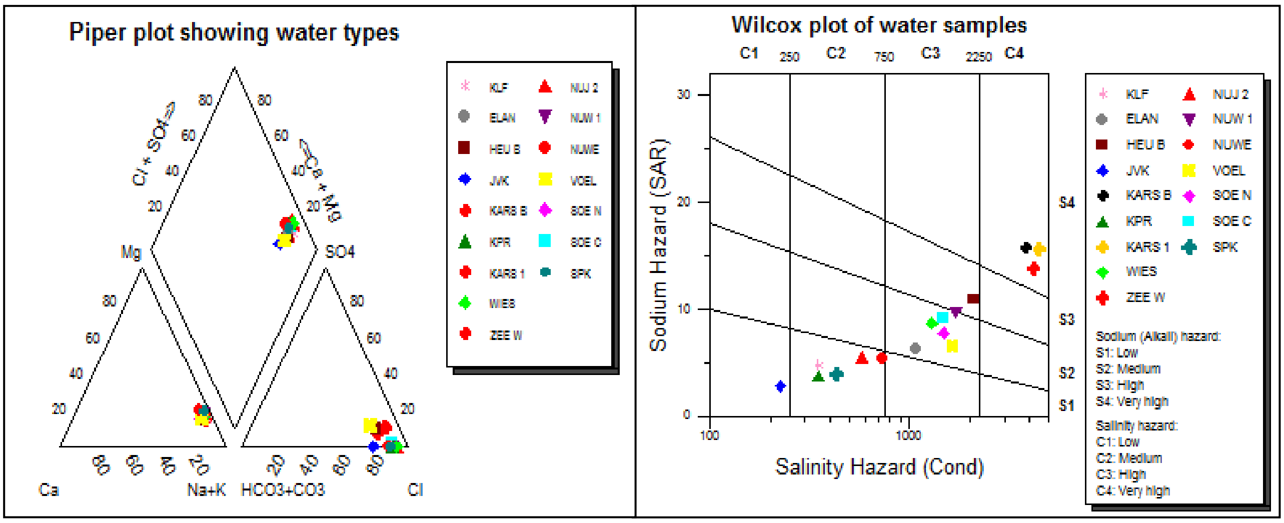

Figure 4-1: Piper and Wilcox plots summarising the water types in the area

The Wilcox plot above shows the gradual salinity and sodicity increase from the mountain towards the sea.

The plot shows the KARS 1, KARS B and ZEE W as having very high salinity and very high sodium-adsorption-ratio (SAR). Seven of the samples had medium-high SAR and high salinity hazard. Samples from rivers which had the occurrences of the IAPs rather had low SAR and low-medium salinity hazard. The low electrical conductivities of JVK, KPR, KLF, NUWE and NUJ 2 also reflected in the low levels of phosphates, nitrates and other constituents.

The Stiff plots in Figure 4-2 showed the dominant constituents of water bodies in the area as Na^+ and Cl^-, followed by Mg^{2+} and HCO_3^- , SO_4^{2-} and Ca^{2+}.

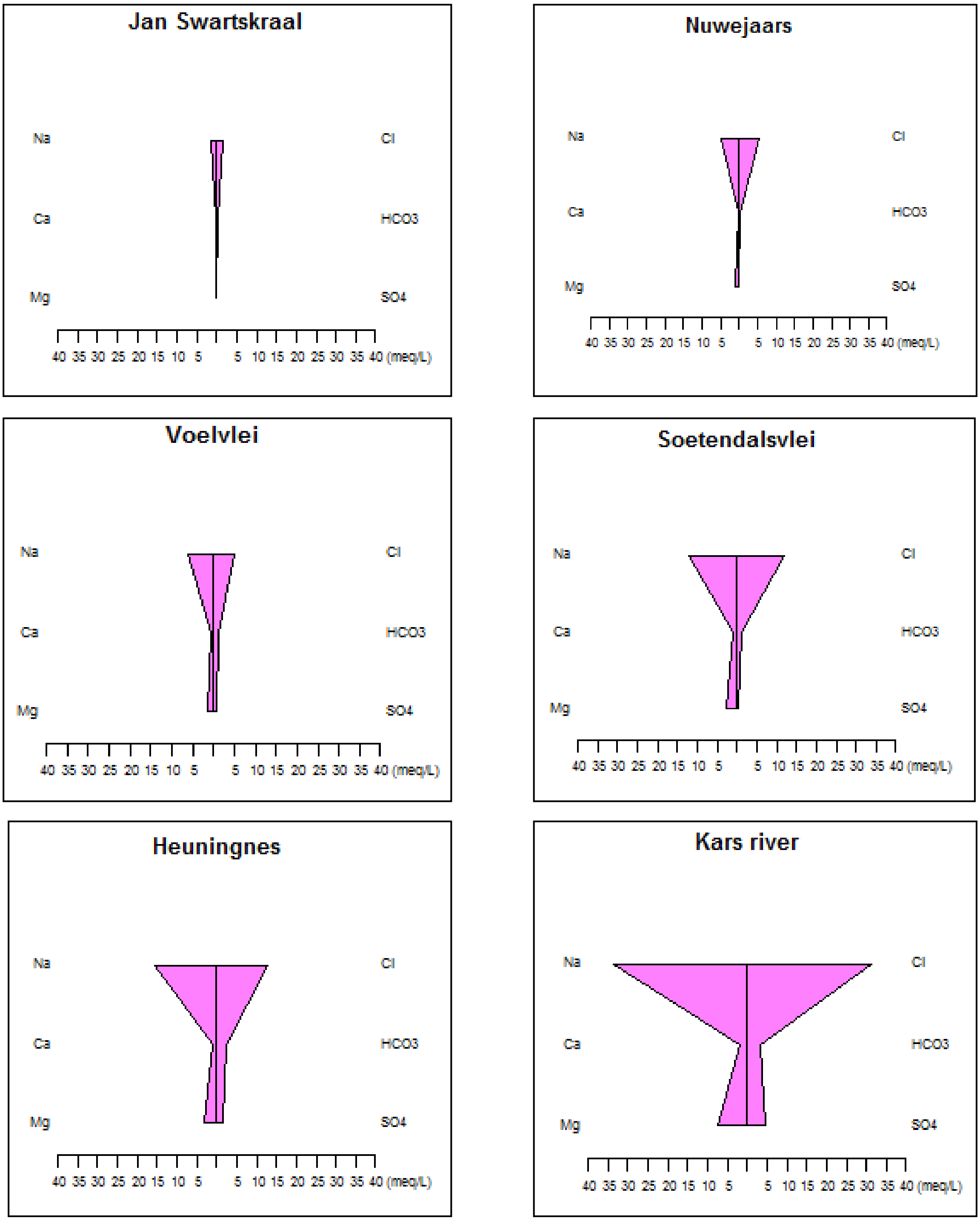

Figure 4-2: Stiff plots showing dominant constituents of six of the samples

	Water type	No. of samples	Percentage water type
1.	Na-Cl	14	87%
2.	Na-Mg-Cl	2	12%

Table 4-2: Summary of the water types

4.4. Land cover classification

4.4.1. Accuracy assessment

In order to assess the accuracy of the classified image, an error (confusion) matrix was constructed using ground truth data which was different from that used in the training set for the classification. Owing to the fact that the ground truth data was collected in the year 2014, the accuracy assessment was done for the 2014 image only. The error matrix is as given below in Table 4-3. In all, a total of 74 ground control points were used to validate the classified image.

The user's accuracy, producer's accuracy, and the kappa statistic making up the overall accuracy, were derived from the error matrix. The overall accuracy was 92.75% giving a kappa coefficient of 0.87. The value of the kappa coefficient indicates that there is 87% better accuracy than if the classification was produced from an unsupervised one, instead of the support vector machine method used in this case. It was calculated from the result of the land cover classification, with seven classes as shown in the error matrix below.

Monserud & Leemans, 1992 intimated kappa values < 0.4 as poor agreement, 0.4 - 0.55 as fair, 0.55 - 0.70 as good, 0.70 – 0.85 as very good and >0.85 as excellent. It can therefore be said that classification for this research indicates an excellent agreement.

Producer's accuracy for five of the classes were between 80 – 100% except for the alien vegetation and the bare land. This shows that the method used in this research and the satellite data for the land cover classification allowed for the identification of the majority of reference points as belonging to one of the selected classes.

The locations of the ground control points used for the classification are shown in Appendix I.

Overall Accuracy = 92.75%
Kappa coefficient = 0.87

	Ground Truth (Pixels)							
Classes	**Alien Vegetation**	**Bare land**	**Cultivated land**	**Residential**	**Sand dune**	**Shrubs**	**Waterbody**	**User's Accuracy (%)**
Alien vegetation	25	0	0	0	0	10	0	71.4
Bare land	0	1164	1	6	0	0	0	99.4
Cultivated land	0	0	2130	0	0	0	0	100
Residential	0	1	0	70	0	0	0	98.6
Sand dune	0	0	0	0	105	0	0	100
Shrubs	149	0	4	2	0	12981	36	98.5
Waterbody	0	1881	0	0	0	3120	50229	90.9
Producer's Accuracy (%)	**14.4**	**38.2**	**99.8**	**89.7**	**100**	**80.6**	**99.9**	

Table 4-3: Confusion matrix of land cover classification for July, 2014

4.5. Land cover map

The land cover map for August, 1989 showed about 57% shrubs, 3.8% bare land, 27.45% cultivated land, 6.15% water bodies, about 1.07% sand dune and 2.5% making up residential. That of July, 2014 showed 63% shrubs, 9% bare land, 17% cultivated land, 5.3% water bodies, about 0.69% sand dune and about 1.8% making up residential as seen in the graphs presented in Figure 4-3.

From the classification results, it was observed that there were increases in some land covers as well as decreases over the period, which is from 1989. However, these changes cannot be said to be regular or constant as can be seen from Figure 4-3 due to reasons such as interventions that were rolled out in the years to preserve the biodiversity of the Agulhas plain especially concerning that of the IAPs.

Figures 4-4 and 4-5 present classified images of the area in both dry and wet seasons over a 36 –year period.

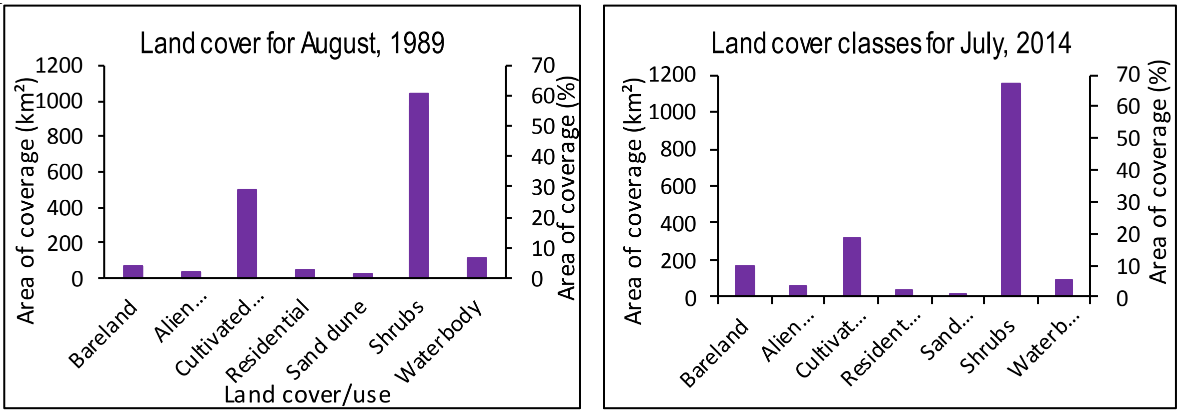

Figure 4-3: Graphs showing land cover classes in 1989 and 2014

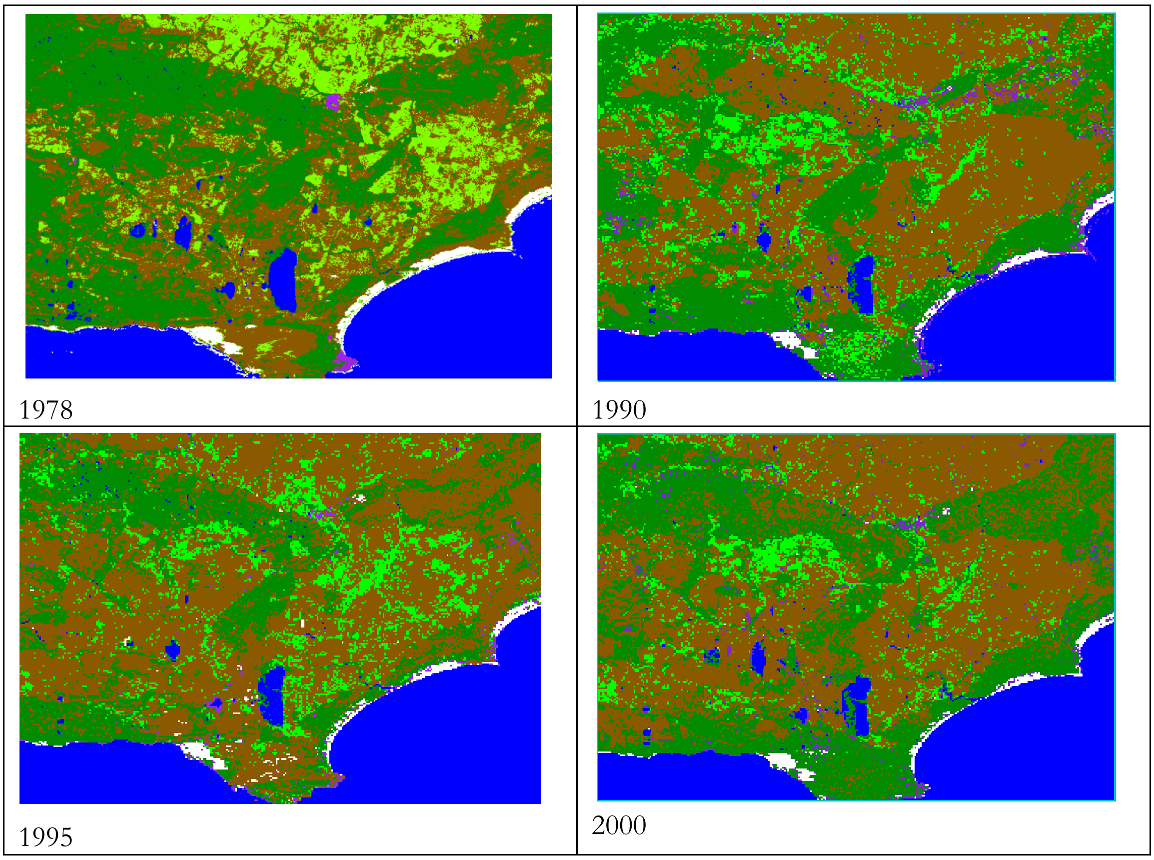

Figure 4-4: Classified maps of the dry season in three different years

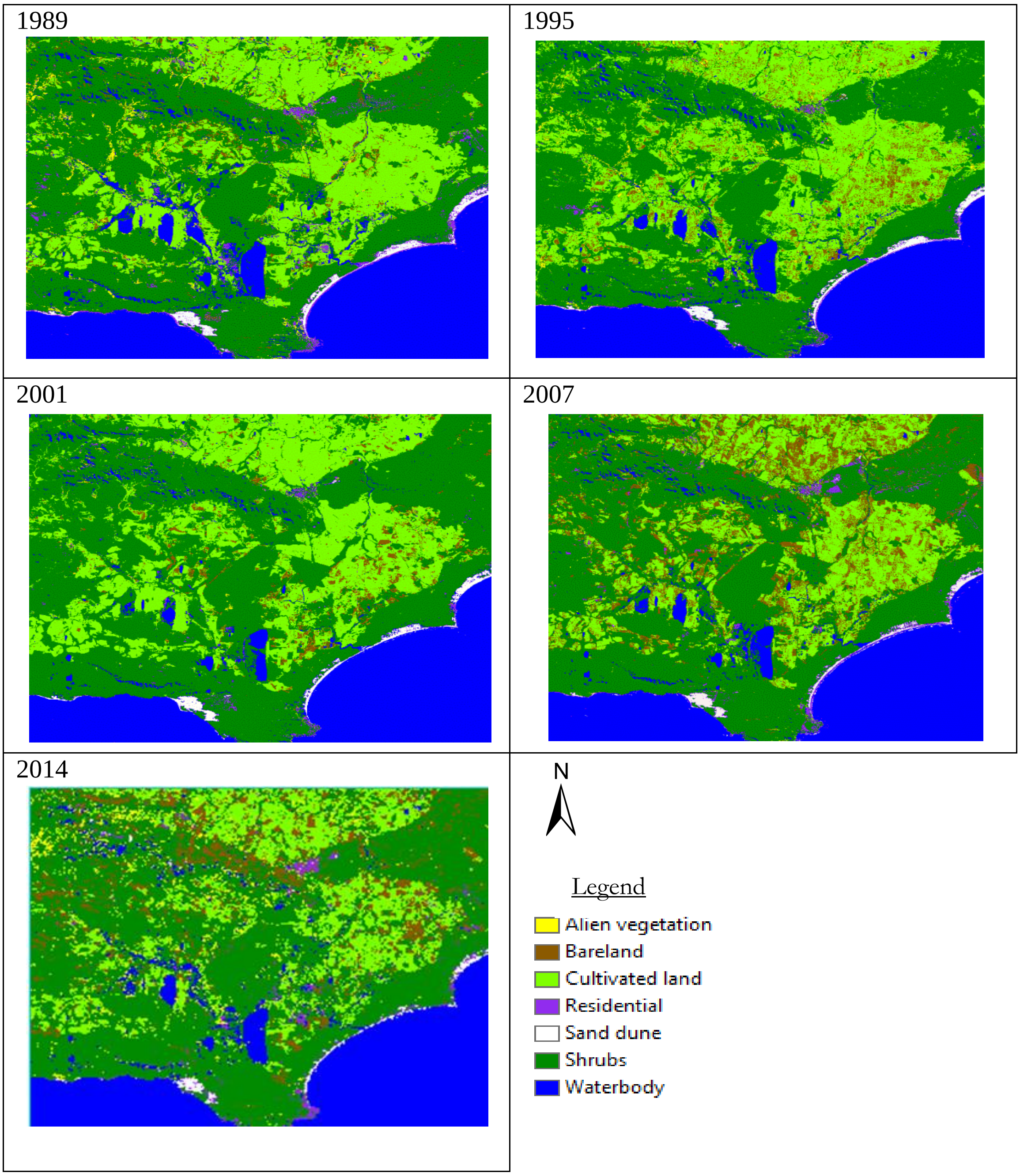

Figure 4-5: Classified Images over a 36-year period (Wet season)

Land Cover/ Use	August, 1989		Sept., 1995		August, 2001		August, 2007		July, 2014	
	Area(Km²)	Percent (%)	Area (Km²)	Percent (%)	Area (Km²)	Percent (%)	Area (Km²)	Percent (%)	Area (Km²)	Percent (%)
Bare land	69.66	3.82	99.16	5.44	61.42	3.37	235.02	12.89	166.15	9.08
Alien Vegetation	36	1.97	23	1.26	6.4	0.35	6.64	0.36	58.41	3.19
Cultivated land	500.54	27.45	568.44	31.18	538.3	29.52	410.8	22.53	313.78	17.16
Residential	45.67	2.50	21.56	1.18	15.88	0.87	35.2	1.93	32.74	1.79
Sand dune	19.55	1.07	19.25	1.06	18.6	1.02	14.28	0.78	12.55	0.69
Shrubs	1039.83	57.03	989.33	54.26	1117.41	61.28	1048.03	57.48	1148.92	62.82
Waterbody	112.08	6.15	102.57	5.63	65.32	3.58	73.36	4.02	96.45	5.27

Table 4-4: Summary of LULC classes over a 25-year period (wet season)

Land Cover/Use	1989 - 1995		1995 -2001		2001 -2007		2007 - 2014	
	Area (Km²)	Area (%)	Area (Km²)	Area (%)	Area (Km²)	Area (%)	Area (Km²)	Area (%)
Bare land	29.5	1.62	-37.74	-2.07	173.6	9.52	-68.87	-3.81
Alien Vegetation	-13	-0.71	-16.6	-0.91	0.24	0.01	51.77	2.83
Cultivated land	67.9	3.72	-30.14	-1.65	-127.5	-6.99	-97.02	-5.37
Residential	-24.11	-1.32	-5.68	-0.31	19.32	1.06	-2.46	-0.14
Sand dune	-0.3	-0.02	-0.65	-0.04	-4.32	-0.24	-1.73	-0.10
Shrubs	-50.5	-2.77	128.08	7.02	-69.38	-3.81	100.89	5.34
Waterbody	-9.51	-0.52	-37.25	-2.04	8.04	0.44	23.09	1.25

Table 4-5: Summary of land cover changes over 6 to 7 year interval by simple differencing of Table 4-4

The positive and negative values in the Table 4-5 above indicate respectively the increase and decrease in the various land covers during the periods specified.
The part of the sea found on the classified images approximately 381.68 km², was deducted from the total area of waterbodies after the classification.

Land Cover/Use	1978-1989		1989 - 2001		2001 - 2014	
	Area (Km²)	Percent (%)	Area (Km²)	Percent (%)	Area (Km²)	Percent (%)
Bare land	-619.32	-33.97	-8.24	-0.45	104.73	5.72
Alien Vegetation	36.00	1.97	-29.6	-1.62	52.01	2.84
Cultivated land	211.71	11.61	37.76	2.07	-224.52	-12.37
Residential	44.52	2.44	-29.79	-1.63	16.86	0.92
Sand dune	-15.94	-0.87	-0.95	-0.05	-6.05	-0.33
Shrubs	270.94	14.86	77.58	4.25	31.51	1.53
Waterbody	72.28	3.96	-46.76	-2.56	31.13	1.69

Table 4-6: Land cover changes over a 10-year period

		Initial state - 1989							
	Classes	Alien Vegetation	Bare land	Cultivated Land	Residential	Sand dune	Shrubs	Waterbody	Class total
Final State 2014	Alien vegetation	**6.79**	4.72	11.51	0.82	0.03	25.66	8.81	58.34
	Bare land	1.12	**14.18**	75.33	2.52	0.06	72.54	0.37	166.12
	Cultivated land	1.91	19.12	**268.19**	0.63	0.06	22.36	1.49	313.77
	Residential	0.49	0.49	6.47	**10.46**	4.14	9.29	1.31	32.64
	Sand dune	0	0.04	0.02	1.48	**9.78**	1.01	0.22	12.54
	Shrubs	25.1	30.7	136.71	18.79	3.92	**898.45**	33.91	1147.57
	Waterbody	0.57	0.41	2.32	10.97	1.57	10.52	**65.96**	92.33
	Class total	36	69.66	500.54	45.67	19.55	1039.83	112.08	
	Class changes	29.2	55.47	232.35	35.2	9.77	141.38	46.12	
	Image difference	22.35	96.47	-186.77	-13.02	-7.01	107.75	-19.76	

Table 4-7: Change detection matrix between 1989 and 2014 (wet season) in square kilometres

Land Cover/Use	October, 1978		February,1990		February, 1995		October, 2000	
	Area (Km²)	Area (%)	Area (Km²)	Area (%)	Area (Km²)	Area (%)	Area (Km²)	Area (%)
Bare land	688.98	37.79	931.89	51.11	1028.5	56.41	943.56	51.75
Alien Vegetation	0.00	0.00	0	0.00	0	0.00	0.0162	0.00
Cultivated land	288.83	15.84	206.5	11.33	192.65	10.57	134.98	7.40
Residential	1.15	0.06	45.51	2.50	19.16	1.05	32.74	1.80
Sand dune	35.49	1.95	20.53	1.13	25.05	1.37	22	1.21
Shrubs	768.89	42.17	612.2	33.58	463.27	25.41	677.28	37.15
Waterbody	39.80	2.18	6.7	0.37	94.69	5.19	12.75	0.70
Total	**1823.14**	**100.00**	**1823.33**	**100.00**	**1823.32**	**100**	**1823.33**	**100.00**

Land Cover/Use	1978 - 1990		1990 - 1995		1995 - 2000	
	Area (Km²)	Area (%)	Area (Km²)	Area (%)	Area (Km²)	Area (%)
Bare land	242.91	13.32	96.61	5.30	-84.94	-4.66
Alien Vegetation	0.00	0.00	0	0.00	0.0162	0.00
Cultivated land	-82.33	-4.52	-13.85	-0.76	-57.67	-3.16
Residential	44.36	2.43	-26.35	-1.45	13.58	0.74
Sand dune	-14.96	-0.82	4.52	0.25	-3.05	-0.17
Shrubs	-156.69	-8.60	-148.93	-8.17	214.01	11.74
Waterbody	-33.10	-1.82	87.99	4.83	-81.94	-4.49

Table 4-8: Summary of LULC and changes in the dry season

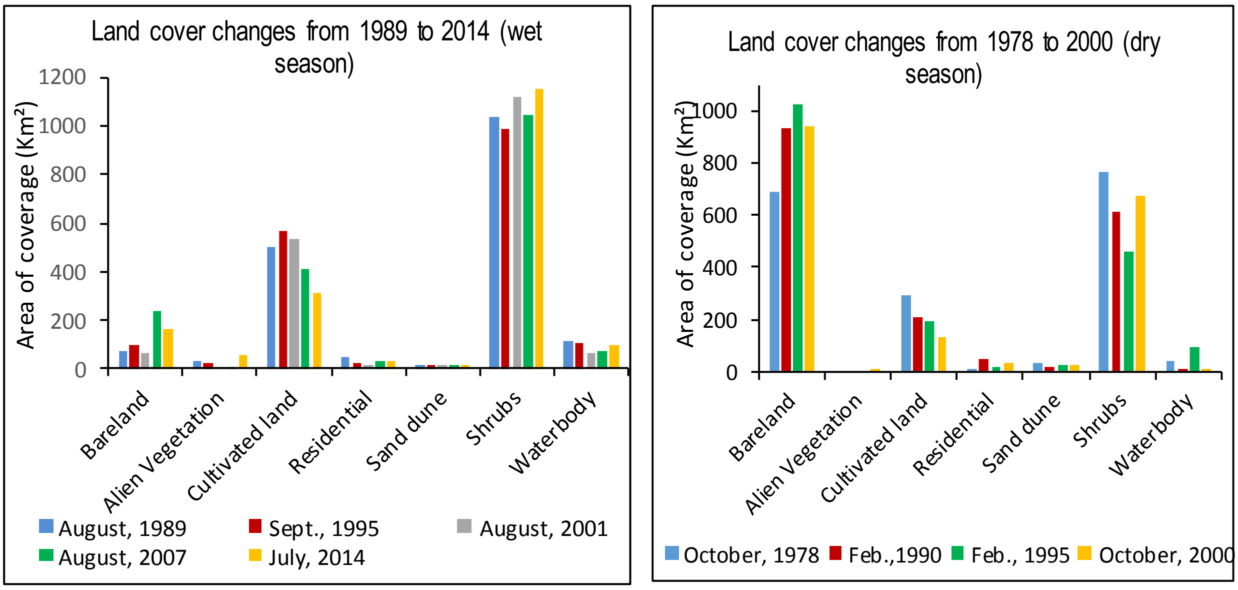

Figure 4-6: Graphs showing trends in land cover in the wet and dry seasons

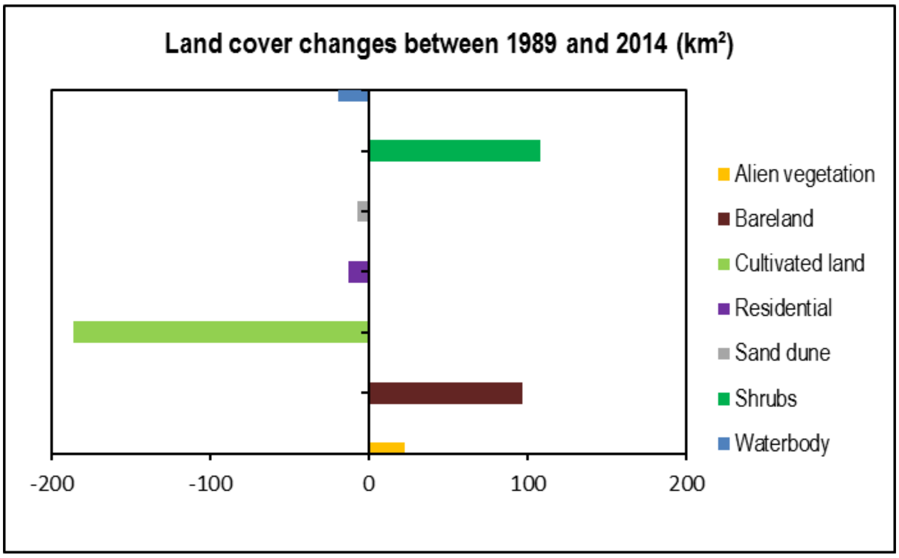

Figure 4-7: LULC changes between 1989 and 2014 in square kilometres using Table 4-7

The diagonal elements in bold presented in Table 4-7 indicate surface area of land covers which remained unchanged in 2014 while the off diagonal elements show the surface areas which were converted from one LULC to the other.

In the matrix table, the initial state (1989) classes are listed in the columns while the final state (2014) classes are in the rows. For each initial state class (that is, each column), the table shows the extent of areas which were classified in the final state image. The row indicating Class Total refers to the total area in each initial state class, and that in the column refers to the total area in each final state class. All final state areas of coverage that fell into the selected initial state classes is what makes the Row Total column. This is a class-by-class summation. The Class Changes row is the sum of all changes that occurred in a class. The Image Difference row is the difference in the total area of equivalently classed coverages in the two images. It is computed by subtracting the Initial State Class Totals from the Final State Class Totals (ENVI, 2013; Mahmoodzadeh, 2007).

4.6. Descriptive Statistics of Climate Data

Although rainfall data were available from 1909, that of temperature was available from 1973. The Figure 4-8 below shows the distribution of the rainfall data over the years.

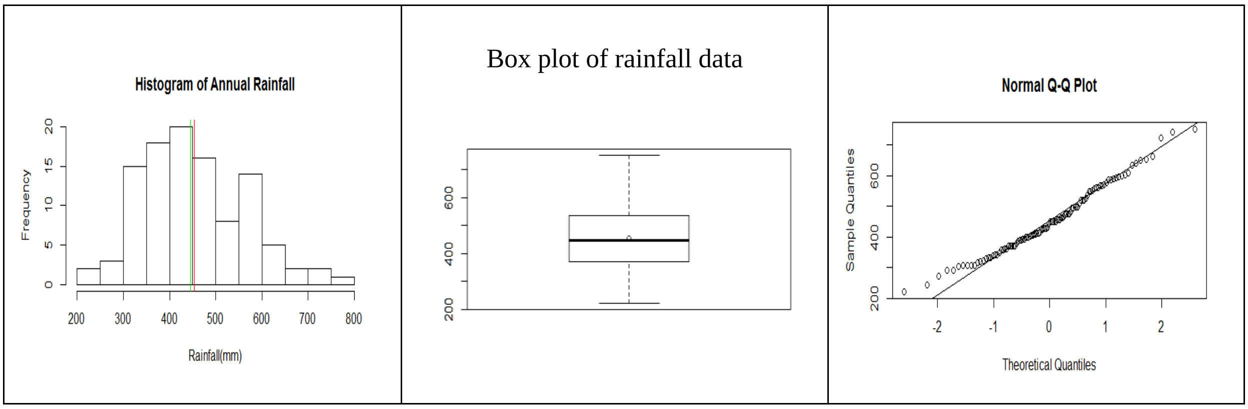

Figure 4-8: Plots showing the distribution of rainfall data from 1909

The rainfall data was normally distributed with a mean of 453.37mm and median as 445.25mm. This is evident from the plots above with the mean and median between the 400mm and 500mm. The closeness of the mean to the median is seen in the box plot where the mean represented as a circle falls on the median (represented by the horizontal line). The Q-Q plot shows majority of the points falling on the Q-Q line. The linearity of the points indicates the normal distribution of the data. The data can be said to be symmetrical about the mean.

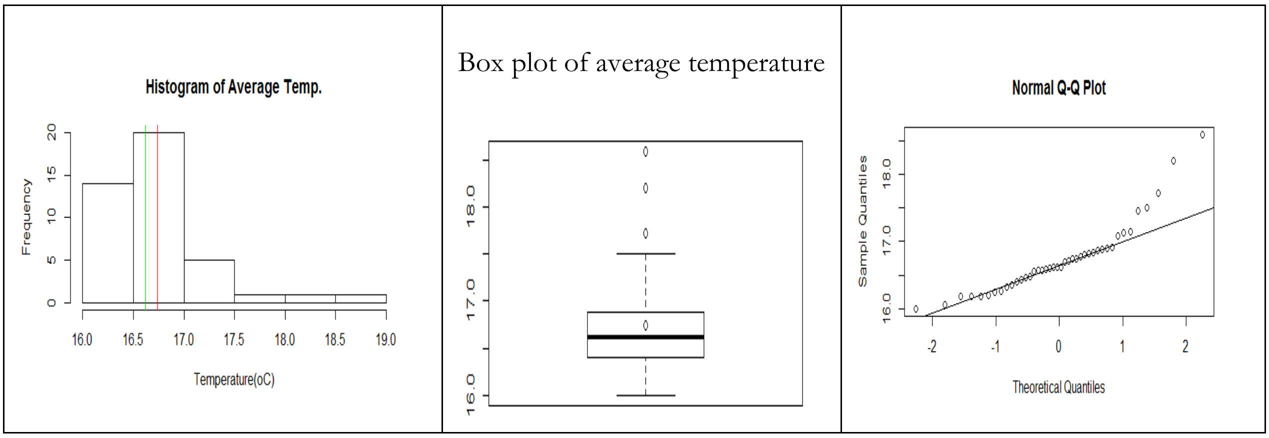

Figure 4-9: Plots showing the distribution of average temperature since 1973

The temperature data available from 1973 was skewed to the right as seen in Figure 4-9. It had a mean of 16.74^{o}C and a median of 16.62^{o}C. The data was log transformed in order to have a normal distribution (see Figure 4-10). From the box and Q-Q plots, there was no significant difference between the original data and the log transformed data. The original data was therefore used in further analysis.

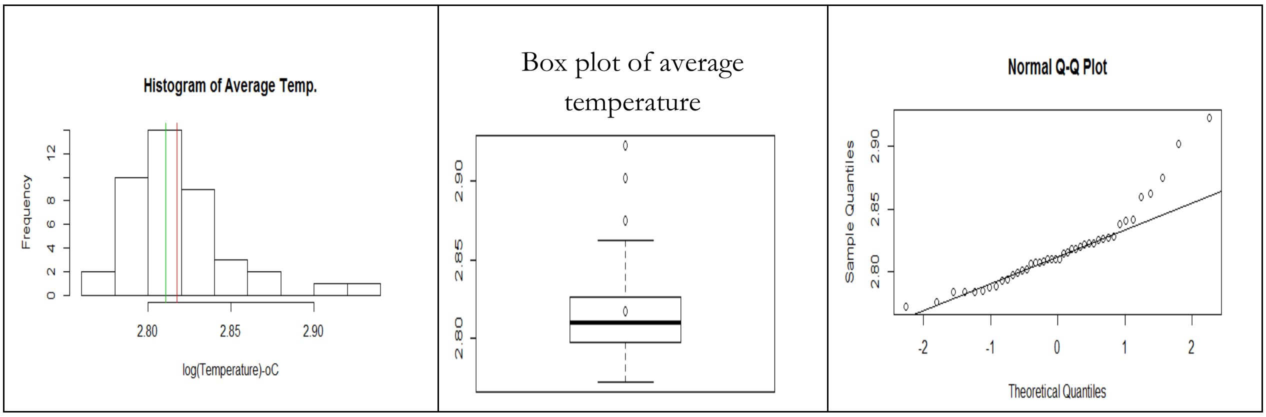

Figure 4-10: Log transformed temperature data

4.7. Trend Analysis of Rainfall and Temperature data

The rainfall data was averaged with ten years to aid visualize the trend in the climate. This is shown in Figure 4-11. A polynomial trend line of order 6 overlaid on the rainfall graph showed a trend in the form of a multidecadal cycle. Linear regression applied on the averaged rainfall data gave a p-value of 0.00045 at 95% confidence level and an R^2 of 0.12. About 60 – 70% of the annual rainfall was in the wet (winter) season (see Appendix G).

The temperature data averaged with 10 years revealed the occurrences of high temperature years in the decade between years 2000 and 2010. Beyond those years, the temperatures dropped drastically. The temperature data rather gave a p-value of 0.75, which can be said to be not significant at 95% confidence level.

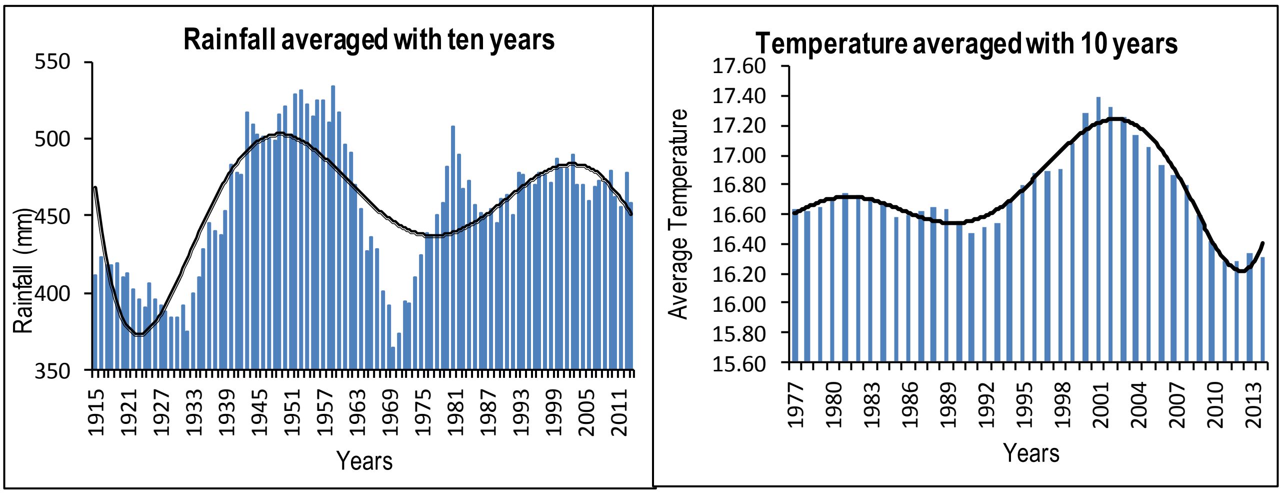

Figure 4-11: Graph showing trend in Rainfall over a 100 year and temperature over a 30 year period

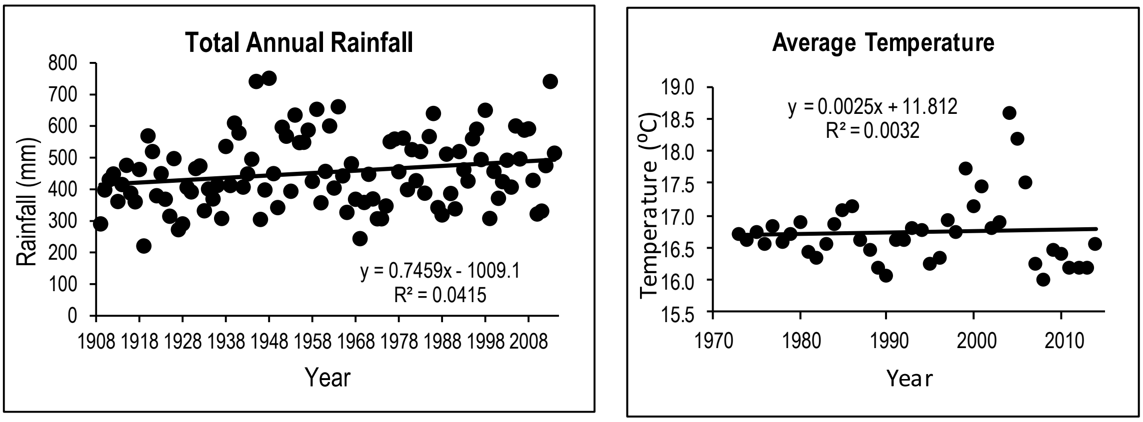

Figure 4-12: Scatter plots of rainfall and temperature

A scatter plot of the rainfall data showed a small positive linear trend with the slope being significant from zero. It can therefore be concluded that a linear trend exists. The t-test gave a t-stat of 2.12 and a t-critical of 1.98. With the t-stat being greater than the t-critical (2.12 >1.98), it can be concluded that the slope is significant at the 5% level of significance (Sanders et al., 1983).

However, a scatter plot of the temperature data showed otherwise. Although there was a small positive linear trend and the slope was significant from zero, the t-stat (0.36) was less than the t-critical (2.02). It can hence be concluded that the slope is not significant at the 5% level of significance. The regression tables can be found in Appendix J.

Assuming the following hypothesis is made;
H_0: $b = 0$, Null hypothesis
H_1: $b \neq 0$, Alternative hypothesis
The Null hypothesis stating that there is no increasing or decreasing slope trend in the data at the 5% level of significance is rejected.

5. DISCUSSION

5.1. Water Quality Analysis and Data Interpretation

5.1.1. Reliability Analysis

With reference to the location of the sampling points in Figure 3-2, all samples passed the $K^+/Na^+ + K^+$ test which means Na^+ was more abundant than the K^+. This is so due to the fact that K^+ is naturally less abundant and also always readily removed from solution by plants and clay minerals than Na^+.

The samples failed the $Mg^{2+}/Ca^{2+}+Mg^{2+}$ test because the concentrations of Mg^{2+} were more than that of the Ca^{2+}. This could be explained by the high degree of silicate weathering and the removal of calcium by precipitation and/or ion exchange.

Five (5) of the samples failed the $Ca^{2+}/Ca^{2+} + SO_4^{2-}$ test due to the very low Ca^{2+} levels. The samples which were VOEL, ZEE W, HEU B, KARS 1 and KARS B can be said to be slightly acidic.

Nine (9) samples failed the Na^+/Na^++Cl^- test indicating that Cl^- was more than that of the Na^+. It is likely that the Na^+ have been removed from the water by reverse ion exchange as seen in the case of brines.

The hydrochemical reliability checks are tests to verify hydrochemical data consistency of natural waters. In most natural waters, having been in contact with soil, rocks and minerals for a certain period, these evaluation ratios and interrelationships hold and were derived for average conditions (from a large hydrochemical data sample) (Hounslow, 1995).

Undeniably, deviation (or not passing a certain ratio test) does not mean the hydro chemical data are wrong, but the interpreter is justified is saying that something is unique on the water sample (like e.g. source origin, age, etc.).

In this Cape Agulhas hydro chemical data set also, this is observed for a number of tests.

The data are from surface water samples i.e. river flows, water bodies. Although surface streamflow is in fact strongly related to shallow groundwater (baseflow) to a large extent especially in the dry season, we may consider most samples to be young freshwater.

However, two distinct groups should be visible, i.e. the Nuwejaars and Kars river systems with both draining towards the Heuningnes river.

The two main water types as seen in the plots indicated sources such as saline and typical of marine and deep ancient ground waters. Silberbauer & King (1991) identified Na^+ and Cl^- as the dominant ions present in wetlands near the coast. This is also confirmed by the River Health Programme (2011) report that the high salinity of the waters in the area make them unsuitable for domestic or irrigation use (see also Wilcox plot in Figure 4-1).

5.1.2. The Nuwejaars river system

The Nuwejaars river starts its drainage at source from mainly quartzite hills (and a small area with granite), from the Table Mountain Group (TMG) geological formation. Near the source (e.g. JVK), rather low EC (± 200 μS/cm) values are measured and a distinct Na-Cl hydrochemical water type (low concentration).
On the Piper plot in Figure 4-1, this is not visible (as a Piper does not reflect concentrations), but on a Stiff diagram as in Figure 4-2 and also a Wilcox, this can be noted.

Actually, we may suggest that this water is rather young rainwater, which drained the hills for a rather short time only. Due to its close proximity to the Southern Atlantic Ocean (and main source origin of rainfall), the Na-Cl signature is very prominent. These types of source (and spring) waters are found throughout the Western Cape; very lowly mineralized waters with a Na-Cl signature.
Upon its path downstream, salinity gradually builds up and more ions become visible, although there is a surprising dominance of the sodium and chloride. This hints to the TMG source rock and rainfall derived from nearby ocean waters as main streamflow source origin, in this coastal zone. Especially the absence of calcium (and magnesium) and consequently the low hardness (soft water) is typical.

Due to their soft and slightly acid nature, these waters have a strong dissolution capacity of organic matter, which can well be seen, as most of the streamflow draining these hills are dark-brown in colour, but not turbid. The colour is due to high CDOM (dissolved organic matter) contents, originating from soil organic matter, and especially the upland peat (Palmiet - *Prionium serratum*) found especially in the colluvial depressions along the drainage system in the higher parts of the hills.
Once the Nuwejaars reaches the plain (downstream Elim), turbidity increases as the river network broadens and starts meandering through these depositional areas towards the Soetendalsvlei.
Other tributaries (Voelvlei) join the network. Here we observed higher EC and salinities over 1000 μS/cm.

5.1.3. The Kars river system

Although the upper Kars River was not sampled during this campaign (due to time and practical constraints), three samples of the Kars system were taken and used in the analysis (see Figure 3-2 for locations).
The Kars hydrochemistry is different, because this system drains mainly the "Bokkeveld" shales, an old sedimentary lithological formation, known to contain natural salinity, typical for shale. Of course the hills and reliefs bounding the Kars catchment are from the TMG (Table Mountain Group geology), quartzite, sandstone, etc. (and low EC water springs can be found; ref. near Bredasdorp).
EC values of 3,000 - 4,000 μS/cm are typical for the lower Kars streamflow, indicating important salt loads of this river system, entering the Agulhas plain.
We can observe these differences well on the Stiff diagram and also on the Wilcox plot in Chapter 4.

5.2. An Account of low concentrations of phosphates and high EC values

The rather low levels of phosphates could probably be due to the complex nature of phosphorus. It is transported in water as adsorbed-P to organic matter or suspended sediments. They mostly occur in low concentrations in surface water ranging from 0.005 to 0.020 mg/l because plants readily abstract them before they get to the water bodies (Chapman, 1996). Moreover, according to Chamier et al., (2012) the production of secondary plant compounds such as polyphenolics by the fynbos vegetation account for the humic and weak organic acids in the area. The humic acids which subsequently leach into the water bodies results in the dark colour of the waters, reduce their pH and more importantly the phosphorus concentrations. Similarly, Jones et al. (2000) in their paper, reported on previous research undertaken by J.M. King in 1989 on the chemical and physical properties of the wetlands in the Agulhas plain. In that report the amounts of Nitrogen measured in the wetlands ranged from 0.049mg/l to 2.103mg/l while that of phosphates (total P) ranged from 0.001mg/l to 0.049mg/l. The results gotten in this study can therefore be said to be fair even though some of the reliability tests showed unacceptable results.

One important function of wetlands can be to purify water and detoxify wastes. The EC measurement and concentrations of other nutrients from the Nuwejaars River (Inflow to the Soetendalsvlei) was expected to be higher than that of the Heuningnes River (outflow). This was rather not the case.
Historical evidence and some research has indicated that there is marine influence on the Heuningnes River since it flows into the sea. During periods when the Soetendalsvlei is at low level and freshwater inflow is severely limited, there is no outflow into the Heuningnes River but rather an inflow from the sea. The condition of the mouth of the Heuningnes estuary is also said to affect the water quality of the river. Conditions such as permanently open and temporarily open/closed are used to describe the mouth of the estuary. Temporarily open/closed is used when the estuary is separated from the sea by a sandbar due to the low freshwater inflow being insufficient to maintain an open connection. When adequate water levels are reached, the mouth is reopened ensuring tidal exchange (Gordon, 2012 & Bickerton, 1984). This tidal exchange is what is likely to be the reason for the high EC values recorded for the sample taken from the Heuningnes River, as compared to the Soetendalsvlei or the Nuwejaars River.

Additionally, the two main rivers that feed the Heuningnes are the Nuwejaars through the Soetendalsvlei and the Kars River. From the water quality data, the Kars river has the highest concentrations of ions and nutrients because the river takes its source from Bokkeveld shales which are highly saline (Jones et al., 2000). The salinity of the Kars River coupled with that of the influence from the sea causes the saline nature of the Heuningnes.

Conductivity is very much linked to the concentrations of total dissolved solids and major ions and so high levels of it may indicate pollution or severe land run-off (Chapman, 1996). Unexpectedly, the low electrical conductivities of JVK, KPR, KLF, NUWE and NUJ 2 as shown in Figure 5-1 also reflected in the low levels of phosphates, nitrates and other constituents which were rather contrary to the initial assumption that the presence of the IAPs in the riparian zone of these water bodies will indicate high concentrations of nutrients and ions (Chamier et al., 2012). These sampling locations were surrounded by the alien vegetation. This observation tends to agree with that of Coetzee (1967) cited by Gordon (2012) who intimated that pollen grains thrive in acid-waterlogged (low EC) environments. This probably implies that the IAPs survive and propagate along these riparian areas which have low EC values. Locations that had the occurrences of the invasive acacias had pH values between 5 and 7.

One challenge that could inhibit good analysis is the different instruments used over the years to measure water quality parameters. While some researches made use of the Crison types of instruments (Silberbauer

& King, 1991; Jones et al., 2000), others used the YSI (Gordon, 2012 and current research at UWC). In essence, there is need for calibration when comparing data from different sources and instruments. Despite the difference in instruments, a look at the EC values recorded over the years for the southern part of the Soetendalsvlei revealed declining EC values. Thus, there is a tendency to agree with Gordon (2012) that the Soetendalsvlei is becoming more freshwater in nature.

The graph in Figure 5-1 showed a general increase in EC values downstream as the wet season ends. Estimations in October for most of the samples taken were higher than the previous sampling dates. The red rings indicated around some of the measurements show locations which had the occurrences of alien vegetation.

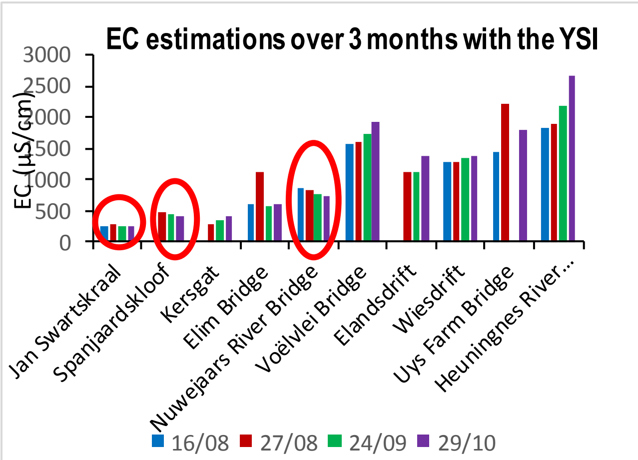

Figure 5-1: Graph showing EC estimations from TDS measurements with the YSI

The sample at Voelvlei Bridge rather showed higher EC values than the two succeeding locations downstream. Notwithstanding, Gordon (2012) in his assessment of three of the wetlands in the plain, pointed out about the health status of the Voelvlei as more eutrophic compared to the others. This was attributed to the unique hydrology of the Voelvlei in that only one channel serves as both inflow and outflow. Water residence time was thus identified as long enough to result in high phytoplankton dominance.

5.3. Land Cover classification

The graphs and tables presented from Figure 4-3 to Figure 4-7 and from Table 4-3 to Table 4-8, showed decreases in the cultivated lands in the wet season from 1995 and this can be said to have reflected in increase in the bare lands and shrubs. Within the framework of the Working for Wetlands project, the South African National Parks (SANParks) in 1999 bought a number of private farmlands (cultivated lands) with the intention of formally protecting the Agulhas plain (DWAF, 1999). This could be said to have accounted for the decline in the acreages of farmlands cultivated after 1995. It is therefore obvious that the natural vegetation (fynbos) which are shrubs have increased.

Even though alien vegetation is said to be propagating at faster rates, it is still around 1% of the total area. This is likely due to the activities of the Working for Wetlands programme in which the clearing of the IAPs is being undertaken. This is in line with what Zenni et al. (2009) intimated concerning the *A. paradoxa* that the IAPs even though propagate fast can still be controlled with focused clearing operations. Research by Mucina & Rutherford (2006) cited by Hoekstra & Waller (2014) summarising the ecosystem status of the vegetation in the area indicated the natural vegetation as least threatened. Degraded natural vegetation are below 1% of the total area (16.77km^2) of the natural vegetation cover (See tables in Appendix H). This is rather contrary to the assertions some researches have presented on the threat of the natural vegetation. However, the positive impacts of the Working for water/wetlands programme cannot be overlooked in analysing the low occurrences of the IAPs by the interventions of mechanical and biological controls (Wilgen et al., 2012). It is also worth noting however, that this research focused on only the *Acacias* even though there are other invasive species like the *Eucalyptus* and the *Pinus*. Hence, the extent of the IAPs gotten in this study may not be very representative.

The extent of settlements (residential areas) still hovers around a mean of 1% as presented in the report of River Health Programme (2011) and Gordon (2012).

Despite the fact that waterbodies decreased for the period 1989-2001 by 2.56%, they also increased during the period 2001-2014 by 1.69% albeit less than the decrease. The increase was greater from 1978 to 1989 of about 3.96%. Table 4-6 presents this result of a summary of the land cover changes over a 10-year period. This could be attributed to the increase in the annual rainfall during the year 1989 of about 511mm from 456mm in 1978. Also, since the image of 1978 was that of the dry season, it could be expected that the areal extent of the water bodies had been reduced due to evaporation and less rainfall in that season. Water body areal extent and subsequently the volumes can therefore be said to be largely influenced by annual precipitation.

A plot of land cover changes in the dry season showed a decrease in the shrubs while there was a substantial increase in the bare lands. This is logical since during the dry season most of the shrubs die off due to lack of water and are taken over by bare lands. Also, owing to the fact that most of the cultivated lands are harvested at the end of the wet season in October, the lands become fallow and bare, thereby increasing the total area of bare lands. There were still areas of cultivated land in the dry season because of the livestock rearing activities in the area. Some grasslands still remain for the feeding of the animals in the dry season.

Figure 4-7 is a graph plotted using Table 4-7 summarising the changes in the surface area of the land covers between 1989 and 2014. The bars to the right of the zero axis represent land covers which

expanded in surface area (km^2) while those to the left hand side are for land covers which decreased in surface area during the period under review. The graph is similar to that of Figure 4-6 which shows trends in the LULC changes. From the results of the change detection performed in ENVI 5.1 using the two years, the decreases in most of the land covers seen in the matrix of
Table 4-7 could be attributed to the fact that they had been converted to shrubs. That is the reason why the shrubs had the largest increase in surface area of 107.75 km^2. The graph presented do not however, capture the changes that occurred in the other years between 1989 and 2014.

5.3.1. Classification of Alien vegetation

The extent of the invasiveness of the alien vegetation remains around 1% even though they are said to be propagating faster. This is not seen in the classification of the land cover over the years. It is probably due to the fact that these alien vegetation are found among the shrubs which are the natural vegetation of the area. Their spectral reflectances are not distinguishable with Landsat as seen from the feature space plots in Figure 5-2. Bands 1 and 5 and Bands 2 and 7 which had low correlations of 0.10 and 0.32 respectively were plotted in the feature space, and although the other classes were separable, that of the shrubs and the alien vegetation were not.

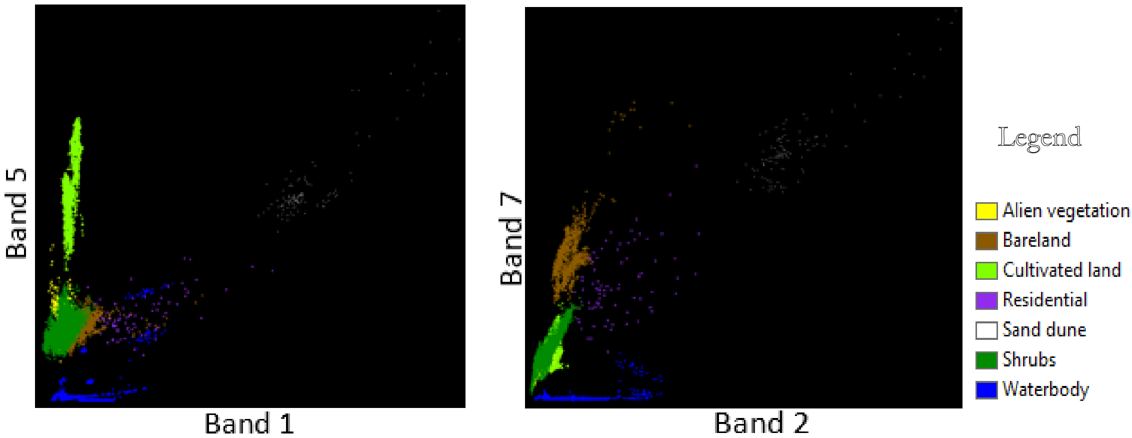

Figure 5-2: Feature space plots of Bands 1&5 and Bands 2&7

Assigning pixels identified as alien vegetation in 2014 was a challenge on images of the previous years from 1978 owing to the fact that there is no knowledge on how long these plants have been in the present locations where they are occurring.
The topographic map of 1997 at a scale of 1:50000 was a good reference for validating some of the land covers, but not the IAPs. There was much generalization in the capturing of vegetation which made the alien vegetation not distinguishable. Around the water bodies, trees were captured as rows of trees. Therefore, validation of the alien vegetation was not possible.
Detecting, mapping and monitoring of IAPs from satellite images although difficult, is not impossible. It however, requires high spatial resolution (about 3 – 12m^2) multispectral images like the AVIRIS (Ustin & Santos, 2010; Jr., 2010; Hunt, 2007) or a continuous observation of spectral reflectances in addition to moderate resolution images like the Landsat in order to detect seasonal dynamics of reflectance properties (Somers & Asner, 2012). Even though there could be some increased separabilities in the visible and shortwave-infrared wavelengths because of the nitrogen fixing ability of the invasive species, Somers & Asner (2012) admitted that there is no specific time window or a single spectral region from which the separability of both the native and invasive species could be defined. Therefore, an intensive monitoring of plant phenology and the use of the full-range electromagnetic spectrum was highly recommended.

5.4. Trend Analysis of Rainfall and Temperature data

In general, the trend of the climate can be described as a cycle and therefore repeats itself. This follows a similar observation by Fröhlich (2006) in his description of the Total solar irradiance (TSI) as shown in Figure 5-3. A similar research by Willems (2013) showed also a multi-decadal variation in precipitation extremes in Europe.

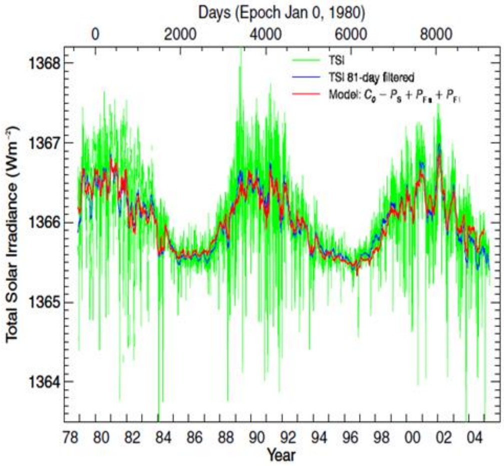

Figure 5-3: Solar Irradiance variability since 1978

Climate change scenarios have been modelled by a number of researchers including Storch (2005) but the complex interactions between the atmosphere, biosphere and hydrological cycle have presented a lot of uncertainties especially since 1979 (IPCC, 2001) coupled with the fact that most of the climate change simulations are more useful on large scales i.e. global, continental and subcontinental levels (Storch, 2005). There is no doubt that global changes have ripple effects on the local scales, but specifics at the local level need to be considered before one can really understand the importance of climate change issues when being analysed at the country level (Storch, 2005). Roads et al. (2006) and other researchers have reiterated the fact of the hydrological cycle that an increase in the earth's surface temperature leads to an increase in evapotranspiration which subsequently corresponds to precipitation rates. The IPCC (2001) report has it that there was a general increase of 2% in precipitation over the land in the twentieth century even though the increases were not uniform both spatially and temporally. In the southern part of Africa, the report intimates a decrease in precipitation in the warm (dry) season and increase in cold (wet) season. This observation is quite similar to the graphs presented in Figure 5-4. Predictions from model simulations can therefore not be entirely inaccurate even though as stated earlier, some more specifics will have to be considered at the local scale.

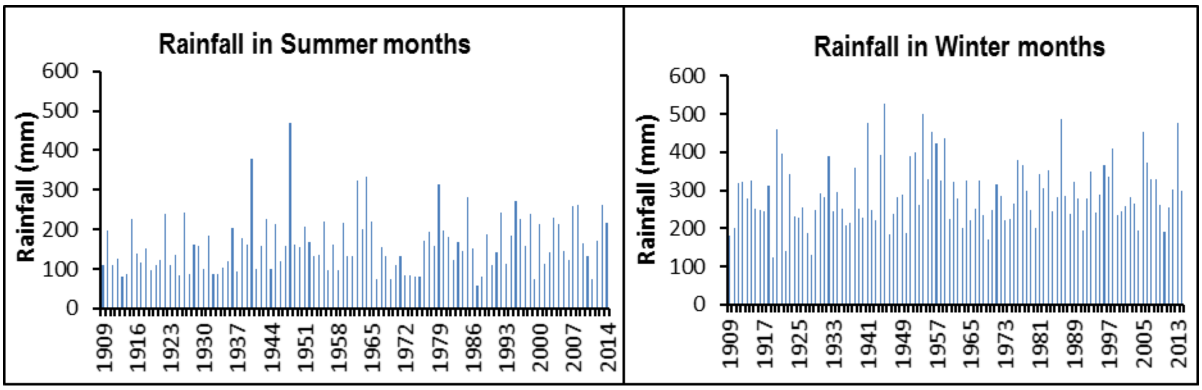

Figure 5-4: Graphs showing rainfall in summer and winter months

5.5. Comparative Analyses

Month/Year	Alien vegetation (km²)	Cultivated lands (km²)	Monthly Rainfall	Preceding 3 months rainfall	Annual Rainfall	Temp.
October, 1978	0	239.7	16	194.5	456	16.59
August, 1989	36	500.54	46	161	511	16.19
February, 1990	0	206.5	25	50	387	16.06
February, 1995	0	192.65	8	103	560	16.25
September, 1995	23	568.44	65	140	560	16.25
October, 2000	0.016	134.98	17	141	456.5	17.13
August, 2001	6.4	538.3	57.5	127.5	371.5	17.46
August, 2007	6.64	410.8	57	205	587	16.26
July, 2014	43.66	333.02	61.3	164.3	514.4	16.57

X (response)	Y (predictor)	p-value	R^2
Monthly rainfall	Cultivated lands	0.003507	0.727
3 months rainfall	Cultivated lands	0.47418	0.076
Cultivated lands	Alien vegetation	0.79303	0.4465
Monthly rainfall	Alien vegetation	0.21823	
Annual rainfall	Alien vegetation	0.39415	0.1053
3 months rainfall	Alien vegetation	0.45809	0.0809

Table 5-1: Results of regression analysis

Regression analysis to estimate the relationship among the variables in Table 5-1 gave p-values not statistically significant at 95% confidence level except for that of cultivated lands and monthly rainfall values. This means that changes in rainfall does not in any way affect the alien vegetation. The monthly rainfall values tends to have an effect on the cultivated lands. This is in line with scientific knowledge and nature whereby plants grow and thrive in the presence of water, a major component needed in the process of photosynthesis.

The alien vegetation, although are also plants cannot be said to follow the same trend as the cultivated lands in relation to rainfall. They can therefore be said to thrive irrespective of the climate as some researches have proven them to be drought resistant.
There is not enough water quality data to confirm whether the increase in cultivated lands culminated in the increase of nutrients in the water bodies.
The impacts of IAPs on water quality are said to be prevalent after intense fires which cause increase in soil erosion, consequence of which is the decrease in water quality (Chamier et al., 2012).

The aspect of the utilisation of the water resources in the area which includes abstraction of the water for watering the livestock and for construction have not been explored and quantified to help explain whether that has contributed in the reduction or drying up of the water bodies. A research is currently underway to understand how much water is being used by residents of the area. Steynor (2009) concluded in his research that there is a decline in runoff from climate change predictions. This decline in runoff together with water abstraction have been identified to result in about 14 to 32% reduction (New, 2002) in stream flow quantity which is one way by which wetlands are replenished and maintained.

5.6. Validation

Researches carried out in the validation of time-series of satellite images have been assessed to be very challenging.

The most common method used has been the visual interpretation of aerial photographs (Kennedy et al., 2007; Huang et al., 2010; Schroeder et al., 2011; Kayastha et al., 2012). A number of points that can be observed on the aerial photos of 1938 and 1962, the topographic maps and google earth were chosen to verify the changes.

a. b. c.

d. e.

Figure 5-5: Aerial photos of 1938 and 1962 showing some changes in LULC

The aerial photos a, b and d presented in Figure 5-5 are that of 1938 while c and e are photos of 1962.

The obvious identifiable feature in the photos is the Soetendalsvlei. The photos show changes in LULC over a 24-year period (from 1938 to 1962). The dominant changes seen involved the conversion of shrubs into farmlands as observed in the portions within the black rings marked on the photos.

Current satellite images, topographical maps and google earth show the areas marked as either shrubs and/or bare lands. This confirms the statement earlier made on the acquisition of the private farms by SANParks. This acquisition could probably be the reason why some of the cultivated lands seen in the

1962 photos are no more and have been replaced by shrubs and/or bare lands in the current images. These LULC which have large extents are very easy to verify and validate from the aerial photos. The level of ease cannot be said to be the same in identifying the IAPs from the photographs, satellite images and topographical maps.

The use of google earth which enables one to zoom in to street view was a very good source of data for validation especially for the current years.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The general objective of this research was to identify impacts of invasive plants species on water quantity and quality of the Agulhas Plain and lacustrine wetlands and to investigate the expansion of the invasion of these species in the riparian areas in relation to land use land cover change and climate. This was to be accomplished by answering a number of research questions.

From the results and analysis of the land cover classification, exploration of the climate data and some water quality data, the following conclusions could be drawn;

1. There is no identifiable relationship between the hydrochemistry of the waters (environment) e.g. the salinity and the occurrence of alien vegetation species. The alien vegetation patches are observed on slightly acid very low mineralized head waters of the catchment (e.g. JVK) as well as the brackish waters in some areas of the Agulhas plain.
2. In our opinion, their propagation seems to be wind-driven (pollen), which then through surface runoff (diffusive wash) concentrate by preference in the drainage network system (riparian zone).
3. In the headwaters of some catchments (KPR etc.) they compete there with valuable native Palmiet species, dwelling also around the drainage lines of higher order streams.
4. The detection of small patches of alien species using Landsat imagery was not very successful using the SVM multispectral classification method because of their overlapping spectral reflectances with the native species. It is a fact that when larger stands of aliens > 1ha are present, Landsat obviously can be used but that was quite rare in the area (e.g. near Black Oyster farm/Nuwejaars river). High resolution imagery could be obtained as complementary source of data.
   However, we also observed that the massive removal of alien species around the drainage lines in the higher parts of the catchment also damages (removes) the natural habitat of the native Palmiet (*Prionium serratum*) vegetation, considered a valuable ecological fynbos asset in the catchment.
   As a result, higher runoff peaks can be expected with consequence of more flash flooding near the foot slopes of the hills and plains. An (alien) eradication method which keeps native species more intact should be developed.
5. The gradual decrease in cultivated (farm) land could be observed from the image time series analysis. This can be attributed to the country's acquisition programs of SANParks which buys out certain farmers to restore patches in the Cape Agulhas nature reserve.
6. Results obtained from the exploration of climate data, did not indicate the climate getting wetter (cooler) or drier (hotter) but rather showed a multi-decadal oscillation type of behaviour (Fröhlich, 2006; Willems, 2013)
7. The invasive alien plants thrive irrespective of the climate getting drier or wetter.

6.2. Recommendations

As a follow up to this preliminary research on the detection of the occurrence of the IAPs, the following can be recommended;

1. To acquire and use higher resolution imagery (like AVIRIS, WorldView, GeoEye etc.) for improved detection of alien vegetation distribution in the area.
2. Measurement of spectral responses of the different vegetation (and soils) in support of the vegetation pattern recognition if the long term impacts of the Working for water/wetlands programme is to be effectively monitored.
3. Improve on ground truthing e.g. using new methods such as Geo-Wiki (citizen based) in order to obtain a baseline for future monitoring.

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APPENDICES

Appendix A: Geological Map of the Southern Part of the Overberg District of which the Agulhas plain is part (Cleaver & Brown, 2005)

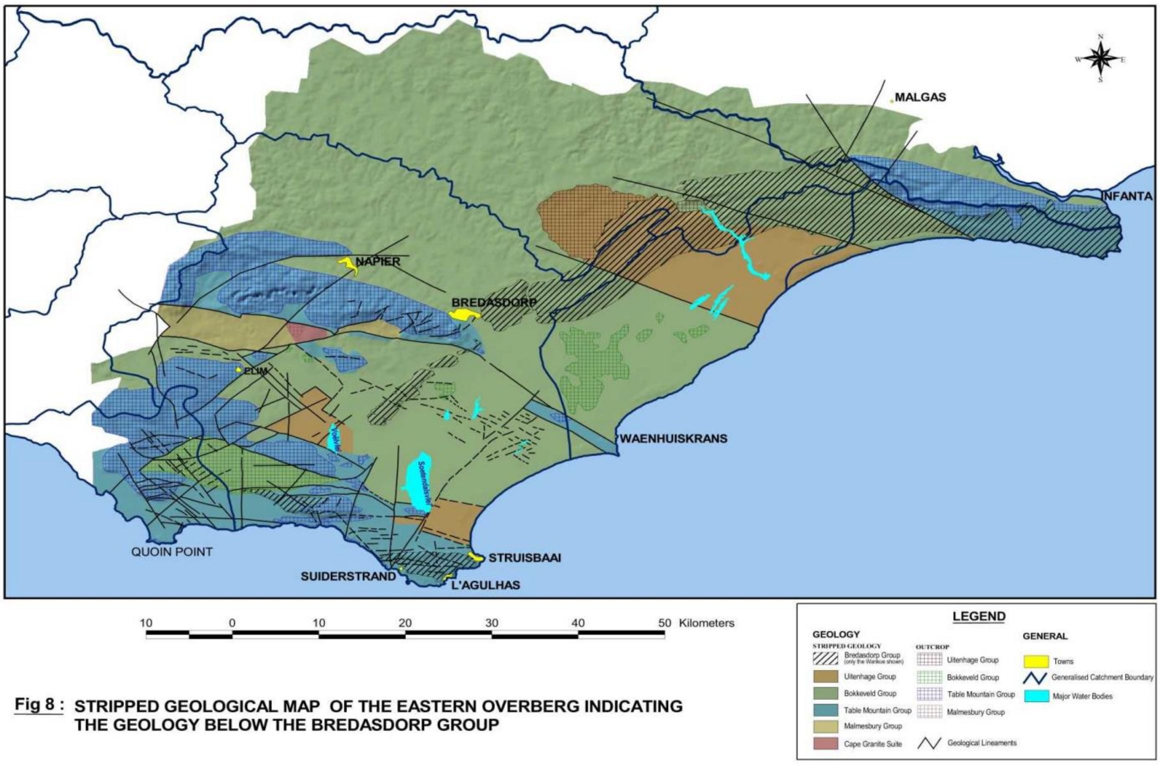


Fig 8 : STRIPPED GEOLOGICAL MAP OF THE EASTERN OVERBERG INDICATING THE GEOLOGY BELOW THE BREDASDORP GROUP

Appendix B: Source-rock Deduction and Summary of Reasoning as used in Aquachem software (Hounslow, 1995)

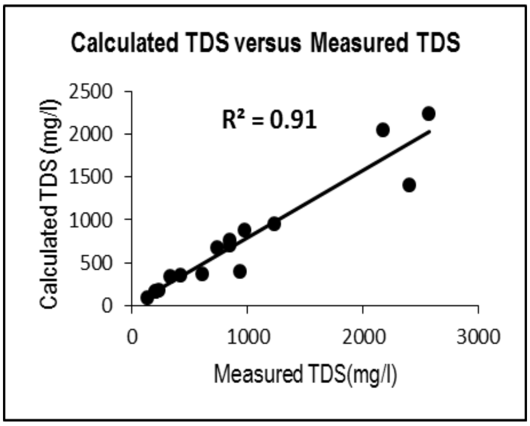
Parameters	Values	Conclusion
HCO_3^-/SiO_2	>10	Carbonate Weathering
	>5 and <10	Ambiguous
	<5	Silicate Weathering
$SiO_2/(Na^+ + K^+ - Cl^-)$	<1	Cation Exchange
	>1 and <2	Albite Weathering
	>2	Ferromagnesian Minerals
$(Na^+ + K^+ - Cl^-)/(Na^+ + K^+ - C^{l-} + Ca^{2+})$	>0.2 and <0.8	Plagioclase Weathering Possible
	<0.2 or >0.8	Plagioclase Weathering Unlikely
$Na^+/(Na^+ + Cl^-)$	>0.5	Sodium Source other than Halite-Albite, Ion Exchange
	=0	Halite Solution
	<0.5 TDS >500	Revers Softening, Seawater
	<0.5 TDS >500>50	Analysis Error
	<0.5 TDS<50	Rainwater
$Mg^{2+}/(Ca^{2+} + Mg^{2+})$	HCO_3^-/SiO_2 >10	Carbonate Weathering
	=0.5	Dolomite Weathering
	<0.5	Limestone-Dolomite Weathering
	>0.5	Dolomite Dissolution, Calcite Precipitation or Seawater
	HCO_3^-/SiO_2 <5	Silicate Weathering
	>0.5	Ferromagnesian Minerals
	<0.5	Granitic Weathering
$Ca^{2+}/(Ca^{2+} SO_4^{2-})$	=0.5	Gypsum Dissolution
	<0.5 pH <5.5	Pyrite Oxidation
	<0.5 neutral	Calcium Removal-Ion Exchange or Calcite Precipitation
	>0.5	Calcium Source other than Gypsum-Carbonate or Silicate
$(Ca^{2+} + Mg^{2+})/ SO_4^{2-}$	>0.8 and < 1.2	Dedolomitization

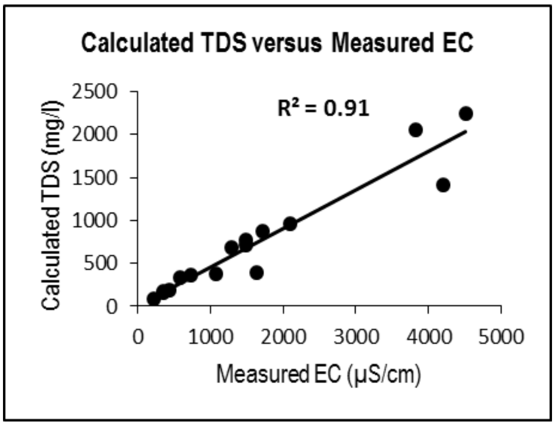
Appendix C: Reliability Analysis (check) of ions

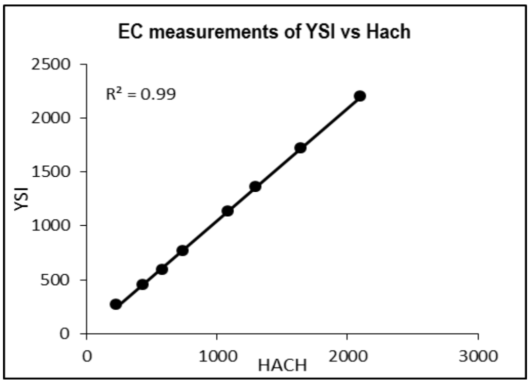
	$K^+/Na^+ + K^+$	$Mg^{2+}/Ca^{2+}+Mg^{2+}$	$Ca^{2+}/Ca^{2+} + SO_4^{2-}$	$Na^+/Na^+ +Cl^-$
Acceptance value	**< 20%**	**< 40%**	**> 50%**	**> 50%**
ELAN	1.38	**77.8**	100	**48.9**
HEU B	1.14	**73.7**	**39**	55
JVK	0.79	**80**	100	**45.3**
KARS 1	0.94	**80**	**28.5**	52
KARS B	0.84	**77.2**	**34**	52.4
KLF	1.46	**78**	100	50.2
KPR	1.74	**83**	100	**44**
NUJ 2	2.69	**78**	100	**45**
NUW 1	1.3	**79.7**	100	**49**
NUWE	1.17	**78**	100	**46**
SOE C	1.7	**74.86**	90	50.6
SOE N	1.73	**68**	100	**41.74**
SPK	0.86	**87**	100	**41.6**
VOEL	1.88	**72.5**	**37.6**	55.2
WIES	1.24	**78.7**	100	**47.75**
ZEE W	1.07	**75**	**43**	54

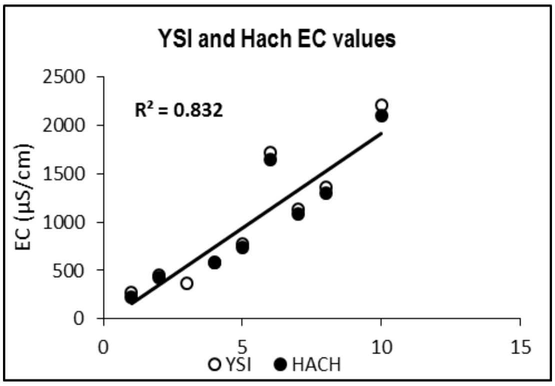
Values in bold did not meet the reliability check acceptance values

Appendix D: Scatter plots showing correlation of EC and TDS









Appendix E: Results from in-situ and laboratory analyses of water samples

				Field Measurements									Laboratory Measurements												
S/N	Sample Code	UTM coordinates		Temp (°C)	Total Hardness (mmol/l)	pH	HCO_3^- (mmol/l)	EC (µS/cm)	O_2 (mg/l)	Silicate	PO_4^{2-}	Nitrogen species (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Mn^{2+} (mg/l)	Al^{3+} (mg/l)	Fe^{3+} (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	$NH4^+$ (mg/l)	Fl^- (mg/l)	PO_4^{2-} (mg/l)	SO_4^{2-} (mg/l)	Cl^- (mg/l)
		Northing	Easting																					
1	NUJ 2 (Nuwejaar)	34° 34' 42.8"	19° 45' 28.5"	25.5	0.7	6.41	0.4	578	6.96	3	0 - 0.25	0 - 10	6.5	13.8	0.02	0.36	2.27	5.07	108	1.132	-	-	-	200
2	KPR (Klein Petersilie erivier)	34° 32' 50.1"	19° 48' 26.4"	23.8	0.4	5.43	0.3	349	8.57	2	0 - 0.25	0 - 10	2.5	7.3	0.03	0.53	0.67	1.55	52	0.704	-	-	0	100
3	KLF (Boskloof)	34° 32' 32.6"	19° 49' 8.9"	22.5	0.45	4.96	0.3	348	8.78	3	0 - 0.25	0 - 10	2.9	6.1	-	0.7	1.21	1.51	62	2.904	-	-	0	95
4	HEU B (Heuningnes bridge)	34° 41' 19.4"	20° 01' 59.6"	19.9	2.5	7.39	2.4	2098	6.87	0.6	0 - 0.25	0 - 10	21.7	36.7	-	0.1	0.38	7.19	359	0.582	0.19	-	80	450
5	WIES (Wiesdrift)	34° 41' 14.7"	19° 55' 35.9"	19.8	1.4	6.75	0.8	1297	5.62	0.6	0 - 0.25	0 - 10	12.1	27	-	0.05	0.55	5.01	237	0.763	0.17	-	0	400
6	ELAN (Elandsdrift)	34° 38' 47.2"	19° 53' 30.6"	21.1	1.1	6.64	0.8	1082	5.71	2	0 - 0.25	0 - 10	7.3	15.3	-	0.1	0.58	3.02	131	1.036	0.22	-	0	211
7	VOEL (Voelvlei bridge)	34° 38' 51.5"	19° 53' 7.6"	20.2	1.7	7.35	1.2	1642	8.26	3	0 - 0.25	0 - 10	10	16.1	-	0.04	0.11	4.85	144	0.672	0.02	-	40	180
8	NUWE (Nuwejaar)	34° 38' 1.0"	19° 51' 53.2"	21.3	0.7	6.52	0.8	733	6.23	2	0 - 0.25	0 - 10	7.8	16.9	0.03	0.3	2.09	2.19	116	0.792	0.04	-	0	211
9	SPK (Spanjaarsklof)	34° 31' 49.5"	19° 44' 53.6"	17.2	0.3	4.75	0.4	431	8.53	4	0 - 0.25	0 - 10	1.8	7.4	0.06	0.25	0.45	0.91	53	-	0.14	-	0	115
10	JVK (Janstuartskraal)	34° 30' 39.7"	19° 42' 51.0"	17.9	0.3	5.25	0.4	225	8.28	2	0 - 0.25	0 - 10	1.6	3.9	-	0.52	0.74	0.44	29	0.784	0.05	-	0	54
11	KARS B(Kars river Nacht wacht)	34° 34' 48.6"	20° 6' 38.5"	16.9	4	7.6	3	3820	7.51	3	0 - 0.25	0 - 10	37.1	76.1	-	0.07	0.56	10.47	729	0.783	0.29	0.031	170	1020
12	KARS 1 (Upstream)	34° 29' 7.0"	20° 05' 27.4 "	16.9	4.5	7.65	3.1	4510	8.03	2	0 - 0.25	0 - 10		89.9	0.04	0.12	1.94	12.49	772	2.03	0.31	-	220	1100
13	SOE N (Soetendalsvlei north)	34° 43'8.4"	19° 59'54.0"	17.9	1.8	7.68	1.4	1483	8.66	0.6	0 - 0.25	0 - 10	17.4	22.8	-	0.11	0.36	6.4	209	0.736	0.1	-	0	450
14	ZEE W(Zeekoevlei weir)	34° 39'30.2"	20° 00'52.6"	17.9	4.9	7.51	3.6	4210	7.87	0.6	0 - 0.25	0 - 10	28.2	51.5	-	0.01	0.26	9.78	533	0.826	0.06	-	90	700
15	SOE C (Soetendalsvlei central)	34° 44' 54.4"	19° 59' 50.2"	17.6	1.76	8.31	1.2	1479	10.62	0.3	0 - 0.25	0 - 10	17.8	32.2	-	0.23	0.79	8.15	279	0.739	0.17	-	10	420
16	NUW 1	34° 44' 00.6"	19° 58' 16.6"	16.6	2.2	7.28	1.5	1716	8.73	0.1	0 - 0.25	0 - 10	16.3	38.7	-	0.07	0.47	7	315	0.72	0.19	-	0	500

Appendix F: Rainfall data (since 1909) and temperature data (since 1973) available from SAWS and a private farmer

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total Annual Rainfall	Rainfall averaged over 10 years	Temperature (Average)
1909				21.5	34.5	7.5	53.5	52	12.5	48.5	7.5	53.5	291		
1910	6.5	18	89	8.5	53.5	64	39.5	33.5	3	40.5	28	14	398		
1911	35	22.5	6	2.5	109.5	56.5	73.5	33.5	44	34.5	10	2.5	430		
1912	38.5	0	38	27.5	89	51	35.5	59	60	11	26.5	12.5	448.5		
1913	16.5	16.5	6.5	25	45	10.5	54	85.5	59	13	23	6.5	361		
1914	12.5	0	11	44.5	47	57.5	37	67.5	73.5	7.5	50.5	7	415.5		
1915	84.5	0	12	37.5	24.5	78.5	37	30.5	42.5	25.5	80	23	475.5	411.773	
1916	33	23	46.5	20.5	24	70	32	65	37.5	14.5	10	11.5	387.5	422.773	
1917	10.5	0	59.5	16.5	34.5	41	94	30.5	28	39	4.5	2.5	360.5	418.227	
1918	2.5	15	41.5	6.5	65	53	119.5	7	61	44	37.5	10.5	463	418.364	
1919	21.5	18	3.5	28.5	21.5	4.5	29.5	4.5	35.5	38	14.5	1.5	221	419.045	
1920	2	12.5	23	4.5	100.5	143.5	134	37.5	40	15.5	26.5	29.5	569	409.909	
1921	14	42	2.5	23	0	178	96	42.5	56	15	5	45	519	411.864	
1922	63.5	12.5	43	3	35	36	18	48	2	18	98.5	2.5	380	401.409	
1923	32	5	0	78.5	86.5	61	67	36	12	24	45.5	2.5	450	395.091	
1924	18	21.5	14	19	12.5	91.5	24.5	57.5	28	19.5	61	1.5	368.5	389.864	
1925	26.5	2.5	7.5	16.5	11	91.5	25.5	36	49	23	12.5	13.5	315	405.409	
1926	5.5	0	29.5	8	36.5	40.5	85	53	32.5	170	36.5	0	497	396.045	
1927	2.5	32	1	27	43.5	15	17	80.5	3.5	10.5	20	20	272.5	391.955	
1928	24	9.5	45	1.5	10	42	7	27	42.5	6	61.5	15	291	387.591	
1929	5.5	34.5	38	24.5	40	30	105.5	28	19.5	15	19.5	45.5	405.5	383.136	
1930	4	28	14.5	66.5	42	22.5	18.5	57.5	85	22	22	9.5	392	383.273	
1931	19	20	27	104	27	14	33	83.5	21.5	93.5	5	18.5	466	392.091	

1932	17	24	2.5	0	53.5	55.5	58.5	19.5	201	16.5	9	17	474	374.909	
1933	0	0	29	9	47.5	74.5	42	64	9	1.5	51.5	4	332	398.864	
1934	18	8.5	10	0	13.5	2.5	88.5	133.5	59	41	16.5	10	401	409.909	
1935	2	9.5	21.5	52.5	67	66.5	17.5	5	42	10	58.5	18	370	428.455	
1936	43	12.5	9.5	0	76	23	34	27	47	35	53.5	51.5	412	445.364	
1937	0	0	39.5	21	11	59.5	73.5	12.5	38	24.5	28.5	0	308	440.000	
1938	23.5	5.5	58.5	70.5	46.5	37.5	52	64	89	69.5	17.5	2	536	437.727	
1939	8	49	62.5	30	34.5	34.5	53	75	24.5	15.5	11	15	412.5	452.591	
1940	2.5	292	18.5	68.5	16.5	83.5	38	23	0	21	44.5	1.5	609.5	483.545	
1941	14.5	7	14.5	124	73	84.5	49	41	105	2.5	37.5	25.5	578	477.591	
1942	28.5	5.5	28.5	17.5	88	79	17.5	25.5	22	7.5	5	82.5	407	476.273	
1943	66.5	18.5	45.5	33.5	0	76.5	28	60.5	22.5	23	59	15.5	449	516.591	
1944	16.5	4	25.5	8	70.5	94	7.5	85.5	129	26	23	6	495.5	508.773	
1945	3	6.5	4	50	154	134.5	75.5	103.5	10	169.5	12.5	18.5	741.5	502.364	
1946	12	0	40	19	22.5	26.5	31	8	79	43.5	14	9	304.5	501.136	
1947	14	19.5	74	22.5	26	16.5	124	35	15.5	14	28.5	8	397.5	500.227	
1948	8	9.5	81	72.5	65	54.5	52.5	0	39	343	0	26.5	751.5	499.000	
1949	17	20.5	6	79.5	64.5	24	27.5	76.5	15	6.5	109	4	450	515.864	
1950	10	1	5.5	56.5	23.5	9	45	18	35.5	55.5	57.5	25	342	520.591	
1951	76.5	7.5	48	96	43	103	39.5	35.5	73	51.5	15.5	7	596	503.091	
1952	0	15.5	11.5	15.5	27.5	51	51	86.5	167.5	36.5	103	2.5	568	528.818	
1953	44.5	11.5	5	64	22	36	92.5	22	25	15	49.5	6.5	393.5	531.364	
1954	5	11.5	63	64	157.5	59.5	103.5	103.5	11	24.5	20	11.5	634.5	522.455	
1955	8	93	28.5	25.5	10	50	84.5	130.5	28	53.5	17	19	547.5	514.000	
1956	1	13	12	28	100	146	108	49	22	27.5	2.5	40	549	524.409	
1957	0	21.5	49.5	23	86	147	37.5	77.5	53.5	92	0	0	587.5	524.818	
1958	0	9	46.5	37.5	162.5	21.5	7.5	84.5	13.5	22	14.5	6.5	425.5	509.864	
1959	43.5	40	40.5	189	69	6.5	55.5	90.5	27.5	66.5	8	17	653.5	534.182	
1960	25	7	18	26.5	51.5	52	56	26	13	18	10.5	53.5	357	516.727	

1961	47	12	41.5	28	58.5	63	68	55	50.5	9	0	24	456.5	496.727	
1962	69.5	27	110	35	26.5	75	31	95	14.5	84	28	5	600.5	490.500	
1963	8.5	41.5	47	32.5	13.5	18.5	71.5	50	16.5	36.5	19.5	48	403.5	470.636	
1964	14	55	45	29	21	130	32.5	70	44.5	25	193	2	661	454.136	
1965	28	47	62.5	38	64.5	23	53.5	29	13	40	25	19	442.5	427.318	
1966	2.5	14.5	18	30.5	37	14	60.5	77.5	33	17	12.5	10.5	327.5	435.591	
1967	8.5	10.5	34	129.5	46.5	67	44.5	28.5	10.5	39	55.5	6.5	480.5	427.682	
1968	19.5	10	13	18.5	30.5	88.5	11.5	61.5	25.5	45.5	40.5	4.5	369	401.000	
1969	17.5	4	24	49	14	46.5	24	30	7	23.5	2.5	2	244	392.182	
1970	1	36	2	15.5	25.5	56.5	77	44.5	30	44.5	9.5	16.5	358.5	363.682	
1971	0	29	23.5	58	43.5	38	72	75	28	24	31.5	25.5	448	373.545	
1972	10.5	25	14	56.5	52.5	35	35.5	44.5	60	8	13	15	369.5	394.545	
1973	11.5	14	21	36	56	17	40.5	33.5	39.5	7.5	20.5	10	307	392.318	16.69
1974	13.5	18	4	4	75	3.5	17	83.5	41.5	36	6	4.5	306.5	409.864	16.61
1975	25.5	0	4	37	62	24	43.5	76	23	35	15.5	2	347.5	423.909	16.75
1976	5	14.5	23.5	99	25	95.5	69.5	68.5	23	49	62	16.5	551	439.091	16.57
1977	4.5	55.5	17.5	54.5	101.5	57	75.5	51	26	10.5	16	89	558.5	437.227	16.83
1978	8	41	32.5	49	29	25	98	60	36.5	16	15	46	456	450.818	16.59
1979	25.5	183.5	2.5	6.5	47	55.5	76	39	24.5	83.5	3.5	15	562	458.136	16.71
1980	24	9	1.5	36.5	38.5	73	9	27	17	37.5	47.5	78	398.5	481.773	16.90
1981	85.5	19	35	126.5	19	44.5	59	59.5	35	6	21	15.5	525.5	508.318	16.43
1982	27	14	22	135.5	7	56	30	58.5	19	37	6.5	15	427.5	489.327	16.33
1983	3	50	32.5	43.5	77	88.5	71	49.5	22.5	15.5	51	15	519	467.555	16.56
1984	4.5	19.5	26.5	36	78.5	23.5	46.5	16.5	42.5	44.5	11	38	387.5	472.555	16.87
1985	94	65.5	21.5	61	20	35	119	31.5	17	68	23.5	10.5	566.5	456.645	17.09
1986	4	19	37	27	12	44	58	44.5	302	22	63	7	639.5	451.145	17.14
1987	4	14.5	9	65.7	28.4	49.5	38	62	41	8	4	18	342.1	450.555	16.62
1988	1	12	4	70	36	40	35	38	18	28	11	26	319	453.691	16.48
1989	20	21	79	50	17	106	38	46	65	52	14	3	511	445.236	16.19

1990	20	25	26	111	55	48	29	23	12	8	14	16	387	460.918	16.06
1991	27	6	19	7	38	50	38	21	41	61	17	13	338	463.055	16.62
1992	30	27	31	31	56	43	26	64	57	130	19	5	519	449.873	16.62
1993	7	48	7	110	41	33	120	23	21	3	14	35	462	477.864	16.81
1994	10	26	22	41	22	107	31	28	13	31	4	91	426	476.864	16.78
1995	3	8	124	34	50	23	65	52	65	36	45	55	560	471.909	16.25
1996	9	19	16	15	9	40	217	36	48	118	35	28	590	470.500	16.35
1997	8	25	17.5	51.5	127	65	14.5	60.5	17	53	44	11.5	494.5	478.364	16.92
1998	18.5	8	79.5	187	99	36	39	29	19	10	95	30	650	475.955	16.75
1999	16	9	7	46	24	22	29	41	73	26	8	7	308	470.955	17.72
2000	86	10	84	23.5	50	30	61	33	47	17	3	12	456.5	486.773	17.13
2001	9	18	13	25.5	32	23	72.5	57.5	49.5	31	31.5	9	371.5	481.000	17.46
2002	72.5	28	12	27	41	57.5	73	49	33.5	16	13	2	424.5	480.727	16.82
2003	39	3	120	18	78	14	32.5	86	35	34	12	21	492.5	489.545	16.89
2004	3	17	43	42	17	41	53	21	19	116	20	15	407	469.364	18.59
2005	85	10	9	219	64	76	24	41	29	18	20	5	600	470.636	18.20
2006	23	15	15	67	65	22	148	56.5	15	31	27	12	496.5	459.273	17.50
2007	7	37	22	45	60	65	80	57	21	55	99	39	587	468.682	16.26
2008	14	57	24	20	100	37.5	67	62	43	23	100	44	591.5	473.100	16.00
2009	27	10	14	12	48	67	59	30	47	95	16	3	428	470.944	16.46
2010	4.5	19	21	11	33	63	54	11.5	17	47	23	18	322	478.938	16.40
2011	4	13	3.5	36.5	59	46.5	61	42	11.5	18	22.5	14	331.5	461.643	16.18
2012	7	27	10	39	21	54	81	76	31	110	17	2	475	455.833	16.20
2013	13	11	71.36	51.75	38.57	115.97	45.9	183.6	42.4	46.4	118.1	3.4	741.45	486.264	16.19
2014	62.5	22.6	55.8	39.9	18.7	105.7	61.3	43	30	18	56.9		514.4	468.725	16.57

Appendix G: Comparison of rainfall in winter (wet season) and summer (dry season)

Year	Winter	Summer	Winter (10-year)	Summer (10-year)	Winter to Total
1909	181.5	109.5			
1910	202	196			
1911	319.5	110.5			
1912	322	126.5			
1913	279	82			
1914	327	88.5			
1915	250.5	225	280.86	130.91	0.68
1916	249	138.5	298.45	130.91	0.71
1917	244.5	116	282.32	124.32	0.68
1918	312	151	284.05	135.91	0.68
1919	124	97	279.86	134.32	0.67
1920	460	109	271.00	139.18	0.66
1921	395.5	123.5	271.45	138.91	0.66
1922	142	238	265.77	140.41	0.66
1923	341	109	255.36	135.64	0.65
1924	233	135.5	249.50	139.73	0.64
1925	229.5	85.5	264.77	140.36	0.65
1926	255.5	241.5	248.68	140.64	0.63
1927	186.5	86	248.00	147.36	0.63
1928	130	161	257.45	143.95	0.66
1929	247.5	158	253.45	130.14	0.66
1930	292	100	255.05	129.68	0.67
1931	283	183	253.00	128.23	0.65
1932	388	86	249.36	139.09	0.67
1933	246	86	265.09	125.55	0.66
1934	297	104	276.14	133.77	0.67
1935	250.5	119.5	274.50	133.77	0.64
1936	207	205	291.27	153.95	0.65
1937	215.5	92.5	288.23	154.09	0.66
1938	359.5	176.5	273.05	151.77	0.62
1939	251.5	161	286.55	164.68	0.63
1940	229.5	380	307.50	166.05	0.64
1941	476.5	101.5	301.64	176.05	0.63
1942	249.5	157.5	304.59	175.95	0.64
1943	221	228	310.77	171.68	0.60
1944	394.5	101	304.18	205.82	0.60
1945	527.5	214	298.36	204.59	0.59
1946	186	118.5	312.95	204.00	0.62
1947	239.5	158	305.91	188.18	0.61
1948	283.5	468	307.00	194.32	0.62

1949	287	163	332.27	192.00	0.64
1950	187.5	154.5	326.27	183.59	0.63
1951	390	206	319.50	194.32	0.64
1952	399	169	341.18	183.59	0.65
1953	261.5	132	349.14	187.64	0.66
1954	499	135.5	363.18	182.23	0.70
1955	328.5	219	357.55	159.27	0.70
1956	453	96	369.86	156.45	0.71
1957	424.5	163	359.59	154.55	0.69
1958	327	98.5	341.73	165.23	0.67
1959	438	215.5	347.68	168.14	0.65
1960	225	132	322.41	186.50	0.62
1961	323	133.5	315.50	194.32	0.64
1962	277	323.5	304.00	181.23	0.62
1963	202.5	201	286.86	186.50	0.61
1964	327	334	272.64	183.77	0.60
1965	221	221.5	255.45	181.50	0.60
1966	252.5	75	263.59	171.86	0.61
1967	326.5	154	260.05	172.00	0.61
1968	236	133	255.09	167.64	0.64
1969	170.5	73.5	257.09	145.91	0.66
1970	249	109.5	251.50	135.09	0.69
1971	314.5	133.5	266.00	112.18	0.71
1972	284	85.5	276.27	107.55	0.70
1973	222.5	84.5	273.64	118.27	0.70
1974	224.5	82	274.77	118.68	0.67
1975	265.5	82	277.55	135.09	0.65
1976	380.5	170.5	286.14	146.36	0.65
1977	365.5	193	285.36	152.95	0.65
1978	297.5	158.5	291.55	151.86	0.65
1979	248.5	313.5	293.45	159.27	0.64
1980	201	197.5	298.82	164.68	0.62
1981	343.5	182	319.00	182.95	0.63
1982	306	121.5	310.28	189.32	0.63
1983	352	167	298.60	179.05	0.64
1984	243.5	144	300.83	168.95	0.64
1985	283.5	283	303.51	171.73	0.66
1986	487.5	152	302.96	153.14	0.67
1987	284.6	57.5	296.92	148.18	0.66
1988	237	82	300.74	153.64	0.66
1989	322	189	290.74	152.95	0.65
1990	278	109	294.87	154.50	0.64
1991	195	143	302.28	166.05	0.65
1992	277	242	288.46	160.77	0.64

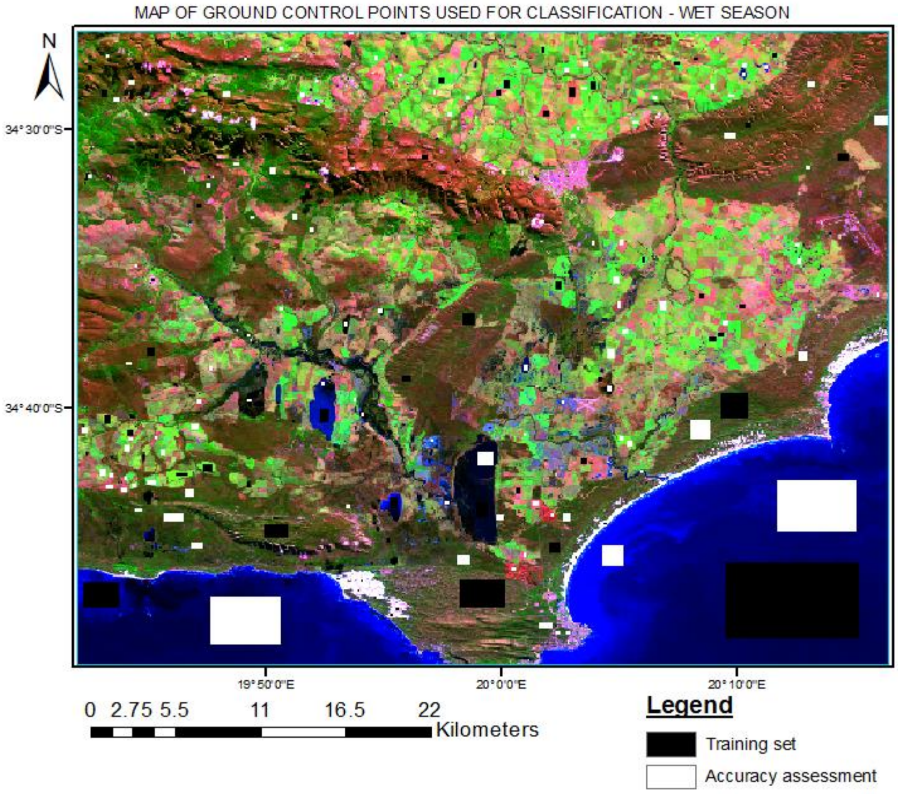
1993	348	114	299.77	161.41	0.63
1994	242	184	299.59	178.09	0.63
1995	289	271	292.55	177.27	0.62
1996	365	225	290.91	179.36	0.62
1997	335.5	159	298.73	179.59	0.62
1998	409	241	297.50	179.64	0.63
1999	235	73	283.41	178.45	0.60
2000	244.5	212	302.59	187.55	0.62
2001	260	111.5	310.27	184.18	0.65
2002	281	143.5	306.91	170.73	0.64
2003	263.5	229	306.36	173.82	0.63
2004	193	214	293.09	183.18	0.62
2005	453	147	288.95	176.27	0.61
2006	373.5	123	290.05	181.68	0.63
2007	328	259	293.86	169.23	0.63
2008	329.5	262	309.13	174.82	0.65
2009	263	165	312.94	177.95	0.66
2010	189.5	132.5	323.84	172.28	0.68
2011	256.5	75	310.93	167.06	0.67
2012	302	173	303.97	169.93	0.67
2013	478.19	263.26	300.97	189.97	0.62
2014	298.6	215.8	296.89	183.79	0.63

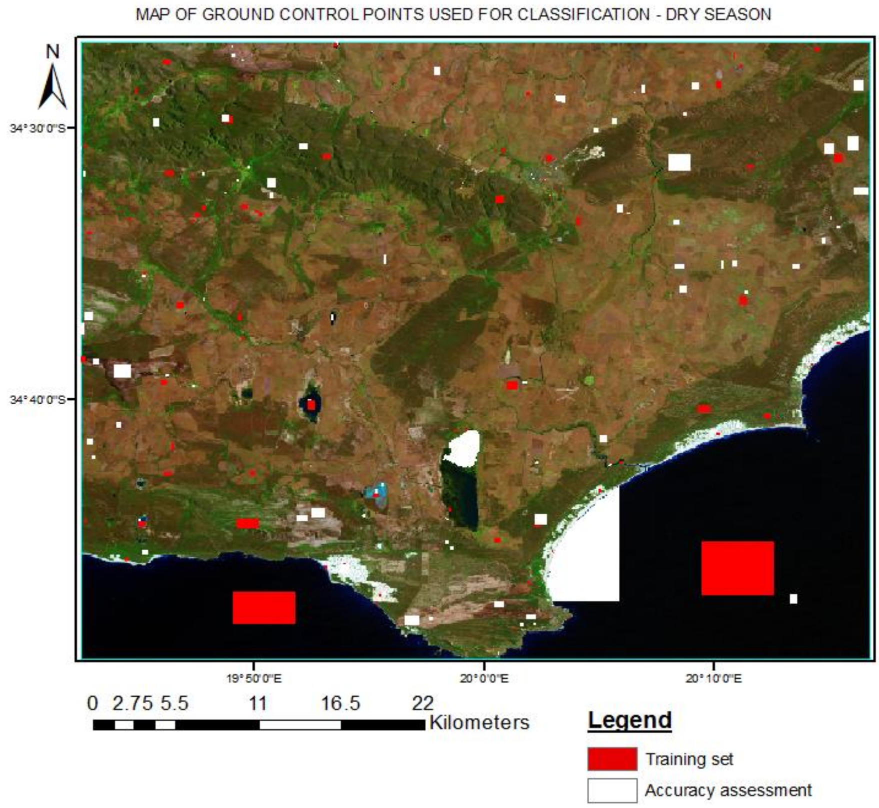
Appendix H: South African vegetation units within the De Mond Reserve Complex (Tables are taken from Hoekstra & Waller, 2014)

SA Vegetation equivalent	Habitat subtype	hectares	Habitat Condition	Hectares
Overberg Dune Strandveld (FS7)	Duneveld	408.3	Natural	360.138
			Near Natural	41.279
			Degraded	6.884
	Stabilised Duneveld	310.9	Natural	309.919
			Degraded	0.973
	Strandveld	162.3	Natural	161.728
			Near Natural	0.464
			Degraded	0.010
			No Natural Habitat	0.111
De Hoop Limestone Fynbos (FFl 2)	Limestone Fynbos	68.9	Natural	68.875
Southern Coastal Forest (FOz 6)	Milkwood Thicket	3.7	Natural	2.169
			Near Natural	1.511
			No Natural Habitat	0.004
Cape Seashore Vegetation (AZd 3)	Rock & Rocky Platforms	26.5	Natural	21.047
			Near Natural	4.503
			Degraded	0.952
	Beach & Mobile Sands	201.6	Natural	198.011
			Degraded	3.347
			No Natural Habitat	0.212
Cape Inland Salt Pans (AZi9)	Cape Inland Salt Pans	414.6	Natural	414.562
Cape Estuarine Salt Marshes (AZe2)	Estuarine Salt Marsh	21.8	Natural	21.403
			Degraded	0.365
n/a	Estuary	59.1		59.060
Total				1 677.5

SA Vegetation equivalent	Conservation Threshold	Formally Protected (2006)	Remaining (of original extent)	Ecosystem Status	ha.	%
Overberg Dune Strandveld (FS7)	36%	30%	94.8%	Least Threatened	881.5	52.5%
De Hoop Limestone Fynbos (FFl 2)	32%	26%	97.8%	Least Threatened	68.9	4.1%
Southern Coastal Forest (FOz 6)	40%	53.4%	94.3%	Least Threatened	3.7	0.2%
Cape Seashore Vegetation (AZd 3)	20%	44.5%	86.2%	Least Threatened	228.1	13.6%
Cape Inland Salt Pans (AZi9)	24	20	86.9	Least Threatened	414.6	24.7%
Cape Estuarine Salt Marshes (AZe2)	24%	22.8%	89.3%	Least Threatened	21.8	1.3%
n/a (Estuary)	-	-	-	Critically Endangered	59.1	3.5%
Total					1 677.5	

Appendix I: Locations of ground control points used for classification in the wet and dry seasons





Appendix J: Regression tables of climate data

Rainfall data

Regression Statistics	
Multiple R	0.203610665
R Square	0.041457303
Adj. R Square	0.032240546
Standard Error	110.7940643
Observations	106

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	55214.9	55214.85	4.498036	0.03631104
Residual	104	1276634	12275.32		
Total	105	1331849			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1009.116003	689.936	-1.46262	0.146586	-2377.2849	359.0529329	-2377.284938	359.0529329
Year	0.745897423	0.3517	**2.120857**	0.036311	0.04847071	1.443324137	0.048470709	1.443324137

t-critical = T.INV.2T(in excel) = **1.98**

Temperature data

Regression Statistics	
Multiple R	0.056810
R Square	0.003227
Adj. R Square	-0.021692
Standard Error	0.539691
Observations	42

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.037723086	0.037723	0.129514	0.720829723
Residual	40	11.65066166	0.291267		
Total	41	11.68838475			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	11.811739	13.696493	0.862391	0.393613	-15.869906	39.493385	-15.869906	39.493385
Year	0.002473	0.006870	**0.359880**	0.720830	-0.011413	0.016358	-0.011413	0.016358

t-critical = T.INV.2T(in excel) = **2.02**

Appendix K: Some field and laboratory photos captured during the research