

**Quantifying decadal changes in land cover in the Duiwenhoks catchment  
using spatial analysis techniques**

by

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## **Abstract**

The main objective of this study is to quantify changes in land cover and land uses at the Duiwenhoks catchment situated in the Western Cape of South Africa in order to monitor impacts of land cover change from 1940 to 2010. Assessing land cover dynamics at long scales such as 70 years coupled with attribute climatic data and streamflow dynamics represents the first step in modelling future hydrologic patterns, ecosystem services sustainability and resilience to natural and anthropogenic impacts such as floods and increased vegetation clearing for agricultural purposes respectively in the 21<sup>st</sup> half century using an ACRU model (Agricultural Catchments Research Unit). To achieve this, black and white Aerial Photographs (AP's) were used to build the land cover maps in a roughly decadal series (1940, 1950, 1960, 1970, 1990 and 2010) with the exception of 1980 due to bad raw datasets which was technically deemed impractical to be used for this study. Research tools for the project were advanced software in GIS (ArcGIS 10.1) and Remote Sensing (ERDAS Intergraph 2014 and ENVI 4.4) to perform desktop applications like geo-referencing, image cropping, mosaicking, projection and post classification. The project used remote sensing tools for textural analysis, Principal Component Analysis (PCA), supervised and unsupervised classification to build the spatial land cover maps. An error matrix using 30 and 80 sampling points per land cover class and ground truthing was used to quantify the degree of correctness. Kappa indices of 0.58, 0.59 and 0.71 (1960, 1990 and 2010 respectively) were obtained for the various classification methods. Ancillary datasets from the Department of Water Affairs (DWA), South African Weather Services (SAWS), (National Freshwater Priority Areas (NFPEPA) was also used to further interrogate the spatial trends derived from the land cover maps. Findings of the study show a loss of natural vegetation from the 1940's especially in riparian zones of the middle catchment. The observed increase in dam construction also indicate the increase in demand for irrigation water for both crops and livestock production.

## Declaration

I ..... Mpfunzeni Tshindane.....declare that

1. The research reported in this dissertation, except where otherwise indicated, is my original research.
2. This dissertation has not been submitted for any degree or examination at any other university.
3. This dissertation does not contain other person's data, pictures, graphs or information, unless specifically acknowledged as being sourced from other persons.
4. This dissertation does not contain other person's writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted,
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## **Abbreviations**

AA	Accuracy Assessment
AP	Aerial Photograph
CIR	Colour Infrared Images
CZP	Coastal Zone Policy
GCP	Ground Control Points
GIS	Geographic Information Systems
DBI	Digital Baseline Information
DWAF	Department of Water Affairs and Forestry
DWUA	Duiwenhoks Water User Association
EbA	Ecosystem based Adaptation
IDP	Integrated Development Plan
ISODATA	Iterative Self-Organizing Data Analysis Technique
LTAS	Long Term Adaptation Scenarios
NEMA	National Environmental Management Act
NFEPA	National Freshwater Ecosystem Priority Areas
NGI	National Geospatial Information
NIE	National Implementation Entity
PCA	Principal Component Analysis
SANBI	South African Biodiversity Institute
SAWS	South African Weather Services
WfW	Working for Wetlands

## **Chapter 1: Introduction**

Humankind has become a dominant force of change on planet earth, and the relationship between people and the environment has changed irrevocably since the industrial revolution (Steffen et al. 2011). At a global scale, people transformed 25 to 30% of the planet's terrestrial land from the start of the industrial era to 1950 through intensive land use practices. This has greatly altered animal diversity over vast areas, especially by reducing and even eliminating populations of many mammal species, and replacing these with domestic stock (Steffen et al. 2007). This land cover transformation, which has been due to the conversion of natural ecosystems to support a variety of human livelihoods and commercial activities, provides direct benefits such as greater volumes and quality of food production. This improves wellbeing in human society and is also linked to improvements in the wealth and the livelihoods of land owners (Sanchez & Leakey, 1997; Foyer et al. 2005). Adverse effects of land transformation include degradation of soils, increased nitrogen inputs and associated pollution of water flows, over-extraction and inefficient use of surface water supplies and destruction of endemic and indigenous plant and animal species (DeFries et al. 2004).

Ecosystems with lowered biodiversity levels are thought to be less resilient to environmental disturbance and change (Yachi & Loreau, 1999; Peterson et al. 1998). Indirect impacts that are driven by this anthropogenic activity disturbs biogeochemical cycles and ultimately alters feedbacks to the global climate change which may be irreversible if current trends continue (Vitousek et al. 1997; Leemans, 1999).

Such effects may even propagate from the land surface into the oceans. For example, long term declines in coastal and marine fisheries in regions like coastal California are anticipated with a major cause identified as the disturbance of the nitrogen cycle in terrestrial and marine ecosystems (Vitousek et al. 1997). An increase of this mobile element in other ecosystems

causes soil nutrient loss and fresh water aquatic acidification which adversely affects aquatic biota (Vitousek et al. 1997). All of these adverse impacts affect ecosystem service provisioning which are of value not only at the local level, but also the regional and global levels. It is only relatively recently that the value of ecosystem services has even entered the discourse on optimal allocation of land resources (Costanza, 1999; MEA 2005).

While intensive and extensive land transformation dates back millennia to its first expressions in the Middle East and Europe, it is a relatively new phenomenon in southern Africa, and in South Africa it accelerated only several centuries after initial European colonization in the 1600's. In the southern Cape of South Africa, intensive land use accelerated considerably after the 2<sup>nd</sup> world war, This provides a useful study area for exploring the impacts and drivers of land use that have occurred over a relatively short period of time, with significant areas remaining that are still in their pre-transformation state. The study area also provides an interesting political setting due to the socio-economic and political transition that occurred in South Africa in the mid 1990's.

### 1.1 Brief Historical Background

Early modern humans appear to have survived through glacial times (150 000 to 15 000 years ago) in the southern Cape, living mainly off marine resources, but also hunting and using plant resources such as geophytes (Marean, 2010). Anthropologists now believe that agricultural societies emerged in the Middle East between 10 000 and 6 000 years ago, once interglacial climatic conditions became established (Chiras, 2013). In Africa, pastoralists with flocks of sheep, goats and cattle roamed the Sahara 7000 years ago (Cowan et al. 2006). Furthermore, in order to understand the relationships of people and domesticating plants, archaeologists have been examining the time ranges for human origins of the Bantu Iron Age expansion. Their records indicate that intensive agriculture arrived relatively late in Southern Africa compared to sub-Saharan regions (Cowan et al. 2006).

Little is known about land use practices by people of the southern Cape prior to European colonization, but it appears that people of the then Zwellendam would have been Hottentot peoples before the 17<sup>th</sup> century (Skead, 2009). Historical records show that land use and land cover responded differently to the practices of the local people and colonizing Europeans in the “Zwellendam” which is today known as Swellendam (Skead, 2009). The Hottentot people’s system of pastoral farming more closely mimicked the impacts of wild game, by moving livestock around as they browsed and grazed (Skead, 2009). European colonists, by contrast, introduced the concept of individual land ownership, leading to intense grazing on the same ground year after year causing overgrazing because they had higher stock concentrations *in situ* than Hottentot peoples did.

In a study of land degradation in South Africa, Hoffman & Ashwell (2001) suggested that land degradation in a given area have a direct relationship with land ownership, land tenure and labour. Hoffman and Ashwell (2001) pointed out that in South Africa, war and political aspirations severely changed the settlement types of San and Khoe-khoen peoples, thus affecting the determinants of degradation through changes in land ownership and land use. For example, during the era of 1700’s, aloes grew in abundance between the Duiwenhoks River at Heidelberg and the Gourits River which runs about 65 km to the East, and in some places entirely covered the hills and the sides of the mountains. This encouraged aloe farming by a local farmer known as De Wett, but today this practice has been converted into intensive development of aloe derived products in the region (Skead, 2009).

Early records of terrestrial veld deterioration and disturbance in 1775 are reported by Sparrman near Heidelberg and Riversdale (Skead, 2009). Veld deterioration is generally the decline in surface vegetation cover mostly due to overgrazing and extension of farming activities. In South Africa, this has been monitored quite extensively from 1935 (Botha & Stevens, 1999). Most Southern African biome types have experienced a transformation that

has negatively affected inland water bodies and reducing the original extent of the biome through encroachment of intensive and extensive agriculture (Campbell & Child, 1971; Hudak & Wessman, 1998).

Sparman suggested that cultivation and land clearing encouraged the encroachment of Renosterbos (*Elytropappus rhinocerotis*) (Skead, 2009). Indeed Levyns (1956) viewed Renosterbos as a “fire-weed” and suggested that burning acted as a stimulus to seedling development and rapid encroachment onto nutrient rich soils. However, more recent views are that this endemic species has long been a common element of the vegetation (Bergh et al. 2014). Thus, while it was believed that the clearing and burning of vegetation for agricultural purposes in the Duiwenhoks catchment encouraged the spread of Renosterbos, this does not appear to be supported and is now difficult if not impossible to reassess due to the widespread conversion of Renosterbos into intensively worked farmland (Mucina & Rutherford, 2006).

The Duiwenhoks River was named in 1689 by an explorer called Izaak Schryver after seeing a flock of doves in the region – “duiwenhok” translates to “dovecote” in English (Carter & Brownlie, 1990). Adjacent to the river is the town of Heidelberg which was established in 1885. The first land grant was made in 1725 to a “Doornboom” farm meaning the Thorn Tree which is a species of the Mimosa family for livestock grazing (Verdoorn, 1954, Mutti et al. 2006). The Duiwenhoks catchment was well settled by the mid to late 18<sup>th</sup> century (Bohen, 1986). Urbanized areas have seen very little growth from the 19<sup>th</sup> century in terms of area coverage based on remotely-sensed observations, and dated buildings and churches of the 18<sup>th</sup> century. However, it is believed that an increase in apparently unsustainable farming practices over the years, together with changing climatic conditions, have disturbed the natural functioning of the catchment (Price, 2006). Nonetheless, considerable cover of untransformed natural vegetation remains in the upper catchment. Agricultural production increased only in the middle and lower catchment (Carter & Brownlie, 1990).

Heidelberg town, the second biggest inland town in the Hessequa region, has an economy that is heavily dependent on commercial agriculture (Hessequa Municipality, 2013). Hessequa was the most affected town within the Western Cape Province after extreme rainfall events in 2004. Price (2006) profiled the impacts of such “cut-off flow” events and pointed out that the floods caused damage to infrastructure and agricultural land in and around Heidelberg leading to significant losses for the agricultural sector. De Waal (2012) also indicated that severe floods in the Western Cape over the past several years have caused significant damage to hydraulic structures such as dams, pipelines and drainage systems. Other infrastructures such as roads and buildings and bridges were also affected. Out of 137 rainfall stations, De Waal (2012) found a 62% increase in 50 year flood return, A typical example is the extreme rainfall patterns which caused the 2004 floods in Duiwenhoks on the 22<sup>nd</sup> of December indicating rapid rainfalls induced by climate change (Price, 2006).

Studies carried out in and around the Duiwenhoks River catchment have emphasized a need for future planning to avoid extreme rainfall driven impacts, which can be ameliorated at least by more sustainable land management practices. For example, Price (2006) indicated that the flash floods which occurred in 2004 were exacerbated by factors such as inappropriate farming practices, badly planned settlements and removal of natural vegetation types in the catchment and alongside rivers.

## 1.2 Rationale

Many studies have been conducted to monitor the effects of land use changes on streamflow and hydrology in South African Mediterranean climates of the Western Cape over the past decades on rainfall, evaporation and the loss of ground-water flow (Wicht, 1942; Wicht et al. 1969). In South Africa, after much progress in ecosystem service research, implementation of

landscape management and development activities on the ground has begun to benefit land management programmes. However, there remain significant gaps in understanding biophysical and socio economic impacts of climate change (Sitas et al. 2013; Ziervogel et al. 2014), which includes threats to ecosystem services and human wellbeing (Reyers et al. 2009). Filling these gaps is essential if, for example, future development of ecosystem based adaptation responses to climate change are to be developed and implemented which will reduce adverse outcomes (IPCC, 2014).

Given that there is limited time in which to develop an understanding of how natural ecosystems respond to management interventions as climate begins to change, it is important both to reconstruct as far as possible into the past, and to monitor now and into the future, how the physical environment (land cover) responds after alterations due to natural and anthropogenic activities. This is a critical step for learning as much as possible about, how land use practices may catalyse adverse or beneficial environmental impacts. From this understanding, it should be possible to understand the role of effects on biodiversity which may support long term ecosystem resilience of natural-human systems (Biggs et al. 2012). Ecological resilience is significant because it is the amount of disturbance that a system can absorb without changing or deteriorating in state (Gunderson, 2000).

Relatively few land cover and land use studies in South Africa have used historical land cover changes based on aerial gray-scale photography at local levels, which extends the land cover record much earlier than satellite based imagery (Le Maitre et al. 2000; Morgan et al. 2010). Aerial photographs provide a potential wealth of information about historic climate change which would be critical to understand trends in adverse impacts that have emerged in the past decades, and to develop adaptation responses to reduce such impacts (Morgan et al. 2010).

This study, set in the Duiwenhoks catchment, will provide a basis for work of this kind by quantifying historical land cover change using advanced GIS and Remote Sensing desktop tools. This fundamental platform will be essential in further assessing and making future projections on land cover change which negatively affects ecosystem services on a subsequent study. This will ultimately allow innovative socio-economical and informed environmental development on management strategies and policy-relevant guidance on a subsequent project at the Duiwenhoks catchment.

### 1.3 Research Objectives

#### 1.3.1 Primary Objective

The primary objective of this study is to quantify changes in land cover and land uses between 1940 and 2010 at the Duiwenhoks catchment.

### 1.4 Research Questions

- (i) How has land cover changed in the Duiwenhoks River catchment since 1940?
- (ii) Which of the changes observed are natural and which are anthropogenic?
- (iii) What are the observed environmental impacts caused by land cover change at the Duiwenhoks?
- (iv) What has been the impact of changing government policies and adaptation mechanisms in the catchment?

### 1.5 Applied aspects of this study

With the project's main objective of quantifying land cover change in the Duiwenhoks catchment, the land cover database will be a foundation for monitoring land cover and land

use changes over a 70 year period from 1940 to 2010. The database developed will also be used further to assess the effectiveness of adaptation mechanisms for implementation actions to restore and conserve ecosystems and their services in a subsequent study.

The historic land cover trends produced as a result of this work will also be relevant in assessing and modelling the future impacts of climate change at the Duiwenhoks catchment. The Intergovernmental Panel on Climate Change (IPCC) has pointed out that there will be a general warming larger than the global mean predicted for all seasons across the African continent (IPCC, 2007). Without sufficient adaptation measures, South Africa will suffer adverse impacts on the agricultural sector ( Lobell et al. 2008; Zinyengere et al. 2013). Additionally, with most ecosystem services having a direct link to natural hydrological dynamics (Brauman et al. 2007), there is concern over their resilience to changing land use and land cover over the long run. The recent increase in mean annual temperatures by at least 1.5 times of the observed global average of 0.65 °C in South Africa over the past 5 decades has resulted in the increase in frequency of extreme rainfall events (Ziervogel et al. 2014). This signals a need to assess and promote optimal adaptation strategies in water catchments. An understanding of land cover dynamics and hydrological implications will be an important element of such an assessment.

Ziervogel et al. (2014) indicates that urgent socio economic development and adaptive responses in anticipation of future climate variability and change are critical. A subsequent project will use the statistical database produced on historic land cover changes in this study to model future hydrological trends in the catchment, since water use underpins the sustainability of ecosystem services in the catchment. Secondly, the project will use the database to assess the effectiveness of current environmental policies and adaptation mechanisms more widely. This study is performed at a fine scale (catchment level)

compared to other studies done at national and municipal levels, thus providing insights into detecting subtle trends on land cover change which cannot be observed at a large scale.

## 1.6 Study Area

### 1.6.1 Background of study area

The Duiwenhoks catchment (34°22' S; 20°00' E) is situated approximately 20 km north-east of Cape Infanta and west of the coastal town of Mossel bay in the Western Cape (see figure 1 below). The river is 82.7 km long with a catchment area of 1361 km<sup>2</sup>. The catchment has a number of small dams as well as one large reservoir (Duiwenhoks dam). The catchment falls into a climatic region that receives rain almost equally in all seasons (Harrison, 1999). Natural land cover consists of mostly mountain Fynbos in its upper reaches and Renosterveld scrublands and grassland at lower altitudes, with Fynbos and Thicket vegetation types in the coastal reaches (Mucina & Rutherford, 2006). Dominant vegetation types in the coastal belt include Limestone Fynbos; Central Mountain Renosterveld; Mountain Fynbos; Laterite Fynbos; Dune Thicket patches of Afromontane Forest (Kleynhans, 2005). The Duiwenhoks catchment falls within the Eastern Ruens Shale Renosterveld eco-region which is critically endangered, but the required target of 27% land conserved cannot be attained since over 80% of the area has already been transformed mostly for cropland (Mucina & Rutherford, 2006).

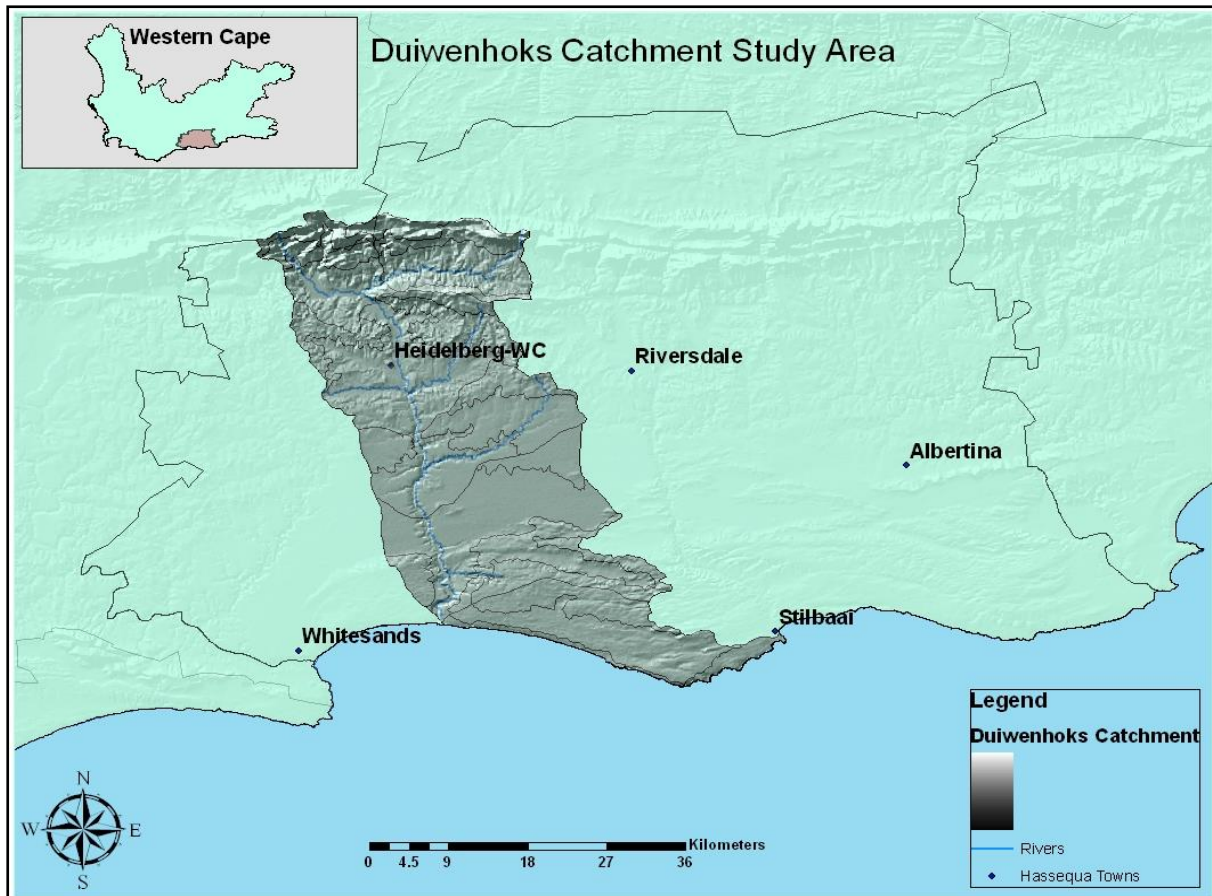


Figure 1: Duiwenhoks catchment study area

The Duiwenhoks catchment is within Hessequa local municipality (River Health Programme, 2007). Land use within the catchments mostly comprises dryland and irrigated agriculture and commercial forestry. Urban development is limited and mainly comprises residential and industrial developments associated with the coastal settlement of Stilbaai and the inland towns of Riversdale and Heidelberg (River Health Programme, 2007). The catchment falls within the Gouritz Water Management Area (WMA) which has three distinct water resource zones; The semi-arid Great Karoo, The Olifants River and the Duiwenhoks sub area (DWAf, 2004). Land use in the coastal belt of the Gouritz WMA is dominated by forestry, dairy farming and tourism. The area has numerous indigenous forests, wetlands and estuaries of high conservation status (River Health Programme, 2007). The Gouritz WMA covers a portion of the coastal line of the Western Cape in the Eden district.

### 1.6.2 Topography and rainfall

The Duiwenhoks catchment falls within the Southern Coastal Belt Ecoregion 22 and has a size of 1361km<sup>2</sup>. The ecoregion has a moderate Mean Annual Precipitation (MAP) with a low to medium drainage density. The rainfall seasonality in the area is predominantly winter to all year (Kleynhans, 2005). Although rainfall falls mainly in winter, precipitation is not entirely absent in other seasons at this coastal catchment. Due to extensive farming activities, only patches on the steepest slopes remain in a more or less natural state (Mucina & Rutherford, 2006). The MAP at tertiary catchment level is 504mm for the Duiwenhoks catchment. The Duiwenhoks River rises in the Langeberg Mountains and flows via the town of Heidelberg to the sea (Indian Ocean). The Duiwenhoks River Dam has a capacity of 6.4 million m<sup>3</sup> and an estimated 1 in 50 year yield of 9.8 million m<sup>3</sup>/a. It is owned by the Department of Water Affairs and Forestry (DWAF), and operated by the Duiwenhoks River Irrigation Board, which utilises approximately 3.7 million m<sup>3</sup>/a (1 in 50 year level of assurance of supply) for irrigation purposes. A further 1.1 million m<sup>3</sup>/a is used to supply the Duiwenhoks Rural Water Supply Scheme, of which 0.7 million m<sup>3</sup>/a is transferred into the Breede WMA to supply farmers. Heidelberg town which lies at the centre of the catchment is also supplied from the dam and has an estimated annual requirement of approximately 1 million m<sup>3</sup>/a (DWAF, 2004). At a larger scale, the topography of the Gouritz WMA as a whole is characterised by flat open plains of the semi- arid Great Karoo, Little Karoo and a narrow coastal plain with its deeply incised river valleys (River Health Programme, 2007)

### 1.6.3 Human demography

Coloured peoples are by far the most populous race group in the Hessequa municipality (Hessequa Municipality, 2013). Demographic findings of the 2011 census found that Hessequa Municipality has a population of 52 642 with a 68.5% racial population of

coloureds. Whites and Blacks had 23.2% and 7.4% population densities respectively. Afrikaans is the most widely spoken language amongst the residents, being spoken by 90.3% of the population, followed by English at 3.5 and IsiXhosa at 2% (StatsSA, 2011).

#### 1.6.4 Catchment delineation

The study's spatial classification was done at a quinary scale (Schulze & Horan, 2010) in order to understand detailed changes in land cover, land uses and ecological indicators that show stress in ecosystem status. The main idea behind this was to understand impacts at an appropriately fine scale for planning in future large projects. To do this, established catchment delineation shapefiles obtained from the Department of Water Affairs and Forestry were used to identify the homogeneous quinary catchments which are categorized with regard to rainfall, temperature, slope, soil attributes and typical land uses. This is important in assessing ecological flow responses as well as in developing adaptation strategies to climate change in which implementation depends very much on landscape characteristics (Schulze et al. 2011).

The South African government, through DWAF, has a system of catchment delineations used for planning and management. These catchments are nested hydrological units from the primary drainage basin, through to secondary and tertiary catchments, with the smallest operational unit being a quaternary catchment (Driver, 2011). Additional to this are 5<sup>th</sup> generation quinary catchment which can simply be defined as sub-delineated fifth level hydrological homogeneous sub-catchments from quaternary catchments according to altitude criteria (Schulze et al. 2011). Primary catchments in South Africa amount to 22 followed by secondary catchment totalling 148. Further delineation of secondary catchments produces tertiary catchments which total to 278. Quaternary catchments amount to 1 946 and lastly, the quinary catchments add up to 5 838 in South Africa.

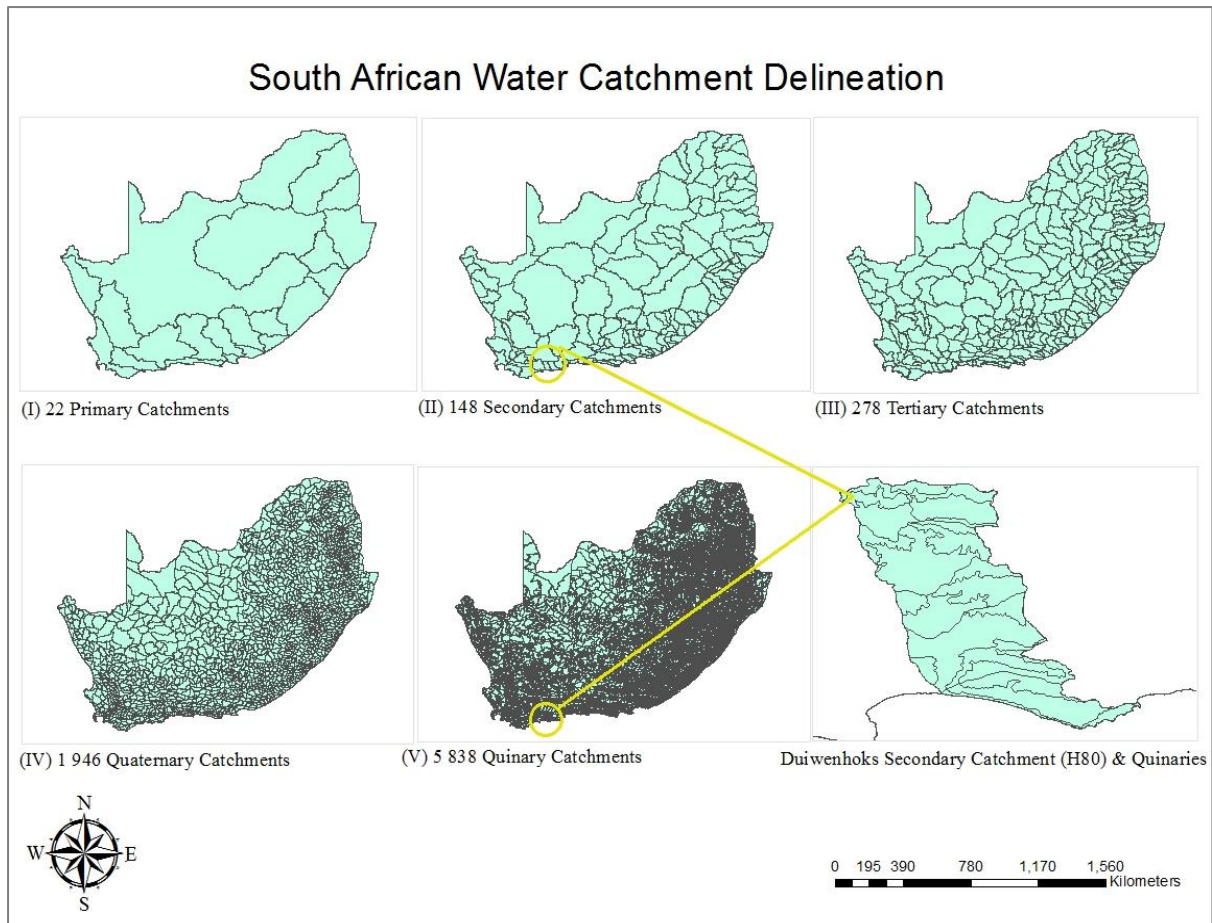


Figure 2: Sub-delineation of South Africa into 5838 quinary (Schulze et al. 2011).

## 1.7 Thesis Structure

This thesis consists of 5 chapters which are briefly described below in figure 3. Appendices to the thesis include land cover maps, statistics of secondary digitized classes and accuracy assessment scores from different classification algorithms.

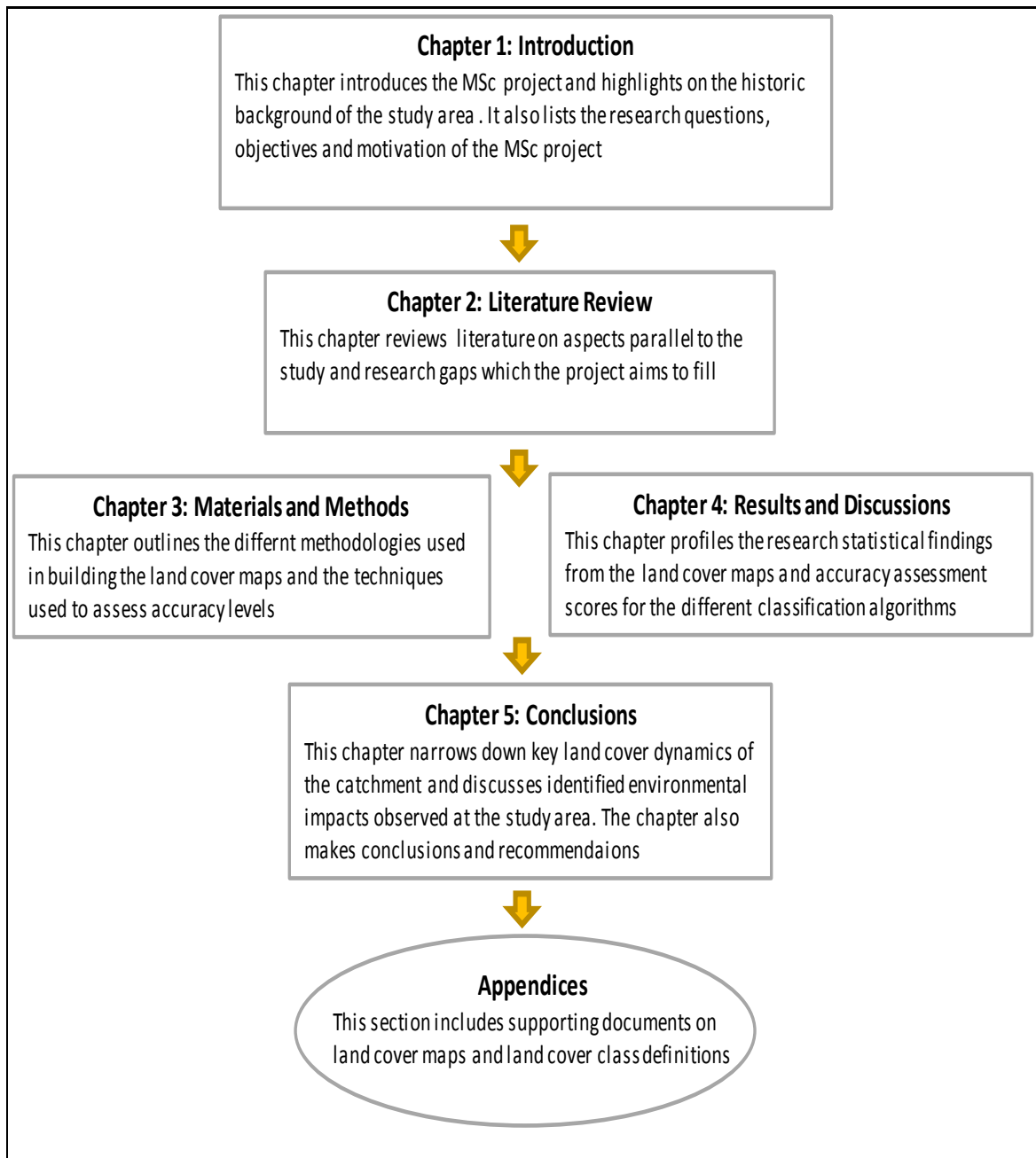


Figure 3: Thesis structure

## **Chapter 2: Literature Review**

### **2.1 Introduction**

The literature covered in this section focuses mainly on land use and land cover changes and their interdependent relationship with environmental impacts, ecosystem services and resilience. The chapter also reviews environmental impacts associated with inappropriate land uses either due to inadequate foresight about the consequences of land cover change or poor environmental conservation policies within catchments. This section also profiles scientific work that has been done to understand how the biophysical environment adapts to the effects of land use and land cover changes with the aim of optimising ecosystem service delivery.

### **2.2 Land use and land cover change**

Land use and land cover are closely related terms but should not be used interchangeably. Land cover refers to the physical surface of the earth, including various combinations of vegetation types, soils, exposed rocks and water bodies. The term can also describe “the vegetation and artificial constructions covering the land surface” (Burley, 1961). Land use, on the other hand, means the purpose to which the land cover is committed or man’s activities on it, which may include a wide variety and combination of activities (Clawson & Stewart, 1965). With the advent of image photographing technology, land cover can be observed on the surface of the earth by instruments like earth orbiting satellite sensors which remotely capture the physical structure of the earth at different scales and seasons for human planning and environmental monitoring. Therefore, land use is inferred from land cover derived from remote sensing together with on the ground verification (Clawson & Stewart, 1965).

### 2.2.1 Monitoring land cover change

In order to sustain arable land and the environment in general for the purpose of making future projections on food provision, spatial planning, disaster risk management and early warning signs on catastrophic events such as floods, it is important to monitor trends and dynamics of land cover changes (Lambin et al. 2000). Monitoring land cover change and its land use drivers is fundamental to the understanding of numerous social, economic and environmental problems because of the inter-connections of humans and their immediate environment (Foley et al. 2005). Some observations of land use and land cover change indicate that it is amongst the most important alterations of Earth's land surface (Pelorosso et al. 2009). Most often, localised catchment's long term observations of land use and land cover change patterns is often unavailable. Moreover, information on the consequences of land cover change for ecosystem services and human wellbeing at local scales is largely absent (Reyers et al. 2009). Land cover change has been identified as one of the most important drivers of change in ecosystem services, especially because it has a direct effect on hydrological processes through its link with evapotranspiration regimes on one hand and on the other hand the degree and type of ground cover has enormous impacts on mitigation of surface runoff (Reyers et al. 2009).

### 2.2.2 Change detection on land use and land cover change

Over the past decades, the increasing availability of modern technology such as satellite imagery, Geographic Information Systems (GIS) and Remote Sensing (RS) analysis systems coupled with Global Positioning Systems (GPS) and modern tools have allowed the production of reliable spatial statistical data on land use and land cover changes (Jansen & Di Gregorio, 2003). Change detection of the Earth's surface provides a foundation for better understanding on relationships and interactions between human beings and natural

phenomena. Throughout the advent of earth observation discoveries, processes have evolved using different instruments and datasets to detect changes. Common amongst these is the application of multi-temporal datasets to quantify and analyse temporal effects on the Earth's surface (Bartholomé & Belward, 2005). There are various methods of detecting change on land cover and these are generally achieved by the use of Geographical Information System (GIS) approaches, Remote Sensing (RS) for classification, visual analysis, and repeated photography (Lu et al. 2004; Stow et al. 2004). The change detection classification category using desktop tools includes image classification comparison methods, spectral-temporal combined analysis using specially designed algorithms (Lu et al. 2004). With most human developmental activities like urban environment growth and the expansion in agricultural activities associated with adverse impacts on the physical environment, such land use and land cover can be detected and modelled for future planning and sustainable developments (Lambin, 1997, Jansen & Gregorio, 2002, Bartholomé & Belward, 2005).

### 2.3 Environmental impacts of land use and land cover change

If unabated, unsustainable land use and land cover trends can negatively affect the physical environment and this may result in irreversible environmental impacts on fragile ecosystems such as wetlands (Chapin et al. 2000). Both inland terrestrial and coastal environments are susceptible to deterioration through poor land use planning and land cover change.

The Duiwenhoks catchment falls in a coastal environment in the Western Cape's south eastern coastline. Coastal ecosystems and the transitional strip of land that straddles the coastline contains some of the most productive and valuable habitats of the biosphere including coastal wetlands and estuaries (Clark, 1995). Therefore, impacts on coastal ecosystems from terrestrial activity include industrial and agricultural pollution, siltation and eroded uplands (Clark, 1995). Environmental impacts can be observed after decadal spatial datasets are available and compared either through desktop analysis or by visual

observations. For example, Dinka (2012) used remote sensing techniques to monitor land use changes from 1973 to 2000 at Lake Basaka catchment. The study findings indicate that the catchment experienced drastic changes over the last 4-5 decades due to an increase in human settlement, deforestation and the establishment of irrigation schemes.

Scientific evidence indicates that anthropogenic climate change also is likely to have severe impacts on the environment (Rockström et al. 2009). Land use and land cover change together with climate change poses a significant threat to water resources, food security, health, infrastructure and ecosystem services (Ziervogel et al. 2014). In most cases, environmental impacts caused by land use driven land cover affect the bio-physical environment via interrelated impacts on aquatic ecosystems and terrestrial ecosystems.

### 2.3.1 Terrestrial impacts of land use and land cover change

Common environmental impacts of land use activities include biophysical impacts like soil erosion, deforestation and desertification whereby natural endemic biodiversity may be impacted (Bellot et al. 2001; Cebecauer & Hofierka, 2008). Secondary impacts also include feedback effects on climate change, by reducing the regulation of climate and air quality (Foley et al. 2005). Soil erosion, which has been monitored by various techniques including GIS and repeated photography, comprises the principal degradation process and leads to a decrease in the top soil effective root depth and water nutrient (Arshad & Coen, 1992; Yang et al. 2003). It is a major threat to the sustainability and productive capacity of agriculture. Soil erosion by water is sometimes considered to be a purely natural process caused by water flow and wind (La, 2007). However, important land parameters such as soil texture, soil depth, topography, parent material and climatic conditions are related to vegetation performance and the degree of erosion (Kosmas et al. 2000).

Human activities greatly aggravate erosion of soil through alteration of land cover and disturbance of soil (Yang et al. 2003). The abandonment of agricultural lands due to economic and social changes can be followed by significant impacts on soil erosion. Land abandonment may have positive or negative impacts on soil protection from erosion (Koulouri & Giourga, 2007). With land use and land cover being the most important factors that influence the occurrence and intensity of surface and soil erosion, proper regulation of land use and land cover can greatly improve soil properties and minimize secondary impacts that it is associated with it.

In the Southern Cape, alien vegetation infestations have been a great cause for concern about environmental sustainability. Common invasive alien species in the Duiwenhoks includes Black Wattle (*Acacia mearnsii*), which is known to have high rates of water use relative to natural vegetation. A study in the Southern Cape's Krom River has assessed its impact on wetland transformation and deterioration with a change in adjacent land cover over 50 years. Findings from the study indicate that this alien tree species has drastically reduced both streamflow and baseflow (Rebelo, 2012). Other alien species located along the Duiwenhoks River channel and feeding streams include the Australian golden wattle (*Acacia saligna*) (located at historically cultivated lands which are now used for pastoral activities), and the Silky hakea (*Hakea sericea*) (located on the upper high altitude catchment). Through time, and if conservative measures are not put in place, alien vegetation with a changing land cover system impacts negatively on ecosystem sustainability and resilience (Rebelo, 2012).

### 2.3.2 Aquatic impacts of land use and land cover change

Although land use activities generally occur in the terrestrial environment, adverse impacts find their way to aquatic ecosystems either directly or indirectly (LeBlanc et al. 1997; Allan, 1997; Allan, 2004). A good example is intensive agricultural activity during which

unsustainable cultivation methods and fertilization may lead to river sedimentation, siltation, salinization subsequently causing alkalinisation on aquatic ecosystems (Szabolcs, 1990). This may cause aquatic biodiversity to be affected indirectly through siltation and alkalinisation of water resources. In some instances, increased runoff from agricultural fields greatly disturbs stream flow regimes and transports fertilizer chemicals to other sensitive ecosystems and affects ground water quality (Cooper & Carliell-Marquet, 2013). Aquifer disturbance in wetland ecosystems exacerbates drought and groundwater recharge (Boulton & Lake, 2008; Cooper & Carliell-Marquet, 2013). Improper land management may lead to severe water runoff and soil loss on mountain sides which causes gully development, leading to further increases in the sediment load in rivers (Peng & Wang, 2012). The total amount of rainfall is one of the determining elements of the severity of surface runoff and erosion processes coupled with many other factors such as land use and land cover change. Non uniform variations in land use and vegetation coverage also impacts on hydrological responses in river catchments (Wei et al. 2007).

#### 2.4 Ecosystem services and resilience to land use and land cover change

Ecosystem services have been defined broadly both in the science academic fields, government and institutional organisations response mechanisms. The Millennium Ecosystem Assessment (MEA) initiated in 2001 to study and assess ecosystem changes and its resulting effects on service delivery to support human well-being distinguishes four categories of ecosystem services. These include provisioning, regulating, supporting and cultural services. Under the provisioning services, goods and services such as food and water storage respectively are provided. The latter two (supporting and cultural) are generally socially or human orientated services while ecosystem regulating services refer to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and

life support systems through bio-geochemical cycles and other biospheric classes (MEA, 2005; Reid et al. 2002).

From more than 100 years ago, biodiversity loss and its impact on global change have been observed, resulting in the identification of the importance of ecological functioning for ecological resilience (Walker & Steffen, 1996). Ecosystem functions refer to the interlinked habitats, system properties and processes of ecosystems which ultimately provide goods and services to human beings (Costanza et al. 2007). Egoh et al. (2007) further indicates that ecosystem services have been described differently when approached from the different perspectives of conservation management and policy planning. Terms such as ecosystem function, ecological services, ecological function, environmental services and environmental function are sometimes used interchangeably with the term ecosystem services. In most of its definitions, the term is mostly human orientated towards benefits that people can derive from naturally occurring ecosystems.

Ecosystems not only provide directly tangible goods such as food, fuel, water and timber, but also provide indirectly regulating services such as flood mitigation and climate regulation, and much less tangible services such as spiritual and aesthetic wellbeing (Van Jaarsveld et al. 2005). Furthermore, while services such as water storage, pollination, pest control and cultural values have been viewed as “indirect services”, it is now clear that these ultimately provide tangible benefits (Lautenbach et al. 2011), and it is now widely appreciated that human wellbeing is fundamentally supported by services from the natural environment.

Sound policy and management decisions can often ameliorate or reverse ecosystem degradation and increase the contribution of ecosystem services to human wellbeing. Knowing how and when to intervene requires significant understanding of both ecological

and social systems involved (Mooney et al. 2004). For this project, the widely used MEA ecosystem services definition will be adopted.

#### 2.4.1 Hydrological ecosystem services

Hydrological services can be organized into five broad categories: improvement of extractive water supply, improvement of in-stream water supply, water damage mitigation, provision of water related cultural services, and water-associated supporting services (Brauman et al. 2007). From the supply of water for household use to the mitigation of flood damages, people rely on ecosystems to provide many water related services (Brauman et al. 2007). Additionally, hydrological processes have been identified as delivering ecosystem services that are fundamental to both human wellbeing and the maintenance of biodiversity (Pert et al. 2010). Ecosystems provide hydrologic services in tandem with a variety of other essential services, including air quality, carbon dioxide sequestration, and soil generation (Brauman et al. 2007). Changes in vegetation/land cover can affect runoff generation and concentration by altering hydrologic processes and influence the magnitude of deterioration in water quality and spatial distribution of water resources. Therefore, a thorough understanding of land cover dynamics is necessary for reconstructing past land cover scenarios and predicting potential scenarios (Zhang et al. 2012).

#### 2.4.2 Ecosystem resilience and hydrological responses to land use and land cover

The repeated occurrence of adverse anthropogenic impacts on the natural environment may reach a threshold where multiple natural responses are triggered. Lenton (2013) identifies these as “tipping points” and points out that once environmental impacts reach a threshold in climatic or Earth ecosystems; they are often difficult to reverse. A small “perturbation” of this nature ultimately disturbs functioning bio-geophysical, bio-geochemical, bio-geomorphological and ecological processes and resilience. Stone et al (1996) defines

ecosystem resilience as the speed at which a system returns to quasi-equilibrium after perturbation. A highly resilient system would thus return to equilibrium rapidly after disturbance. It is thus important to monitor these “tipping points” in order to cushion the effect of negative impacts and promote ecosystem resilience. Lenton (2013) suggest that structural and statistical indicators may be good indicators to identify tipping points by simply looking for generic indicators of loss and appearance in multiple factors and by using spatial data to assess resilience over time. Species diversity is often cited as a key feature of ecosystem resilience and nutrient cycling has often been used as a measure of ecosystem stability (Mitchell et al. 2000).

Predicting the hydrological impact of land use and land cover changes is critical for water resource management. Over the past century, a large number of field experiments has been conducted to quantify the impact of vegetation changes on catchment water balance (Oudin et al. 2008). Changes in land use, particularly in the terrestrial ecological land use categories may significantly affect ecosystem processes. Analysis at catchment level in Menglun, Xishuangbanna, southwest of China showed that there were significant changes in ecological functions such as nutrient cycling, erosion control, climate regulation and water treatment as well as recreation (Hu et al. 2008).

## 2.5 Ecological indicators of degrading ecosystems and their services

Historically, the health of an ecosystem has been measured using indices of a particular species or components. Such indices are inadequate because they are not broad enough to reflect the complexity of ecosystems (Xu et al. 1999). South Africa’s terrestrial and fresh water ecosystems are not in pristine condition, but rather in a modified and often damaged state. These results in pressures on biodiversity and environmental resources caused by indirect factors such as the ever-changing land use associated with natural vegetation clearing

(DEAT, 2005). This is usually through human exploitation, by virtue of a lack of sustainable practices through which the ecosystem is exploited and the failure to enforce policy (Maloti Drakensberg Transfrontier Project, 2007).

Ecological indicators are used to assess the condition of the environment, to provide early warning signal of changes in the environment, or to diagnose the cause of an environmental problem. They can also be used to assess the condition of the environment or to monitor trends in condition over time (Dale & Beyeler, 2001). They represent a numerical or a descriptive categorization of environmental data. This is frequently based on discrete pieces of information that reflect the status of large environmental systems (Manoliadis, 2002). Ecological indicators are usually developed by scientists and focused on aspects of ecosystems they believe are important for the assessment of a condition (Niemi & McDonald, 2013).

The technical report on the National Ecosystem Priority Areas project (NFEPa) is a multi-partner collaboration of biodiversity conservation planners and researchers. It identifies Freshwater Ecosystem Priority Areas and develops a basis for implementing effective implementation measures. The main objective of the NFEPa establishment is to provide strategic spatial priorities for conserving the countries freshwater ecosystems. An array of maps is amongst some of the products produced in order to aid in decision making from numerous stakeholders. According to the NFEPa findings, much of the Duiwenhoks River and the surrounding wetland ecosystems are critically endangered (Nel et al. 2009).

## 2.6 Adaptation to impacts induced by land cover change

At a global scale, environmental adaptation, conservation and management practices have been introduced to promote environmental and biodiversity sustainability due to land cover dynamics and climate change. Some of these have been successful and effective in managing

forests, national private parks and some private lands (Barrett et al. 2001; Adger et al. 2003). Many NGO's, government organisations and conservancies at international, national and local scales are having increased presence on the ground to conserve, manage, rehabilitate and monitor the physical environment like WWF (World Wide Fund) and Conservation International (Groves et al. 2002). Work on the ground has been increasing due to the increased scientific evidence of a changing climate which exacerbates more terrestrial impacts due to land use and land cover change. Over the past decades, international dialogues through the United Nations Framework Convention on Climate Change (UNFCCC) have developed a holistic and impactful response to climate change (Adger et al. 2003).

International agreements and response mechanisms to climate change have led to the development of new adaptation mechanisms such as Ecosystem-based Adaptation (EbA) and Ecological Infrastructures (McCann et al. 2015). EbA essentially uses biodiversity and ecosystem services to help people adapt to negative effects of climate change (Stein et al 2013). It is thought to be cost effective because it generates social, economic and cultural benefits without significant economic inputs, while also contributing to biodiversity conservation (CBD AHTEG. 2011; Munang et al. 2013). Additionally, policy measures have been identified that take into account the role of ecosystem services in reducing the vulnerability of society to climate change in a multi-sectoral and multiscale approach (Vignola et al. 2009).

Ecosystem-based adaptation approaches address the crucial links between climate change, biodiversity and sustainable resource management by preserving and enhancing ecosystems (Munang et al. 2013). The capacity of ecosystems to provide services to sectors of the society is pressured by land use change and climate change. Economies and human wellbeing depend on ecosystem. Thus, policies for adaptation to climate change should take into account the role of these ecosystems in increasing the resilience of society. Adaptation mechanisms

involve national and regional governments, local communities, private companies and NGOs in addressing the different pressures on ecosystem services (Vignola et al. 2009).

Multiple mechanisms and approaches should be integrated when developing adaptation strategies and actions. Land-use planning, natural systems adaptation, community and social adaptation, economic instruments, policies and plans are tools that can be used as adaptation techniques to enhance ecosystem sustainability (Tuan et al. 2012). Therefore, attention to a broad spectrum of adaptation options is urgently needed (Munang et al. 2013). However, only limited opportunities for adaptation exist in natural ecosystems as listed below in table 1.

Table 1: Adaptation options to ecosystems (Adapted from Running & Mills, 2009)

<b>Key areas of concern</b>	<b>Adaptation options</b>
1. Adaptation of stream systems	<ul style="list-style-type: none"> <li>• Develop small high mountain water storage reservoirs</li> <li>• Protect and enhance riparian ecosystems and wetlands as hydrological buffers</li> </ul>
2. Vegetation management	<ul style="list-style-type: none"> <li>• Control of invasive plants</li> <li>• Planting and cutting of trees</li> </ul>
3. Resilience management	<ul style="list-style-type: none"> <li>• Restoring spatial heterogeneity</li> <li>• Facilitate the movement of species beyond their current occupied range</li> </ul>

### 2.6.1 Adaptation programmes

Climate change, land cover change and ecosystem services adaptive programmes and mechanisms are rolled out to conserve, rehabilitate and restore ecosystems and their services. Funding for these processes is through local government and international agencies. The

Adaptation Fund (AF) is one of the international agencies which cushions financial aid for adaptation initiatives. It finances concrete adaptation projects and programmes with particular emphasis on the most vulnerable communities. It is well known for being the first institution offering direct access modality as an option to developing countries in the context of climate change finance. Vulnerable developing countries nominate domestic institutions for accreditation as National Implementing Entities (NIEs) which are responsible for endorsing project and program proposals from their countries and are also direct recipients of the funding (Adaptation Fund Board, 2009).

A key feature of adaptation responses is that they have a much stronger local context than do mitigation responses and their benefits may appear much faster and are often more tangible, such as an improvement in local environmental quality (National Climate Change Response White Paper, 2011). Although adaptation to climate change is designed at a national level and implemented at provincial and local governments, the National Climate Change Response White Paper makes substantial demands related to adaptation and planning in key sectors like agriculture, forestry, marine and water sectors (Ziervogel et al. 2014). This has seen incorporation of adaptation strategies at local municipal plans such as IDP's (Integrated Development Plan).

- (i) Integrated Development Plan (IDP) and Integrated Environmental Management Plan (IEMP)

The Integrated Development Plans are 5 year plans for South African local governments at municipal or district levels which cover planned initiatives for various sectors. IDP's are tools set out by government to support intergovernmental planning. The Duiwenhoks catchment which falls in the Hessequa Municipality has recognized, when drafting their 3rd IDP that there is a need for an Integrated Environmental Management Plan (IEMP) because of the importance of managing natural resources in a sustainable way. The municipality recognized

the need for a balance between the preservation and utilization of these resources (Hessequa Municipality, 2013). The IEMP forms part of Hessequa’s Municipal Integrated Development Plan by means of a sector plan which is legally required in the IDP guide packs. Incorporation of the IEMP within the IDP essentially guarantees that environmental best practices are integrated with the outcomes of the IDP process (Hessequa Municipality, 2013). Below, table 2 shows the main environmental themes that the Hessequa local municipality attempts to manage. Additionally, the table shows related policies or management plans that are incorporated in Hessequa Municipality’s IDP – IEMP incorporation listed on Table 2 below.

Table 2: Hessequa Municipality IDP policy and environmental management mandated tools

<b>Theme</b>	<b>Tool mandated</b>
1. Biodiversity	Biodiversity Sector Plan
2. Land Use	Spatial Development Framework – LUPO/Municipal Systems Act
3. Estuary Management	Estuary Management Plan – Integrated Coastal Management Act
4. River Health	River Management Plan

The IEM concept is often used to refer to the increased efforts being made at aligning and giving common direction to the policies, programmes, plans, projects and institutional arrangements of government with regard to the environment (DEAT, 2004). In South Africa, the administration of this legislation applies to the environmental media (e.g. air, land use, soil, natural resources, water and waste). It is based on the recognition within the National Environmental Act of 1998 (NEMA) that controls environmental issues. The IEM is

underpinned by a number of principles which include sustainability principles, adaptation, polluter pays, environmental justice, and continental improvement (DEAT, 2004).

#### (ii) Working for Wetlands and Cape Nature

The need for wetland rehabilitation in South Africa is compelling. This comes after the loss and degradation of wetlands has been massive. The South African national policy and legislation provides a clear direction and support for rehabilitation (Ellery et al. 2011). The Working for Wetland programme is a national initiative that seeks to promote the protection, rehabilitation and wise use of wetlands in South Africa (Ellery et al. 2011). The programme clears mountain catchments and riparian zones of invasive alien plants to restore natural fire regimes, the productive potential of land, biodiversity and hydrological functioning (Turpie et al. 2008). The programme is a joint initiative of the Departments of Environmental Affairs (DEA), the Department of Water and Sanitation (DWS) and the Department of Agriculture, Forestry and Fisheries (DAFF). According to Cape Nature, the programme focuses on the rehabilitation, wise use and protection of wetlands in a manner that maximises employment creation and supports small businesses and skills transfer. In 2007, the Goukou Duiwenhoks Working for Wetlands project started rolling out rehabilitation activities in the two catchments (Goukou and Duiwenhoks). The project was involved in wetland rehabilitation characterised by Palmiet and Peat vegetation. These are extremely valuable contributors to flood attenuation and water storage with the latter in particular being important in terms of the Climate Change challenge.

#### 2.7 Policies governing land use and land cover change

Throughout the 20<sup>th</sup> century, environmental factors and geo-political conflicts have played a significant role in the drafting of policies to ensure human well-being and environmental

sustainability for food supply. In Southern Africa, the second half of the 20<sup>th</sup> century saw developments of SADC (Southern African Development Community) communities in 1980 to address socio-economic effects of a changing environment and develop Southern African countries. Intense and historic political changes like new constitutional government transition such as the democratic dispensation in South Africa in 1994 played a major role within the SADC to address environmental degradation (Holloway, 2000). These political influences and regional assemblies of Southern Africa paved the way to new policies of addressing human's land use of the environment and promote sustainability at international, national and local scales (Holloway, 2000).

Currently, the South African government through the City of Cape Town (CoCT) uses geo-spatial and scale attributes to spatially demarcate the coastal zone for policy implementation. The coastal zone is seen as the area along the coast that ranges from 50 to 100 km wide extending from the beach to the first significant mountains (CoCT, 2003). The Coastal Zone Policy (CZP) now known as the Coastal Management Act was initiated in 1997 and has been amended to national environmental policies and bioregional planning approaches of the provincial government of the Western Cape (DEADP, 2003). It aims at addressing issues such as rehabilitation of ecosystems and their habitats, mitigating development impacts and conserving biodiversity by incorporating the directives of applicable legislation at all three levels of governance namely national, provincial and local governance levels.

(i) White Paper for Sustainable Coastal Development

The Duiwenhoks catchment which lies on the south eastern coastal belt is governed and administered in the Western Cape by legislation affecting the Coastal Zone Policy (CZP) and a range of different government departments and agencies (DEAT, 2000). The CZP builds on a number of previous programmes aimed at addressing coastal environments, its context draws largely from a wide range of national Acts such as the National Environmental

Management Act (107 of 1998), the Environmental Conservation Act (75 of 1989), the Marine and Living Resources Act (18 of 1998) and the Sea-Shore Act (21 of 1935). All these Acts contain principles which are narrowed down and are applicable at coastal level to address risk awareness and precaution, accountability and responsibility, integration and participation, economic development and ecological integrity.

- (ii) National Environmental Management Act (NEMA) and the National Water Act (NWA)

In South Africa, the physical environment and all biodiversity that inhabit it are managed and conserved by the National Environmental Management Act. The act has seen the development of various government institutions that are mandated to be custodians of biodiversity richness and the physical environment at large like SANParks (South African National Parks) and SANBI (South African National Biodiversity Institute).

The National Water Act of 1998 on the other hand is an Act passed by the South African government to provide fundamental reform law relating to water resources. The Act's central guiding principles are for the protection, management and control of water resources in the Republic. The guiding principles recognize the basic human needs of present and future generations and the need to promote social and economic development. With these as its main driving principles, the Act also aims to protect aquatic and associated ecosystems and their biological diversity; reduce pollution and prevent degradation of water resources; managing and floods and droughts etc. The NWA of 1998 through the Department of Water Affairs also acts as a custodian on Catchment Management Strategies. This is achieved by allowing catchment management agencies to progressively develop strategies for each Water Management Area (WMA). Localised WMA should take into account the geology, demography, land use, climate, vegetation, and water works within its management area

when developing strategies to conserve, store and distribute water resources (Karodia & Weston, 2001).

## 2.8 Summary

This chapter has outlined literature on land use and land cover changes and its associated impacts. It also profiled the evolution of land use and land cover change detection studies to quantify land cover and its decadal dynamics with a view to make informed decisions on environmental management. The chapter also defined and elaborated on the key ecological terms which are core elements of this project, and the broader policy context in which they are to be applied.

## **Chapter 3: Materials and Methods**

### **3.1 Introduction**

This chapter outlines the steps taken in building the Duiwenhoks catchment historical land covers datasets decadal from 1940 through to 2010. It also outlines the steps used to perform Accuracy Assessment on the three types of datasets produced by supervised classification on Principal Component (PCA) classes, unsupervised classification directly on the raw aerial photographs (AP) and manual digitizing on 2010 Colour Infrared Images (CIR). The chapter also highlights the four main primary steps involved in the study used on the aerial photographs. These are desktop aerial photograph preparation, textural analysis, land cover classification and manual digitizing. Other ancillary datasets to monitor land use and land cover change was collected from the South African Weather Services (SAWS), the Department of Water Affairs (DWA), and SANBI's National Freshwater Ecosystem Priority Areas.

### **3.2 Aerial Photograph data preparation**

The first step was to prepare the collected raw aerial photographs using four major steps driven by GIS and Remote Sensing software. The main objective of this was to build decadal imagery of the entire catchment size for the Duiwenhoks catchment. The greyscale aerial photographs datasets were from 1940 which was the benchmark to 1990 although 1980 was discarded due to a bad quality. The raw aerial photographs were collected from the National Geospatial Institute (NGI) housed within the Department of Rural Development and Land Reform (RD&LR) at Mowbray, Cape Town. After collecting the historical AP's, image georeferencing (ArcGIS 9.2), image cropping (ArcGIS 9.2), image mosaicking (ERDAS Imagine 9.1) and image clipping (ArcGIS 9.2) was operated.

Georeferencing, which is the process of assigning a geographic location on raw image photographs to the physical environment (Li & Briggs, 2006; Grapentine & Kowalski, 2010) required a high degree of accuracy, and thus involved a series of technical steps. An RMS (Root Mean Square) error of <30 metre was used in order to standardize and optimize correct feature spatial location. For continuity purposes and in order to conform to other established land cover maps (e.g. 2007 fine scale land cover), the process was performed at a relatively fine scale of 1:10 000.

The georeferenced images were then cropped, clipped and mosaicked to remove the raw black frames and labels in order for the spatial imagery features to concentrate within the Duiwenhoks catchment spatial extent. In order to maintain spatial congruence with ancillary land cover datasets, common elements and attributes of the datasets such as the pixel depth and projection had to be maintained starting from the 1940 baseline data continually with all other spatial decadal datasets. Thus, a pixel depth of 8 bit unsigned integer was used from the onset in data preparation when processing data during image cropping, mosaicking and clipping into the Area of Interest (AOI). The final aerial photographic datasets used a geographic coordinate system of GCS WGS 1984 and an Albers projection using a WGS 1984 coordinate system. The linear unit was in Meters whilst the central meridian was at 25.00000000. The standard parallel 1 and the standard parallel 2 was -33.00000000 and -24.00000000 respectively.

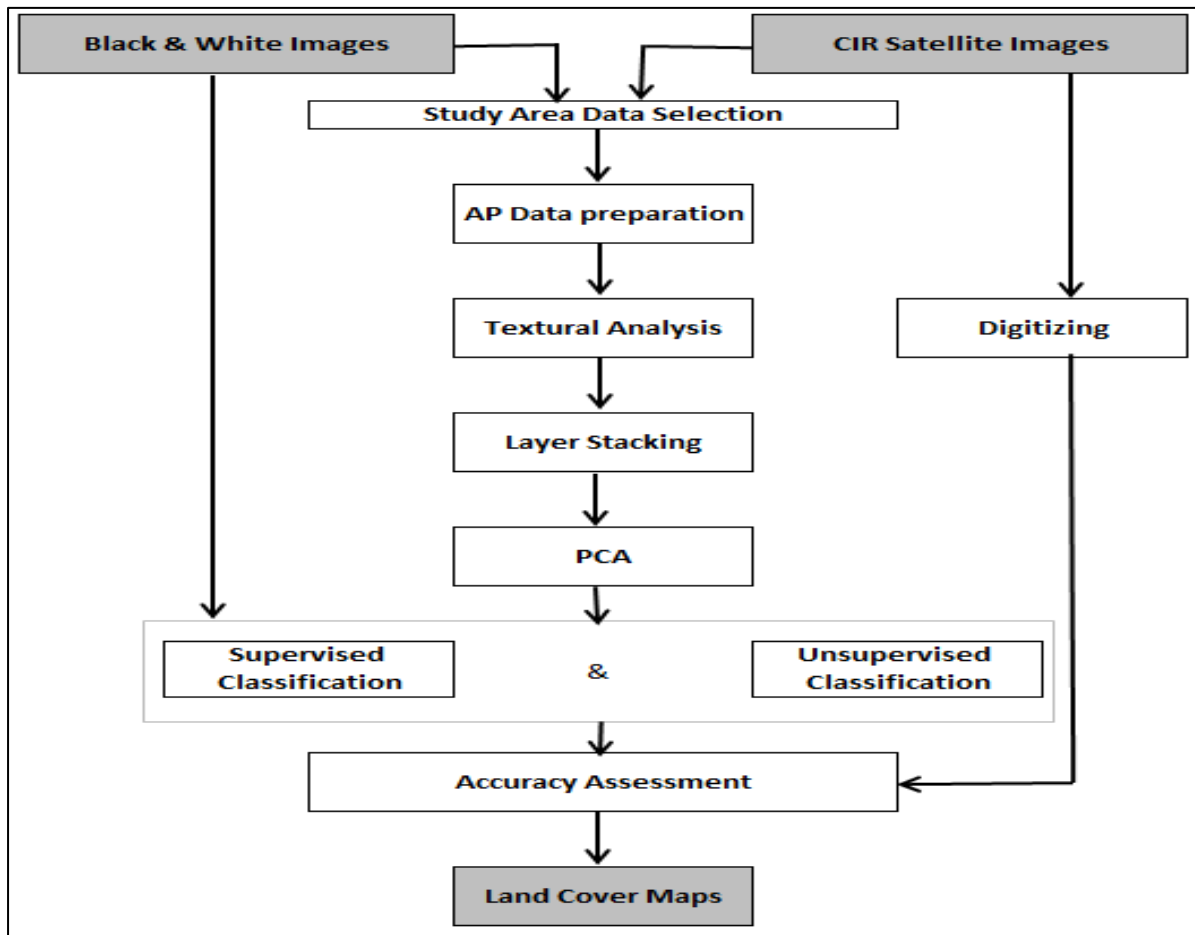


Figure 4: Methodology skeleton

Table 3: Aerial Photographs metadata

Job Number	Year	First Day of Capture	Final Day of Capture	Scale of Photo	Focal Length	Camera/Lens	Format	Final Dataset
Job # 8	1942	0	0	1:34 000	5"	F24	5'X5'	1. 1940 AP
Job # 170	1942			1:34 000	5"	F24	5'X5'	
Job # 344	1954	Mar-54	Apr-54	1:30 000		05 169	9'X9'	2. 1950 AP
Job # 444	1960	Dec-60	Dec-60	1:36 000	152.36mm	15AG 39	9'X9'	3. 1960 AP
Job # 564	1966-67	11-Dec-67	08-May-66	1:38 000	152.44mm	ZEISS RMK A	9'X9'	
Job # 735	1974	27-May-74	14-Sep-74	1:50 000-1:60 000		Wild RC10		4. 1970 AP
Job # 498	1983	08-Jun-83	08-Jun-83	1:30 000	153mm	ZEISS RMK A		5. 1980 AP
Job # 959	1991	12-Aug-91	04-Oct-91	1:50 000		ZEISS RMK A		6. 1990 AP

0= no records

Table 4: Aerial Photograph job capturing seasons

Job Number	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Final Dataset
Job # 8	0	0	0	0	0	0	0	0	0	0	0	0	1940
Job # 170	0	0	0	0	0	0	0	0	0	0	0	0	
Job # 344			√	√									1950
Job # 444												√	1960
Job # 564				√	√								
Job # 735					√	√			√				1970
Job # 498						√							1980
Job # 959								√	√	√			1990

0= no monthly records

### 3.3 Textural analysis

Texture is one of the basic image interpretation elements that have been used for decades to classify raw aerial photographic maps. It can be used to make a judgement by either visually interpreting its spatial distribution or through desktop analysis (Laliberte et al. 2004). Today, GIS and remote sensing software have devised algorithms to classify land cover features based on the surface roughness and coarseness. In aerial photographic interpretations, texture refers to the apparent minute pattern of detail for a given area (Hsu, 1978). It is further defined by terms such as smoothness, fineness, roughness and coarseness of an image. Textural differences represent important tonal information about the structural characteristics of features in the image (Hsu, 1978; Lillesand & Kiefer, 2000)

With the advent of technological tools used to make judgement on spatial features by digital processing, pixel distribution and tonal density can be used to group pixels for image classification (Hsu 1978). A number of variables and classification measures can be used to interpret pixels based on their brightness values for texture analysis and image classification. Desktop interpretation techniques by means of textural analysis has led to the development of

textural measures and filtering windows (Tsai & Chou, 2006). This is because different variables work better in different kernels/window sizes e.g. 3x3, 5x5 and 25x25 for feature detection.

Common statistical operators including skewness, kurtosis, variation, standard deviation, maximum and mean Euclidean distance have been developed and are used for texture analysis in image processing to characterize the distribution of grey levels in an image (Awwad, 2003; Dekker, 2003). This is essential in defining an image's gradient relativity before grouping and classifying pixels. Textural filters help in obtaining attributes such as textural intensity and density. The intensity shows the difference of one pixel with its neighbours. Once pixel intensities are identified, it is easier to make a distinction between a set of pixels near each other. The latter (textural density) is used to show the frequency of textural extraction according to mathematic methods (Sun & Qin, 1992). This study uses four broadly used textural measures (variance, kurtosis, skewness, and euclidean distance) on five moving kernels/windows (3x3, 5x5, 7x7, 13x13 and 25x25). This is mainly because different spatial features are extracted best using fewer filters and window sizes. However, each of the textural filters is optimized for feature detection and variation.

(i) Variance

This filtering measure categorizes and separates pixels in an image by assessing pixel variability. ERDAS, a widely used remote sensing software in spatial analysis iterates the variance textural measure by measuring the distribution of their variability in an image (ERDAS Field Guide, 2010). Using different textural filter sizes on a grey image builds pixel brightness values which are then grouped together (Anys et al. 1994; Asner et al. 2002). Therefore, this filtering measure does not carry information about the texture but shows the image's average lighting conditions (Materka & Strzelecki, 1998). The variance filtering

measure is relatively a simple technique whereby the contrast of an image is characterised by measuring the variation intensity around the mean on a desktop operation. (Tamura et al. 1978; Materka & Strzelecki, 1998; Ojala et al. 2002;).

(ii) Kurtosis

The Kurtosis measure on the other hand measures the peakedness and flatness of an image histogram (Materka and Strzelecki, 1998). During textural analysis, the Kurtosis filtering measure measures the pixel distribution in relation to the length and size of its tails (Pinamonti et al. 1989).

(iii) Skewness and Euclidean distance

In image textural analysis, the skewness textural measure measures the asymmetry in an image histogram (Pinamonti et al. 1989; ERDAS Field Guide, 2010) whilst the Euclidean distance textural measure measures the distance between  $x$  and  $y$  coordinates of pixels with remotely sensed datasets (Carr & Miranda, 1998).

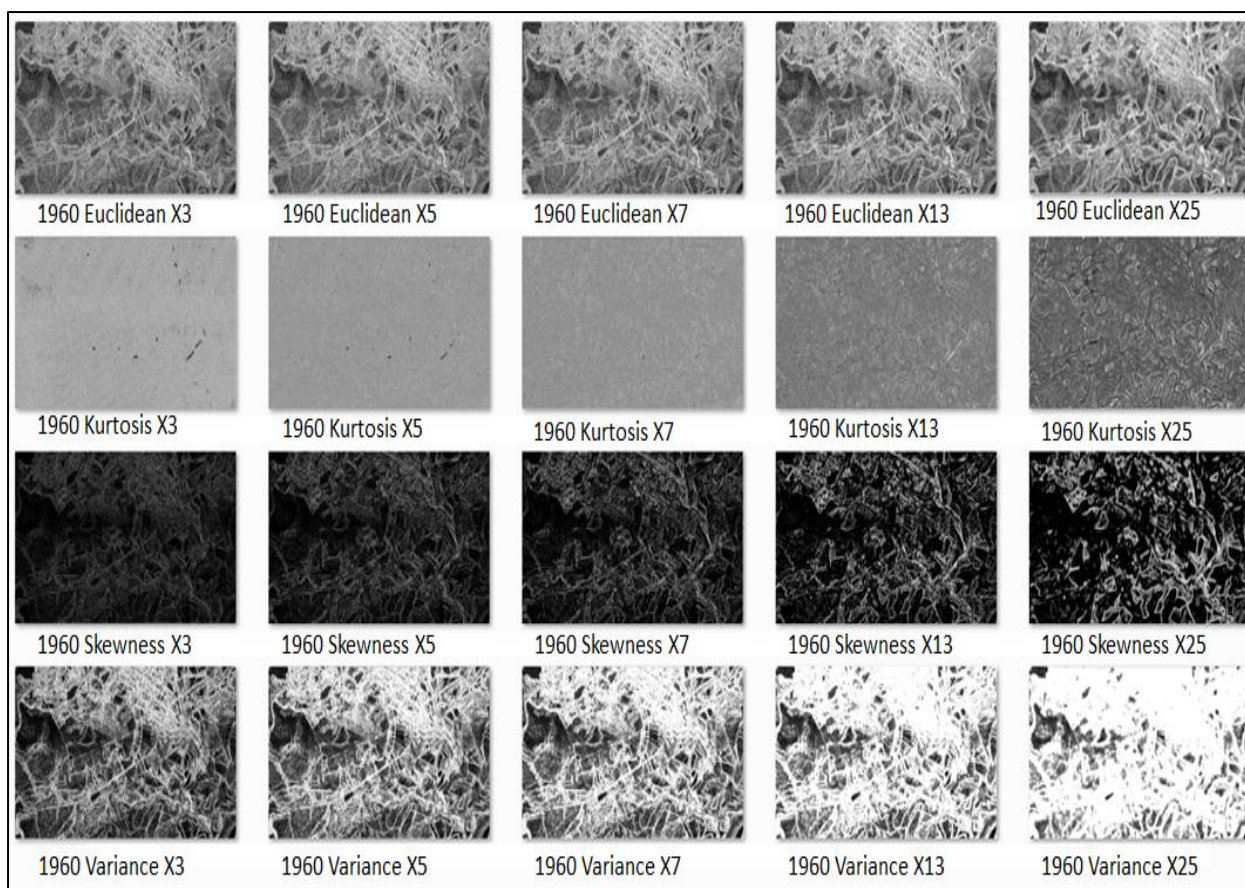


Figure 5: Four textural filters and 5 window size output produced by Erdas Intergraph

Figure 5 above shows outputs of textural measures applied in different window sizes which enhance edge detection between different land covers in an image. For the purpose of this study, all four of the textural measures in five window sizes produced 20 layers ( $4 \times 5 = 20$ ). In addition to this, the original image was added to produce a colour composite or pseudo-colour image composed of 21 bands which improves and defines edges in a process called layer stacking. A combination of textural measures in different window sizes is ideal for feature detection at a catchment level scale because different textural measures and window sizes are optimized spatial attributes. Therefore, the use of different textural measures and filters ultimately simplifies human interpretation of classification results after performing either supervised or unsupervised classification (Zhang, 1999). Figure 6 below shows the 1960 dataset on a 21 band image viewed from ENVI remote sensing software. The overall

method on image textural classification of aerial photographs throughout to PCA classification is indicated on figure 6 below.

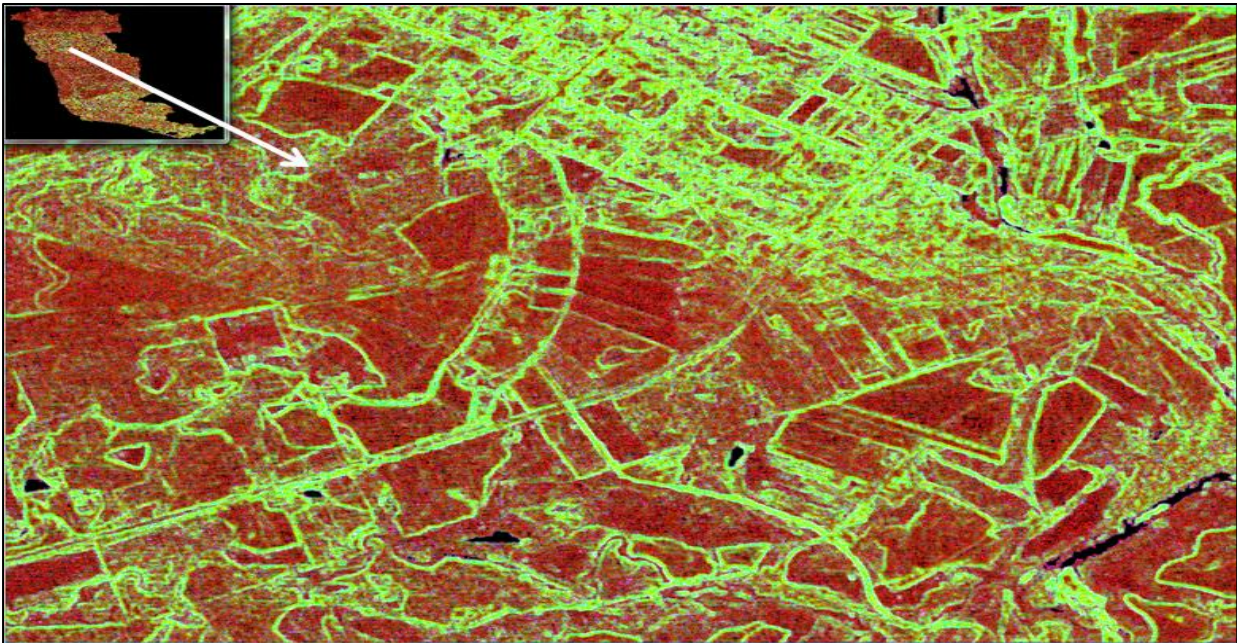


Figure 6: A 21 Band image of 1960 consisting of all filters and the original image

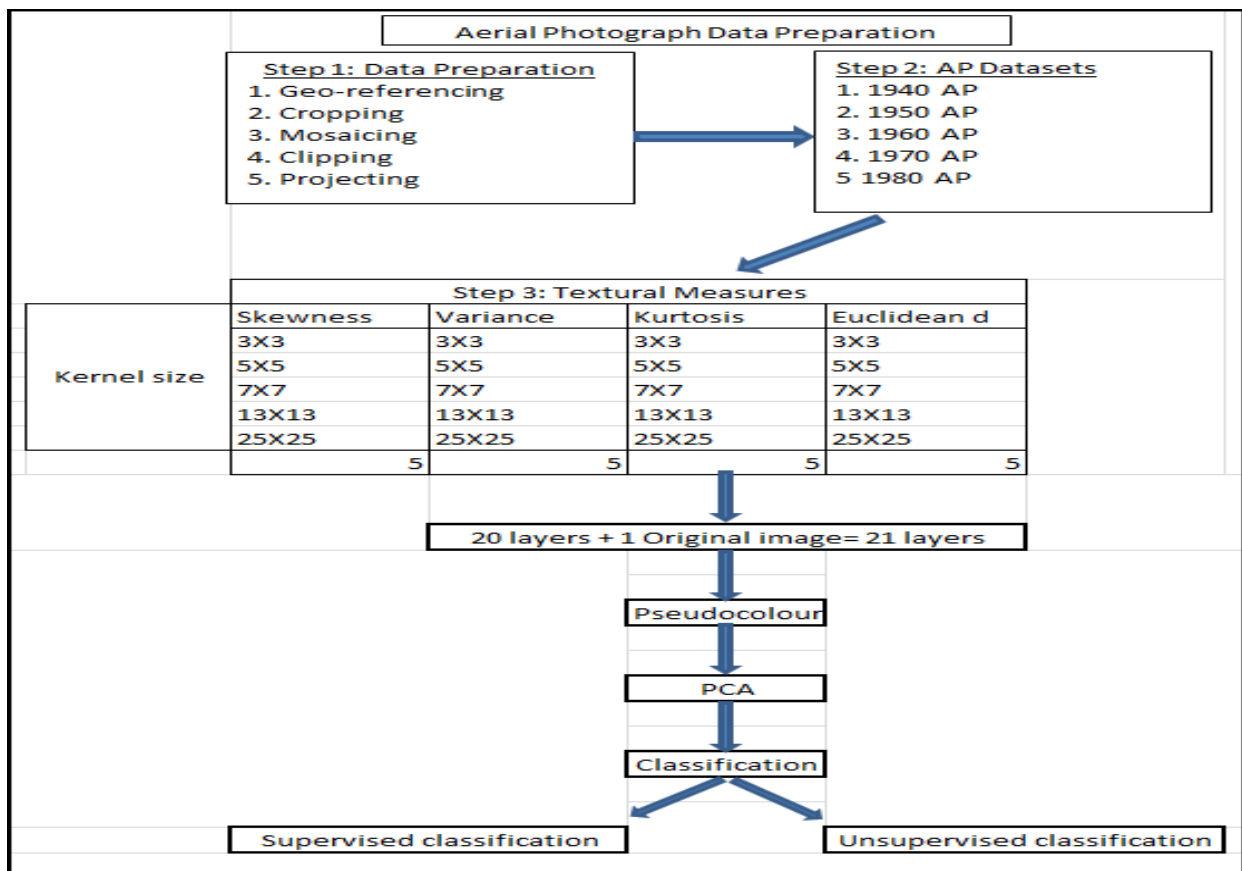


Figure 7: Elementary steps of the textural analysis procedure

### 3.3.1 Statistical correlation

After the textural measures in different window sizes were combined with the original image to build a colour composite image, statistical correlation was quantified between the datasets with an objective to select the best band combinations for a subsequent process called PCA (Principal Component Analysis). The image matrices of correlation coefficient between bands were ran and assessed using remote sensing software (ERDAS). The correlation coefficient is a measure of similarity between two images. The higher the coefficient, the greater the similarity between their respective pixel values (ERDAS, 2010). Furthermore, the correlation threshold is used to accept or discard points. Correlation relation values ranges from -1.000 to +1.000 (ERDAS, 2010). The former indicates a perfect inverse match whilst the latter indicates a perfect match (0 would indicate a bad match).

Table 5 below shows the correlation coefficient for the Duiwenhoks AP's dataset, a perfect match (+1.000) was obtained on similar band relationships across the board with other supporting bands having a poor correlation threshold ranging from +0.0 to +0.5. On the example below, the first 5 bands are shown from a 21 band image of the 1960 dataset.

Table 5: A correlation coefficient matrix of the 1960 layer stacked imagery

Correlation	Band 1	Band 2	Band 3	Band 4	Band 5
Band 1	1.000000	0.580971	0.335764	0.482865	0.514398
Band 2	0.580971	1.000000	0.421919	0.185001	0.398399
Band 3	0.335764	0.421919	1.000000	0.158843	0.145210
Band 4	0.482865	0.185001	0.158843	1.000000	0.120550
Band 5	0.514398	0.398399	0.145210	0.120550	1.000000
Band 6	0.474977	0.224778	0.036324	0.421045	0.401365
Band 7	0.313723	0.207778	0.254995	0.195165	0.222515
Band 8	0.466817	0.133175	0.262447	0.230260	0.239193
Band 9	0.330862	0.123204	0.109614	0.240497	0.168121
Band 10	0.151837	0.110978	0.080286	0.084570	0.076859
Band 11	0.339693	0.155297	0.113347	0.172711	0.224109
Band 12	0.404157	0.159652	0.159466	0.208816	0.297352
Band 13	0.139910	0.127601	0.064764	0.076237	0.093435
Band 14	0.364508	0.099436	0.139498	0.190279	0.231015
Band 15	0.332735	0.082186	0.086302	0.234383	0.145267
Band 16	0.397531	0.138767	0.163263	0.199345	0.246103
Band 17	0.320489	0.349064	0.178541	0.206925	0.194369
Band 18	0.384705	0.132718	0.186882	0.192205	0.211447
Band 19	0.237180	0.212689	0.145626	0.165772	0.106924
Band 20	0.259362	0.223743	0.184501	0.141264	0.094114
Band 21	0.358122	0.096164	0.161591	0.223795	0.170287

### 3.3.2 Principle Component Analysis (PCA)

After assessing the statistical correlation, a Principle Component Analysis exercise was applied on all the 21 band colour composite images to reduce data redundancy. PCA is a technique that transforms the original remotely sensed dataset into a substantially smaller and easier to interpret set of uncorrelated variables that represents most of the information present in the original dataset (Jensen, 2005). PCA typically removes the correlation contained within the multiband imagery by creating a new set of components, which are often more interpretable than the original images. It generates images that are uncorrelated and ordered by decreasing variance (Li & Narayanan, 2004).

### 3.3.3 Eigenvalues

Eigenvalues for the imagery was also obtained from the PCA analysis. These make it easier to select band combinations for image classification. Eigenvalue statistics help to determine the best band combinations by filtering the 21 bands numerically by descending order of the standard deviation and eigenvalue scores. To do this, a degree of variability had to be assessed by using the eigenvalues statistical outputs. From the computed statistics, the variance in each principal component or band has to be determined (Materka and Strzelecki, 1998; Jensen, 2005).

Table 6 below shows eigenvalues for the 1960 Duiwenhoks dataset which consists of 21 stacked layers. It is clearly visible that band combinations with a high degree of variance appear on the top compared to least representable layers which usually contain unwanted noise information. These were later discarded prior to running classification because the first components contain the maximum variation of the dataset and the last ones contain all the unwanted noise in the data. In essence, eigenvalues are usually ordered according to the magnitudes of the variance from largest to smallest ( Awwad, 2003; Esbensen, 2009).

Table 6: Eigenvalues results for the 1960 layer stacked imagery

Basic Stats	Min	Max	Mean	Stdev	Num	Eigenvalue
Band 1	0	255	76.353811	107.490283	1	12787.630701
Band 2	0	255	25.909428	49.694727	2	1636.588943
Band 3	0	255	12.199952	31.714053	3	754.870426
Band 4	0	207	5.643157	16.986293	4	221.051023
Band 5	0	161	4.050930	12.008775	5	105.483838
Band 6	0	122	2.168006	7.158994	6	70.716585
Band 7	0	255	2.558885	8.630832	7	32.009018
Band 8	0	135	1.590631	4.686318	8	22.702197
Band 9	0	183	1.047506	4.072628	9	12.883177
Band 10	0	241	0.797108	4.608339	10	10.054009
Band 11	0	163	0.702639	2.829684	11	6.485351
Band 12	0	81	0.581126	2.202147	12	4.661336
Band 13	0	160	0.439306	2.468079	13	3.567826
Band 14	0	116	0.419361	1.531086	14	1.778425
Band 15	0	95	0.328751	1.322113	15	1.076653
Band 16	0	98	0.318865	1.183263	16	1.040034
Band 17	0	29	0.150441	0.632433	17	0.401168
Band 18	0	44	0.192420	0.700214	18	0.360337
Band 19	0	23	0.164599	0.567583	19	0.182439
Band 20	0	8	0.154028	0.507385	20	0.168981
Band 21	0	19	0.085533	0.341699	21	0.094320

### 3.3.4 Band selection for classification

For the Duiwenhoks catchment study, a set of uncorrelated bands were selected in preparation for supervised classification. It is seen on table 7 below that best components were the first PCA 5 bands in descending order. The first PCA 3 bands accounted for 96.8 representations, the first four at 98.2 and the first 5 accounted for 98.9 representations on the 21 bands. With either one of these, supervised or unsupervised classification is simple because all the uncorrelated bands are removed.

Table 7: Band selection (3, 4 and 5 bands) on Principal Component Results

1960 PCA Stats									
Basic Stats	Min	Max	Mean	Stdev	Num	Eigenvalue	Band %		
Band 1	0	255	76.35381	107.4903	1	12787.6307	81.58599168		
Band 2	0	255	25.90943	49.69473	2	1636.588943	10.44155364		
Band 3	0	255	12.19995	31.71405	3	754.870426	4.816126907	3 Bands	96.84
Band 4	0	207	5.643157	16.98629	4	221.051023	1.410321219	4 Bands	98.25
Band 5	0	161	4.05093	12.00878	5	105.483838	0.672994375	5 Bands	98.93
Band 6	0	122	2.168006	7.158994	6	70.716585	0.451176833		
Band 7	0	255	2.558885	8.630832	7	32.009018	0.204219807		
Band 8	0	135	1.590631	4.686318	8	22.702197	0.144841629		
Band 9	0	183	1.047506	4.072628	9	12.883177	0.082195584		
Band 10	0	241	0.797108	4.608339	10	10.054009	0.064145291		
Band 11	0	163	0.702639	2.829684	11	6.485351	0.041377		
Band 12	0	81	0.581126	2.202147	12	4.661336	0.029739655		
Band 13	0	160	0.439306	2.468079	13	3.567826	0.022762983		
Band 14	0	116	0.419361	1.531086	14	1.778425	0.011346478		
Band 15	0	95	0.328751	1.322113	15	1.076653	0.006869123		
Band 16	0	98	0.318865	1.183263	16	1.040034	0.006635491		
Band 17	0	29	0.150441	0.632433	17	0.401168	0.00255948		
Band 18	0	44	0.19242	0.700214	18	0.360337	0.002298976		
Band 19	0	23	0.164599	0.567583	19	0.182439	0.001163974		
Band 20	0	8	0.154028	0.507385	20	0.168981	0.001078111		
Band 21	0	19	0.085533	0.341699	21	0.09432	0.000601768		
						15673.80679	100		

From figure 8 below, an improved colour composite image can be seen in comparison with the one shown in figure 6. The PCA band results helped to improve edge detection in the image for spatial analysis and classification purposes (Coppin & Bauer, 1996; Mas, 1999). This is because only the top four Principal Component bands were selected prior to running supervised classification. Edge detection is also improved for easier classification of different land use and land cover classes.

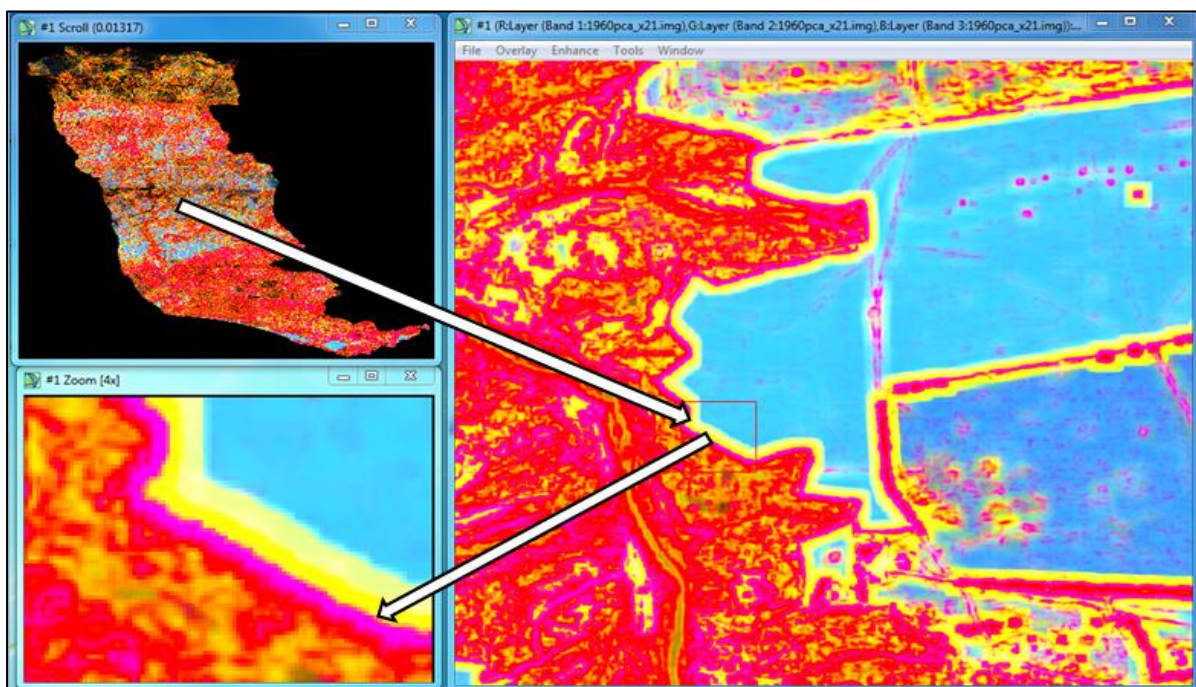


Figure 8: A colour composite 4 band image of 1960 seen from ENVI 4.4

### 3.4. Classification

The major remote sensing task in this study was the classification process of images based on their spectral and spatial properties. There are two basic types of classifications, namely supervised and unsupervised classification (Jensen, 1996). For the purpose of this project, black and white photos were the primary datasets because they play an important role in the field of land use and land cover analysis. Aerial photographs are versatile in application and

can be adopted for imaging systems in a number of ways like texture-tone variables for land cover classification (Hsu, 1978).

The majority of land cover and land use classification schemes available have been developed around specific user objectives like agriculture and conservation (Thompson, 1996) so it is always best to identify the study objectives before adopting a classification method. Additional to classification method selection, there is a need for standardization and synergizing classes when performing land cover classification in remote sensing (Thompson, 1996). Furthermore, (Anderson et al. 1976) indicates that agencies should develop more detailed land use classifications in order to meet their needs and at the same time remain compatible with each other and the national system. This avoids duplication of data and is also good for comparative and modelling projects for planning purposes. The scale of different land cover classification methods is very important because various agencies employ different scales depending on the size of the project and their project requirements (Anderson et al. 1976).

With the Duiwenhoks catchment having different grey level datasets from decade to decade caused by camera differences and raw data formats (See table 3), a pilot classification was conducted using the algorithms to determine the best classification methods and algorithms for the respective decades. Determining the best classification method for the decadal datasets was measured later in the project through accuracy assessment. Finally, both supervised and unsupervised classification was used to extract land cover classes on the black and white aerial photographs with priority given to land cover types whose spatial statistics are mandatory or prerequisites inputs in modelling and running the Agricultural Catchments Research Unit (ACRU) hydrological model. These were later synthesized to ecological classes in the next chapter.

Due to variations in classification quality outputs of both methods (supervised and unsupervised), some classes were optimized on either of these two classification schemes. Again, a trial and error approach using different class output numbers and scale sizes for the subset AOI (Area of Interest) was used to select the best set, scale and technique. Desktop resources used to perform this process were ERDAS Intergraph and ArcGIS 10.1.

One major challenge of classifying black and white aerial photography is the similarity and overlapping of DN (Digital Number) values between two or more distinct classes in a 0-255 histogram. This is because spatial surface variation of identical features was caused by different sun illumination on the earth surface. However, various algorithmic methods and radiance calibrations have been developed to deal with overlapping DN values. These methods are aimed at the improvement of merging differently acquired remotely sensed datasets and those that have overlapping DN values due to similar spectral characteristics.

Not all classes produced overlapping DN values. However, some classes appear in different spectral intensities such as water due to differences in colour and dam/river depth (Roberts, 1999; Lucieer & Kraak, 2004). There are various DN sorting methods ranging from statistical, visual and desktop graphical analysis which differ in application and complexity. The latter method (graphical analysis) uses the imagery DN to generate graphs and assess spectral intensity characteristics (Chavez et al. 1991 and Roberts, 1999). This study used the visual analysis by assessing the overlapping class (DN values) pattern, association and distribution. From the raw datasets at the Duiwenhoks catchment, some classes were misclassified due to variations in their grey-level DN values in the histogram spectrum ranging from 0 to 255. However, these classes were later split after running the classification process using GIS software and designated to their rightful classes. Again, knowledge and the use of satellite imagery assisted in this subjective decision-making process when conducting post classification.

### 3.4.1 Unsupervised classification

Unsupervised classification is a technique widely adopted when the user is unfamiliar with the classification area under concern. To perform this, the computer automatically groups pixels within similar spectral characteristics into unique clusters (Jensen, 2005; Duda, 2001) hence the technique requires only minimal initial input from the analyst. To do this, the computer performs a number of set iterative on the image and groups pixels based on polarimetric homogeneity characteristics such as brightness, density and intensity values (Lim et al. 1989; Lee & Lewicki, 2002; ERDAS, 2010). Although the unsupervised classification method is relatively simple to operate without human input, the only major task required from the analyst is interpreting the classes that are created by the unsupervised training algorithm (Jiménez et al. 2005).

For this study, unsupervised classification was initially run on the Aerial Photograph datasets and on the PCA multiband imagery using different number of classes to compare the output quality. The unsupervised classification on PCA results and the direct unsupervised classification (object-orientated) were piloted to assess the best method. The object-orientated method was more flexible because the analyst is not constrained to using just spectral information but rather basic aspects like mean spectral information and shape (Jensen, 2005). Algorithms using this form of image analysis incorporate texture and spatial statistics into the classification of high resolution aerial imagery, especially single channel panchromatic photographs (Benz, 2001; Middleton & Sutinen, 2008; Jensen, 2005;).

Whilst conducting the pilot assessment in order to find the best algorithmic and number of class input within the software interface, the exercise found that the more classes were assigned to the software, the more pixelated the classified output image became. This made it complex and difficult to analyse. To reduce this, a smaller set of classes was assigned on the

software interface to improve the classification output for easy reading using the k-means algorithm. To perform this, the k-means classifying interface in ERDAS Intergraph was used to set a number of classes provided by the analyst. It finds a partition such that the squared error between the empirical mean of a cluster is minimal (Jain, 2010). The k-means classification algorithm is popular and widely used in imagery classification to partition data into clusters due to its simplicity (Kanungo et al. 2002; Jain, 2010). The algorithm iteratively uses many clustering techniques assuming that the number of clusters is known in advance starting with the cluster centres (Likas et al. 2003; Zhang et al. 2008).

For the Duiwenhoks catchment, a set of 8, 14 and 20 classes were assessed. It was found that the scale of the subset or Region of Interest (ROI) affects the quality output of the classified image. Classification at a small ROI (e.g. quinary) produced far much better results as compared with a larger area even if the output classes were kept constant. See figure 9 and 10 below which shows output quality versus classification sizes of the areas of interest (AOI).

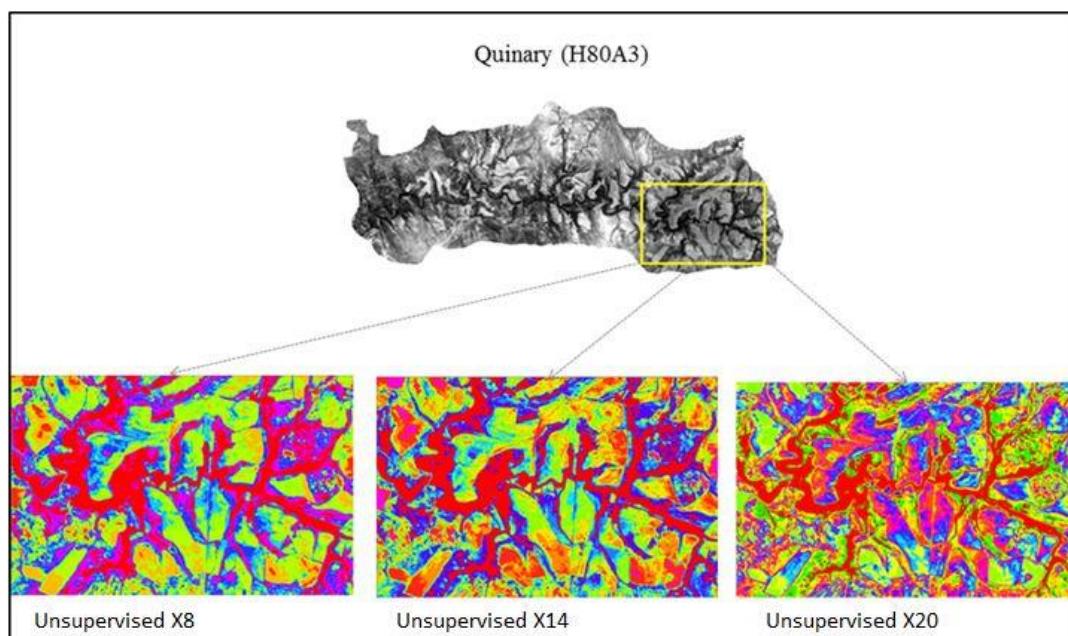


Figure 9: Unsupervised classification output quality output for 10, 14 and 20 classes

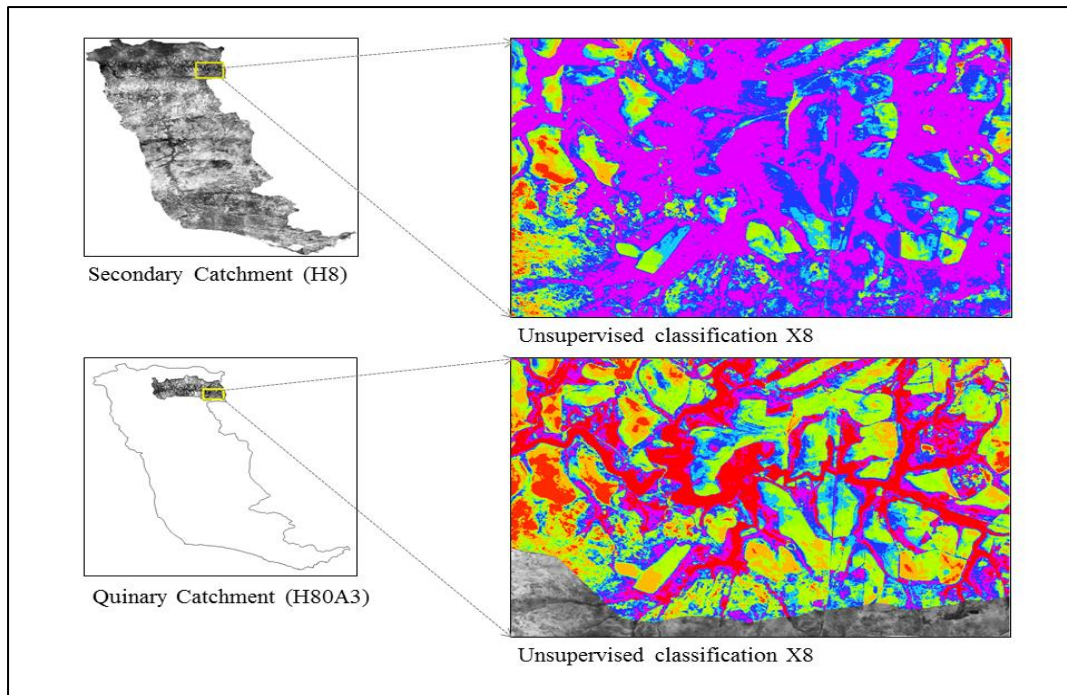


Figure 10: Catchment and quinary classification AOI quality differences using 8 classes

### 3.4.2 Supervised classification

Supervised classification is also one of the broadly used feature detection classification method used in remote sensing. In this method, a set of training sites are selected to guide the iterative desktop process in assigning land cover classes. This is one of the defining element of supervised classification were the training classes are responsible for determining and grouping pixel membership (Wang, 1990; Keuchel et al. 2003). Thus, the researcher or analyst needs to know the area under classification.

Unlike unsupervised classification, the researcher's knowledge of the study-area of the Duiwenhoks catchment through field visits and together with the aid of satellite imagery and Google earth timeline enhanced interpretation of land use and land cover classes during the supervised classification process. In supervised classification, the identity and location of some of the land cover types are known through field work, photograph interpretation, map analysis and personal experience (Hodgson et al. 2003; Jensen, 2005). For this study, a range of 8 to 14 primary classes listed in figure 11 were used to supervise the PCA results for

individual quinarys throughout the image. However, other quinarys did not have all the classes due to spatial distribution differences of other classes (e.g. Cultivation land cover in the coastline quinarys). Furthermore, the seven image interpretation elements (tone, colour, size, shape, association, pattern, height and texture) were used to select training samples. Satellite imagery was used as reference data to minimize misclassification.

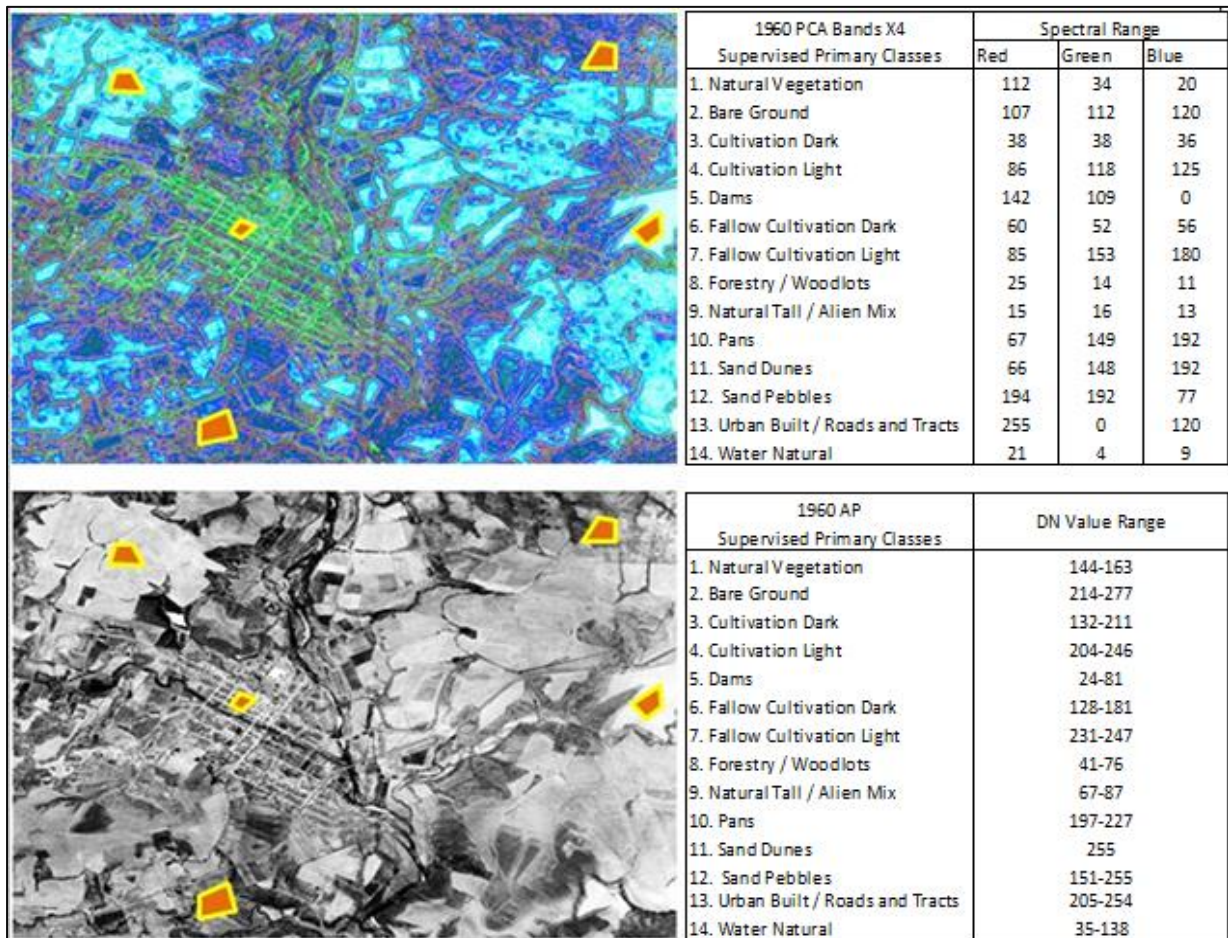


Figure 11: Supervised training sites with underlying values for PCA and direct classification

Irrespective of similarities in class DN values, the training samples were manually selected and later split and designated to their land cover classes after running the process via post classification using ArcGIS 10.1. Also, see figure 12 below for the grey-level histogram spectrum which shows DN value ranges.

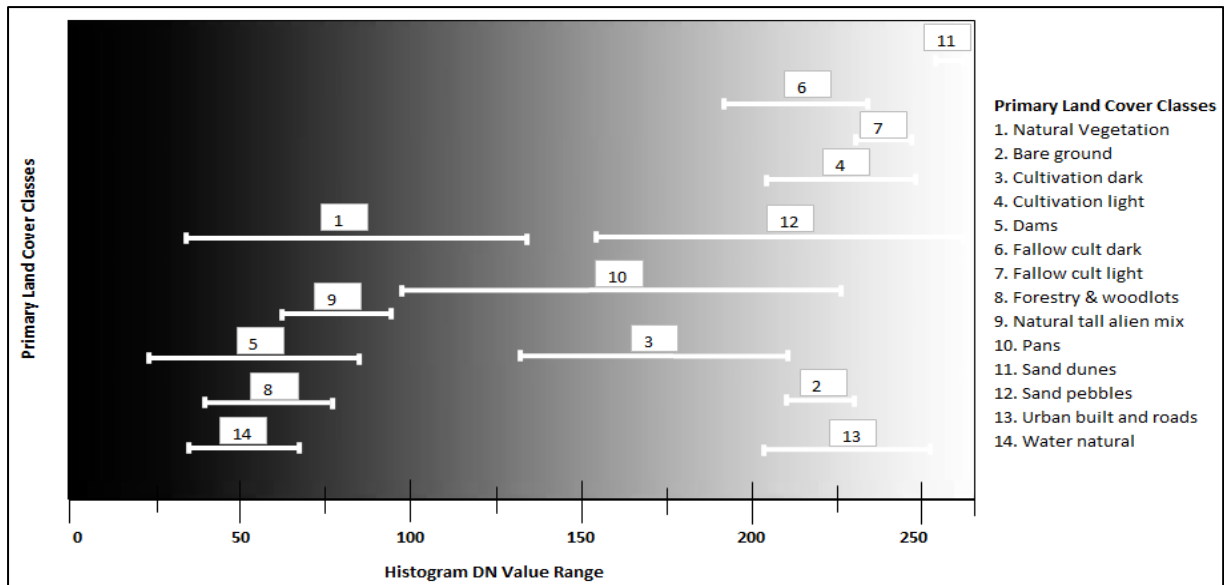


Figure 12: Primary land cover histogram with overlapping DN value ranges

For the Duiwenhoks study, the ERDAS Intergraph software was used to perform this process (unsupervised classification) due to its advanced array of tools and quality outputs as compared with ArcGIS 10.1 which also has a classification toolkit but with limited algorithms and user preferential settings. Additional to its ease of use, the ERDAS Intergraph software has a number of classification algorithms optimized for different land cover outputs.

A trial and error approach was also used in this study by comparing outputs from commonly used algorithms which are Maximum likelihood Classifier, Minimum Distance and the Mahalanobis Distance Classification schemes. However, the Maximum Likelihood Classifier (MLC) proved to produce acceptable results as compared to other classification algorithms. The advantage of the MLC is that its rules are based on the probability that pixels belong to a particular class by assuming that probabilities are equal for all classes (ERDAS, 2010). Other land classifications using satellite sensor data consider it a very standard approach even though it is very robust in distribution assumption (Emrahoğlu et al. 2003). Additionally, the MLC as a parametric classifier takes into account the variance and covariance within the class distributions and for normally distributed data performing better than the other known parametric classifiers (Otukey & Blaschke, 2010).

### 3.5 Accuracy Assessment (AA) and Ground truthing

After most remote sensing and image classification exercises are performed, there is a strong need to validate the quality of the output datasets by measuring the success and failures of the exercise (Jensen, 2005). This process is known as accuracy assessment in the GIS and remote sensing fields. The increase technological development and the demand for information derived from remotely sensed datasets or environmental models at local, regional and global scales has to reduce errors accumulated during various steps of processing (Johannsen et al. 2003; Jensen, 2005). An error assessment is therefore necessary to identify the type and amount of error in remotely sensed datasets (Lunetta, 1991; Bossler et al. 2004). It is also a good practice to conduct accuracy assessment on remotely sensed derived thematic maps before being used in scientific investigations and policy decisions (Stehman & Czaplewski, 1998; Pain & Kiser, 2003).

#### 3.5.1 Confusion matrix for Accuracy Assessment

There are many methods of conducting accuracy assessment of algorithmic classification. However, the confusion matrix or contingency table is at the core of most applications (Foody, 2002). This study used the confusion matrix because it produces more statistical attributes like the overall classification accuracy and kappa indices (Okeke & Karnieli, 2006). The overall accuracy is the total number of correctly classified pixels, divided by the total number of reference pixels (Jensen, 1996; Resler et al. 2004). Kappa values are a discrete multivariate measure of use in accuracy assessment. Kappa analysis in this context yields statistics which measure the agreement or accuracy between remote sensing derived classification data and the reference data (Congalton & Mead, 1983). *K* (kappa) values between 0.49 and 0.80 represent moderate agreement whilst values less than 0.40 (40%) represent poor agreement (Landis & Koch, 1977). An accuracy score of 59% is observed to

be the most achieved agreement after performing accuracy assessment applications in land cover classification projects. However, an 85%+ result is considered the best outcome. Classification errors, sampling issues and the lack of adequate spatial referencing data are amongst the common limitations from achieving the best result (Foody, 2002).

### 3.5.2 Limitations of Accuracy Assessment of historic land cover imagery

One of the most serious limitations to aerial photograph classification is ground-truthing because the imagery is decades old and most objects and land cover forms have changed or no longer exist on the ground. For this study, Accuracy Assessment was performed on all three techniques for 1960, 1990 and 2010 (supervised, unsupervised and manual digitization respectively). A total of 30 sampling points for each generic class on historic 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> edition 1:50 000 topographical maps collected from the National Geospatial Institute in Cape Town was used as reference datasets and site visits. One limitation was that the topographical maps did not cover the entire Duiwenhoks catchment. However, the available portions were used to perform the Accuracy Assessment exercise. The algorithmic output land cover classes were grouped into six generic classes (ecological classes) for this process. Land cover class grouping is further discussed in the next chapter. Each class was represented by 30 points making a total of 180 sampling points per classification method (supervised, unsupervised and manual digitizing).

Secondly, a bigger sample size of 80 points was used for the entire catchment using a manually prepared Digital Baseline Information (DBI) referencing map. The digitized reference DBI was assumed to have perfect accuracy (Foody, 2002), and thus served as a pseudo ground truthed image. Accuracy Assessment was also done by using an error/confusion matrix to measure accuracy levels of individual classes for the supervised and unsupervised classification (overall accuracy). The simple-random sampling method was

used in ArcGIS to select sample units such that every one of the possible distinct samples has an equal chance of being selected (Jensen, 2005; Hashemian et al. 2004, Stehman, 2009). Advantage of working with random samples is that an important assumptions underlying many statistical techniques are satisfied (Jensen, 2005).

### 3.6 Overall limitations

Notable limitations occur on the spatial accuracy of some the spatial land cover classes. Most of these are caused by data dimensional variation on the raw black and white images. The most common is the scale difference which ranges from 1:30 000 to 1:60 000 (See Table 3) used when capturing the images. Amongst other limitations, the camera lenses and the focal length also differ from year to year. The raw images were also produced at varying formats ranging from 5'x 5' and 9'x 9' inches (See Table 3). This caused stretching of some images during image georeferencing and thus resulting in slightly deformed land cover classes. The time of day and the angle of capture at which aerial photograph images are taken are very important elements of remote sensing. It is quite evident that some images were taken at different angles and day times in some of the images. This is seen by shadow effects which reduce accuracy when selecting ground control points (GCP).

Furthermore, urban development and man-made infrastructure (road intersections, field intersections, buildings etc.) which are good GCP's were minimal in the early decades (1940 to 1950) limiting the accuracy of geographic referencing points on the black and white aerial photographs. To minimise this effect, the georeferencing RMS (Root Mean Square) was kept below a 30 meter range which is a rule of thumb (Mostafa & Hutton, 2001; Hutton & Mostafa, 2005; ERDAS, 2010). The RMS is the distance between the input GCP (Ground Control Point) location and the retransformed location for the same GCP after georeferencing (ERDAS, 2010). From the raw images, angle variations are clearly visible at mountain slopes

and valleys. This makes it challenging to monitor changes on a time series on the same geographical point.

### 3.7 Summary and conclusions

This chapter outlined and elaborated on key GIS and Remote Sensing applications used to classify aerial images over the years from black and white aerial photographs to current pseudo-colour land cover images which make the quantification of spatial distributions and historic trends feasible. The chapter identified the potential use of the advancement in desktop technological classification of panchromatic aerial photographs to show spatial land cover types which are important for modern day research in having a retrospective view of historic trends in order to develop potential future projections and conservation mechanisms. The desktop tools and the technical methods outlined in this chapter indicates that the much neglected historic aerial photographs are still valuable for research aimed at chronicling land cover trends before the advent of today's multispectral orbiting satellite technology.

Following the classification of images, the R-statistical software was used to run a Markov chain analysis to assess future implications of land cover change using the datasets. The following chapter, which is the core of the thesis, shows the degree of success of the method through its quantification of land cover, accuracy assessment scores and assessing future implications of land cover change. After quantifying land cover datasets, ancillary data from the South African Weather Services (SAWS), Department of Water Affairs (DWA) and information from farmers at Duiwenhoks was used to profile and observe environmental impacts at the Duiwenhoks catchment.

## **Chapter 4: Land cover trends in the Duiwenhoks catchment 1940 - 2010**

### 4.1 Introduction

This chapter presents findings relating to land cover change classification methods and profiles major trends acquired from colour enhancement GIS-based analysis of grey-scale aerial photographs of the Duiwenhoks catchment in the Southern Cape. The chapter also gives findings on observed environmental impacts at the Duiwenhoks catchment during study site visits. Additional to land cover change findings, the chapter also presents findings from a Markov chain analysis on future land cover implications.

### 4.2 Land use and land cover classification outputs and results

The classification methods which were used to develop the land cover maps (supervised, unsupervised and manual digitization) gave quantitative findings of land cover dynamics in the Duiwenhoks catchment. Due to the limitations of remote sensing and GIS software to distinguish specific land cover classes, the researcher's knowledge of the study area (based on field trips) was used to interpret the results derived from the classification schemes and to perform post classification on misclassified classes.

#### 4.2.1 Post classification

Post classification was done to improve the classification results from the supervised and unsupervised classification methods. However, it is important to note that the use of post classification processes is determined by the quality and the accuracies of individual classification methods (Petit et al. 2001). The post classification process for this study was done by manually correcting classes through splitting and merging in ArcGIS. The researcher's knowledge and the use of reference datasets helped to device this subjective approach by identifying misclassified classes and designating them to their primary class.

The seven elements of image analysis in remote sensing (tone, texture, size, height, association, pattern and shape) were also used to identify classes. Misclassification was caused by land cover classes which may sometimes appear in different tones and textures in the classified images due to overlapping Digital Number values (DN) in a histogram and Red Green & Blue (RGB) signatures. DN values in this case indicate land cover reflectance as recorded on a histogram from 0-255 (Lucieer & Kraak, 2004). From the Duiwenhoks datasets, some cultivated areas appeared in both lighter and darker shaded spatial tones and textures. This was due to the use of fire and soil tilling processes (dark cultivated fields) and crop production (light cultivated fields). The same can be said about gravel and tarred roads which appeared in different tonal levels. This was corrected by performing post classification on the produced datasets.

Classification results from both unsupervised and supervised algorithms produced satisfactory results of 10 algorithmic classes at quinary level. These were further post processed to develop a set of 14 algorithmic classes before synthesizing them with other established datasets into ecological classes. Figure 13 below provides a classification flow chart from the classification results. The manually digitized dataset produced 34 secondary classes with wetlands and irrigation canals being special cases identified for hydrological modelling and collected as ancillary datasets. These (34 secondary) were later grouped to be congruent with supervised and unsupervised classes by setting rules discussed later in the chapter. See appendix A for secondary class descriptions.

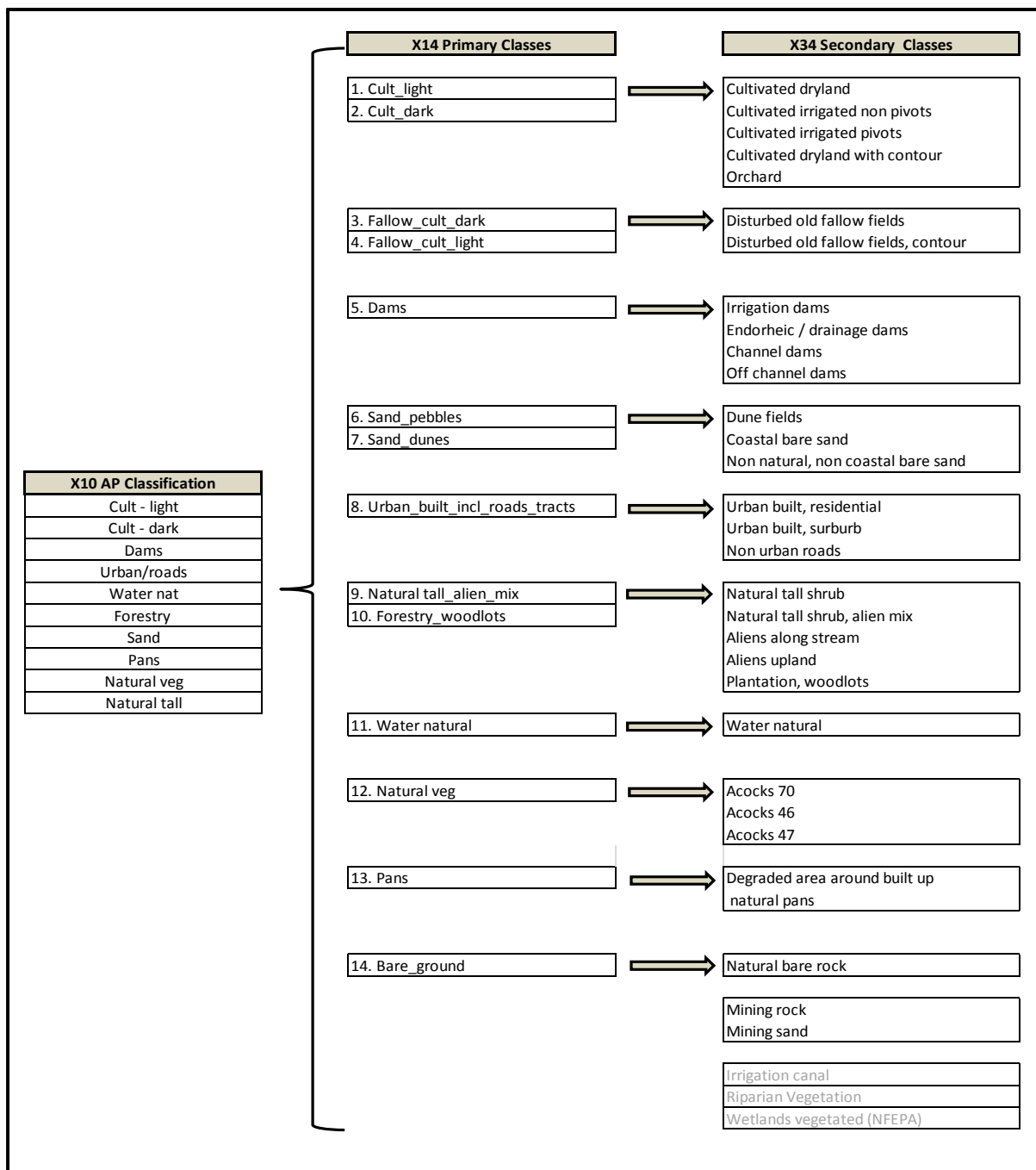


Figure 13: Classification flow chart from the classification results of 10 classes

Although being a tedious desktop operation, post classification was used only as an aid to algorithmic classification outputs. The post classification thus constituted a very minimal contribution to the output land cover maps. The post-classification operation on all the decadal datasets took less than two weeks to perform. The approach was done at a constant scale of 1:10 000.

#### 4.2.2 Classification results

For congruence with other established datasets, the classified algorithmic land cover outputs were synthesized for comparison with other datasets like the SANBI (South African National Biodiversity Institutes) land cover maps of 2009 and the Republic of South Africa’s 1:50 000 topographical maps. Therefore, the 14 algorithmic classification outputs were grouped to build 12 primary land cover classes which were also further reduced to 6 ecological land cover classes (with the exception of mining which is the seventh class due to its absence at the Duiwenhoks catchment) for comparison with SANBI’s national land cover maps. Table 8 below shows the grouping of land cover classes for congruence and accuracy measurements discussed below.

Table 8: Land use and land cover synthesis table

Algorithmic Land Cover	Project Land Cover Classes	2009 Land Cover Map	1:50 000 Topographical Map
1. Natural Vegetation	1. Natural Vegetation	1. Natural	1. Protected Areas
2. Natural Tall/ Alien Mix	2. Natural Tall/ Alien Mix		2. Marsh & Vlei
3. Bare Ground	3. Bare Ground	2. Degraded	3. Coastal Rocks
4. Pans	4. Pans		4. Dry Pan
5. Sand Dunes	5. Sand Dunes		5. Erosion & Sand
6. Sand Pebbles	6. Sand Pebbles		
7. Cultivation Dark	7. Cultivation	3. Cultivation	6. Cultivated Land
8. Cultivation Light			7. Recreation Ground
9. Fallow Cultivation Dark			8. Prominent Crop & Outcrop
10. Fallow Cultivation Light	8. Fallow Abandoned Fields		9. Orchard & Vineyards
11. Dams	9. Dams	4. Water Bodies	10. Perennial River
12. Water Natural	10. Water Natural		11. Perennial Water
			12. Dry Water Course
13. Forestry / Woodlots	11. Forestry/Woodlots/Plantations	5. Plantations	13. Pipeline
			14. Water Tower & Reservoir
14. Urban Built/ Roads & Tracts	12. Urban Built & Roads	6. Urban Built	15. Woodland
			16. Row of Trees
		7. Mines	17. Urban Built/ Roads & Tracts

### 4.2.3 Accuracy Assessment results

Results obtained from the Accuracy Assessment exercise are presented below on table 9 using a confusion matrix. Kappa calculations results are also presented, where  $k$  is the total number of rows (land cover classes) in the matrix,  $x_{ii}$  being the total number of observations in row  $i$  and column  $i$  respectively.  $N$  represents the total number of observations. After generating 30 random sampling points for the 6 generic classes using the ArcGIS 10.1 toolkit for supervised, unsupervised and manually digitized classification methods (1960, 1990 and 2010 datasets respectively), accuracy assessment and kappa values was calculated to compare land cover change based on 1:50 000 topographical maps.

Table 9: Accuracy assessment confusion matrix for the three classification methods

(a)								(b)							
1960 Supervised Classes	1:50 000 Topographical Map						Row	1990 Unsupervised Classes	1:50 000 Topographical Map						Row
	Cult	Deg	Nat	Pla	Urb	Wat	Total		Cult	Deg	Nat	Pla	Urb	Wat	Total
Cult	17	0	13	0	0	0	30	Cult	24	2	2	0	1	1	30
Deg	2	9	19	0	0	0	30	Deg	4	16	5	0	4	1	30
Nat	6	0	20	0	2	2	30	Nat	3	4	13	1	6	3	30
Pla	0	0	8	18	4	0	30	Pla	0	0	5	25	0	0	30
Urb	4	0	3	0	21	2	30	Urb	5	2	4	0	19	0	30
Wat	3	1	10	0	0	16	30	Wat	3	7	0	1	2	17	30
Statistics	32	10	73	18	27	20	101	Statistics	39	31	29	27	32	22	114
Producer Accuracy	53.1	90	27.4	100	77.8	80		Producer Accuracy	61.5	51.6	44.8	92.6	59.4	77.3	
User Accuracy	56.7	30	66.7	60	70	53.3		User Accuracy	80	53.3	43.3	83.3	63.3	56.7	
Overall Accuracy	56%							Overall Accuracy	63%						
Kappa Index	0.51						180	Kappa Index	0.59						180

(c)							
2010 Digitized Classes	1:50 000 Topographical Map						Row
	Cult	Deg	Nat	Pla	Urb	Wat	Total
Cult	26	0	2	0	2	0	30
Deg	2	21	1	0	6	0	30
Nat	1	0	25	0	3	1	30
Pla	0	0	14	12	4	0	30
Urb	1	0	1	0	28	0	30
Wat	1	4	0	0	2	23	30
Statistics	31	25	43	12	45	24	135
Producer Accuracy	83.9	84.0	58.1	100.0	62.2	95.8	
User Accuracy	86.7	70	83.3	40	93.3	76.7	
Overall Accuracy	75%						
Kappa Index	0.71						180

$k$  = number of rows (land cover classes) in the matrix  
 $x_{ii}$  = number of observations in row  $i$  and column  $i$   
 $x_{i+}$  = marginal number of rows  
 $x_{+i}$  = marginal total number of columns  
 $N$  = Total number of observations

The different classification methods which were used yielded different statistical scores. It was found that the unsupervised classification and the manual digitization methods produced acceptable results of 63% and 75% overall accuracies. Kappa indices were also calculated for

all the classification methods with the 1960 supervised dataset producing 0.51, unsupervised 1990 dataset at 0.59 and the 2010 manually digitized image at 0.71 kappa indices. Below is the formula that was used to calculate the indices with an example for the 2010 dataset.

$$K = \frac{N \sum_{i=1}^k x_{ii} - \sum_{i=1}^k (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^k (x_{i+} * x_{+i})}$$

$$= \frac{180(135) - 4050}{(180)^2 - 4050}$$

$$= 0.71$$

After obtaining accuracy results from the two sample sizes (30 and 80 sampling points), it was found that smaller sampling points make it easier collect and analyse generic spatial datasets as compared to numerous land cover classes using a bigger pool of sampling points. Another advantage of using smaller sampling sizes on generic classes was the avoidance of performing Accuracy Assessment on classes which are very fine and are not widely represented in all the quinquaries across the catchment. Good examples of such classes include sand, pans and farm dams. The study findings were that the overall accuracy between the two techniques was higher using small samples compared to bigger samples (See Appendix B).

Table 10 below presents findings from 80 sampling points. The Accuracy Assessment was performed 14 algorithmic classes which were obtained from the classification outputs. Using manual digitized Digital Baseline Information (DBI) and the classified image (1960) did not yield significant benefits compared to using established historic 1:50 000 topographical maps.

The 80 samples and 14 classes provided and overlall accuracy assessment of 60% and a Kappa Index of 58.

Table 10: Accuracy Assessment for the manual Digital Baseline Information

	1960 Reference Digital Baseline Information														Row	Producer	Error of
	NV	BG	CD	CL	DMS	FCD	FCL	FW	NTA	PNS	SD	SP	UBR	WN	Total	Accuracy	Omission
NV	51	8	28	9	17	11	26	7	12	25	2	34	13	9	252	20%	80%
BG	1	64	0	0	0	0	0	0	0	0	0	0	2	0	67	96%	4%
CD	2	0	24	4	0	5	0	2	0	5	0	0	2	1	45	53%	47%
CL	3	6	25	66	5	20	4	1	1	38	0	4	8	0	181	36%	64%
DMS	0	0	0	0	29	0	0	0	0	0	0	0	0	0	29	100%	0%
FCD	0	0	0	0	0	30	0	0	0	0	0	0	0	0	30	100%	0%
FCL	2	0	0	0	0	0	48	0	0	0	0	2	1	0	53	91%	9%
FW	0	0	0	0	0	0	0	62	0	0	0	0	0	0	62	100%	0%
NTA	18	1	2	1	29	12	0	8	67	1	0	1	5	8	153	44%	56%
PNS	0	0	0	0	0	0	0	0	0	11	0	0	0	0	11	100%	0%
SD	0	0	0	0	0	0	0	0	0	0	75	4	0	0	79	95%	5%
SP	3	1	0	0	0	2	1	0	0	0	2	34	0	0	43	79%	21%
UBR	0	0	1	0	0	0	1	0	0	0	1	1	49	0	53	92%	6%
WN	0	0	0	0	0	0	0	0	0	0	0	0	0	62	62	100%	0%
<b>Total Samples</b>	80	80	80	80	80	80	80	80	80	80	80	80	80	80	672		
<b>User Accuracy</b>	64%	80%	30%	83%	36%	38%	60%	78%	84%	14%	94%	43%	61%	78%			
<b>Error of Commision</b>	36%	20%	70%	17%	64%	62%	40%	22%	16%	86%	6%	57%	39%	22%			
<b>Overall Accuracy</b>	60%																
<b>Kappa Index</b>	58%														1120		

Natural Vegetation (NV), Bare Ground (BG), Cultivation Dark (CD), Cultivation Light (CL), Dams (DMS), Fallow Cultivation Dark (FCD), Fallow Cultivation Light (FCL), Forestry Woodlots (FW), Natural Tall/Alien Mix (NTA), Pans (PNS), Sand Dunes (SD), Sand Pebbles (SP), Urban Built (URB), Water Natural (WN).

### 4.3 Land cover maps for the Duiwenhoks catchment

Figure 14 below displays the land cover maps that were produced through the different classification methods and after synthezing the algorithmic outputs into hydrological and ecological classes. These maps consist of finer classes (hydrological classes) which are used to assess impacts of land cover changes later in the chapter. However, for the purpose of accuracy assessment and synergizing data with other established datasets, the maps are grouped into six broad ecological classes for the Duiwenhoks catchment. More detailed individual land cover classes are included as annexure files for this project.

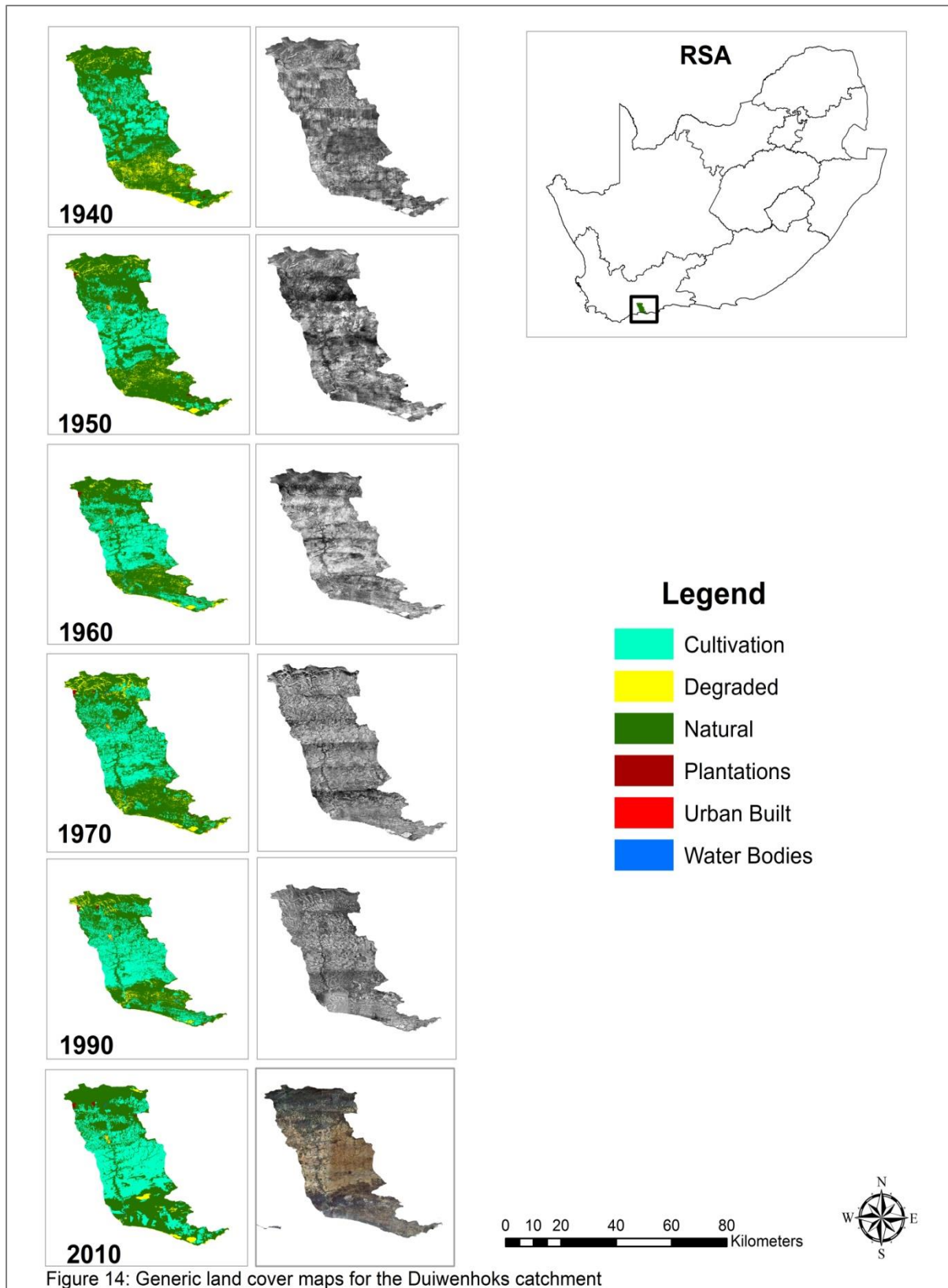


Figure 14: Generic ecological land cover maps for the Duiwenhoks catchment

For detailed decadal maps, See Appendix C for figure 14a,14b,14c,14d and 14e as attached annexures.

#### 4.4 Decadal land cover changes and quantities at Duiwenhoks catchment

Using the GIS Software, land cover statistics were generated for the Duiwenhoks study area to monitor quantity trends and spatial changes. The “natural” area land cover class includes all three types of natural vegetation found within the Duiwenhoks catchment, which are South Coast Fynbos, Eastern Coast Renosterveld and the Eastern Fynbos Renosterveld Bioregions (Mucina and Rutherford, 2006). The “degraded” class areas include all disturbed and dry spatial features like pans, dunes, sand pebbles along rivers and exposed rocks of the Laingsburg Mountains. The “cultivated” areas class in this generic grouping include both previously cultivated (fallow) and active cultivated fields as captured on the raw aerial photographs appearing in light and dark tones. “Water bodies” include all man-made and natural drainage dams. These include, channel dams, off channel dams, endorheic dams and irrigation dams. “All private woodlots, government owned forestry plantations and farm wind-breaks are grouped into “plantations”. Lastly, the “urban built” class includes housing, roads, tracts and the Heidelberg CBD. More comprehensive definitions are available as annexure files.

The datasets produced made it practical to quantify land cover changes. Table 11 below shows findings of the spatial coverage of 6 the ecological classes as adopted by the South African National Biodiversity Institute namely (SANBI) , natural, degraded, cultivation, water bodies, plantations and urban built area in square kilometres. From the baseline dataset (1940), the catchment is dominated by natural vegetation, degraded and cultivated areas. The Heidelberg town and other housing establishments are still minimal at this early stage in comparison with other subsequent decades. The spatial statistics were generated on ArcGIS 10.1 software and calculated on a square kilometre scale on Albers projected land cover maps table 11 (a). The calculated geographical coverage of the land cover classes was used to

determine their catchment percentage representations 11(b) from the overall 1361 km<sup>2</sup> catchment size.

Table 11: Decadal land cover quantities for the Duiwenhoks catchment

(a)							
Decadal Land Cover Quantities in km <sup>2</sup>							Area Total
Year	Cultivation	Degraded	Natural	Plantations	Urban Built	Water Bodies	
1940	293.1	110.1	951.7	1.6	2.8	2.2	1361
1950	343.9	65.8	943.6	2.7	3.5	2.3	1362
1960	507.7	51.2	791.4	3.3	5.0	2.8	1361
1970	446.0	78.8	823.8	4.0	5.6	3.1	1361
1990	566.6	52.7	726.8	4.9	7.4	3.1	1361
2010	580.7	28.7	740.4	5.1	4.1	3.5	1362

(b)							
Decadal Land Cover Quantities in %							Area Total
Year	Cultivation	Degraded	Natural	Plantations	Urban Built	Water Bodies	
1940	21.5	8.1	69.9	0.1	0.2	0.2	100
1950	25.3	4.8	69.3	0.2	0.3	0.2	100
1960	37.3	3.8	58.1	0.2	0.4	0.2	100
1970	32.8	5.8	60.5	0.3	0.4	0.2	100
1990	41.6	3.9	53.4	0.4	0.5	0.2	100
2010	42.6	2.1	54.3	0.4	0.3	0.3	100

From the quantified land cover spatial coverage statistics, it is easier to monitor land cover changes for future projections and designing conservation measures to rehabilitate degraded ecosystems. Significant attributes of the ecosystem can be assessed with each other to detect trends over a long time frame. Statistical findings give declining; increasing, conversion/ transition of land cover classes from one state to another at the Duiwenhoks catchment over the 70 year assessment. Most of the dynamic classes being cultivation and the natural land cover class.

Below, on figure 15, relationships between land use and land cover classes at the Duiwenhoks catchment are plotted in order to monitor and observe historic trends. This helps in detecting underlying causes of natural and anthropogenic induced impacts.

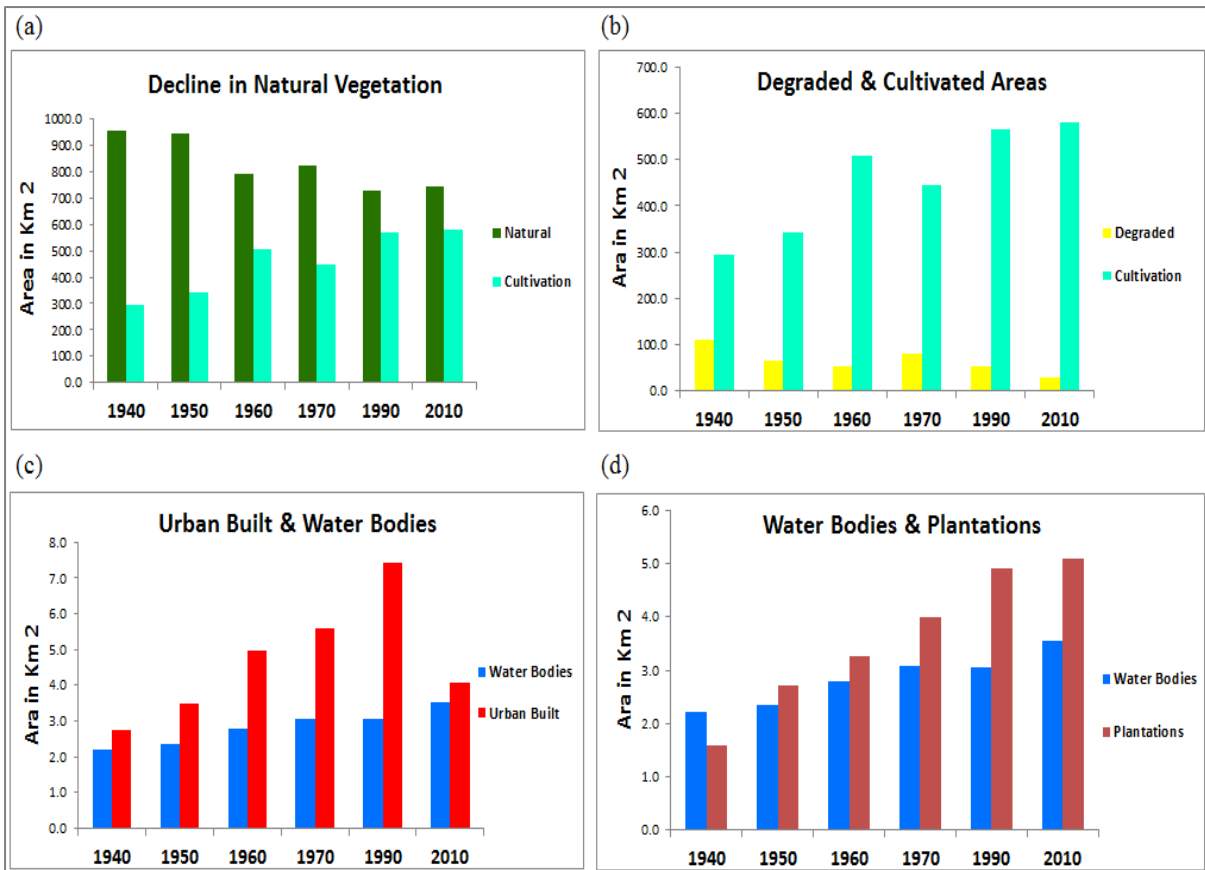


Figure 15: Comparative decadal trends of land use and land cover classes

As discussed quantitatively decade by decade in the sections below, the datasets shows an overall reduction of natural vegetation due to the increase of cultivated fields within the catchment. The plotted trend on figure 15 (a) shows the 70 year natural vegetation reduction rate. Decade by decade, degraded areas were also converted to cultivated areas 15(b). Actual land cover quantities per km<sup>2</sup> are dissected decadally in subsections below. Hydrological patterns from the statistical findings showed that farmers had their privately owned dams within the Duiwenhoks catchment. These (inland water bodies) were also seen to have increased proportionally with the increase in cultivated fields and the construction of the government owned Duiwenhoks dam located in the top of the catchment. The dam is operated by the Department of Water Affairs and supplies water to the Heidelberg town and farms in and around the catchment.

With an increase in urban built up areas from 1940 figure 15 (c), the demand of water also increased decade by decade. Furthermore, plantations on the upper catchment owned by the Department of forestry increased decadal 15(d). In 1940, plantations which include state owned forestry developments, privately owned windbreaks and woodlots only amounted to 1.6 8 km<sup>2</sup> whilst in 2010, these amounted to 5.1 8 km<sup>2</sup>.

#### 4.4.1 Decadal spatial land cover trends at Duiwenhoks

The use of desktop GIS spatial analysis also makes it feasible to monitor land use and land cover trends within geographic locations. The produced decadal datasets for the Duiwenhoks catchment were intersected to monitor decadal trends of losses and gains within the catchment. Most of the losses throughout the 70 year time series were a loss of natural vegetation and an increase in agricultural land. See Figure 16 below for historic land cover trends within the Duiwenhoks catchment.

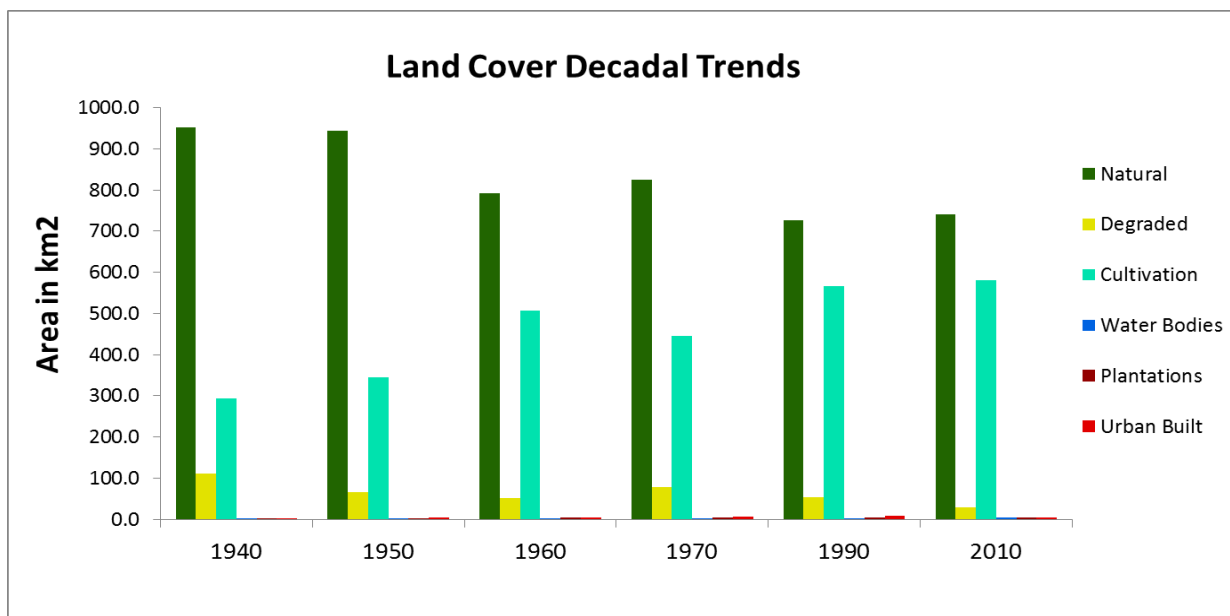


Figure 16: Land cover decadal trends for the Duiwenhoks

(i) 1940 to 1950 decadal changes

The first benchmark dataset of 1940 compared with the next decadal dataset of 1950 show systematic transitions in land cover. Statistical findings indicate that natural vegetation

changed from a geographical spatial coverage of 951 km<sup>2</sup> in 1940 to coverage of 943 km<sup>2</sup>. This decline was mainly due to agricultural expansion and degradation of the catchment. The overall reduction of natural vegetation amounted to an area size of -8.1 km<sup>2</sup> during the first 10 years. From the 70 year time series whereby cultivation increased by 287 km<sup>2</sup>, this decade alone had an increase cultivated area of 50.8 km<sup>2</sup> (17.7%). Very few inland dams (water bodies) were observed from the classification output in the early decadal datasets. However, this increased proportionally with the increase in farming activities (see table 12 below).

Table 12: Decadal reduction and increment of land cover classes

(a)						
Decadal Km2 Change						
	Natural	Degraded	Cultivation	Water Bodies	Plantations	Urban Built
1950 - 1940	-8.1	-44.3	50.8	0.1	1.1	0.7
1960 - 1950	-152.2	-14.6	163.8	0.4	0.5	1.5
1970 - 1960	32.4	27.6	-61.7	0.3	0.7	0.7
1990 - 1970	-97.0	-26.1	120.6	0.0	0.9	1.8
2010 - 1990	13.6	-24.0	14.1	0.5	0.2	-3.3
Overall Sum of Change	-211.3	-81.4	287.6	1.3	3.5	1.3
(b)						
Decadal Percentage Change (%)						
	Natural	Degraded	Cultivation	Water Bodies	Plantations	Urban Built
1950 - 1940	-3.8	-54.4	17.7	10.1	32.3	56.0
1960 - 1950	-72.0	-17.9	56.9	33.6	15.1	110.6
1970 - 1960	15.3	33.9	-21.4	21.7	20.9	50.1
1990 - 1970	-45.9	-32.1	41.9	-2.0	26.0	136.6
2010 - 1990	6.4	-29.5	4.9	36.6	5.6	-253.2

(ii) 1950 to 1960 decadal changes

The 1950 to 1960 decadal dataset showed the highest reduction of natural vegetation coverage of 152 km<sup>2</sup>. This amounts to a total of 72% in comparison to the 70 year natural

vegetation total reduction of 211 km<sup>2</sup>. This substantial reduction was due to the increase in cultivated fields and vegetation degradation on what is thought to be via vegetation clearing for agricultural field preparation. This is validated by spatial analysis whereby bare degraded fields are converted to cultivated areas in subsequent decades. Cultivation in this decade increased exponentially by 163 km<sup>2</sup>. This rapid increase amounted to 56.9% which was found to be the highest within the 70 year assessment whereby an overall increase of 287 km<sup>2</sup> was detected.

(iii) 1960 to 1970 decadal changes

From the 70 year historic datasets, it is only within the 1960 to 1970 decade that a slight reversion of natural vegetation was observed. This may have been caused by fallow vegetation or abandoned fields rejuvenating to their original natural state. From this decade, 32 km<sup>2</sup> was reverted or classified back as natural vegetation whilst the rapid increase of cultivated fields slowed down to 61.7 km<sup>2</sup> as compared to 163 km<sup>2</sup> for the previous decade. It was also within this decade that the Duiwenhoks dam was constructed which led to the increase of inland water bodies in subsequent datasets. The underlying imagery of this decade was captured before the Duiwenhoks dam was filled hence the increment of inland surface water bodies does not reflect on this decade.

(iv) 1970 to 1990 decadal changes

Statistical geographical findings from this decade produced the second highest reduction in natural vegetation spatial coverage. A total of 97 km<sup>2</sup> in natural vegetation was converted due to cultivation and degradation. From the 70 year total natural vegetation loss of 211 km<sup>2</sup>, this decade alone accounted for 45.9%. It was also within this decade that there was the highest increase of urban built up and road construction in the catchment. Statistical findings on the total urban area in terms of perimeter coverage (suburb and residential) as measured in

ArcGIS amounted to 3.3 km<sup>2</sup> by 2010. In comparison with the 1940 benchmark dataset were only 1.3 km<sup>2</sup> of the Duiwenhoks catchment was urban. This shows a low urban expansion over a 70 year time series.

(v) 1990 to 2010 decadal changes (20 years)

Due to the 1980 dataset being discarded because the raw aerial photographs were unusable because of a bad texture and tonal format, the last dataset comprises 20 year interval. It is within this period that there was stability in land cover class coverage. There was a reduction in degraded areas and cultivation area increment was minimal in comparison with other datasets only at 14 km<sup>2</sup> (4.9%). However, it was within this decade that an increase in the total number of water bodies (inland dams) was observed. The benchmark dataset had very few inland water bodies but by 2010, surface water representation amounted to 3.5 km<sup>2</sup> with a major fraction of this going to the Duiwenhoks dam.

From the Accuracy Assessment results, the classification of urban built up areas produced very low accuracy scores due to the small spatial distribution of buildings and narrow roads which are difficult to sample. To overcome this, the perimeter of the urban area was manually digitized throughout the datasets to compare the increase in urban built up area of the Heidelberg Town and nearby settlement. By 2010, residential and urban developments increased from 1.3 km<sup>2</sup> in 1940 to 3.3 km<sup>2</sup> in 2010.

#### 4.5 Land cover transition and probability matrix at Duiwenhoks catchment

In order to make future predictions on land use and land cover changes, it is important to assess the historic transition matrices of land use and land cover types in a given location over time. This also helps in developing a probability matrix which quantifies the probability of a land cover class from one state to another. Predictions of future short term and long term

land cover dynamics can be determined by the calculation of transition matrices for a given location (Petit et al. 2001). The use of the Markov model helps in determining land cover dynamics in the future and understanding links between human induced socio- economic process like farming (Brown et al. 2000; Petit et al. 2001).

The Markov statistical matrix for future projections in this study was adopted from an analysis of wetland trend changes in arid Yinchuan Plain (Zhang et al. 2011). The Markov chain makes future predictions-based sequential assessment of land cover states and transition trends and probabilities (Lambin, 1997, Lopez et al. 2001; Zhang et al. 2011). For the Duiwenhoks study, future projections were modelled using a baseline initial state matrix of 1990 to 2010. A Markov chain analysis was ran using the R-statistical software to determine future land cover quantities, stability and convergence.

Table 13: Land cover transition matrix for 1990 to 2010

		Land Cover Transition Matrix for 1990 - 2010 (km <sup>2</sup> /20 Years)					
1990	2010						
	Cultivation	Degraded	Natural	Plantations	Urban Built	Water Bodies	Grand Total
Cultivation	427	3	133	1	2	0	566
Degraded	3	8	42	0	0	0	53
Natural	147	16	559	2	1	2	727
Plantations	0		2	2	0		5
Urban Built	3	1	3	0	1	0	7
Water Bodies	0	0	2	0	0	1	3
Grand Total	580	28	740	5	4	4	1361

The transition matrix was developed through ArcGIS by overlaying and intersecting the two datasets (1990 and 2010) and assessing spatial changes of land cover states from one form to another between the two. Findings on the major land cover transition were on natural areas to cultivated fields. This transition between the two datasets amounted to a spatial geographical coverage of 133 km<sup>2</sup>. Only 427 km<sup>2</sup> and 559 km<sup>2</sup> of cultivated land and natural areas

remained the same without transitioning into another land cover class at Duiwenhoks catchment (See table 13 above).

Table 14: Land cover transition probability matrix and Markov predictions for the 1990 – 2010 initial state

(a)						
1990	Initial state transition probability matrix from 1990 to 2010 (20 Years)					
	2010					
	Cultivation	Degraded	Natural	Plantations	Urban Built	Water Bodies
Cultivation	0.754341729	0.005871047	0.234245219	0.001481563	0.003203220	0.000857221
Degraded	0.053257217	0.143126024	0.797617086	0.000679133	0.003939637	0.001380904
Natural	0.201798810	0.022556716	0.768868208	0.002529464	0.002009766	0.002237036
Plantations	0.051242389	0.000000000	0.466145094	0.480999067	0.001613450	0.000000000
Urban Built	0.389389962	0.123983608	0.404510004	0.002901251	0.077498444	0.001716730
Water Bodies	0.044044845	0.028955469	0.497138795	0.000295048	0.000597739	0.428968104
(b)						
Years (n)	Predicted land cover changes using Markov chains (km <sup>2</sup> )					
	Cultivation	Degraded	Natural	Plantations	Urban Built	Water Bodies
10	604.24	23.77	720.12	5.29	3.78	3.80
15	604.37	23.77	720.00	5.29	3.78	3.80
30	604.37	<b>23.77</b>	719.99	5.29	3.78	3.80
40	<b>604.37</b>	<b>23.77</b>	<b>719.99</b>	5.29	<b>3.78</b>	<b>3.80</b>
45	<b>604.37</b>	<b>23.77</b>	<b>719.99</b>	5.29	<b>3.78</b>	<b>3.80</b>

As presented in Table 14, findings on the land cover transition probability matrix 14 (a) and future predictions 14 (b) based on the Markov chain analysis is shown for the ecological land cover classes from 1990 to 2010 at the Duiwenhoks catchment. Findings from the Markov prediction ran by the R-software used the transition probability matrix as the initial state and simulated future predictions in years (n-values). Therefore, the Markov predictions is underlined by (n) multiplied by the initial state duration (20 years). From table 14 (b), land cover distribution according to the Markov model will be in a steady state after 300 years for cultivated areas, degraded fields and natural areas if the initial state's (1990-2010) land use management is maintained throughout. By then, cultivation will comprise 604.37 km<sup>2</sup>, degraded fields at 23.77 km<sup>2</sup> and natural land cover at 719 km<sup>2</sup>.

A Markov-based projection for the Duiwenhoks dataset was also modelled for the earlier classified datasets (1940 to 1950) when agricultural activities were still minimal. Projections based on this 10 year initial matrix were relatively sustainable as compared to the 1990-2010 predictions. Table 15 below shows the transition matrix whereby 15 (a) is the initial state between 1940 and 1950 followed by the Markov predictions 17 (b). Markov chain predictions findings were that cultivation, degraded areas and natural areas will be in a steady state after 400 years if land use management and land cover trends was maintained. By then cultivation will comprise 402 km<sup>2</sup>, degraded areas 41 km<sup>2</sup> and natural areas 906 km<sup>2</sup>.

Table 15: Land cover transition probability matrix and Markov predictions for the 1940 – 1950 initial state

(a)						
1940	Initial state transition probability matrix from 1940 to 1950 (10 Years)					
	1950					
	Cultivation	Degraded	Natural	Plantations	Urban Built	Water Bodies
Cultivation	0.617596172	0.005883839	0.373386597	0.000096732	0.002579666	0.000456995
Degraded	0.020704640	0.342391188	0.631072863	0.000281983	0.004646604	0.000902723
Natural	0.167621331	0.027090845	0.800811698	0.001569707	0.001728986	0.001177433
Plantations	0.001740183	0.007284128	0.261998381	0.728739251	0.000238057	0.000000000
Urban Built	0.308193805	0.090986497	0.378855316	0.001089561	0.209665481	0.011209340
Water Bodies	0.052842249	0.096160685	0.418483357	0.000000000	0.001401298	0.431112411
(b)						
Years (n)	Predicted land cover changes using Markov chains (km2)					
	Cultivation	Degraded	Natural	Plantations	Urban Built	Water Bodies
10	402.67	41.84	906.29	5.32	3.55	2.34
15	402.69	41.83	906.18	5.42	3.55	2.34
30	402.68	<b>41.83</b>	906.17	5.44	3.55	2.34
40	<b>402.68</b>	<b>41.83</b>	<b>906.17</b>	5.45	<b>3.55</b>	<b>2.34</b>
45	<b>402.68</b>	<b>41.83</b>	<b>906.17</b>	5.45	<b>3.55</b>	<b>2.34</b>

#### 4.6 Summary of main land cover change trends

Spatial analysis of the land cover maps show land cover change being driven by human activities through the demand and increase in agricultural farming area. From the baseline dataset, natural vegetation between 1940 and 1950 is seen to be lost to cultivated land or bare

ground which signals the preparation of land with an intention to expand and the demarcation of more agricultural fields. During field visits, it was found that most agricultural fields near the coast were not only rested, but the farmers abandoned practicing cultivation the coastal areas and rather introduced livestock farming.

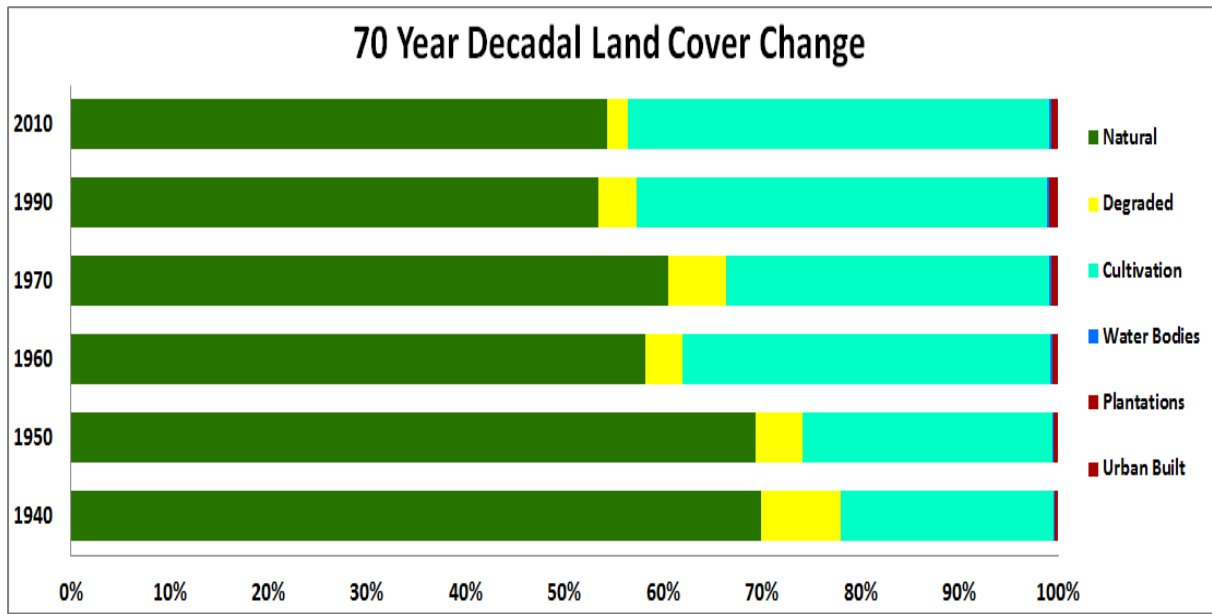


Figure 17: Major land cover changes at Duiwenhoks catchment.

From the statistical land transition and probability matrix, the dominant forces of land cover change at Duiwenhoks catchment (see figure 17 above) has been underpinned by the expansion in agricultural areas and the reduction in natural vegetation.

Land cover was dynamic throughout the 70 year assessment. Figure 18 below shows the major transitions in a flow diagram format from 1940 to 2010. The figure assumes that the baseline decade (1940) was the original pre-colonialization status of natural vegetation. Transitions from natural vegetation into cultivated areas began a decade later after superimposing the 1950 dataset with the 1940 dataset. Patches of cleared natural area and demarcation lines can be seen on the raw aerial photographs on areas which were later established private cultivated. However, a rejuvenation of natural vegetation was observed on

the 1970 dataset as compared with the 1960 decade. This was assumed to be cultivated fields being rested or left fallow leading to misclassification in the study of fallow areas.

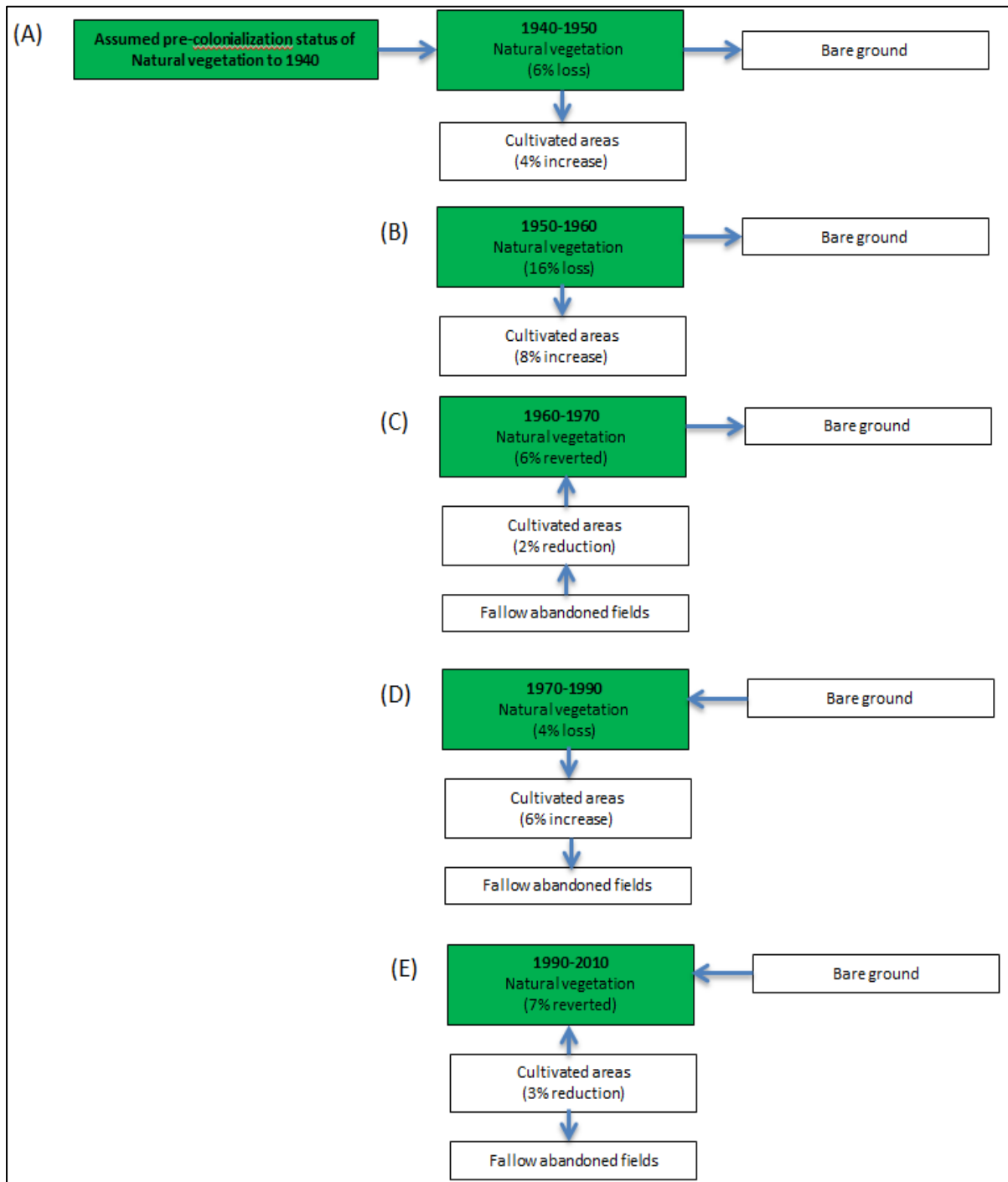


Figure 18: Main drivers of decadal trends in the Duiwenhoks catchment from 1940 – 2010. Aerial coverage of “Natural Vegetation, Cultivated Areas, Fallow Abandoned Fields and Bare Ground” was based on algorithmic classification of grey-scale aerial photographic images from 1940 to 1990, and manual digitizing of the same classes from a Colour Infra-Red (CIR) image for 2010.

#### 4.7 Observed environmental impacts caused by land use and land cover change

Impacts were assessed and studied using the decadal datasets and field visits to the Duiwenhoks catchment. Ancillary established datasets were also used to further assess the findings of the land cover maps obtained from the South African Weather Services (SAWS). This came in the form of historic rainfall data from a station (station number 0009815) at Heidelberg town. The Department of Water Affairs (DWA) streamflow gauging station (H8H001) was also used to monitor water stream flow dynamics in the midst of a changing land use and land cover in the catchment. The National Freshwater Ecosystem Priority Areas (NFEPA) datasets also helped identify underlying ecosystems like wetlands.

After superimposing the remotely sensed datasets to assess changes, most impacts were caused by a resultant of agricultural expansion and occurred on sensitive wetland environments like seep wetlands, valley head seep wetlands, floodplain wetlands, channelled valley-bottom and unchannelled valley-bottom wetlands which all have different conservation and condition statuses as classified by NFEPA datasets. Most of the wetland vegetation on the foot slopes of the Langeberg Mountains moving down to the Citrus farm / orchard and further down to the Heidelberg town was classified as “C” meaning that they are not in their intrinsic state but rather moderately modified with 25%-75% remaining as natural. Although it is difficult to categorise land cover impacts according to their culprits due to their direct and indirect relationships, it was observed that agricultural impacts leading to riparian vegetation reduction was caused by human activities whilst erosion was catalysed by a changing climate in the form of climate variability through intensive rainfall amounts over a short period of time over the previous decades.

#### 4.7.1 Anthropogenic changes and impacts

Land cover findings on natural and cultivated fields showed a decline in riparian vegetation. Below on figure 19, agricultural expansion is shown in the middle catchment leading to a decadal wipe out of natural vegetation on both sides of the Duiwenhoks River.

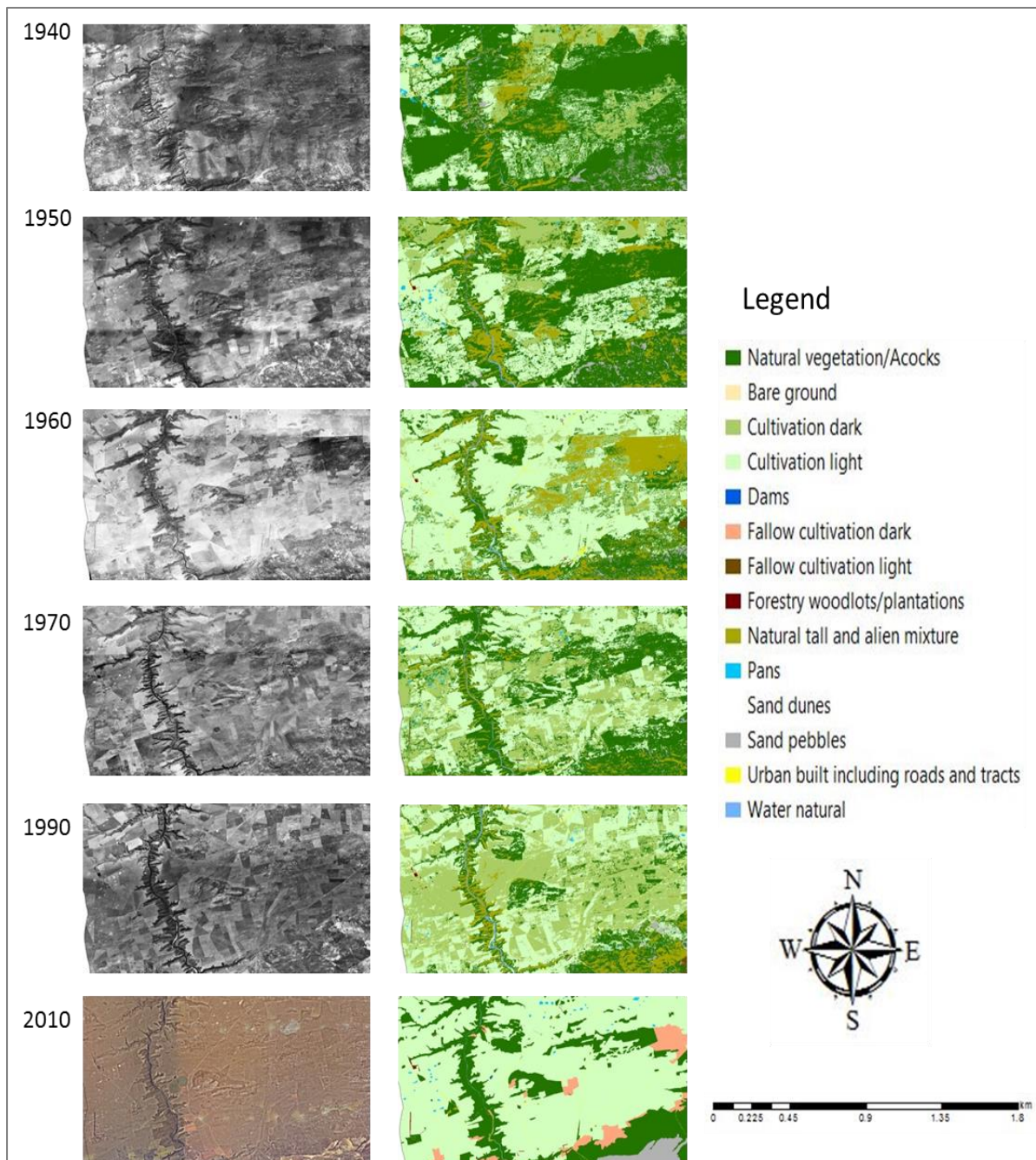


Figure 19: Decadal trends of the riparian vegetation from 1940 – 2010. Aerial coverage of the riverine primary land cover classes were based on algorithmic classification of grey-scale aerial photographic images from 1940 to 1990, and manual digitizing of the same classes from a Colour Infra-Red (CIR) image for 2010.

Due to the need for more arable land and the rapid progress of industrialization during the 20<sup>th</sup> century, a lot of land was lost to the increasing demand of agricultural fields. Cultivation activities from the land cover classes was seen to be operated on fragile wetland ecosystems as described in the NFEPA wetland ancillary dataset. Decadally, agricultural activities crept slowly on the riparian zone and beyond the 100m buffer zone from the river channel.

#### 4.7.2 Natural changes and impacts

Additional to the NFEPA ancillary data on wetlands, it was observed that the heavy rainfall season (winter) produces rapid runoff on un-terraced fields which lie on steep slopes (Koulouri & Giourga, 2007). This washes away debris and topsoil further downstream to the river channel and other feeding streams causing siltation and sedimentation. This process also introduces indirect secondary environmental impacts like the increase in alkalinity of water pointed out by a conservative farmer. The 2010 secondary classes obtained through manual digitizing, field work and ground truthing provided findings that very few fields within the catchment were terraced on steep slopes. This increases the occurrence of erosion, sedimentation and water pollution at Duiwenhoks during flash floods.

Due to limitations of the remotely sensed derived land cover maps to classify a distinct class of alien vegetation, impacts were studied and assessed during ground truthing, and interacting with conservation planners, farmers and CapeNature staff stationed at the Duiwenhoks catchment. Findings during the study visits showed alien infestation along the riparian zone, streams and wetlands at the middle of the catchment and on the foot slopes of the Langeberg Mountains. Common amongst these was the ever thirsty Black Wattle (*Acacia mearnsii*) located along the Duiwenhoks River channel and feeding streams, the Australian golden wattle (*Acacia saligna*) located at historically cultivated lands which are now used for pastoral activities, the Silky hakea (*Hakea sericea*) located on the upper high altitude

catchment. The Cluster pine/ Pine tree (*Pinus pinaster*) nested on river banks. Figure 20 below shows land cover responses on steep slopes which have instigated erosion and wetland disturbance. The figure shows a section at the top quinary were cultivation began on a sensitive wetland from 1950. By 2010, a pivot irrigation system was installed in the sensitive ecosystem.

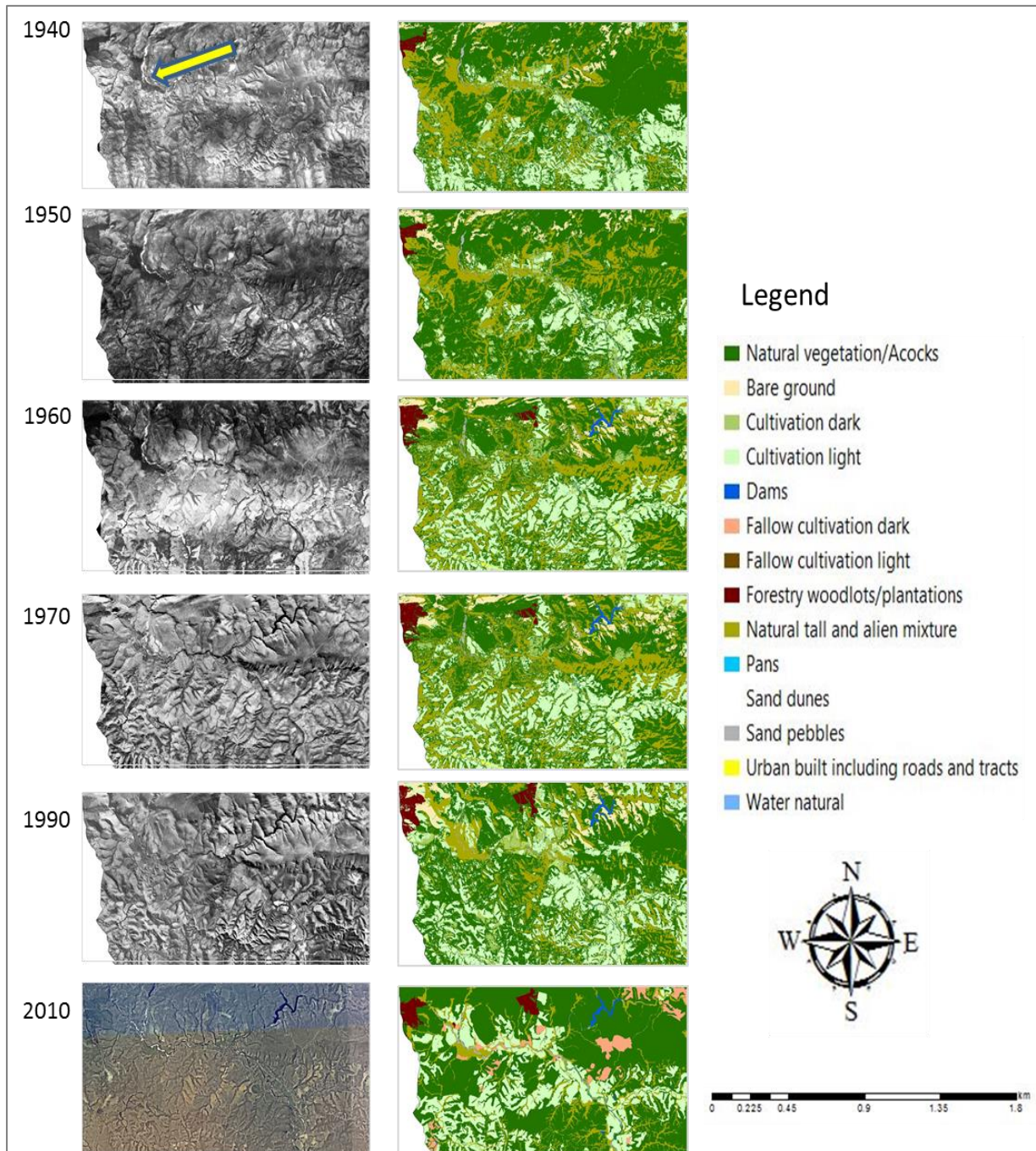


Figure 20: Decadal trends of land cover response at steep slopes and cultivation on wetlands from 1940 – 2010. Aerial coverage of the primary land cover classes were based on

algorithmic classification of grey-scale aerial photographic images from 1940 to 1990, and manual digitizing of the same classes from a Colour Infra-Red (CIR) image for 2010 (the yellow arrow indicates a wetland before being surrounded by cultivated fields which instigated soil erosion on the upper catchment at Duiwenhoks starting from 1960).

#### 4.8 Effects of land cover change on hydrologic ecosystem services

During field trip visits and interactions with farmers, environmental managers and the water irrigation board within the catchment, it was found that most ecosystem services at Duiwenhoks catchment are derived from and connected to the hydrological cycle. Common ecosystem services observed include water provision from farm dams and groundwater pumping, flood mitigation by wetlands which act as a sponge to collect rapid runoff and later releasing it at a slower pace. Other secondary services pointed out by a hydrological specialist include carbon sequestration.

It is fair to say that the land cover maps showing the reduction in natural vegetation has negatively affected some ecosystems which are very sensitive and fragile in nature like wetlands and riparian habitats. Their disturbance affects species diversity which is a strong indicator of ecosystem resilience to a changing environment. The reduction of the riparian zone together with different flow regimes of the Duiwenhoks River channel may also negatively affected aquatic species diversity. The riparian vegetation alone is home to a lot of species because it serves as a corridor for species movement.

Anthropogenic impacts observed at the catchment are also hydrologically connected. The drainage system at the Heidelberg rural residential area is also not environmentally sustainable because water is channelled directly from a poor road drainage system and informal houses to a wetland which seems to be in a stress condition due to the excessive litter pollution. Figure 21 shows the different drainage systems for the urban and rural parts of the catchment.

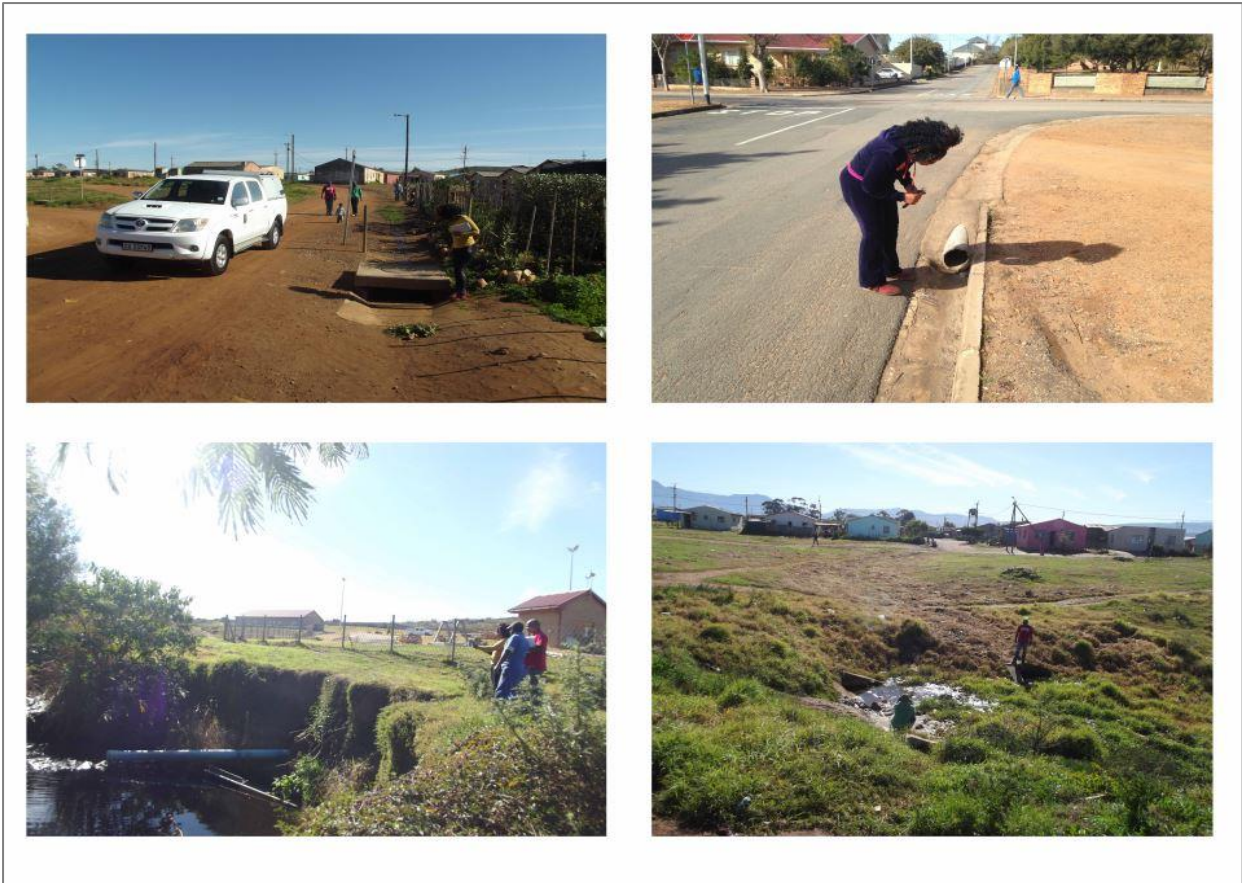


Figure 21: Heidelberg suburb: Local detail of features relevant to parameterize urban and rural drainage systems. Top left: Un-tarred but compacted road in township with uncanalized drainage flow; Top right: Tared road in main town of Heidelberg with canalized flow for road drainage; Bottom left: Sewage treated water channelled back to the Duiwenhoks River; Bottom right; Stressed wetland from litter. Photographs were taken during a field trip (16 July 2014).

Other findings on hydrological ecosystem trends were observed by assessing streamflow regimes and rainfall datasets available for the Duiwenhoks catchment from the past decades. Data on streamflow was collected from the Department of Water Affairs which has a streamflow gauging station (H8H001) at the bottom of the catchment (34°15'6.01"S and 20°59'30.98"E). It is located at a very good position to assess the impact of legal and illegal water abstraction from the Duiwenhoks River because no irrigated agricultural fields are located after its geographical position heading to the Duiwenhoks estuary and finally into the Indian Ocean. The gauging station's geographical position is also ideal to measure seasonal fluctuations in agricultural abstraction from the main river. The streamflow station has been

operational since 1967 with very little damage (data gaps) compared to other gauging stations located further inland which continuously fail due to damages after heavy floods. Additionally, the streamflow's regime was collectively assessed with rainfall patterns from 1940 – 2010 using summer and winter seasons only. Findings from the South African Weather Services (SAWS) rainfall station located at Heidelberg town (station 0009815) show that the catchment falls in a fairly all-year round regions with the most precipitation occurring in winter months (May, June, July and August) compared to summer months (November, December, January, February). However, the number of rainy days in the summer season was very low as compared to winter.

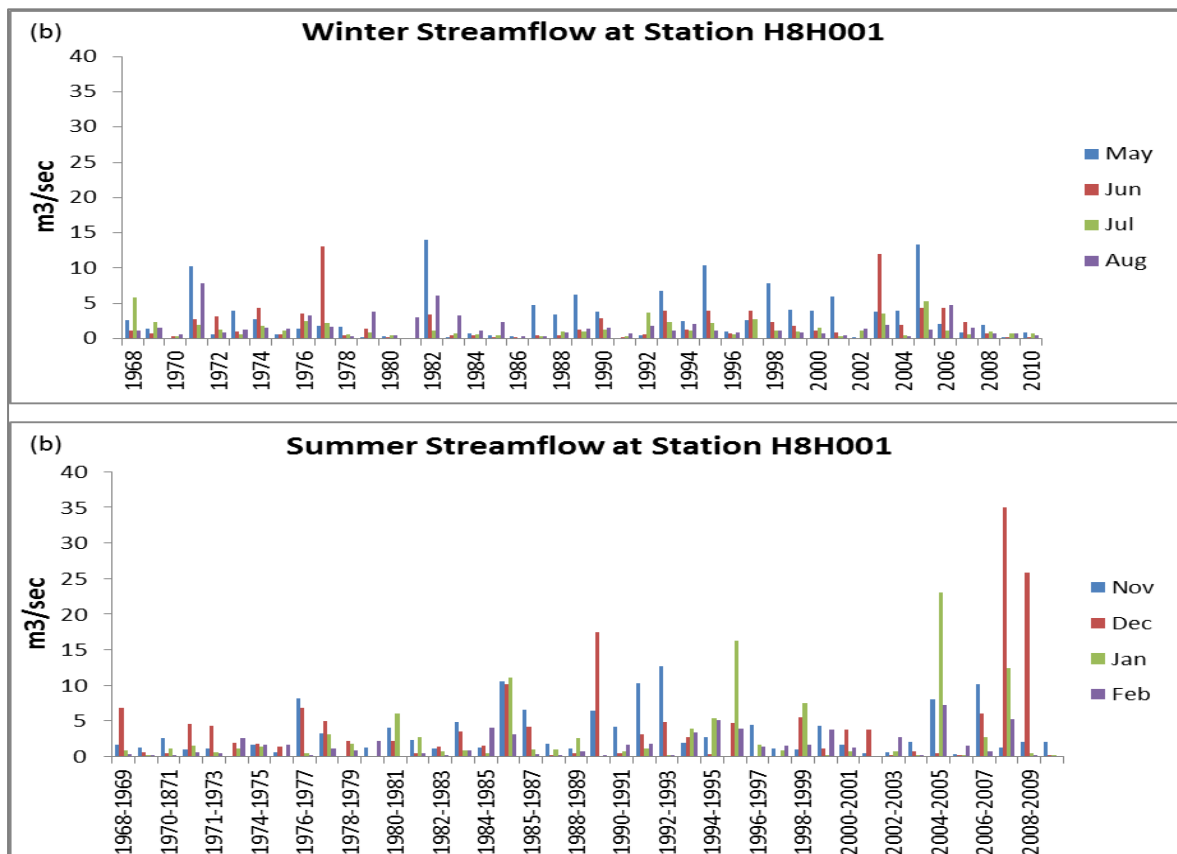


Figure 22: Streamflow dynamics for station H8H001 from 1968 – 2010 (DWA, 2013)

Streamflow in summer was found not to be constant as compared to the winter seasonal streamflow (See figure 22). This is thought to be driven by climate variability events like flooding activities and rapid-runoff from agricultural fields. The streamflow data was

assessed together with the rainfall data showing daily and monthly rainfall recordings. The summer floods of 1989 caused a streamflow recording of 17.4 m<sup>3</sup>/sec. This was the highest recording after 22 years of streamflow measurements (1967 – 1989). The next flooding event of 2004 was also higher reaching 23 m<sup>3</sup>/sec. However, the year 2007 had the highest summer streamflow records reaching a peak of 35 m<sup>3</sup>/sec in November from a monthly rainfall of 269.9 mm (see figure 23 below). From figure 22 above, winter streamflow is fairly uniform 22 (a) as compared with the summer season 22 (b) with a monthly of average of 2.13 m<sup>3</sup>/sec and 3.15m<sup>3</sup>/sec respectively from 1960 to 2010 at the H8H001 station. More findings affecting the streamflow regimes was found at the Duiwenhoks Water User Association which pointed out that there is a very high demand of irrigation water from farmers in summer as compared with the winter season. Rainfall patterns showed in figure 23 below shows an increasing pattern in rainfall variability in early summer seasons (November).

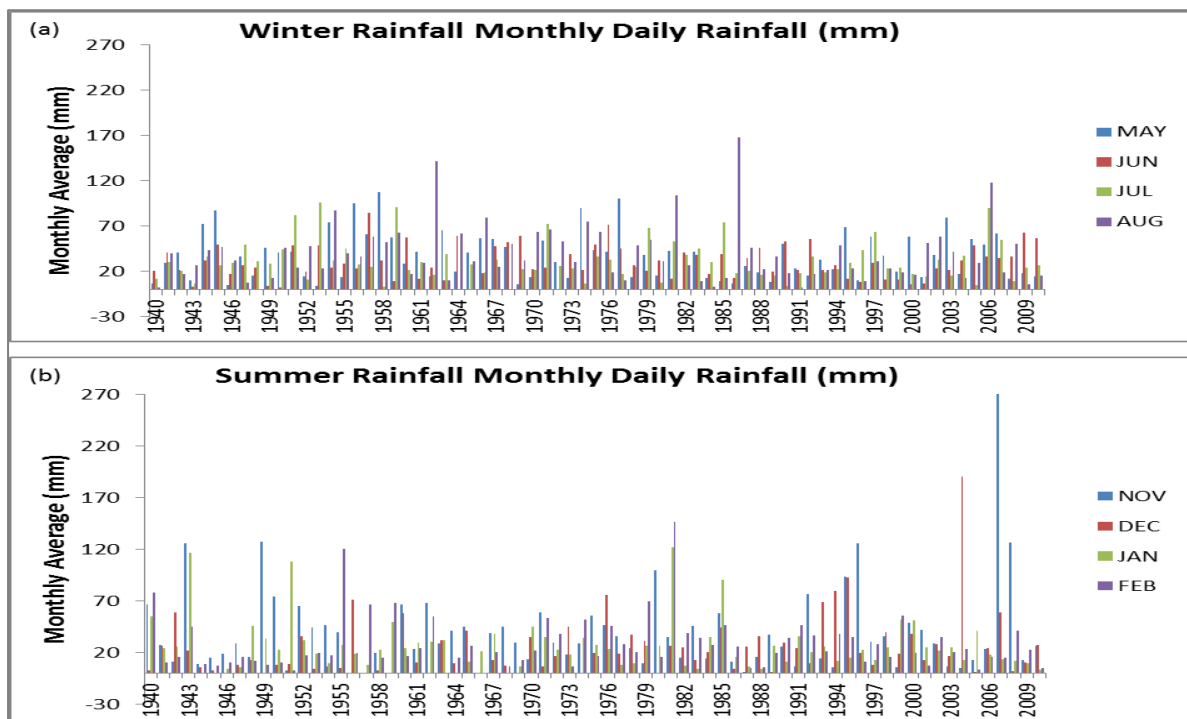


Figure 23: Summer and winter rainfall dynamics at Heidelberg from 1940 – 2010 (SAWS, 2014)

#### 4.9 Impact and effects of changing government policies and adaptation mechanisms

Literature and interviews with conservation planners at Duiwenhoks Catchment (CapeNature and Nature Conservation) suggest that the then Cape colony (today Western Cape Province) has been the frontier in designing and planning of environmental conservation efforts (Hey, 1982). Legislation is not a tangible environmental conservation effort but rather a guideline to use and manage the environment in a non-deteriorating way. Early and strict measures put in place designed to conserve biodiversity and wildlife resources like hanging and blinding have been amended and augmented periodically by law incorporations (Hey, 1982). Provincial ordinances have been amended and consolidated to meet changing times and conditions. The main aim of the provincial ordinances has been to regulate hunting, fishing, and the picking of wild flowers. The Cape Ordinances was aimed at basically at the conservation of wildlife in the sense of wild management. This included the protection of all rare, useful and harmless species of both the animal and plant kingdom (Hey, 1982). After the Democratic dispensation, the physical environment accelerated to modern local and international recognized policies. Adaptation measures and treaties have been put in place in most of South African threatened ecosystems to conserve and rehabilitate degraded ecosystems.

The Department of Environmental Affairs through the Long Term-Adaptation Scenario Flagship Research Programme (LTAS) which is specifically aimed at responding to the South African Climate Change Response White Paper (NCCRP) within all levels of governance also alludes for continuous implementation of the Integrated Coastal Management programmes and terrestrial ecosystems. The main objective of this has been to promote diversification of activities to enhance resilience in the face of uncertainty and variability at coastal communities with priority given to the Indian coastal belt (DEA, 2013).

#### 4.9.1 Ecosystem adaptation mechanisms at Duiwenhoks

Adaptation mechanisms found during study site visits and whilst performing ground truthing with CapeNature staff included the Duiwenhoks Goukou Wetland Rehabilitation project. The project constructs gabion structure on river and stream banks to halt erosion whilst maintaining streamflow (see figure 24). The project started in September 2009 and was funded by the South African National Biodiversity Institute's (SANBI) Working for Wetlands. Black wattle (*Acacia mearnsii*) and Braambos bramble (*Rubus cuneifolius*) alien plants appear very densely and are sucking up the wetland at the lower end of the structure. The project is implemented by both men and women involved in the labour intense work with a majority number being in the youth age group (60%).



Figure 24: Duiwenhoks Goukou Wetland Rehabilitation Project adaptation mechanism. Top left; signpost positioned to inform public of on-going conservation programmes at Duiwenhoks catchment; top right; gabion structure in process of construction during the study site visit (16 July 2014).

Observations during the study site visits indicated that there are increasing efforts towards environmental management and sustainable development especially with regard to the control of alien invasive plants, rapid erosion on river banks and streamflow management by

different government stakeholders. Above, figure 24 shows a project by the Working for Wetlands programme on wetland rehabilitation.

#### 4.10 Summary and conclusions

This chapter discussed key findings from the built decadal land cover maps and assessed the statistical quantities decadal and spatial trends supported by ground truthing and field visits. Accuracy assessment levels of the different classification methods were also measured to identify the best classification mechanism on the datasets. Additionally, the chapter also profiles the effects of environmental policies and adaptation mechanisms aimed at ecosystem management in the study area. The main findings after doing spatial analyses from the produced land cover maps were that there was an exponential increase of agricultural areas from the early 20<sup>th</sup> century. In assessment of the produced land cover maps the demand for cultivated areas increased decade by decade reducing the spatial coverage of natural vegetation at the catchment. This caused impacts such as rapid soil erosion, alien vegetation infestation, and other secondary impacts. This chapter lays the basis for the next which discusses the historical land cover dynamics and highlights future possible projections, and whether trends in land use and land cover change is unsustainable.

## **Chapter 5: Discussions and Conclusions**

### **5.1 Introduction**

This chapter synthesizes results obtained from the spatial land cover maps produced in this study which consists of six generic ecological classes. The classes include cultivation, natural, plantations, water bodies, urban built and degraded fields. The classes are assessed and related to ancillary datasets such as temporal data on streamflow from the Department of Water Affairs (DWA) and temporal data on weather collected by the South African Weather Services (SAWS). Spatial data on vegetation types developed by the South African National Biodiversity Institute (SANBI) is also used as a guideline to define the produced ecological classes. Informal discussions with farmers, conservation planners and the Duiwenhoks Water User Association are summarised in order to provide additional insights relating to historic land use and land cover changes at the Duiwenhoks catchment. Finally, the chapter provides conclusions from the land cover findings by tentative recommendations on land cover management in order to promote the health of ecosystem and environmental sustainability.

### **5.2 Primary land cover and land use types and their historical trends**

Historical land use and land cover trends at the Duiwenhoks catchment have occurred mainly between two dominant land cover types observed in the produced land cover maps, namely cultivation (land use) and natural vegetation (land cover). Based on the 70 year decadal time series observed in the study (1940 to 2010), a sharp decline in natural vegetation cover between the 1950's and 1960's was the predominant change that observed through desktop GIS and Remote Sensing analytical and quantification processes. The decadal datasets of 1940, 1950, 1960, 1970, 1990 and 2010 showed a decreasing series of natural vegetation cover of 59%, 54%, 38%, 44%, 47% and ultimately a 40% respectively from the entire catchment. Of all the decadal land cover maps observed in the catchment, cultivation, bare-

ground, fallow and abandoned cultivated fields were the main land cover types that increased whilst losses were on natural vegetation at all catchment levels (Upper, Middle and Lower catchment). However, because the middle catchment is characterised by mainly flat terrain with arable land of clay and loamy soils derived from the Bokkeveld group of shales (Mucina and Rutherford, 2006), that particular vegetation type (Coastal Renosterbosveld) has been the most affected.

From a socio-economic contextual point of view, the increase in demand for agricultural activities coupled with the increase in human population from 1940 to 2010 saw an increase in catchment active cultivated fields from 21% to 35% excluding other land uses such as fallow abandoned fields, which had an 8% increase in the 70 year time series. It is interesting to note that the largest conversion of natural vegetation to cropland occurred prior to the increase in inland water bodies (dams). The largest increase of water bodies was between 1960 and 1970 after the construction of the Duiwenhoks dam, and again between 1990 and 2010 due to private farm dam construction for irrigation and pastoral activities.

Further work could usefully investigate if the greater intensity of production under irrigation may have acted to increase profitability and thus reduce the pressure for land conversion, or whether these were the result of land use or agricultural policy changes. It is noteworthy that land adjacent to water courses (mainly the Duiwenhoks River) were exposed to increased conversion/transition from natural to croplands, suggesting that this was the result of economic forces and not policy changes.

### 5.3 Anthropogenic and natural environmental impacts

Most of the environmental impacts observed in the catchment are connected or driven by the hydrological cycle and climate variability through effects like flash floods which cause rapid run-off. These impacts are likely exacerbated by lack of farmers adhering to sustainable land

use practices and policies designed to conserve ecological resources. Examples include farmers who cultivate on steep slopes and those who cultivate on existing threatened wetlands. Cultivation on steep slopes was seen in the study to instigate rapid run-off because most fields in the steep terrain are not terraced and prepared to cope with flash floods resulting in siltation and stream alkalinity caused by washed out fertilizers from the agricultural fields. Wetland cultivation threatens the wetlands' ability to reduce flood impacts, store water and purify water.

Assessing the produced land cover maps and comparing them with South African population growth over the past 70 years, it is reasonable to assume that socio-economic forces drove the search for arable land in the Duiwenhoks catchment. However, unsustainable use of arable land is likely to reduce production yields due to projected long term water security declines and the frequency of climate variability impacts. The Duiwenhoks catchment provides an ideal test case to explore these relationships in the past and into the future. The Long Term Adaptation Scenario (DEA, 2013) suggests that an increase in irrigation demand will occur on South Africa due to 4-6% annual increase irrigation water and evapotranspiration. This will negatively impact the production cost of key cereal crops like maize in the summer rainfall regions and wheat in the winter wheat in the winter rainfall regions (Ziervogel et al. 2014).

The rapid increase in clearing natural vegetation to develop arable land at the Duiwenhoks catchment would also have been accompanied by indirect impacts on biodiversity, in particular in sensitive habitats on the riparian buffer zone of the Duiwenhoks river channel. Agricultural fields crept in decade by decade wiping out the natural vegetation mostly in the middle catchment which is characterised by the Coastal Renosterbosveld natural vegetation type. This will have resulted in the disturbance of the species richness in and movement because river buffer zones act as species corridors for migration, preying and reproduction,

and could be detected in future work by exploring changes in biological trends such as via the SA Bird Atlas Project.

It is clear from these that in some instances, threatened wetlands are continuously being degraded, in direct contravention of environmental policy. At two separate geographical locations in the upper and middle catchment, observations and assessments using the land cover maps and ancillary data saw establishments of irrigation pivots directly on the threatened wetlands. This is seen as a very detrimental land use on such a fragile ecosystem which produces multiple ecosystem services ranging from water cleaning and storage, flood mitigation and food provision. It is however important to indicate that ancillary data requires further ground truthing and error correction in order to increase the robustness of these results.

A further adverse land use practice observed during field visits was the impacts of two pivot irrigation systems on a river buffer zone. This practice seemed to result in water being channelled directly from the main river channel to the agricultural field. Not only does this disturb ecological streamflow, but it also makes monitoring the total water usage by the Duiwenhoks Water User Irrigation board a challenge.

#### 5.4 Environmental policies and adaptation mechanisms

Policies and plans for ecosystem management and conserving of the overall physical environment are drawn and designed at a wide array of spatial scales, from local municipality through the national to the international level. South Africa is amongst the leaders in environmental sustainability management not only in Africa, but also internationally (Balmford, 2003) to design and implement environmental legislation to conserve our rich biodiversity. However, there is a need to integrate the top-down approaches, whereby planning and policy design is at a national and international level, with planning and

implementation at local level. A hierarchy of environmental and ecosystem management has proven to be successful in other quinary catchments with uniform geophysical and temporal characteristics like relief, slope, soil, climate and geology like quinary H80C3 and H80F2 at Duiwenhoks catchment. However, through quantifying impacts of land cover change at a 70 year time series, this study found that many impacts are subtle and can only be detected and managed at a local level, meaning that slope, rainfall and soil types should be taken into consideration together with the threatened status of different vegetation types.

The observed shift in water flow data in summer and winter months through the catchment has a relationship with the adjacent land use type in the form of agricultural activities at either side of the Duiwenhoks River. Although rainfall patterns recorded at the Heidelberg station by the South African Weather Services (SAWS) at the catchment from 1940 to 2010 has fairly remained constant at an average of 400mm and seldom dropping to below 300mm, irrigation water abstraction, alien vegetation infestation and poor buffer zone management lies central to the fluctuations in stream flow.

Different biophysical characteristics of the landscapes react differently to climate variability. Thus, climate impacts vary greatly depending on the biophysical factors such as altitude, location and proximity to the coast. (Easterling, et al. 2007; Wiid et al. 2012) Thus, applying policies which have been successful at larger geographical scales will not yield the same results if these factors are not taken into consideration at a regional and local context when planning and designing adaptation options. The governance system in South Africa is comprised of three spheres which are national, provincial and local government. Following the transition to democracy in 1994, a number of legislative and policy provisions have increased the responsibility of the local government from service provider to an active development agent (Sitas et al. 2013). Most environmental governance and adaptation applied at catchment level are inspired by the National Environmental Management Act, the

White Paper for Sustainable Coastal Development and the on National Climate Change Response White Paper. These are the three national forerunning policies which have been observed to influence establishments of NGO's like SANBI, CapeNature, Working for Wetlands (WfW) and Working for Water. These organisations together with local government at municipal level design tools like the SDF'S and IDP's which have some of their goals directed at addressing ecosystem service management together with the built environment at large.

## 5.5 Conclusions and Recommendations

With good national and international policies in place to promote environmental sustainability in South African Water Catchment Management Areas, there is great potential for rehabilitation and conservation of ecosystems and the physical environment. However, the limitation of application of policy at a local fine scale level is one of the reasons which appear to lead to failure of preventing unsustainable land cover change such as in riparian zones. Firstly, catchments differ in their heterogeneous statuses signalling a need to structure locally developed environmental adaptation tools. Other studies indicate that the hierarchical list of planning documents and environmental issues become diluted in terms of their relevance to local development due to a weak alignment of policies and legislation (Sitas et al. 2013). There is an important role of local role players in addressing environmental impacts. A baseline framework has been developed (Hyogo Framework for Action) of 2005 to 2015 which points out the importance of early warning and disaster risk reduction at local level policy planning to ensure environmental, social and economic sustainability (Holloway et al 2012).

The on-going gabion construction project (Duiwenhoks Goukou Wetland Rehabilitation project) is one of the success adaptation mechanisms being rolled out in the Duiwenhoks

catchment because prior to its conclusion, several of the objectives like maintaining streamflow and halting river bank erosion appear to have been achieved. Additional to the gabion construction adaptation response, the alien vegetation clearing exercise has also proved to be yielding substantial results in the middle catchment. However, at the upper catchment below the Langeberg Mountains, the alien clearing programme should have immediately followed up the clearing exercise by planting endemic plants that will protect the soil from further erosion due to its looseness and exposure to runoff. Therefore, alien clearing should take note of the seasons in which to act on because performing the exercise in mid-winter makes the exposed soil erosion debris which waits to be washed into the main river and other feeding streams.

Few, if any, practical implementation programmes are in place in relation to longer-term climate change adaptation. With the South African Long Term Adaptation Scenarios reports indicating that under all scenarios considered, higher frequencies of flooding and drought events are likely to happen (Ziervogel et al. 2014) it would be advisable for the catchment management authorities to consider sustainable management plans for this eventuality. At the same time, land use practices designed to manage hydrological variability seem to be essential. A good example is terracing. Terraced fields respond differently from un-terraced fields during extreme climate events such as flash floods. Rapid erosion was seen to be frequent alongside roads of un-terraced fields as compared with terraced fields. It is thus important to continue encouraging this proven form of land use management in order to prevent erosion which also leads to secondary adverse impacts such as siltation and increasing soil water alkalinity.

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## Appendix A: Secondary classes descriptions

Secondary Class	Class description and characteristics
1. Cultivated dryland	- These are currently cultivated fields without signs of irrigation
2. Cultivated irrigated non pivots	- These are cultivated fields which show signs of irrigation - Frequent along irrigation dams, canals and river streams
3. Cultivated irrigated pivots	- These are circular cultivated fields irrigated by pivot irrigation system
4. Cultivated dryland with contour	- These are cultivated fields in steep slopes which are terraced to reduce runoff
5. Orchard	- These are vineyards with wind-breaks between them
6. Disturbed old fallow fields	- Fields which show signs of cultivation during previous planting seasons - Fields with new shooting vegetation sprouts
7. Disturbed old fallow fields, contour	- Fields which show signs of cultivation during previous planting seasons on terraced fields - Fields with new shooting vegetation sprouts on terraced fields
8. Irrigation dams	- These are manmade dams with concrete walls
9. Endorheic / Drainage dams	- These are dams situated in low lying terrain where water cannot escape - Distinguishable with the aid of contour lines shapefiles
10. Channel dams	- These are dams in small tributaries where water flow is minimal
11. Off channel dams	- These are dams which are manmade and fed by the river canal, groundwater or underground piping from the main river
12. Dune fields	- Dense coastal bare clotted near the coast
13. Coastal bare sand	- These are sands along the coastal planes and beach sands
14. Non natural, non coastal bare sand	- These are sands alongside river streams caused by river meandering, erosion and sediment deposits
15. Natural tall shrub	- These are tall trees which are endemic and native to the catchment
16. Plantation, woodlots	- These are tree plantations planned, grown and controlled by humans - Identifiable by organized pattern of tree growth or definite boundaries which separate them with other land cover classe
17. Natural tall shrub, alien mix	- This is a mixture of both native tall shrub and encroaching aliens

18. Aliens along stream	<ul style="list-style-type: none"> <li>- These are alien vegetation which are common alongside river streams</li> <li>- <i>Acacia mearnsii</i> (Black wattle) and <i>Acacia saligna</i> (Orange wattle)</li> </ul>
19. Aliens upland	<ul style="list-style-type: none"> <li>- These are aliens which have encroached upland natural vegetation</li> </ul>
20. Urban built, residential	<ul style="list-style-type: none"> <li>- These are urban residential areas found next to Heidelberg town</li> <li>- Identifiable by buildings patterns, location and well established tarred roads</li> </ul>
21. Urban built, suburb	<ul style="list-style-type: none"> <li>- This is the main Central Business District (CBD) of Heidelberg town</li> <li>- Identifiable by buildings, factories and well established tarred roads</li> </ul>
22. Non urban roads	<ul style="list-style-type: none"> <li>- Gravel roads</li> </ul>
23. Water natural	<ul style="list-style-type: none"> <li>- This shows natural flowing water i.e. Duiwenhoks river</li> </ul>
24. Acocks 70	<ul style="list-style-type: none"> <li>- Identified using Acocks vegetation type maps and handbook as False Macchia</li> </ul>
25. Acocks 46	<ul style="list-style-type: none"> <li>- Identified using Acocks vegetation type maps and handbook as Coastal Rhenosterbosveld</li> </ul>
26. Acocks 47	<ul style="list-style-type: none"> <li>- Identified using Acocks vegetation type maps and handbook as Coastal Macchia</li> </ul>
27. Mining, rock	<ul style="list-style-type: none"> <li>- Rock mining activities in the catchment</li> </ul>
28. Mining, sand	<ul style="list-style-type: none"> <li>- Sand mining activities in the catchment</li> </ul>
29. Degraded area around built up	<ul style="list-style-type: none"> <li>- Bare ground cleared for human development</li> <li>- Often next to farm houses</li> </ul>
30. Degraded natural pans	<ul style="list-style-type: none"> <li>- Degraded bare ground enclosed in cultivation fields</li> <li>- Sometimes have a water pond for livestock</li> </ul>
31. Natural bare rock	<ul style="list-style-type: none"> <li>- Mountain bare rock</li> </ul>
32. Irrigation canal	<ul style="list-style-type: none"> <li>- Concrete canal used to transport water from the main river to irrigation dams and off-channel dams</li> </ul>
33. Riparian vegetation*	<ul style="list-style-type: none"> <li>- Acocks (70, 46, 47) vegetation along river or streams</li> </ul>
34. Wetlands vegetated (NFEP)*	<ul style="list-style-type: none"> <li>- Seep, valleyhead seep, floodplain, channelled valley-bottom and unchannelled valley-bottom wetlands</li> </ul>

- Swamp vegetation along river streams
- Identifiable by Palmet vegetation

## Appendix B: Accuracy Assessment Results

1960		1:50 000 Topographical Map						Row
Supervised Classes	Cult	Deg	Nat	Pla	Urb	Wat	Total	
Cult	17	0	13	0	0	0	30	
Deg	2	9	19	0	0	0	30	
Nat	6	0	20	0	2	2	30	
Pla	0	0	8	18	4	0	30	
Urb	4	0	3	0	21	2	30	
Wat	3	1	10	0	0	16	30	
	32	10	73	18	27	20	101	
Producer Accuracy	53.1	90	27.4	100	77.8	80		
User Accuracy	56.7	30	66.7	60	70	53.3		
Overall Accuracy	56%							
Kappa Index							180	

1990		1:50 000 Topographical Map						Row
Unsupervised Classes	Cult	Deg	Nat	Pla	Urb	Wat	Total	
Cult	24	2	2	0	1	1	30	
Deg	4	16	5	0	4	1	30	
Nat	3	4	13	1	6	3	30	
Pla	0	0	5	25	0	0	30	
Urb	5	2	4	0	19	0	30	
Wat	3	7	0	1	2	17	30	
	39	31	29	27	32	22	114	
Producer Accuracy	61.5	51.6	44.8	92.6	59.4	77.3		
User Accuracy	80	53.3	43.3	83.3	63.3	56.7		
Overall Accuracy	63%							
Kappa Index							180	

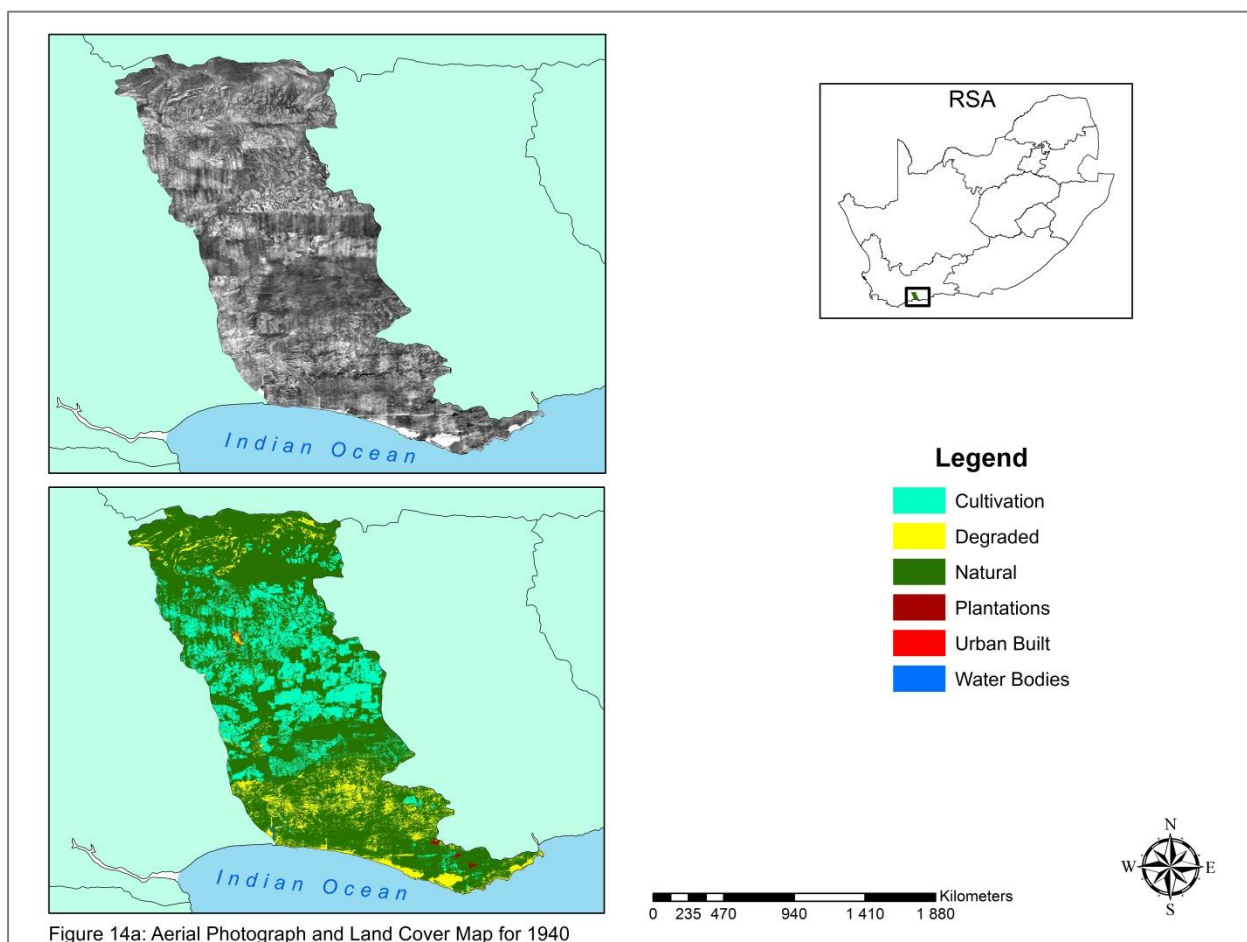
2010		1:50 000 Topographical Map						Row
Digitized Classes	Cult	Deg	Nat	Pla	Urb	Wat	Total	
Cult	26	0	2	0	2	0	30	
Deg	2	21	1	0	6	0	30	
Nat	1	0	25	0	3	1	30	
Pla	0	0	14	12	4	0	30	
Urb	1	0	1	0	28	0	30	
Wat	1	4	0	0	2	23	30	
	31	25	43	12	45	24	135	
Producer Accuracy	83.9	84.0	58.1	100.0	62.2	95.8		
User Accuracy	86.7	70	83.3	40	93.3	76.7		
Overall Accuracy	75%							
Kappa Index							180	

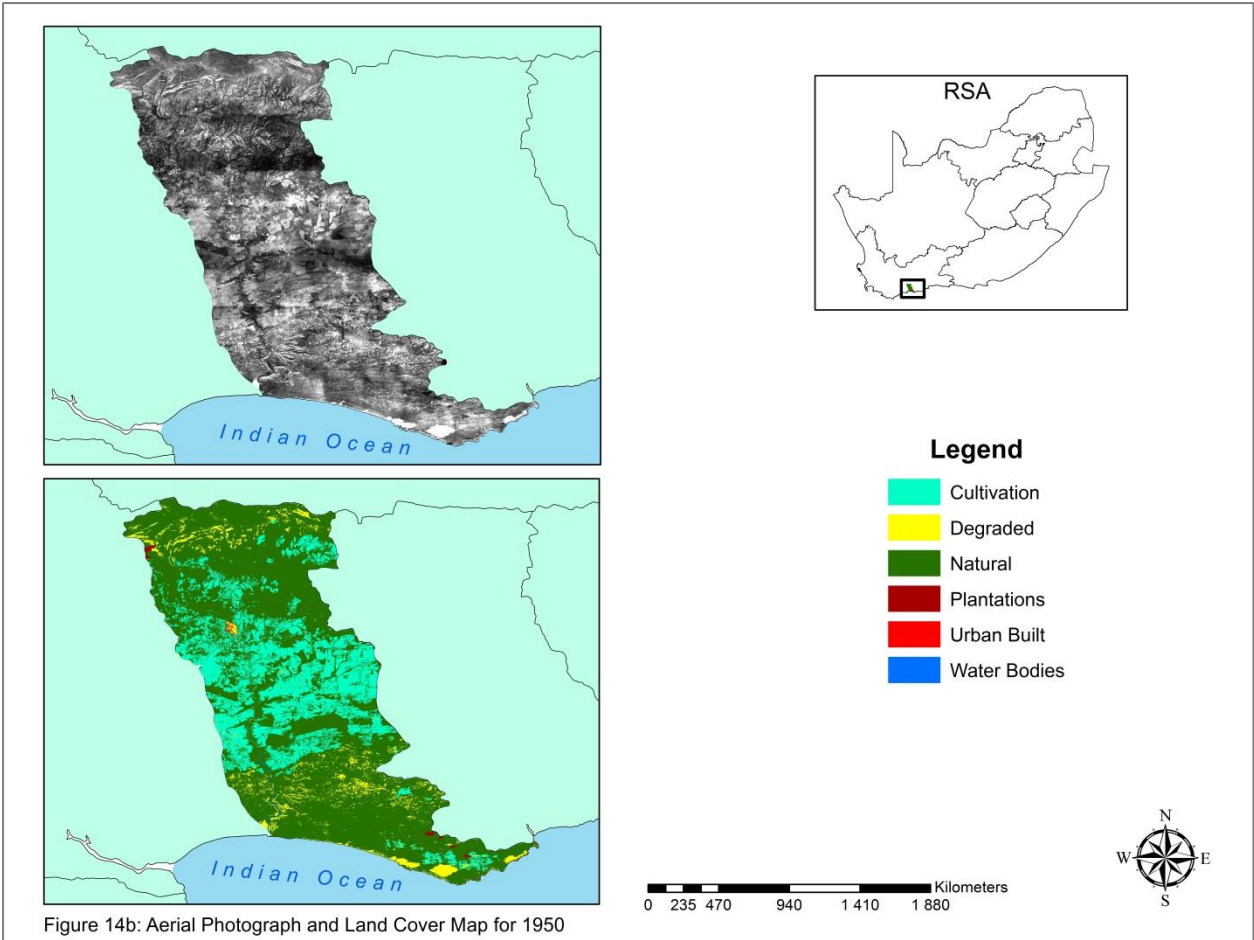
  

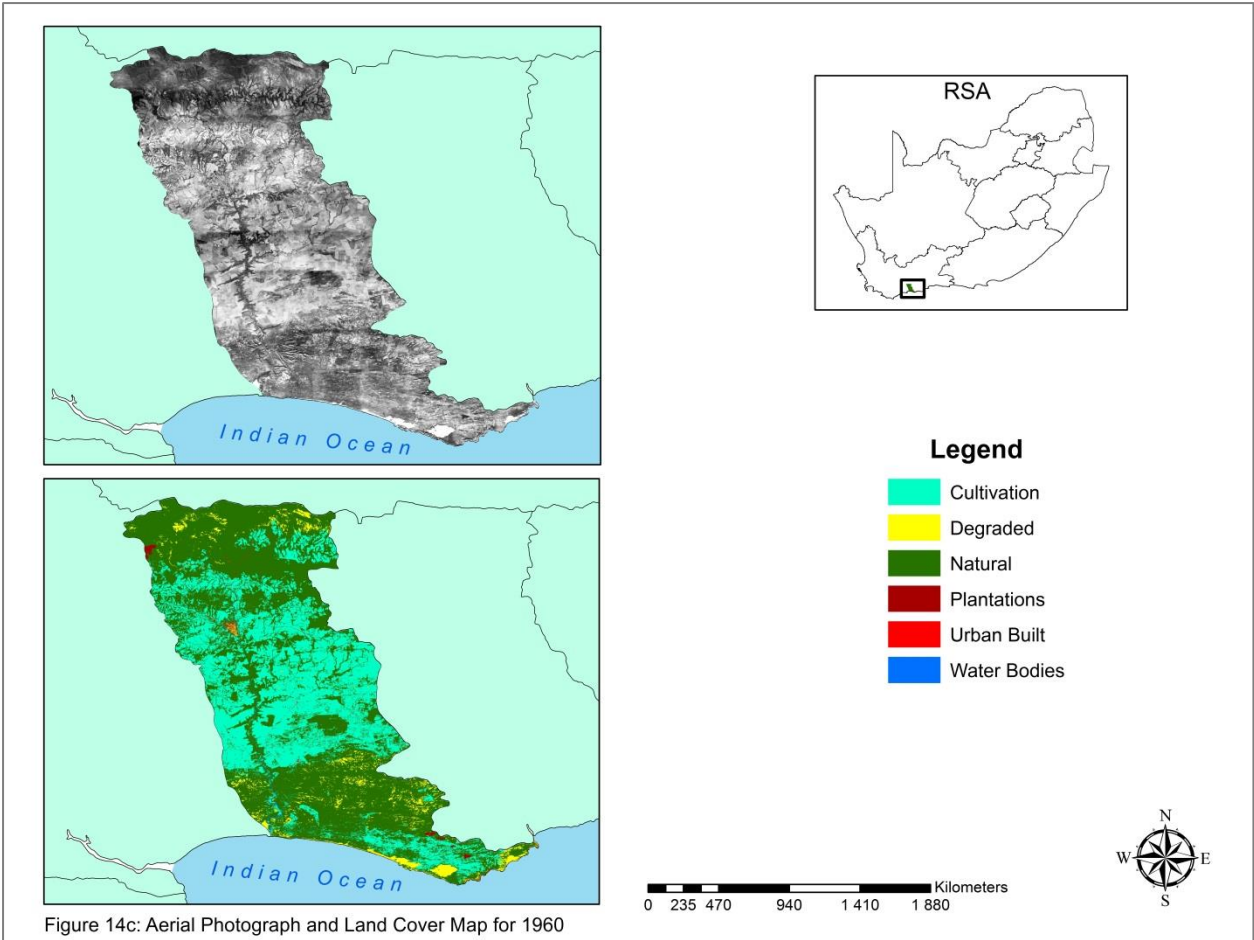
1960 Classified Image	1960 Reference Digital Baseline Information														Row	Producer	Error of
	NV	BG	CD	CL	DMS	FCD	FCL	FW	NTA	PNS	SD	SP	UBR	WN	Total	Accuracy	Omission
NV	51	8	28	9	17	11	26	7	12	25	2	34	13	9	252	20%	80%
BG	1	64	0	0	0	0	0	0	0	0	0	0	2	0	67	96%	4%
CD	2	0	24	4	0	5	0	2	0	5	0	0	2	1	45	53%	47%
CL	3	6	25	66	5	20	4	1	1	38	0	4	8	0	181	36%	64%
DMS	0	0	0	0	29	0	0	0	0	0	0	0	0	0	29	100%	0%
FCD	0	0	0	0	0	30	0	0	0	0	0	0	0	0	30	100%	0%
FCL	2	0	0	0	0	0	48	0	0	0	0	2	1	0	53	91%	9%
FW	0	0	0	0	0	0	0	62	0	0	0	0	0	0	62	100%	0%
NTA	18	1	2	1	29	12	0	8	67	1	0	1	5	8	153	44%	56%
PNS	0	0	0	0	0	0	0	0	0	11	0	0	0	0	11	100%	0%
SD	0	0	0	0	0	0	0	0	0	0	75	4	0	0	79	95%	5%
SP	3	1	0	0	0	2	1	0	0	2	34	0	0	0	43	79%	21%
UBR	0	0	1	0	0	0	1	0	0	0	1	1	49	0	53	92%	6%
WN	0	0	0	0	0	0	0	0	0	0	0	0	0	62	62	100%	0%
Total Samples	80	80	80	80	80	80	80	80	80	80	80	80	80	80	672		
User Accuracy	64%	80%	30%	83%	36%	38%	60%	78%	84%	14%	94%	43%	61%	78%			
Error of Commission	36%	20%	70%	17%	64%	62%	40%	22%	16%	86%	6%	57%	39%	22%			
Overall Accuracy	60%																
Kappa Index	58%														1120		

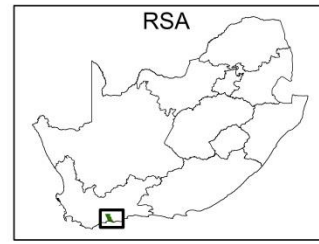
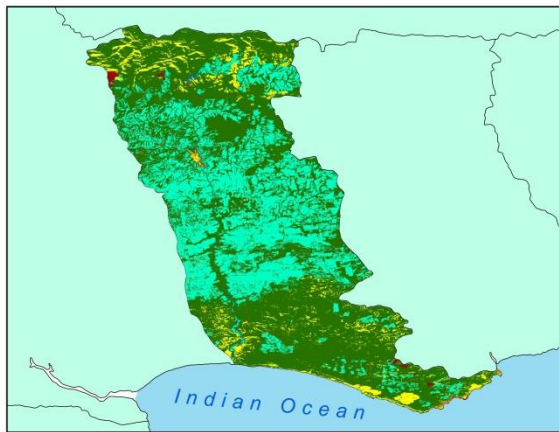
Natural Vegetation (NV), Bare Ground (BG), Cultivation Dark (CD), Cultivation Light (CL), Dams (DMS), Fallow Cultivation Dark (FCD), Fallow Cultivation Light (FCL), Forestry Woodlots (FW), Natural Tall/Alien Mix (NTA), Pans (PNS), Sand Dunes (SD), Sand Pebbles (SP), Urban Built (URB), Water Natural (WN).

**Appendix C: Land cover maps (See attachments for 1940, 1950, 1960, 1970 1990 and 2010 land cover maps)**









**Legend**

-  Cultivation
-  Degraded
-  Natural
-  Plantations
-  Urban Built
-  Water Bodies

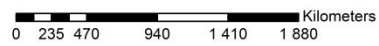
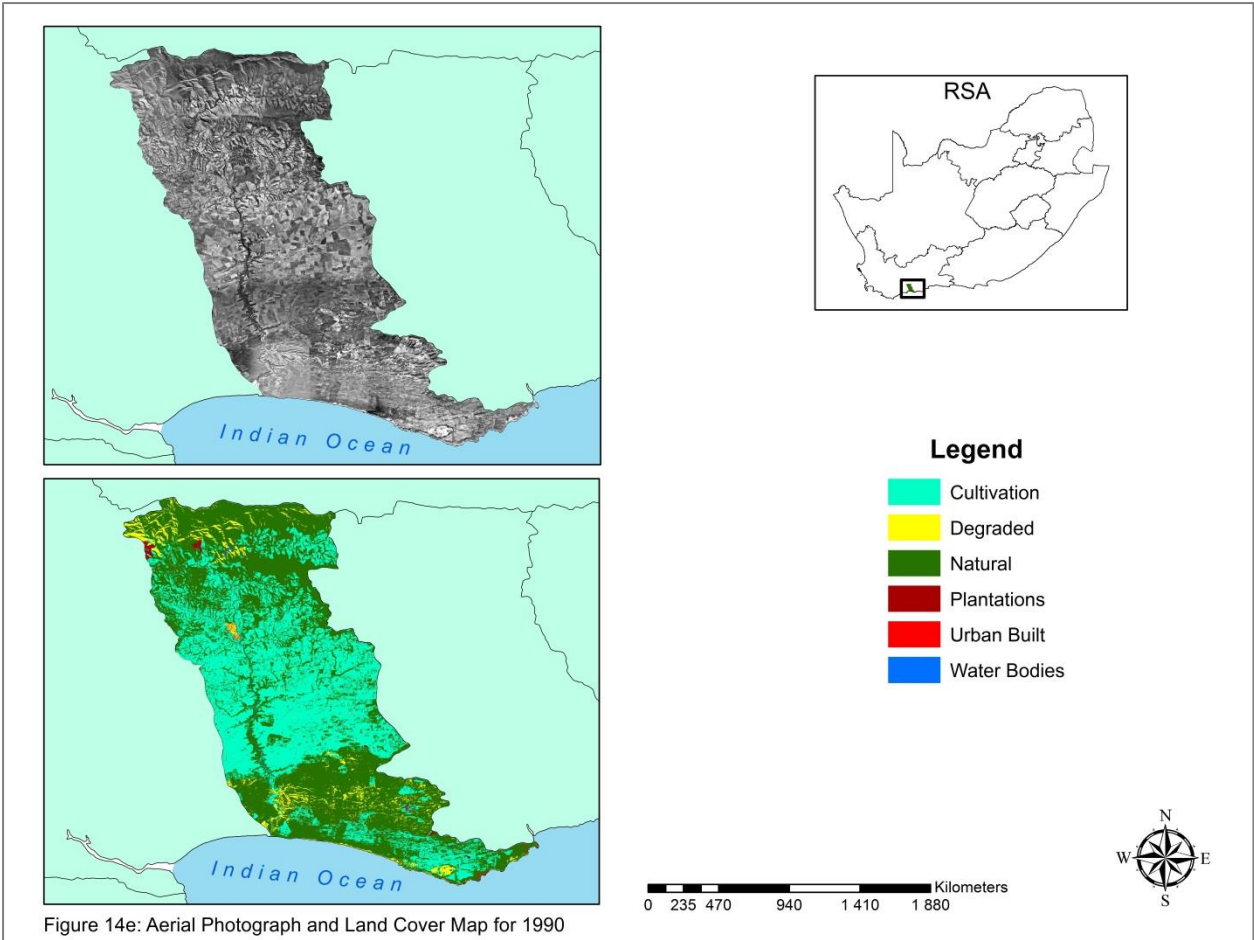
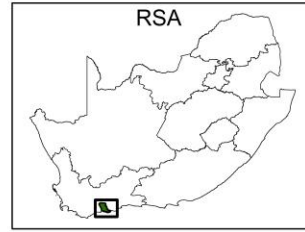
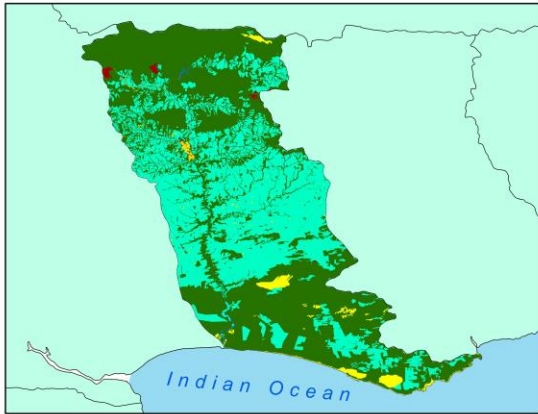


Figure 14d: Aerial Photograph and Land Cover Map for 1970





**Legend**

- Cultivation
- Degraded
- Natural
- Plantations
- Urban Built
- Water Bodies

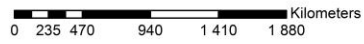


Figure 14f: Aerial Photograph (RGB) and Land Cover Map for 2010