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Land Use/Cover Changes and Vulnerability to Flooding in the Harts Catchment, South Africa.

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DECLARATION

I, Tabaro Hashim Kabanda, hereby declare that the thesis for the degree of Master of Environmental Science at North West University hereby submitted has not previously been submitted by me for a degree at this university or any other university, that it is my own work in design and execution and that all material contained herein has been duly acknowledged.

SIGNED: ____________ DATE: 03/09/2012

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SIGNED: ____________ DATE: 03/09/2012

Supervisor: Dr. L. G. Palamuleni

DEDICATION

To Salah and Siti

With love, appreciation, and thanks

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To Nahom Fajji, you have been so helpful in guiding me through the technical operations of remote sensing. I extend my very special thanks and sincere gratitude to my family for their love, support and encouragement throughout my study especially my father Prof. T.A Kabanda and mother Leilah Kabanda.

In the Name of Allah

The Most Beneficent, The Most Merciful

After praising Allah and praying for the bestowal of blessings and peace upon our master, the Messenger of Allah, Muhammad. I would like to thank Allah, for the spiritual guidance and good health that enabled me to complete my study.

ABSTRACT

The purpose of this study was to determine the hydrological impacts of land use/land cover (LULC) change in the Harts River catchment from 1990 to 2010 using an integration of remote sensing, Geographic Information System and statistical methods. Hydrological data of rainfall and river discharge were statistically analysed to reveal the changes and trends from 1990 to 2010. Changes in year-to-year relationships between precipitation and discharge suggested that discharge was relatively higher in the second half than in the first half of the study period. In fact, a weak correlation of 0.39 was found between precipitation and river discharge. The positive trend in discharge in the Harts River coincided with major changes in land cover over the study area. The LULC changes showed a decrease of vegetation cover from 758345 ha in 1990 to 736879ha in 2008, while barren land increased from 226670 ha in 1990 to 324322 ha in 2008 (an increase of 97652 ha). The coupling of surface observations, remote sensing, and statistical analysis demonstrated the impact of changes in LULC on peak river discharge and hence flooding behaviour on the Harts River catchment.

Keywords: Remote sensing, GIS, land use change, river discharge, Harts River

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ABBREVIATIONS

CN	Curve Number
CSIR	Council for Scientific and Industrial Research
CVA	Change Vector Analysis
DVI	Difference Vegetation Index
DWA	Department of Water Affairs
EMS	Electromagnetic Spectrum
ET	Evapotranspiration
GCP	Ground Control Point
GIS	Geographic Information System
GTLM	Greater Taung Local Municipality
ha	Hectares
IFOV	Instantaneous Field Of View
ISRIC	International Soil Reference and Information Centre
LULC	Land use and land cover
MSS	Multispectral scanner
NDVI	Normalised Difference Vegetation Index
PCA	Principal Component Analysis
PVI	Perpendicular Vegetation Index
RMS	Root Mean Square
RVI	Ratio Vegetation Index
SABC	South Africa Broadcasting Cooperation
SARVI	Soil Adjusted Ratio Vegetation Index
SAVI	Soil Adjusted Vegetation Index
SAWS	South African Weather Services
SWAT	Soil and Water Assessment Tool
TD	Transformed Divergence

TM	Thematic Mapper
TSAVI	Transformed Soil Adjusted Vegetation Index
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator

DEFINITION OF TERMS

The following terms will be taken to have the meanings presented below throughout this thesis

- Accuracy assessment – a measure of how many ground truth pixels were classified correctly (Bottomley, 1998).
- Catchment – area of land bounded by watersheds draining into a river, basin, or reservoir.
- Change detection – comparison and contrast of multi-temporal images of the same geographical area(Hsiung and Ju, 2000).
- Correlation –the methods for measuring the degree of association among variables(Kazmier and Pohl, 1984).
- Ground truth – refer to a process in which a pixel on a satellite image is compared to what is there in reality (at the present time) in order to verify the contents of the pixel on the image (Lillesand *et al.*, 2008).
- Histogram equalisation – technique that generates a gray map which changes the histogram of an image and redistributes all pixels values to be as close as possible to a user–specified desired histogram (Stark, 2000).
- Image classification – extraction of different classes or themes, such as land use and land cover categories from raw remotely sensed digital satellite data (Gorham, 1999).
- Image enhancement – improving visual interpretability of an image by increasing the apparent distinction between features in the scene (Lillesand *et al.*, 2008).
- Land cover – physical material at the surface of the Earth.
- Land use – involves the management and modification of natural environment.
- Remote sensing – acquisition of information about objects through analysis of data collected through instruments that are not in physical contact with the objects of investigation(Miller and Baldyga, 2004).

1. INTRODUCTION

1.1 Background

Land use and land cover (LULC) changes especially those caused by human activities are the most important component of global environmental change, with impacts possibly greater than the other global changes (Turner *et al.,* 1994). Land cover changes in watersheds result from a variety of natural and anthropogenic sources. Some natural changes are often rapid, such as those following wildfire or those that are a consequence of habitat overuse by populations of some wildlife species; whereas plant succession driven by climate variation is slow and occurs over long periods of time (Hu *et al.,* 2005). Land use changes caused byhuman intervention such as land clearance, agricultural intensification, and urbanisation, are currently the most consequential components of global change (Munasinghe and Shearer, 1995). Land cover changes affect biodiversity, water budgets and other processes that cumulatively affect regional and global climate so the information of changing LULC around a watershed is vital for evaluating the health of an ecosystem at a particular time. The increase in urban population density and built-up areas directly or indirectly affects hydrological processes, through: a) change in total runoff or stream flow, b) alteration of peak flow characteristics, c) reduction of permeable lands which increases the surface floods and d) changes in river amenities (Hall, 1984). Furthermore, potential climatic shifts as part of climate change may lead to heat waves, sea level rise, water constraints and various kinds of floods and storms that impact on millions of urban dwellers in Africa (IPPC, 2009).

South Africa is not prone to spectaculardestructive disasters such as volcanic eruptions, massive earthquakes and *tsunamis*.Most disasters are localised incidents of *veld* fires, informal settlement fires, seasonal flooding in vulnerable communities, droughts and human-induced disasters such as oil spills and mining accidents (Jacobs, 2009). Several inundations have occurred in South Africa, causing loss of life and financial deficits due to various factors such as urbanisation, population growth, destruction of natural environment and climate change (Smith, 2011). Following floods and heavy storms in 2011, 33 municipalities in eight of South Africa's nine provinces were declared disaster areas. The death toll was at least 123 people, with 88 in KwaZulu-Natal alone, while the number of people displaced was roughly 20000 (Project 90 by 2030, 2011). Within the Harts Catchment, the Greater Taung Local Municipality (GTLM) in North West Province received 1380 mm of rain for the period January to June 2006 and the extent of flooding was equal to a 1 in 50 year flood and seriously affected 12 villages (Department of Provincial and Local Government, 2008). Also in 2006, farmers in the Jan Kempdorp area in the Northern Cape called on the government to declare the area a disaster area after floods destroyed most of their crops. GTLM also suffered severe storms in 2003 (South African Government Information, 2004) and in 2010 (Watersense, 2010) the GTLM was declared a disaster zone after one person drowned and about 150 households were left destitute, roads leading to areas such as Manokwane and Mokgareng had also become flooded. After these disasters, it is necessary to determine if the increased scale of flooding is exacerbated by the development of the impervious areas caused by changing land use/cover.

There is therefore a great deal of concern about the effects that human activities can have on the river flow regime and surrounding landscape. To provide more efficiency in detecting land cover changes, remote sensing is often paired with Geographic Information System (GIS) techniques. Remote sensing and GIS have been widely used jointly in land cover change detection as they are both cost-effective and allow for efficient and quantitative resource mapping (Melesse*et al.*, 2007). Remotely sensed imagery provides up-to-date, as well as over time, natural resource information such as land cover change caused by resource exploitation or renewal, available resource estimates, and effects on surrounding areas (Miller and Baldyga, 2004).

Understanding the implications of past, present and future patterns of human land use for biodiversity and ecosystem function is increasingly important in landscape ecology (Turner *et al*, 2007). According to Mustard *et al.*(2005) of the challenges facing the Earth over the next century, land use and cover changes are likely to be the most significant. Historical land use and cover patterns are a means to evaluate the complex causes and responses in order to better project future trends of human activities and land use/land cover change. If land use/land cover changes are not carried out scientifically, the negative impacts on both the environment and the socio-economic settings are not easily measurable (Gete, 2000). The study of LULC aims to yield valuable information for analysis of the environmental impacts of human activities, climate change, and other forces (Belay, 2002). This is necessary, as changes in land use and land cover increasingly affect the livelihoods of societies. As a result, the knowledge of land use/land cover changes of an area is important to take corrective actions on land and its use for balanced living.

This study is a first step to help remedy the situation between the high level flooding of the Harts catchment and the low level of attention given to the problem of land-cover change. Focusing on the areas surrounding of the Harts River, the study documents changes in land cover over two decades in the Harts catchment. The study employs a procedure that combines remote sensing and GIS for analysis of land cover change while statistical methodsare used to assess changes in river discharge.

1.2 Aim and objectives

The main aim of this research was to explore the detailed impacts of land use and land cover change and their linkage with river discharge by using remote sensing and GIS techniques.

The specific objectives were:

(a) Map LULC dynamics of the Harts Catchment using multi-temporal Landsat Thematic Mapper (TM) data in 1990, 2005 and 2008.

(b) Quantify the spatial and temporal LULC changes in the Harts Catchment.

(c) Examine the changes of rainfall-river discharge interactions.

(d) Analyse the effects of land use change on river discharge.

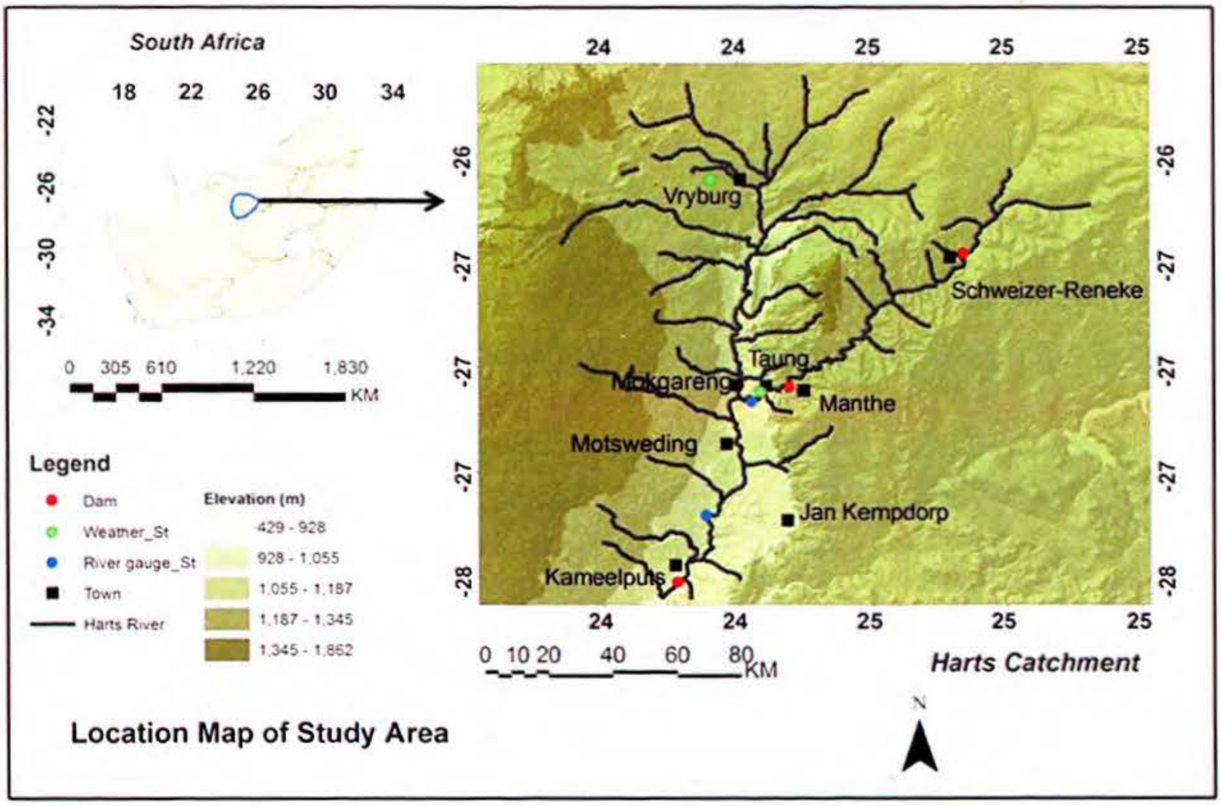

Figure 1: Location of the Harts Catchment

1.3 Delimitation of study area

The Harts River is a northern tributary of the Vaal River, which in turn is the largest tributary of the Orange River (also known as the Gariep River, the largest river in South Africa). It rises on the far south-western slopes of the Witwatersrand and flows for 320 km (about 200 miles) in a south-westerly direction (mostly through very flat areas of the North West Province) before flowing into the Vaal River near Delportshoop about 100 km above the confluence of that river with the Orange River (EWISA, 2011). The Little Harts River, which rises near Cologny joins the Great Harts River, which rises near Lichtenburg, to form the main river. Near Taung, the Dry Harts River, a seasonal river with its headwaters in the Vryburg area, also joins it. The Dry Harts River is characterised by highly intermittent runoff, but is regulated to optimise water usage.

Upstream, the town of Schweizer-Reneke (founded in October 1888) lies on the banks of the river and further downstream lie the settlements of Pampierstad, Motsweding, Mokgareng, Manthesad and Taung (EWISA, 2011). To the west of Taung, the Taung Dam (-27 3' 14" S and 24 5' 06" E) was built on the Harts River while the settlements of Kameelputs, Madithamaga and Kgomotso lie north of Spitskop Dam (-28 05' 28" S and 24 32' 11" E).

1.4. Environmental settings

1.4.1 Climate

Taung receives about 318mm of rain per year, with rainfall occurring mainly during summer, it receives the lowest rainfall (0 mm) in June and the highest (65 mm) in February. Monthly distribution of average midday temperatures for Taung ranges from 18.7°C in June to 32.5°C in January. The region is the coldest during July when the mercury drops to 0.7° C on average during the night with likely frosts in winter (SA Explorer, 2011).

In Schweizer-Reneke average daily maximum temperatures range from 18°C in June to 31°C in January. The region is the coldest during July with night-time temperatures avereging 0°C on average during the night. Schweizer-Reneke normally receives about 350 mm of rain per year, with rainfall occurring mainly during summer.Schweizer-Reneke receives the lowest rainfall (0 mm) in June and the highest (66 mm) in January (SA Explorer, 2011).

Vryburg receives about 344 mm of rain per year, with most rainfall occurring mainly during summer and average daily maximum temperatures range from 19°C in June to 32.9°C in January (SA Explorer, 2011).

1.4.2 Soil type

The Harts Catchment (Figure 1) is characterised by sandy soils consisting of sandy-clay-loam, sand-clay, sand-loam, clay-loam and loam-sand (Department of Water Affairs and Forestry, 2004). The area lies predominantly in the "Red yellow apedal and freely drained soils that are less than 300 mm deep" and refers to yellow and red coloured soils where a free water table is not encountered (Rossouw and van der Walls, 2010. Figure 2 shows the dominant soil groups in the Harts Catchment.

- Arenosols Haplic (ARh) has the following soil properties: topsoil texture is coarse, topsoil sand fraction of 89%, topsoil silt fraction of 6%, USDA texture classification of sand, drainage class of somewhat excessive (0-0.5%).

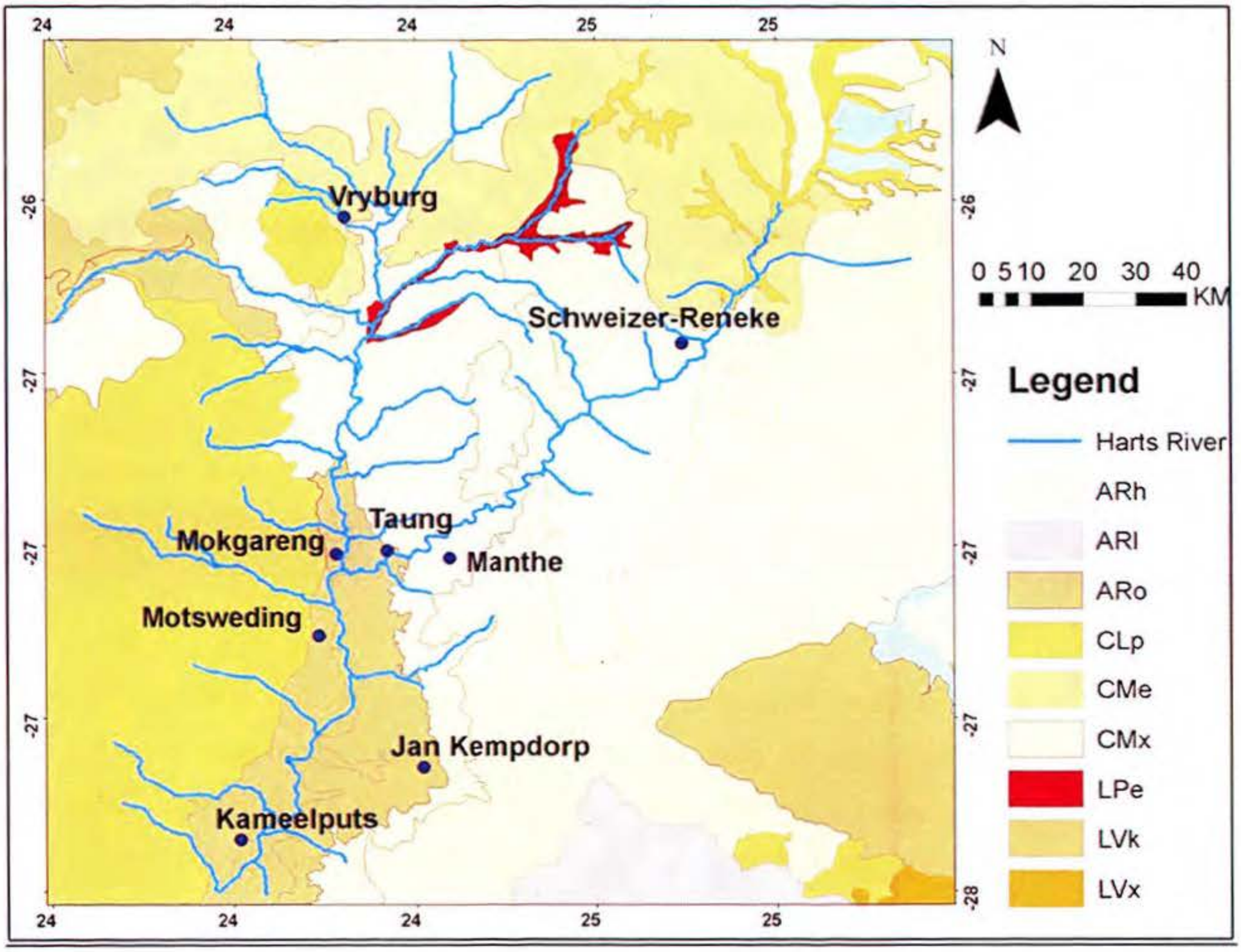

Figure 2: Soil groups of the Harts Catchment

- Arenosols Ferralic (ARo) has the following soil properties: topsoil texture is coarse, topsoil sand fraction of 93%, topsoil silt fraction of 1%, USDA (United States Department of Agriculture) texture classification of sand and a drainage class of somewhat excessive (0-0.5%).
- Calcisols Petric (CLp), has the following soil properties: topsoil texture is medium, topsoil sand fraction of 62%, topsoil silt fraction of 18%, USDA texture classification of sand clay loam and drainage class is moderately well (0-0.5%).

- Cambisol Eutric (CMe) has the following soil properties: dark reddish brown friable sandy clay loam underlain by gravely red loam to light clay. The soil is well drained and has good physical properties and is slightly acid (Jaetzold and Schmidt, 1982).
- Cambisols Chromic (CMx) has the following soil properties: topsoil texture is medium, topsoil sand fraction of 76%, topsoil silt fraction of 7%, USDA texture classification of sandy loam and drainage class is moderately well (0-0.5%).
- Leptosols Eutric (LPe) has the following soil properties: topsoil texture is medium, topsoil sand fraction of 50%, topsoil silt fraction of 30%, USDA texture classification is loam and drainage class is imperfect (0-0.5%).
- Luvisols Calcic (LVk) has the following soil properties: topsoil texture is fine, topsoil sand fraction of 29%, topsoil silt fraction of 27%, USDA texture classification is clay (light) and drainage class is moderately well (0-0.5%).

Geology of the area consists of mudstone, sandstone, tillite, quartzitic sand-stone, sand quartzite, and schist (Jaetzold and Schmidt, 1982). The soil data were acquired from the International Soil Reference and Information Centre (ISRIC).

1.4.3 Water body

Two rivers – Harts and Dry Harts– exist in the surroundings of Taung and come under the Lower Vaal water management (Municipal BiodiversitySummary Project, 2010). The Harts catchment has three large dams, the Wentzel (27 09' 42" and 25 20' 46"), Taung and Spitskop Dam. The Harts River plays an important role in the water supply to domestic and agricultural users in the area. Land use is predominantly urban (both formal and informal) and agricultural (irrigation and stock watering). Industrial users receive water from the Vaalharts irrigation scheme (Department of Water Affairs and Forestry, 2004). Near the confluence of the Harts and Vaal Rivers a major irrigation system, the – Vaal-Harts Scheme– was set up in 1933 as part of the national reconstruction effort after the Depression. A system of canals drawswater from both the Vaal and the Harts rivers, intensively irrigating numerous smallholdings in an otherwise dry area of the country and supporting towns such as Jankempdorp and Vaalharts(Van Vreeden, 1961).

1.4.4 Vegetation

The vegetation types vary and include Ghaap Plateau Vaalbosveld (53.18%), Kimberly Thornveld (16.5%), Kuruman Vaalbosveld (13.33%), Mafikeng Bushveld (9%), Schmidtsdrif Thornveld (7.94%), Southern Kalahari Salt Pans (0.03%), (Municipal BiodiversitySummary Project, 2010). The dominant biome is savannah. Agriculture is the dominant land use with mixed crop farming like barley, wheat, maize, cotton, sunflower and nuts in the eastern side, and livestock farming in the western side of the area - producing some of the best beef in the country. Subsistence agriculture is practiced widely by rural communities, while commercial agriculture contributed almost R34 million (4.1%) to total GDP (Municipal in South Africa, 2010).

1.4.5 Economy

The economy of Taung relies heavily on agriculture, mineral resources and tourism. The Vaal-Harts Irrigation Scheme extends into the high-potential agricultural soil of the GTLM area, which has the potential to serve as an incubator for local economic development (Municipal in South Africa, 2010). The principal crops of the region around Schweizer-Reneke are mainly maize, sorghum, groundnuts and sunflower seeds. In addition, cattle and sheep farming is practiced in the region on a relatively large scale on the grasslands where the soil is unsuitable for cultivation.

Mineral resources, such as diamonds, and water resources, such as the Taung Dam, can be utilised to improve the wellbeing of the residents.Alluvial diamond mining still occurs in ancient river beds within the Harts River catchment area. The Newlands Mine is located some 60 km northwest of Kimberley on the river. It is currently being mined at a rate of 3000 tonnes per month by the company Dwyka Diamonds Limited. Noble Minerals, in cooperation with the local Ba-Ga-Maidi tribe, has set up an operation to exploit the alluvial diamonds within 20 square kilometres of diamantiferous gravels of the river system, near Taung(Dwyka diamonds limited, 2005). Schweizer-Reneke is rich in diamond deposits. This led to large scale private diamond mining in the area (Municipal Demarcation Board, 2003). In 1924 the skull of a child, said to be over 2.5 million years old, was found in Buxton lime quarries by mine workers, a monument to the discovery of the Taung skull has been erected at this prehistoric site and today attracts significant tourism.

1.4.6 Population and demographic

The population of Schweizer-Reneke (3.81 km^2) is approximately 70214 (Mongabay, 2012a). According to the 2001 Schweizer-Reneke Census, 69.8% of the people of the town proper described themselves as "White", whereas black African made up 11.3%. The population of Vryburg is approximately 49588 (Mongabay, 2012b). According to the 2001 Vryburg Census, 23.1% of the people are White, black African made up 28.0%, whereas Coloured's made up 44.6%. Greater Taung has a population of about 193 000, and a geographical size of 5696.5 km^2.

1.5 Statement of the problem

Within the Harts catchment, GTLM received nearly double its average annual rainfall for the area (over 700 mm) in just the first three months of 2006, causing severe flooding (Heslop, 2008). In 2010, one person drowned, about 150 households were left destitute and roads leading to areas such as Manokwane, Mokgareng and Pudimoe were also flooded (Watersense, 2010). In

2003, Taung suffered severe storms that killed four people and the heavy rains and hail destroyed about 60 houses, roads and other property (BuaNews, 2003).The disasters that occurred within the Harts catchment in early 2010, 2006 and 2003 provided an opportunity to look closely at under-resourced communities in a developing country to understand land-cover change and vulnerability to flooding in relation to their activities/land use.

1.6 Research hypothesis

Unsustainable changes in land cover due to human activities were significantly altering aggregate catchment conditions, giving rise to long-term, potentially irreversible changes in river flow characteristics.

1.7 Significance of the study

The South African government aims to reduce the impact of floods on human life, health, infrastructure and financial loss. The study of LULC change could play an important role in assisting Government realise this goal because it provides means for assessing the effectiveness of current mitigation projects and for coming up with recommendations for future mitigation plans. The study of LULC dynamics and population influence in the Harts Catchment could encourage policy makers to launch balanced land use policies that would consider both economic development and environmental management. The results could encourage local governments, local residents, and farmers to address environmental problems in their regions.

1.8 Overview of the thesis

Chapter 1 forms the introduction and discusses the problem statement, objectives and significance of the study. It brings to focus the problems experienced in this region in light of the changing environment and socio-economic issues. Chapter 2 is a literature review. The purpose of this chapter is to provide a general overview of application of remote sensing and GIS technique to explore the detailed impacts of land use on land cover change and their linkage with river discharge.This chapter reviews four topics that are core to this research, namely land use and land cover (LULC) change, change detection techniques, effects of land use/cover change on hydrological parameters and catchment discharge.

The methodology and data analysis techniques are presented in Chapter 3.This chapter presents the types of data and methods used in this study, in order to investigate the temporal and spatial characteristics of land use/cover, rainfall and river discharge. The data sources where the data were obtained are highlighted in this chapter. It presents the methodology employed for land cover classification of satellite imagery, change detection and classification accuracy is presented, and the observed land cover changes discussed. Also the statistical and trend analysis of hydro-meteorological data is discussed to establish whether or not there have been significant trends in hydro-meteorological data.

Chapter 4 presents the outcome of LULC change analysis and statistical analysis of hydro-meteorological data to assess the impacts of land cover changes. It discusses the catchment response, especially stream discharge, in relation to rainfall and changes in land cover. Differences in land cover types in the context of surface runoff are determined. It also determines which of the two changes, land cover and rainfall, contributes more to the increase in stream discharge.

Chapter 5 presents the conclusion and recommendations for further research. This chapter summarises the contribution of this research and suggests related future research issues. It highlights the important findings and outlines the major challenges in terms of study limitations and adequacy of data.

2. LITERATURE REVIEW

The purpose of this chapter is to provide a general overview of the application of remote sensing and GIS technique to explore the detailed impacts of land use on land cover change and their linkage with river discharge.This chapter reviews four topics that are core to this research, namely land use and land cover (LULC) change, and techniques for change detectioneffects of LULC cover change on hydrological parameters and catchment discharge.

2.1 Land use and land cover (LULC) changes

Every parcel of land on the Earth's surface is unique in the cover it possesses (Meyer, 1995). Land use and land cover are dissimilar yet closely related features of the Earth's surface. The term land cover originally referred to the kind and state of vegetation, such as forest or grass cover, but it has broadened in subsequent usage to include other things such as human structures, soil type, biodiversity, surface and ground water (Meyer, 1995). In contrast to land cover, land use involves the way humans use the land, and could be grazing, agriculture, urban development, logging, and mining among many others. Two land parcels may have similar land cover types, but different land use types and *vice versa* (Aydinoglu *et al.*, 2010).

Land use affects land cover and changes in land cover affect land use although a change in either however is not necessarily the product of the other and changes in land cover by land use do not necessarily imply degradation of the land (Opeyemi, 2006). However, many shifting land use patterns driven by a variety of social causes result in land cover changes that affects biodiversity, water and radiation budgets, trace gas emissions and other processes that come together to affect climate and biosphere (Turner *et al.*, 1994). In the quest of meeting society's needs, the natural landscape is manipulated for purposes of livelihood in both physical terms (for example land conversion) and chemical terms (for instance pollutant production) with some impact on water resources (Schulze, 2003). Water-impacting land use affects rainwater partitioning through soil and vegetation (Falkenmark *et al.*, 1999) hence the importance of assessing its effects on the hydrologic response.

Land cover can also be altered by natural factors (such as natural disaster and natural degeneration). Globally, land cover today has changed mainly by direct human use through cultivation and livestock-raising, logging and timber harvesting and urban and suburban development. There are also incidental impacts on land cover from other human activities such as forests and lakes damaged by acid rain from fossil fuel combustion, and crops near cities damaged by tropospheric ozone resulting from automobile exhaust (Meyer, 1995). In order to use land optimally, it is necessary to have information on present LULC and be able to monitor the dynamics of land use resulting from changing demands of increasing population and forces of nature acting to shape the landscape. Turner *et al.* (2007) present a diagram of the base phenomenon and process of LULC model (Figure 3).

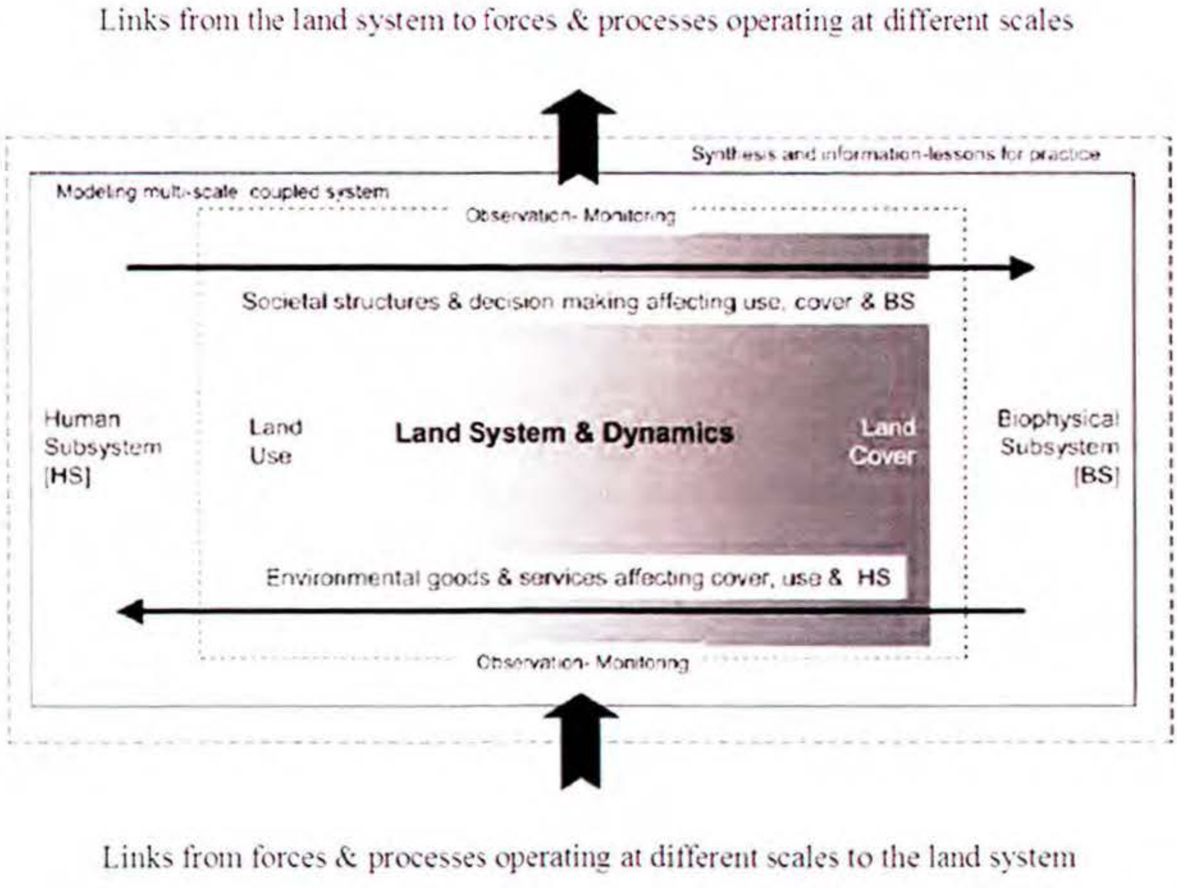

Figure 3: The base phenomenon and process of land change model (Turner *et al.*, 2007)

This diagram represents the linkage of the land system and dynamics between the human subsystem and the biophysical subsystem. Land use in the human subsystem with societal structures and decision-making can affect land cover in the biophysical subsystem. An example of this can be seen in shifting cultivation in tropical forests, which results in in a lack of soil phosphorous for growth of forests in the third cycle of cultivation (Turner *et al.*, 2007).

2.2 Land-cover change and vulnerability to flooding with Landsat

Various Earth observation satellites are orbiting our planet to provide frequent imagery of the surface (Nath and Deb, 2009). Remote sensing provides the most accurate means of identifying the areal extent and rate of land use and land cover mapping (Cohen and Goward, 2004). Of all remotely sensed data, those acquired by Landsat sensors have played the most important role in spatial and temporal analysis (Cohen and Goward, 2004). Landsat multispectral and temporal imagery is a particularly important source of data for observing changes, as it provides the longest archive (21 years) of moderately high spatial resolution satellite image data and contains bands that are sensitive to changes in vegetation coverage and soil moisture (Ndzeidze, 2008). Landsat MSS and Landsat TM imagery provide us with a wide view of entire regions, allowing us to track broad changes in LULC, while at the same time providing us with a detailed view of localised changes (Todd, 1977). The approximate 79-metre resolution of Landsat MSS and 30-metre resolution of Landsat TM imagery makes it possible to detect areas as small as 0.6 and 0.1 hectares, respectively (Lunetta and Elvidge, 2000). Landsat TM is an optical mechanical whiskbroom sensor located on the Landsat 5 satellite, which was launched by NASA on March 1, 1984. Landsat TM has seven spectral bands. The VNIR (Very Near Infra-Red) wavelengths, bands 1-5, and 7, range from 0.45 to 2.35 μm and have a spatial resolution of 30 x 30 m. Band 6 is a thermal band that ranges from10.4-12.5μm and has a spatial resolution of 120 x 120 m and the Landsat TM's swath width is 185 km (Nath and Deb, 2009).

Remote sensing and GIS have been widely used jointly in change detection methods, and to provide more efficiency in detecting land cover changes, remote sensing is often paired with Geographic Information System (GIS) techniques (Lu *et al.*, 2004). GIS technology for creating, storing, analyzing, and managing spatial and temporal data associated with their attributes (Longley *et al.*, 2005). These two sets of technologies offer ability to map land use characteristics and dynamics by combining existing remotely sensed data and historic maps in various environments such as tropical forests, urban areas, and coastal zone and different land transformations such as deforestation, urban development, and desertification (Campbell, 2002; Turner *et al.*, 2007).

2.3 Change detection techniques

Timely and accurate change detection of Earth's surface features is extremely important for understanding relationships and interactions between human activity and natural phenomena in order to promote better decision making (Lu *et al.*, 2004). Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Change detection is defined by Hsiung and Ju (2000) as the comparison and contrast of multi-temporal images of the same geographical area. It is realised by image-handling techniques to analyse the transformed areas of the geographical area at different times. Change detection research provides information on area change and change rate, spatial distribution of transformed areas, change trajectories of land-cover areas and the accuracy assessment of change detection results.

Lambin and Strahler (1994) listed five categories of causes that influence land-cover change: long-term natural changes in climate conditions; geomorphological and ecological processes such as soil erosion and vegetation succession; human-induced alterations of vegetation cover and landscapes such as deforestation and land degradation; inter-annual climate variability; and the greenhouse effect caused by human activities. A study by Manonmani and Suganya (2010) aimed to detect land use changes from 1990 to 2005 using satellite images from Landsat 7 ETM+ (1990) and Indian Remote Sensing Linear Imaging Self-Scanning System III (2005). Change detection showed that the built up area increased between 1990 and 2005 by 43% from 6513.3 ha to 9300.9 ha. In addition, the area with irrigated land farms fell by 436.9 ha (2.5%) and the shrub land decreased to 5.2%. Change detection is thus suitable in identifying differences in the state of an object by observing it at different times.

When implementing a change detection project, three major steps are involved: (1) image pre-processing including geometrical rectification and image registration, radiometric and atmospheric correction, and topographic correction if the study area is in mountainous regions;

(2) selection of suitable techniques to implement change detection analyses; and (3) accuracy assessment (Lu *et al.,* 2004). Additional research by Dai and Khorram (1998) obtained after the preprocessing phase was complete indicate that due to misregistration the accuracy of remotely sensed change detection can be substantially degraded. Results of their analysis on Landsat TM data indicated that a registration accuracy of less than one-fifth of a pixel (0.2 m) is required to achieve a change detection error of less than 10%. However, Dai and Khorram (1998) also suggest that there are inherent differences between TM image pairs which may be more or less sensitive to image misregistration than other pairs.

2.3.1 Data Acquisition and pre-processing

Data should be obtained from a sensor system that acquires data at approximately the same time of day and on the same day in different years, as this eliminates diurnal sun angle effects which can cause anomalous differences in the reflectance properties of the remotely sensed data and plant phenological differences which can destroy a change detection project (Estes *et al.*, 1998).

Raw digital images usually have some geometric distortions as a result of variations in the altitude, attitude, Earth curvature, atmospheric refraction, relief displacement, and nonlinearities in the sweep of a sensor's IFOV (Lillesand *et al.,* 2008). These errors should be corrected to ensure accuracy of the final results. According to Lu *et al.*(2004) the importance of accurate spatial registration of multi-temporal imagery is obvious because largely spurious results of change detection will result if there is misregistration. The atmosphere affects the radiance received by the sensor by scattering, absorbing, and refracting light; and correction for these effects, as well as for sensor gains and offsets, solar irradiance, and solar zenith angles are necessary, and these must be included in the radiometric corrections procedures that are used to convert satellite recorded digital counts to ground reflectances (Chavez, 1996).

Dealing with multi-date image datasets requires that images obtained by sensors at different times are comparable in terms of radiometric characteristics (Mas, 1999). Conversion of digital numbers to radiance or surface reflectance is a requirement for any quantitative analysis of multi-temporal images; and several methods such as dark object subtraction (DOS), relative calibration and second simulation of the satellite signal in the solar spectrum have been developed for atmospheric normalisation (Lillesand *et al.*, 2008). The COST model (Chavez, 1996) is an improved DOS technique and includes the use of the cosine of the solar zenith angle to achieve results similar to those of physical models.

2.3.2 Image enhancement

The main goal of image enhancement is improving visual interpretability of an image by increasing the apparent distinction between features in the scene (Lillesand *et al.*, 2008). This ensures that features appears clear and increases the ability to distinguish different features. Different techniques are used in image enhancement including principal component analysis and histogram equalisation.

2.3.2.1 Histogram equalisation

Histogram equalisation is a technique that generates a grey map which changes the histogram of an image and redistributes all pixel values to be as close as possible to a user-specified desired histogram (Stark, 2000). Histogram equalisation allows for areas of lower local contrast to gain a higher contrast and automatically determines a transformation function seeking to produce an output image with a uniform histogram. Yeganeh *et al.* (2008) discussed histogrambased techniques and found it is one of the important digital image processing techniques which can be used for image enhancement due to the simplicity of implementation of the algorithm. Individual images in this study were enhanced using histogram equalisation.

2.3.2.2 Principal component analysis (PCA)

The aim of PCA is to reorganise the data so that they are no longer correlated. Lu *et al.* (2004) points out that PCA is performed in one of two ways: (1) by merging two or more date images as a single data file, and then running the PCA to analyse all component images for change information, or (2) by running the PCA separately, then subtracting second data principal component image from the rest. Yu *et al.* (2007) used PCA to study land use/cover changes and environmental vulnerability of Birahi Ganga sub-watershed in Garhwal Himalaya using satellite data from 1976, 1990 to 2005. Analysis of spatial principal component analysis showed that environmental vulnerability initially decreased from 1976 to 1990 and then increased from 1990 to 2005. Areas with warmer conditions, lower elevations and steep slopes were the most vulnerable. PCA does not allow diagnostic comparison across sites, and wavelengths identified by PCA do not necessarily represent wavelengths that indicate biophysical attributes of interest. Furthermore, narrow bands captured by hyperspectral sensors need to be substantially re-sampled and/or smoothed in order for PCA to identify useful information. Principal component analysis has a number of practical applications, including compression, pre-processing for classification, and false-colour viewing.

2.3.3 Image classification

Multispectral image classification is the process of sorting out pixels to finite numbers or class themes based on the data file values. The overall objective of image classification procedures is automatically categorising all the pixel values in an image into land cover classes or themes (Lillesand *et al.*, 2008). The most widely used classification methods include supervised and unsupervised classification schemes. Both supervised and unsupervised classification algorithms typically use hard classification logic to produce a classification map that consists of hard, discrete classes (Jensen, 2006). Before classification is carried out, the specific target classes should be identified. This requires the use of a classification scheme containing taxonomically correct definitions of classes of information that are organised according to logical criteria (Jensen, 2006).

2.3.3.1 Hybrid change detection techniques

In addition to the single techniques, hybrid change detection techniques are also used. Hybrid change detection involves the combination of two or more techniques, selects suitable thresholds to identify the change and non-change areas, and develops accurate classification results (Lu *et al.*, 2004). It is useful especially for generating higher accuracies in change maps. For example, a study conducted by Petit *et al.* (2001) used image differencing and post-classification to detect detailed 'from–to' land cover change in south-eastern Zambia. The study found that the combination of such hybrid techniques yielded better accuracies than using a single post-classification comparison technique. Silapaswan *et al.* (2001) used change vector analysis (CVA) techniques, and unsupervised classification, followed by aerial photographs to detect land cover change. The combination of CVA and unsupervised classification provided better results of change information than a single method.

Supervised classification requires knowledge of the area and/or detailed field data. Effective classification of remote sensing image data depends upon separating land cover types of interest into sets of spectral classes (signatures) that represent the data in a form suited to the particular classifier algorithm used (Richard and Kelly, 1984). Supervised classification processes involve the initial selection of areas (training sets) on the image, which represent specific land classes to be mapped (Eljack *et al.*, 2010). Algorithms commonly used in supervised image classification include parallelepiped classification, minimum distance classification and maximum likelihood classification. The maximum likelihood is, however, the most widely used per-pixel algorithm (Pillay, 2009) and is based on statistics mean, variance/covariance and a probability function is calculated from the input for classes established from training sites (Sallaba, 2009).

A maximum likelihood classifier was applied to each image to define land cover classes in this study. Unsupervised classification requires minimum initial input from the analyst, but the output takes a significant amount of time to assign the computer-generated clusters to a known land cover. Hybrid combines the benefits of both techniques. Unsupervised has the benefit of a non-biased, statistical method to separate clusters, while supervised classification utilizes the analyst's knowledge of the area.

The advantage of hybrid change detection is that it excludes unchanged pixels from classification to reduce classification error, while the disadvantage is it requires selection of thresholds to implement classification making it somewhat complicated to identify change trajectories (Lu *et al.,* 2004). A hybrid supervised/unsupervised classification approach coupled with GIS analyses is employed in this study to generate land use/cover maps. Regardless of the technique used, the accomplishment of change detection from imagery depends on both the character of the change involved and the success of the image pre-processing and classification measures. Nonetheless, Sepehry and Liu (2006) pointed out, if the nature of change within a particular scene is either abrupt or at a scale appropriate to the collected imagery, then change should be relatively easy to detect; problems occur only if spatial change is subtly distributed and hence not obvious within any one image pixel.

2.3.4 Accuracy assessment

Accuracy assessment is a measure of how many ground truth pixels were classified correctly (Bottomley, 1998). The most common and typical method used by researchers to assess classification accuracy is with the use of an error matrix,sometimes called a confusion matrix or contingency table (Congalton, 1991). This is a square representing the number of sample units assigned to a particular category relative to the actual category as confirmed on the ground (Congalton and Green, 1999). The rows in the matrix represent the remote sensing derived land use map, while the columns represent the reference data that were collected from field work. These tables produce many statistical measures of thematic accuracy including overall classification accuracy, percentage of omission and commission error, and Kappa coefficient – an index that estimates the influence of chance (Congalton and Green, 1999). Error of omission is the percentage of pixels that should have been put into a given class but were not.Error of commission indicates pixels that were placed in a given class when they actually belong to another.

These values are based on a sample of error-checking pixels of known land cover that are compared to classification on the map. Error of commission and omission can be expressed in terms of user's accuracy and producer's accuracy.User's accuracy represents the probability that a given pixel will appear on the ground as it is classed, while producer's accuracy represents the percentage of a given class that is correctly identified on the map (Congalton and Green, 1999). On the other hand, Kappa coefficient is a measure of the interpreter agreement. The Kappa statistics incorporates the off-diagonal elements of the error matrices (i.e., classification errors) and represent agreement obtained after removing the proportion of agreement that could be expected to occur by chance (Congalton and Green, 1999). One of the problems with the confusion matrix and the Kappa coefficient is that they do not provide a spatial distribution of errors (Foody, 2002). The kappa coefficient (κ) is shown in equation 2.1.

$$K = \frac{N\sum_{i=1}^{r} Xii - \sum_{i=1}^{r}(X_{i+}.X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i}.X_{+i})}$$ Equation 2.1

Where:

r is the number of rows in the error matrix, N is the total number of cells in the error matrix, Xii are the total number of correct cells in a class and Xi+, X+i are the total number of pixels in row

i and column i respectively (the square matrix contains equal number of rows and columns corresponding to the number of classes whose accuracy is being assessed).

2.3.5 Change detection techniques

A variety of change detection techniques have been developed and new techniques are constantly being developed. Lu *et al.* (2004) classified change detection techniques into seven categories namely: (1) Algebra, (2) Transformation, (3) Classification, (4) Advanced models, (5) Geographic Information Systems (GIS), (6) Visual analysis and (7) other techniques. Ernani and Gabriels (2006) point out that change detection analysis encompasses a broad range of techniques used to identify, describe, and quantify differences between images of the same scene at different times or under different conditions. Lu *et al.* (2004) highlighted the importance of selecting a suitable change detection technique to be used in a specific application area.

In general, change detection techniques can be grouped into two groups. These groups are bi-temporal change detection and temporal trajectory analysis (Zhou *et al.*, 2008). The former measures land cover changes based on a 'two-epoch' timescale, i.e. the comparison between two dates. Even if land cover information is sometimes acquired for more than two epochs, the changes are still measured on the basis of pairs of dates. The latter group analyses the changes based on a continuous timescale, i.e. the focus of the analysis is not only on what has changed between dates, but also on the progress of the change over the time period (Zhou *et al.*, 2008). Image differencing, principal component analysis and post-classification comparison are the most common methods used for change detection. In recent years, spectral mixture analysis, artificial neural networks and integration of geographical information system and remote sensing data have become important techniques for change detection applications.

2.3.5.1 Image differencing

Image differencing (Figure 4) is the subtraction of one date imagery from a second date that has been precisely registered to the first (Lu *et al.*, 2004). In a study conducted to detect prior forest conversion to pasture lands in Arkansas County from 1984–1999, Bottomley (1998) used the image differencing technique on Landsat TM imagery. The research was built upon previous work by Maus *et al.* (1992) and Green *et al.* (1994), who were able to detect, delineate, and classify forest canopy changes using image differencing with multi-temporal Landsat TM images.

Date 1	8	10	6	11	3	3	1	6
	220	11	8	20	125	2	0	-2
	205	210	201	50	106	109	1	172
	220	90	82	45	118	-7	-168	-165
Date 2	5	7	5	5				
	95	9	8	22	Difference Image = Image1 - Image 2			
	99	101	202	222				
	102	97	250	210				

Figure 4: Illustration of an image differencing technique adapted from Kennedy (Pillay, 2009).

Image differencing has the advantage that it is very simple and data is easily interpreted. Its disadvantages are that the technique cannot provide a detailed change matrix and it requires selection of thresholds. The key factor is that it identifies suitable image bands and thresholds (Lu *et al.*, 2004).

2.3.5.2 Vegetation index differencing

Vegetation indices, among other methods in remote sensing,have been reliable for monitoring temporal changes associated with vegetation, and theNormalised Difference Vegetation Index (NDVI) is widely used for vegetation monitoring. Vegetation indices usually include: Normalised Vegetation Index Ratio, Vegetation Index, and Transformed Vegetation Index.

Comparing seven vegetation indices for change detection of vegetation and land cover Lyon *et al.* (1998) used three different dates of MSS data. The vegetation indices were: Normalised Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI), Perpendicular Vegetation Index (PVI), Ratio Vegetation Index (RVI), Soil Adjusted Vegetation Index (SAVI), Soil Adjusted Ratio Vegetation Index (SARVI) and Transformed Soil Adjusted Vegetation Index (TSAVI). Results showed that (1) the seven vegetation indices could be grouped into three categories with respect to computational procedures if a normalisation technique were used; (2) among all indices only NDVI showed a normal distribution histogram, and (3) the NDVI group was least affected by topographic factors. All groups could clearly distinguish between land surfaces, water surfaces and cloud covers. Among the seven algorithms, NDVI demonstrated the best vegetation change detection according to the field result.

The NDVI approach is based on the fact that healthy vegetation has low reflectance in the visible portion of the electromagnetic spectrum (EMS) due to chlorophyll and other pigment absorption and has high reflectance in the near infrared (NIR) because of the internal reflectance by the mesophyll spongy tissue of green leaf (Campbell, 2002). NDVI can be calculated as a ratio of red and the NIR bands of a sensor system. NDVI values range from -1 to +1, and because of high reflectance in the NIR portion of the EMS, healthy vegetation is represented by high NDVI values between 0.1 and 1. Conversely, non-vegetated surfaces, such as water bodies, yield negative values of NDVI because of the electromagnetic absorption quality of water. Bare soil areas represent NDVI values which are closest to 0 due to high reflectance in both the visible and NIR portions of the EMS (Lillesand *et al.*, 2008).

The Normalised Difference Vegetation Index (NDVI) is obtained from the formulae stated below:

$$NDVI=\frac{Infrared - Red}{Infrared + Red} \qquad \text{(Equation 2.2)}$$

Ahmadi and Nusrath (2010) investigated vegetation change detection of the Neka River in Iran by using remote sensing and GIS. In order to analyse landscape fragmentation, land-use change was calculated using NDVI, and results show NDVI changed from 0.9597 to 0.2876 in 1977 to 0.6420 to 0.187 in 2001, which shows that bare land has increased while woodland areas decreased. Abdel-Rahman (2010) studied the potential for using narrow NDVI-based vegetation indices calculated from Hyperion data to quantify stress in and predict yield of sugarcane (Saccharum spp. hybrid) in KwaZulu-Natal. The results indicated that specific wavelengths located in the visible region of the electromagnetic spectrum have the highest possibility of detecting sugarcane Thrips damage.

2.3.5.3 Post-classification comparison

This involves independently produced spectral classification results from each end of the time interval of interest, followed by a pixel-by-pixel or segment-by-segment comparison to detect changes in cover type (Coppin *et al.*, 2004). Through coding the classification results, a complete matrix of change is obtained, and change classes can be defined by the analyst. The principal advantage of post-classification lies in the fact that the two dates of imagery are separately classifiedthereby minimises the problem of radiometric calibration between dates (Coppin *et al.*, 2004). This results in the production of a change detection matrix as illustrated in Figure 5. Post-classification comparison is important for landscape monitoring. Yang and Liu (2005) used a post-classification method to identify that the Pensacola estuarine in Mexico has experienced shrinking patterns of the spatial distribution of evergreen forest and woody wetlands. The decline of evergreen forest and woody wetlands was clearly the result of the intensification of human economic activities and fast urban development. Dewani and Yamaguchi (2009) also made use of post-classification method, adopting aGIS overlay procedure to obtain the spatial changes in LULC during three intervals: 1975–1992, 1992–2003 and 1975–2003.

Application of this technique resulted in a two-way cross-matrix, describing the main types of change in the study area. Cross tabulation analysis on a (pixel-by-pixel) basis facilitated the determination of the quantity of conversions from a particular land cover class to other land use categories and their corresponding area over the period evaluated. A new thematic layer containing different combinations of "from–to" change classes was also produced for each of the three periods.

This study applies the methodology of post-classification change detection to map and monitor land cover changes in the Harts catchment and to obtain "from–to" statistics and change detection maps.

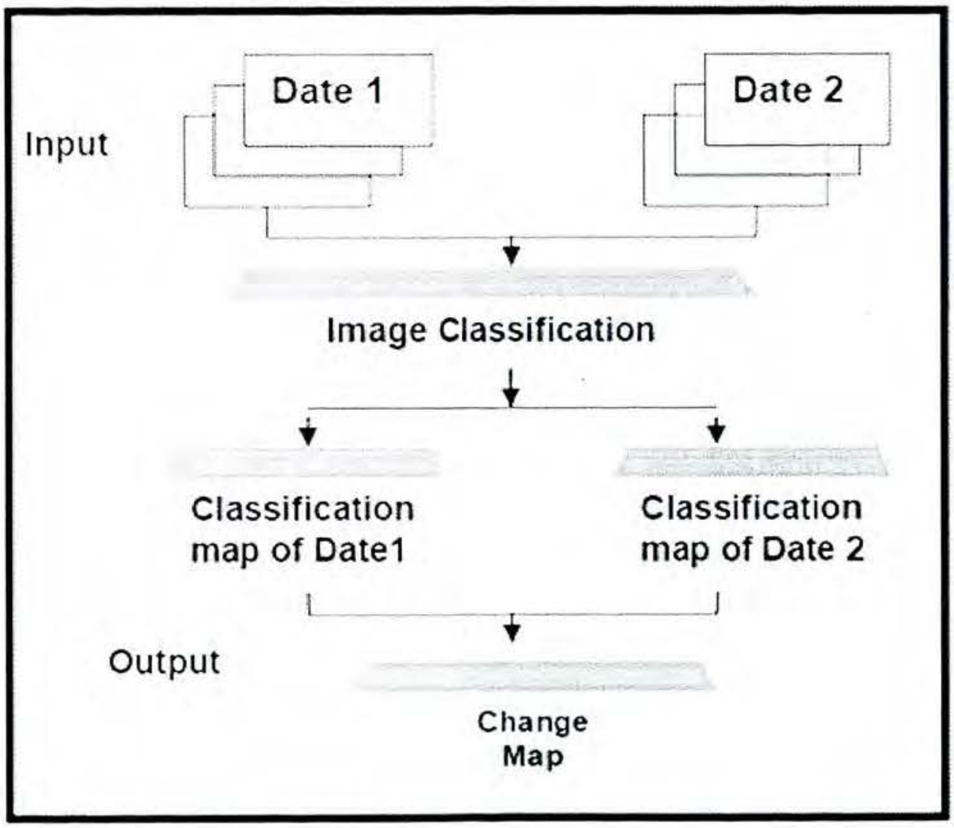

Figure 5: A flowchart of post-classification change detection technique.

Appendix 1provides a summary of the aforementioned change detection techniques, their key characteristics, advantages and disadvantages, as well as application areas and studies that have used them. It can be concluded that the post-classification comparison technique is widely used in land use and land cover applications, and hence was selected for use in this study.

2.4 Effects of changes in land cover on catchment discharge

The relationship between land cover change and hydrology is complex, with linkages existing at a wide variety of spatial and temporal scales. However, land cover/land use change unquestionably has a strong influence on global water yield as LULC directly affects the amount of evaporation, groundwater infiltration and overland runoff that occurs during and after precipitation events (Frenierre, 2009). The conversion of vegetation such as tropical forest or savannah to grassland disrupts the hydrological cycle of a drainage basin by altering the balance between rainfall and evaporation and, consequently, the runoff response of the area. The higher surface albedo, the lower surface aerodynamic roughness, the lower leaf area and the shallower rooting depth of pasture compared with forest/cerrado all contribute to reduce evapotranspiration (ET) and increase the long-term discharge (Zhang *et al.,* 2001; Costa, 2003). In addition, low-productivity grasses, like natural grassland pasture, have lower leaf area and produce less litter than the original vegetation. With a lower leaf area, the pasture does not intercept as much rainfall as the forest/cerrado does, and a higher fraction reaches the ground. With less litter, the capacity of surface retention is decreased, and a greater proportion of the rainfall runs off as overland flow. If surface runoff increases substantially and infiltration is critically reduced, soil moisture may also decrease, contributing to a further reduction in the ET (Costa *et al.,* 2003).

The conversion of the land surface from native cover to managed cropland has an effect on the evapotranspiration, infiltration and overland runoff characteristics of a watershed (Frenierre, 2009). Depending on the type of product being grown, croplands tend to have a percentage of bare ground even during the peak of the growing season, and may be completely bare prior to being planted. In both instances, most of the precipitation that lands on these denuded areas will be discharged directly into the stream channel rather than infiltrating into the soil or evaporating/transpiring from the plant surfaces. As a result, conversion to cropland tends to increase water yield compared to native vegetation (Mustard and Fisher, 2004). Of the rain that falls on the land, vegetation, depending on its biomass and surface area, will intercept the rain to varying degrees. Forest has a higher interceptive potential than grassland, arable land lower than grassland (although this varies with the crop and the season), and manmade surfaces such as tarmac have the lowest interceptive characteristic (Haslam, 1987).

2.5 Effects of land use change on hydrological parameters

Most knowledge of the effects of land use change on catchment runoff comes from experimental catchment studies, hydrological models and statistical methods. Huang (2006) studied the runoff characteristics and the influence of land cover in dry lands of Western Texas. Huang's study consisted of four major components.Firstly, an experimental study at Honey Creek upland catchment (19 ha) assessed vegetation treatment effects on runoff by hydrometric and isotopic methods. Secondly, a hydro-chemical study evaluatedthe hydrologic linkage between the upland and bottomland at the second-order Honey Creek watershed. The third study involved a detailed precipitation-stream flow analysis at North Concho River basin to assess long-term and large-scale precipitation-stream flow vegetation dynamics, and the fourth involved a comparison of stream flow in North, Middle, and South Concho River basins and a regional stream flow trend analysis for the entire western Texas. The study indicated that runoff in the dry lands of western Texas is dominated by a few large runoff-producing events. The small catchment experiment indicated that runoff increased substantially by about 40 mm per year when 60% of woody plants were removed. This effect may relate to the presence of a base flow component, but was not verified in regional trend analysis for the Edwards Plateau region – where most rivers are spring-fed. Stream flow in the North Concho River basin has declined since the 1950s, and this is in large part related to the enhanced infiltration capacity from reduced grazing pressure and improved vegetation cover.

Hydrological models have also been extensively used to evaluate the effects of land use change on catchment runoff. In order to determine spatial distribution of floods caused by the effect of the LULC change on the hydrologic regime of the Madarsu Basin in Golestan province of Iran, Panahi *et al.* (2010) calculated the Curve Number (CN) for each land use/cover type according to the US Soil Conservation System (SCS) model. Palamuleni *et al.* (2011) investigated land cover changes in the degradation of the hydrological flow regimes of the Upper Shire River in Malawi using remote sensing techniques. Hydrological data were analysed to reveal the alterations and trends for two periods in 1989 and 2002. The study revealed significant changes in magnitude and direction that have occurred in the catchment between 1989 and 2002, mainly in areas of human habitation. Trends in land cover change in the Upper Shire River catchment depict land cover transition from woodlands to mostly cultivated/ grazing and built-up areas. The land cover mapping showed that 23% of the land was covered by agricultural land in 1989. Subsistence agricultural area occupied 18% of the study area in 1989, rising to 41% by 2002. The effects of the derived land cover changes on river flow in the Upper Shire River were investigated using the semi distributed soil and water assessment tool (SWAT) model. River flows were found to be highly variable and sensitive to land cover changes. Simulation results showed that 2002 land cover data produced higher flow peaks and faster travel times compared to the 1989 land cover data. The changes detected indicated the effects of land use pressure in the catchment.

Other studies have examined the effects of the land-use change on hydrological parameters using statistical methods. Using a double mass curve analysis, Alansi *et al.* (2009) studied the effect of development and land use change on rainfall-runoff and runoff-sediment relationships under humid tropical condition in the Bernam's watershed in Malaysia. Archer *et al.* (2010) investigated the changes in rates of rise in the Axe catchment located on the south west coast of England (288 km^2) by comparing annual maximum and peaks over a threshold flows for different periods. Also by comparing rates of rise associated with given daily rainfall and by adapting the method of flow variability analysis for use of rates of change rather than flow itself. All these methods demonstrate significant changes in river flow dynamics which seem to correspond to land use changes even when the influence of climate variability from year to year has been taken into account. Rates of change in discharge appear to respond to land use changes and thus provide a potential basis for application to land use management policies.

Singo (2008) used statistical analysis such as standardisation, time series, correlation and spectral analysis over the Luvuvhu River catchment of the Limpopo province of South Africa to study temporal characteristics of rainfall and its influence in river discharge. The study revealed a strong positive linear correlation and a statistically significant relationship between rainfall and river discharge. El Nino Southern Oscillation and sunspots seem to have pronounced influence on the recurrence of rainfall and river discharge events in the area. The study however did not evaluate any effects from LULC in the area. Alexander (2000) used South Africa Weather Services district rainfall data that were amalgamated and re-processed into chronological order to produce district rainfall maps based on millimetres and probabilities. This information proved to be invaluable in identifying the location, magnitude and areal distribution of severe flood-producing rainfall in South Africa. It also demonstrated conclusively that extreme floods were the result of wide-area rainfall events and not confined to single catchments. Also, the district rainfall data were used to determine whether there were significant correlations between severe rainfall in one district and that in adjacent districts. While the results were less conclusive, they nevertheless provided some new insights into the location of regions that are more prone to severe floods than others. At this stage there was very clear evidence that large-area, severe flood-producing rainfall was far more frequent than had been previously realised, and that there appeared to be some regional grouping. Next they analysed the rainfall on a daily basis rather than a monthly basis to see if more insight could be gained on the relative severity of the rainfall in each of the larger regions. This analysis provided a greater quantitative assessment than was possible using district rainfall. It confirmed the presence of regions that were more flood-prone than others, and that the central Highveld region is less prone to floods than other regions in the interior of South Africa.

A study by Juahir *et al.* (2010) was carried out to detect the spatial and temporal change (1974-2000) in hydrological trend and its relationship to land use changes in the Langat River Basin, Kuala Lumpur. The study used GIS and non-parametric Mann-Kendall (MK) statistical test, where the significance of trend in hydrological and land use time series was measured. Trend analyses showed a significant relationship between discharge and direct runoff, and land use types – agriculture, forest, urban, waterbody and others. This analysis indicates that rainfall intensity does not play an important role as a pollutant contributor via the rainfall runoff process nor does it directly influence the peak discharges. Mann-Kendall test of trend shows an increasing trend ($p\text{-value}<0.01$) of annual maximum-minimum ratio. There is evidence that regional variability in discharge behaviour is strongly related to land use or land cover changes along the river basin.

Detectable changes in stream flow may be expected where large areas of forest vegetation have been replaced by annual cropping rather than left to regenerate. Madduma-Bandara and Kuruppuarachchi (1988), also cited by Bruijnzeel (1990), reported an increase in mean annual flow for the 1108 km^2 Mahaweli basin in Sri Lanka, despite a weak negative trend in rainfall over the same period (1944–81). Although both trends were not statistically significant at the 5% significance level, the increase in the annual runoff ratio was highly significant. Bruijnzeel (2003) highlights the importance of considering the rates and extent of urbanisation in the analysis. For example, Van der Weert (1994) compared streamflow totals for the 4133 km^2 Citarum River basin in West Java, Indonesia, for the periods 1922–1929 and 1979–1986. Average annual rainfall totals for the two periods were very similar at 2454 and 2470 mm, respectively. The corresponding average streamflow totals were 1137 and 1261 mm (an increase of 11%), suggesting a decrease in catchment evapotranspiration of about 110 mm yr^{-1} Little forest clearance was reported for the former period, although in 1985 almost 50% of the catchment was covered by forest, plantations or mixed gardens, whereas settlements and irrigated rice fields occupied 7% and 34%, respectively, with rainfed fields making up the remainder (Van der Weert, 1994). Despite the conversions from forest to agriculture, Bruijnzeel (2003) argues that the increase in water yield must be attributed primarily to the increase in areas with compacted surfaces, such as roads and settlements.

In the Harts catchment, a lack of observational data, such as solar radiation, evapotranspiration and spatial averaged rainfall data over the watershed eliminates the possibility of using experimental catchment studies and rainfall–runoff models to assess the influence of the land cover change on streamflow. An alternative approach is to use a statistical method to assess whether a change in observed streamflow series is significant. This study used a linear correlation (Pearsons correlation) to determine the relationship between rainfall and river discharge. The time series was also used in this study as it assists in the evaluation of any irregularities of rainfall and river discharge.

2.6 Factors affecting sream flow

Stream flows can increase as a result of a change in land use if the infiltration capacity of the soil is reduced, for example through soil compaction or erosion, or if drainage capacity is increased (Kiersch, 2000). Stream flows may increase when vegetation is reduced. As the amount of precipitation increases, influence on storm flow of soil and plant cover diminishes (Bruijnzeel, 1990). An increase of stream flows may be due to an increase of impervious surfaces. Studies in the north-western USA have shown that the construction of forest roads can intensify peak runoff from forested areas significantly (La Marche and Lettenmaier, 1998). Consolidation of smaller plots to large fields can lead to higher runoff rates, due to drainage systems and asphalt access roads (Falkenmark and Chapin, 1989). Conversely, peak flows may decrease as a result of an increased soil infiltration capacity. In larger basins, effects of land use practices on peak flow are offset due to time lag between different tributaries, different land use and variations in rainfall (Bruijnzeel, 1990). In larger watersheds, this de-synchronisation effect can lead to a reduction in peak discharge, although overall storm flow increases due to land use changes in individual subwatersheds (Brooks *et al.*, 1991).

2.7 The Impact of the Recent Floods and Related Disasters on the Lives of People

Floods is one of the most common of all environmental hazards, this is due to the geographical distribution of river valleys and the obvious attraction for human settlement.The average yearly rainfall for the Taung area is 418 mm. In January to June 2006, it received 1,380mm, resulting in severe flooding from 20 February 2006. The extent of the flooding was equal to a 1 in 50 year flood and seriously affected 12 villages in Greater Taung Local Municipality (Department of Provincial and Local Government, 2008). Due to the serious effect the floods had on the population of these villages, the Greater Taung Local Municipality regarded it as its duty to intervene in the affected area. According to media reports, six people drowned in the flooding and approximately 1040 families lost their homes; two children were seriously injured after their house collapsed on them. In addition, theNational Broadcaster, reported: "desperate communities in the flood-hit villages have been eating the carcasses of animals, despite a warning from health authorities that they could become severely ill." (SABC News, 2006a). Three years earlier, in the 2003 floods, Taung had suffered severe storms that killed four people.The heavy rains and hail destroyed about 60 houses, roads and other property in its wake (South African Government Information, 2004). "Experts say Taung is situated in a basin, making the area vulnerable to waters flowing from higher situated areas" (SABC News, 2006b). Farmers in the Jan Kempdorp area in the Northern Cape called on the government to declare the area a disaster area after floods destroyed most of their crops after the 2006 floods. The area, which is only about 30km from Taung in North West, was also struggling with floods. Dries Groenewald, one of the biggest Lucerne farmers at Jan Kempdorp lost his entire crop of 320 hectares and says damages to the area were estimated at around R44 million (SABC News, 2006b). The floods were caused by four overflowing rivers, good rains and an overfull Spitzkop Dam. Most of the farms are close to the dam, which is more than 100% full (SABC News, 2006b).

Alluvial floodplains are flat, fertile, and close to water bodies. As a result they are attractive for residential, farming, and development. Usually the flow in a river is controlled within its banks, but after unusually heavy rain the level of the water in the river may rise above the banks and flow onto nearby land. At first villages were built on terraces that were relatively safe from floods because they are situated higher in elevation than the natural flood plain and are still close to fertile land,but as population increases extra land is needed near rivers and therefore people move closer to the water courses (Vlachos, 1995). This affinity for floodplain occupancy serves as a backdrop for understanding the dilemma between noticeable production and settlement advantages, and the disastrous human and economic costs that follow overflow of rivers (Vlachos, 1995). This is the context within which this thesis is also discussed.

2.7 Summary

The review of literature presented above has outlined the various change detection techniques used for different application areas. Following the review, a brief summary of the commonly used techniques has been provided. In addition, the effects of land use and cover change on hydrological parameters and catchment discharge has been discussed. The next chapter presents the methodology used to execute the study.

3. INTRODUCTION

In this chapter the research methodology ispresented. The data sources and the different analytical techniques employed are detailed. To distinguish different methods and their importance, the various methods for each objective set in Chapter One are discussed.

3.1 Data Sources

The sources of data included remotely sensed data (Landsat images covering Harts Catchment) ancillary data (1: 50000 topographical and aerial photo maps) climatic data, stream flow data and soil data.

3.2 Satellite Data

Information requirements necessitated accurate mapping of land cover classes in the Harts catchment to provide input data. Automatic interpretation of multispectral satellite imagery has proven to be an efficient procedure for consistent and accurate land cover mapping. Map productions using satellite data benefit from all the advantages related to the use of digital data, including its periodical acquisition, and coverage of large areas at a relatively low cost. A comprehensive assessment of the spatial and temporal distribution of land cover dynamics between 1990 and 2008 was critical for understanding and documenting change, as well as impacts of such change on the land hydrological processes within the catchment.

The approach adopted in this research work is summarised in Figure 6. This approach provided a framework and a guide of all study activities leading to the generation of the statistics of land use dynamics and study findings.

3.2.1 Selection of satellite images

Landsat images of level 1G were obtained from the Council for Scientific and Industrial Research (CSIR) South Africa. Within the constraints of a limited number of suitable images in the archive, a strategy for selecting Landsat imagery for development of land cover database for the Harts River catchment was governed by cost-free available multi-temporal images, vegetation phenology and image quality (absence of cloudiness and haze).

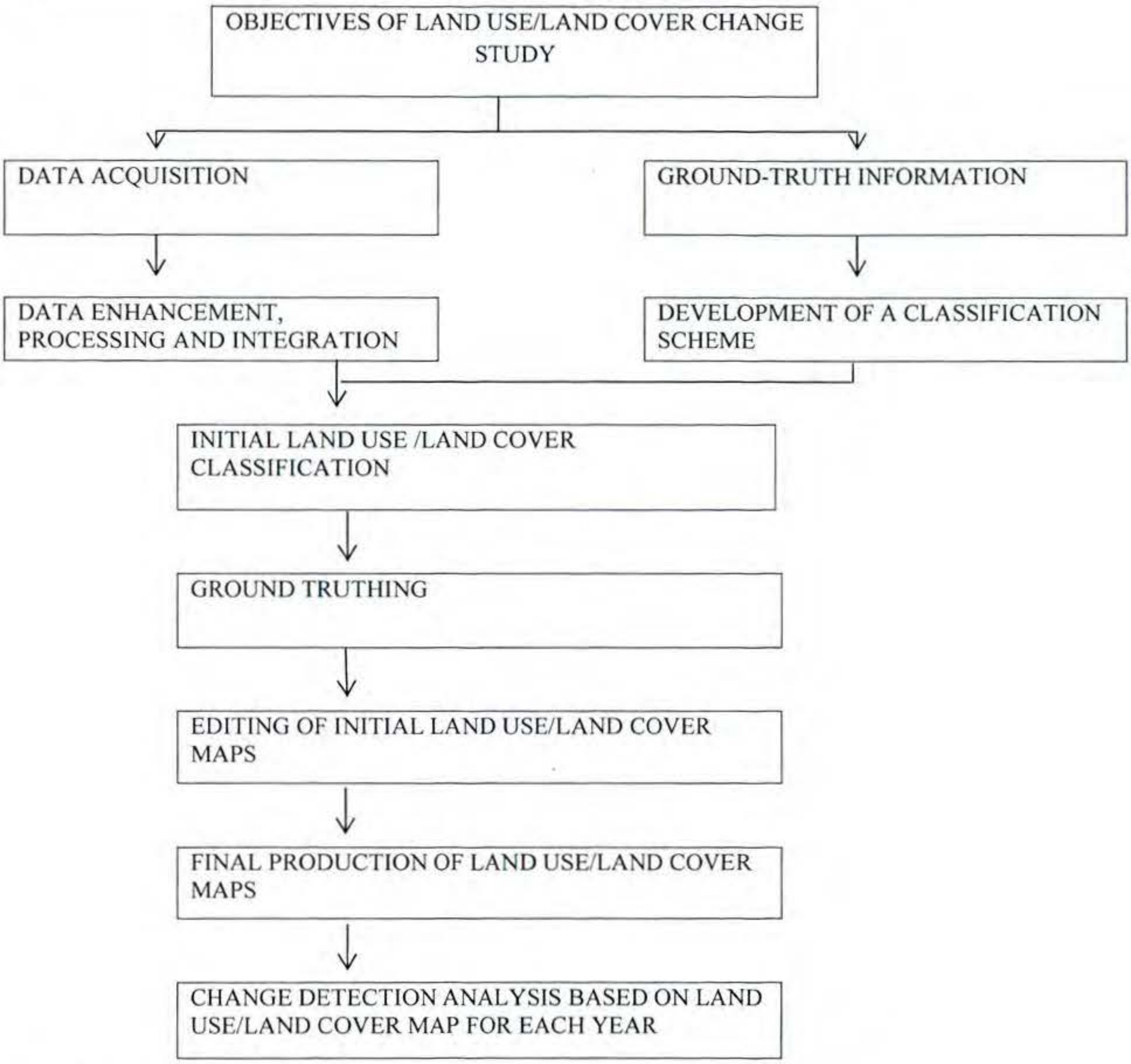

Figure 6: Conceptual framework that guided land cover change detection

Hence, springtime satellite images were chosen as the images are cloud free and the effect of spring rainfall on vegetation is clearly visible on the image. Table 1 shows the detailed description of the three spring time (September) Landsat TM images for 1990, 2005 and 2008 that were obtained for use in the study.

Table 1: Characteristics of satellite images

Acquisition Date	Satellite	Sensor	Path	Row	Resolution
1990/09/25	Landsat 4-5	TM	172	79	30 m
2005/09/18	Landsat 4-5	TM	172	79	30 m
2008/09/26	Landsat 4-5	TM	172	79	30 m

3.2.2 Pre-processing

Pre-processing procedures prepare data for subsequent analysis. Therefore, a number of initial pre-processing procedures prior to post-classification change detection data analysis may be required. These include:

ERDAS Imagine 2010 was used for image processing in the study.

i. *Correcting for systematic error* – Each data set needs to be quality inspected and the presence of any error detected. This can be achieved by simply displaying and summarising data through the use of frequency histograms, scattergrams, or statistical summaries (Jensen, 2006). It is important to note that radiometric corrections and radiometric data normalisation procedures are not usually necessary for post-classification change detection analysis (Kim and Elman 1990). This is because each data set, for each time period is classified independently and changes are then detected from comparison of the derived classification layers for each time period (HCC-Report. 2011).

ii. *Geometric rectification* – Geometric rectification of imagery involves resampling or changing the pixel grid to fit that of a map projection or another reference image. This becomes especially important when scene to scene comparisons of individual pixels in applications such as change detection are being sought (ERDAS, 1999). To conform the pixel grids and remove any geometric distortions in the TM imagery, the September 26, 2008 image was registered to UTM map projection (zone 35S, datum WGS84) using nearest neighbour resampling routine. Based upon thirty-six ground control points collected from topographical map (1:50000), the resampling process maintained the original 30m resolution. The 1990 and 2005 images were co-registered to the 2008 image utilising similar sets of ground control points (GCP's).

An image-to-image registration was used to co-register all of the images to the base image with a Root Mean Square (RMS) error of less than 30 meters (1 pixel). RMS error is the distance between the input (source) location of a GCP, and the resampled location of the same GCP (ERDAS, 1999). Theimage-to-image registration of 2008 to 2005 resulted in RMS error of 3.6 meters while 2008 to 1990 resulted in RMS error of 5.9 meters.

iii. *Subset of study area* – Landsat TM scenes, in some cases are much larger than a project study area. It is thus beneficial to reduce the size of the image file to include only the area of interest. In order to subset the study area from each of the three Landsat images, a vector file defining the Harts River boundary with the same georeferenced coordinates as the Landsat images (UTM zone 35S, datum WGS84) was imported into ERDAS. The Department of Water Affairs (DWAF) provided the Harts River shapefile. The Harts River boundary vector file was used to create an "Area of Interest" file which was subsequently overlaid over each of the TM images. Figure 7 shows the subset of TM imagery with special focus on the Harts catchment.

3.2.3 Image enhancement

Image enhancement involves operations that improve visual representation of selected distributions on an image for the purpose of subsequent manual interpretation (HCC-Report, 2011). Histogram equalisation technique was applied to obtain the best visual display for interpretation and analysis. The histogram was integrated to obtain the cumulative density-probability function and finally the lookup function was used to transform the output image (IDL Online help, 2007). Individual images for the study area were therefore enhanced.

3.2.4 Image classification

Within the scope of this project, image classification is defined as the extraction of different classes or themes, land use and land cover categories from raw remotely sensed digital satellite data (Gorham, 1999).

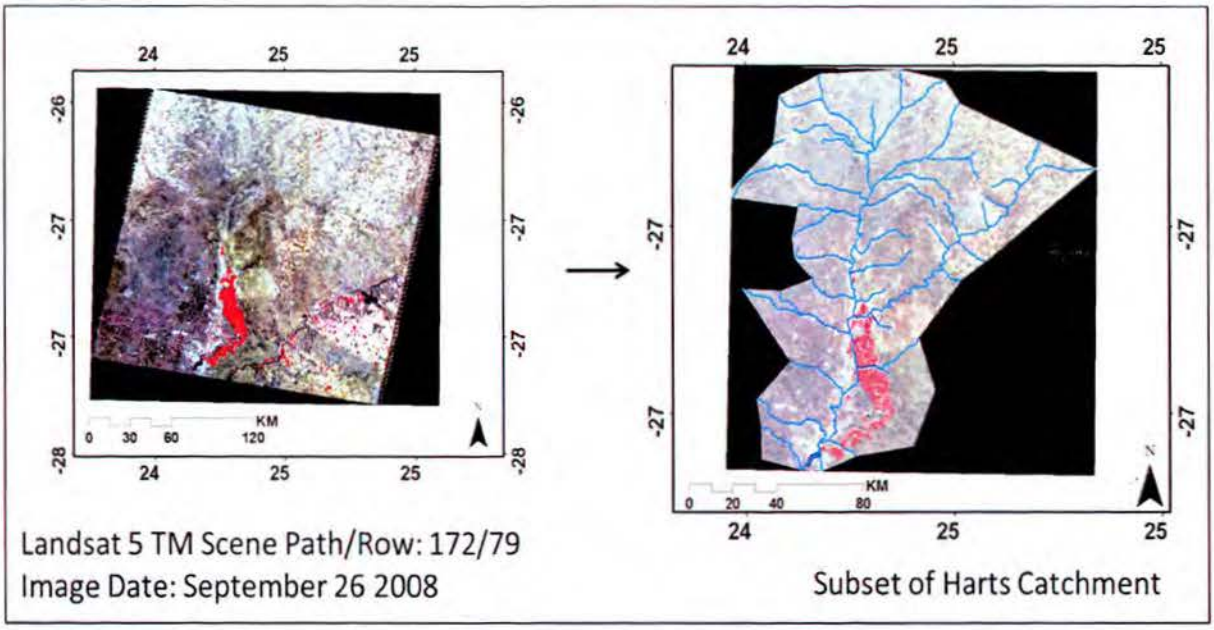

Figure 7: Subset of TM imagery to focus study area

Hybrid classification is the use of both supervised and unsupervised techniques to classify an image. Initially the images were classified each into seven classes by unsupervised classification using the program ERDAS Imagine 2010. Then supervised classification with the knowledge of topography and cluster busting reduced the classes to five. Thus, composing both unsupervised and supervised classification.

Training sites were located and circumscribed by polygonal boundaries as shown in Figure 8.The seed calibration strategy was chosen for this study, because it selects spectrally similar pixels and is an effective way of selecting homogenous training data (Pillay, 2009). For each class outlined, mean values and variances of the digital numbers (DNs) for each band used to classify were calculated from all pixels enclosed in the site. The training sites were proportionally distributed for each cover type with at least six sites per cover type. Using reference images such as aerial photo map (1:8000) of 1991, topographical map (1:50000) of 2005 and 2008 and Google Maps, training samples were gathered from more than 30 sites as signatures for each Landsat image for the supervised classification.

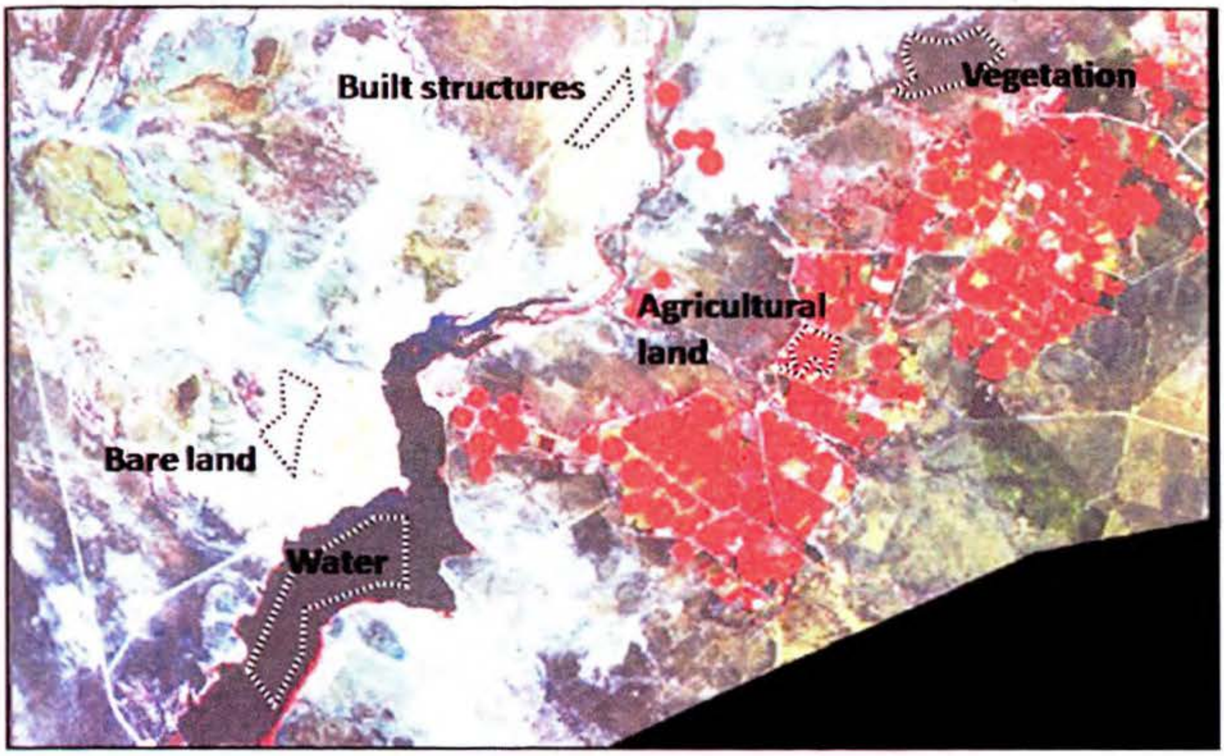

Figure 8: Training sites in Landsat TM of Harts catchment

A signature is a set of data that defines a training sample or cluster and corresponds to a class in a classification process (ERDAS Field guide, 2005). Five signature classes were created using signature editor of ERDAS and this process was performed on all three images. The user-defined class codes and classes used for creating the signatures are presented in Table 2.

Following signature creation, the signature separability between the five classes was evaluated using a transformed divergence measurement and viewed in a feature space plot. Signature separability is a statistical measure of the spectral distance between two signatures and can be calculated for any combination of bands that is used in a classification, enabling bands not useful in a classification to be ruled out (Jensen, 2006). A commonly used measure of spectral separability is the transformed divergence (TD). The TD gives an exponentially decreasing weight to increasing distances between classes and scales the divergence values to lie between 0 and 2000. A TD value of 1500 or greater generally indicates an acceptable separability between classes (Haack, 2007).

Table 2: The user defined class codes and classes used for creating the signatures

Class Code	Class Name
1	Water bodies
2	Agricultural land
3	Vegetation
4	Barren land
5	Built structures

The 1990 image had an average and minimum separability measure of 1950 and 1578 respectively, while 2005 image had 1945 and 1539 respectively and the 2008 image at 1937 and 1467 respectively, reflecting an acceptable distinction between the classes. A maximum likelihood classifier was applied to each image to define five land cover classes into classes using the signature with the best separability measure.

3.2.5 Classification scheme

This study attempted to account for the major land-cover areas presented in the images. The classification scheme was therefore arrived at on the basis of the cover types in the study area that were present in large quantities. The classes shown in Table 3were extracted as thematic classes from the images and for which area statistics were generated.

Table 3: Land use and Land cover class definition

<table>
<tr><td>Water bodies
</td><td colspan="2">All open bodies of water, including: streams, rivers - Dry Harts River and the Harts River and dams –Taung, Spitskop and Wentzel.</td></tr>
<tr><td>Vegetation
</td><td>Schweizer-Reneke Bushveld occurs on the eastern part of the catchment and consists of open woodland with a fairly dense shrub layer, with trees: Acacia erioloba, A. karroo, A. tortilis, Rhus lancea and shrubs: A. hebeclada, Diospyros lycioides, Grewia flava and Tarchonanthus camphoratus.

Kimberley Thornveld occurs in the central and southern part of the catchment and consists of a well-developed tree layer: Acacia erioloba, Acacia tortilis, Acacia karroo, Rhus lancea and Boscia albitrunca and shrub</td><td>layer: dense stands of Tarchonanthus camphorates, Rhus tridactyla, Ehrethia rigida, Grewia flava andgrass layer open

Ghaap Plateau Vaalbosveld occurs on the western part of the catchment and consists of open tree layer characterised by Acacia erioloba, A. karroo, Rhus lancea and shrub layer of Grewia flava, Tarchonanthus camphoratus and grass layer open.</td></tr>
</table>

Built Structures 	An area where there is permanent concentration of people, buildings and manmade structures and activities, ranging from large village to city scale
Barren Land 	Any piece of land that fall in any of the following categories: (a) bare rock/sand/clay - perennially barren areas of bedrock, desert pavement and other accumulations of Earth and material: (b)quarries/strip mines/gravel pits - areas of extractive mining activities: and (c)transitional - areas of sparse vegetative cover that are dynamically changing from one land cover to another.
Agricultural Land 	Large and small scale farms with varying levels of grass, trees, shrubs, fallow and crop covers

3.2.6 Post- classification filtering

Classified data often manifest a salt-and-pepper appearance due to the inherent spectral variability encountered by a classifier when applied on a pixel-by-pixel basis (Lillesand *et al.*, 2008). In the desire to "smooth" the classified output and to show only the dominant classes, one means of classification smoothing involves a majority filter. A majority filter involves passing a moving window through the classified data set and determining the majority class within the window. In this study, a 3*3 pixel majority filter was used to clean the classified images to the generalisation of the Harts River catchment maps.

3.2.7 Classification accuracy assessment

Land cover maps derived from the classification of images usually contain some errors due to several factors that range from classification techniques to methods of satellite data capture. Hence, evaluation of results is an important process in the classification procedure. An error matrix can be used to assess the accuracy of an image classification and can be used to refine the classification (Congalton and Green, 1999). The basic principle of the error matrix is to systematically compare two sources of information: (i) pixels or polygons in a remote sensing-derived classification; and (ii) ground reference test information (Jensen, 2006).

ERDAS Imagine Accuracy Assessment tool was used to conduct an accuracy assessment in this study. Three different types of distribution are offered for selecting the random pixels. These are random, whereby no rules are used; stratified random, whereby the number of points is stratified to the distribution of thematic layer classes; and equalised random, whereby each class has an equal number of random points (ERDAS Field guide, 2005). To assess the accuracy of each land-cover classification, a set of reference points were generated to compare their classification in the final thematic map. A total of 300 reference data points were generated for the imagery of each of the years. ERDAS Imagine Accuracy Assessment tool was used to select stratified random reference points that included a minimum of fifty points in each of the five land cover categories of interest. Congalton (1991) stated that it has been shown that more than 250 reference pixels are needed to estimate the mean accuracy of a class to within plus or minus five percent.

Aerial photo map (1:8000) of 1991 and topographical map (1:50000) of 2005 and 2008 were used as a reference for the 1990, 2005 and 2008 classified imagery respectively. The aerial photo maps were obtained from the Department of Geography and Environmental Studies at the North West University and acquired from Aircraft Operating Company while the topographic maps were obtained from the Chief Directorate: Surveys and Mapping. The aerial photographs were scanned to Join Photographic Experts Group (JPEG) on a high-resolution scanner. The JPEG files gave a resolution of less than 1 meter on the ground. Visual interpretation of various features on the aerial photographs was done based on the shade, shape, size and location of the features.

Table 4: Error Matrix for the classification of the Landsat TM for 2008

		REFERENCE DATA						
		W	**A**	**V**	**Ba**	**Bu**	**Total**	**User accuracy (%)**
CLASSIFICATION DATA	**W**	50	0	0	0	0	50	100
	A	1	50	0	0	0	51	98
	V	0	0	70	7	1	78	89.74
	Ba	0	0	7	56	0	63	88.89
	Bu	0	19	0	0	39	58	67.24
	Total	51	69	77	63	40	300	
Producer accuracy (%)		98.04	72.46	90.91	88.89	100		**Overall accuracy = 88.3%**

Legend: W-Water body, A-Agricultural land, V-Vegetation, Ba-Barren land, Bu-Built structures

Table 5: Error Matrix for the classification of the Landsat TM for 2005

		REFERENCE DATA						
		W	**A**	**V**	**Ba**	**Bu**	**Total**	**User accuracy (%)**
CLASSIFICATION DATA	**W**	50	0	0	0	0	50	100
	A	1	47	3	0	0	51	92.16
	V	0	0	74	5	0	79	93.67
	Ba	0	0	6	55	0	61	90.16
	Bu	0	24	0	1	34	59	57.63
	Total	51	71	83	61	34	300	
Producer accuracy (%)		98.04	66.2	89.16	90.16	100		**Overall accuracy = 86.67%**

Legend: W-Water body, A-Agricultural land, V-Vegetation, Ba-Barren land, Bu-Built structures

Table 6: Error Matrix for the classification of the Landsat TM for 1990

		REFERENCE DATA						
		W	**A**	**V**	**Ba**	**Bu**	**Total**	**User accuracy (%)**
CLASSIFICATION DATA	**W**	50	0	0	0	0	50	100
	A	1	48	2	0	0	51	94.12
	V	0	0	79	1	0	80	98.75
	Ba	0	0	4	55	0	59	93.22
	Bu	0	24	1	0	35	60	58.33
	Total	51	72	86	56	35	300	
Producer accuracy (%)		98.04	66.67	91.86	91.2	100		**Overall accuracy = 89%**

Legend: W-Water body, A-Agricultural land, V-Vegetation, Ba-Barren land, Bu-Built structures

Tables 4, 5 and 6 present the error matrices for the three sets of Landsat TM images. The results show an accuracy of 88.3% for the classification on the 2008 image, 86.7% for the classification on the 2005 image and 89% for the classification on the 1990 image. The overall Kappa Statistics were 0.85 for the 2008 image, 0.83 for the 2005 and 0.86 for the 1990 image.

3.2.8 Ground-truth Information

Table 7: Matrix for the classification of the Landsat TM for 2008

		GROUND TRUTH DATA						
		W	**A**	**V**	**Ba**	**Bu**	**Total**	**User accuracy (%)**
CLASSIFICATION DATA	**W**	10	0	0	0	0	10	100
	A	0	14	1	0	0	15	86.67
	V	2	12	144	9	1	168	85.71
	Ba	0	2	12	58	0	72	80.56
	Bu	0	2	5	6	22	35	62.86
	Total	12	30	162	73	23	300	
Producer accuracy (%)		83.33	43.83	88.89	79.45	95.7		**Overall accuracy = 82.33%**

Ground truthing was done using aerial photographs and field site information. This was because the set of satellite imagery were historical with the most recent one having been acquiredthree years before the study commenced which meant that, the interpretation and classification based on them could not be entirely checked against ground truth only. Ground truth sites were selected using stratified random sampling scheme in ERDAS. Up to 300 randomly generated points were used for comparing classified cells and reference cells as shown in Figure 9. Forty-five reference points were verified by field visits and 255 reference points through comparison with 1:50000 topographical map.

The points for field verification were selected based on natural and manmade features on the ground, uniformly distributed, clearly visible, and easily accessible. The accessible points were then imported into a Global Positioning System to validate these reference points in the field. Collecting groundtruth data through aerial photographs has an edge over conventional method of survey because of its speed, accuracy, and cost effectiveness (Awotwi, 2009; Blasco *et al.*, 2004). From Table 7, the results show an accuracy of 82.33% for the 2008 image and an overall Kappa Statistics of 0.717.

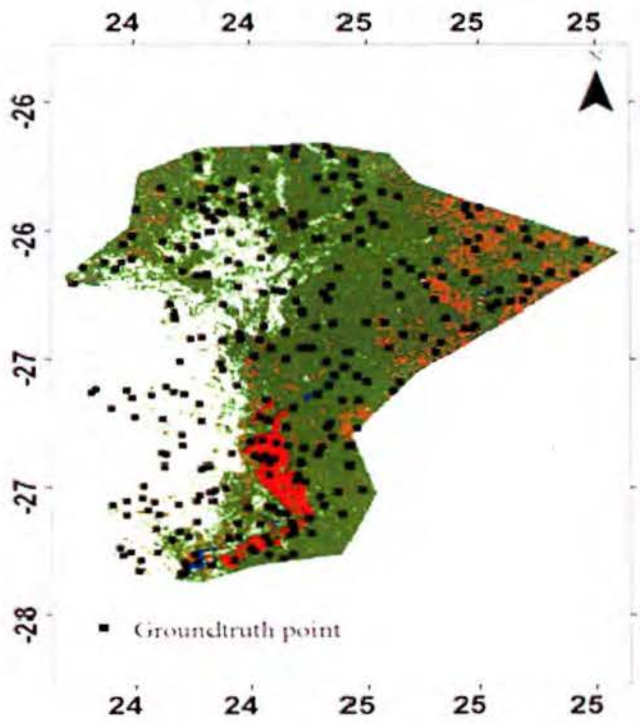

Figure 9: Location of ground truth sampling points

3.2.9 Change detection

Change information can be extracted to determine how much change has resulted from different land covers over time. Change detection was done for 1990–2008 to get 'from–to' information of changes in land use and land cover in the study area using the post-classification cross-tabulation approach in ERDAS Imagine software. Post classification comparison proved to be the most effective technique because data from three dates were separately classified, thereby minimizing the problem of normalising for atmospheric and sensor differences between two dates (Lu *et al.*, 2004). The cross operation allows the analyst to know the extent and nature of changes observed, particularly the transition between different land use and land cover classes and the correspondent area of change (Lu *et al.*, 2004).

For this study, five land classes were identified. Each of the five identified land classes was assigned a base value in the sequence. A 25-cell table (5 x 5) of *change detection codes* was created for each possible pair of "changed from" and "changed to" combinations. This table is interpretable by presenting tabular results quantifying change between classes, such as the change from agricultural land to built structures. The table shows the degree of change, the pixel prior classification, and the pixel post classification. In addition, by applying the change detection codes to the comparison of two classified images, a new layer referred to as post classification change layer is produced, with each pair of pixels represented by a change detection code. Change detection maps are generated from the change detection layer, to visualise areas of change by assigning colours to single or grouped categories of change.

Land cover change areal statistics were also summarised to express the net land cover lost and gained by each class. This was accomplished by subtracting the total amount of land cover gain from the total amount of loss. Statistics were compiled using the Microsoft Excel to determine the specific nature of changes between the acquisition dates of the three imagery specifically the size of the differences between the dates and the direction (gain and loss) of change in each land cover type.

3.3 Hydro-meteorological data

It is widely accepted that climate change and human activities are the main driving forces for hydrological variability (Milliman *et al.*, 2008; Zhao *et al.*, 2009; Xu, 2010). However, distinguishing the causes for the flow regime shifts is still a major challenge in hydrology, and studies have shown that flow regime shifts in river basins can be ascribed to the changes in land cover and land use, climatic variables, river regulations, and other human activities such as soil and water conservation measures (Yang *et al.*, 2011). To address the role of climatic factors and river regulations in controlling discharge trends, statistics were computed for precipitation and river discharge in the Harts catchment over different periods of time. It was believed that these periods were long enough to include a representative sample of climate, while having considerable changes in land cover between them.

Hydro-meteorological data used in this study consisted of daily and monthly statistics for both rainfall and river discharge, from the stations within the Harts catchment. The study used hydro-meteorological data from 1990 to 2010. The climatic data were obtained from the South African Weather Services (SAWS). The data were based on major rainfall season for the study area which is from October to April of the following year. The Department of Water Affairs (DWA) provided continuous and reliable historical daily stream flow data. All recorded data were measured in cubic meters per second ($m^3 s^{-1}$). Annual river discharge data also run from October 1990 to March 1991. Table 8 shows the stations that provided rainfall and stream flow data for Harts Catchment.

Table 8: Weather stations and river gauging stations in the Harts River catchment

Rainfall	Station No	Latitude	Longitude	Height
	03604536	-27.55	24.77	1124m
	04322373	-26.95	24.63	1234m
	03612959	-27.91	25.15	1207m
River discharge	Station No	Latitude	Longitude	Catchment Area
	C3H003(Taung)	-27.57	24.75	9219 (km^2)
	C3H007 (Espagsdrif)	-27.90	24.62	24097(km^2)

3.3.1 Changes in Harts River flow regime

Statistical approaches assist in presenting data in simplified and understandable forms. The statistical parameters investigated in this study included mean and standard deviation of rainfall and river discharge totals. The mean was used to determine the missing data. When the month had about 30 days, the mean was the sum of all days readings divided by 30 or any number of days in that month.

$$\overline{X} = \frac{\sum x_i}{n} \qquad \text{Equation 3.1}$$

Where:

$\overline{X}$ = Historical mean

x_i = Individual data point

n = Number of data

The standard deviation was computed using the following formula:

$$\sigma = \sqrt{\frac{\sum(\overline{x} - x)^2}{n-1}} \qquad \text{Equation 3.2}$$

Where:

σ =Standard deviation

Σ = Sum

$\overline{x}$= Mean

3.3.2 Seasonal analysis

The seasonal analysis is done by compositing both rainfall and river discharge data. A composite is simply a thing made up of several parts or elements (Kazmier and Pohl, 1984). By compositing both rainfall and river discharge, the values for each parameter were separated into normal, below normal and above normal categories. This was done using the standardisation formula:

$$Z = \frac{(x_i - \overline{x})}{\sigma} \qquad \text{Equation 3.3}$$

Where:

Z = standardised anomaly index

x_i = individuals data points

σ = historical sample standard deviation

$\bar{x}$ = Mean

Using Microsoft Excel, the data were first normalised using long term mean and then standardised by dividing them by the standard deviation to more easily compare the seasonal data and time series, and to more easily identify wet and dry periods. The standardisation of data is important because a number of statistical methods such as the *t*-test, variance and correlation analysis require that the data are normally distributed (Singo, 2008). A study by Goddard and Melville (1996) revealed that any distribution of standardised values has a mean of zero value and a standard deviation of +1.

The interpretation of the data is as follows: standardising rainfall and river discharge data and separating them into normal, near normal, below normal and above normal categories. This helps in identifying wet and dry periods within the period 1990 – 2010 and in computing a standardised time series for each data set. Those anomalies with positive values feature wet spells while those anomalies with negative values feature dry spells. Anomalies with values greater than +1 are termed extreme wet spells. Anomalies with values greater than – 1 are termed dry spells (Makarau, 1995; McPhee *et al.*, 1994). This criterion was used in this study to identify wet and dry spells.

3.3.3 Correlation analysis

Correlation analysis refers to the methods for measuring the degree of association among the variables (Kazmier and Pohl, 1984). Rainfall and river discharge data sets were correlated to determine the strength of linear relationship. The relationship between the variables can be positive, negative or non-existent. The analysis can help objectively in assessing the extent to which one variable really influence another (Larson and Farber, 2000). Correlation analysis is applied using the correlation coefficient (r). The correlation is computed statistically, using the formula: (Brink, 1987).

$$r = \frac{\sum (X - x)(Y - y)}{\sqrt{\sum (X - x)^2 (Y - y)^2}}$$ Equation 3.4

Where:

r = correlation coefficient

X = individual score for variable X

x = mean score for variable x

Y = individual score for variable Y

y = mean score for variable y

Correlation coefficient (r) is an index that measures the strength of linear relationship between the two parameters. If the two variables were perfectly correlated, the correlation coefficient expressing the relationship would be 1.0. When the two variables are totally unrelated, the correlation coefficient is equal to zero. When there is a perfect inverse relationship between the variables, the correlation coefficient will be equal to -1. A correlation coefficient of 0.75 to 0.99 indicates a high degree of relatedness (Mashile, 2002).

3.4 Summary

This chapter outlined the materials and equipment used, and provided a detailed explanation of the various steps followed in the execution of the change detection study and in the analysis of hydro-meteorological data. Reference was also made to the ERDAS software used for image processing and for performing time series change analysis. Statistical techniques used here for hydro-meteorological data analysis include mean, standard deviationand correlation analysis. The next chapter presents the results and a discussion of the findings.

4. RESULTS AND DISCUSSION

The objectives as presented in the first chapter provided the basis of all the analyses carried out in this study. This chapter presents the results obtained from the various analyses presented in the preceding chapter. It also provides interpretation and discussion of the results. Some of the areas of emphasis in the discussion include the assessment of the accuracy of the change maps generated; and analysis of the nature, extent and rate of land cover changes. Statistical trend analysis results of rainfall and river discharge are also discussed. The results are presented in the form of tables, bar charts and land use and land cover (LULC) change maps.

4.1 ACCURACY ASSESSMENT

Evaluation of classification results is an important process in satellite image classification procedure. For this confusion/error matrices were used – the most commonly employed approach for evaluating per-pixel classification (Congalton and Green, 1999). The accuracy was assessed with cross-validation against the digital aerial photo map, topographic maps and Google Earth Imageries. Using these reference data and the classified maps, confusion matrices were constructed (Tables 4, 5 and 6) for the three periods. The resulting Landsat land use/cover maps generated from the 1990, 2005 and 2008 images had an overall accuracy of 89%, 86.7% and 88.3%. These were reasonably good overall accuracy levels and were therefore accepted for the subsequent analysis and change detection. User's accuracy of individual classes ranged from 57% to 100 % and producer's accuracy ranged from 66% to 100%. Kappa statistics/index was computed for each classified map to measure the accuracy of the results. Kappa values are characterised into 3 groups: a value greater than 0.80 represents strong agreement, a value between 0.40 and 0.80 (40 - 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement (Congalton, 1991). The overall Kappa statistics were 0.85 for the 2008 image, 0.83 for the 2005 and 0.86 for the 1990 image, showing strong agreement between the classification map and the ground reference information.

Water bodies were classified correctly at 100% in all the images (1990, 2005 and 2008) while built structures recorded the lowest user accuracy with values of 58.3%, 57.6% and

67.2%respectively. Agricultural land had the lowest producer accuracy with values of 66.7%, 66.2% and 72.5% respectively. This is possibly due to images being acquired during the spring season of the region (September), when the spectral signatures of agricultural land and built structures have greater similarity leading to high spectral confusion. During this season most of the agricultural fields had been cleared and there is little chlorophyll in the vegetation making it difficult to distinguish the two classes. As a result, 24% of agricultural lands were classified as built structures on the 1990 and 2005 images, and 19% on the 2008 image.

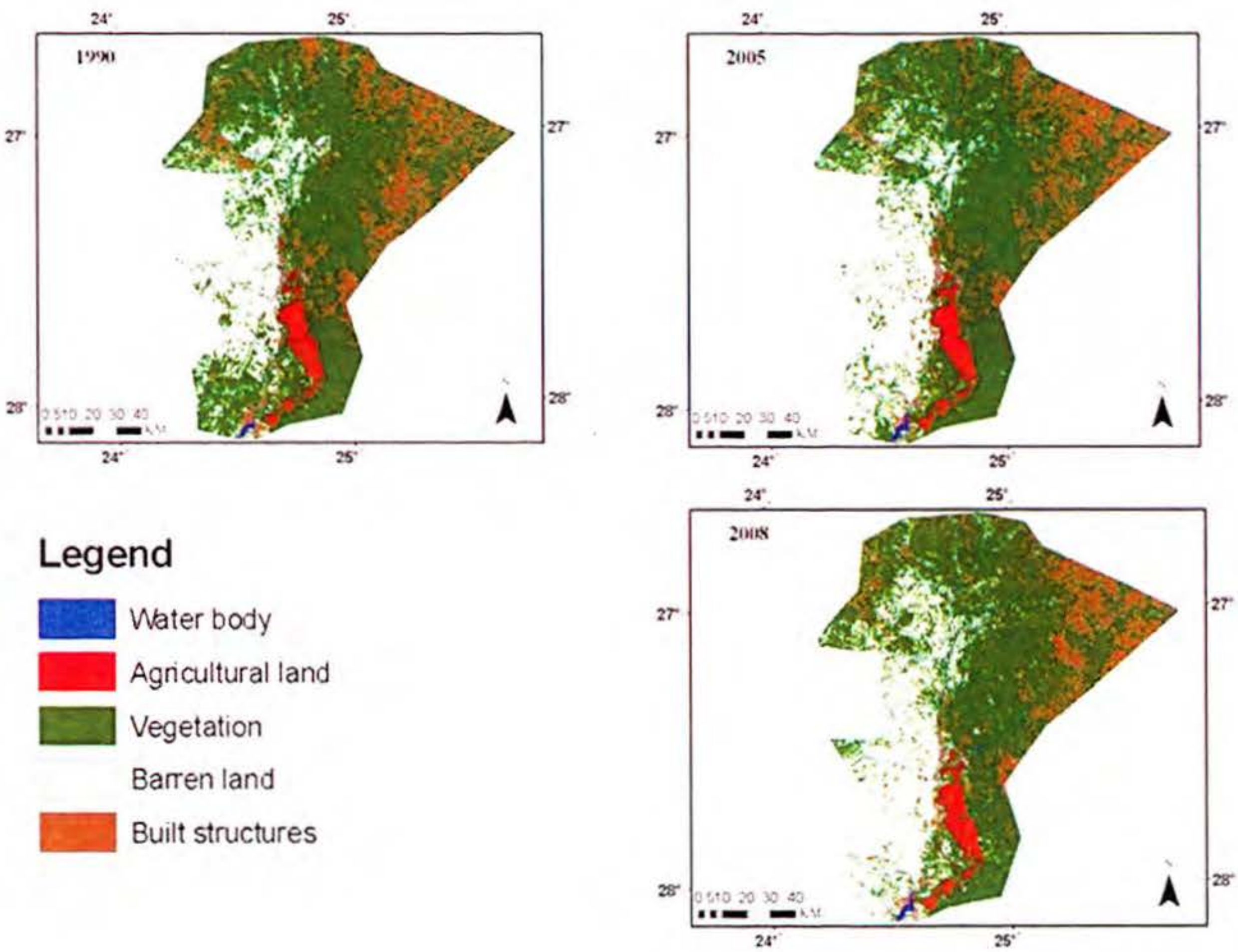

Figure 10: Derived from Landsat image of Harts catchment

4.2 Land cover dynamics in the Harts River catchment

The Harts River catchment land cover classification presented here is a result of the Maximum

Likelihood classifier. Five land use and land cover classes were identified in the Harts River catchment as displayed in Figure 10. The classified land cover categories in the Harts River catchment were water body, agricultural land, vegetation, barren land and built structures.

4.2.1 Spatial distributions of land cover classes in 1990

Five land use and land cover classes namely water body, agriculture land, vegetation, barren land and built structures were identified in the study area (Table 2). Vegetation, barren land and built structures constituted the predominant type of land cover with an approximate area of 97.3% in their spatial extent in the region. Water body and agriculture land accounted for 2.7% of the total area of the region representing the small proportion of the land cover classification as seen in Table 9. Vegetation covers 792901 ha which is 60.4% of the area and was therefore the most dominant land cover in the area. Also, agriculture seemed to be practised moderately, occupying2.6% of the total area based on the classification of the 1990 image. The same classification revealed that water covered the least proportion of the area at just 0.1% of the total area.

4.2.2 Spatial distributions of land cover classes in 2005

Vegetation, barren land and built structures constituted the predominant types of land cover as they together covered an approximate of 96.8 % of the area while the spatial extent of water bodies and agriculture land increased to 3.1 % of the total area of the region, still constituting the smallest proportion of the land cover just as was the case on the 1990 image. Overall vegetation still occupied the largest proportion of the area at 57.8%.Barren land occupied 21.5% of the total area, while built structures and agricultural land covers occupied 17.7 and 2.9% of the area respectively. Water bodies took up 0.2% of the area, this increase may be due to the fact that the Taung Dam was established in 1993.

4.2.3 Spatial distributions of land cover classes in 2008

In 2008, vegetation, barren land and built structures constituted the predominant types of land cover with an approximate area of 96.9% while water body and agriculture remained at 3.1 % of the total area of the region. It is clear from Table 9 that the latter two land cover classes together occupied a small proportion of the land.Vegetation was once again the largest class extending over 56.1% of the area. Barren land was the second largest land cover stretching over 24.7% of the area, while built structures and agricultural land covers occupied 16.2 and 2.8% of the total area respectively.As on the classification maps of the 1990 and 2005 images, the classification map of the 2005 image also revealed that water bodies was a land cover with the least spatial extent at 0.2% of the area.

Table 9: Land Use Land Cover Distribution (1990, 2005, 2008)

LANDUSE/LAND COVER CATEGORIES	1990		2005		2008	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Water body	1220.9	0.1	2526.48	0.2	2386.87	0.2
Agricultural land	34402.8	2.6	37884.8	2.9	37035.38	2.8
Vegetation	792901.6	60.4	758345	57.8	736879.4	56.1
Barren land	226670	17.3	281707.9	21.5	324321.5	24.7
Built structures	257455	19.6	232185.7	17.7	212026.7	16.2
Total	**1312650**	**100.0**	**1312650**	**100.0**	**1312650**	**100.0**

4.2.4 General distributions of land cover categories

The general distributions of land cover categories in the Harts catchment are discussed below:

4.2.4.1 Built structures

Built structures are predominantly found in the north-eastern part of the Harts catchment. North-eastern part consists of Cambisol Eutric (CMe) and Cambisols Chromic (CMx) soils, where the soils are dark reddish brown and friable sandy clay loam underlain by gravelly red loam to light clay. The soil is well drained and has good physical properties – the topsoil texture is medium and sand fraction of 76% (Jaetzold and Schmidt, 1982). The built-structure areas are mainly concentrated in the higher-precipitation part of the catchment; mean annual precipitation in South Africa increases fairly uniformly eastwards."

4.2.4.2 Water bodies

Water bodies is predominantly occur downstream of the Harts catchment to assist in the growing of agricultural crops. In addition to dams such as Taung Dam and Spitskop Dam, a total of 1120km of main canal, feeder, community and drainage canals criss-cross this area, delivering water to hundreds of commercial and emerging farmers according to a set allocation (The Water Wheel, 2009).

4.2.4.3 Agricultural land

Agricultural crops are found downstream of the Harts catchment at the confluence of the Vaal River and Harts River. The agricultural area is situated in a glacial valley, known as the Vaalharts Valley. It derives its name from the two rivers, the Vaal and the Harts Rivers that flow though it (Quo Vadis Southern Africa, 2009). The Vaal and the Harts Rivers support the 36950ha Vaalharts Irrigation Scheme and some 1250 farms.The soils in the area are alluvial and described as Kalahari Sand (Hough and Rudolph, 2003). Crops like pecan nuts, cotton, olives, citrus fruits, lucerne, groundnuts, maize, barley, wines, grapes, watermelon and peaches are grown in the Vaalharts agricultural valley.

4.2.4.4 Barren land

Barren land is dominant on the western part of the Harts catchment. This area is characterised by red-yellow apedal soils where the bedrock comes right to surface. These types of soils are very sensitive to wind erosion, due to the low erratic rainfall are not cultivated, and are mostly utilised as natural veld (de Jager, 2011). Some mining activities also take place on the western part of the catchment.

4.2.4.5 Vegetation

Vegetation cover is dominant in the central and towards the eastern part of the catchment. The dominant biome is savannah. The vegetation types vary and include Kimberly Thornveld, Kuruman Vaalbosveld, Mafikeng Bushveld, Schmidtsdrif Thornveld, Southern Kalahari Salt

Pans and Ghaap Plateau Vaalbosveld (Municipal BiodiversitySummary Project, 2010). The Ghaap Plateau Vaalbosveld covers about half of this zone (central, eastern and southern parts).

4.3 Land use land cover change: trend, rate and magnitude

Table 10: Land cover changes of Harts catchment: 1990-2005, 2005-2008, 1990-2008.

	1990-2005		**2005-2008**		**1990-2008**	
	Change		**Change**		**Change**	
Land Cover Class	**ha)**	**%**	**ha**	**%**	**ha**	**%**
Water body	+1305.5	+106.9	-139.6	-5.5	+1165.9	+95.5
Agriculture land	+3482	+10.1	-849.4	-2.2	+2632.5	+7.7
Vegetation	-34556.6	-4.4	-21465.5	-2.8	-56022.2	-7.1
Barren land	+55037.9	+24.3	+42613.5	+15.1	+97651.5	+43.1
Built structures	-25269.3	-9.8	-20158.9	-8.7	-45428.3	-17.6

NB: (+) indicates increase, (-) indicates decrease

From Table 10, there is a positive change, thus an increase in agriculture land between 1990 and 2005. This may be linked to the change in the economic base of the catchment to commercial agriculture. The extent of water bodies increased by 106.9% while that of vegetation decreased by 4.4%. Also, there was a general decrease in the spatial extent of land under built structures (9.8%) between 1990 and 2005.

The period between 2005 and 2008 witnessed a drop in the rate at which change within the catchment was going as against 1990 and 2005 due to the short period of study. For instance, the spatial extent of barren land increased by just 15.1% compared to the increase by 24.3% that took place between 1990 and 2005. This is also evident in the drop of 2.8% in the spatial extent of land under vegetation cover between 2005 and 2008. Also, over the same periods there was a general decrease in the size of the area 5.5% falling under the class of water bodies. Similarly, there was a general decrease by 2.2% and 8.7% in the spatial extent of land under agriculture and built structures respectively between these periods.

Overall, the period between 1990 and 2008 saw significant changes within the Harts catchment. The area classified as water bodies increased by 95.5% due to the development of the Vaalharts Irrigation Scheme. Land classified as agriculture land increased by 7.7% while that classified as vegetation decreased by 7.1%. In addition, there was a general increase in the spatial extent of land classified as barren land (43.1%) and decrease in the extent of land classified as built structures (17.6%) respectively between 1990 and 2008.

4.4 Post classification and land cover change

Results from post-classification analysis are presented using a series of change maps for visualisation, and statistical tables to provide quantitative measures of change. Spatiotemporal analysis of change detection with respect to observed classified land cover and land use from the three Landsat images used for change detection (1990, 2005, and 2008) reveals considerable changes within the entire Harts catchment.

An important aspect of change detection is to determine what is actually changing to what, in other words which land use class is changing to the other. This analysis revealed both the desirable and undesirable changes and classes that are "relatively" stable overtime. Using the approaches adopted in the methodology, the post-classification comparison change detection technique was employed.

4.4.1 Nature and location of change in land use land cover

The cross operation of using two classified images from different time allows the interpreter to know the extent and nature of changes in LULC – transition between different land cover classes and corresponding area of change. This method involved the comparison of three independently classified images of land use and land cover as presented in Tables 9 and 10 between 1990 and 2008. During the investigation periods, distinct changes had occurred on the major land use/land cover types.

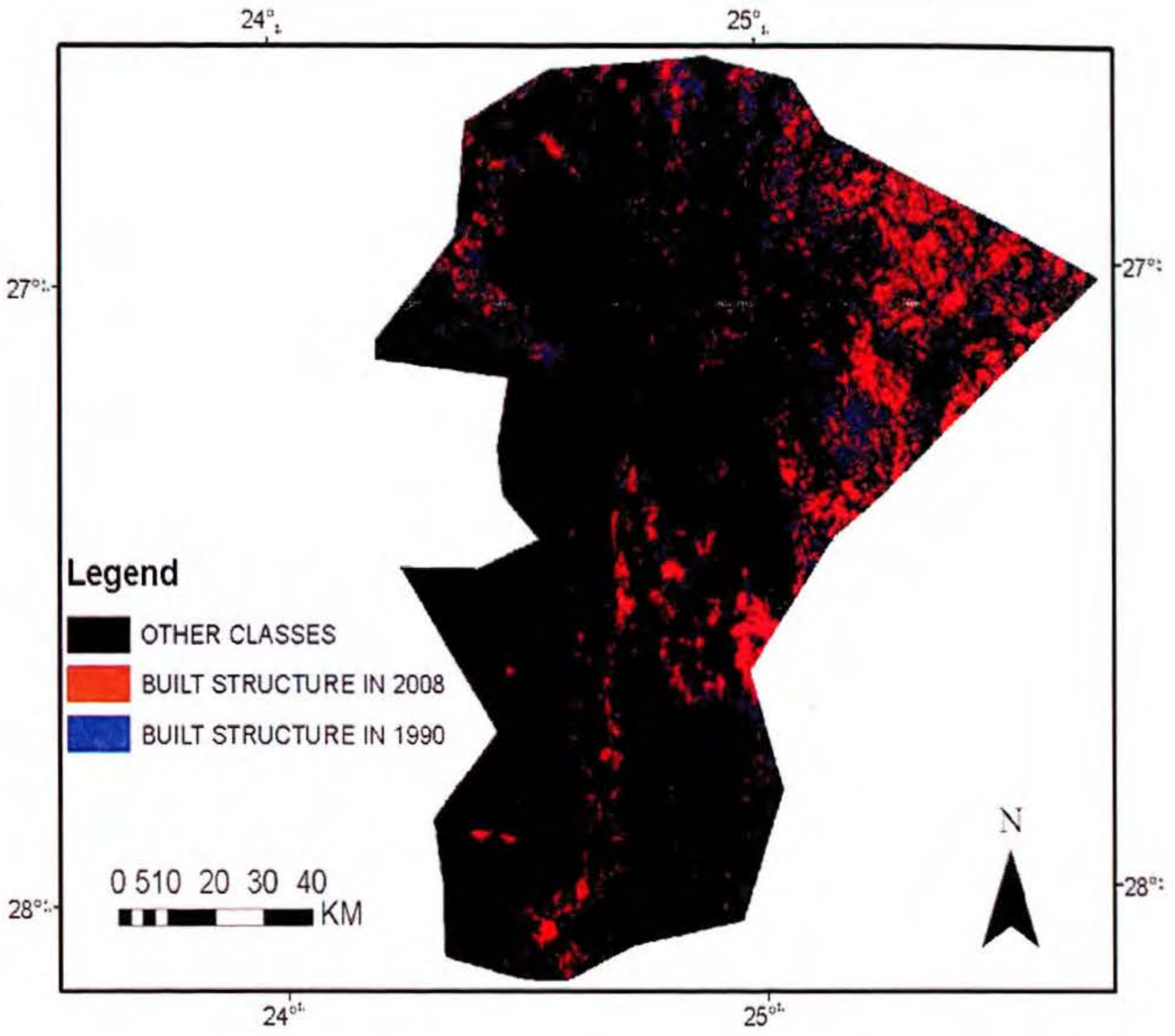

Figure 11: Derived from the overlay of 1990 and 2008 Land use land cover map

Between 1990 and 2008 as shown in Figure 11, there were drastic reductions in the spatial extent of the built structures predominantly in the north eastern part of the catchment. The only noticeable extensions in built structures seem to have taken place were on the edges of the areas that were classified as built structures on the 1990 imagery, specifically downstream of the Harts catchment comprising of Taung, Jan Kempdorp, Vryburg and Schweizer-Reneke towns.

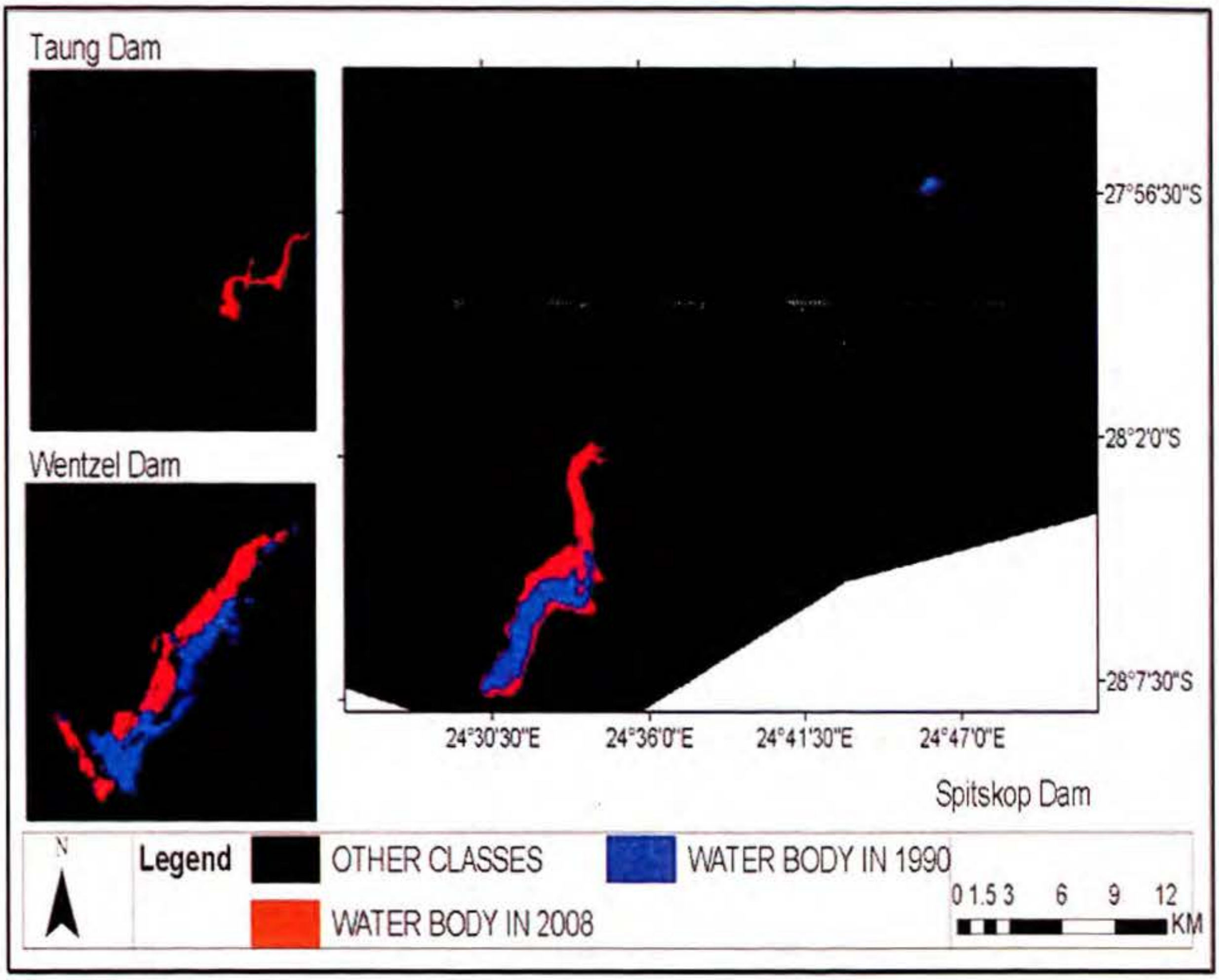

Figure 12: Derived from the overlay of 1990 and 2008 Land use land cover map

The increase in water body was due to constructionin 1993 of the Taung Dam, which became a major land cover in the floodplain and the increased capacity of both Spitskop and Wentzel Dam as shown in Figure 12. Taung Dam was constructed for irrigation and domestic use. Since the creation of the dam, large spatio-temporal changes have occurred within this zone as observed and assessed using classified images from 1990 to 2008. Rapid growth was observed in the major settlements around Taung Dam; meanwhile during the same period saw the reduction in the extent of settlements around the Spitskop Dam(Figure 13) as the dam expanded.

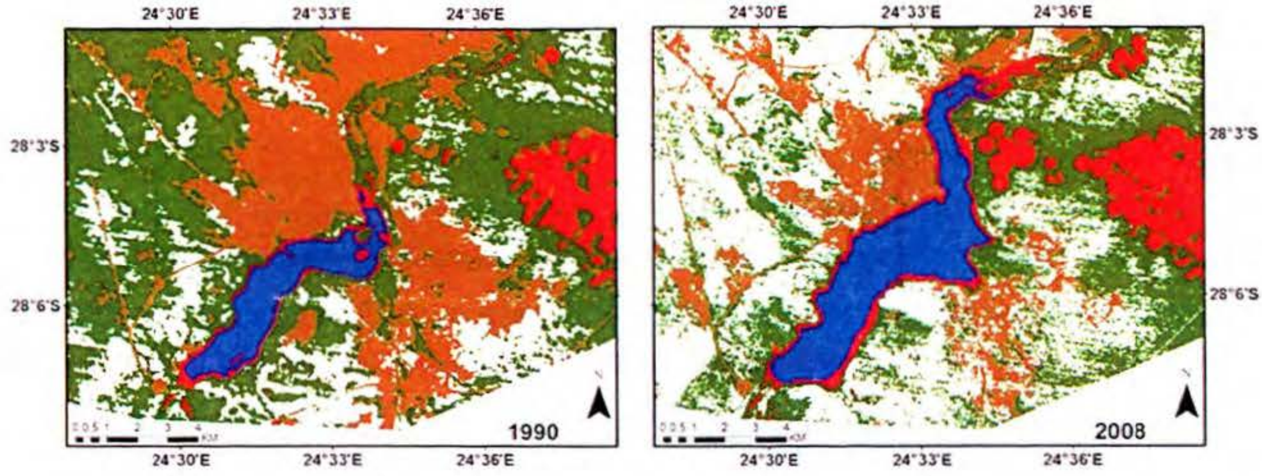

Figure 13: Comparative change detection around the Spitskop Dam (in blue colour) from 1990 to 2008 with settlements shown in brown colour

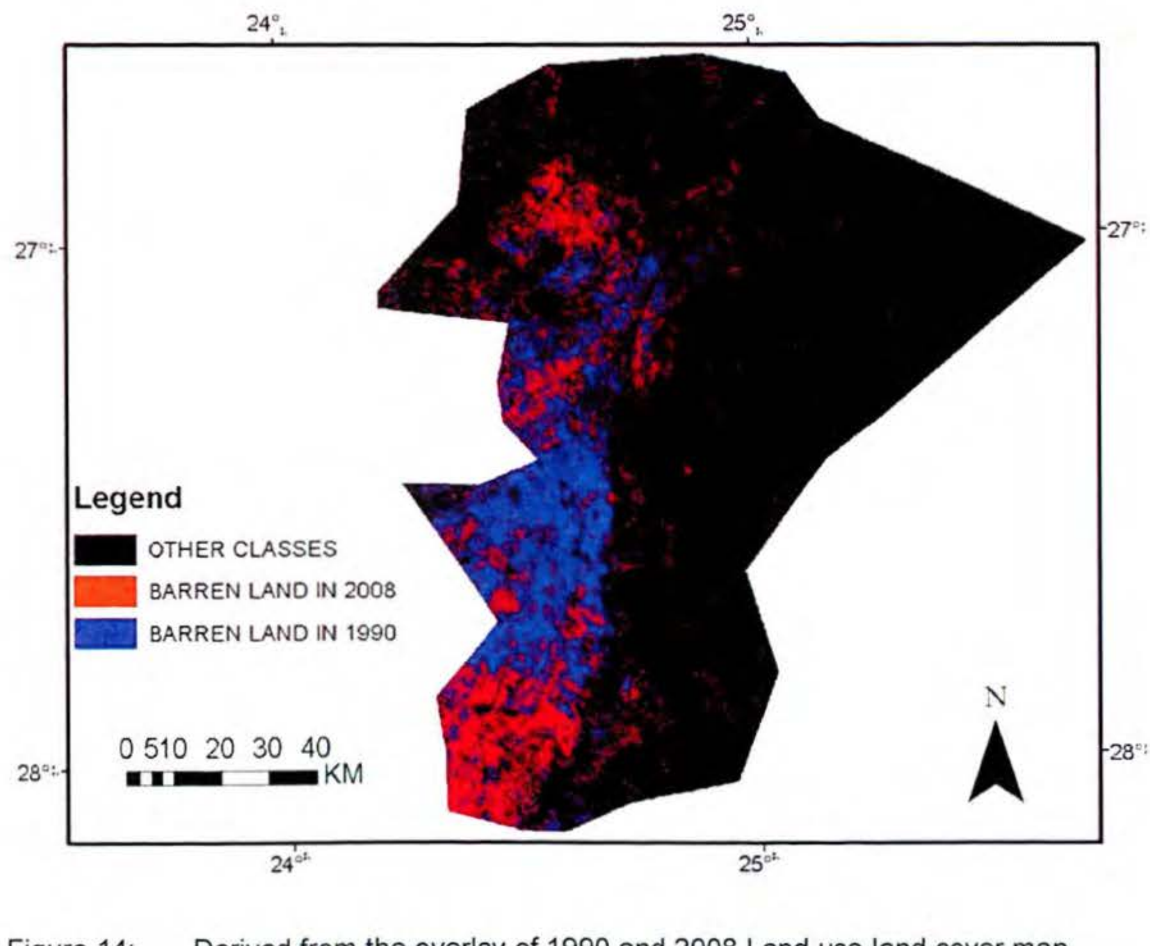

Figure 14: Derived from the overlay of 1990 and 2008 Land use land cover map

Figure 14 shows an increase of barren land (depicted by red colour) between 1990 and 2008 in the western part of the Harts catchment.In the south-western part of the catchment, new barren land is highly concentrated while in the upper central part, the new barren land is largely dispersed. Low erratic rainfall coupled with a decrease in vegetated areas has exposed these very sensitive soils to wind erosioncausing gully formation and barren swatches of land.

4.4.2 Overall change statistics

4.4.2.1 Land use/cover changes between 1990 and 2005

Changes in LULC between the various land use/cover classes from 1990 to 2005 are shown in Table 11.

Table 11: Land cover changes of the Harts Catchment from 1990 to 2005

	Total area in land class at 1990 (ha)	**Total area changed to per land class (ha)**	**Total area changed from per land class (ha)**	**Net gain (loss) (ha)**	**Net change (%)**
Water body	1220.94	1483.0	177.48	1305.5	106.9
Agricultural land	34402.8	14093.6	10611.8	3482	10.1
Vegetation	792901.6	182180.8	216736.8	-34556.6	-4.4
Barren land	226670	121007.6	65969.62	55037.9	24.3
Built structures	257455	99971.6	125240.9	-25269.3	-9.8
Total area	**1312650**	**418736.6**	**418736.6**		

Changed areas for each land cover type are calculated by summing the respective numbers of from-to change pixels occurring in the change detection matrix for each change classification code. Reference is made to the changed land area of the catchment amounting to 418736.6 ha, thus the total changed area represents 31.9% of the land area of the catchment. The following section discusses changes within water body and agricultural land class.

4.4.2.1.1 Water bodies

The total area within the Harts catchment that was converted from various classes to water bodies amounted to 1483 ha (Table 11). The increase in water body occurred mainly at the expense of agricultural land and built structures. Water body expansion took 0.65% of 1990 agricultural land and 0.18% of built-structure area (see Table 12 and Figure 13).

Table 12: Areas changed into water body from 1990 to 2005

From	Total area in land class at 1990 (ha)	Area changed to water body (ha)	% change per class♦
Agricultural land	34402.8	224.64	0.65
Vegetation	792901.6	769.5	0.10
Barren land	226670	33.3	0.01
Built structures	257455	455.58	0.18
Total area	**1311429**	**1483.02**	

♦ Percentages calculated as fraction of the original area of the class

4.4.2.1.2 Agricultural land

Table 13: Areas changed to agricultural land from 1990 to 2005

From	Total area in land class at 1990 (ha)	Area changed to agricultural land (ha)	% change per class♦
Water body	1220.94	61.65	5.0
Vegetation	792901.6	10730.1	1.4
Barren land	226670	179.82	0.1
Built structures	257455	3122.01	1.2
Total area	**1278248**	**14093.58**	

♦ Percentages calculated as fraction of the original area of the class

The total area within the Harts catchment that was converted from various classes to agricultural land amounted to 14093.58 ha (Table 11). The increase in agricultural land occurred mainly at the expense of vegetation and built structures. Agricultural land expanded by 61.65 ha (5%) from previously water body areas, 10730.1 ha (1.4%) from vegetated areas and 3122.01 ha (1.2%) from previously built structures (Table 13).

4.4.2.2 Land use/cover changes between 2005 and 2008

Table 14: Land cover changes of the Harts Catchment from 2005 to 2008

	Total area in land class at 2005 (ha)	**Total area changed to per land class (ha)**	**Total area changed from per land class (ha)**	**Net gain (loss) (ha)**	**Net change (%)**
Water body	2526.5	338.8	478.41	-139.6	-5.5
Agricultural land	37884.8	9526.7	10376.1	-849.4	-2.2
Vegetation	758345	15558	177049.6	-21465.5	-2.8
Barren land	281707.9	110655	68041.4	42613.5	15.1
Built structures	232185.7	77317.86	97476.82	-20158.9	-8.7
Total area	**1312650**	**353422.4**	**353422.4**		

A decline in water body, agricultural land, built structures and vegetation was observed for the period 2005 to 2008 as presented in Table 14. For example, total changed areas from all land cover types of the catchment amounted to 353422.4 ha, representing a significant decrease to 26.9% of the total changed area of the catchment. In contrast, a rapid increase of barren land is clearly evident. The following section discusses changes within barren land class.

4.4.2.2.1 Barren land

The total area within the Harts catchment that was converted from various classes to barren land amounted to 110655 ha (Table 14). The increase in barren land occurred at the expense of vegetated and built structures. Barren land expanded by 7924.37 ha (3.4%) from previously built structures and 102388 ha (13.5%) vegetated areasof the Harts catchment were lost to barren land from 2005 to 2008 as shown in Table 15.

Table 15: Areas changed to barren land from 2005 to 2008

From	Total area in land class at 2005 (ha)	Area changed to barren land (ha)	% change per class♦
Water body	2526.48	4.66	0.2
Agricultural land	37884.8	337.96	0.9
Vegetation	758345	102388	13.5
Built structures	232185.7	7924.37	3.4
Total area	**1030942**	**110655**	

♦ Percentages calculated as fraction of the original area of the class

4.4.2.3 Land use/cover changes from 1990 to 2008

Overall, between 1990 and 2008, land use/cover changes occurred in all land use/cover classes as shown in the cross tabulation matrix presented in Table 16. Based on the classification maps (Figure 10), a rapid decline of vegetation and built structures is visible.

Table 16: Land cover changes of the Harts Catchment from 1990 to 2008

	Total area in land class at 1990 (ha)	Total area changed to per land class (ha)	Total area changed from per land class (ha)	Net gain (loss) (ha)	Net change (%)
Water body	1220.94	1311.78	147.84	1165.9	95.5
Agricultural land	34402.8	14008.01	11373.03	2632.5	7.7
Vegetation	792901.6	188265.2	244268.6	-56022.2	-7.1
Barren land	226670	157804.4	60219.58	97651.49	43.1
Built structures	257455	94148.61	139528.9	-45428.3	-17.6
Total area	**1312650**	**455538**	**455538**		

Changed areas for each land cover type of the catchment amounted to 455538 ha, representing

34.7% of the total changed area of the catchment. At the same time, water body, agricultural land and barren land significantly increased during the same period.

The following section discusses changes within vegetation and built structures between 1990 and 2008.

4.4.2.3.1 Vegetation

Table 17: Areas changed to vegetation from 1990 to 2008

From	Total area in land class at 1990 (ha)	Area changed to vegetation (ha)	% change per class♦
Water body	1220.94	52.89	4.3
Agricultural land	34402.8	7971.51	23.2
Barren land	226670	54405.8	24.0
Built structures	257455	125835	48.9
Total area	**519748.7**	**188265.2**	

♦ Percentages calculated as fraction of the original area of the class

The total area within the Harts catchment that was converted from various classes to vegetationamounted to 188265.2 ha (Table 17). The increase in vegetationoccurred mostly at the expense of agricultural land, barren land and built structures. Vegetation expanded by 7971.51 ha (23.2%) from previously agricultural land, 54405.8 ha (24%) from previously barren land and 125835 ha (48.9%) from previously built structures.

4.4.2.3.2 Built structures

The total area within the Harts catchment that was converted from various classes to built structures amounted to 94148.61 ha (Table 18). The increase in built structuresoccurred largely at the expense of agricultural land and vegetation. Built structures expanded by 2726.83 ha (7.9%) from previously agricultural land and 32.44 ha (2.7%) from previously vegetated areas.

Table 18: Areas changed into built structures from 1990 to 2008

From	Total area in land class at 1990 (ha)	Area changed to built structures (ha)	% change per class♦
Water body	1220.94	32.44	2.7
Agricultural land	34402.8	2726.83	7.9
Vegetation	792901.6	85782.7	10.8
Barren land	226670	5606.64	2.5
Total area	**1055195**	**94148.61**	

♦ Percentages calculated as fraction of the original area of the class

4.5 Causes of land cover changes in the Harts Catchment

4.5.1 Mining

The decrease in the extent of vegetated areas could be attributed to the mining activities operating in the catchment. Alluvial diamond mining still occurs in ancient river beds within the Harts River catchment. Newlands Mine is operatedby Dwyka Diamonds Limited is located 60 km northwest of Kimberley on the Harts River, while Noble Minerals exploits the alluvial diamonds within 20 square kilometres of diamantiferous gravels of the river system, near Taung.Mining activity causes enormous changes of LULC pattern and fragmentation to the flora, fauna, hydrological relations and soil biological properties of the systems.

Typical mining activities include ground clearing (removal of vegetative cover and topsoil), compacting of soils by heavy duty vehicles, diversion of water courses from natural flow patterns, and possible contamination of water courses through discharge of point source pollutants. Extraction of alluvial material from within or near a streambed has a direct impact on the stream's physical habitat characteristics. These characteristics include channel geometry, bed elevation, substrate composition and stability, instream roughness elements (large woody debris, boulders, etc.) depth, velocity, turbidity, sediment transport, stream discharge and temperature (Hill and Kleynhans, 1999).

4.5.2 Agriculture

South Africa has a general annual population growth rate of 1.2% (2009) and a mid-year population estimate report of 49.99 million in 2011(STATSSA, 2011). The growth rate is a factor in determining how great a burden would be forced on a country by the varying needs of its people for resources such as food. Thus between 1990 and 2008, there has been a rapid increase in the extent of land under agricultural crop production to provide food for the growing population, raw materials for industry, and to earn needed foreign exchange by exporting surplus production. The Vaalharts Valley in the Harts catchment has turned into a southern African bread basket (Nutcracker SA, 2011). Though agricultural expansion has occurred in the Harts catchment, the supposedly marked decrease in the extent of land under built structures and thus population in the Harts catchment could be attributed to challenges of spectral separability of built structures *vis a vis* fallow agricultural land on the imagery. There was definite spectral mixing and spectral confusion between built structures and fallow agriculture lands, and this is one of the most prevalent sources of error in image classification.

4.5.3 Industry

Industrial activities in the catchment largely support the mining, agriculture and agro-processing projects. The result is a greater impact on the aquatic and terrestrial environment. These industries exert an influence through the demand for water, the requirement for labour living close to the place of work, and through discharging of waste by-products to the environment.

4.5.4 Tourism

Tourism and game ranching depend on a healthy environment. The tourism sector places pressure on the environmental resources of the catchment through the need for water-supply services, increased water consumption and conversion of land surfaces for recreation facilities such as golf courses, tennis courts, swimming pools. Wentzel Dam north of Schweizer-Reneke, is used for recreation, such as water sports.These factors may be outweighed by the positive aspects of tourism such as increased conservation of nature and traditional culture and the general contribution to the local economy.

4.6 Consequences of land cover change on river discharge

4.6.1 Agriculture

Among the various hydrologic processes that take place in a catchment, surface runoff, groundwater flow and evapotranspiration (ET) are most essential. As with deforestation, the conversion of the land surface from native cover to managed cropland has an effect on the ET, infiltration and overland runoff characteristics of a catchment (Frenierre, 2009). Crops like pecan nuts, cotton, olives, citrus fruits, lucerne, groundnuts, maize, barley, grapes, watermelon and peaches are grown in the Vaalharts agricultural valley. Croplands tend to have a percentage of bare ground even during the peak of the growing season, and may be completely bare prior to being planted. In both instances, most of the precipitation that lands on these denuded areas will be discharged directly into the stream channel rather than infiltrating into the soil or evaporating/transpiring from the plant surfaces. Raindrops falling on bare soil also can compact the soil surface in ploughed fields, leading to increased runoff and erosion of farmland. Studies have shown that when agricultural land is tilled, compaction of lower soil horizons occurs and this lowers infiltration rates and increases bulk density (Logsdon *et al.*, 1990; Nidal, 2003). This compaction reduces water retention as rainfall saturates the soil profile faster in agricultural lands than in the forested areas, thus producing more runoff. If vegetation clearing is followed by land use practices that compact soils and expose them to erosion, decreased percolation to groundwater can result (Bruijnzeel, 2003).

4.6.2 Deforestation

Vegetated areasand litter layer of dead vegetation assist to lessen flood risk by increasing the time it takes for water to get to a river (longer lag time) by promoting infiltration (roots opening up the soil), blocking water by their leaves, and taking up water in their roots. Conversion of built structures to vegetation occurred in the northern western part of the Harts catchment, in areas such as Ganyesa and Stella.Indeed there has not been any incidence of floods over the period of study in these parts. Studies by Trimble *et al.* (1987), Costa, *et al.* (2003), among others, indicated a similar observation where runoff is reduced as a result of afforestation.

Generally,the extent of vegetated areas decreased over the catchment by up to 56022.2 ha (7.1%) from 1990 to 2008. Areas denuded through deforestation would respond quickly to rainfall due to the reduced interception. Kiersch (2000) and Allan (2004) noted that an increase in storm runoff is mainly due to the reduced infiltration rate when other land cover classes convert to previously forested areas. Thus, the increase in streamflow could be attributed to a decrease in evapotranspiration(Githui, 2011).

4.6.3 Barren land

Infiltration rate is governed by the type of soil, plant and animal groups it carries, and by human activities (Water Encyclopedia, 2010). Where soil is bare and little-fractured bedrock is exposed, water cannot soak in and will run off rapidly. The soil surface acts as a filter that lets water pass through (infiltrate) at a rate known as the infiltration rate or infiltration capacity. Runoff may be produced when precipitation or snowmelt adds water to the soil surface faster than it can be absorbed (Water Encyclopedia, 2010). The excess water remains on the surface and may flow downslope as runoff.

The Harts catchment is characterised by nine types of soil group with texture classification of sandy soils consisting of sandy-clay-loam, sand-clay, sand-loam, clay-loam and loam-sand (Chapter 1, Section: soil type). Drainage class of the soil group ranges from somewhat excessive (Arenosols Ferralic and Arenosols Haplic) to moderately well drained (Cambisol Eutric, Cambisols Chromic, Calcisols Petric). Areas such as Jan Kempdorp, Taung, Manthe, Motsweding and Mokgareng, that experienced devastating floods in early 2003, 2006 and 2010 all occur within the Arenosols Ferralic soil group and are downstream of the Harts catchment in at elevation ranges of 928 m – 1187 m. Coarse-textured soils drain excessively and thus water is removed from the soil rapidly. Such soils have high saturated hydraulic conductivity or are very shallow. Hence the increase in the extent of bare land that exposes the well-drained soils, from 1990 to 2008, has resulted in an increase in surface runoff and thus river discharge.

Topography, including the slope of drainage basins, influences the rate of flow and enhances lateral flow instead of vertical percolation (Ko and Cheng, 2004). Most of the runoff generated in the cultivated lands and impervious surfaces constitutes storm flow, especially at the beginning of the rainy season between October and April (see Appendix 4).

4.6.4 Urbanisation (Built structures)

Change that involved the conversion of land into built structures took place over a relatively small proportion of total land in the area. The results further indicate that actually there was a marked reduction in the spatial extent of land under built structures in the northern part of the catchment (see Figure 11); but in increase in the extent of land under built structures downstream of the catchment in areas such as Jan Kempdorp, Taung, Manthe, Motsweding and Mokgareng. These areas are also near the floodplain and are therefore flat, fertile, and close to water bodies. However, after unusually heavy rain, the level of the water in the river may rise above the banks and flow onto nearby land. Thus, downstream areas were highly affected during the floods of early 2003, 2006 and 2010.

Hydrologic effects of urbanisation can affect a considerable number of people and may range far beyond the boundaries of the urban area. In terms of hydrology, the most important impact of urbanisation is the increase of impervious surfaces within a catchment (Frenierre, 2009). Impervious surfaces prohibit infiltration of water into the soil during precipitation events, thus inhibiting groundwater recharge and increasing overland runoff during precipitation events (Mustard and Fisher, 2004; Shanahan and Jacobs, 2007). In addition, the compaction of soils reduces the size of pore spaces and the infiltration rate, thus water commonly runs off areas that were compacted through repeated passage of people, large animals, or heavy machinery (Water Encyclopedia, 2010). Consequently, urban hydrographs typically feature higher peak flows during storms: put simply much more water arrives into a stream much more quickly, resulting in an increased likelihood of more frequent and more severe flooding.

4.6.5 Water body

Human-constructed dams are built for water storage, generation of electrical power, and flood control. Dam failures are relatively rare, but can cause enormous damage and loss of life when they do occur. All types of dams may give way with the rapid release of water into the downstream drainage (Nelson, 2011). The flood hazard areas of dams in the Harts catchment are subject to periodic inundation, which can result in increase of river discharge and resulting in loss of life, property, health and safety hazards. Due to high flows in the Harts River in early 2006, the Spitskop Damand Taung Dam (Figure 15) overflowed, and residents downstream were "strongly advised" to evacuate (DWA, 2009), the excessive rains also resulted in the overflow of three dams in the Greater Taung Local Municipality in 2006 (IOL, 2006) and in 2003 (South African Government Information, 2004).

Figure 15: Taung Dam overflow in 2006 (Source: SABC News)

4.7 Correlation coefficient between precipitation data and stream flow data

The pattern of river flow over a period of time is commonly referred to as the river's flow regime. It is widely accepted that climate change and human activities are the main driving forces for hydrological variability (Xu, 2010). However, distinguishing the causes for the flow regime shifts is still a major challenge in hydrology. Changes in land cover (Costa *et al.*, 2003; Poff *et al.*, 2006) and land use (Masih *et al.*, 2011) would eventually alter the river discharge by influencing the runoff generation and infiltration processes. From the foregoing discussion, the Harts catchment has experienced remarkable land cover changes which could result to changes in river discharge. However, it is beyond the scope of this study to determine whether these land cover changes could be linked to the changes in flow regimes where the catchment has suffered numerous flooding episodes. Nonetheless, available meteorological data within the catchment was used to explain whether the changes in flow discharge are due to climate change variations.Owing to the periodicity of the weather, hydro-meteorological time series usually exhibit seasonality. This arises greatly from seasonal variations in precipitation volume, as well as the rate of evapotranspiration.

Appendix 4 shows the monthly rainfall data for each month. The months of October to April had above 25 mm of rainfall and months of May to September had below 25 mm of rainfall monthly. However, comparatively, April and October values are much higher than the months of June to September and in this study, the two months (April and October) are assumed to be transitional months from the wet season to the dry season. Much of the rainfall is experienced during the month of January with a peak value of 91.9 mm. Thus, the Harts catchment receives a unimodal rainfall season; where rainfall starts in October and ends in April of the following year and is centred on January, The unimodal characteristics of summer rainfall have been observed in various studies of Southern Africa rainfall (Singo, 2008; Kabanda, 2004; Makarau, 1995; Preston-Whyte and Tyson, 1988). The months of May to September receive below 25 mm of rainfall, featuring July the driest month with a mean rainfall of only 1.9 mm. Therefore, this period (May to September) can be confidently categorised as dry season. Hence, from these observations, the seasons in the study area can be grouped into dry and wet season, based on the mean monthly rainfall (Appendix 4).

4.7.1 Mean seasonal rainfall

Seasonal rainfall departures (anomalies) were obtained using seasonal (Oct-April) mean, long term mean and the standard deviation to produce a standardised time series. The anomaly identifies events as normal, below normal or above normal with respect to the area rainfall. Anomalies identify events and are good indicators of extreme events such as floods or droughts. The long term rainfall mean was found to be 57.5 mm while the standard deviation was 13.7 mm. Rainfall departures in Appendix 2 were computed by normalising and standardising the seasonal rainfall data.

From Figure 16, seasons 1997, 1999; 2000 and 2003 fall into the near normal category with departures ranging from -0.2 to 0.4. Seasons 1992, 1993, 1995, 2004, 2007, 2006 and 2009 depict below normal rainfall with departures ranging from -0.5 to -2.4. Seasons 1990; 1996;

1998, 2001, 2005, 2006 and 2008 were above normal category, with departures ranging from 0.5 to 1.7. No season had normal rainfall over the Harts catchment, over a period of 21 years from October 1990 to March 2011. Overall the trend of rainfall was constant during the study period over the Harts catchment.

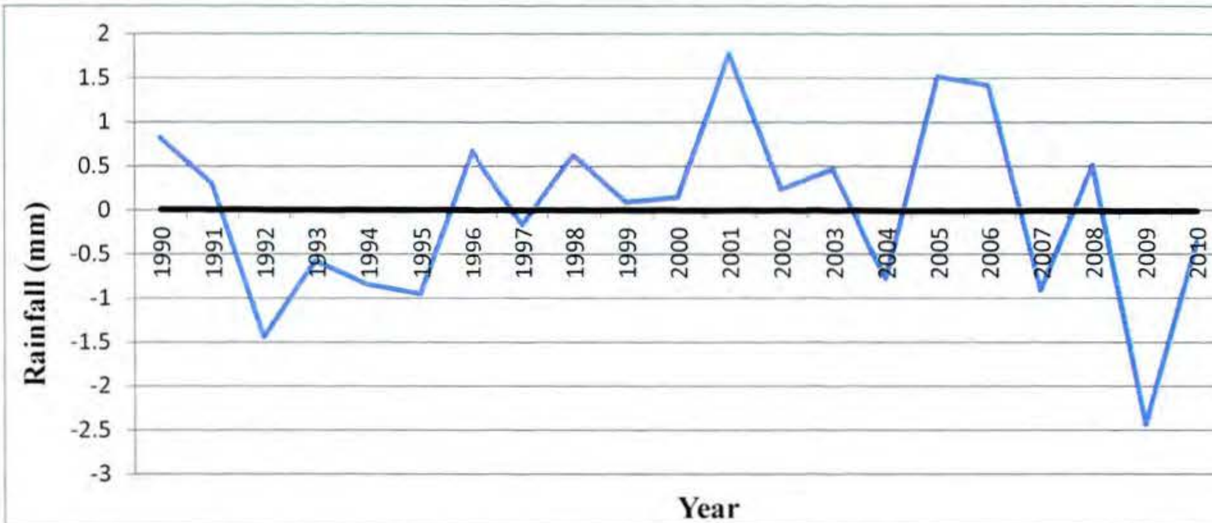

Figure 16: Seasonal rainfall departures from 1990 to 2010.

4.7.2 Mean seasonal river discharge

River discharge anomalies were analysed by compositing all the months of October to April in order to define periods of above and below normal river discharge during the study period. The long term seasonal mean for the Harts catchment was found to be 149 $m^3 s^{-1}$and the standard deviation was 181.1 $m^3 s^{-1}$. Figure 17 shows the seasonal river discharge departures from 1990 to 2010 over the Harts catchment. River discharge departures in (Appendix 5) were computed by normalising and standardising the seasonal river discharge data.

The period from 1991 to 1998 experienced below normal river discharge, with the lowest occurring during the 1991 season at -0.7 $m^3 s^{-1}$ below normal. From 2004 to 2010 the river discharge was above normal except for the season 2007 to 2008, with the highest occurring during the 2005 season at 4 $m^3 s^{-1}$ above normal. Below normal river discharge departures ranged from -0.1 to -0.7 $m^3 s^{-1}$ while above normal departures ranged from 0.2 to 4 $m^3 s^{-1}$.

Overall the trend during 1990 to 2010 saw a rise in river discharge over the Harts catchment.

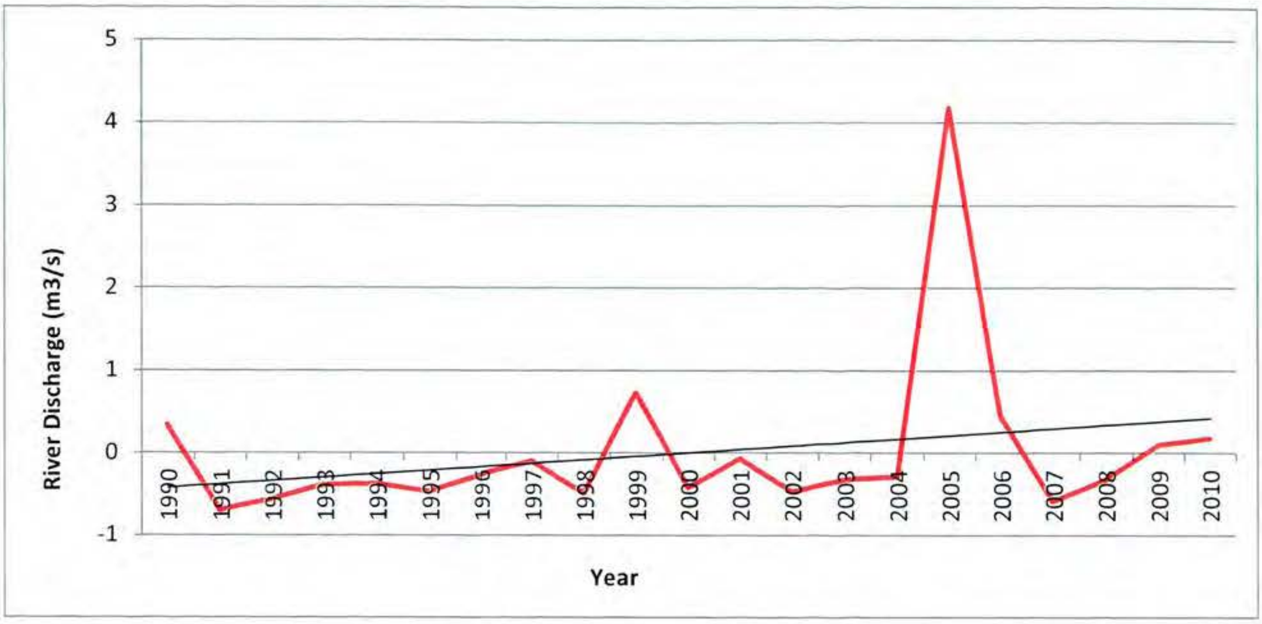

Figure 17: Seasonal river discharge departures from 1990 to 2010.

4.7.3 Rainfall and river discharge relationship

Appendix 3 shows both rainfall and river discharge seasonal means and departures from 1990 to 2010, over the Harts catchment. The study shows that there is a temporal fluctuation in rainfall and river discharge in seasonal performance.

The rainfall and river discharge are analysed together to determine the association of these two variables within the Harts catchment during the period 1990 to 2010. However, these two variables have different units (rainfall is in mm while river discharge is in $m^3 s^{-1}$) and in order to compare the two variables, standardisation procedure was used to obtain dimensionless values (Singo, 2008). For better analysis the departure data in Appendix 3 is plotted to produce a graph (Figure 18) which represents standardised time series (departures) of rainfall and river discharge in Harts Catchment. For the periods 1990-1991, 1996-1999, 2000-2003 rainfall and river discharge were in phase while from 1992 to 1996, 2004 to 2007 and 2008 to 2010 reveal some degrees out of phase. It should be noted that a rainfall anomaly of a given magnitude does not necessarily produce a river discharge anomaly of the same magnitude.

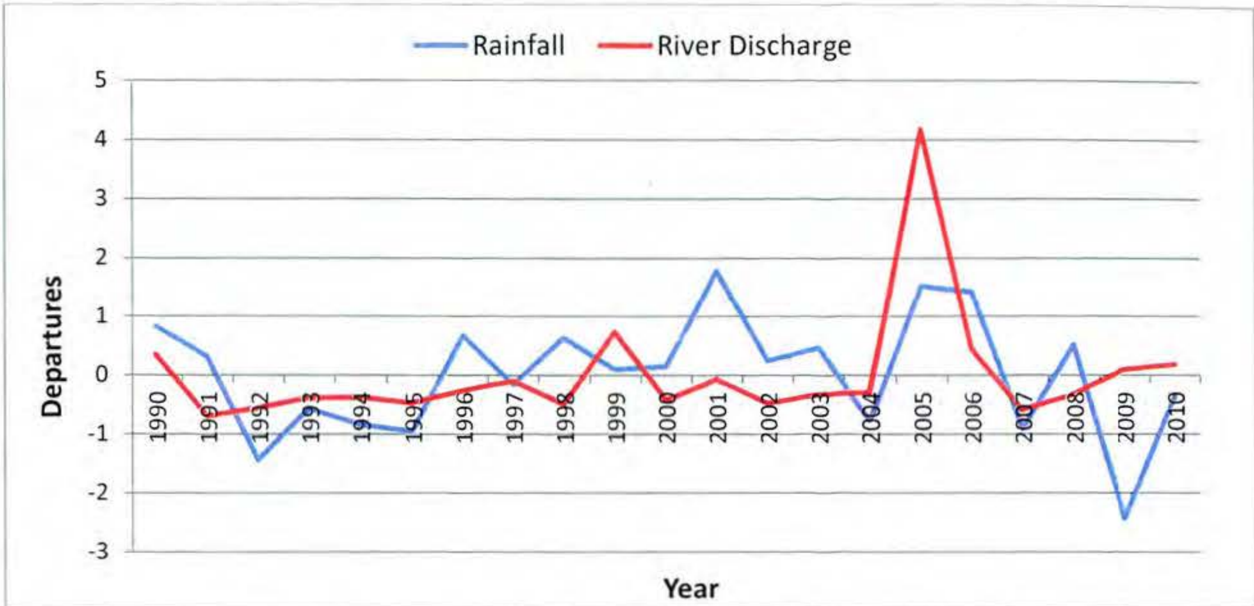

Figure 18: Time series of standardised seasonal rainfall and river discharge departures in Harts Catchment

In order to determine the mutual relationship between rainfall and river discharge, correlation analysis was used. A rainfall season was correlated with the river discharge of the same year and the correlation values are presented in Appendix 6, where X is the rainfall variable, Y is the river discharge variable, and x and y are their respective means. Under this method correlation co-efficient, *r*, was calculated. The co-efficient of correlation was found to be +0.393. A correlation co-efficient of 0.2 to 0.4 shows a weak or low association (Salkind 2000). Thus correlation value of 0.39 obtained in this study shows that there is weak relationship between rainfall and river discharge. This means that between the two parameters, when the rainfall is high a high river discharge may not be expected. Similarly, when the rainfall is low, the river discharge may not be low. This is not always the case, though. As presented on tables and graphs, there are specials cases where the rainfall gets a positive response from the river discharge – i.e. high rainfall resulting in high river discharge. For example, in 1997, 1999 and 2010 had the seasonal mean rainfall of 55.2 mm, 58.7 mm and 52.5 mm, while the river discharge was recorded as 130.5 $m^3 s^{-1}$, 279.9 $m^3 s^{-1}$ and 179.5 $m^3 s^{-1}$. On the other hand, the low rainfall season had low river discharge. In 1992 and 2007, the seasonal mean rainfall was 37.8 mm and 44.9 mm respectively, while the river discharge was recorded as 46.3 $m^3 s^{-1}$ and 41.02 mm respectively.

4.7 Summary

This chapter presented the results obtained from the study in the form of tables, graphs and maps, followed by interpretation and discussion of the findings. The results of image processing procedures performed on the images for 1990, 2005 and 2008 were presented in error matrix tabulations, classified maps, and cross tabulations of land use and land cover as quantitative data for change analysis. Maps that were generated as part of the process of detecting 'from–to' changes in land cover and land use, have also been presented and discussed. Similarly, results of the hydro-meteorological analysis that was undertaken using correlation methods to determine whether the changes in flow discharge were due to climate change variations have been presented interpreted and discussed.

5. CONCLUSION AND RECOMMENDATIONS

In general, two main factors govern river discharge: *a*) climate (especially precipitation); and b) land use/ land cover. Both factors affect major hydrological processes such as evapotranspiration, including interception, and determine the components of the hydrological cycle at the basin scale. Seasonal river discharge showed greater variability than rainfall at all time scale. The study showed that there is a temporal fluctuation in rainfall and river discharge and that river discharge is not entirely dependent on the amount of rainfall received. Changes in year-to-year relationships between precipitation and discharge suggested that discharge was relatively higher in the second half than in the first half of the study period. In fact, a weak correlation was found between precipitation and river discharge. The difference between the trends in climate and discharge implies that a non-climatic, time dependent factor is determining the fluctuations in discharge. The positive trend in discharge in the Harts River coincided with major changes in land cover over the study area. Change detection results showed an increase in the spatial extent of barren land, agricultural land and a decrease in vegetation cover. The study concluded that the modification of the land use and cover has resulted in changes in temporal distribution of river discharge within the Harts catchment.

5.1 Conclusions with respect to study objectives and hypothesis

The main aim of this study was to explore the detailed impacts of land use and land cover change and their linkage with river discharge by using remote sensing, GIS techniques and hydro-metrological data.The specific objectives were a) map LULC dynamics of the Harts Catchment using multi-temporal Landsat Thematic Mapper (TM) data in 1990, 2005 and 2008; b) quantify the spatial and temporal LULC changes in the Harts Catchment; c) examine the changes of rainfall-river discharge interactions; d) analyse the effects of land use change on river discharge. The key conclusions with respect to these initial objectives of the study are summarised below.

5.1.1 Mapping and quantifying land use/cover dynamics

With respect to the first two specific objectives, this study has demonstrated that the utilisation of remote sensing and GIS techniques in the spatial mapping of the distribution and quantification of LULC changes from 1990 to 2008 provide relatively accurate results, and that the information generated could be very useful in planning the prevention and/or mitigation of flood hazards in the study area.

The results showed that between the periods 1990 and 2008, there were significant changes of LULC between all LULC classes in the Harts catchment. Reference was made to the changed land area of the catchment amounting to 418736.6 ha, and representing 31.9% of the land area of the catchment. These land cover conversions have caused land degradation (in terms of vegetation decrease and increased barren land) in different regions and have interfered with biodiversity and ecosystems. As the demand for food, water and other social amenities increases, mainly due to population and economic pressures, more land degradation is likely to occur. However, this can be reversed by implementation of environmental-friendly policies, such as the rehabilitation of open spaces and wetland reclamation programs.The results obtained in this study corresponds with results obtained by other authors in this report like Boakye *et al.* (2008); Mengistu (2008);Yang and Liu (2005) in their analysis of change detection of land use and land cover in a catchment using remote sensing and GIS.

5.1.2 Rainfall and river discharge interactions

Various methods were used to analyse the historical trends of hydro-meteorological data. Statistical techniques used here for computation of hydro-meteorological data analysis include mean, standard deviationand correlation analysis. Owing to the periodicity of the weather, hydro-meteorological time series usually exhibit seasonality. The seasonal analysis was done by compositing both rainfall and river discharge, the values for each parameter was separated into normal, below normal and above normal categories. This was done using the standardisation formula. Harts Catchment receives a unimodal summer rainfall season; where rainfall starts in October and ends in April of the following year and is centered in January. The results of standardised anomalies of seasonal rainfall and river discharge showed that the area experienced normal, near normal, above normal and below normal values. In this study, wet seasons are above the long term normal while dry seasons are anomalies whose values fall below the long term normal. Wet seasons in the Harts Catchment were experienced from 1996 to 2008 with the exception of 1997, 2004 and 2007 seasons. Extreme dry conditions were experienced from 1992 to 1995 and during the 2009 season. The standardised anomalies of river discharge showed that abnormally wet seasons were experienced during the 1999 and 2005 rainy seasons. On the other hand abnormally dry seasons were experienced during 1991, 1992 and 2007 seasons. A correlation coefficient of 0.39 was obtained in this study and shows that there is weak relationship between rainfall and river discharge. This means that between the two parameters, when the rainfall is high a high river discharge may not be expected. Similarly, when the rainfall is low, the river discharge may not be low and hence one can conclude that other factors influence river discharge in the catchment.

5.1.3 Effects of land use/cover change on river discharge and hence flooding

The flow regime in the Harts catchment has changed significantly as a result of increased human interventions which have led to modification of land covers and change in land use.The modifications of natural vegetation cover as well as soil conditions usually lead to modified runoff production and consequently to changing flow regimes (Kashaigili, 2008). Major changes have been observed in recent years which are related to such modifications. Conversion to previously vegetated areas occurred predominantly downstream of the catchment in areas such as Jan Kempdorp, Taung, Manthe, Motsweding and Mokgareng where there has been an increase in barren land, water body and agriculture. This is in contrast to the conversion to vegetated areas up stream of the catchment in areas such as Vryburg, Stella, Ganyesa and Schweizer-Reneke. Hence downstream of the catchment is more prone to inundation due to the increase in surface runoff and thus river discharge, this coupled with its elevation ranges of 928 m – 1187 m while upstream values range from 1266 m to 1504 m and as the SABC (SABC News, 2006a) noted, making the area vulnerable to waters flowing from higher situated areas. According to Juahir *et al.* (2010) there is evidence that regional variability in discharge behaviour is strongly related to land use or land cover changes along the river basin.

Floods is one of the most common of all environmental hazards, this is due to the geographical distribution of river valleys and the obvious attraction for human settlement. At the same time flood intensifying conditions such as urbanisation and deforestation increase the magnitude, frequency, and intensity of floods. Furthermore, there are concerns of human vulnerability and an environment that gets mismanaged. In brief, this research has documented the impact of land use/cover change on the degradation of the stable environment and established that not taking into account this influence would increase the destroying agents such as torrential floods in an exponential way.

5.2 General concluding remarks

The study not only examined the actual changes that took place but also the direction and relative magnitude of changes in stream flow that could be associated with various conditions of the potential LULC and climate change scenarios for the future. The following general concluding remarks could be drawn to sum up the achievements in the study.

- Enormous quantity of spatial and temporal data relating the hydro-meteorology and land use land cover in the study area has been acquired, processed and prepared in a consistent way. These data were gathered from different institutions and organisations and constitute a complete hydrologic data set for the Harts River Catchment.
- It has been acknowledged that changes in land cover has resulted more to the increase of river discharge than climatic changes although both these changes have occurred together to have an even greater impact than if each were acting alone. Hence alleviation measures with regard to problems of environmental degradation, and flooding should consider both climate change and variability as well as LULC changes, as these do not act in isolation.
- The concept of land cover changes on river discharge has been explored not only from a statistical perspective, but also from the remote sensing viewpoint. Due to regular flooding in the recent past in the Harts catchment, there have been assorted hypotheses as to the cause, the two most common being land cover changes and climate change. Results of the study have responded to these hypotheses and the need to understand the implications of these changes on the physical behaviour of the catchment.

5.3 Recommendations

Based on the findings of this research, several recommendations can be made.

- A follow-up study is required to investigateland use/ cover changes on flow regime and incorporating the heterogeneity of the watershed and spatial distribution of topography, vegetation, land use, soil characteristics, rainfall and evaporation.
- In recent years, hydrologic models have increasingly been used in management strategies in the areas of flood control, impact of land use and climate change, and environmental pollution control. Hydrologic models are symbolic or mathematical representation of known or assumed functions expressing the various components of a hydrologic cycle (Seth, 1999). They are able to exploit the quasi-totality of all information and knowledge concerning the catchment that is being modelled (Abbottand Refsgaard, 1996). Since the satellite technology continues to advance, the satellite images with higher spatial and spectral resolution can be utilised for future study, which will not only improve the classification accuracy but also help to classify in more detail. SPOT is recommended since it is a higher spatial resolution satellite sensor.
- Measures such as construction of drains, de-silting, general management of structures, education about flood mitigation, management, reporting and ensuring that settlement plans are drawn according to stipulated guidelines within communities could be made.
- It is highly recommended that the natural resources managers and planners should take this finding into consideration and monitor the changing of the land cover. For management and restoration actions to be effective, we must diagnose cause as well as assess harm, which requires an improved understanding of the mechanisms through which land use impacts stream ecosystems. Archer *et al.* (2010) noted that, rates of change in discharge appear to respond to land use changes and thus provide a potential basis for application to land use management policies.

5.5 Limitations of the Research

Despite the fair proceeding and accomplishment of the research, a number of challenges were encountered in the process. To mention some of them:

- The unavailability of 2000 and 2010 Landsat images as initially the research considered dividing the study into two periods i.e. 1990 to 2000 to 2010.

- Limited access to different digital orthophotos and other ancillary data with full coverage of the Harts catchment from various years to collect training sample from the study area created limitation on visual interpretation and the classification process.

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APPENDICES

Appendix 1: Summary of change detection techniques (adapted from Lu *et al.*, 2004)

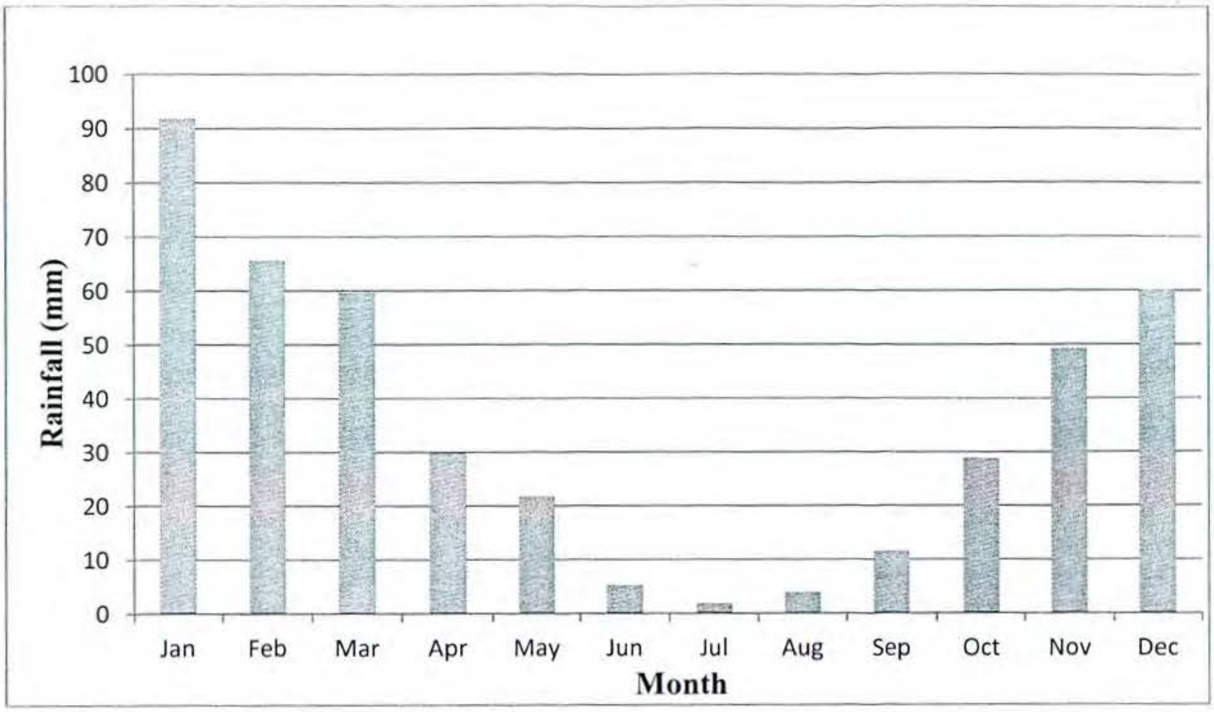
Techniques	Characteristics	Advantages	Disadvantages	Application areas
Image Differencing	Subtract date 1 from date 2. Picks a threshold for change.	Simple and easy to interpret data.	Cannot complete matrices of change information.	Land use and land cover (Bottomley, 1998).
Principal Component Analysis	Assumes multi temporal data are linked and change information can be derived in the new components.	Reduces data redundancy between bands and the focus of change information in the given components..	PCA is scene dependent. Change detection results between different dates difficult to interpret and label. Cannot complete matrices of change information.	Multi temporal Landsat TM imagery to detect LULC changes in Al-Hassa, Saudi Arabia (Aldakheel & Al-Hussaini, 2005).
Spectral Mixture Analysis	Model based on the assumption of linear mixing of two or more pure spectra different components within a pixel known as end members.	Fraction images extracted by this technique contain different land cover components within a pixel (Palaniswami *et al.*, 2006). The results are found to be accurate, consistent and repeatable (Lu *et al.*, 2004).	Time consuming, difficult to convert image reflectance values to biophysical parameters, considered an advanced technique and is seen to be complex (Lu *et al.*, 2004).	SMA for sub-pixel classification of coconut (Palaniswami *et al.*, 2006). LULC on crop classification using Multi temporal high resolution spot images (Löhnertz *et al.*, 2006).
Artificial Neural Network	The input used to train ANN is the spectral data of the period of change.	Reduces data redundancy between bands.	Hidden layers are poorly known. Time is required for training data and ANN is sensitive to the amount of training data used. ANN functions rarely found in image processing software	Land cover classifications in a heterogeneous savanna environment (Allan, 2007).
Post Classification Comparison	Classifies date 1 and date 2 imagery and compares the classified imagery pixel by pixel.	Minimizes impacts of atmospheric, sensor, environmental differences between multi temporal images. Complete matrices of change information.	Require knowledge, expertise, and time to create classified result.	Informal urban settlement (Hurskainen & Pellikka, 2004), Land use and cover, (Shalaby & Tateishi, 2007) and (Feleke, 2003).

Appendix 2: Monthly rainfall data used in the study

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean
1990	3.9	16.4	45.8	220.9	72.4	91.2	31.2	68.8
1991	82.2	18.1	62.2	136.8	55.8	76.6	0.0	61.7
1992	14.7	55.0	31.8	51.0	65.6	27.9	18.4	37.8
1993	28.8	41.8	67.1	80.3	88.5	22.0	19.0	49.6
1994	2.2	30.6	15.8	95.4	70.0	90.2	17.2	45.9
1995	36.8	16.0	111.4	46.8	28.3	68.0	3.7	44.4
1996	14.1	114.9	91.7	80.7	64.0	59.6	41.3	66.6
1997	57.6	2.5	49.8	22.2	56.1	111.7	86.9	55.2
1998	34.3	102.4	72.0	78.0	84.8	74.9	15.6	66.0
1999	32.2	17.3	139.1	116.5	25.2	63.6	17.2	58.7
2000	14.3	84.3	103.1	118.5	37.9	37.5	20.4	59.4
2001	63.5	89.9	105.8	87.7	44.9	56.3	123.7	81.7
2002	67.3	25.5	102.9	99.7	69.3	50.8	9.1	60.6
2003	10.8	100.9	32.4	139.4	93.0	65.0	4.9	63.7
2004	1.6	31.1	73.6	80.4	32.8	76.6	31.8	46.8
2005	17.1	62.7	26.8	119.8	174.3	90.1	56.8	78.2
2006	30.6	56.5	49.2	68.8	193.1	83.8	55.7	76.8
2007	65.0	51.2	58.1	77.4	7.6	12.0	43.3	44.9
2008	11.7	127.8	17.6	106.8	124.7	61.7	0.6	64.4
2009	13.6	0.0	5.3	71.2	57.2	17.4	3.3	24.0
2010	0.0	41.8	52.8	141.4	56.8	45.6	28.8	52.5
Mean	**28.7**	**51.7**	**62.6**	**97.1**	**71.5**	**61.0**	**29.9**	**57.5**
STDEV								**13.7**

Appendix 3: Monthly river discharge data used in the study

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean
1990	12.3	11.8	49.7	445.4	734.1	197.7	16.6	209.7
1991	33.9	22.0	25.1	15.5	16.5	18.4	19.5	21.5
1992	27.3	52.2	64.7	23.1	111.6	27.3	18.0	46.3
1993	82.6	22.7	68.6	226.2	81.0	47.1	17.5	77.9
1994	26.8	27.8	22.7	130.4	31.4	301.5	17.8	79.8
1995	17.4	19.8	107.0	50.4	106.5	49.8	88.4	62.8
1996	27.8	156.5	99.7	59.7	31.2	146.7	180.6	100.3
1997	45.3	31.0	207.4	329.9	124.1	125.2	50.7	130.5
1998	43.2	66.3	67.5	50.5	39.6	45.3	102.4	59.3
1999	56.3	33.7	247.1	1164.0	112.6	313.3	32.1	279.9
2000	26.4	50.1	63.4	42.4	53.1	113.5	153.9	71.8
2001	63.4	128.3	352.3	151.4	22.2	63.0	167.7	135.5
2002	57.4	52.0	65.1	62.8	58.2	96.2	45.2	62.4
2003	41.4	158.8	39.8	99.8	84.8	159.2	46.1	90.0
2004	36.4	58.6	174.7	166.5	47.5	117.4	77.4	96.9
2005	61.2	81.6	129.2	297.9	2498.0	3200.7	60.9	904.2
2006	40.1	51.9	35.3	62.7	51.6	69.3	1293.4	229.2
2007	45.9	34.3	42.5	53.5	40.1	46.0	24.9	41.0
2008	29.2	34.4	38.6	39.9	386.4	50.6	37.1	88.0
2009	78.6	30.6	30.3	743.6	136.7	100.7	32.9	164.8
2010	44.9	52.1	124.0	401.7	269.7	325.9	38.4	179.5
Mean	**42.7**	**56.0**	**97.8**	**219.9**	**239.9**	**267.4**	**120.1**	**149.1**
STDEV								**181**



Appendix 4: Mean monthly rainfall of the Harts Catchment during the period 1990 to 2010 (Rainfall season begins from October to April).

Appendix 5: Rainfall and river discharge seasonal means and departures from 1990 to 2010 over the Harts Catchment

	Rainfall				River Discharge	
Season	**Mean**	**Departure**		**Season**	**Mean**	**Departure**
1990	68.8	0.8		1990	209.66	0.33
1991	61.65	0.29		1991	21.54	-0.69
1992	37.75	-1.4		1992	46.31	-0.55
1993	49.62	-0.55		1993	77.93	-0.38
1994	45.88	-0.82		1994	79.78	-0.37
1995	44.4	-0.92		1995	62.76	-0.47
1996	66.6	0.64		1996	100.32	-0.26
1997	55.22	-0.16		1997	130.51	-0.10
1998	65.95	0.59		1998	59.26	-0.48
1999	58.69	0.08		1999	279.87	0.70
2000	59.4	0.13		2000	71.82	-0.42
2001	81.67	1.71		2001	135.48	-0.07
2002	60.64	0.22		2002	62.41	-0.47
2003	63.72	0.44		2003	89.99	-0.32
2004	46.82	-0.75		2004	96.93	-0.28
2005	78.19	1.46		2005	904.21	4.07
2006	76.78	1.36		2006	229.18	0.43
2007	44.93	-0.89		2007	41.02	-0.58
2008	64.4	0.48		2008	88.02	-0.33
2009	24	-2.37		2009	164.79	0.08
2010	52.45	-0.35		2010	179.52	0.16
Mean	**57.5**			Mean	**149.1**	
STDEV	**13.7**			STDEV	**181.1**	

Appendix 6: Correlation table with the variables X and Y representing rainfall and river discharge respectively while x and y are their respective means

Season	X	Y	(X-x)	(Y-y)	(X-x)2	(Y-y)2	(X-x)(Y-y)
1990	68.8	209.66	11.3	60.551	127.690	3666.409	684.225
1991	61.65	21.54	4.15	-127.570	17.223	16274.109	-529.416
1992	37.75	46.31	-19.8	-102.805	390.063	10568.869	2030.399
1993	49.62	77.93	-7.88	-71.176	62.094	5065.964	560.864
1994	45.88	79.78	-11.620	-69.334	135.024	4807.271	805.667
1995	44.4	62.76	-13.100	-86.347	171.610	7455.775	1131.143
1996	66.6	100.32	9.100	-48.794	82.810	2380.901	-444.030
1997	55.22	130.51	-2.280	-18.604	5.198	346.121	42.418
1998	65.95	59.26	8.450	-89.848	71.403	8072.710	-759.218
1999	58.69	279.87	1.190	130.761	1.416	17098.446	155.606
2000	59.4	71.82	1.900	-77.286	3.610	5973.111	-146.843
2001	81.67	135.48	24.170	-13.627	584.189	185.708	-329.376
2002	60.64	62.41	3.140	-86.702	9.860	7517.208	-272.244
2003	63.72	89.99	6.220	-59.123	38.688	3495.560	-367.747
2004	46.82	96.93	-8.680	-52.178	75.342	2722.578	452.908
2005	78.19	904.21	20.687	755.095	427.958	570168.066	15620.753
2006	76.78	229.18	19.277	80.074	371.608	6411.815	1543.594
2007	44.93	41.02	-12.573	-108.090	158.077	11683.473	1359.002
2008	64.4	88.02	6.897	-61.086	47.571	3731.531	-421.321
2009	24	164.79	-33.503	15.679	1122.441	245.830	-525.290
2010	52.45	179.52	-5.053	30.413	25.531	924.936	-153.671
Sum of (∑)	**1207.56**	**3131.315462**	**2.043**	**0.000**	**3929.406**	**688796.392**	**20437.423**