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Assessment of the Changing Urban Dynamics in Johannesburg City Regions as a Consequence of Re-mining the Tailings Dumps Using Geographical Information System and Remote Sensing

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by

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A research report submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science (Environmental Sciences) at the School of Geography, Archaeology & Environmental Studies

Supervisor: **Dr Elhadi Adam**

Johannesburg, 2017

Declaration

I hereby declare that this dissertation is my own unaided work. It is submitted for the degree of Master of Science at the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any other degree or examination at any other university.

Tseliso John Mahao



Johannesburg, 11 August 2017

ABSTRACT

There is a growing interest in the reclamation of the old gold mines' tailings dumps in Johannesburg city region driven by the economic value of the remaining gold resource. This reclamation activity is accompanied by various rehabilitation methods to reduce issues such as acid mine drainage and wind pollution. The impact of land use and land cover change (LULCC) can have an enormous impact on land development and planning. Monitoring of LULCC is very important in the planning and decision making processes. Remote sensing (RS) as the source of basic data for monitoring change is very highly recommended as tool to monitor changes occurring in the Johannesburg City Region as a result of rehabilitation and reclamation of the gold mines' tailings deposits. The main aim of the study is to understand how the reclamation and rehabilitation of the historical tailings dumps in Johannesburg are changing land use patterns of the city and its precincts. The objectives are to quantify the changes in land use and land cover as the results of mining rehabilitation using Landsat earth observation data over a period of 30 years at five years intervals and; to recommend on how the land cleared of waste dumps could be used for looking at the surrounding environment spatially. Various Geographical Information Systems techniques are applied here for change detection analysis and monitoring of potential changes in urban dynamics patterns. The results show rate of rehabilitation and reclamation to be slow, taking several years to see a meaningful change. There is some form of bias towards transforming the reclaimed land into industrial zones as opposed to other activities. The success of tailings dumps rehabilitation through revegetation process is highlighted.

Key words: tailings dumps, remote sensing, land use land cover change, reclamation, rehabilitation

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ABBREVIATIONS AND ACRONYMS

AMD	Acid mine drainage
ASTER	Advanced Space-borne Thermal Emission and Reflectance Radiometer
AVHRR	Advanced Very High Resolution Radiometer
ETM	Enhanced Thematic Mapper
GDP	Gross domestic product
GIS	Geographical Information System
Ha	Hectare
IRSS	Indian Remote Sensing Satellites
JCR	Johannesburg city regions
KIA	Kappa Index of Agreement
LiDAR	Light Detection and Ranging
LULCC	Land use land cover change
MODIS	Moderate Resolution Imaging Spectroradiometer
MPRDA	Mines and Petroleum Resources Development Act of 2002
MSS	Multispectral Scanner System
NDVI	Normalized Difference Vegetation Index
NEMA	National Environmental Management Act No. 62 of 2008
NIR	Near-infrared
NOAA	National Oceanic Atmospheric Administration
OLI	Operational Land Imager
RADAR	Radio Detection and Ranging
RED	Red Response
RS	Remote sensing

RSA	Republic of South Africa
SD	Sustainable development
SPCA	Selective principal component analysis
SPOT	Systeme Probatoire d’Observation de la Terre
STATSSA	Statistics South Africa
TIRS	Thermal Infrared Sensor
USGS	United States Geological Survey

CHAPTER ONE

INTRODUCTION

1.1. General Introduction

The impact of land use and land cover change (LULCC) has great effect on humanity as a result of modifications in natural conditions of the environment such as land degradation (Sánchez-Cuervo *et al*., 2012). The detection, and the assessment of the LULCC is an essential component of land use management, which enables us to understand the interaction between human and the natural system. Quantifying the LULCC provides information essential for land use preparation and sustainable management of resources (Verburg *et al*., 1997). The analysis of historical and present data on LULCC provides comparative information that allows to draw solutions for the current socio-economic and environmental problems (Abd El-Kawy *et al.*, 2011)

The province of Gauteng inherited its name from its abundant gold resources known as *gauta* in the Sotho language. Gold was, for over 100 years, the backbone of the country's economy and generated jobs which attracted local and international migrants into the area. Johannesburg is now popularly known as the economic hub of South Africa and Africa, and according to the City of Johannesburg (2015) it contributes 17% to the country's gross domestic product (GDP). According to Sutton *et al*. (2006) gold was first discovered in Langlaagte Johannesburg in 1886 by an Australian prospector George Harrison. Gauteng is currently divided into five metropolitans namely: the city of Tshwane, the city of Johannesburg (also known as Central Rand), West Rand, Sedibeng and Ekurhuleni (commonly known as the East Rand). Gold was discovered and mined in abundance in the East Rand, Central Rand and West Rand (Nhlengetwa & Hein, 2015). The mining of gold reached its peak around 1970s, and has since been declining rapidly due to the cost of running operations and safety reasons (Nhlengetwa & Hein, 2015).

The mining of gold did not only boost the economy of South Africa, but also it brought massive landscape changes and environmental problems, among which are the acid mine drainage, air and visual pollution (Tutu *et al*. 2008). Therefore, due to the large scale gold mining activities in Gauteng for over 100 years, it is a challenge to monitor

all mine dumps in the region and implement extensive reclamation and rehabilitation measures.

Environmental resource contamination and health problems as a result of arsenic were discovered in the active and abandoned gold mines of Mangalur greenstone belt of Karnataka, India (Chakraborti *et al*., 2013). Chronic arsenic exposure through ingestion can cause severe adverse effects on human health, especially via the consumption of contaminated groundwater (Chakraborti *et al*. 2013). Though arsenic problem has not been an issue in the South African context, this goes to show that environmental problems associated with gold mining can be diverse and deadly. Therefore, this calls for a need to have a continual monitoring of these waste dumps to reduce or eliminate unintended consequences. Thus far acid mine drainage (AMD) is a serious threat for the City of Johannesburg and its neighbouring metropolitans. The generation of AMD is as follows:

$$FeS_{2(s)}+\frac{7}{2}O_2+H_2O \rightarrow 2S_4^{2-}+FE^{2+}+2H^+ \quad \text{(step 1)}$$

$$Fe^{2+}+\frac{1}{4}O_2+H^+ \rightarrow Fe^{3+}+\frac{1}{2}H_2O \quad \text{(step 2)}$$

$$FeS_2+14Fe^{3+}+8H_2O \rightarrow 15Fe^{2+}+2SO_4^{2-}+16H^+ \quad \text{(step 3)}$$

$$Fe^{3+}+3H_2O \rightarrow 15Fe(OH)_3+3H^+ \quad \text{(step 4)}$$

Source: (Tutu *et al*., 2008).

The precipitation of iron hydroxide ($Fe(OH)_3$) results in the generation of acid and buffers the pH to 2.5 and 3.5 for Witwatersrand gold deposit (Tutu *et al*. 2008). The presence of pyrite (FeS_2) in the tailings dumps is the main driver of acid pollution. This acid becomes a serious issue as soon as it reacts with fresh water resources like underground groundwater and streams.

The issue of rehabilitation problems of the existing mine dumps in South Africa can be attributed to the lack of the past enforcement laws that ensure mining companies liability to rehabilitate and restore mining sites after mining closure. This means that the financial burden of cleaning up the waste left by gold mining companies in the past lies in the hands of the tax payers in the country. This legal deficiency is now addressed in Section 41 of the current Minerals and Petroleum Resource

Development Act of 2002 (RSA, 2002), which makes mining companies liable for their environmental damage and are legally forced to put upfront a certain amount of money before they are awarded the licence to mine.

There are on-going activities of re-mining the old abandoned tailing dumps in all the three regions around the City of Johannesburg, which for the purpose of this study adopt the phrase 'Johannesburg city regions (JCR)'. This re-mining of tailings dumps is impacting on the city's land use and landscape patterns. New land portions are being released for use by the municipalities, as a result new opportunities and challenges arise. These call for a stringent monitoring system, and geographical information system (GIS) and remote sensing (RS) are some of the tools which can be used to address the monitoring of land use and land cover changes applying a process of change detection.

1.2. Problem Statement

There is huge pressure from the government to have old gold mines' tailing dumps in and around Johannesburg rehabilitated to fight the environmental impacts of acid mine drainage, air pollution and other associated issues. Mining companies have seized this opportunity through the use of latest technologies to extract the gold remaining in the abandoned mine dumps. This is motivated by better trading prices for gold in the markets for the mining companies. The dumps occupy important space in the city where there is a high demand for land. This land could have been used for housing, recreational activities, commercial and light industrial development (Tilsley, 2014). The opening up of new land spaces as a result of re-mining and rehabilitation programmes of existing mine dumps creates changes in the urban dynamics. It is therefore, the purpose of this research to monitor and quantify the impact of the rehabilitated land on spatial patterns of land use and land cover changes around the city of Johannesburg and surrounding metropolitan regions.

1.3. Aim of the Study

The aim of the research is to understand how the reclamation and rehabilitation of the historical tailings dumps in Johannesburg are changing land use patterns of the city and its precincts.

1.4. Objectives of the Study

The objectives are:

1. To quantify the changes in land use and land cover as the results of mining rehabilitation using Landsat earth observation data over a period of 30 years at five years intervals;
2. To recommend on how the land cleared of waste dumps could be used for looking at the surrounding environment spatially.

1.5. Research Questions

- Has there been an occurrence land use and land cover change as a result of reclamation of gold mines tailings deposits between 1985 and 2015?
- What is the impact of reclamation of tailings dumps on the urban dynamics?
- Can Landsat data successfully quantify urban dynamics changes in relation to reclamation and rehabilitation of the tailings deposits?

CHAPTER TWO

LITERATURE REVIEW

2.1. Background

Mining is known to have positive impacts on the gross domestic product of a country and the people in general. The presence of mineral resources is known to attract foreign investment and in return trigger economic, social and human development in a country. The city of Johannesburg was born out of the mining of gold deposits which brought with it local, regional, and international migration (Nhlengetwa & Hein, 2015). However, this brought along with it massive environmental challenges resulting from waste disposal.

The tailings produced by the gold (Au) mining companies are mostly basic rather than acidic due to lime added to arsenic during separation of Au from the ore (Tutu *et al*. 2008). It has been found that the re-mining of the Witwatersrand tailings deposits, which is driven by higher gold prices in the markets as demonstrated on the graph below, has resulted in the generation of the acid mine drainage; and other sources of AMD are the extraction of underground water generated from the abandoned Au mines (Tutu *et al*. 2008). Water around the tailings dumps has been found to be highly contaminated with heavy metals ions, but the situation improves moving away from the tailing dumps; this is associated with the dilution of the contaminated water with the fresh water from the rain during rainy seasons, and also by the wet lands which trap many of the heavy metals (Tutu *et al*. 2008).

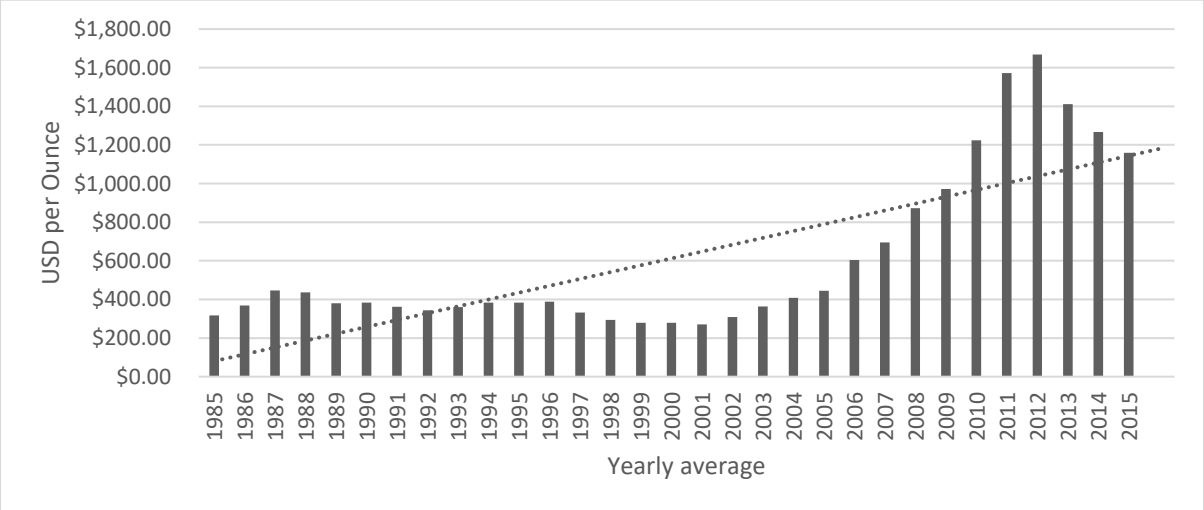


Figure 1: Graph of historical gold records from 1985 to 2015 (WGS, 2016).

Rösner & Schalkwyk (2000) have written extensively about the impacts of gold mining tailings dams on soil and underground water resource contamination. The tailings dams in the East Rand have been found to be the main sources of AMD with a possible contamination of the soil and ground water resources. The soil in the tailing dams is not suitable for plant growth limiting the revegetation programmes of tailings dams' tops. The amount of Co, Cr, Cu, Ni and Zn metal contaminants found in Brakpan area in the East Rand gold mine tailings exceeded the extractable threshold concentration for soils. Liming has been chosen as the better solution in limiting the damaging due to its neutralising effects on AMD and allows vegetation growth as a rehabilitation measure (Rösner & van Schalkwyk, 2000).

2.2. Methods of Mining Rehabilitation

Rehabilitation of mining sites and waste is a concept which has gained incredible recognition over the years. It is not only an issue which affects South Africa. It is a problem which has extensively been recognised everywhere where mining in all forms occurs. Li *et al.,* (2015); Mudd, (2007); Owen & Kemp, (2013); Pimentel, (2016); Gonzalez, & Barbosa, (2016); Schoenberger, (2008) are some of the scholars who have written extensively about the complexity of mining from social, economic, political and environmental impacts.

Mining methods can broadly be classified as either surface (where all mining activities happen in the open area) or underground mining (where extraction of minerals occurs underground). Gold mining in the Witwatersrand basin occurred mainly through underground mining methods ((Durand, 2012; Nhlengetwa & Hein, 2015). Waste from underground mining is deposited onto the surface causing many unwanted environmental problems. This is where rehabilitation of mine waste plays an important role in controlling the waste and reclaiming the land.

Mining rehabilitation is all about blending waste generated from mining processes with the surrounding landscape (Nichols *et al.*, 1985). In Australia, the process of rehabilitating mining waste started as early as 1930s with the revegetation of the mining sites in the Broken Hill area which also influenced legislation on rehabilitation (Jones, 2011). Mine closure is not something which is always planned, and Laurence,

(2006) points out that more often than not occurs earlier than projected. This calls for strong policies and legislations from the governments as custodians of mineral resources.

According to Mudd (2007) the lack of mining in promoting sustainable development was first introduced and documented officially in the 1987 World Commission on Sustainable Development (SD) (WCED). Since then the focus has been on making mining companies liable for their waste as was enforced in the 2002 Johannesburg Earth Summit where reporting on SD and performance of the industry was agreed upon (Mudd, 2007).

Meanwhile, mine rehabilitation should not be viewed only as a revegetation and tree plantation process but as an avenue to generate income. In Indonesia, economic development in the form of pasture development for beef cattle breeding; aquaculture; plantation forest; cultivation of crops; and ecotourism development have been realised from a coal mine waste rehabilitation (Kodir *et al.*, 2016).

2.2.1. Environmental Legislation and Policy

Mining according to Bridge (2004) is a segregative process where a valuable material is separated from tonnes of waste which causes environmental and health related issues. Reichardt (2013) wrote comprehensively about the history of gold mine rehabilitation in South Africa focussing on the type of grass used in revegetation of the rehabilitated land. A study by Reichardt (2013) stated that the society currently requires better uses of the rehabilitated mine dumps especially in urban areas, where every little piece of available land is vital to meet the people's needs. The 1991 Mines and Minerals Act (MPRDA) of the Republic of South Africa played a significant role in the enforcement and promotion of mining rehabilitation and the provision of the financial trust responsible for rehabilitation during decommissioning (Reichardt, 2013). MPRDA requirements for mining rights are a comprehensive environmental management programme, rehabilitation plan and the estimated cost thereof (RSA, 2002). The estimated cost for rehabilitation remained a contentious issue as to how much is enough to finance the rehabilitation process. Stacey *et al.,* (2010) highlighted that in the past mining companies could abandon mines legally and leave the cost of

rehabilitation with the government making this tax payers problem. This is not a case anymore after recognition by government that providing a closure certificate for a successful rehabilitation of mining sites is a mammoth task.

Having realised and acknowledged issues related to mine waste rehabilitation, the National Environmental Management Amendment Act (NEMA), No 62 of 2008 was amended to enforce provision of finance for rehabilitation after mine closure and the certificate of compliance is only issued after the department of Environmental Affairs is convinced that companies have fulfilled their liability mandates (RSA, 2008). This has shifted the accountability of mining waste rehabilitation processes away from the government and tax payers to the mining companies themselves.

Environmental protection involves four main steps for consideration, which are avoidance, mitigation, restoration and offsets (Kiesecker *et al.*, 2010). Mitigation of environmental problems and restoration of land back to its original state are the main possibilities in the rehabilitation of the tailings dumps in the Johannesburg city region because the damage is already there. The mining waste found in the JCR span over 100 years. According to Reichardt, (2013) only a select type of grass can survive on the tailings deposits as rehabilitation measures. Eucalyptus trees which are found on many of the tailings dumps foothills have been noted as successful in reducing wind and water erosion due to their roots which grow horizontally hence avoiding contact with the acidic conditions deeper in the soil (Reichardt, 2013).

The removal and relocation of the tailings dumps has opened new channels of opportunities for the city of Johannesburg to expand, grow and solve some of the challenges it has had for years as a result of mining waste and limited space. The availability of new land means that new or expansion of industrial zones can be achieved to revitalise the economic activities of the city. Human settlement issues as well as other infrastructure development could be addressed through provision of housing as more portions of land for use are created by the re-mining, reclamation and rehabilitation programmes.

2.3. Remote sensing for LULCC

Change detection is the practice of identifying and analysing transformations in the condition of an object or phenomenon by revisiting its data captured at different times (Singh, 1989). This is because many regions around the world are currently undergoing rapid changes in land cover and land use (Mas, 1999). Therefore, it is crucial that these changes are constantly monitored to deal with issues that may arise as a result. The use of RS to monitor land use cover and change has been investigated before in many other countries before.

Satellite RS data is the commonly used resource database for change detection, quantification and mapping of LULCC owing to its ability to acquire data in a digital format appropriate for computer processing, and accurate geo-referencing processes (Abd El-Kawy *et al.*, 2011; Chen *et al.*, 2005; Jensen, 1986; Lu *et al.*, 2004). RS has been widely used to quantify LULCC, from productive agricultural land to impermeable rough terrains (Miles *et al.*, 2003). Multi-temporal Landsat images in remote sensing are used to monitor spatio-temporal LULCC at different intervals. Landsat satellites have been capturing images from as early as 1972 with Landsat 1 all the way to today with Landsat 8 (NASA, 2012) as demonstrated in the figure 2 below.

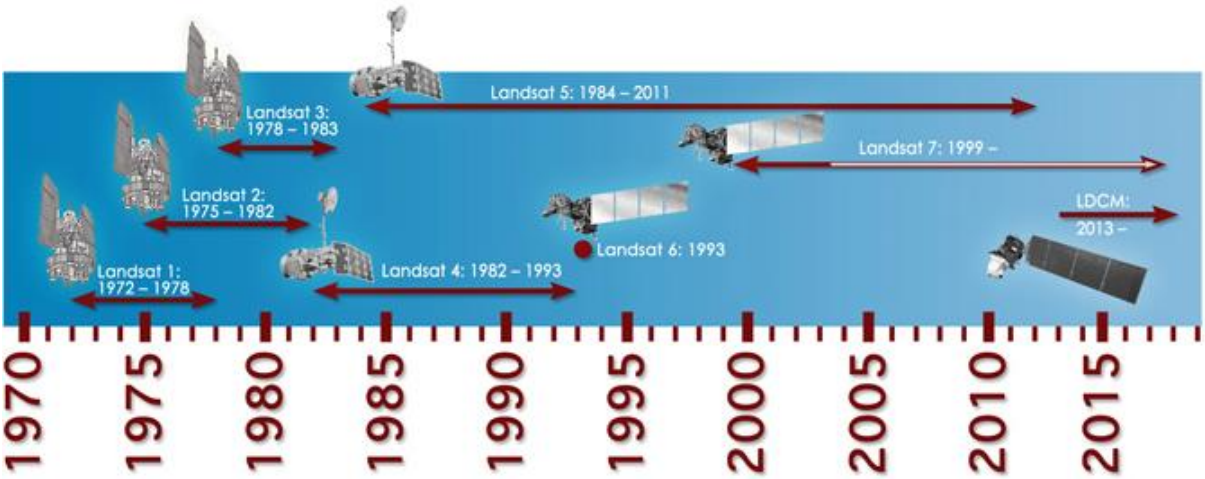


Figure 2: History of Landsat Satellites (NASA, 2012).

In change detection, the Landsat data is used as it is unique and makes available historical and continuous record of imagery (Abd El-Kawy *et al*., 2011). The techniques of Landsat image processing can accurately provide the land use and land cover for

large areas and over an extended period of time, which is extremely important in observing, mapping, and management of LULCC (Wulder *et al*., 2008). Landsat data has been used in a number of studies to address LULCC and has proved to be an effective tool (Abd El-Kawy *et al*., 2011).

This change detection method monitors changes regardless of whether they are positive or negative. Identified changes could help in zonal planning for the JCR for infrastructure upgrades and; environmental monitoring to prevent associated health risks. Failure to do this monitoring could result in catastrophic events like mass movement as there are people staying adjacent to tailings dumps, and disease outbreaks from contaminated water and soil. There is limited literature coverage of land use and land cover changes with regard to the reclamation and rehabilitation of gold mines tailings dams in South Africa. Furthermore, the change in the urban dynamics as a result of mine tailings dams' reclamation and rehabilitation programmes has not been investigated. This study will therefore, monitor the relationship between the removal of the mine dumps and the changes in the urban dynamics using remote sensing information acquired in the last thirty years at an interval of five years.

LULCC studies have grown in leaps and bounds recently, and have promoted rapid development and advancement in planning for the future. Developments in the ability of computers; improvements in the capturing of Geographical Information Systems (GIS) and; remote sensing (RS) data available in compatible digital formats have made it possible for data manipulation and modelling while equally allowing researchers to confront with confidence difficulties previously considered analytically impossible (Lambin & Geist, 2007). The introduction of satellite imagery and aerial photography resulted in significant developments in change detection landscape evolution (Shroder, 2013). Sohl & Sleeter, (2012) emphasised that without historical data and latest sources of RS, monitoring and measuring landscape change parameters would be difficult to address.

RS as a monitoring tool of LCLCC, is indispensable in the sphere of science. It is possible through RS to observe and acquire data across large areas on the Earth's surface. Therefore, RS makes available information which may possibly be challenging and demanding to acquire by means of ground-based observations (Lillesand, Kiefer, & Chipman, 2014). This is achieved through the use of remote

sensing techniques in the form of Radio Detection and Ranging (RADAR) and Light Detection and Ranging (LiDAR) sensors in the form of multi-spectral scanners and cameras mounted on air and space-borne platforms (Argall & Sica, 2007).

Land use and land cover mapping has become one of the most commonly used applications of RS techniques. The mapping of large parts of the land surface using this technique has developed into considerable popularity in recent years (Cihlar, 2000). New technological development in response to the need to do things better and efficiently is driving the growth and understanding of the applications of satellite RS in mapping (Cihlar, 2000). Multi-temporal imagery in RS development provide both local, regional and global data on LULCC classification (Wright & Morrice, 1997) which is fundamental in the scientific analysis.

The imagery used in RS come from various satellite data sources and differ in resolution (Ellis, 2013). There are those offering high resolution RS data such as IKONOS and Quickbird, as well as low resolution (e.g., MODIS), and those providing regional data sets produced at regular interval (e.g., Landsat and SPOT) (Ellis, 2013). The ability of certain satellites to provide remotely sensed data at regular interval is of crucial importance in change detection analysis, especially where there is a rapid change in a phenomenon. Landsat images have improved a lot over the last few years. High resolution sensors, similar to Landsat Thematic Mapper (TM, 30m resolution) or the Systeme Probatoire d'Observation de la Terre (SPOT, 20m or 10m resolution) and the Multispectral Scanner (MSS, 79m resolution), are important resources recommended for the study of land use and land cover (Duadze, 2004). Zhang *et al*. (2014) in their study paid a distinct compliment on the importance of Landsat data in its ability to provide the longest record, making it possible to address dynamics of LULCC using medium spatial resolution imagery with high temporal frequency as opposed to various sources of multispectral remotely sensed imagery.

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). The use of RS to monitor land use cover and change has been investigated before in many other countries. This is because many regions around the world are currently undergoing rapid changes in land cover and land use (Mas, 1999). Therefore, it is critical that these changes are

constantly monitored to deal with issues that may arise as a result and, possibly eliminate surprises and shocks therefore.

Landsat data has been used in a number of studies to address LULCC and has proved to be an effective tool (Abd El-Kawy *et al*., 2011). Analysing and mapping both the present LULC situation, as well as the changes in LULC over time is recognized as important to better understand and provide solutions for social, economic, and environmental problems (Abd El-Kawy *et al*. 2011). In their study of land use and land cover change in Greater Dhaka, Bangladesh, Dewan and Yamaguchi (2009) used Landsat data to promote sustainable urbanization using MSS, TM and ETM+ images from 1975 to 2003 and socio-economic data. This demonstrated how much rapid urbanization brought about severe consequences of rapid development, which also included dilemmas like flooding and environmental degradation in Greater Dhaka.

Another study by Abd El-Kawy *et al*. (2011) looked into the use of Landsat images using TM image acquired on 11 September, 1984 and three Enhanced Thematic Mapper Plus (ETM+) images acquired on 2 December, 1999 to monitor land use and land cover change in the western Nile delta of Egypt. The study used four Landsat images to provide historical LULC of the western Nile Delta. It shows how development and limited environmental policies have continued to degrade land over time and continues to suggest that some of the quarrying activities could be done in other environmentally stressed areas in Egypt.

Many studies have been published on monitoring of land use and land change over time. Mining industry land use and change has also been monitored for diverse reasons. For instance Prakash and Gupta (1998) published a study on land use mapping and change detection in a coal mining area in the Jharia coalfield in India. This study was significant in highlighting the various uses of the land in the mining environment. These mining activities include opencast, overburden dump and waste sites. Landsat TM false colour composites of bands 4, 3 and 2; false colour composites 7, 5, and 3; and false colour composites bands of 5, 4, and 2 ratio provided very useful information for land-use mapping (Prakash & Gupta, 1998).

Singh (1989) in a study of digital change detection techniques using remotely-sensed data, applied methods of univariate image differencing. In this process two images of the same locality differing in time (t1–t2) are subtracted from each other pixel by pixel

mathematically to produce another image representing change in time. The similar process of isolating changed pixels was mentioned by Mas (1999) to monitor land cover changes in comparison with different change detection techniques.

Another important aspect of change detection is vegetation index differencing. This is a RS technique related to data transformation of green biomass (Mas, 1999). The Normalized Difference Vegetation Index (NDVI) is calculated by NDVI= (NIR-RED)/ (NIR+RED) where NIR is the near-infrared band response for a particular pixel, MSS band 4 and RED is the red response, MSS band 2 (Mas, 1999). The vegetation index was calculated for the study years. Mas (1999) elaborated further on other change detection techniques like selective principal components analysis (SPCA); direct multi-date classification; post-classification analysis; combination image enhancement and; accuracy assessment.

In their study, Abd *et al*. (2011) used Landsat TM and ETM_+ images to monitor land use and land cover changes in the western Nile delta in Egypt. All visible and infrared bands (except for the thermal infrared band) were included in the analysis. Their study's methodology took into consideration various image pre-processing techniques which included geometric correction, ETM_+ gap filling, and image enhancement and interpretation. The techniques used in their study will be applied to monitor land use and land cover changes related to mine-tailings in JCR. This is driven by the availability of free Landsat images from the United States Geological Survey (http://earthexplorer.usgs.gov/).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

The focus of the case study is based in Johannesburg city regions (JCR) which covers parts of Johannesburg Metropolitan, Ekurhuleni Metropolitan and West Rand District Municipality falling within the Gauteng Province as shown in figure 3 below. The area is characterised by remnants of highly intensive gold mining activities, human settlements, business clusters and industrial zones.

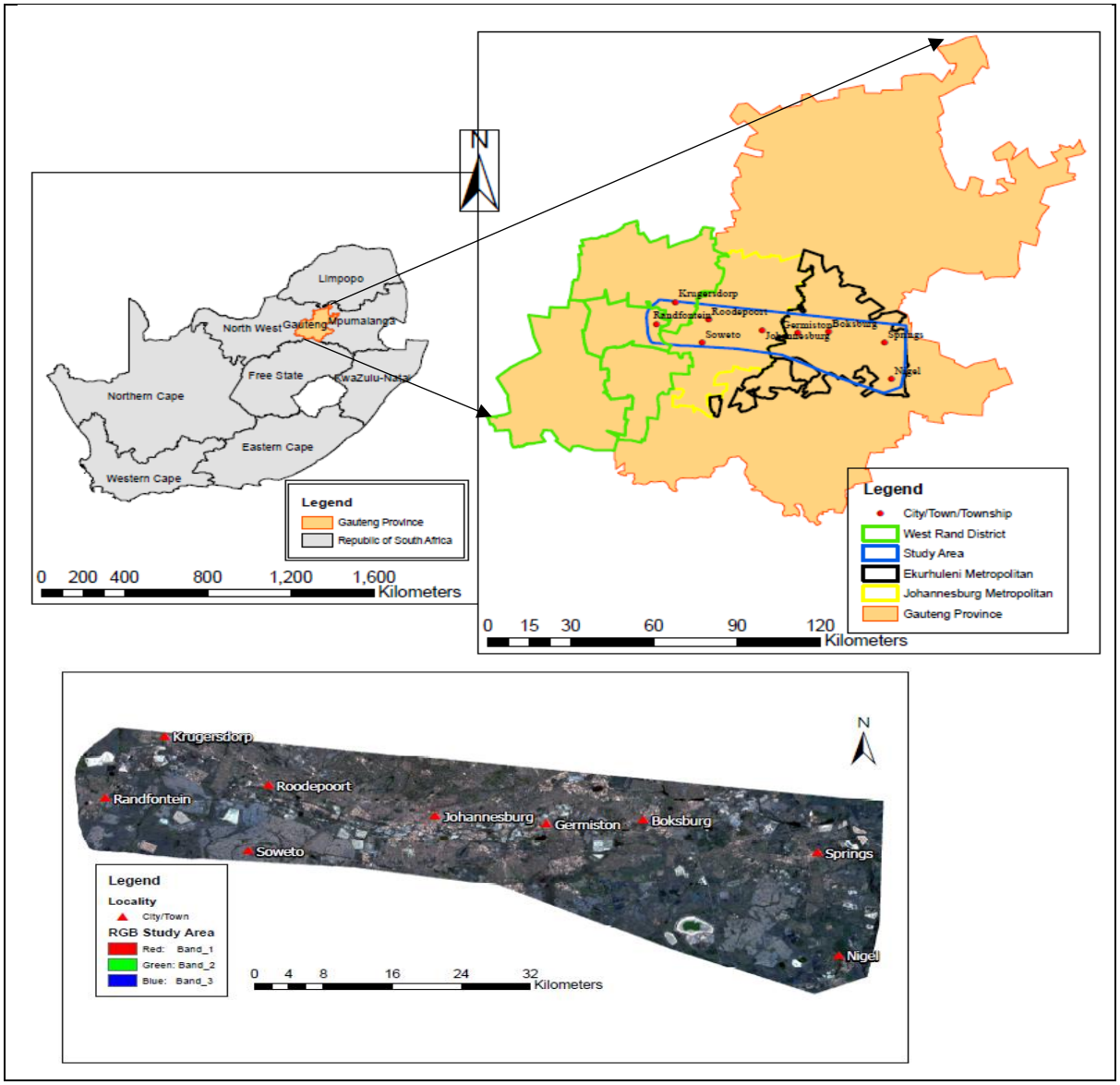


Figure 3: The study area in relation to the country and the Gauteng Province.

According to 2011 national census information from Statistics South Africa, Gauteng makes the largest share of South Africa's population, comprising of 23.8% (STATSSA, 2012). Ironically it is the smallest province of all in terms of size. Johannesburg and Ekurhuleni are the most densely populated municipalities in the province as demonstrated in figure 4 below. JCR (study area) is located on the Highveld plateau of the Witwatersrand ridges, and has subtropical highland climate with intense tropical convective showers in summer (average daily temperatures of 25.6ºC) and mild dry winter (average temperature 16ºC) (Goldreich, 1992).

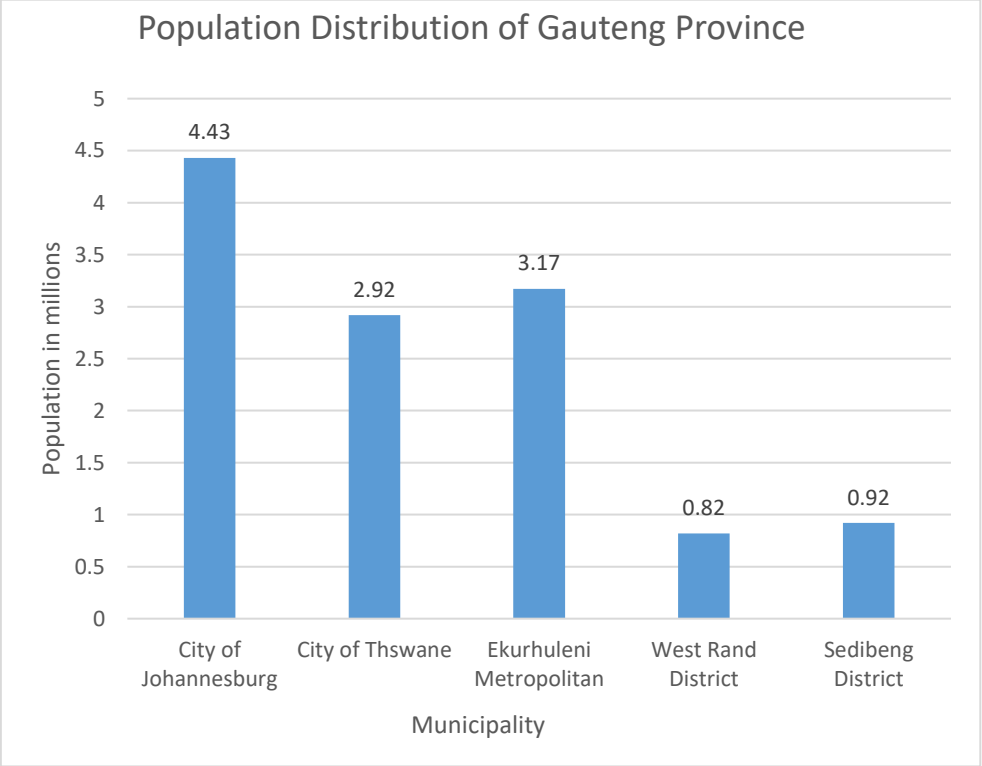


Figure 4: Population statistics of Gauteng Municipalities as per census 2011 by Statistics South Africa (STATSSA) records (STATSSA, 2012)

As summarised in Table 1 below, the study region shares some trademarks and, possesses some distinct traits likewise. East and Central Rand share many aspects of urban dynamics such as thriving industrial zones, sprawling urban settlements and highest quality of life. They also share the negative aspects of dying underground mining activities and increasing informal settlement zones. West Rand remains the backbone of the current gold mining activity in the region. Many of these mining activities fall beyond the study area in places like Carletonville and Westonaria. Other than mining, West Rand offers very limited avenues for sources of revenue and income generation.

Table 1: Summary of the characteristics of the three metropolitans

Metropolitan	Size in hectares	Characteristics	Status of Mining
Ekurhuleni/East Rand	197,883	• Highly industrialised • Sprawling urbanisation • Increasing informal settlements • Boksburg major services town	• Ongoing underground mining activities • location of the largest megadump in Brakpan
Johannesburg/ Central Rand	164,801	• Highly industrialised • Vibrant urban spaces • Highest population density • Major business centres, e.g., Johannesburg, Sandton, Midrand etc. • Host to the Johannesburg Stock Exchanges. • Mining hub, headquarters to big mining companies	• Very few ongoing underground mining activities • Increased focus on tailing dumps reclamation and rehabilitation
West Rand	409,500	• Amalgamation of 4 local Municipalities • Lot of open spaces and agricultural activities • Least developed • Less populated • Krugersdorp and Randfontein are major services towns	• Highly active underground mining activities extending to Carletonville • Numerous tailings dumps • Ongoing rehabilitation and reclamation around Krugersdorp

Figure 5 below demonstrates the land portions which were and or are leased to the mining industry. This shows the extent to which mining footprint runs across the study area.

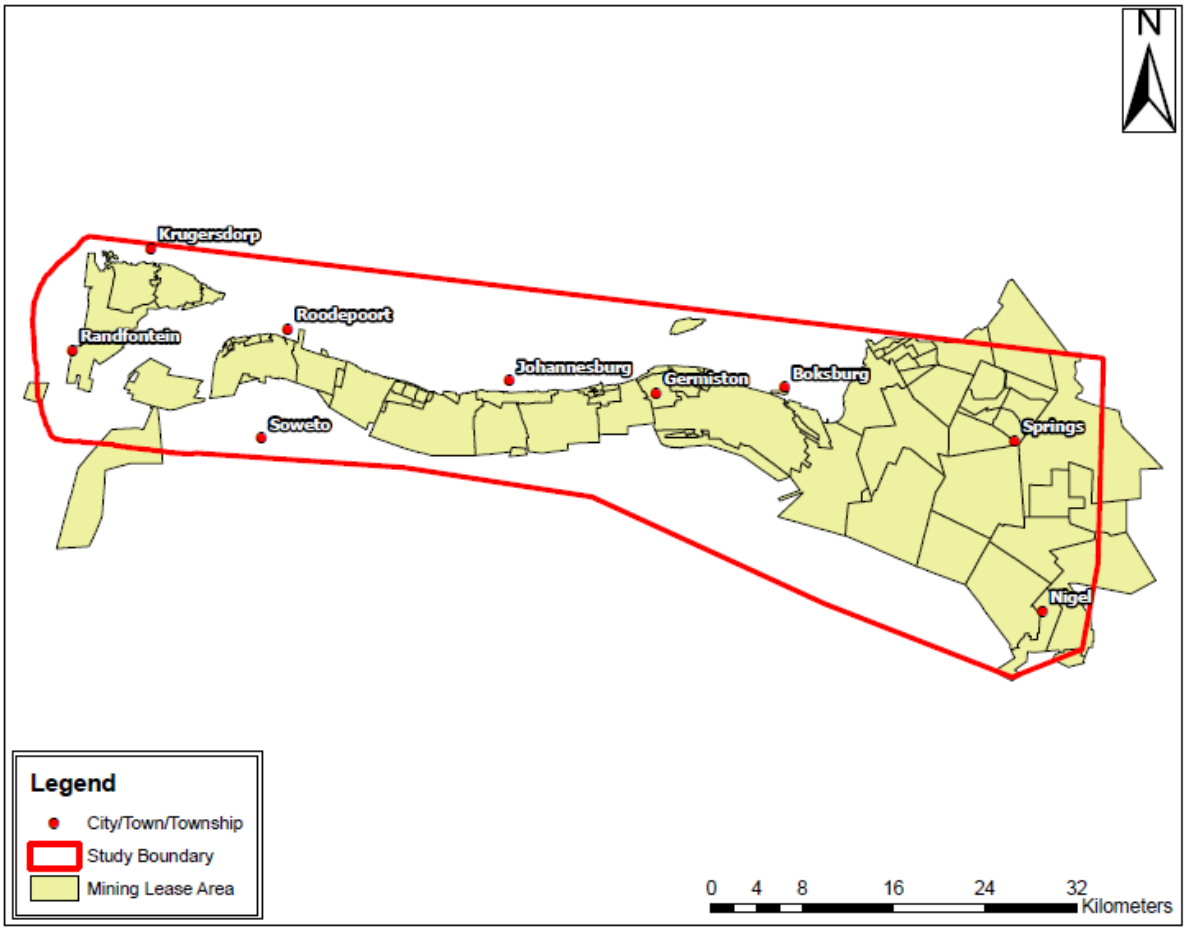


Figure 5: Leased mining land within the study area in the year 2010 (Source: Department of Minerals)

3.2. Remote sensing data acquisition and pre-processing

3.2.1. Remote sensing data acquisition

Different types of data from different sources were used in this study to increase the accuracy of the results. Landsat images from United States Geological Survey (USGS) were used to perform change detection techniques. Site visits and Google Earth images were used for ground truthing and demarcation of the study area.

The use of RS in change detection is used due to its ability to model and present data taken in different dates in a manner which is easy to use on a dedicated mapping software and a basic workstation. Landsat data acquired in the years 1985, 1991, 1995, 2000, 2005, 2009 and 2015 were used in LULCC of JCR. Table 1 below represents properties of the Landsat images used.

Table 2: Information of Landsat data used (USGS, 2015)

Year	Acquisition date	Sensor and spectral range	Path	Row	Spatial Resolution (meters)
1985	1985-02-01	Landsat 1 - 5 MSS	170	78	30
1991	1991-04-07	Landsat 4 - 5 TM	170	78	30
1995	1995-08-08	Landsat 4 - 5 TM	170	78	30
2000	2000-10-16	Landsat 7 ETM+ (SLC on)	170	78	30
2005	2005-06-16	Landsat 4 - 5 TM	170	78	30
2009	2009-05-26	Landsat 7 ETM+ (SLC off)	170	78	30
2015	2015-07-14	Landsat 8 OLI/TRS	170	78	30

The images were acquired over a five-year interval for change detection. There was a deliberate attempt to use only Landsat images without cloud cover to reduce reprocessing and inaccuracy of the output results. The 1991 and 2009 Landsat images used deviate from the planned five year interval. The 1990 Landsat images had a slightly poorer quality when compared to the 1991 images. The 2010 images show faulty camera sensor band which affects the visibility of many pixels in the study area. There was also an attempt to avoid Landsat images taken in summer because it is the rain season, and probability of clouds cover contamination is very high. Acquisition date of data ranged between April and October, only 1985 Landsat image deviates from that order because it was the best image available in that year from the archives.

3.2.2. Image pre-processing

The Landsat images used were acquired at different times using different satellites. Therefore, this calls for Landsat image pre-processing as highlighted by Lu *et al.* (2004) that historical and recent Landsat images differ in atmospheric correctness, radiometric and geometric precision. As a result, correction of these irregularities is crucial in order to improve LULCC mapping results.

ArcMap 10.3 was used to construct band combination of 3, 2, 1 for Landsat 1-5 MSS, 4 and 7 (images for 1985, 1991, 1995, 2000, 2005 and 2009) and 4, 3, 2 band combination for Landsat 8 image. The true colour images were clipped to the study area boundary in ArcMap 10.3 before they were imported into TerrSet Geospatial

Monitoring and Modelling System. The land use and land cover types were categorised using the acquired Landsat images. Maximum likelihood (MAXLIKE) supervised classification was performed using TerrSet where training and validation samples were obtained in order to develop a classifier. This is a method of assigning pixels of an image to classes creating identifiers which are used to find pixels of similar identity. Representative samples were selected for each land cover and land use class from the Landsat satellite images. Training samples or sites were digitized to represent the land use and land cover classes. The classification of the representative samples for land use and land cover were based on the spectral signature which was defined in the training set.

3.3. Reference Data for training and validation

The LULC classes were selected based on what constitutes the JCR urban dynamics. These classes were identified through the process of pixels and statistical analysis. According to Mesev (2010) training classes help in providing geographical features which can be followed and understood by many. Polygons were created for all the land use classes using signature development technique in TerrSet. Qualification of training sites into classes is determined by pixels of 30 and above which increases the accuracy of the final results.

3.4. Image Classification

Table 3: Land Cover classes and attributes

Land use and land cover class	Attribute
1. Tailings Dump (TD)	Gold mining tailings deposits
2. Industrial Zone (IZ)	Light and heavy Industrial park or estate
3. Residential Urban (RU)	Suburban area, high class residential
4. Residential Township (RT)	Low to medium class, informal settlement
5. Water Body (WB)	Dams, reservoirs, ponds rivers and streams
6. Farming and Grassland (FG)	Commercial agriculture and fields for animal feed
7. Woody vegetation (WV)	Forests and shrubs

Seven land cover classes, namely tailings dumps, industrial zone, residential urban, residential township, water body, farming and grassland, and woody vegetation, were defined in details. Representative classes as summarised in Table 3 above were classified for LULC according to the spectral signature development in the training

sites. Site visits and images acquired from Google Earth (http://earth.google.com) were used for ground-truthing.

3.5. Accuracy Assessment

Accuracy assessment is the process used to verify the validity of the mapping results from signature development and supervised classification. Due to the fact that images were captured some time ago, ground reference information may not be available (Witmer, 2008). Accuracy assessment can reduce spectral confusion caused by noise and inconsistency of classification algorithms (Liu *et al.*, 2014). ERRMAT module on TerrSet was used to conduct accuracy assessment for all classified images. Coordinates collected during site visits for the classes and Google Earth images were used for land cover classes' reference points. A new reference image with shapefiles overlaid was created. This reference image was used against the classified images to calculate overall accuracy. Kappa coefficient, which according to Landis & Koch (1977) ranges between 0 and 1, was automatically calculated using ERRMAT in TerrSet.

3.6. Change Detection

Change detection is used in this study because of its ability to allow identification of an object or phenomenon by observing it at different times (Singh, 1989). It allows one to monitor determine where change is occurring and at what rate is occurring. The use of Landsat to monitor land use cover and change is not a new exercise due to ongoing environmental and ecological changes in many regions around the world (Mas, 1999).

In this study TerrSet software was used to statistically monitor changes LULC for the JCR using the acquired Landsat images. The 1985 image was subtracted from the 1991 image; the 1991 image from 1995 image; 1995 image from 2000 image; 2000 image from 2005 image; 2005 image from 2009 image; and 2009 image from 2015. These provided change detection maps used to statistically detect change over the 30 year period.

CHAPTER FOUR

RESULTS

4.1. Land Use and Land Cover Mapping

The land use land cover change map of 1985 shows that 9.88% of the 170,130 hectares of land was covered by tailings dumps as demonstrated in figure 6 and the histograms showing LULC classes in figure 7. Industrial zone has a share of 9.39%; residential urban has 22.27%; residential township has 13.07%; water body shows 0.52%; farming and grassland has 31.17% and; woody vegetation cover takes 13.69% of land use and land cover. The 2015 LULC map results show mixed changes between the land cover classes with residential township and farming and grassland showing the most rapid changes. Residential townships in 2015 have more than doubled from the 1985 baseline to 28.91%. This shows a rapid increase in urbanisation and immigration which is not an alarming effect in a developing country and the economic hub of South Africa, Gauteng. Farming and grassland have declined by more than three-fold to 9.52% in 2015 which is attributed to urbanisation mainly. Tailings dumps decreased by half to 4.75%; industrial zone increased slightly to 15.14%; residential urban increased to 30.47% and; water bodies and woody vegetation show minor decline to 0.46% and 10.75% respectively.

The reclamation of tailings dumps is a very slow process, making it difficult to quantify over a short period of time. Another important aspect noted is that the tailing dumps material does not disappear from the JCR but only moved from one location to another within the JCR to form megadumps similar to one in Brakpan. This makes detection of substituting classes rather complex, and that complexity is dealt with better through ground truthing in a form of site visits and Google earth images which can roll as far back as 1984 for the study area albeit with poor image resolution initially.

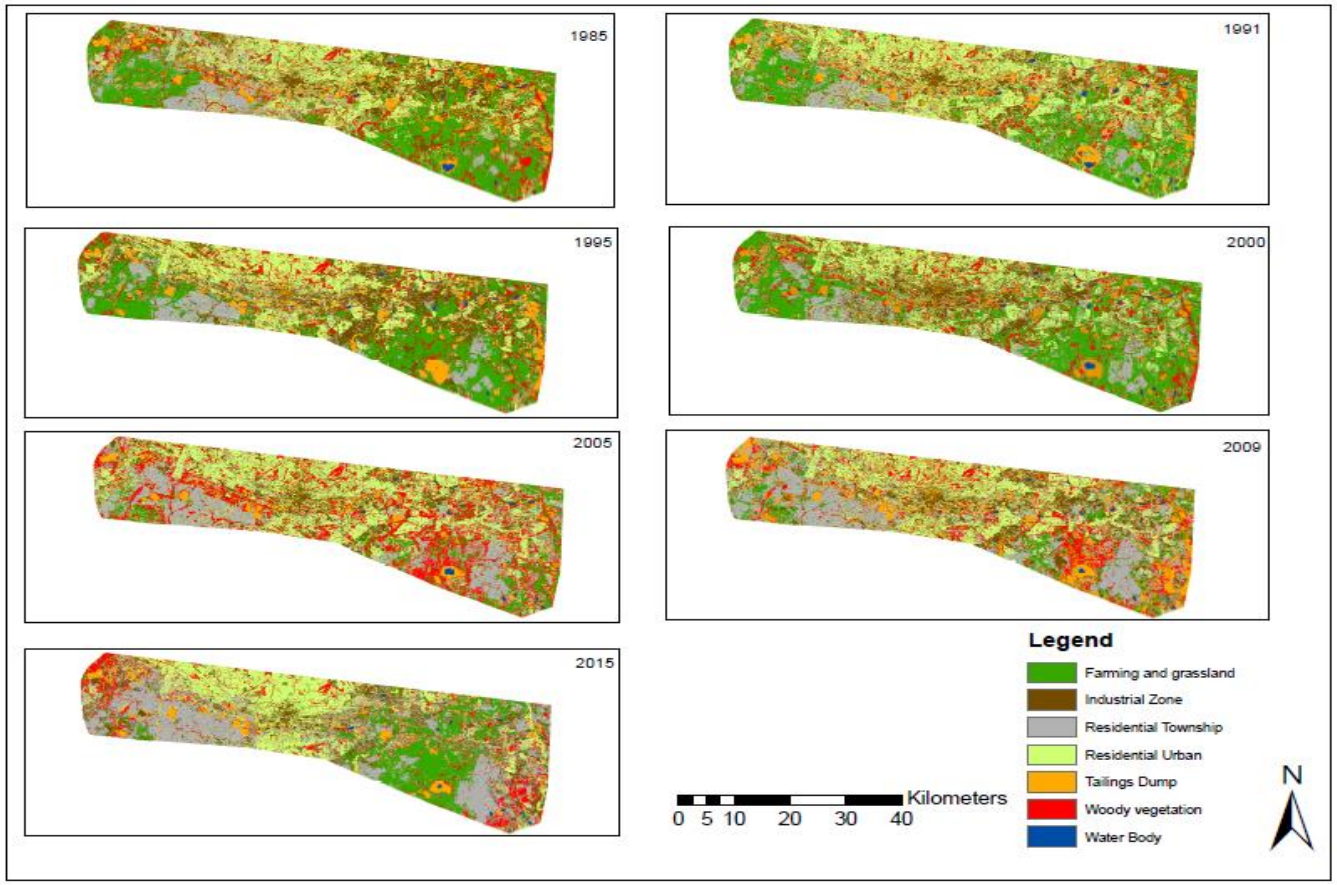
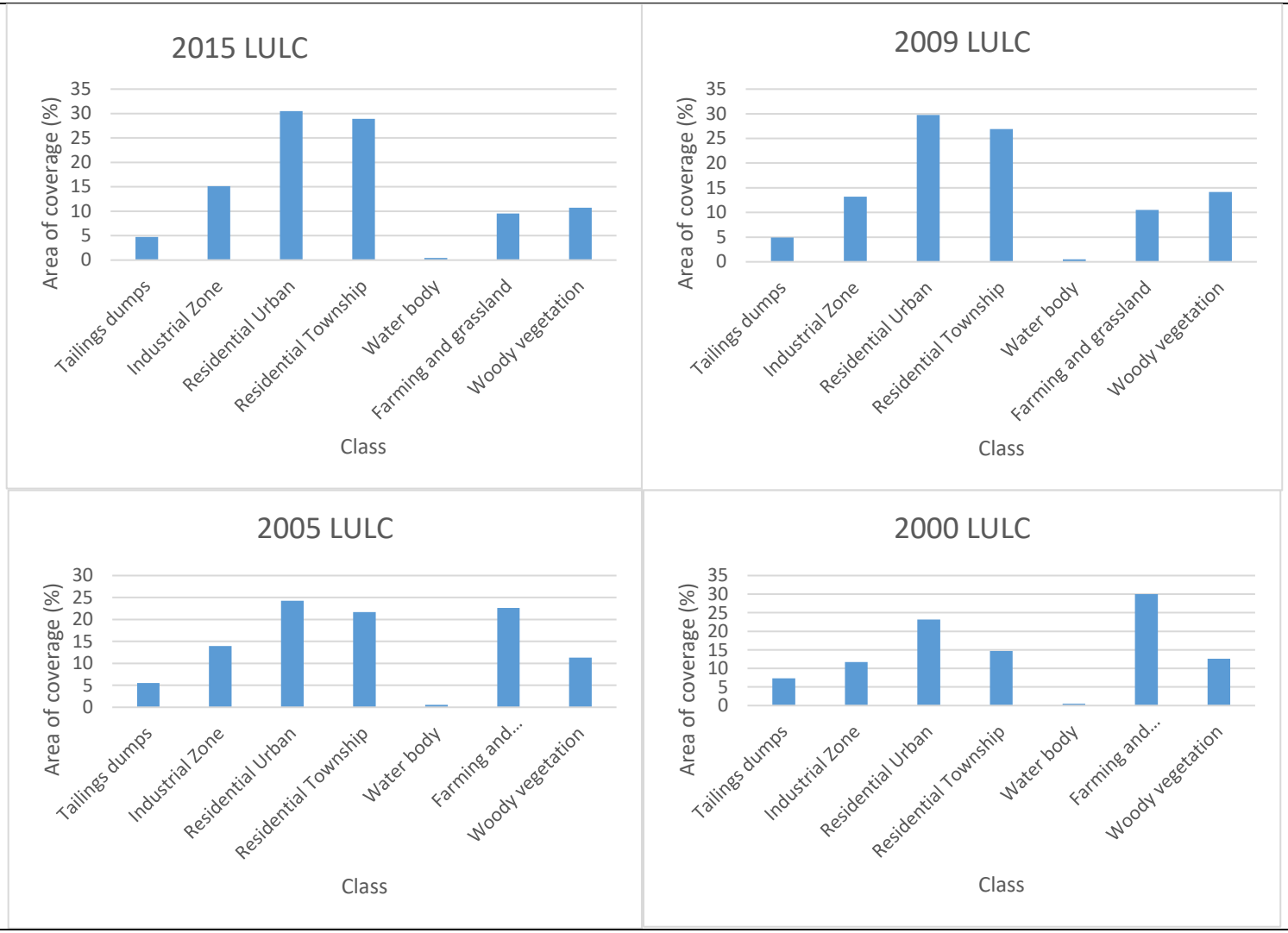


Figure 6: LULC map of Johannesburg city regions in 1985, 1991, 1995, 2000, 2005, 2009 and 2015.


2015 LULC
Area of coverage (%)
35
30
25
20
15
10
5
0
Tailings dumps
Industrial Zone
Residential Urban
Residential Township
Water body
Farming and grassland
Woody vegetation
Class
2009 LULC
Area of coverage (%)
35
30
25
20
15
10
5
0
Tailings dumps
Industrial Zone
Residential Urban
Residential Township
Water body
Farming and grassland
Woody vegetation
Class
2005 LULC
Area of coverage (%)
30
25
20
15
10
5
0
Tailings dumps
Industrial Zone
Residential Urban
Residential Township
Water body
Farming and...
Woody vegetation
Class
2000 LULC
Area of coverage (%)
35
30
25
20
15
10
5
0
Tailings dumps
Industrial Zone
Residential Urban
Residential Township
Water body
Farming and...
Woody vegetation
Class

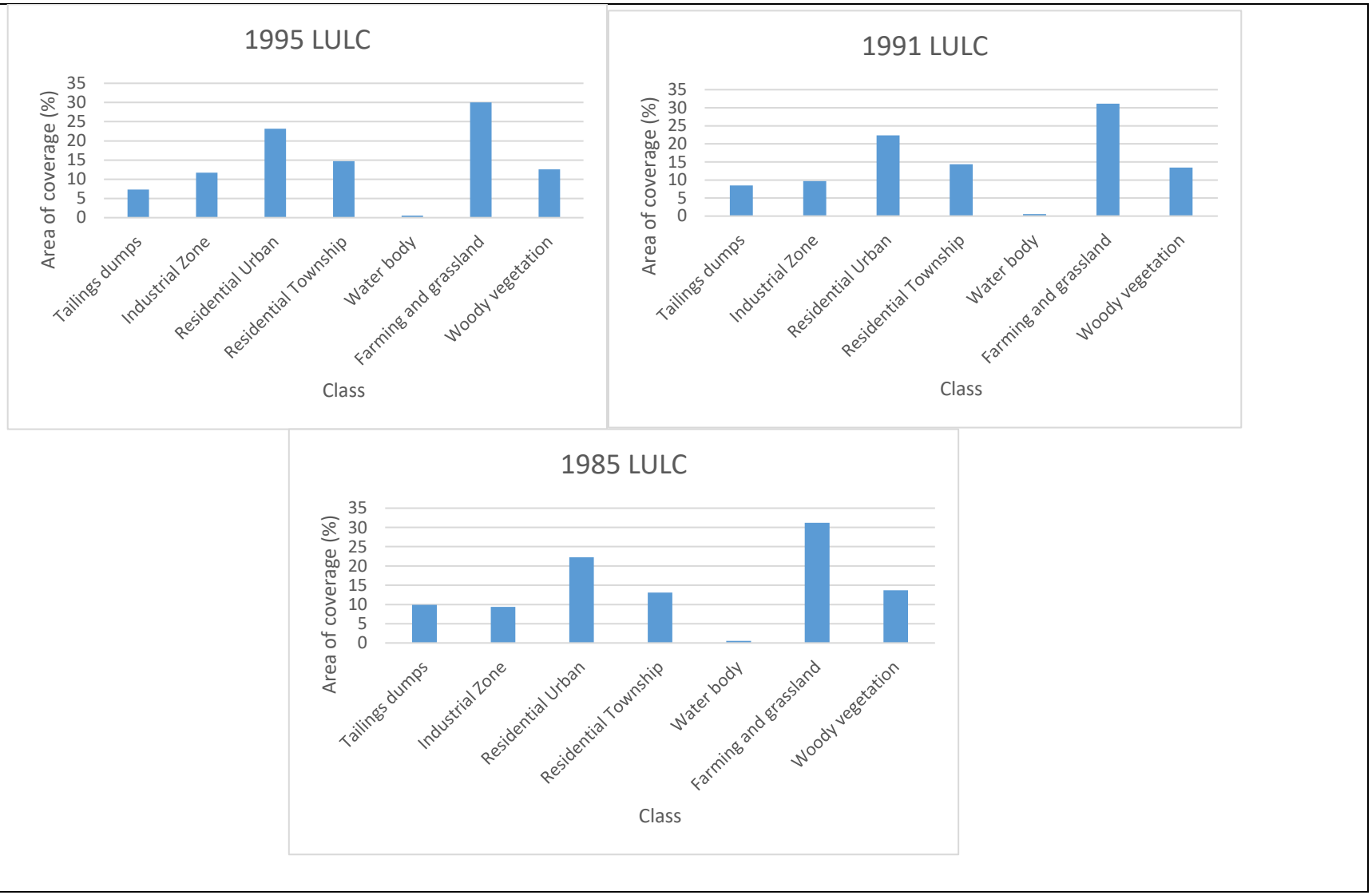


Figure 7: Histograms of LULC coverage for 1985, 1991, 1995, 2000, 2005, 2009 and 2015.

Table 4: Land use and land cover change from 1985 to 2015.

	1985		1991		1995		2000		2005		2009		2015	
LULC class	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
TD	16815.51	9.88	14374.46	8.45	12492.55	7.34	9842.75	5.79	9458.73	5.56	8380.44	4.93	8083.71	4.75
IZ	15974.73	9.39	16517.89	9.71	19891.40	11.69	21754.26	12.79	23767.63	13.97	22506.75	13.23	25757.97	15.14
RU	37891.89	22.27	38069.22	22.38	39360.42	23.14	38839.32	22.83	41265.27	24.26	50661.45	29.78	51835.61	30.47
RT	22231.53	13.07	24360.14	14.32	24983.81	14.69	25306.40	14.87	36937.71	21.71	45736.83	26.88	49183.25	28.91
WB	884.25	0.52	985.32	0.58	875.60	0.51	991.20	0.58	970.40	0.57	867.60	0.51	787.23	0.46
FG	53032.50	31.17	52976.62	31.14	51101.12	30.04	53699.15	31.56	38503.35	22.63	17928.00	10.54	16200.68	9.52
WV	23299.20	13.69	22845.96	13.43	21424.71	12.59	19696.53	11.58	19226.52	11.30	24048.54	14.14	18281.16	10.75

Note: TD=Tailings dump, IZ=Industrial Zone, RU=Residential Urban, RT=Residential Township, WB=Water body, FG=Farming and grassland and WV=Woody vegetation.

4.1. Accuracy Assessment

Table 5: Confusion matrices for validation of 1985, 1991, 2000, 2005, 2009 and 2015 LULC maps

Year	Overall accuracy (%)	Kappa Coefficient	Accuracy type	Farming and Grassland (%)	Industrial zone (%)	Residential Township (%)	Residential Urban (%)	Tailings dumps (%)	Woody Vegetation (%)	Water body (%)
1985	73.6	0.84	Producer's	81.8	79.6	89.7	65.4	65.4	53.4	80.2
			User’s	65.8	78.8	76.7	87.7	91.6	46.1	100
1991	74.6	0.79	Producer's	69.3	73.9	64	81.5	88.4	51.6	93.2
			User’s	86.2	77.2	55.5	69.1	77	52.5	86.2
1995	78.6	0.88	Producer's	79.2	84.2	58.5	80.6	96.7	93.1	58.2
			User’s	79.5	55.3	94.9	91.5	78.8	51.5	100
2000	74.2	0.81	Producer's	78.7	84.6	65.6	69.5	81.1	59.4	80.2
			User’s	87.9	54.1	59.5	79.6	85.8	54.8	87.9
2005	81.6	0.75	Producer's	76.2	83.6	77.6	76.4	84.7	72.5	100
			User’s	47.1	75.8	57.6	78.2	89.8	54.7	85.6
2009	82.3	0.75	Producer's	73.4	83.6	92.6	77.4	96.7	70.9	81.7
			User’s	82.5	63.7	55.8	89.9	46.5	36.7	90
2015	68.0	0.79	Producer's	56.9	72.2	87	83.8	62.1	41.9	72.4
			User’s	65.8	70.3	76.7	73.5	78.2	52.2	100

Table 5 above shows accuracy assessment results for the classes. The overall accuracy is fairly high with the values ranging from 68 to 82.3 per cent. On the other hand, tailings dumps shows an average accuracy, this suggests that the class is sharing reflectance properties with other classes like bare soil in farming, road cuttings and eroded surfaces. The same can be said with woody vegetation which suggests that it may have been adopted by other classes like farming and grassland. The Kappa Index of Agreement (KIA) for the study sites showed a higher rating ranging from 0.75 to 0.88. According to Landis & Koch (1977) a KIA strength of between 0.61 – 0.80 is "substantial" and between 0.81 – 1.00 is "almost perfect".

4.2. Change detection

Table 6: Summary of LULC changes for JCR for 1985 - 2015

LULC class	**1985-1991**	**1991-1995**	**1995-2000**	**2000-2005**	**2005-2009**	**2009-2015**
TD	-1.43	-1.11	-1.55	-0.23	-0.63	-0.18
IZ	0.32	1.98	1.1	1.18	-0.74	1.91
RU	0.11	0.76	-0.31	1.43	5.52	0.69
RT	1.25	0.37	0.18	6.84	5.17	2.03
WB	0.06	-0.07	0.07	-0.01	-0.06	-0.05
FG	-0.03	-1.1	1.52	-8.93	-12.09	-1.02
WV	-0.26	-0.84	-1.01	-0.28	2.84	-3.39

Note: TD=Tailings dump, IZ=Industrial Zone, RU=Residential Urban, RT=Residential Township, WB=Water body, FG=Farming and grassland and WV=Woody vegetation.

In table 6 above, the positive signs demonstrates gains in land cover classes and the negative signs depicts losses in classes. There is a meaningful change realised in all the LULC classes except for water body which shows a negligible change from 1985 to 2015. Farming and grassland together with woody vegetation show notable decline throughout the years, and these can be attributed to urbanisation in the form of human settlements and industrialisation. All other classes like industrial zones and human settlements have been increasing in land cover which is not surprising in an urban area.

4.3. Tailings Dump Rehabilitation and Vegetation

4.3.1. Dump Rehabilitation



Figure 8: Brakpan megadump tailings deposit in East Rand.

The Brakpan megadump rehabilitation project is applied here to demonstrate the success of rehabilitating the tailings dump through the re-vegetation process. Figure 9a - 9g shows the changes in normalised difference vegetation index (NDVI) of the Brakpan megadump over the years 1985, 1991, 1995, 2000, 2005, 2009 and 2015. The scale of the map ranges from red to yellow and to green colour. The red colour represents bare soil; the yellow colours represents moderate vegetation cover and; the green colour denotes high vegetation cover. The NDVI index ranges from -1 (no vegetation cover) to +1 (complete vegetation cover).

The first NDVI map of 1985 in figure 9a below shows the Brakpan dump having a healthy vegetation cover to the northern section which is also aided by the fact that the Landsat image used was taken in February, which is the final month of the wet summer season. The same area in 1991 (figure 9b below) shows degraded health of the vegetation.

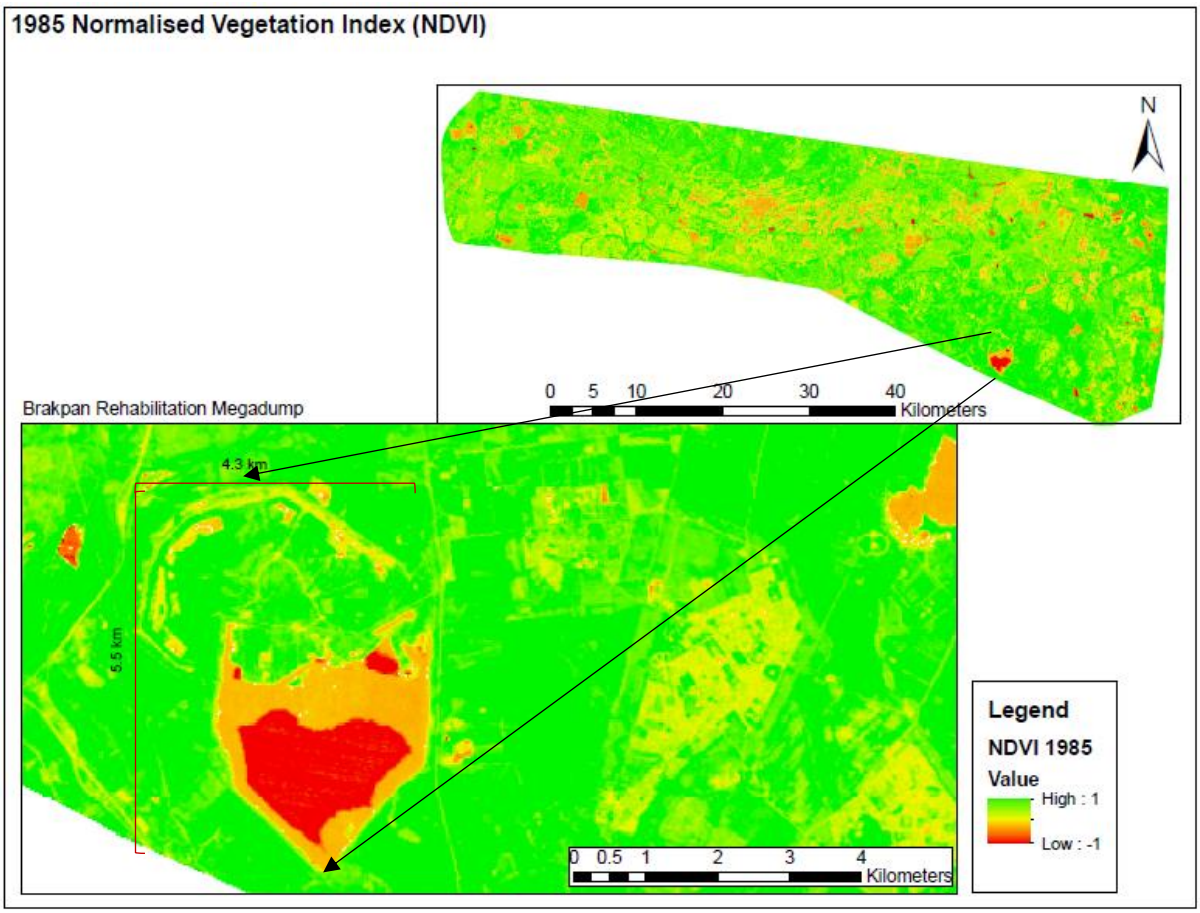


Figure 9a: 1985 Normalised Difference Vegetation Index of the Brakpan Rehabilitation Megadump, East Rand.

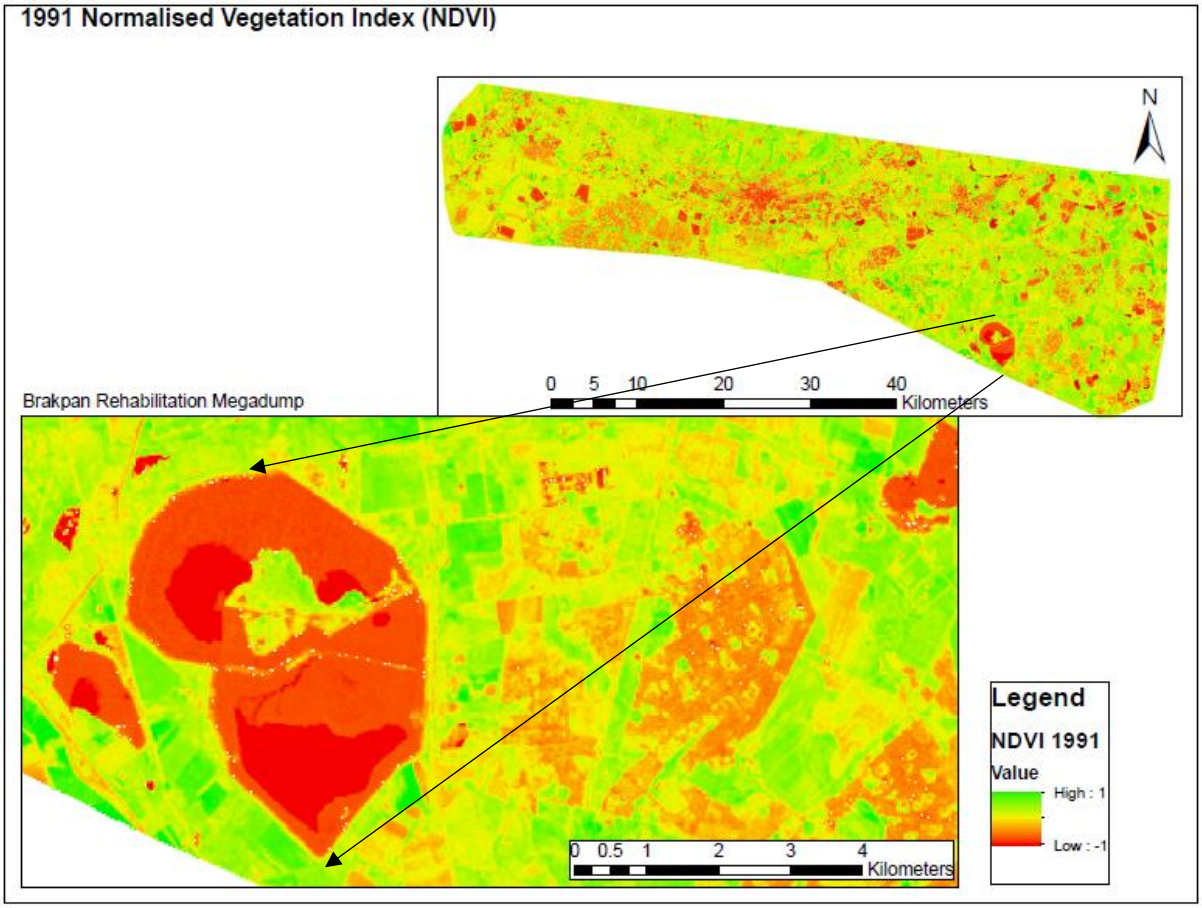


Figure 9b: 1991 Normalised Difference Vegetation Index of the Brakpan Rehabilitation Megadump, East Rand.

The 1995 map in figure 9c below shows a fair amount of vegetation recovery all over the dump. The 2000 NDVI map (figure 9d) shows the beginning of the tailings dump rehabilitation activity towards the southern tip of the dump. This is demonstrated by a higher value of NDVI which suggests healthy vegetation cover hence successful rehabilitation programme.

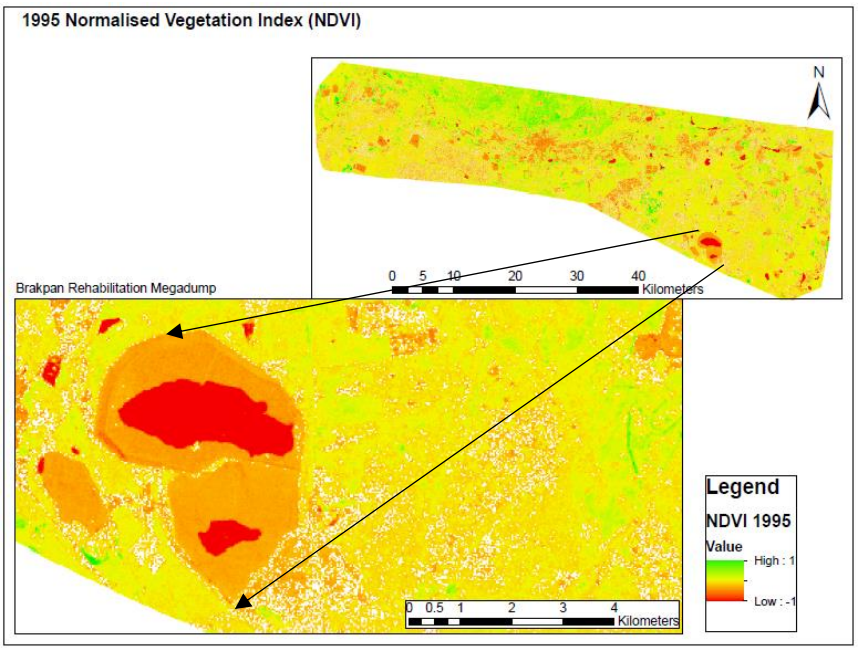


Figure 9c: 1995 Normalised Difference Vegetation Index of the Brakpan Rehabilitation Megadump, East Rand.

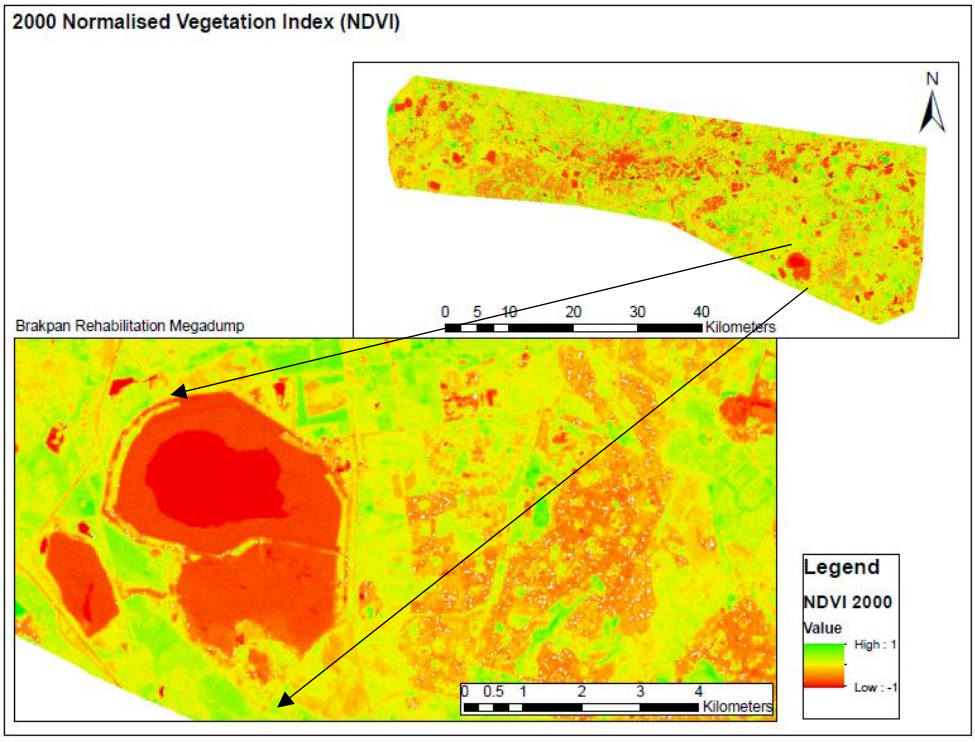


Figure 9d: 2000 Normalised Difference Vegetation Index of the Brakpan Rehabilitation Megadump, East Rand.

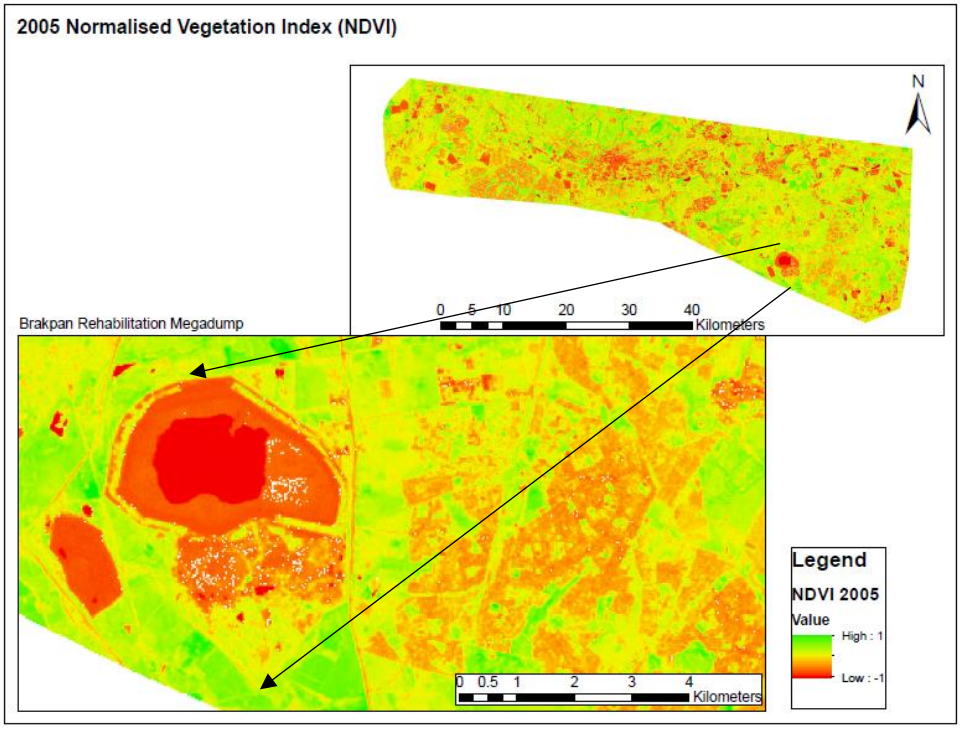


Figure 9e: 2005 Normalised Difference Vegetation Index of the Brakpan Rehabilitation Megadump, East Rand.

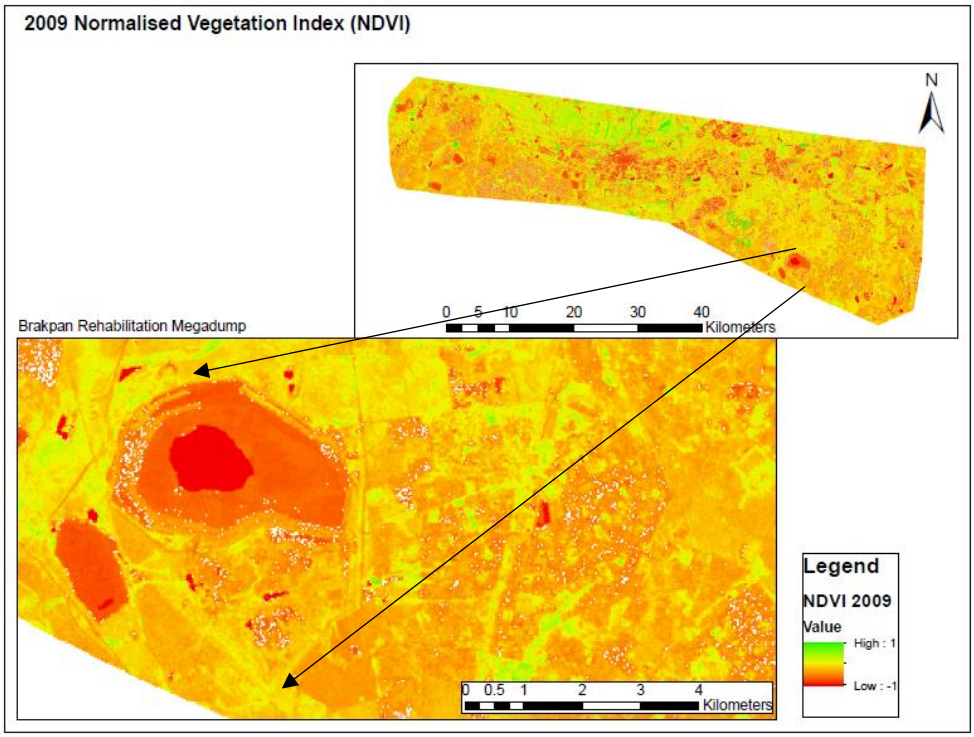


Figure 9f: 2009 Normalised Difference Vegetation Index of the Brakpan Rehabilitation Megadump, East Rand.

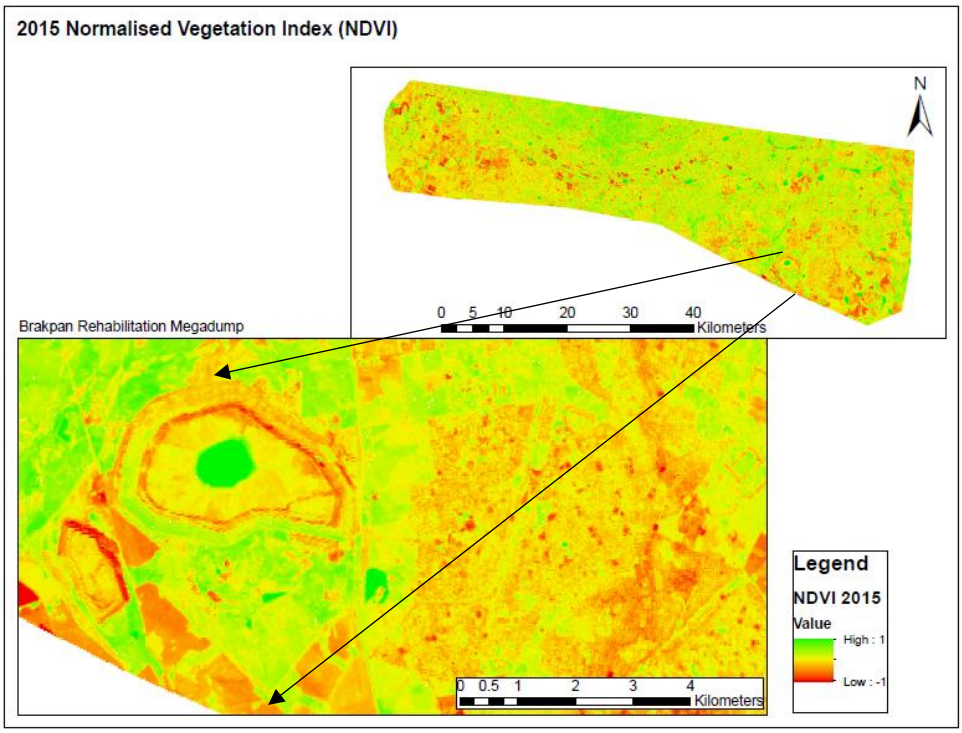


Figure 9g: 2015 Normalised Difference Vegetation Index of the Brakpan Rehabilitation Megadump, East Rand.

In Figure 10 below is appears that the reclamation of the Brakpan tailings dump relocated the tailings to the megadump rehabilitation site to the north. Therefore, the 2005 NDVI map (figure 9e) through to 2015 maps (figure 9g) shows a gradual improvement in the health of the vegetation on the reclaimed land and the megadump, demonstrating rehabilitation success. The slopes of the megadump site in figures 2 and 7 show successful vegetation cover and a positive value of NDVI on 2015 map.

Site visits taken to some of the tailings deposits under rehabilitation stages have demonstrated the amount of expertise and dedication required from those who are involved in the rehabilitation processes. There are difficulties involved in vegetating the dumps due to the steepness of the slopes and higher rate of wind and water erosion as shown in figure 11 below.

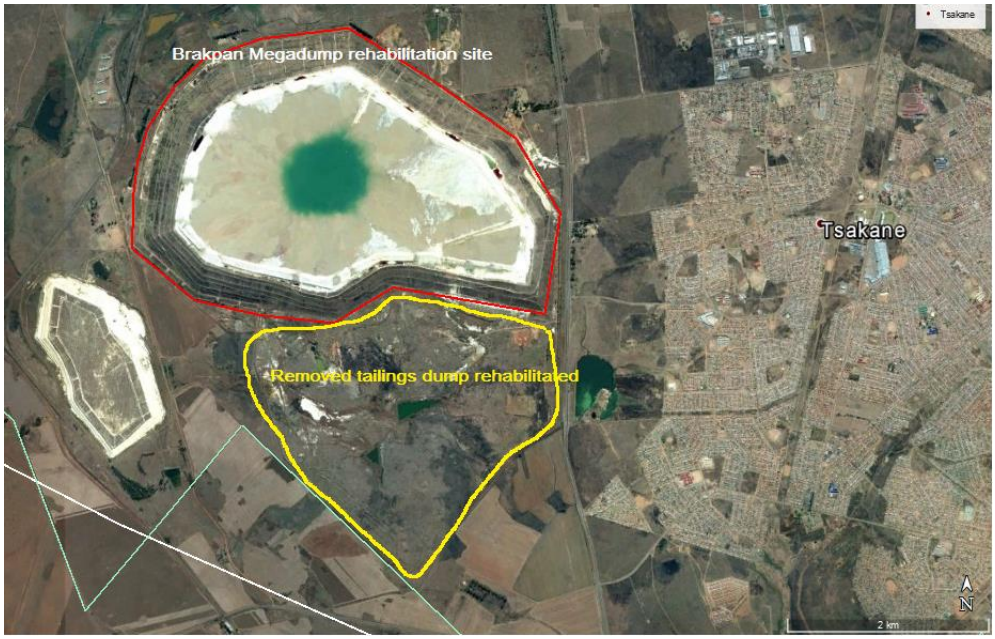


Figure 10: Google earth satellite image of Brakpan Megadump taken on the 13th August 2015. The Red boundary shows the megadump, and the yellow boundary shows an area formerly covered by a tailings dump.



Figure 11: Demonstration of difficulties in the revegetation of the dumps slopes.

CHAPTER FIVE

DISCUSSION

5.1. Change detection

First Research Question: ***Has there been an occurrence land use and land cover change as a result of reclamation of gold mines tailings deposits between 1985 and 2015?***

The discussion is based on change detection, rehabilitation and reclamation processes. There is LULCC in the study area as demonstrated in Table 6. It can be noted that tailings dumps deposits have been going through a gradual decline from 1985 to 2015, and this can be associated to rehabilitation and reclamation processes which started in the late 1980s according to Reichardt (2013). Ground truthing shows disappearance of certain tailings deposits as a result of reclamation, and industrial zones taking over the new pockets of land as can be demonstrated in Crown City, Selby, Ophirton, City Deep, Germiston Driehoek, etc. The most interesting outcome is that there is direct correction between gains in industrial zone and losses in tailings deposit. In table 4, tailings deposit class declined by half from 16815.5 ha in 1985 to 8083.71 ha in 2015, and industrial zone increased by over 60% from 15974.7 ha in 1985 to 25757.9 ha in 2015. It is important to note that change detection is not able to interpret the fact that tailings materials are moved from one location within the study area to the other (a megadump) still within the study area.

One important aspect of urbanisation most importantly, human settlements, is realised. There is a strong correlation between gains in human settlements and losses in farming and grassland and woody vegetation. In Table 4, 2000-2005 and 2005-2009 are the years showing massive decline in farming and grassland class (from 53699.1 ha in 2000 to 17928 ha in 2009), and the corresponding years shows a sharp increase in residential township (from 25306.4 ha in 2000 to 45736.8 ha in 2009) and residential urban (from 38839.3 ha 2000 to 50661.4 ha in 2009). This demonstrates the effectiveness of change detection modelling in highlighting this scenario which is very well shown in figure 6 and 7.

Second Research Question: ***What is the impact of reclamation of tailings dumps on the urban dynamics?***

The changes in LULC in the change detection shows correlation between tailings dump removal and expansion of industrial zone. Which means that new business avenues are realised within the region as a result of reclamation activities. Business attracts development of infrastructure and services, and these affect urban dynamics because of new activities occurring in areas where there was nothing before reclamation.

5.2. Rehabilitation and reclamation

Third Research Question: ***Can Landsat data successfully quantify urban dynamics changes in relation to reclamation and rehabilitation of the tailings deposits?***

Post mining land use is a concept which is gaining momentum in many places around the world as highlighted by (Limpitlaw & Briel, 2014). This is ever more important in a continuously growing Johannesburg City Region with higher demand for basic human needs and economic revitalisation from ailing gold mining industries to services industries. The use of Landsat data has successfully quantified changes in urban dynamics form 1985 to 2015. In figure 8 through to figure 11 there is a demonstration of tailings dumps rehabilitation program through grassing and tree planting. In this case the Normalised Differenced Vegetation Index (NDNI) is used to demonstrate the health of vegetation growth around the dumps. It is important to acknowledge the importance of remote sensing practises in analysing occurrence/absenteeism of data on quantifiable metrics such as NDVI (Luft *et al*., 2016).

In figure 9a to 9g there is a change in the NDVI of Brakpan megadump with 1985 showing healthy vegetation growth on the dump. But, from 2000 NDVI map there is a clear indication of soil disturbance through rehabilitation with material being moved to the main dump to the north. Latest map of 2015 NDVI of the same area shows an improved rehabilitated portion of land to the south of the megadump and a fair amount of vegetation cover on the megadump slopes. The top most part of the megadump shows a very low NDVI simply because new material from other dumps undergoing

reclamation are being deposited on the megadump. In this instance lack of vegetation cover does not necessarily demonstrate soil contamination as highlighted by Rösner & van Schalwyk (2000) or deprivation of nutrients in the soil.

Meanwhile, there are cases of tailings deposit which are not rehabilitated around the Snake-Park area in Soweto and Kagiso in Krugersdorp to name the few. These dumps have been documented as having potential to cause health issues due to massive wind erosion and water resource contamination from radioactive material (Schonfeld *et al*., 2014). These demonstrates that more work is needed to curb this issues especially because the dumps surround areas of high population density.

5.3. Limitation to Research

Though the study did manage to detect the changes resulting from reclamation and rehabilitation of the tailings deposits, it did fail to address certain questionable aspects. Rezoning of land previously owned or still owned by mining companies is treated as confidential information by the authorities and this decreased the depth of the study. Equally, certain departments which deal directly with the mining companies were not able to share records of rehabilitation processes, land condition post reclamation and licence agreements which created some uncertainties in the final results.

The use of free Landsat data in the study was very effective but also limited. The use of high resolution satellite images, which are available at a cost, are highly recommended for a similar study to this. Such data would be able to increase the accuracy of the change detection and supervised classification through the creation of accurate classifiers and vegetation index analysis. Similarly, not all the Landsat images required for the study were readily available which distorted the idea of utilizing data captured on certain season and years.

The use of dedicated data analysis software tools outside of the University jurisdictions is a challenge for long distance learners due to software licence agreements between the University and the suppliers. Therefore, this slows down the process of data preparation and analysis hence influencing data accuracy and timely completion of the research.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Gold mining activities which took place in the Witwatersrand Basin have changed LULC of the JCR. There are numerous man-made mountains which are affecting the urban dynamics of the JCR. Restrictions of urban development as a result of waste from mining activities should be treated as a serious concern and threat to human wellbeing and development. There is an ongoing process of dumps rehabilitation and reclamation in the JCR, and this activity is changing the regions landscape and urban dynamics. New pockets of land is being made available for new development. This study emphasised the benefits of RS in the assessment of pattern of change and rate of change over a 30 year period from 1985 to 2015. The rate of rehabilitation and reclamation turned out to be slow, taking several years to see a meaningful change. RS techniques are able to detect these slow processes through its ability to compare historical features with the current features pixel by pixel for change detection.

It is noted that there is some form of bias towards transforming the reclaimed land into industrial zones as opposed to other activities. This makes one wonder on whether this is driven by failure to completely rehabilitate that land, once occupied by tailings deposits, to the standard suitable for human habitat. There is a vast area of land in the JCR occupied by tailings dumps which are well vegetated, and green energy generation in the form of solar photovoltaic could make a better use of this land for generation of clean energy.

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