Examining land use and land cover change in the Western Cape, South Africa.

by

Ruan Coetzee

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Student Number: 30195543

Supervisor: Mr Danie Boshoff

Co-Supervisor: Prof. Hector Chikoore

Declaration

I, Ruan Coetzee declare that the dissertation, which I hereby submit for the degree Bachelor of Science Honours in Geography at the North-West University of Vanderbijlpark, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

I declare that:

1) I obtained the applicable research ethics approval.
2) I have observed the ethical standards required in terms of North-West University of Vanderbijlpark's Code of ethics for researchers and the Policy guidelines for responsible research.

Signature: ____________ Student number: 30195543

Date: 2021/11/19

Abstract

Land use land cover change/s (LULCC) are directly linked by the actions of people on their environment according to their needs. LULCC consists of natural, demographic, and socio-economic aspects and how human beings manage it in time and space, whereby LULCC is usually altered by either an increase or decrease in population growth, economic growth, physical factors such as topography, slope condition, climate changes, and different soil types. Most LULCC research that has been done in the past has focused mostly on regions of excessive human-induced activities to evaluate and measure the quantity, significance and effects of land surface changes that have been driven by these pressures. Therefore, there is a need to examine LULCC by focusing mostly on population size and human settlement growth and how it affects the environment as well as the different land cover types in the Western Cape that are being impacted.

This study makes use of census statistics and land cover maps to determine the influence that population has on LULCC, together with remotely sensed imagery of LULCC gathered through Google Earth Engine, SANBI and CHRS for some of the years between 2000 and 2020. The data was analysed and processed by making use of software such as ArcMap to identify and map the changes that took place in the Western Cape, and lastly, the maps and findings were attached to the project to determine the results of the project. The results of the study show that the City of Cape Town is the district in the Western Cape with the largest population count, with the smallest land surface area, and with the densest population. Further, there has been drastic LULCC that took place in the Western Cape, whereas these changes are a combination of both natural and human-induced activities. It is also determined that the Western parts of the Western Cape have received fewer amounts of rainfall than the Eastern parts which led to soil and land degradation over time and a loss in vegetation. Together with the naturally induced factors, there has also been an increase in the population size for the Western parts of the Western Cape which further led to urbanisation and land degradation over time.

Keywords:

Land Use, Land Cover, LULCC, Drivers of LULCC, Population, Population density, Urban built-up, Human settlement growth, rainfall, Water, NDVI, MODIS, El Niño, El Niña, Summer, Winter

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Abbreviations

CDNGI	Chief Director of National Geo-spatial Information
DEADP	Department of Environmental Affairs and Development Planning
DMSLP	Disaster Mitigation for Sustainable Livelihoods Programme
EOS	Earth Observing System
ETM+	Enhanced Thematic Mapper Plus
EVI	Enhanced Vegetation Index
GAMA	Greater Accra Metropolitan Area
GEE	Google Earth Engine
GIS	Geographical Information System
HSGO	Humboldt State Geospatial Online
LULCC	Land Use Land Cover Changes
MDB	Municipal Demarcation Board
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Multispectral Scanner
NDVI	Normalized difference vegetation index
OLI	Operational Land Imager
PSDF	Provincial Spatial Development Framework
SANBI	South African National Biodiversity Institute
SANSA	South African National Space Agency
SOE	State-Owned Enterprise
Stats SA	Statistics South Africa
TM	Thematic Mapper
UNECE	United Nations Economic Commission for Europe
WC	Western Cape

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1. Introduction and background

1.1 Introduction

According to Shunlin *et al*. (2012), land cover refers to both the physical and biological cover over the surface of the land, which includes things such as vegetation, water, artificial structures, and soil, whereas land use can be characterized by activities, arrangements, and inputs that are directly related to how people in a specific land cover type change, produce or maintain these changes. Therefore, land use and land cover are directly linked by the actions of people on their environment. Tewabe and Fentahun (2020), states that land use land cover changes (LULCC), consists of natural, demographic, and socio-economic aspects and how human beings manage it in time and space, whereby LULCC is usually altered by either an increase or decrease in population growth, economic growth, physical factors such as topography, slope condition, climate changes, and different soil types.

LULCC can also be identified as a historical process that relates to how people use and modify the land they live on according to their needs. Additionally, Van der Merwe (2005) has also observed that all ecosystems are dynamic in time and space. It is however determined that not all the effects of LULCC are necessarily negative, whereas many LULCC can also involve things such as resource use efficiency, increases in agricultural production, wealth, and well-being (Bimal & Rashid, 2017). Therefore, to further promote multi-temporal monitoring, it is beneficial to research both the short- and long-term variability of ecosystems so that land degradation and other changes of LULCC may be documented and acted upon.

1.2 Problem statement

According to Tewabe and Fentahun (2020), one of the most important drivers of LULCC, and the changes that take place within the natural environment are because of human activities. Xulu (2014), adds to this by stating that this is because there is an ever-increasing growth taking place in the world's population, which alters the earth's surface, especially in urban spaces, whereby both social and environmental problems can occur, because of the massive rate of urban growth that takes place and because of inadequate management.

Wessels *et al*. (2007) assert that land degradation is also identified as one of the most, severe global environmental problems that can threaten water resources, biodiversity, and food systems, and should therefore be examined. LULCC problems can also be identified as the loss of vegetation cover, forest degradation, lack of sufficient infrastructure and housing for the rapidly growing population, an increase in informal settlements, inadequate waste management, and inadequate city planning and monitoring (Xulu, 2014). LULCC changes can further lead to changes and conditions such as natural hazards, climate changes and other socio-economic problems that can take place on both local and global scales, whereby the increases in population growth together with climate change can also pose a huge threat when it comes to water and resource availability (Tewabe & Fentahun, 2020).

The Western Cape is identified as the fourth largest province in South Africa and covers 10.6% of the country's total land surface, whereby approximately 11.3% of the country's population resides in this area (Tizora *et al.*, 2018). The Western Cape has rich biodiversity together with many unique landscapes that serve as major tourist attractions in South Africa, which helps to boost its economy. Additionally, this region has documented a rapid increase in its population (Ferreira, 2007).

1.3 Research Question

To what extent have rapid population growth and settlement expansion affected land use and land cover types in the Western Cape?

1.4 Research aim and objectives

In response to the primary research question, the main aim of this study is to examine the role population growth has on LULCC in the Western Cape over 20 years (from 2000 to 2020).

The objectives of this study are to:

- Classify the different land cover types.
- Examine and map LULCC.
- Map the population and human settlement growth over 20 years.
- Explore the main drivers that cause LULCC.

1.5 Study Area

Figure 1 on the next page represents the study area, which is further divided into five different district municipalities (West Coast, Cape Winelands, Garden Route, Overberg, and Central Karoo) and a metropolitan municipality (City of Cape Town) to make it more area specific. The area of the Western Cape is 129462.21km².

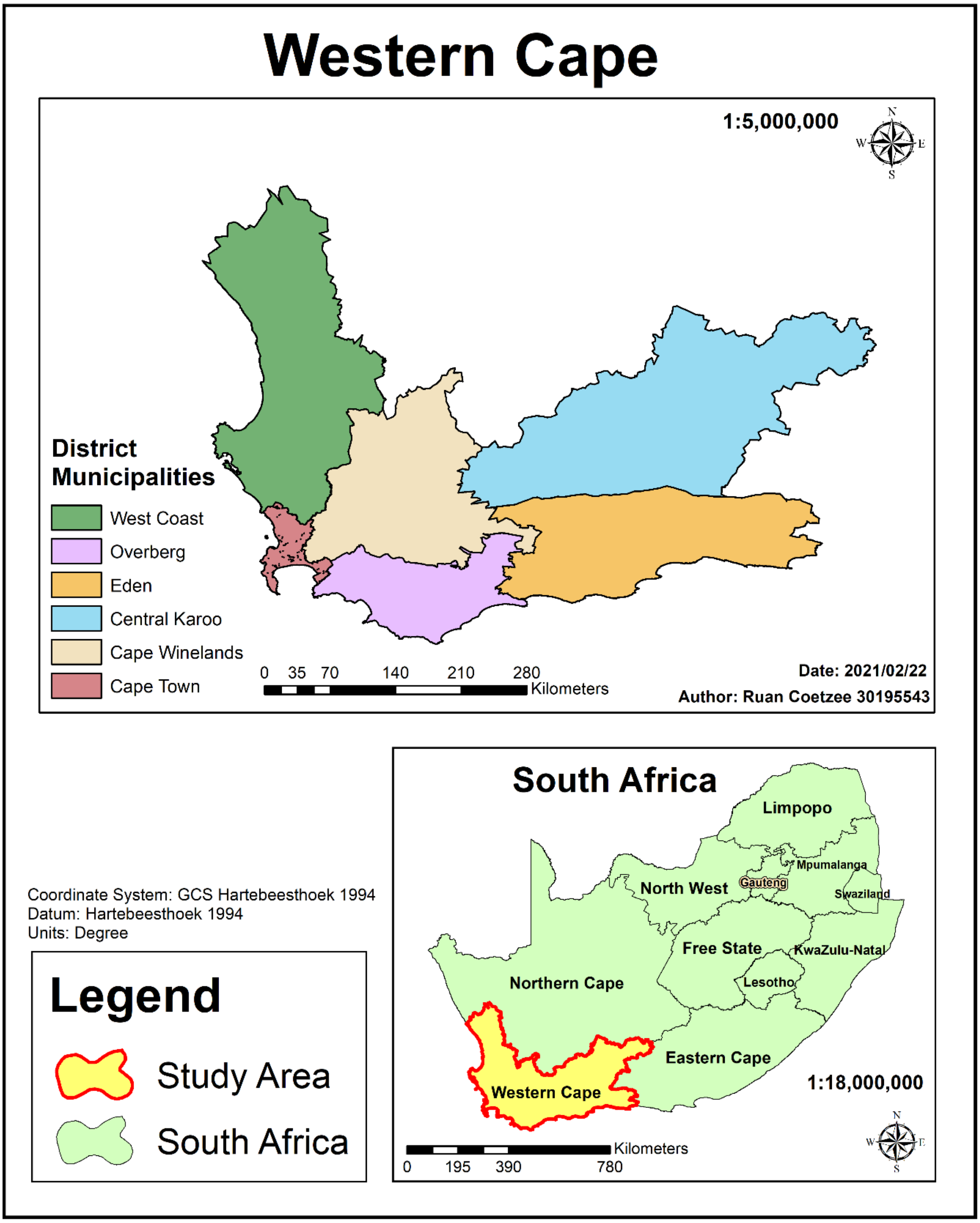


Figure 1: Map of the Western Cape and its district municipalities.

2. Literature Review

2.1 Introduction

This section will be used to review literature derived from naturally induced factors, demographic factors, and socio-economic factors which all form part of the main drivers of LULCC. Additionally, different forms of literature will also be used to determine what is meant by “land use” and “land cover”, followed by the influence that the human population and human settlement growth can have on LULCC in general. According to Shunlin *et al*. (2012), the rates, intensities, and extents of LULCC are presently at their greatest it’s ever been before globally, which causes changes to occur in environmental processes and ecosystems around the world. It is further determined that the driving factors are one of the most important aspects when it comes to acknowledging the challenges, monitoring developments, and lessening the impacts of land-use changes (Tizora *et al.* 2016).

2.2 Defining Land use and Landcover

Tizora *et al.* (2016) assert that Land use and land cover have different meanings, even though it is mostly used interchangeably, whereas land cover is identified as the physical features of the surface of the land, while land use is identified as the actual purpose that land can be used for. It is also identified that various factors can drive the changes that take place in LULCC, whereby these changes can differ from country to country and region to region, from time to time (Xulu, 2014). Figure 2 on the next page indicates the relationship between land cover, land use and land function, whereby land function is identified as the capability of the land to provide goods and services. As indicated below, all these land systems interact with each other in some form or another, depending on the tasks that need to be performed.

Furthermore, in Chapter 1 of the SPLUM (Spatial Planning and Land Use Management Act No 16 of 2013), land use is defined as “the purpose for which land is or may be used lawfully in terms of a land use scheme, existing scheme or in terms of any other authorization, permit or consent issued by a competent authority, and includes any conditions related to such land use purpose.” However, this definition is not entirely correct because people can still take control of land and land use by using it for many different purposes while not necessarily complying with the land use authorization or schemes. Therefore, it is determined that land use is uncertain, whereby it can either be used illegally or legally and that land use does not necessarily end at political boundaries (Cooper, 2014).

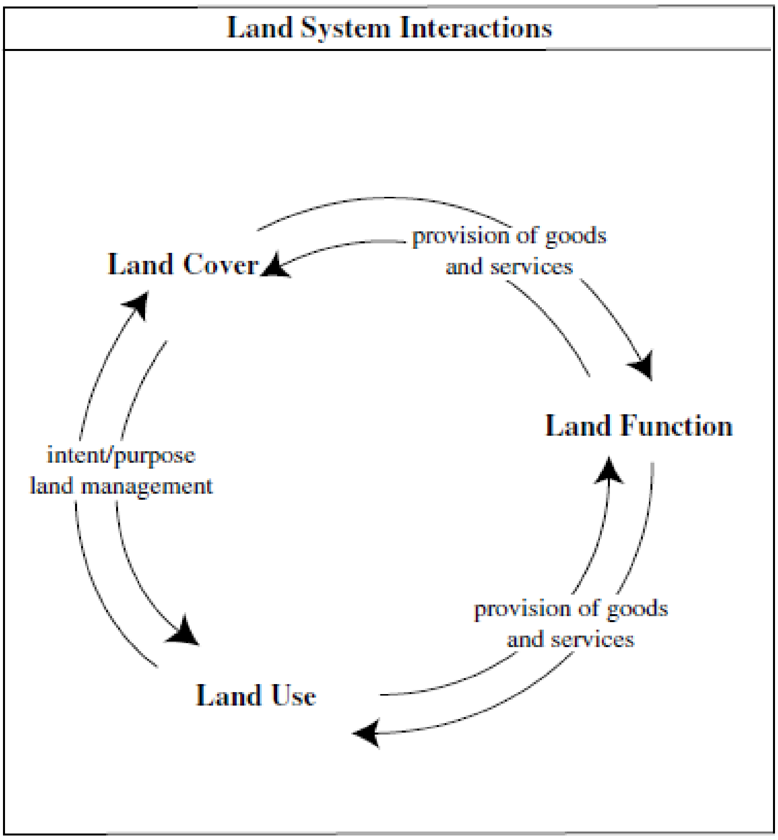


Figure 2:Land cover, Land use and Land Function relationships (Verburg et al., 2009).

2.3 Drivers of LULCC

According to Tewabe and Fentahun (2020), one of the most important drivers of LULCC, and more specifically the changes that take place within the natural environment are because of human activities. This is because human beings are constantly growing in numbers and are constantly changing and developing their surroundings. Therefore, most LULCC research that has been done in the past has focused mostly on regions of excessive human-induced pressures to evaluate and measure the quantity, significance and effects of land surface changes that have been driven by these pressures. Bimal & Rashid (2017) assert that the drivers of LULCC do not only differ over time, but these changes also differ from country to country as well as within different regions within a country. They further state that on a global scale, things such as soil degradation, deforestation, overgrazing, urbanization, rapid population growth and industrialization, among other things are all associated with the drivers of LULCC (Bimal & Rashid, 2017).

2.3.1 Naturally induced factors that cause LULCC

Naturally induced factors can be identified as one of the main reasons for LULCC to take place whereby these factors can be referred to as agro-climatic conditions, which is known as the relationship between agriculture and climate (DEADP, 2019). Agriculture cannot be identified as a naturally induced factor, however, the climatic conditions that effects agriculture directly are identified as naturally induced factors when it comes to LULCC. These agro-climatic conditions consist of things such as rainfall, soil types, water availability, temperature, and slopes, whereby all these conditions influence the type of vegetation within a certain region or area (DEADP, 2019). According to Bimal & Rashid (2017), LULCC can be grouped into four categories known as undisturbed, agricultural, frontier, and urban, whereas undisturbed landscapes are predominantly known for their natural land cover types, and therefore undisturbed landscapes are mostly affected by naturally induced factors with very little to no, human-induced disturbances.

Water availability can also become problematic when examining naturally induced factors, whereby land uses such as agriculture are dependent on water for irrigation (Tizora, 2018). Crop irrigation and agricultural activities are classified as the most predominant users of water in South Africa, whereby South Africans are still facing challenges when it comes to uneven and uncertain rainfall and water availability with just about 450mm of rain per year compared to the world average which is about 860mm of rainfall per year (StatsSA, 2019). Furthermore, Fischer *et al*. (2002) state that there are several pressures and constraints which can exist when it comes to both the chemical and physical properties of soil which are very important when it comes to land use, whereby these pressures can be identified as the soil depth, terrain-slope, soil chemical, soil fertility, soil drainage and soil texture. According to the Minister of Local Government of Environmental Affairs and Development Planning, the Western Cape can be recognized as one of the most disaster-prone provinces in South Africa, whereby ten disasters were announced from the year 2006 to 2010, of which eight of them were declared as disasters by the National Disaster Management Centre, whereby these disasters mostly included droughts, flooding events and the displacement of human beings (DMSLP, 2010).

Most of these disasters that took place were droughts which were reported every year from January 2015 until 13th June 2018, whereby three municipalities were classified as local hydrologic drought areas on the 11th January 2016. Additionally, the National Disaster Management Centre (NDMC) classified a provincial disaster for the Western Cape on the 25th of April 2017, which allowed the Provincial Cabinet to declare a provincial state of disaster on

23rd May 2017. The provincial drought declaration was further reclassified by the NDMC in terms of section 23 (6) of the DMA on 13th February 2018 as a National Disaster (Kwela, 2018). Therefore, from the above literature, it is determined that Natural induced factors do play a huge role when it comes to LULCC in the Western Cape, but it does not necessarily play the biggest role because there are very few changes in landcover that take place naturally, whereas naturally induced changes take place mostly in a sustainable manner and do not affect the environment negatively over a long period unless something drastic happens like a disaster that cannot be predicted or contained, which is also very unlikely. From the above literature on naturally induced factors that cause LULCC, it is determined that the main drivers of LULCC that need to be researched for the Western Cape are deforestation, soil degradation, overgrazing, industrialization, urbanization, as well as rapid population growth. These drivers are mostly affected by conditions such as soil types, rainfall, water availability, temperature, slopes, and excessive human-induced pressures which all affect the type of vegetation and LULCC in the Western Cape and therefore needs to be examined.

2.3.2 Demographic factors that cause LULCC

Human-induced factors can be identified worldwide as the main reason for LULCC to take place, whereby these factors are directly connected to the population size, the population density, as well as how people manage the land they live on over time and space (Tewabe and Fentahun, 2020). According to the WWF (2012), the impact that human settlements have on the environment increases together with settlement growth, population growth, economic growth and an increase in human consumption, whereas all evidence gathered indicates that the impact that human settlements have on environmental resources are also rapidly increasing worldwide. The Minister for Cooperative Governance and Traditional Affairs adds to this by stating that as population increases, urbanization also increases in size, which can be directly coupled with the effects of climate variability, which ultimately develops more pressure on the demand for addressing and determining vulnerabilities to extreme and disastrous events that are being faced by societies (DMSLP, 2010). Therefore, it is very important to monitor population growth when it comes to LULCC in any area or region in the world.

Some of the forms of human-induced factors can be identified by the changes that take place in vegetation because of activities done by humans such as cultivation, timber plantations, urbanization, loss of woodlands, overgrazing by livestock as well as soil erosion that occurs because of settlement expansions and development (McGinley, 2008). Alphan *et al.* (2009) assert that there are currently very fast and extreme land cover changes that are taking place worldwide because of human-induced pressures on the environment, which also have serious implications when it comes to sustainable resource use. These land cover changes typically take place slowly or rapidly, depending on the type of human-induced pressures within a specific area (Xulu, 2014). Nonetheless, Barbier (2000) has also discovered a positive relationship between intensive LULCC and land degradation problems, whereby a similar observation was proclaimed by Maitima *et al*. (2009), which concluded that LULCC can also be described as a central aspect when researching land degradation. Furthermore, there is also evidence gathered by Lowry *et al*. (2005) and Abbas (2009) which indicates that significant LULCC is mostly evident in regions that are experiencing agricultural and developmental demands together with natural pressures. According to Xulu (2014), when it comes to human-induced activities that influence land degradation, land cover change is singled out as being the number one influence of degradation.

Nonetheless, in South Africa, the population size has increased from about 40.6 million in 1996 to 51.8 million in 2011 (increased by about 28%), with an increase of just more than 11 million people, which just indicates the rapid increase in population size over such a short period (StatsSA, 2019). Furthermore, South Africa is also identified as being the 24th largest country in the world when it comes to population size, but South Africa is only the 169th largest country in the world when it comes to population density (41.4 people per km^2), which illustrates that the country has an even bigger problem when it comes to population distribution (StatsSA, 2019). When looking at a more area-specific approach, it is determined that the Western Cape is identified as the fourth largest province in South Africa and covers about 10.6% of the country's total land surface, whereby approximately 11.3% of the country's population resides in this area (Tizora *et al.*, 2018). According to Ferreira (2007), the Western Cape is also an area that is identified as one of South Africa's major tourist attractions, as well as an area with a rapid increase in its population, which all form part of the main drivers of LULCC.

The Western Cape is further recognized in 2019 as being the province with the highest life expectancy at birth for both females and males which further contributes to the rapid growth in its population (StatsSA, 2019). Furthermore, when looking into migration patterns it is determined that both the Western Cape (86577 immigrants) and Gauteng (353592 immigrants) have received the highest amounts of immigrants for all the years from 2006 to 2019, which just again indicates why the population is growing so rapidly within the Western Cape (StatsSA, 2019). Therefore, it is determined that population and human settlement growth plays one of the biggest roles when examining LULCC in the Western Cape and should therefore be treated as one of the most important factors together with human-induced factors. Furthermore, when looking from a more area-specific approach it is identified that there is also rapid and unplanned development that takes place in environmentally sensitive areas in the Western Cape, as well as policies that are being implemented without first taking the impacts of LULCC into account. These rapid and unplanned developments which take place are mainly because of human-induced factors that take place in the Western Cape (Tizora *et al.*, 2018). Therefore, it is evident from the literature that human-induced factors are the leading cause of LULCC, together with rapid and unplanned development and has therefore surpassed naturally induced factors, making it a central aspect to focus on when researching and monitoring LULCC. These human-induced LULCC can be very bad for the environment if they are not managed properly and can therefore have severe consequences when it comes to both long- and short-term changes. From the above literature on human-induced factors that cause LULCC, it is determined that the main driver of LULCC that need to be researched for the Western Cape is rapid population growth, which can be monitored by examining things such as the population size, population density, and human expansion and development.

2.3.3 Socio-economic factors that cause LULCC

According to Brown *et al*. (2013), LULCC is a very complex form of environmental and socio-economic issue that requires a broad understanding when it comes to the synergy and the relationship between both human-induced activities and the environment. Therefore, LULCC is recognized as being one of the most prevalent socio-economic forces when it comes to determining the changes and the level of degradation that takes place within ecosystems. LULCC has also become a central aspect in both present and future strategies when it comes to managing and monitoring environmental changes as well as natural resources (Tiwari and Saxena, 2011). Socio-economic factors can be identified as things such as age, gender, education, household size, wealth and residence size, amongst others (Handavu *et al*., 2019).

Studies that have been done on various land and landscapes indicate that there were changes taking place specifically when it comes to demographic patterns in population density, population growth, and the distribution of populations over long periods, which significantly influenced land use, whereas immigration has been identified as being the most important demographic component that drives LULLC (Lambin *et al*., 2003; Verbist *et al*., 2005; Yohannes *et al*., 2018). LULCC can further be determined by how landowners, governments and communities control land use and how they make choices regarding land use (Tizora *et al.*, 2018). These choices can be influenced by interactions that involve “socioeconomic factors such as population and biophysical factors which vary at different scales" (Tizora *et al.*, 2016). According to the UNECE (2008), it is a government's duty and responsibility to provide spatial plans, as well as effective human settlement strategies which aim towards sustainable socio-economic development. Therefore it is determined that it is mostly the government's responsibility to make sure that LULCC is being investigated and that the necessary plans and strategies are being implemented. From the above literature on socio-economic factors that cause LULCC, it is determined that it is important to examine the demographic patterns in population as also mentioned in both the naturally induced and human-induced factors section, but the most important demographic component that drives LULCC in South Africa and the Western Cape is identified as immigration and should therefore be investigated in more detail.

2.4 Summary

This section was used to review literature based upon naturally induced factors, demographic factors, and socio-economic factors, which all form part of the main drivers of LULCC. There was also, many different forms of literature that were used to determine what is meant by "land use" and "land cover", followed by the influence that the human population and human settlement growth can have on LULCC in general. From the literature gathered, it is determined that Tizora *et al*. has done the most extensive research when it comes to the driving factors of LULCC in South Africa, and more specifically when it comes to the Western Cape in South Africa, and therefore their research serves as a guideline and as one of the primary sources that will be used for this research. Furthermore, it is determined in the literature that one of the most important drivers of LULCC, and more specifically the changes that take place within the natural environment are because of human-induced activities. This is because human beings are constantly growing in numbers and are constantly changing and developing their surroundings. Therefore, it is found that there is a need to examine LULCC by more specifically focusing on population size and human settlement growth and how it affects the environment as well as the different land cover types in the Western Cape that are being impacted. The review of academic literature has further revealed that there have been many attempts by numerous authors to examine LULCC globally whereas there were a little bit fewer attempts within South Africa, and additionally, very few attempts when it comes more to the Western Cape in South Africa.

3. Research Methodology

3.1 Introduction

This section explains the methods used to answer the research question and ultimately achieve the aim and objectives of the research. This was done by firstly explaining the data collection methods that were used, followed by the data analysis methods and approaches.

3.2 Data Collection

The data that was gathered for land-use changes are mostly based upon quantitative data because the study makes use of census statistics and land cover maps to determine the influence that population has on LULCC. Furthermore, the data that was used for land cover changes were gathered and used through Satellite data of LULCC for some of the years between 2000 and 2020 with different sensor types such as:

- Enhanced Thematic Mapper Plus (ETM+), Landsat 7 data
- Operational Land Imager (OLI), Landsat 8 data
- MODIS satellite data used for NDVI data (to examine green vegetation and plant health)

Additionally, for land cover changes some rainfall data was gathered and used to help examine the different soil types and vegetation health found in this area. Landsat 7 was launched on the 15th of April 1999 and will therefore be used for some of the data collection from 2010 to 2020. Furthermore, Landsat 8 was launched on the 11th of February 2013 and will therefore be used for some of the years after 2013. The data was then analysed and processed by making use of software such as ArcGIS and QGIS to identify and map the changes that took place in the Western Cape, and lastly, the maps and findings were attached to the project to determine the results of the project.

For this project, satellite data and ArcGIS shapefiles were gathered from existing datasets such as:

- Google Earth Engine https://earthengine.google.com
- CHRS (Centre for Hydrometeorology and Remote Sensing) https://chrsdata.eng.uci.edu/
- Adrian Frith (Developer & Mapmaker) https://adrian.frith.dev
- SANBI www.sanbi.gov.za
- USGS https://earthexplorer.usgs.gov/
- CDNGI http://www.cdngiportal.co.za/cdngiportal

- SOE https://soer.environment.gov.za/soer/CMSWebSite/GISdata.aspx
- SANSA https://www.sansa.org.za
- Municipal Demarcation Board www.demarcation.org.za

However, the data was mostly gathered from GEE (Google Earth Engine) for the Western Cape between the years 2000 and 2020.

3.3 Data Analysis

This study consists of four major components that are classified as land cover type analysis, examining and mapping LULCC, population and human settlement analysis and the drivers of LULCC.

3.3.1 Land Cover type analysis

Figure 3 below indicates the different methods that can be used to gather data for land cover as well as for land use, whereby it is determined that for land cover analysis, data gathering methods such as remote sensing data, aerial photography and field mapping data can be used, and for land use data it is better to make use of data such as census data and observations made from land cover maps (Verburg *et al*., 2009). This figure serves as a very good guideline that will be used to gather all the data needed for this project.

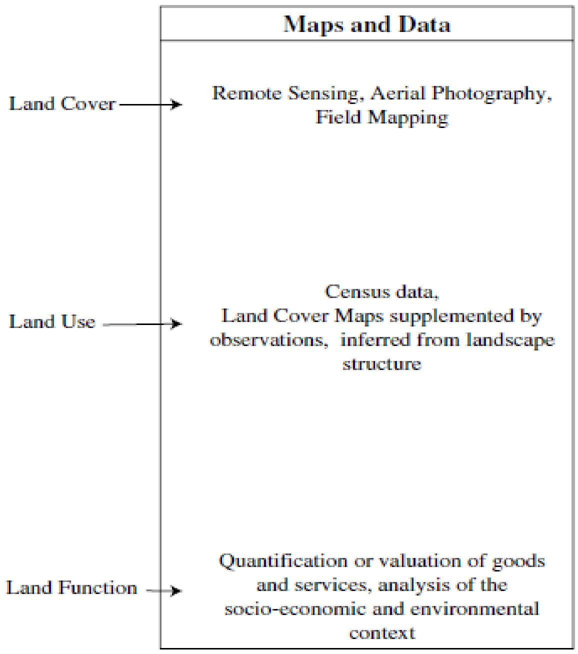


Figure 3: Methods that can be used to collect spatial data (Verburg et al., 2009).

3.3.2 Examining and mapping LULCC

According to Yuan *et al.* (2005), four aspects must be considered before choosing satellite imagery for mapping land cover changes which are identified as the spectral response of surface features, the date the image was acquired (determines the quality of data), the pre-processing stage and lastly the area of interest. These benchmarks will all be considered before choosing secondary satellite imagery that is suitable for this study. Addae and Oppelt (2019) have previously made use of a post-classification change detection method that was used for multiple Landsat images to be able to analyse and map the extent and rate of LULCC that took place between 1991 and 2015 in the GAMA region situated in Ghana, which served as a good indication of how to examine changes in LULCC.

Google Earth Engine (GEE) was used to gather NDVI data for the Western Cape from the year 2000 to 2020 by making use of MOD13Q1 version 6, which is known as MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid. MOD13Q1 data is generated every 16 days at 250-meter spatial resolution as a Level 3 product. Furthermore, MOD13Q1 is used to provide two vegetation layers, whereby the first is NDVI (Normalized Difference Vegetation Index) which can be referred to as the continuity index that is used to indicate the existing National Oceanic and Atmospheric Administration-Advanced Very High-Resolution Radiometer (NOAA-AVHRR) derived NDVI. The second vegetation layer that MOD13Q1 is used for is EVI (Enhanced Vegetation Index), which will not be used for this specific project. The HDF (Hierarchical Data Format) file makes use of MODIS reflectance bands 1 (red), 2 (near-infrared), 3 (blue), and 7 (mid-infrared), as well as four observation layers. MOD13Q1 data can be used from the year 2000/02/18 to the present, making it the ideal fit for the period needed for this project (USGS, 2021).

For this project, the NDVI MODIS data was gathered through GEE between the year 2000 to 2020. The data is gathered every 5 years for January (summer) and June (winter), to be able to receive some understanding of NDVI seasonality over a time series. The data was gathered through GEE by firstly exploring the MODIS datasets that can be found in the Earth Engine Data Catalog on their main website. In this Data Catalog, the scripts that were used in Google Earth Engine's code editor was gathered. Thereafter, Google Earth Engine's code editor was used to generate the NDVI MODIS data for each of the years used and a legend was created afterwards in the code editor. Additionally, all the data gathered was opened with ArcMap 10.5 and exported into a map afterwards which was then used for this project. Additionally, rainfall data was also gathered for the Western Cape by using the PERSIANN-Cloud Classification System (PERSIANN-CCS) which is a real-time global high resolution (0.04° x 0.04° or 4km x

4km) satellite precipitation product developed by the Centre for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI).

Moreover, the PERSIANN-CCS system ensures that the categorization of cloud-patch features can be done by making use of areal extent, cloud height, and variability of texture estimated gathered from satellite imagery. The PERSIANN-CCS classification system makes use of cloud segmentation algorithms together with an approach that identifies and separates individual patches of clouds. These individual patches can then be classified based on geometric properties, texture, cloud top height, and dynamic evolution. Furthermore, these classifications assist in assigning certain rainfall values to pixels within each cloud based on a specific curve by representing the relationship between brightness temperature and the rate of rainfall (CHRS, 2021).

However, the most appropriate method for land-use changes that were used for this study, was to map the population growth and human settlement expansion in the Western Cape by making use of Census statistical data that was gathered free of charge from sources such as Statistics South Africa. This was done by mapping the changes in land cover that took place over 20 years by making use of different types of satellite data that was gathered as mentioned in chapter 3 under the data collection section (Chapter 3.2).

3.3.3 Population and human settlement growth analysis

Addae and Oppelt (2019), made use of another method that was used to examine and analyse the relationship between LULCC and population growth in the southern parts of Ghana by making use of remote sensing techniques, whereby one of the methods that they used, was to examine the relationship between the housing quality index and urban vegetation change while making use of statistical data and remote sensing techniques. This method serves as a good indication of methods that can be used to examine the changes that took place in the Western Cape. Therefore, it is determined by studying some of the methods that Addae and Oppelt used, that there are also some of the same methods that can be used to examine the population and human settlement growth that took place in the Western Cape for some of the years between 2000 and 2020.

3.3.4 Drivers of LULCC

The driving factors of LULCC will be determined by examining the current state of LULCC by reviewing literature that is based on factors that affect things such as land decisions in the

Western Cape. Moreover, this will be done by investigating policies such as the PSDF (Provincial Spatial Development Framework), which is used to resolve future LULCC. The results found from the driving factors of LULCC that will additionally be gathered from previous literature will then determine which additional data will be needed for the rest of the research.

3.4 Limitations

When it comes to viewing and downloading Landsat data, the files can be very large, making it a necessity to have a device with lots of storage capacity. It is also important to make use of an internet device that does not limit the user when downloading all necessary files needed for the project, preferably uncapped internet. Slow internet can also play a big part in how long it will take to view and download the files in Google Earth Engine and other databases. Furthermore, it is also beneficial to have a computer or laptop with good hardware and a good operating system (not older than Windows 10 or 11) that can easily support ArcMap and QGIS. Therefore, in this project the Landsat data used was mostly gathered, processed, and represented by making use of 5-year intervals over the 20 years and not for every single year. Nonetheless, the maps also take up a lot of space on the pages and a lot of time to process in Google Earth Engine and ArcMap, making it much more practical to use the 5-year interval method as done in this project. Covid 19 has also played a huge role since 2019, making it very difficult to travel freely, to do fieldwork, and to see or talk to other students and supervisors in person which meant that new methods for gathering data had to be used and meetings had to be done via online platforms such as Zoom or Microsoft Teams with other students and supervisors.

3.5 Summary

It is found that there is a gap when it comes to mapping the population of human settlement growth in the Western Cape which will therefore be done in this project by mostly making use of census data to determine the land-use changes and by making use of software such as ArcMap to map the findings. Furthermore, it is found that it is important to examine the different land cover changes that took place in the Western Cape in the past 20 years, which is done by making observations and mapping the changes that took place using land cover change data gathered in the form of TIFF files via SANBI as well as satellite data that will mostly be gathered via Google Earth Engine and edited in ArcMap 10.5.

4. Results and discussions

4.1 Introduction

In this section, the census data that has been gathered, together with the secondary Satellite data of LULCC for some of the years between 2000 and 2020 will be used together with software such as ArcGIS to map and determine the outcomes of all the findings.

4.2 Classifying the different land cover types

This section is used to indicate the different land cover types that can be found in the Western Cape which is arranged into different categories in Figure 4 and Figure 5. The different land cover types that can be found in the Western Cape are identified as Barren land, cultivated land, Forests, Shrubland/fynbos, Grasslands, Wetlands, Waterbodies, Mines/quarries, and Urban built-up.

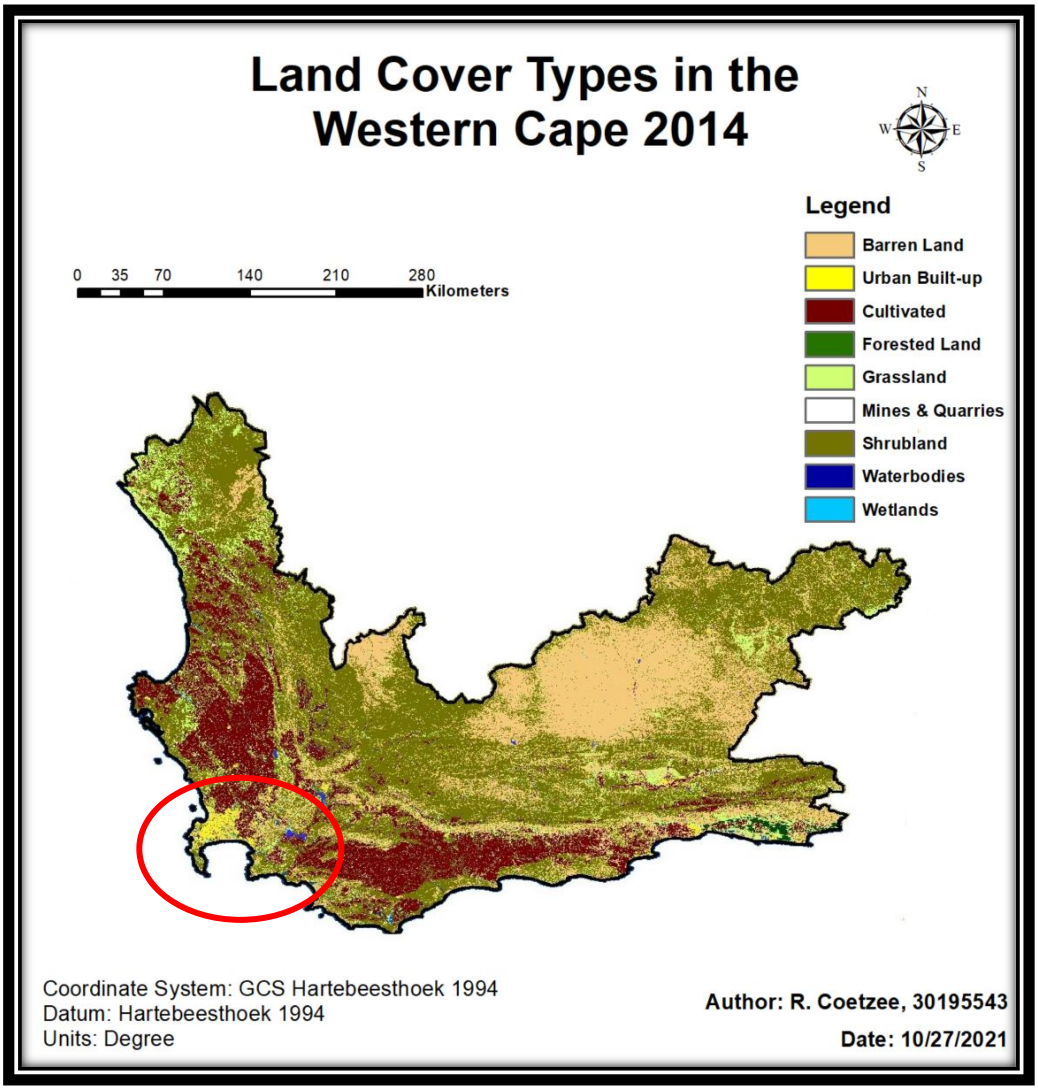


Figure 4: The different land cover types found in the Western Cape, 2014 (SANBI, 2021).

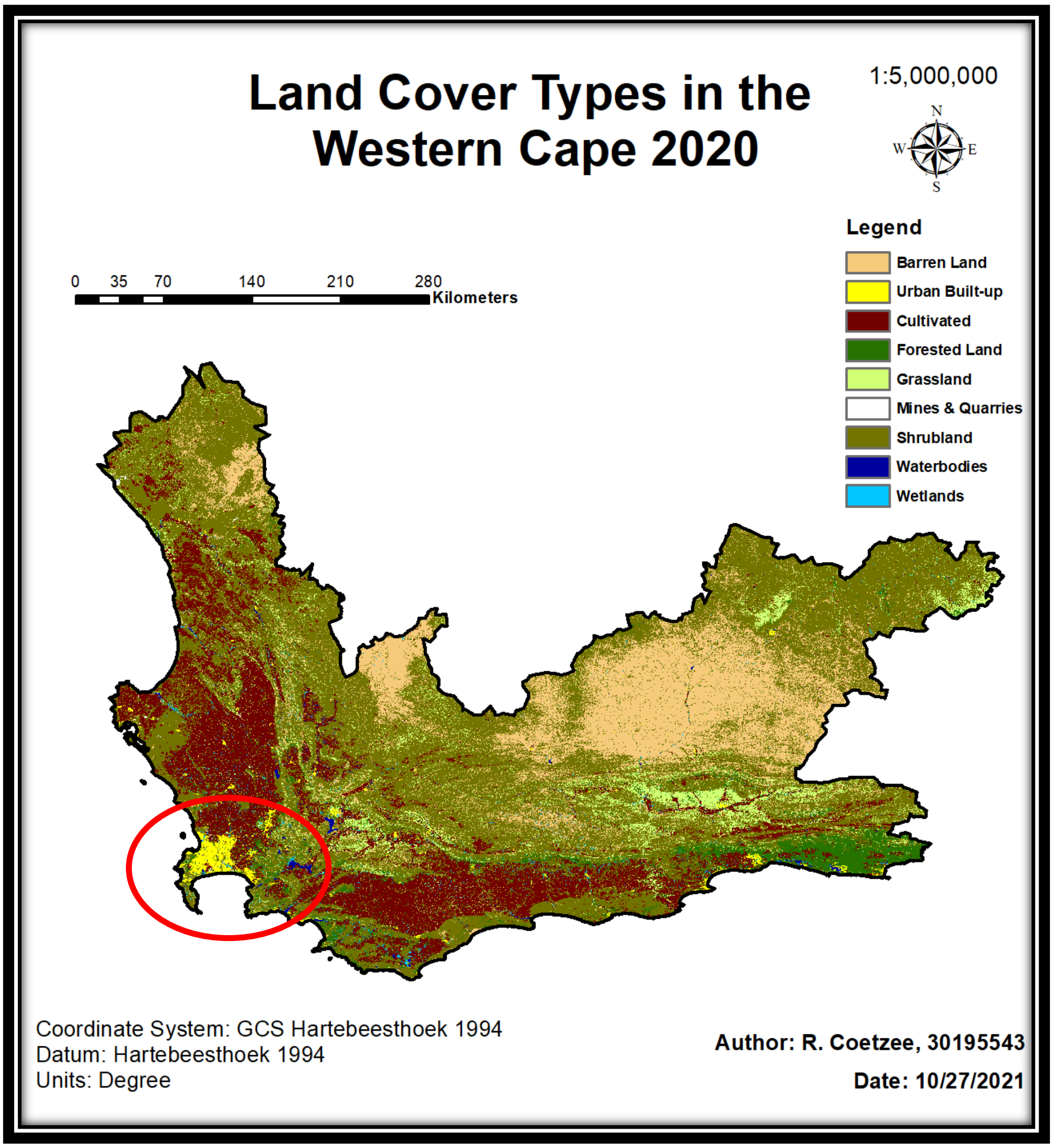


Figure 5: The different land cover types found in the Western Cape, 2020 (SANBI, 2021).

The maps shown above in Figure 4 and Figure 5 were created by making use of TIFF files that were downloaded through SANBI and edited via ArcMap 10.5 to create the maps shown above. These two maps represent the different land cover types that can be found in the Western Cape, whereas these maps were used for the years 2014 and 2020. This is due to data availability, whereas data for the years before 2014 was more difficult to find and not as accurate and detailed as the data gathered from the year 2014 onwards. In these maps the same colour schemes were used for both maps to represent the different land cover types that can be found in the Western Cape, further making it possible to use these two maps to determine the changes that have taken place over the 6 years shown. In these maps it is identified that the urban built-up areas (yellow) are mostly alongside the coastal areas and that the district with the largest urban built-up and the largest growth in urban built-up is identified as Cape Town, making it a very important district to focus on for this project.

4.3 Mapping LULCC in the Western Cape

Secondary Satellite data of LULCC for the Western Cape, for some of the years between 2000 and 2020 with different sensor types are gathered from various sources to examine and map LULCC.

4.3.1 NDVI data for the Western Cape

The Normalized Difference Vegetation Index (NDVI) is mostly used for monitoring vegetation and is a type of vegetation index applied within remote sensing, that can be used for a wide variety of reasons. NDVI can be used to monitor the status and health of crops, to make some predictions for yields, and to make sure exactly what amount of nitrogen fertilizers needs to be used for crops (Gozdowski et al., 2020). Additionally, NDVI data can also be used to analyse the different vegetation dynamics as well as their relationships with extreme climate conditions. In the Western Cape, summer occurs between 1st December and the end of February, whereas winter occurs between 1st June and 31st August. Figure 6 and Figure 7 below indicates the NDVI MODIS data for the Western Cape for the year 2000, while comparing the summer season with the winter season for this year.

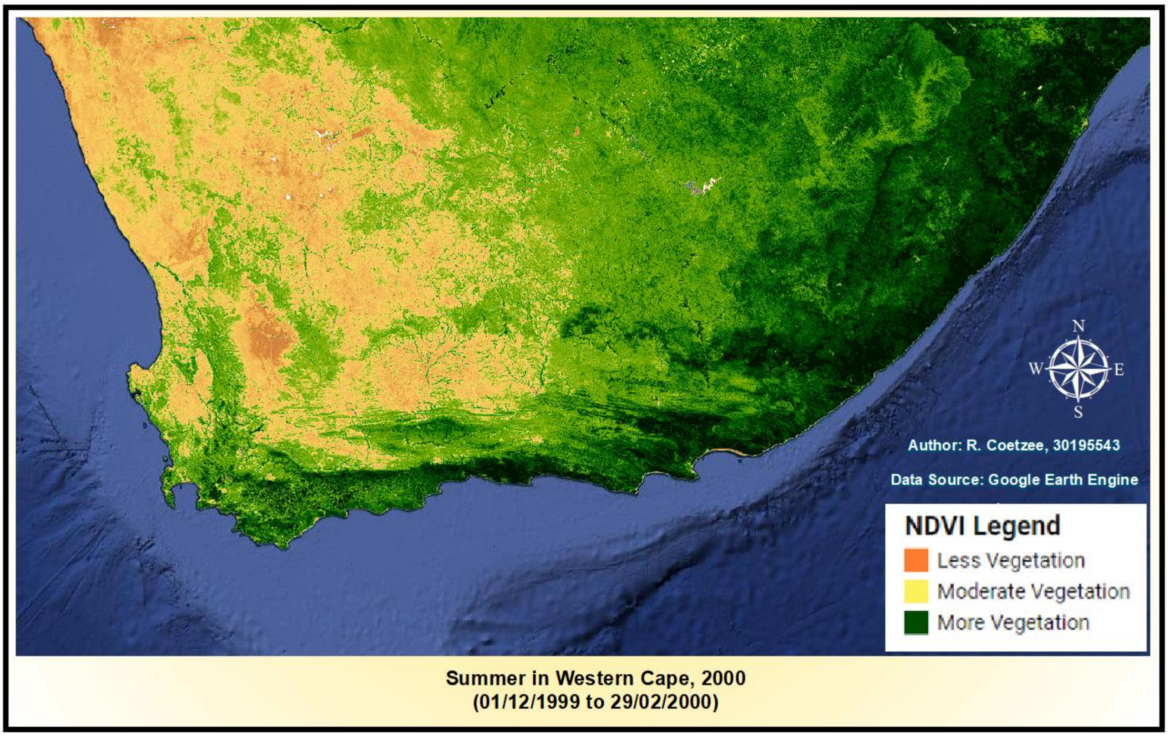


Figure 6: NDVI MODIS Summer data for the Western Cape, 2000.

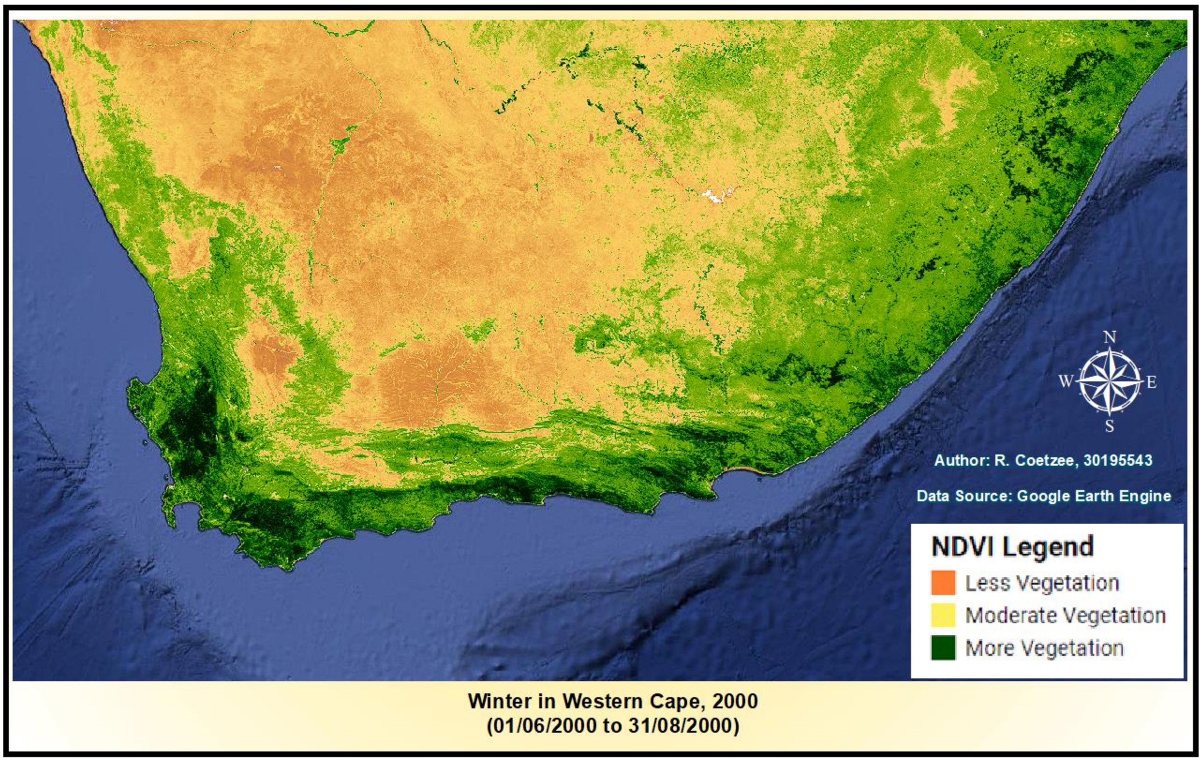


Figure 7: NDVI MODIS Winter data for the Western Cape, 2000.

NDVI MODIS data were compared for the years between 2000 and 2005, by making use of the maps shown in Figure 6, Figure 7, and Figure 8. While comparing the summer seasons with the winter seasons it is observed that the areas closer to the coast have greener vegetation in the winter. This is because every year the rainy season is observed in the winter in the Western Cape, which means that the lush natural surroundings are in their prime in the winter season. There is also an escarpment in the Western Cape, known as the Great Escarpment, which consists of steep slopes from the high central South African plateau that starts in the Karoo and goes downwards in the direction of the ocean. The Great Escarpment plays a large role in the way water flows after rainfall and is known as a very dry area with little vegetation and a lot of rocky surfaces. Further, it is observed that the vegetation found a bit further away from the coast is healthier during the summer seasons. Nonetheless, it is also observed that the vegetation that can be found in the Western Cape that is a bit further away from the coast has lost some of its health during these 5 years and there are also some signs of land degradation taking place over time when looking at the darker orange parts on the maps, especially when looking at the 5-year change for summer seasons. When looking at Figure 9, Figure 10 and Figure 11 below, the NDVI MODIS data were further compared by making use of maps that indicates the changes that took place in the Western Cape using 5-year intervals for the years between 2010 to 2020.

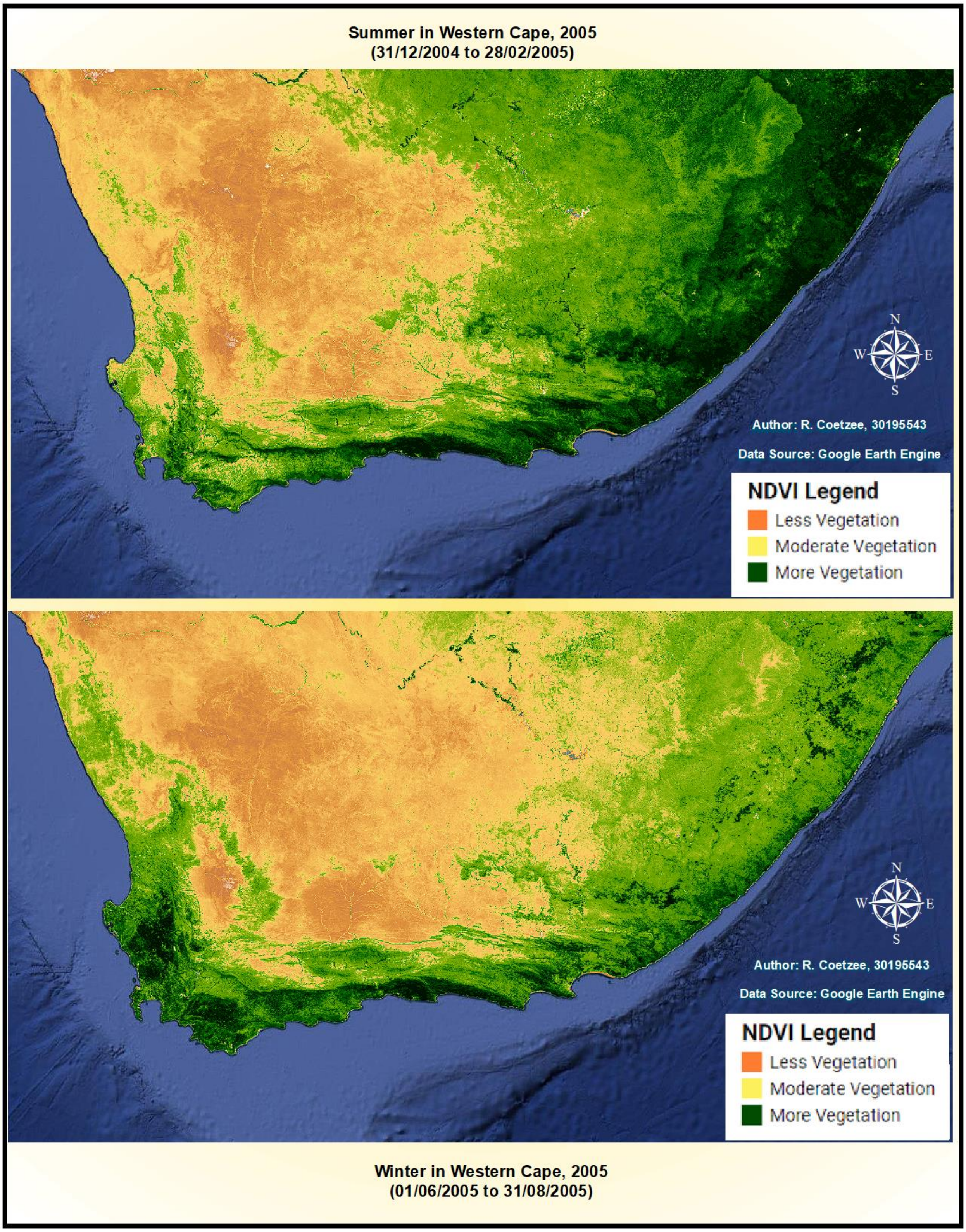


Figure 8: NDVI MODIS data for the Western Cape, 2005.

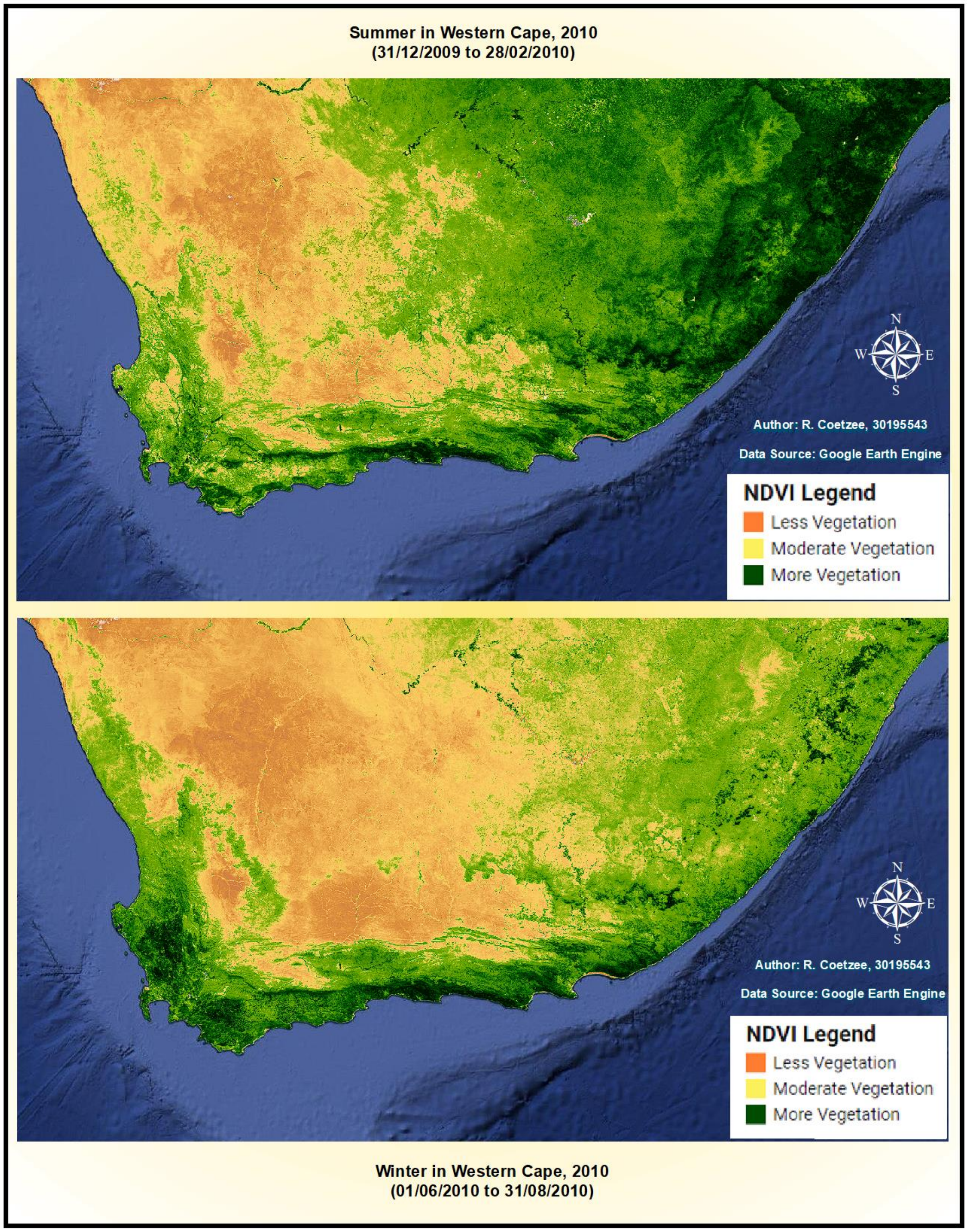


Figure 9: NDVI MODIS data for the Western Cape, 2010.

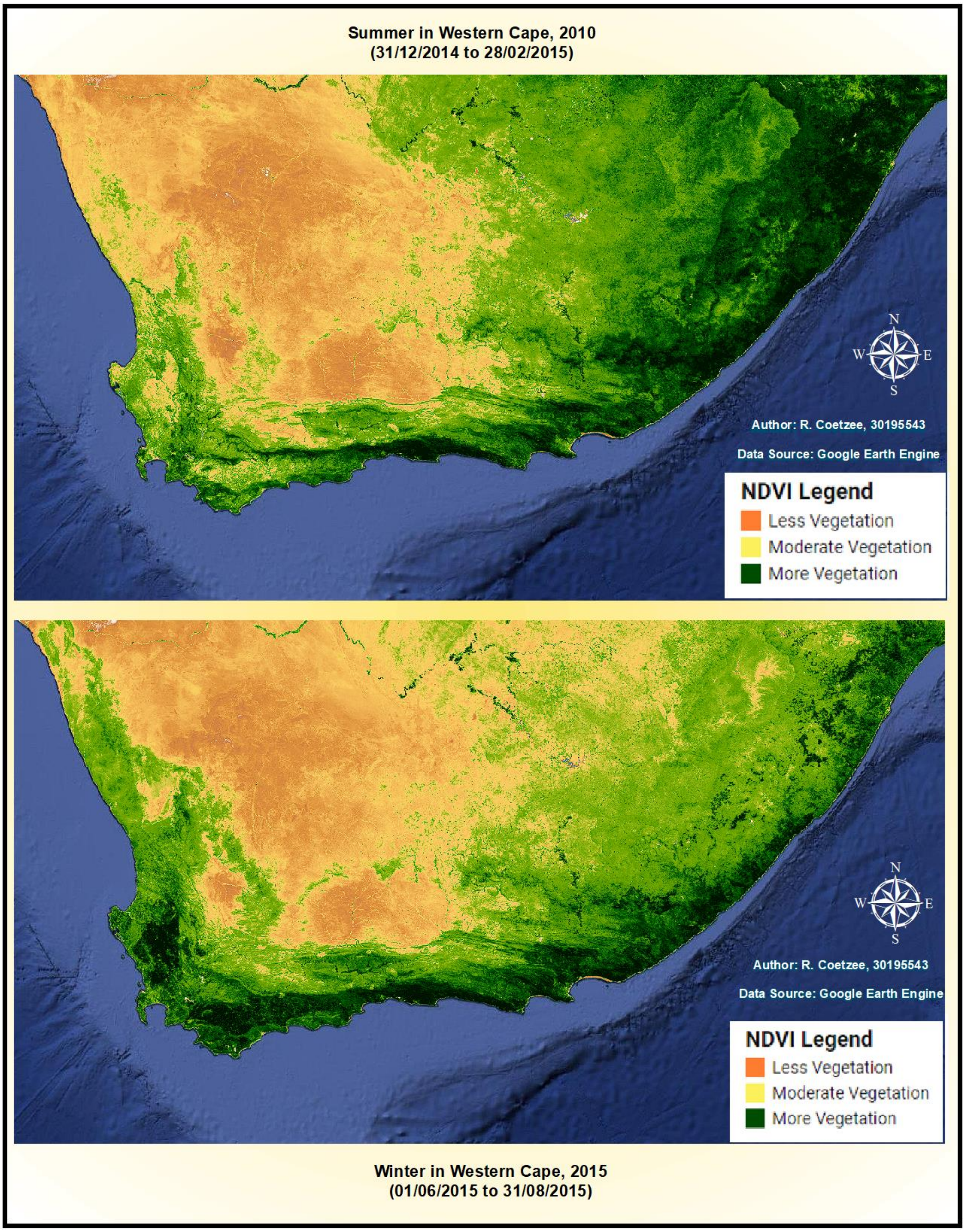


Figure 10: NDVI MODIS data for the Western Cape, 2015.

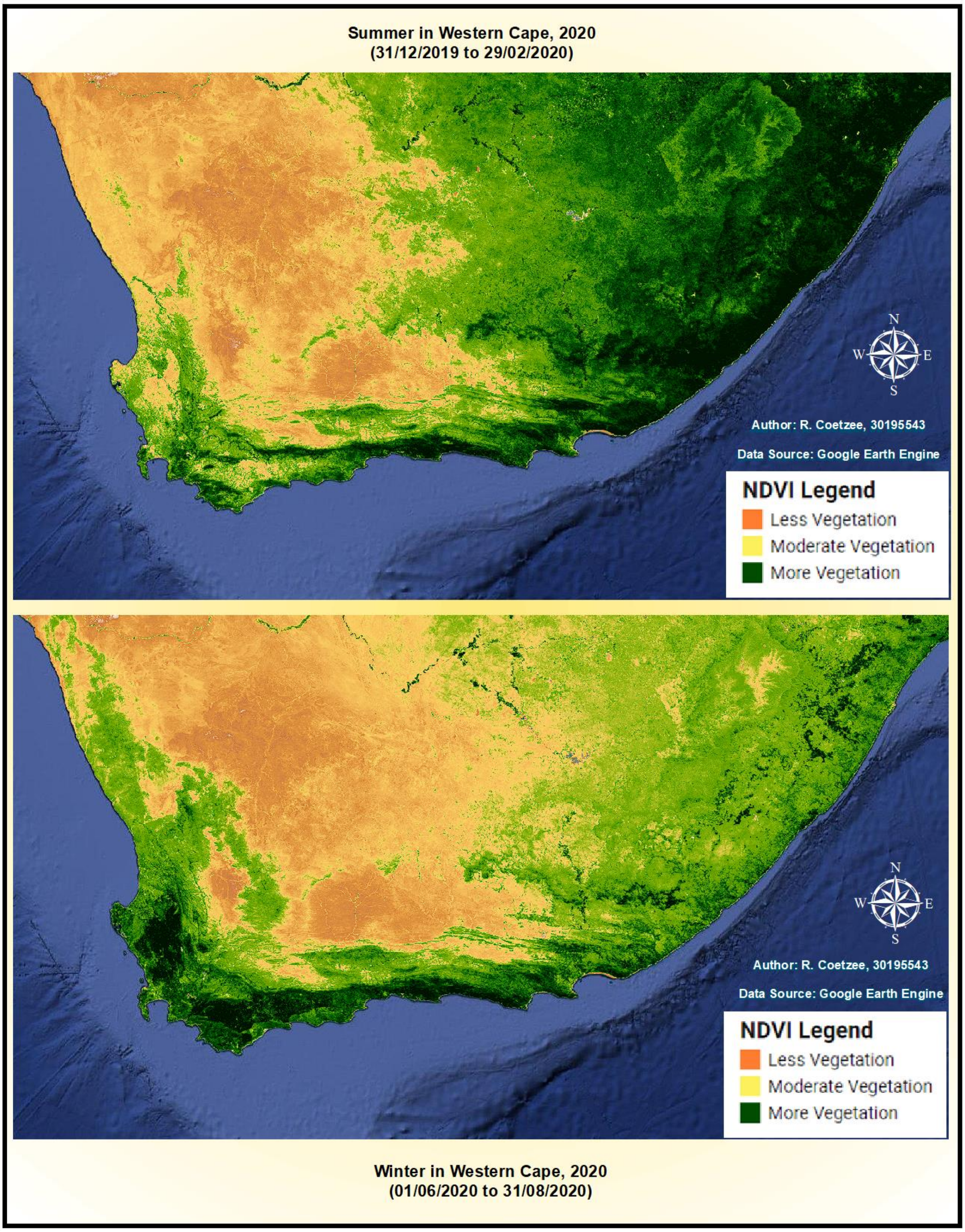


Figure 11: NDVI MODIS data for the Western Cape, 2020.

When examining the 5-year intervals which took place from the years 2000 to 2020 that was shown above in Figure 6 to Figure 11, the changes that took place over this period can be closely observed to indicate which years had the biggest change and to be able to determine how gradually the changes took place. When examining the year 2015 in Figure 10, it is observed that it is has been the year with the least vegetation which is because from the year 2015 to 2016 El Niño effects have taken place, causing unusual warming of surface waters situated in the Eastern equatorial Ocean, which further impacted ocean temperatures, the strength and speed of ocean currents, as well as the amount of rainfall taking place in the Western Cape. This has led to two dryer years with less rainfall, which led to less healthy vegetation for these two years. However, this project aims mostly on the overall changes that took place over 20 years and will therefore be indicated by making use of figure 10 that can be found on the next page. The map that is shown in Figure 12 and Figure 13 gives a better indication of the overall changes that took place in the Western Cape over 20 years while also comparing the summer and winter over this period. For the summer season, it is observed that there is an overall change that took place over 20 years, whereby the yellow and dark orange areas has grown more in parts such as the West Coast, Cape Winelands and small parts of Overberg, which indicates a loss in vegetation and some signs of land degradation that took place over 20 years in these district municipalities throughout the summer seasons. It is further identified that areas such as Overberg, Eden, and small parts of Central Karoo have experienced an increase in vegetation growth throughout the summer seasons at areas that are closer to the coast.

Furthermore, when examining the changes that took place during the winter seasons in the Western Cape, it is determined that the yellow and dark orange areas have also grown over 20 years in parts such as the West Coast, Cape Winelands, Central Karoo and parts of Overberg, which further indicates that there has also been a loss in vegetation and signs of land degradation that took place over 20 years in these district municipalities throughout the winter seasons. It is further identified that there is an increase in vegetation growth throughout the winter seasons over 20 years for areas such as the West Coast, Cape Town, and Overberg at parts that are situated closer to the coast. As a result, when looking at the overall changes that took place over 20 years, it is determined for both summer and winter seasons the yellow and dark orange areas have grown more in the middle parts of the Western Cape in areas such as the West Coast, Cape Winelands, and small parts of Overberg and Central Karoo, which are all situated further away from the coast. This indicates that there is developing a shortage in vegetation in these areas which can occur because of factors such as climate change, rainfall, human settlement growth and other human factors which will further be examined.

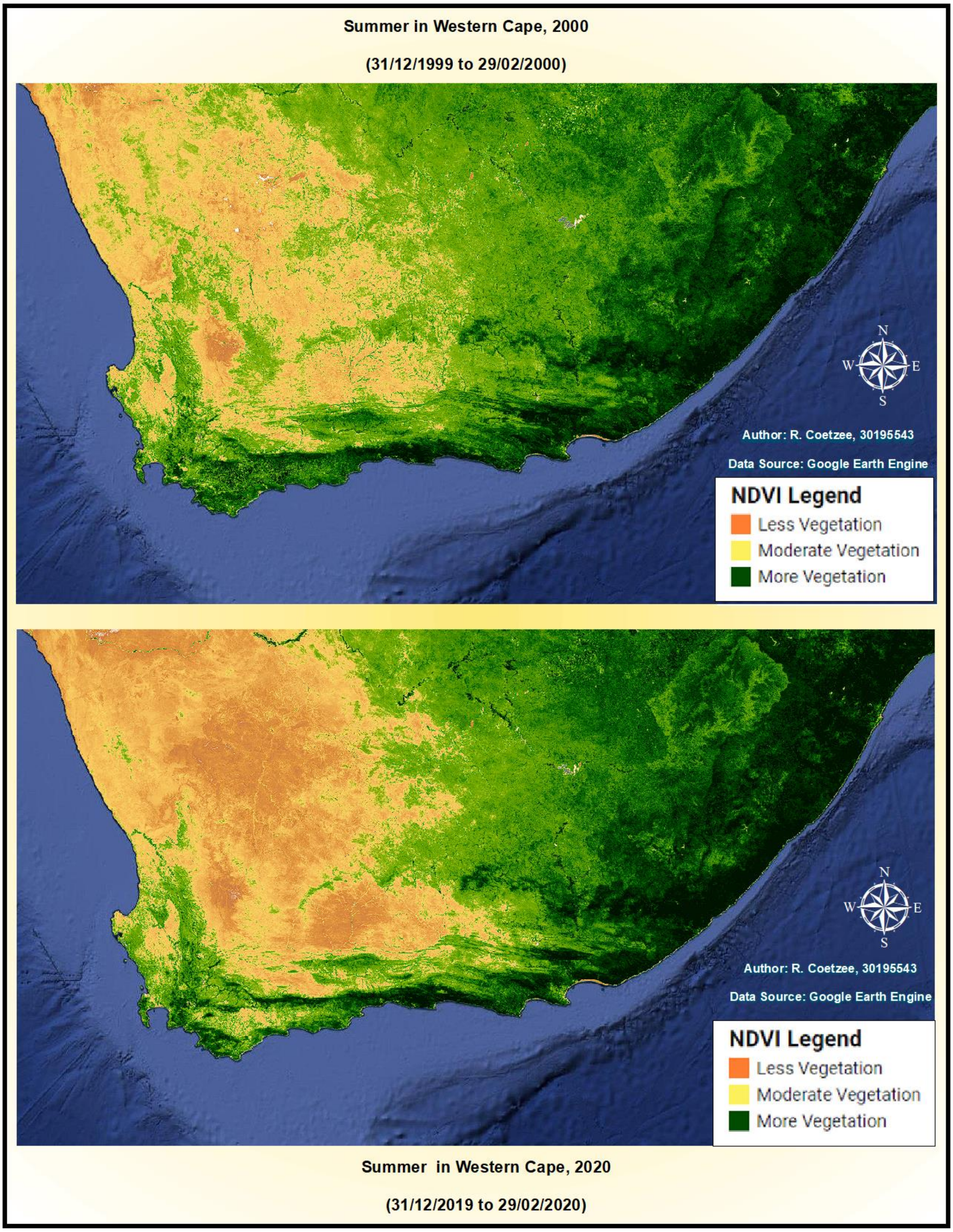


Figure 12: 20-year change in NDVI for the Western Cape (Summer Season).

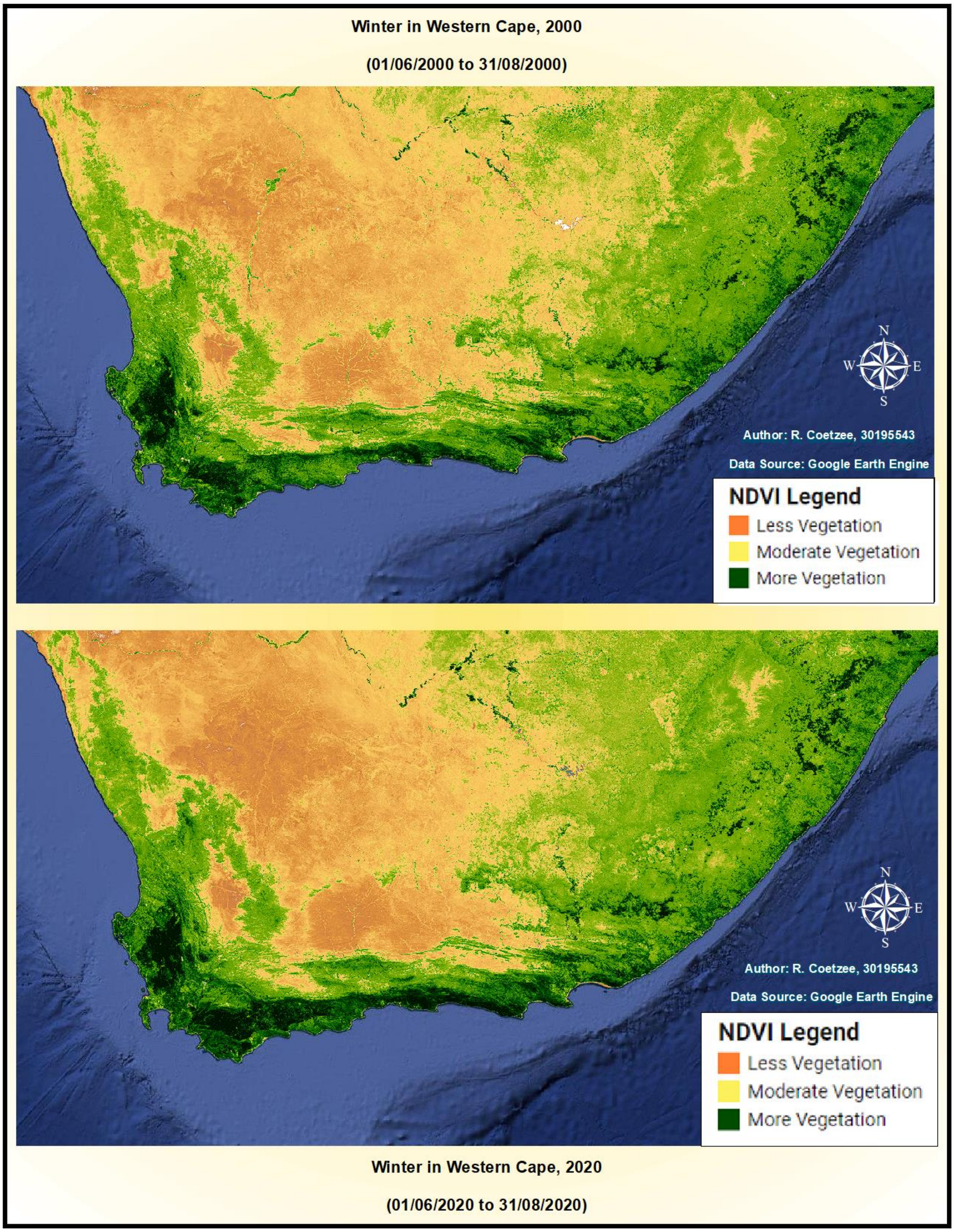


Figure 13: 20-year change in NDVI for the Western Cape (Winter Season).

4.3.2 Rainfall data for the Western Cape

Rainfall is the precipitation of water drops (produced by clouds), in the form of rain that pours down onto the Earth's surface, whether it is on water or land surfaces. Rainfall data is used in this project to find a correlation between NDVI and rainfall and to determine why certain areas have less vegetation than other parts of the Western Cape. In this project, rainfall data have been examined over 15 years to be able to see the areas that have received more rain than other areas in the Western Cape. The data was then downloaded as a .asc file which was opened in ArcMap 10.5 and developed into the maps found below. The reason for only starting from the year 2005 is because of data availability, whereas this type of rainfall data has only been captured from the year 2003 onwards.

The maps shown in this section as Figure 14 to Figure 17 represents the yearly changes in rainfall by using 5-year intervals for the Western Cape from the years 2005 to 2020 by displaying the rainfall data in millimetres per year. Figure 18 follows afterwards by combining these four maps to assist with the interpretation process. In these maps, the amount of rainfall is represented from low to high amounts by making use of different colour schemes, whereby red represents lower yearly rainfall in millimetres and blue represents higher yearly rainfall in millimetres.

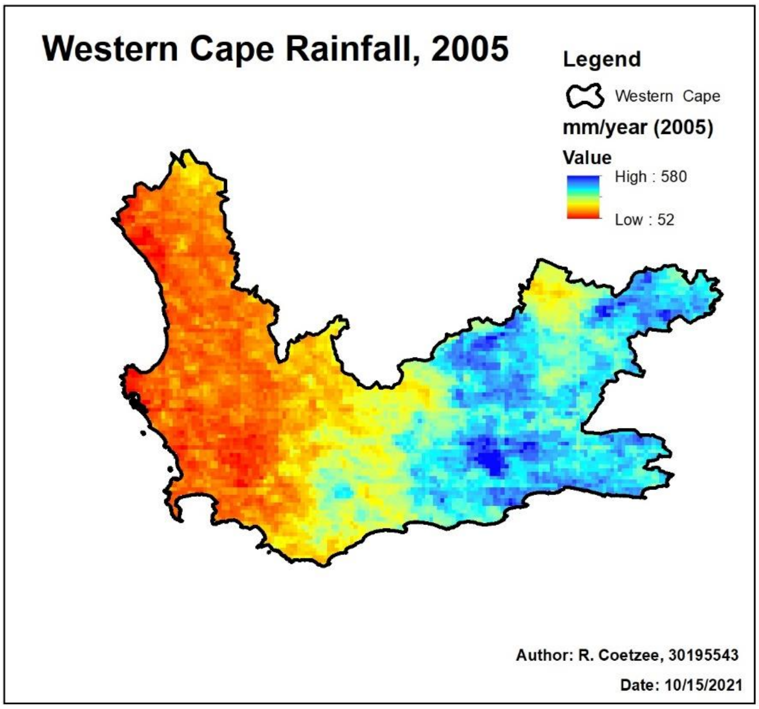


Figure 14: Yearly rainfall for the Western Cape, 2005 (CHRS, 2021).

When looking at Figure 14 above, it is determined that the year 2005 has been the year in the Western Cape that has received the most rainfall in the Eastern parts and at the same time the less amount of rainfall in the Western parts. This is due to earlier summer rainfall and less rainfall in South Africa during the summer than other years, but also more rainfall in South

Africa during winter (rainfall season in the Western Cape), which is why the Western Cape received better rainfall for the year 2005.

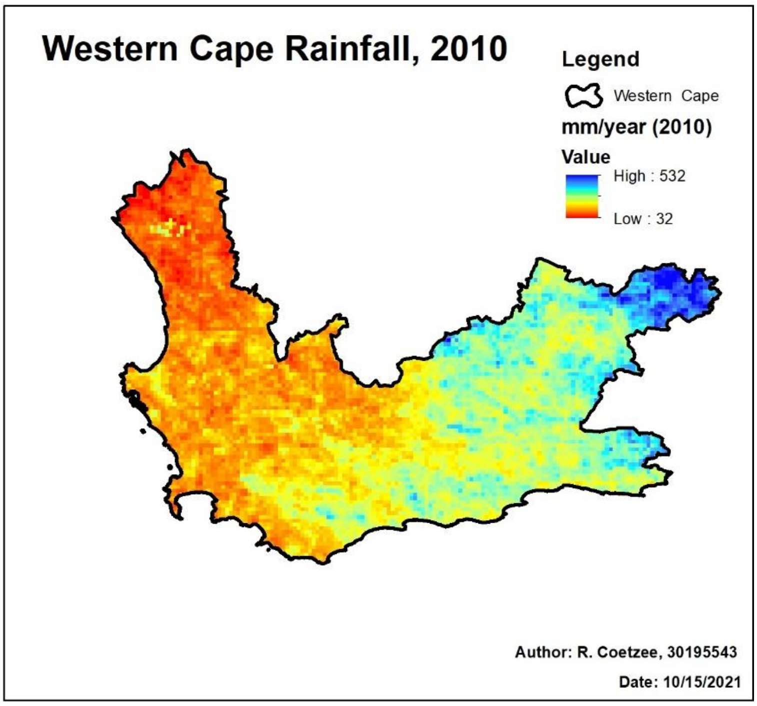


Figure 15: Yearly rainfall for the Western Cape, 2010 (CHRS, 2021).

For the year 2010 in Figure 15, it is observed that rainfall was more evenly distributed across the Western Cape than other years, while the Western parts received less rainfall than other years, while the Eastern parts of the Western Cape still received little amounts of rainfall, but more than most other years. In Figure 16 below it is determined that there has been less rainfall along with the coastal areas than there was for other years, which is because of the El Niño effect that has taken place for both the year 2015 and 2016, leading to dryer summer and winter seasons for the Western Cape. Additionally, when examining the rainfall for the year 2020 in Figure 17 found below, it is determined that it has been the driest summer and winter season in the past 15 years, which is because of another El Niño year which took place, causing drought conditions in most of the Western parts of the Western Cape followed by less rainfall alongside the coast from the Western to the Eastern parts of the Western Cape than for other years.

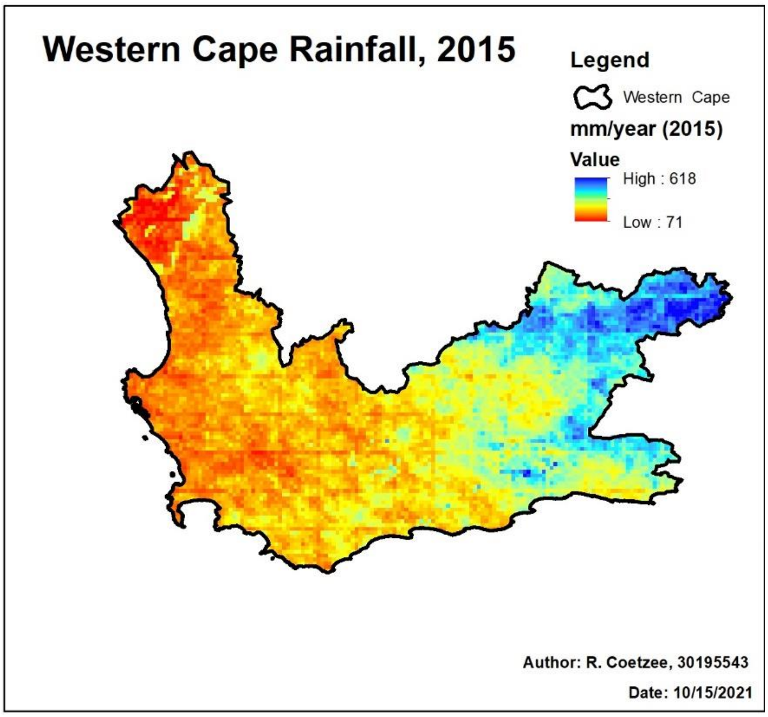


Figure 16: Yearly rainfall for the Western Cape, 2015 (CHRS, 2021).

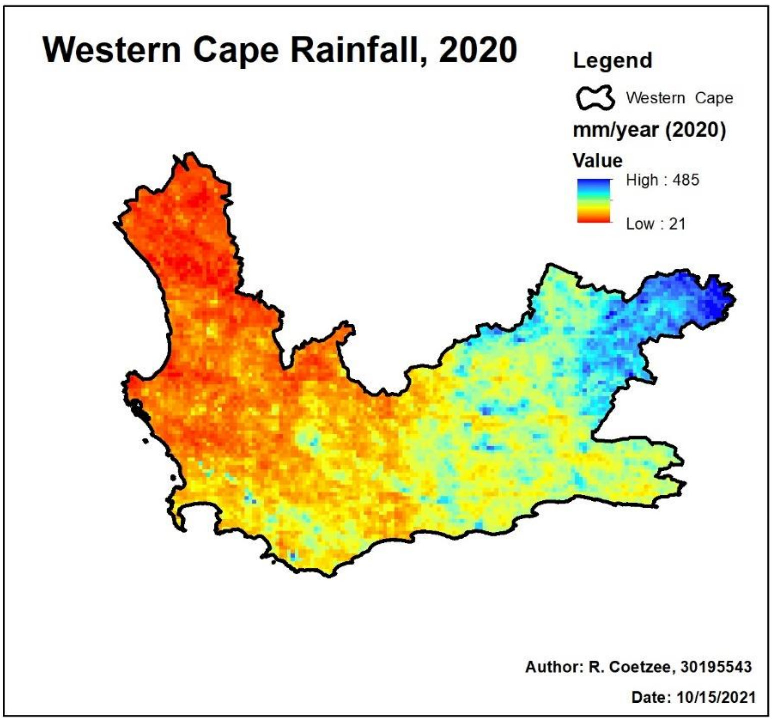


Figure 17: Yearly rainfall for the Western Cape, 2020 (CHRS, 2021).

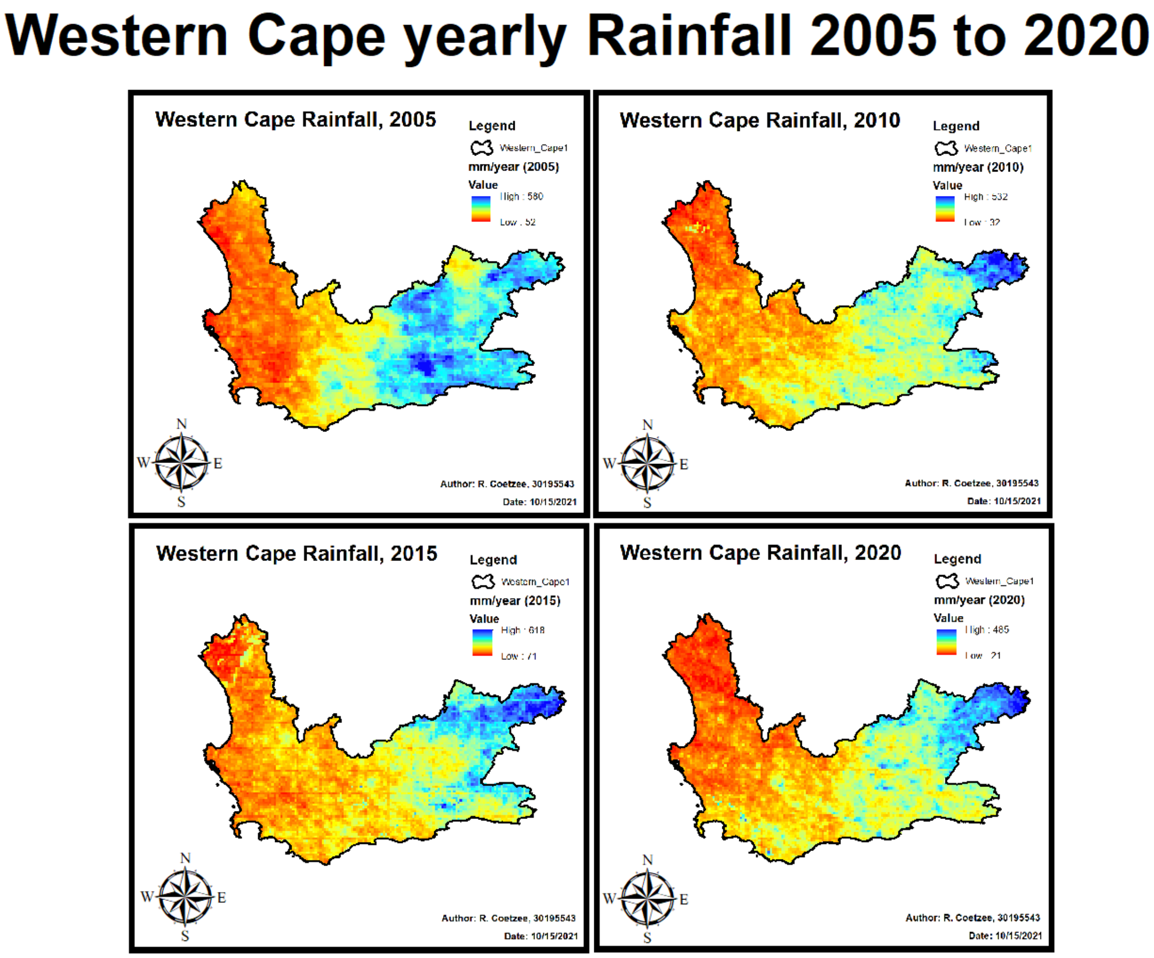


Figure 18: Combined 15-year change in rainfall for the Western Cape (CHRS, 2021).

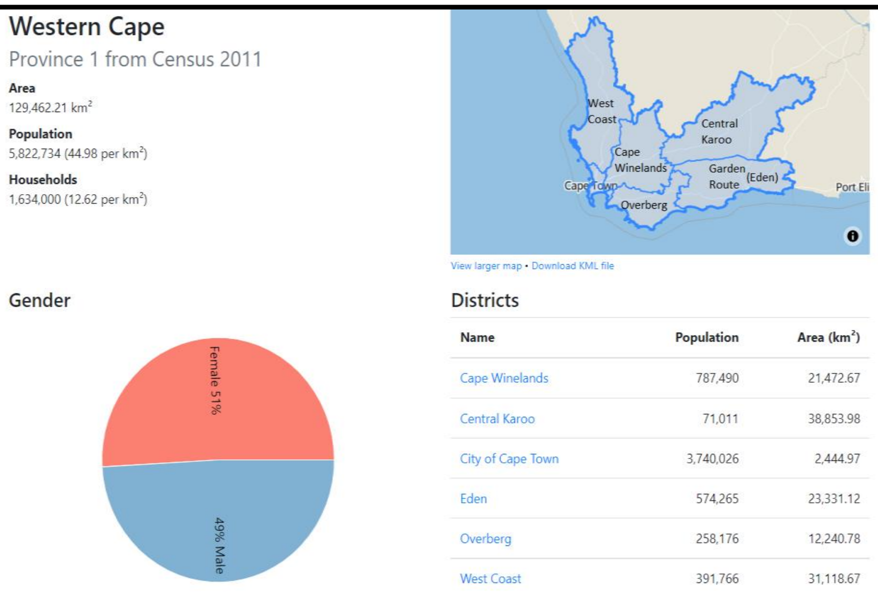
From these maps, it is determined that most of the rainfall for the Western Cape can be found in the Eastern parts, while the least amounts of rainfall can be found in the Western parts. It is also determined that most of the rainfall takes place closer to the coast while most rainfall can be found during the winter season in the Western Cape. Additionally, the rainfall data in Figure 18 can be directly correlated to the NDVI data gathered in Figure 12 and Figure 13 which represented the vegetation health and the rate at which the vegetation grows. Therefore, it is determined that the amount of rainfall that took place, to some extent determines the vegetation health that was indicated above by making use of the NDVI data for the Western Cape.

4.4 Mapping population and human settlement growth in the Western Cape

Census statistics were used to examine and map the population and human settlement growth for some of the years between 2000 and 2020. Additionally, some parts of the research focused on South Africa as a whole, whereas other parts of the research have focused more specifically on the Western Cape, followed by its district municipalities, to ultimately determine where population growth, urban built-up and population density is the biggest problem in the Western Cape. Remotely sensed data gathered from GEE (Google Earth Engine) were also used from the year 2000 to 2020 to further assist with some of the results that were found from the census data used.

4.4.1 Population size and population growth in the Western Cape

The map shown in Figure 19 below is a map and graphs that were created by making use of census statistics gathered from Statistics SA for the year 2011. This map illustrates the different district municipalities while comparing their population size and their area sizes in kilometres, which can further be used to determine the population density between the different district municipalities in the Western Cape for 2011. By making use of Figure 13 the observation can be made that the City of Cape Town is the smallest when comparing sizes between the different district municipalities with an area surface of about 2444.97km² in size. The City of Cape Town is also identified as having the highest population count (an average of 3740026 citizens) between all these districts in 2011, also making it the densest district in the Western Cape, indicating that The City of Cape Town will most likely have the largest human settlement growth between the six districts found in the Western Cape. This theory will be further examined in this section and the section to follow by making use of additional research for some of the years between 2000 and 2020.



Name	Population	Area (km²)
Cape Winelands	787,490	21,472.67
Central Karoo	71,011	38,853.98
City of Cape Town	3,740,026	2,444.97
Eden	574,265	23,331.12
Overberg	258,176	12,240.78
West Coast	391,766	31,118.67

Figure 19: The Western Cape's population size and density as per district, 2011 (Frith, 2021).

The map shown in figure 20 illustrates the number of people who stay in the Western Cape by dividing the data into the different district municipalities and local municipalities found in the Western Cape for the year 2016. This map further indicates the number of people from low to high numbers by making use of different colours which further represent these numbers. The green colours represent the least amount of people staying in a specific area and the orange to red colours represents the highest number of people staying in a specific area. Figure 20 is further supported by Table 1 which can be found below. Table 1 indicates the total population size per district municipality and local municipality as shown in Figure 20, while also comparing the population size between these areas between the years 2011 and 2016. Additionally, Table 1 also shows the percentage of change in population size which took place over 5 years making it easier to identify where population growth took place most or the least in the Western Cape.

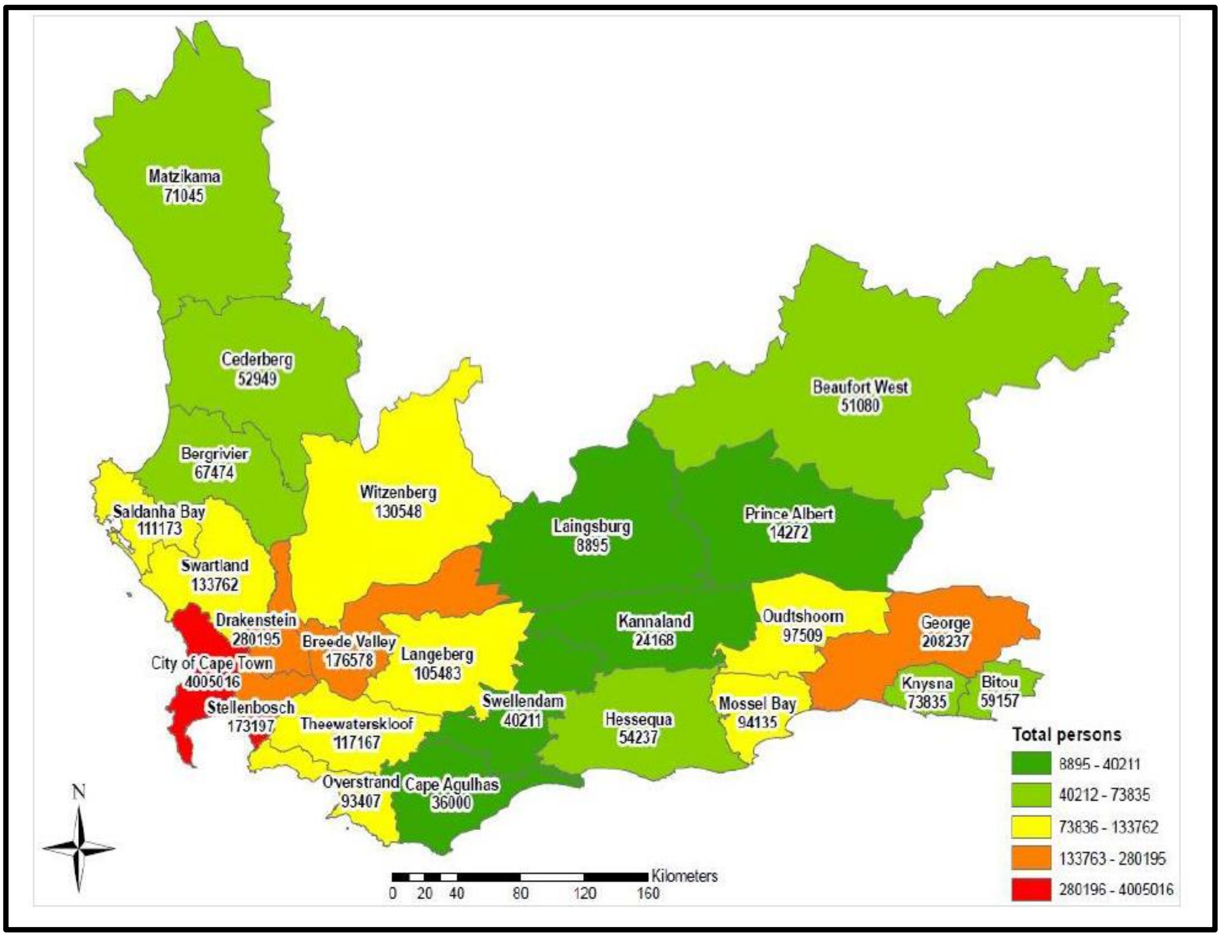


Figure 20: Population distribution by each local municipality in the Western Cape, 2016 (Stats SA 2016).

As identified above in Figure 19, by further making use of Table 1, it is determined that the City of Cape Town has had the highest population count between all the districts for the year

2011 to 2016 with an average of 4005016 citizens by the year 2016. It is however determined that the district municipality with the highest population growth in the Western Cape is the West Coast (11.4%), followed by Overberg (11.1%), and Cape Winelands (10%) for the years 2011 to 2016. Therefore, by making use of the census data gathered for these years it is identified that there are forms of rapid population growth taking place in certain areas in the Western Cape which further contributes to land degradation, human settlement growth and other changes in LULCC. Furthermore, this growth that took place in population size and human settlement can also to some extent be linked to the NDVI data gathered above which indicated that there has been a great loss in vegetation in these three district municipalities from the year 2000 to 2020, especially for the overpopulated areas.

Table 1: Population distribution by district & local municipality in Western Cape, 2011-2016 (Stats SA 2016).

District/municipality	Total population		% change
	2011	2016	
CPT: City of Cape Town	**3 740 031**	**4 005 016**	**7,1**
DC1: West Coast	**391 766**	**436 403**	**11,4**
WC011: Matzikama	67 147	71 045	5,8
WC012: Cederberg	49 768	52 949	6,4
WC013: Bergrivier	61 897	67 474	9,0
WC014: Saldanha Bay	99 193	111 173	12,1
WC015: Swartland	113 762	133 762	17,6
DC2: Cape Winelands	**787 486**	**866 001**	**10,0**
WC022: Witzenberg	115 946	130 548	12,6
WC023: Drakenstein	251 262	280 195	11,5
WC024: Stellenbosch	155 728	173 197	11,2
WC025: Breede Valley	166 825	176 578	5,8
WC026: Langeberg	97 724	105 483	7,9
DC3: Overberg	**258 176**	**286 786**	**11,1**
WC031: Theewaterskloof	108 864	117 167	7,6
WC032: Overstrand	80 358	93 407	16,2
WC033: Cape Agulhas	33 038	36 000	9,0
WC034: Swellendam	35 916	40 211	12,0
DC4: Eden	**574 265**	**611 278**	**6,4**
WC041: Kannaland	24 767	24 168	-2,4
WC042: Hessequa	52 642	54 237	3,0
WC043: Mossel Bay	89 430	94 135	5,3
WC044: George	193 672	208 237	7,5
WC045: Oudtshoorn	95 933	97 509	1,6
WC047: Bitou	49 162	59 157	20,3
WC048: Knysna	68 659	73 835	7,5
DC5: Central Karoo	**71 011**	**74 247**	**4,6**
WC051: Laingsburg	8 289	8 895	7,3
WC052: Prince Albert	13 136	14 272	8,6
WC053: Beaufort West	49 586	51 080	3,0
Western Cape	**5 822 734**	**6 279 730**	**7,8**
South Africa	**51 770 560**	**55 653 654**	**7,5**

The human settlement and population grid are shown below in Figure 21 were used to further examine the changes that took place in urban built-up and population growth for the Western Cape for the years 2000 to 2020 by making use of remotely sensed data that was generated and gather through GEE. In this map the population growth and urban built-up is indicated by making use of the colour white, whereas the areas with little to no population and urban built-up are represented by the colour black, making it much easier to identify. It is further observed that the metropolitan known as Cape Town is by far the district with the highest population number as well as the district with the biggest urban built-up area.

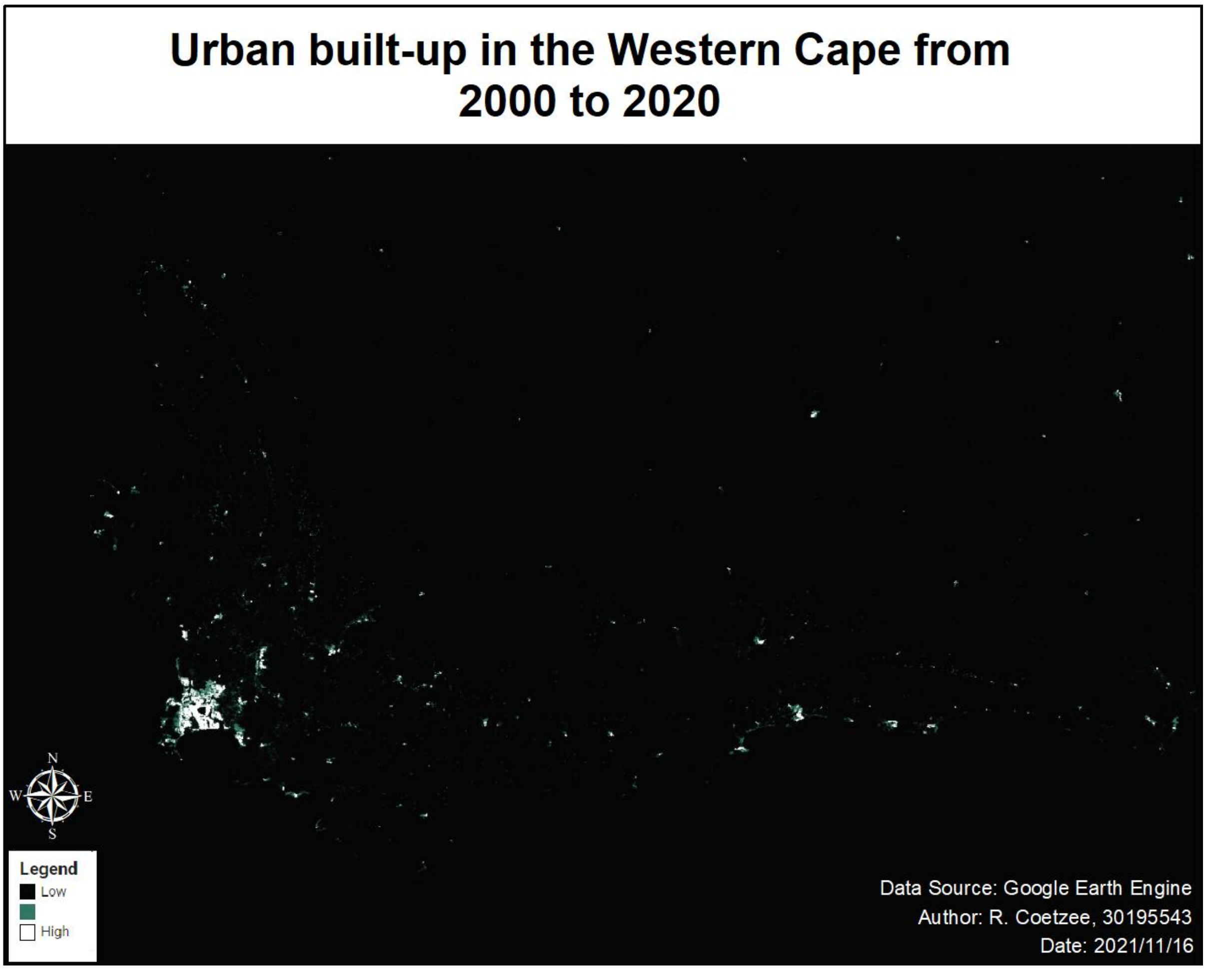


Figure 21: Urban built-up grid in Western Cape from 2000 to 2020 (JRC, 2015).

By making use of Figure 22 the urban built-up and population size of Cape Town was examined by enlarging the map shown above in Figure 21. On the left side, the enlarged map can be found which shows the exact locations that have the highest population and urban built-up in Cape Town and the Western Cape, whereas the map on the right side serves as a navigation tool that is used to assist with indicating exactly where each area can be found on the left side.

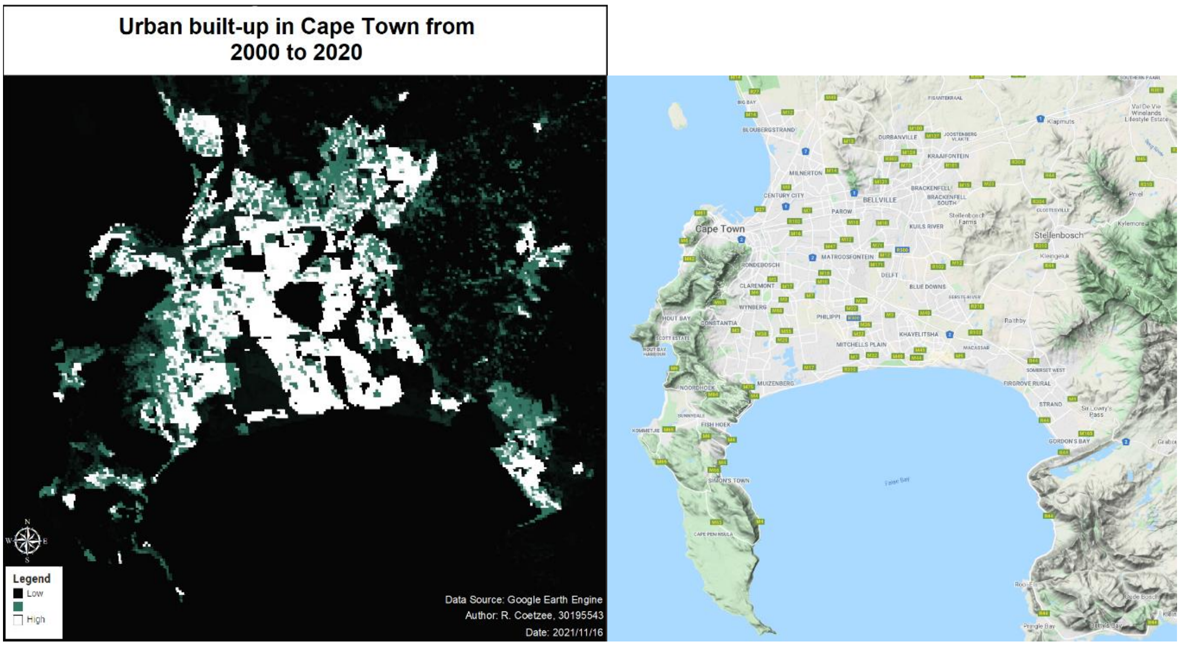


Figure 22: Urban built-up grid in Cape Town from 2000 to 2020 (JRC, 2015).

From Figure 22 the areas that have the highest population and urban built-up has been identified and shown whereas all the towns that are situated around False bay are overpopulated because of the popularity of this area when it comes to tourism and because of its beautiful scenery alongside False Bay.

4.4.2 Changes in population density in South Africa and the Western Cape

In this section, the changes in population density for South Africa and the Western Cape are examined by making use of specific years between the years 1996 and 2020. Figure 23 below illustrates South Africa's population density for the year 2017 followed by South Africa's provinces which also includes the Western Cape. Each dot represents three people per square kilometre, whereby South Africa's population density is estimated at 46 people per square kilometre. The different sizes and the number of dots indicate the different population densities for each province in South Africa. By further making use of Figure 23 it is determined that the Western Cape is not the densest province in South Africa, but still, the 4th densest province that can be found in South Africa, being denser than South Africa, with about 50 people per square kilometre compared to South Africa which has a population density of 46 people per square kilometre. Even though the Western Cape does not look like a very dense province when looking at the total land surface as demonstrated in Figure 23, it still has a large population density when considering the amount of land surface that is liveable. This is because of the huge mountain ranges, forest areas, nature reserves and other landforms which takes up most of the land surface space that cannot be lived on. This means that the liveable spaces in the Western Cape are being targeted by most people causing too many people to move into the most liveable areas such as the areas indicated in Figure 21 and Figure 22.

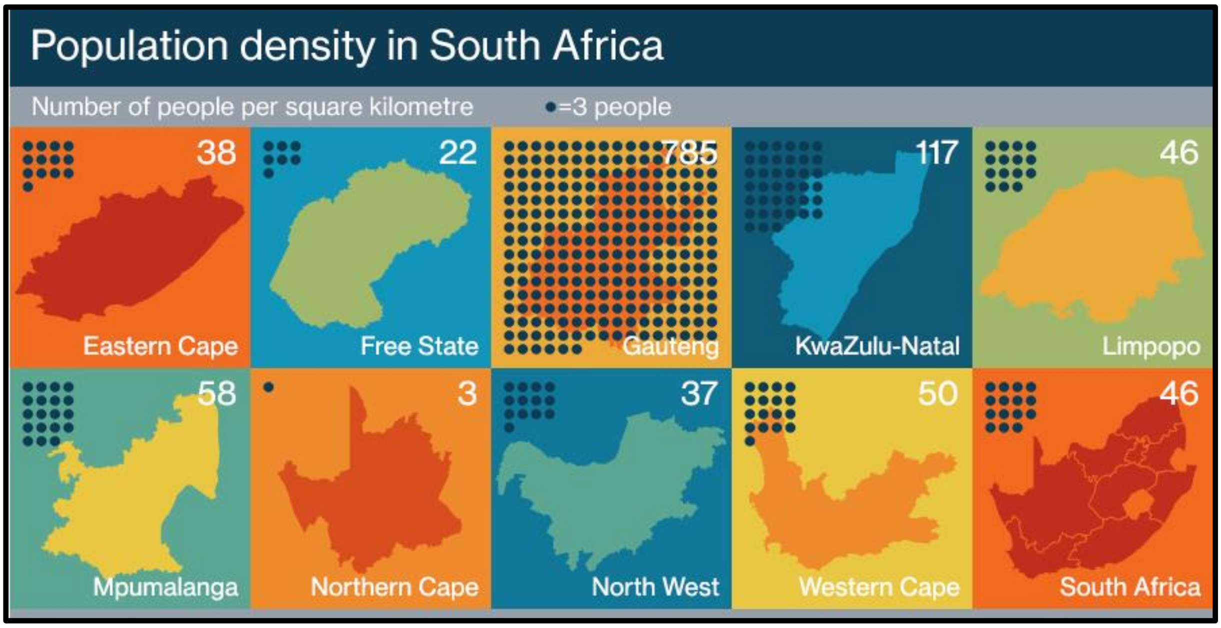


Figure 23: Population Density of South Africa, 2017 (SAG, 2021).

Now that South Africa and the Western Cape's population density has been examined for the year 2017, Figure 24 below will be used to further examine the changes that took place in population density for South Africa and the Western Cape from the year 1996 to 2016 by making use of data gathered from Statistics SA that is generated into a map of South Africa via ArcMap. This map makes use of different colour schemes to arrange the increase (green) and decreases (red) that took place in population density during this period.

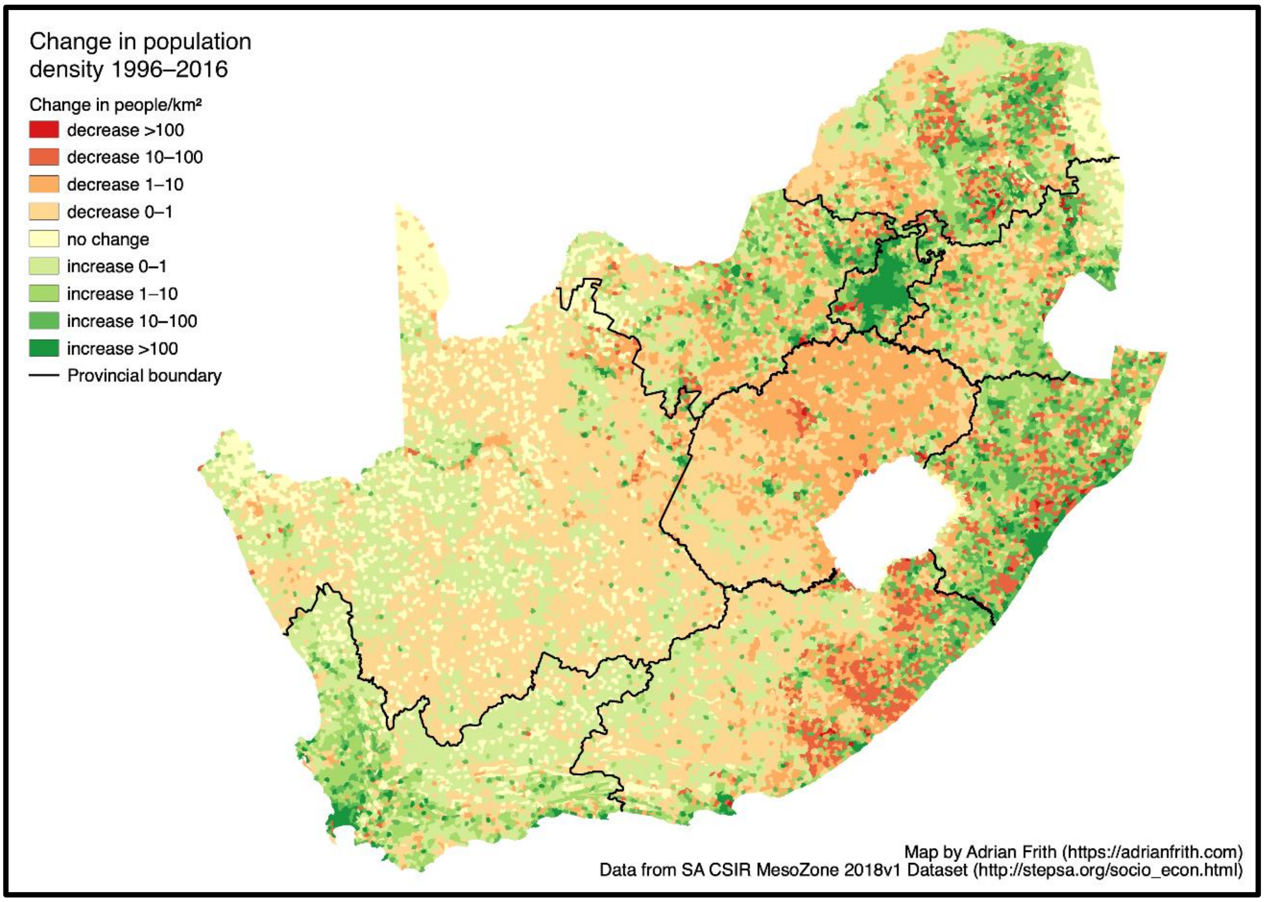


Figure 24: Change in South Africa's population density, 1996-2016 (Frith, 2021).

In the map shown in Figure 24, it is identified that there have been many changes in population density taking place across South Africa in the past 20 years. The four provinces that have experienced the highest increase in population density are categorized as Gauteng, KwaZulu-Natal, Mpumalanga, and the Western Cape. Whereas the four provinces that have experienced the smallest increase in population density are categorized as the Northern Cape, Free State, the Eastern Cape, and North West. When focusing more specifically on the Western Cape the green areas indicates that the district municipalities that have experienced the highest increase in population density are The City of Cape Town, West Coast, Cape Winelands, and Eden alongside the coast. The observation can be made from the maps used that most people who stay in the Western Cape tend to move closer to the coast, causing the areas situated along the coast to become the most densely populated which can also be directly linked to the urban built-up that takes place at these densely populated areas.

The map is shown below as Figure 25 assists with interpreting the data from the map above in Figure 24 by representing the population density in the Western Cape from the year 2000 to 2020 in more detail by making use of different colour schemes to indicate where population density takes place the most. The purple areas indicate the least dense areas in the Western Cape, whereas the green areas indicate the areas that are a bit denser, followed by the yellow areas which indicate the areas that are the densest in the Western Cape. The observation can be made in this map that the Metropolitan known as Cape Town is the densest district in the Western Cape and is therefore enlarged and mapped as Figure 26 to assist in further examining the population density.

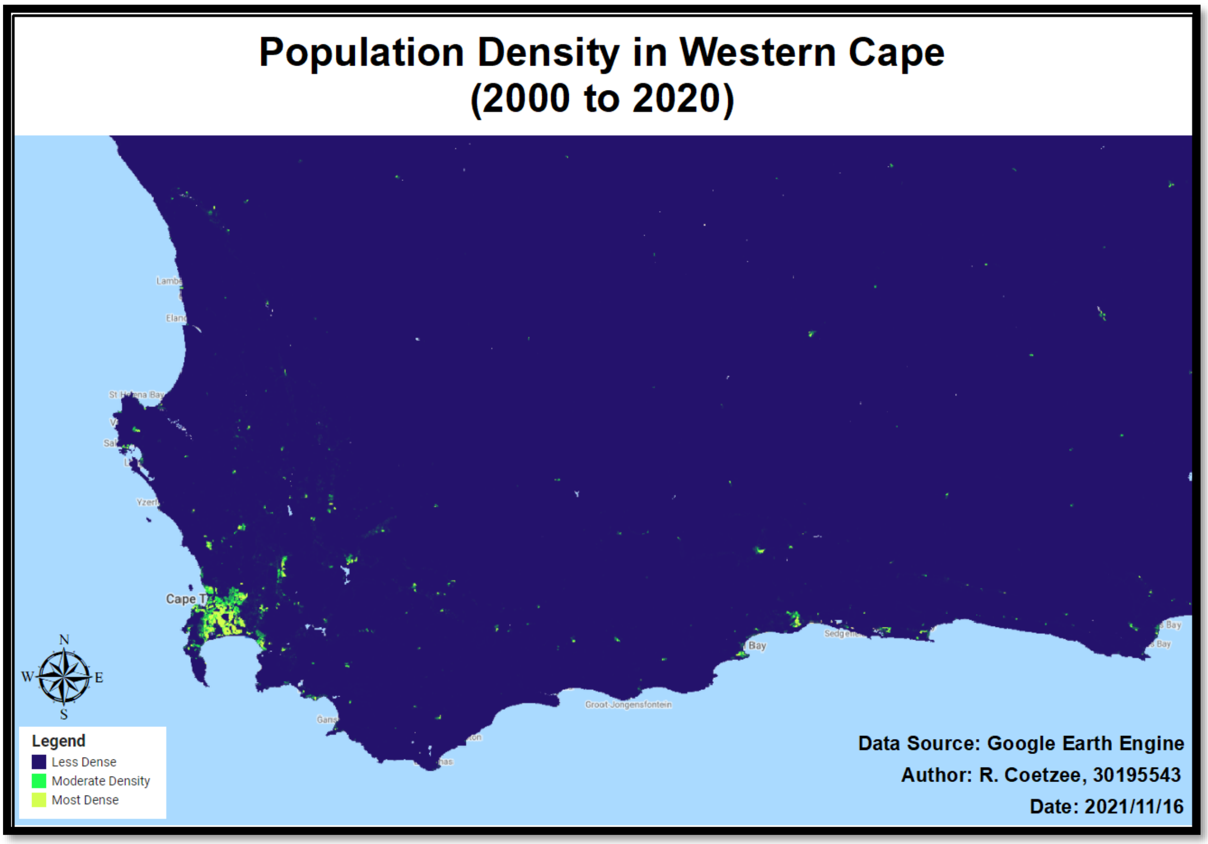


Figure 25: Population Density in Western Cape from 2000 to 2020 (WorldPop, 2021).

Following the results found in Figure 25, the following map in Figure 26 was used to represent the population density in Cape Town from the year 2000 to 2020. The above map was enlarged because it is identified that Cape Town has the densest population in the Western Cape. In Figure 26, the map found at the top represents the population density whereas the bottom map serves as a guideline of the exact areas and the names of each part on the map.

The results that can be found by making use of these maps are that the densest areas in Cape Town are just like the urban built-up results found mostly around False Bay which means that there is a direct correlation between the population count, population density, and the urban built-up that can be found in Cape Town.

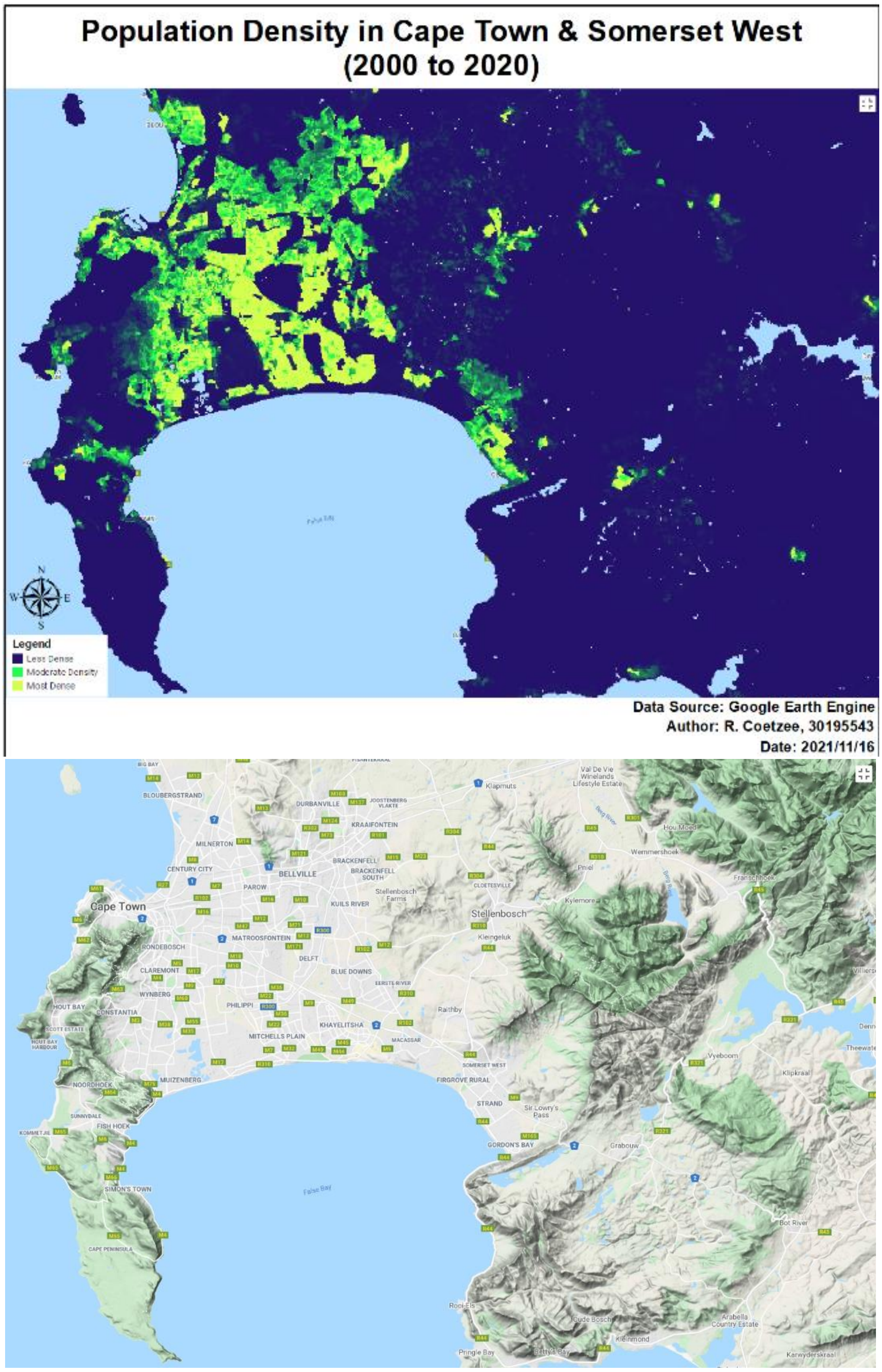


Figure 26: Population Density in Cape Town from 2000 to 2020 (WorldPop, 2021).

4.5 The main drivers that cause LULCC in the Western Cape

In this section, the main drivers of LULCC for the Western Cape were listed and explained in detail, whereas this research has identified both the proximate and underlying driving factors of LULCC in the Western Cape. The proximate factors are things such as agricultural expansion and infrastructure expansion, whilst the underlying factors are things such as cultural, economic, political, technological, environmental, and demographic factors. A summary of all the determining factors for the Western Cape is provided in Figure 27.

4.5.1 Environmental factors

From the research that has been done, it is determined that the effects that climate change has on the Western Cape are evident whereas extreme weather conditions such as heatwaves, droughts (El Niño), and floods (El Niña) can commonly take place in this area. This poses a challenge when it comes to things such as water availability and food production, especially for the ever-increasing population. Hot and dry conditions pose a threat by causing fires in areas that are prone to fire such as plantations and the decline in rainfall leads to a reduction in crop production and profits made by farmers.

4.5.2 Political factors

When it comes to political factors, policies and legislation play a huge role in LULCC in both South Africa and the Western Cape. It is determined that both municipal and provincial policies must be aligned with the national policies and legislation for LULCC, whereas LULCC is influenced by policies and legislation that can either hinder or encourage developments. Policies such as the Urban Edge policy must be put in place which assists with demarcating the outer limits of urban development by defining the Urban Edge and Coastal Edge line of the Western Cape. Policies such as the Urban Edge policy is used to protect natural resources by preventing urban sprawl. This policy is also per the National Environmental Management Act No. 107 of 1998 and the Western Cape PSDF (Provincial Spatial Development Framework). If this policy is implemented correctly future developments in demarcated areas will be restricted to benefit the environment.

4.5.3 Demographic factors

It is determined that the Western Cape is one of the most urbanised provinces in South Africa, with a rapidly daily increase in population size. As shown above with the census data from Stats SA and the remotely sensed data from GEE it is determined that more than 80% of the economic activity and its population is concentrated within the City of Cape Town as well as its neighbouring district municipality known as Cape Winelands which is further characterized by their rapid urbanization which causes informal settlement expansion together with poverty, crime, and a shortage in basic services.

4.5.4 Economic factors

The Western Cape is identified as a province with a strong link between the tourism, Agri-processing, and gas sectors that are being prioritized by the government. The tourism sector currently contributes to about 204 000 formal jobs, as well as about 17 billion GVA (Gross Value Added) in the Western Cape. The tourism sector is estimated to have grown to about 120 000 jobs and about 65% in GVA (R28 billion) in 2019 for the Western Cape (WCG, 2015).

4.5.5 Technological factors

There has been a decrease in the number of farms and the consolidation of farm units to be able to achieve a better economical outcome, whereas the consolidation of farms means that there is an increase in mechanization and less reliance on labour which further results in job losses. There have been many cases especially in the Cape Winelands where workers have lost their jobs due to mechanization taking place in businesses (Tizora, 2018).

4.5.6 Cultural factors

Cultural factors are concerned with the things people believe in as well as their attitudes towards land use and land cover changes. According to Tizora (2018), interviews that have been done with municipal town planners has revealed that land-use decisions within the Western Cape are in the hands of the mayor, politicians, councils, developers, institutions, and the limited influence of the public.

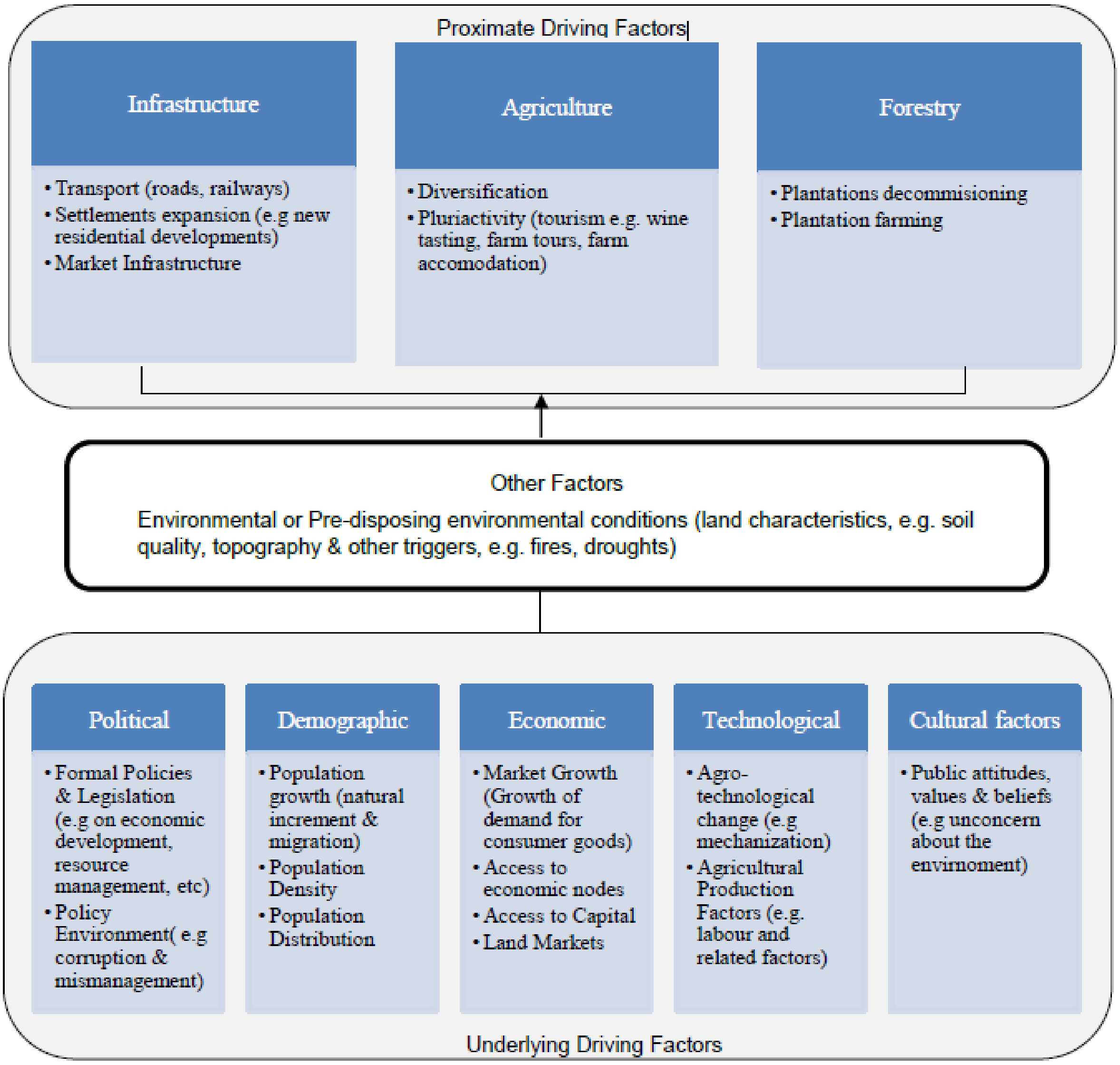


Figure 27: The main drivers of LULCC in the Western Cape (Tizora, 2018).

4.6 Summary

From the census, precipitation and remotely sensed data that has been used for this project, the observation has been made that The City of Cape Town is the district in the Western Cape with the largest population count, with the smallest land surface area, and with the densest population. This means that Cape Town is the district in the Western Cape where LULCC takes place the most and where land degradation will also be the biggest problem in the Western Cape especially if the population count keeps getting higher. It is further determined that the Western parts of the Western Cape have received fewer amounts of rainfall than the Eastern parts have received over the past 20 years and therefore the Western parts have also had less vegetation growth compared to the Eastern parts. Therefore, from the research that has been done, it is determined that the Western parts of the Western Cape are more prone to water shortages, soil erosion, and land degradation and therefore land use and land cover changes are a bigger problem in these areas compared to the Eastern parts presently and possibly in the coming future.

5. Evaluation and Conclusions

The purpose of this study was to examine the role population growth has had on land use and land cover changes in the Western Cape over 20 years by making use of census statistical data and remotely sensed imagery. This chapter provides conclusions of the research that has been done based on the findings from previous chapters while explaining how the research objectives were achieved.

5.1 Evaluation of research objectives

Objective 1: Classify the different land cover types.

The different land cover types have been classified in this study by firstly making use of the literature review to explore previous studies. After this process, a land cover type analysis was used to determine the different methods that can be used to determine the different land cover types whereby remote sensing and field mapping was identified as the most effective methods that can be used. Thereafter data was gathered through SANBI in the form of TIFF files that were used in ArcMap 10.5 to create maps for the year 2014 and 2020 that was used to classify the different land cover types and to further examine urban built-up in the Western Cape. The different land cover types that can be found in the Western Cape were identified as Barren land, cultivated land, Forests, Shrubland/fynbos, Grasslands, Wetlands, Waterbodies, Mines/quarries, and Urban built-up.

Objective 2: Examine and map LULCC.

By making use of a literature review the terms “land use” and “landcover” have been defined in detail by making use of academic work that has been published in the past. Thereafter the different data collection methods were explored whereby Google Earth Explorer, CHRS, and SANBI were used to collect the remotely sensed imagery for the 20-year study period and after the data had been collected, GIS software such as ArcMap 10.5 was used to analyse and create the maps that were used for this study. NDVI MODIS data was gathered through GEE by making use of 5-year intervals whereby the summers and winters were compared for each of these 5 years. Rainfall data was also gathered from the year 2005 to 2020 through CHRS by making use of PERSIANN-CSS to determine and map the amount of rainfall for each of these years and to see how the rainfall data correlates to the NDVI data.

Objective 3: Map the population and human settlement growth over 20 years.

Census statistical data were used to determine the population growth and population density in the Western Cape, which have been supported by maps that have been gathered through

Stats SA and represented in this study. Additional maps were also created with ArcMap and used to represent the urban built-up, population growth, and population density in the Western Cape by making use of GEE's remotely sensed imagery. These maps that were used indicates exactly where population growth has taken place the most and where population density has been at its highest over the past 20 years.

Objective 4: Explore the main drivers that cause LULCC.

All the different drivers of LULCC were firstly explored by compiling a literature review which made use of different academic work to determine the different drivers of LULCC at both an international and national scale. Thereafter, these drivers were researched and analysed by making use of different examples that were used for the Western Cape to be able to determine which drivers are the most important when it comes to the Western Cape. After the different methods have been performed for this research the results were formed and used to determine the most important drivers that cause LULCC in the Western Cape that was represented in Figure 27 in more detail.

5.2 Conclusion

This study has found that significant changes have taken place in both land use and land cover for the Western Cape over the past 20 years. It is determined that remotely sensed imagery has been the most effective method that can be used to examine LULCC because of its level of accuracy and the level of functionality that it has to offer. It is further observed that the main drivers that cause LULCC to take place in the Western Cape are identified as population growth, followed by the rapid urbanization that is caused because of the ever-increasing population growth. These rapid growths in population can be directly linked to the urban built-up areas that were represented in the study, whereas Cape Town has been identified as the district with the highest population count, the highest population density, as well as the district with the largest urban built-up area even though it takes up the smallest area in the Western Cape. It is further determined that Cape Town is one of the districts which receives the least amount of rainfall every year and it is also an area that has a huge shortage of freshwater resources which can pose a huge threat in the future if the necessary plans and infrastructure is not put into place.

5.3 Recommendations

From the research conclusion, the following recommendations regarding spatial planning measures can be put into place:

- Population growth and population density in Cape Town should be continuously monitored to make sure that land degradation, water shortages, housing and other factors do not become a problem in the future.
- Water infrastructure should be made a bigger priority in Cape Town.
- New technologies and methods such as desalination and greywater recycling systems should be researched and put into place for Cape Town to assure that all citizens will have enough water in the future.
- Stricter legislation should also be put into place that prevents citizens and organizations from wasting water.
- Legislation and policies should be put into place in Cape Town to make sure that the environment stays protected from rapid development before it causes too much permanent damage.
- There are also many opportunities in the Western Cape such as the huge amount of barren land surface in the Karroo that can be used for certain developments such as solar power plants or wind farms that are much better alternatives for providing electricity than most conventional methods.
- It is important that continuous mapping of land use is done for the Western Cape to be able to detect the trends in built-up areas and agroforestry influences over natural land cover classes.
- Ecotourism strategies should be developed and put into place to assist in the conservation of the remaining natural resources that can be found in the Western Cape.

References

Abbas, I.I. 2009. An overview of land cover changes in Nigeria, 1975-2005. *Journal of Geography and Regional Planning* 2(1), 62-65.

Addae, B., & Oppelt, N. 2019. Land-Use/Land-Cover Change Analysis and Urban Growth Modelling in the Greater Accra Metropolitan Area (GAMA), Ghana. *Urban Science*, 3(1), 1-20.

Alphan, H., Doygun, H. & Unlukaplan, Y.I. 2009. Post-classification comparison of land cover using multi-temporal Landsat and ASTER imagery: The case of Kahramanmaraş, Turkey. *Environmental Monitoring and Assessment,* 151(1), 327-336.

Barbier, E.B. 2000. Links between economic liberalization and rural resource degradation in the developing regions. *Agricultural Economics,* 23(1), 299-310.

Bimal, P. & Rashid, H. 2017. *Climatic hazards in coastal Bangladesh*. Cambridge: Elsevier Inc.

Brown, D.G., Verburg, P.H., Pontius J.R.G., & Lange, M.D. 2013. Opportunities to improve

CHRS (Centre for Hydrometeorology and Remote Sensing). 2021. Data Portal: PERSIANN-Cloud Classification System. https://chrsdata.eng.uci.edu/ Date accessed: 15 Oct. 2021.

Cooper, A.K. 2014. Meta-language for land-use classification systems. Presentation at the Workshop on the Development of an Interim Framework for the National Land Use Classification Standard, Methodology and Symbology for South Africa. Protea Hotel OR Tambo International Airport, Kempton Park.

DEADP (Department of Environmental Affairs and Development Planning). 2019. Western Cape Land Use Planning Guidelines: Rural Areas.

DMSLP (Disaster Mitigation for Sustainable Livelihoods Programme). 2010. RADAR Western Cape: Risk and Development Annual Review.

Ellis, E. & Pontius, R. 2007. Land-use and land-cover change. Encyclopedia of earth.

EOS (Earth Observing System). 2021. NDVI: EOS crop monitoring. https://eos.com/make-an-analysis/ndvi/#:~:text=Put%20simply%2C%20NDVI%20is%20a,strongly%20reflect%20near%2Dinfrared%20light Date accessed: 28 Apr. 2021.

Ferreira, S. 2007. Role of Tourism and Place Identity in the Development of Small Towns in the Western Cape, South Africa. *Springer*, 18(1), 191–209.

Fischer, G., van Velthuizen, H., Shah, M. & Nachtergaele, F. 2002. Global agro-ecological assessment for agriculture in the 21st century: methodology and results. impact, integration, and evaluation of land change models. *Curr. Opin. Env. Sust.*, 5:452-457.

Frith, A. 2021. A gallery of recent maps. https://adrian.frith.dev/a-gallery-of-recent-maps/ Date accessed: 28 Sep. 2021.

Gibson, D., Paterson, G., Newby, T., Hoffman, T., Laker, M., Henderson, C. & Pretorius, R. 2005. National State of the Environment Project.

Gozdowski, D., Stępień, M., Panek, E., Varghese, J., Bodecka, E., Rozbicki, J., & Samborski, S. 2020. Comparison of winter wheat NDVI data derived from Landsat 8 and active optical sensor at field scale. Remote Sensing Applications: Society and Environment, 20(March). https://doi.org/10.1016/j.rsase.2020.100409

Haberl, H. 2004. Land use and sustainability indicators: An introduction. *Land Use Policy*, 21(1), 193-198.

Handavu, F., Chirwa, P.W.C. & Syampungani, S. Socio-economic factors influencing land-use and land-cover changes in the Miombo woodlands of the Copperbelt province in Zambia. *Elsevier*, 1, 1:40.

HSGO (Humboldt State Geospatial Online). 2019. Introduction to remote sensing: Landsat. http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson3-2/landsat.html# Date accessed: 28 Apr. 2021.

JRC (Joint Research Centre). 2015. GHS population grid, derived from GPW4, multitemporal (1975, 1990, 2000, 2015). Columbia University, Centre for International Earth Science Information Network - CIESIN: European Commission. https://data.europa.eu/89h/jrc-ghsl-ghs_pop_gpw4_globe_r2015a Date accessed: 16 Nov. 2021.

Kwela, N.G. 2018. The Western Cape drought disaster: Preventing day zero. http://www.ndmc.gov.za/Conferences/IDDR/2018/Western%20Cape%20UN-ISDR.pdf Date accessed: 30 Jul. 2021.

Lambin, E.F., Geist, H.J. & Lepers, E. 2003. Dynamics of Land-Use and Land-Cover Change in Tropical regions. *Annual Review of Environmental Resources*, 28:205-241.

Lowry, J.H., Ramsey, R.D., Boykin, K., Bradford, D., Comer, P., Falzarano, S., Kepner, W., Kirby, J., Langs L., Prior-Magee, J., Manis, G., O'Brien, L., Pohs, K, Rieth, W, Sajwaj, T, Schrader, S., Thomas, K.A., Schrupp, D., Schulz, K., Thompson, B., Wallace, C., Velasquez, C., Waller, E. & Wolk, B. 2005. The Southwest regional gap analysis project final report on land cover mapping methods. http://ftp.nr.usu.edu/swgap/swregap_landcover_report.pdf Date accessed 28 Apr. 2021.

Maitima, J.M., Mugatha, S.M., Reid, R.S., Gachimbi, L.N., Majule, A., Lyaruu, H., Pomery, D., Mathai, S. & Mugisha, S. 2009. The linkages between land-use change, land degradation and biodiversity across East Africa. *African Journal of Environmental Science and Technology,* 3(1), 310-325.

SAG (South Africa Gateway). 2021. South Africa's population. https://southafrica-info.com/people/south-africa-population/ Date accessed: 25 Sep. 2021.

SANBI (South African National Biodiversity Institute). 2021. Map Viewers. http://bgis.sanbi.org/MapViewer Date accessed: 28 Sep. 2021.

Shunlin, L., Li, X. & Wang, J. 2012. *Advanced Remote Sensing: Terrestrial information extraction and applications*. Amsterdam: Elsevier Inc.

Statistics South Africa. 2019. Mid-year population estimates. Pretoria: Department of Statistics South Africa.

Tewabe, D., & Fentahun, T. 2020. Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia. *Cogent Environmental Science*, 6(1), 1-11.

Tiwari, M.K. & Saxena, A. 2011. Change detection of land-use/landcover pattern in and around Mandideep and Obedullaganj area using remote sensing and GIS. *Int. J. Techn. Eng. Syst*, 2(3):1-55.

Tizora, P., Le Roux, A., Mans, G. & Cooper, A. 2016. Land Use and Land Cover Change in the Western Cape Province: Quantification of Changes & Understanding of Driving Factors. *ResearchGate*, 2 (1), 108-125.

Tizora, P., Le Roux, A., Mans, G., & Cooper, A. K. 2018. Adapting the Dyna-CLUE model for simulating land use and land cover change in the Western Cape Province. *South African Journal of Geomatics*, 7(2), 190-203.

UNECE (United Nations Economic Commission for Europe). 2008. Spatial planning: A key instrument for development and effective governance with special reference to countries in transition. Geneva: United Nations Economic Commission for Europe Services.

USGS (United States Geological Survey). 2021. Data: MOD13Q1 v006. https://lpdaac.usgs.gov/products/mod13q1v006/ Date accessed: 11 Oct. 2021.

Van der Merwe, J.P.A. 2005. Spatial monitoring of natural resource conditions in Southern Africa. Stellenbosch University. (Thesis - MSc.).

Verbist, B., Putra, A.E.D. & Budidarsono, S. 2005. Factors driving Land-use Change: Effects on watershed functions in a coffee Agroforestry System in Lampung, Sumatra. *Agricultural Systems*, 85:254-270

Verburg, P.H., Van De Steeg, J., Veldkamp, A. & Willemen, L. 2009. From land cover change to land function dynamics: a major challenge to improve land characterization. *Journal of environmental management*, 90(1), 1327-1335.

WCG (Western Cape Government). 2015. Provincial Strategic Plan 2014-2019. In: PREMIER, D. O. T. (ed.).

Wessels K.J, Prince S.D, Malherbe J, Small J, Frost P.E & Van Zyl, D. 2007. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *Journal of Arid Environments* 68(1), 271-297.

WorldPop. 2021. WorldPop Datasets. https://www.worldpop.org/ Date accessed: 16 Nov. 2021.

WWF (World Wide Fund for Nature). 2012. Living Planet Report 2012: Biodiversity, biocapacity and better choices. World Wide Fund for Nature, Gland.

Xulu, S. 2014. Land degradation and settlement intensification in Umhlathze Municipality. Stellenbosch University. (Thesis – MSc.).

Yohannes W.A., Cotter., M., Kelboro G. & Dessalegn W. 2018. Land Use and Land Cover Changes and their effects on the Landscape of Abaya-Chamo Basin, Southern Ethiopia. *Land*, 7(2):1-17.

Yuan, F., Sawaya, K., Loeffelholz, B. & Bauer, M. 2005. Land cover classification and change analysis of the Twin Cities (Minnesota) metropolitan area by multi-temporal Landsat remote sensing. *International Journal of Remote Sensing*, 98(1), 317-328.