



**Trends in NDVI across protected areas in South Africa**

by

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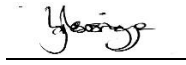
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## **PLAGIARISM DECLARATION**

I understand the penalty that comes with plagiarism, and I declare that is research report titled “Trends in NDVI across protected areas in South Africa” was done by myself. I have correctly referenced everyone whose work I used in my work.

A handwritten signature in black ink, appearing to read "Blessing", is positioned above a solid horizontal line.

Blessing George-Kayode

## **DEDICATION**

I dedicate this research report to God Almighty, myself, and all the animals and plants that lost their existence because of vegetation loss.

## ACKNOWLEDGEMENTS

*“If I have seen further, it is by standing on the shoulders of Giants”* – Sir Isaac Newton

My profound gratitude goes to Almighty God, the One who made me, the author and Finisher, the Alpha and Omega of my life, for His grace, strength, protection, provision and guidance throughout the period of this research report and my study as a whole. Without him, this dream would not have seen the limelight.

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## **ABSTRACT**

Vegetation plays a significant role in the environment as it provides provisioning, supporting, and regulating ecosystem goods and services. Vegetation in protected areas in South Africa is experiencing significant changes in structure and composition as a result of human activities and climate changes. It is imperative that vegetation cover is managed and continuously monitored for it to continue to play its role in ecosystems.

This study aimed at investigating the rate and direction of change in NDVI over a 20-year period (2001-2020) inside, and outside, protected areas in South Africa using remote sensing. NDVI is used as a proxy for vegetation cover, and Google Earth Engine was used to assess the NDVI values for each protected area and its buffers. Grouping the protected areas according to biomes, all the biomes of South Africa except the Forest biome were assessed. No protected area was grouped under the Forest biome because the protected areas studied were grouped under the biome which constituted the largest area. Five protected areas were each studied from Grassland, Savanna, Albany Thicket, Nama-Karoo, Succulent Karoo, and Indian Coast biomes. Three and two protected areas from the Fynbos and Desert biomes, respectively, were studied. Linear regression analysis was done to find the trends in NDVI, and correlation analysis was also done to find the relationship of vegetation change between the protected areas and their buffers. The result of the analysis shows that protected areas in all the biomes except the Grassland and Indian Coast experienced negative trends in NDVI values. This translates to 26 out of the 35 protected areas having negative trends in NDVI. Only 10 of the protected areas have more vegetation cover than their buffers (5 km and 20 km). The protected areas with positive trends in vegetation cover change are gaining vegetation faster or losing vegetation slower than their surroundings. Except for the Oviston Nature Reserve and Orange River Mount Nature Reserve, all the protected areas have strong correlation values with their respective buffers ranging from 0.600 to 1.000. More efforts should be focused on protected areas that have negative trends in NDVI as well as those with negative trends in vegetation cover change.

**Keywords:** Protected area, Biome, Vegetation cover, Remote sensing, NDVI, South Africa, Trends, Google Earth Engine

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## **1. Introduction**

South Africa is known to be one of the world's most biologically diverse countries, having three out of the thirty-six global biodiversity hotspots (Bux et al., 2021). Although the country is known for its array of ecosystems and landscapes and high levels of endemic flora and fauna, it faces threats from human activities such as land use and conversion (Barger et al., 2018; Skowno et al., 2019). Protected areas are established for the purpose of conserving biodiversity especially threatened and endangered species (Small & Sousa, 2016). According to Dudley (2008), a protected area is defined as “a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means to achieve the long-term conservation of nature with associated ecosystem services and cultural values”. However, protected areas face a lot of pressure from human activities, which leads to ecosystem change, land use, land cover change, and vegetation change, which is a major cause of biodiversity loss both inside and around protected areas (Defries & Nagendra, 2017). As a result, vegetation change in and around protected areas is being monitored using remote sensing (Murray et al., 2018). Remote sensing has become a primary and essential tool for the monitoring, mapping, and evaluation of vegetation cover changes especially in protected areas by providing researchers up to date satellite information on vegetation cover (Pereira et al., 2013). Many researchers use the Normalized Difference Vegetation Index (NDVI) introduced by Tucker (1979) which is one of the widely used remotely sensed spectral indices to assess vegetation change at regional and global level (Xu et al., 2016). NDVI is sensitive to the photosynthetic activity (Ning et al., 2015) of the vegetation in the observed area, the value ranges from -1 to 1 where a value between 0 and 1 represents vegetation (the higher the value, the higher the greenness), a value between 0 and -1 represents no vegetation, bare ground, or water.

## **1.1 Problem statement**

In protected areas, vegetation plays important roles as it provides essential provisioning, supporting, and regulating ecosystem goods and services (Madureira et al., 2015; Stolton et al., 2015). Though vegetation adapts to new conditions, it is sensitive to changes in atmospheric carbon dioxide which makes it a major factor in predicting future climate and a warning of climate change (Pan et al., 2018). Vegetation in protected areas is experiencing significant changes in structure and composition as a result of human activities, and changes in climate (De Baan et al., 2013). There has been various research done predicting that the impact of climate change on vegetation will exacerbate as the concentration of CO<sub>2</sub> in the atmosphere increases (Beck et al., 2011).

To make predictions reliable enough to influence future environmental and conservation policies, it is imperative that evaluation of the past is done, and the rate and direction of change is well understood (Luo et al., 2011). This improves our chances of predicting climate extremes as well as coming up with strategies to mitigate the impact of climate change on the ecosystem (Peters et al., 2004).

Many researchers have used NDVI to examine ecosystem dynamics in protected areas which is important for the monitoring, management, and planning of natural resources (Tucker et al., 2005; Alcaraz-Segura et al., 2008; Nemani et al., 2009; Wang et al., 2012). Despite the use of NDVI which is an effective tool to examine vegetation change, most researchers have selected specific areas in South Africa for their studies without examining protected areas in all biomes across South Africa. For example, Wegmann et al. (2014) used NDVI as a proxy to examine vegetation change of several protected areas in Africa. Even though the authors investigated a large study area, they were limited to selecting only few protected areas in South Africa.

In view of the above, this study examined extensively the protected areas in South Africa and expanded on the Wegmann et al. (2014) study of vegetation cover changes inside and outside protected areas from 2001 - 2020. It is important and necessary for this examination to be done because it provides information on the present situation and long-term trend of vegetation change in protected areas and biomes across South Africa. The information obtained from this study may influence management actions, planning, and monitoring of ecosystems towards conservation of biodiversity.

## **1.2 Aims and objectives**

This project aimed at investigating the rate and direction of change in NDVI over a 20-year period (2001-2020) inside and outside protected areas in South Africa

Specific objectives

- 1) To assess the trends in NDVI across protected areas in South Africa from 2001 to 2020.
- 2) To evaluate and compare vegetation cover change trends inside protected areas and their surrounding buffer zones (5 km and 20 km).

## **2. Literature review**

### **2.1 Protected areas**

Protected areas (PA) over the past few decades have experienced a tremendous expansion that has been influenced by the government, NGO, and local communities leading to the rapid growth and recognition of protected areas all over the world (Watson et al., 2014). Due to the rapid growth, the expectations placed by various stakeholders on protected areas have dramatically increased because of the fragmentation of natural ecosystems (Sanderson, 2002). Protected areas are now created not just for the conservation of famous seascapes and landscapes, and to protect threatened and endangered species, but they are also established to improve the livelihood of the local communities surrounding the protected areas, increase the nation's revenue through tourism and play an essential role in species adaptation to the impacts of climate change while mitigating them (Dudley & Stolton, 2010). A protected area is an area of land set aside as a strategy for biodiversity conservation, sustaining ecosystem services, and protect habitat for endemic and endangered species (Margules & Pressey, 2000; Obeng et al., 2021). Even though the area of land set aside as a protected area has increased globally to over 13% of the earth surface area (UNEP-WDPA, 2019), the threats facing biodiversity as a result of land degradation and encroachment have not been alleviated (Hansen & Defries, 2007; Gonzalez-Roglich et al., 2019). Protected areas do not occur in isolation so various factors such as land use, species, and activities in the landscape surrounding the park influence the functioning of a park (Hansen & Defries, 2007).

Protected areas are not a new development, they have been in existence in the form of sacred sites established by local communities (Orsenigo et al., 2019). Nevertheless, protected areas have now been modified and developed in this modern age and have rapidly grown from a few protected areas at the beginning of the 20<sup>th</sup> century to over 162 000 national protected areas that are legally managed making it about 5.6% of the earth's area being protected (Watson et al., 2014). The terrestrial protected areas can be compared to the total land area of South and Central America combined and the area of the marine protected areas can also be compared to the combination of the Bering Sea, South China sea, Caribbean sea and the Mediterranean sea (COP14, 2019). In addition to the legally protected areas, there are many other protected areas

that are not legally managed but are managed by, for instance, the local communities, individuals, religious groups, corporations (COP14, 2019).

In the early development of modern protected areas, protected areas were established solely for the protection of outstanding natural feature, and wildlife (The World Commission on Human and Environment Development, 1987). Although many of these protected areas considered or incorporated public use while protecting landscape and species in their establishment, they did not incorporate tourism until the mid-20<sup>th</sup> century (UN, 1992). In some developing nations, tourism in protected areas boosts the economy of the nation. For instance, Rwanda generates about US\$200M annually from tourists visits to the Volcanoes National Park, which has been the main source of foreign exchange for the country (Aviles-Polanco et al., 2019). Protected areas have also been established due to the concerns raised from environmental degradation. These concerns have increased the importance attributed to in-situ conservation which has led to the expansion of protected areas globally to aid the protection of species and ecosystem from the adverse impacts of rapid environmental changes (Watson et al., 2014). Many studies have justified the use of protected areas as the major conservation strategy and if well managed, PAs are capable of reducing habitat loss (Petraitis, 1989; Janzen, 2004; Kati, 2004; DeFries et al., 2005; Gavin, 2015), and maintain species populations better compared to other management approaches such as the ex-situ conservation approach.

## **2.2 Biodiversity conservation**

Over the years, studies have shown that there is a decline in biodiversity which is attributed to land use/conversion and habitat fragmentation (Krauss et al., 2010; Li et al., 2016). The loss of biodiversity globally is detrimental to the maintenance of environmental function and ecosystem services (Butchart et al., 2010). One of the strategies to mitigate the loss of biodiversity is to investigate and identify areas important to biodiversity conservation and exert conservation efforts to those areas, such as protected areas (Myers, 1988). Threats have an adverse effect on protected areas, which can reduce their function in conserving biodiversity, provisioning of ecosystem services, and reduce the size of the protected area (Balme et al., 2010). There is a correlation between the increase in human activities around the protected area and the extinction rate of species which can be exacerbated by illegal activities in the protected areas, increase in urban settlement, and climate change (Basommi, 2016). Protected areas do not only conserve

biodiversity, but the local communities also around protected areas benefit from the protected areas through programs such as Community Based Natural Resource Management (CBNRM) (Hattter & Southworth, 2009). As a result, it is important to monitor and ensure the effectiveness of protected areas in the delivery of these services.

Developing nations, such as South Africa which is one of the world's most biologically diverse countries, have experienced rapid land use and land cover change over the years (Musakwa & Wang, 2018), which has a significant effect on the environment (Li et al., 2016) and is caused by deforestation and rapid urbanization (Barlow et al., 2016; Richards & Fries, 2016). Depending on the degree of change, land cover change can cause a total change in the existing ecosystem or a partial change (Levine et al., 2016). Several studies have investigated land use and land cover change using vegetation condition as a proxy (Houessou et al., 2013; Zoungrana et al., 2018); because it is easy to observe the direction and extent of vegetation cover change regardless of the causes of the change. This has led it to be the leading indicator used by scientist to investigate land cover change (Reynolds et al., 2007).

Vegetation plays an essential role in ecosystem functioning and is known to react to changes in the environment; thus, it is used to monitor global change. Additionally, vegetation is also responsible for land surface energy exchange, biogeochemical and hydrological cycles (Harrison & Goni, 2010). Vegetation cover degradation has become a concern because it threatens biodiversity, which may result in the degradation of the soil (Yengoh et al., 2015). Land use and land cover (LULC) is usually classified to identify vegetation that has undergone conversions (Xu et al., 2016). According to Xu et al. (2016), conversion is the total substitution of natural vegetation cover by a different land cover, which can be caused by anthropogenic activities such as deforestation and climate change. Oftentimes, modification of vegetation types and pattern are as a result of the effects of human activities in addition to changes in temperature and rainfall conditions on vegetation structure (Adepoju et al., 2019). The vegetation cover, phenology, and production changes when the vegetation structure changes as a result of changes in the environment. Vegetation cover, which is the amount of vegetation in a specific area has proven to be an indicator to monitor environmental changes and also used to differentiate different ecosystems (Zhang et al., 2013).

### **2.3 Effect and projection of climate change on vegetation**

The South African vegetation is at risk of changes to its structure and composition in response to climate change (Ziervogel et al., 2014). According to Von Maltitz et al. (2019), some of the South African biomes such as the Forest, Indian ocean coastal belt, Nama karoo, and Fynbos are becoming vulnerable due to increasing temperature. The biomes are experiencing significant changes like shifting of their boundaries which is caused by climate change (Beck et al., 2011). For instance, the Nama-karoo is shrinking in the west and moving northeast into the Grassland biome as a result of increasing CO<sub>2</sub> and aridification (Midgley et al., 2008). The Grassland biome in turn is shrinking due to the increase of the Savanna biome as a result of the spread of the trees which are favored by the rise in CO<sub>2</sub> and temperature (Midgley & Thuiller, 2011). It was projected by SAEON (2015) that tree density will be on the increase while species diversity will be on the decrease due to an increase in temperature and decrease in rainfall as species lose their resilience to the effect of drought and heat. The study carried out by Buitenwerf et al. (2012), concluded that tree density was increasing majorly due to increasing CO<sub>2</sub> in the atmosphere, which has changed the ecology of trees and grasses in South Africa. Over the years, the adverse effect of climate change on the vegetation in South Africa has been on the increase (King et al., 2015). The Savanna biome is being threatened by the rapid increase of woody plants, which has the ability to change its state into a thicket (Parr et al., 2012). Prevey et al. (2019) proved that there is a link between climate change and plant phenology which is further supported by García Criado et al. (2020), whose study testified that there is a relationship between climate change and wood encroachment. This is possible because the increase in the concentration of CO<sub>2</sub> in the atmosphere increases CO<sub>2</sub> uptake of plants (Kgope et al., 2010) and increases the availability of soil water (Leakey et al., 2009), thereby favoring woody plants. Wood encroachment can cause an alteration in the ecosystem, causing biodiversity loss and reducing ecosystem services to humans. In addition, it has the potential to negatively impact crop production as well as tourism (Honda & Durigan, 2016). Woody encroachment, a term used interchangeably with bush encroachment, which occurs when there is an increase in woody plants, especially in places where they are usually not found is driven by the increase in atmospheric CO<sub>2</sub> (Zhang et al., 2019), change in rainfall pattern as well as human activities. Fire processes maintain the Savanna ecosystem but human activities altering the fire pattern or process by deliberately suppressing fire with construction of fences and roads (Archibald et al.,

2013) will enhance the growth of woody plants (Archer et al., 2017) making the Savanna biome exceptionally vulnerable to woody encroachment (Stevens et al., 2017).

With the alarming rate of global warming, biodiversity worth almost \$200 billion may be lost by 2050 (Seidensticker, 2010), including significant loss of several species in the fynbos biome in South Africa (Skowno et al., 2021). Engelbrecht et al. (2015) projected that rainfall in South Africa would reduce by 30% between 2071 and 2099; likewise, temperature would increase by 3°C by the end of the century. Furthermore, the projection made by Jury (2013) supports Engelbrecht et al. (2015) that there would be an increase in aridity, particularly in the Southwestern region of South Africa at the end of the century, which has been mainly due to the rise in temperature (Serdeczny et al., 2016). It is also expected that the rate of drought would increase by 40% by 2100 (Prudhomme et al., 2014), and this would have an adverse impact on vegetation. South Africa is not only known as a biodiversity hot spot, but it is also known as a climate change hot spot (Hoegh-Guldberg et al., 2019).

## **2.4 Remote sensing and NDVI for monitoring vegetation**

Remote sensing refers to the process of acquiring information about an object through sensors mostly from satellites (Chuvieco et al., 2020). The information is acquired when the electromagnetic energy emitted by the observed object is measured (Geller et al., 2017). Remote sensing has evolved from simple classifications of land cover (Herbreteau et al., 2007) to complex spectral analyses including assessing vegetation condition and crop growth. Now, remote sensing is used to monitor vegetation cover, environment, crop growth, and so on. The imageries produced from remote sensing are a combination of various bands which produce the most appropriate image that is then used for analysis. Images generated are a good representation of what is happening on the ground; an example is the vegetation. This information is fundamental to conservation management as remote sensing has the ability to view the surface of the earth from various perspectives at different spectral dimensions and resolutions (Soberon & Peterson, 2004).

Over the years, remote sensing has been used to evaluate and analyze vegetation cover change over large areas, which is imperative to understand the trends of vegetation change of the area to inform environmental policies and decision making (Okin, 2007). Recently, there have been advancements in remote sensing technology that have increased the accuracy of satellite images

of vegetation cover. Wegmann et al. (2014) used remote sensing to analyze habitat change within and around various protected areas in Africa and their result showed that the rate of vegetation change gave a flat or positive trend for most of the protected areas. Evaluation and analyses of vegetation cover is only possible and reliable if the appropriate remotely sensed images are selected and are converted into the relevant vegetation indices (Barati et al., 2011). Multispectral imageries have been used to derive various vegetation indices such as the Normalized Differential Vegetation Index (NDVI), the Wide Dynamic Range Vegetation Index (WDRVI), and the Enhanced Vegetation Index (EVI) just to mention a few (Jordan, 1969; Huete et al., 1997; Gitelson, 2004; Xue & Su, 2017). Out of the various vegetation indices available, NDVI is popularly known and used to monitor the greenness of an area. It is used to assess and analyze vegetation change because of its potential to quickly detect vegetation decline and stress which is an advantage in the agriculture sector and land use investigation. NDVI is also preferred most time to the other vegetation indices because of its strong correlation with vegetation cover (Xiao et al., 2015).

In the early years of NDVI, the AVHRR was the dominant product used to derive NDVI values (James & Kalluri, 1994). Nowadays, Landsat and MODIS (Moderate Resolution Imaging Spectroradiometer) products have been used to replace the AVHRR because they have high spatial resolutions of 30 m for Landsat and 250 m to 1000 m for MODIS. Hoare and Frost (2004) used remote sensing and the NDVI values provided by AVHRR to describe the phenological characteristics and seasonal dynamics of all the biomes in southern Africa. Cho and Ramoelo (2019) obtained NDVI time series from MODIS product to examine tree-cover change in the Savanna and Grassland biomes of South Africa. Their result shows that there has been an increase in tree-cover between 2001 and 2018.

Various studies have shown the benefits of NDVI, Pettorelli et al. (2005) showed that NDVI could be used to effectively differentiate between biomes, differentiate dense forests from agricultural fields as well as identify seasonal forests and evergreen forests. Furthermore, it is effective in the investigation of vegetation properties, biomass, the concentration of chlorophyll in leaves, vegetation cover, and plant productivity (Pettorelli et al., 2005; Zhu & Liu, 2015; Dutrieux et al., 2015; Tian et al., 2017). All these qualities of NDVI have resulted in it being promoted above other vegetation indices by scientists since the 1970s and these qualities have

informed the decision to enable most remote sensing satellites to capture the necessary wavelengths to enable the calculation of the index, including satellites such as Sentinel, Landsat and MODIS, produce it at different spatial and temporal resolutions (Shao, 2015). NDVI has partly facilitated the use of remote sensing because it simplifies the complexity of vegetation properties; nevertheless, it has some significant drawbacks, such as pointed out by Frantz (2019).

Sensor quality: in the quest to keep producing products that can produce the NDVI values, products with different spatial resolutions, band widths and processing have resulted in different NDVI values.

Atmospheric effects: the red wavelength is shorter and stronger compared to the near infrared wavelength resulting in Rayleigh scattering which affects NDVI calculation. The problem created by Rayleigh scattering can be avoided by using surface reflectance that is atmospherically corrected instead of top of the atmosphere (TOA) radiance (Frantz, 2019).

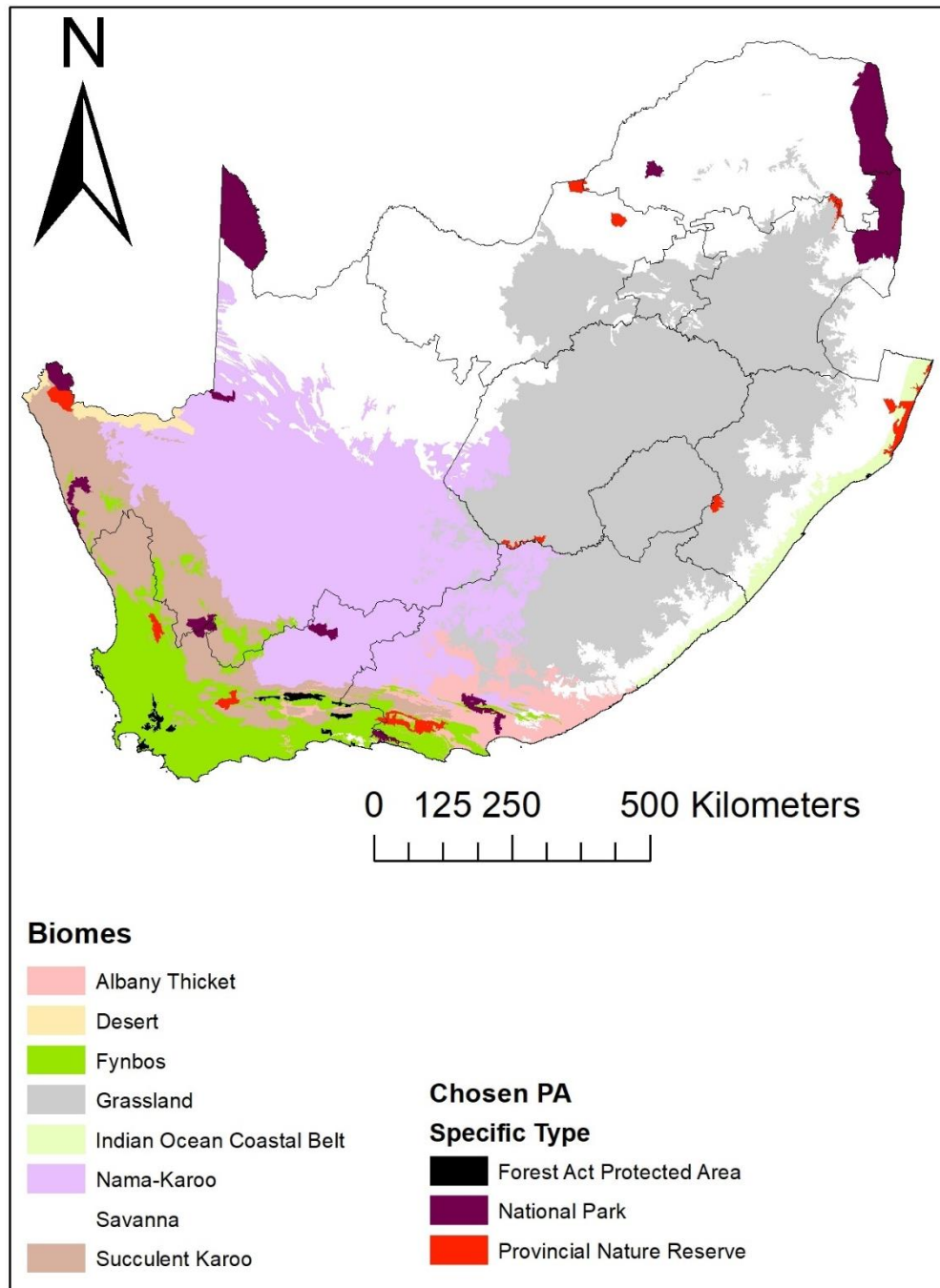
Saturation ease: NDVI becomes insensitive at a certain high level of biomass or environmental changes whereas it is sensitive to the soil, atmosphere and pixel. NDVI values are highest when vegetation is at its greenest; and values become saturated when a forest (high density of woody vegetation) has a high biomass value (Van Der Meor et al., 2001) causing a dense forest to have a higher NDVI value than a green golf course grass.

### **3. Methods**

#### **3.1 Study area**

South Africa is known for biodiversity richness, and concerns have been raised regarding the loss of biodiversity. This study was carried out in protected areas across South Africa and the biomes of South Africa were used to group the protected areas. It was initially proposed that the study would be carried out in five protected areas across each of the nine biomes in South Africa but during the data collection, it was observed that some protected areas have overlapping biomes. Such protected areas were grouped under the biome which constituted the largest area. This arrangement left the forest biome with no protected area and the Fynbos and Desert biomes with only three and two protected areas respectively.

In total, thirty-five protected areas were studied across eight biomes in South Africa which was based on the protected area category and the specific type of protected area. The biomes are Grassland, Savanna, Albany Thicket, Succulent Karoo, Nama-Karoo, Indian Coastal, Fynbos, and Desert and I selected protected areas from the category Formal A which includes specific protected area types such as national parks, provincial nature reserves, and forest act protected areas as categorized in the South African National Biodiversity Institute, National Biodiversity Assessment (NBA) 2011 protected Area layer dataset under the Protected Areas Act (Act 57 of 2003) and were downloaded from SANBI BGIS. The use of the National Biodiversity Assessment (NBA) 2011 file was mainly for selecting the protected areas on ArcMap and also to create the map below (Figure 3.1).



**Figure 3.1:** Map showing the biomes and protected areas in South Africa that were investigated in this study.

### 3.2 Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is a vegetation index used to measure the greenness of an area which is achieved when the vegetation reflects the near infrared wavelength and absorbs the red wavelength of the electromagnetic spectrum (Maskova et al., 2008). NDVI is used in this study because of its simplicity in detecting the status of vegetation growth, vegetation cover and phenology (Huang et al., 2021) over a large spatial area. NDVI uses the reflected and absorbed wavelength to create a value which signifies the photosynthetic activity occurring at a pixel using the formula:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The NDVI value is between -1 and 1 where a high NDVI value signifies a high photosynthetic activity. The degree of greenness of an area is defined by the NDVI value of the area. An area with a dense vegetation would reflect more near-infrared wavelength than red wavelength leading to a high NDVI value, while an area with a sparse or unhealthy vegetation would reflect a lesser near-infrared wavelength than the red wavelength which results in a low NDVI.

For this study, the already calculated NDVI time series from 2001 to 2020 generated by MODIS (MOD13A2, <https://lpdaac.usgs.gov/products/mod13a2v006/>) were used.

### 3.3 MODIS

In this study, the MOD13A2 Version 6 Terra (<https://lpdaac.usgs.gov/products/mod13a2v006/>) Vegetation Indices was used. This dataset provides the NDVI of a pixel at a spatial resolution of 1000 m (Didan, 2015) which is sufficient for the monitoring of the vegetation in the selected protected areas which are at regional level. The MOD13A2 has two primary vegetation layers, which are the Normalized Difference Vegetation index (NDVI), and the Enhanced Vegetation Index (EVI) but this study will be focusing on NDVI. It is a series of 16-day composites, where the best/clearest pixel value is chosen from a composite of 16 days' worth of images. This dataset has the following bands: NDVI, EVI, two detailed QA (quality assurance), and reflective bands 1 (red), 2 (near-infrared), 3 (blue) and 7 (mid-infrared). The MOD13A2 dataset was used as opposed MOD13A1 version 6, which has a spatial resolution of about 500 m because the

MOD13A2 version 6 is available from 2000 to date while MOD13A1 version 6 is only available from 2011.

### **3.4 Methodology**

#### **3.4.1 Trends in NDVI across Protected areas in South Africa from 2001 to 2021**

For this study, the Google Earth Engine (GEE) was utilized. GEE is a platform that houses various satellite images and information, it also functions as a tool that helps scientist to analyze the data obtained from satellites. The GEE Code Editor was used to process the mean NDVI values of each of the protected areas and their buffer zones (5 km, and 20 km). The buffer zones were randomly selected, and the kilometers are enough/adequate to be able to compare the different vegetation cover change. The following datasets were imported into GEE Code Editor: a) Large Scale International Boundary (LSIB) from the National Geospatial-Intelligence Agency (NGA) whose function is to select the country of interest (South Africa), b) The World Database on Protected Areas (WDPA) whose purpose is to select protected areas in the country of interest, and MOD13A2 Terra Vegetation Indices which has the calculated NDVI values. Thereafter, a point of interest on a protected area on the map was picked for processing. In this coder, the JavaScript language was used to compile the code script in order to generate the mean NDVI values for each of the protected areas and their buffers. It is important to clarify that the mean NDVI values generated on the GEE were a composite of 16 days such that 2 mean NDVI values were calculated for each month. A total of 35 protected areas from eight biomes were selected: five protected areas from six biomes (Grassland, Savanna, Albany thicket, Succulent karoo, Nama-Karoo, and Indian coast) each, and three and two protected areas from two different biomes (Fynbos and Desert respectively). Mean NDVI values for each of the 20 years (2001 – 2020) were calculated in GEE for each of the protected areas and their respective buffer zones (5 km and 20 km). A time series was then generated for each of the protected areas and their respective buffer zones.

The NDVI time-series was exported as csv into Microsoft Excel software to calculate annual mean NDVI values, to plot simple linear regression trendlines of the values, and also to derive slope values of the trendlines which were then used to understand the trends in vegetation cover change across protected areas. In addition, correlation analysis was done with Statistical Package for Social Sciences (SPSS) software to generate the Pearson correlation coefficient ( $r$ ) which was

used to analyze the relationship between the trend in the mean annual NDVI in the protected areas and their buffer zones. Pearson correlation coefficient ( $r$ ) values range from 0 to 1 and the higher the value the higher the relationship between the protected areas and their buffers.

### **3.4.2 Vegetation cover change inside protected areas and their surrounding buffer zones (5 km and 20 km)**

The slope values were used to detect the differences in the NDVI linear regression trendlines of the protected areas and the surrounding buffers (Anderson et al., 2005). Areas with negative slope values shows a decreasing vegetation cover and areas with positive slope values shows that there is an increase in vegetation cover. In a situation where the slope value is 0, it indicates that there is no change in vegetation cover in that area over a certain period of time.

To detect the vegetation cover change inside and outside the protected areas, the slope values of the NDVI trendlines the protected areas and buffer zones were examined. There is a positive vegetation cover change when the slope value of the protected area is greater than the slope values of the buffer zones (5 km and 20 km), indicating that vegetation loss is at a higher rate in the buffer zones than inside the protected area or vegetation is increasing at a faster rate inside the protected area than the buffer zones. A negative vegetation cover change shows that the slope values in the buffer zones are greater than the slope value of the protected area which indicates that vegetation loss is at a higher rate inside the protected areas than the buffer zones or vegetation cover is increasing in the buffer zones at a faster rate than inside the protected areas. There is no vegetation cover difference when the slope value of the protected area is the same with the slope values of the buffers and this shows that rate of vegetation gain or loss is the same inside the protected area and in the buffer zones.

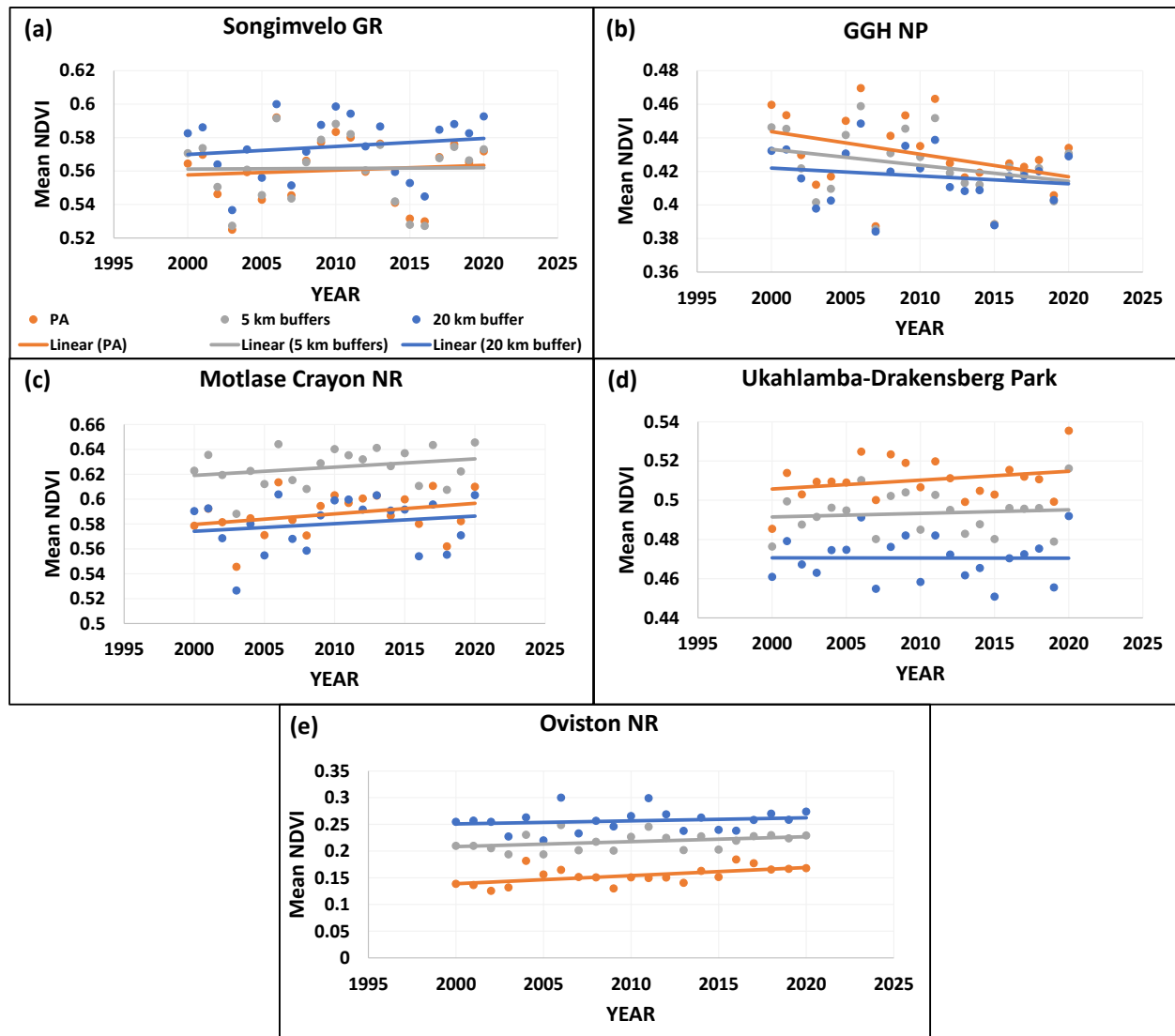
## **4. Results**

### **4.1 Trends in NDVI across protected areas in South Africa from 2001 to 2020**

This subsection presents the time series charts and outlines the trends in the Mean NDVI values of the selected protected areas and buffers (5 km and 20 km) from 2001 to 2020 for each of the biomes; Grassland, Savanna, Albany Thicket, Succulent Karoo, Nama-Karoo, Indian Coast, Fynbos, and Desert. All protected areas in six out of the eight biomes covered have negative trends in mean NDVI. The Grassland biome and the Nama-karoo biome have three to four of the protected areas with positive trend in NDVI.

#### **4.1.1 Grassland Biome**

On the average, there is a positive trend in NDVI for the Grassland biome from 2001 to 2020 as shown in Figure 4.1. All the protected areas in this biome have positive trends in Mean NDVI except the Golden Gate Highland NP which has a negative trend. Strong correlation exists for all parks within the Grassland biome between mean NDVI within the park, and its respective buffer zones with 'r' values ranging from 0.962 to 0.994 (5 km buffer), and 0.881 to 0.974 (20 km buffer) except for Oviston Nature Reserve with r values of 0.23 (5 km buffer) and 0.57 (20 km buffer) in Table 4.1. Ukhahlamba-Drakensberg Park (UDP) and Golden Gate Highlands National Park (GGHNP) have higher ranges of mean NDVI values (0.51 - 0.52; 0.45 – 0.43) than their 5 km buffers (0.49 - 0.50; 0.44 – 0.43) 20 km buffers (0.47 – 0.48; 0.43 – 0.42) whereas Oviston Nature Reserve has lower mean NDVI values (0.120 – 0.135) than its 5 km buffer (0.20 – 0.22) and 20 km buffer (0.23 – 0.235). The range of mean NDVI values inside Songimvelo Game Reserve is similar to its 5 km buffer (0.56 – 0.57), and lower than its 20 km buffer (0.58 – 0.59). In Motlase Crayon Nature Reserve, the range of mean NDVI values (0.58 -0.60) is lower than 5 km buffer (0.62 – 0.64) but higher than 20 km buffer (0.57 – 0.59).

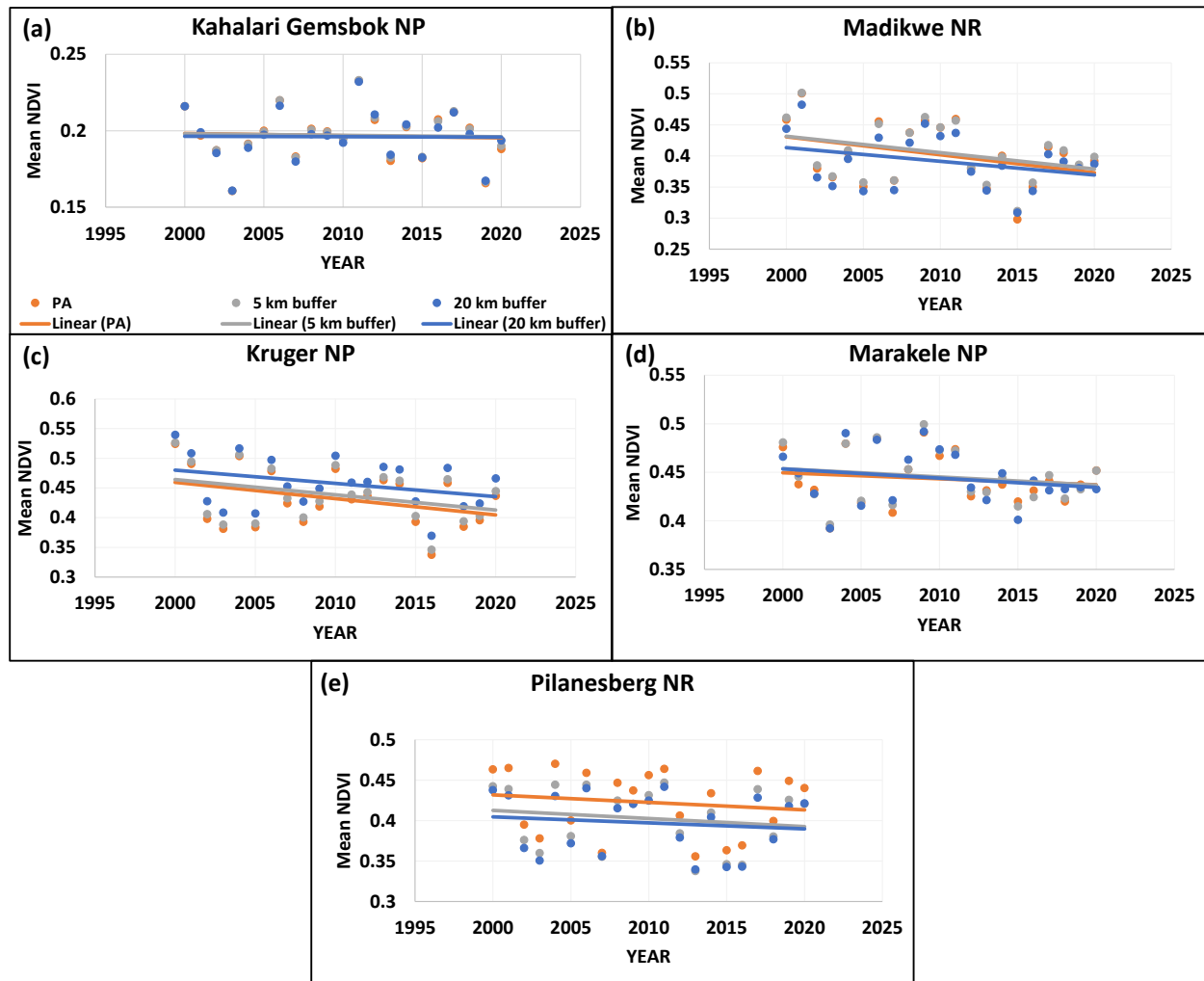


**Figure 4.1:** Time series charts showing trendlines of mean NDVI values from 2001 to 2020 (20 years) for the protected areas and their respective buffers (5 km and 20 km) in the Grassland biome; (a) Songimvelo Game Reserve (GR), (b) Golden Gate Highlands National Park (GGHNP), (c) Motlase Crayon Nature Reserve (NR) (d) Ukahlamba-Drakensberg Park (UDP), and (e) Oviston Nature Reserve (NR).

#### 4.1.2 Savanna Biome

All protected areas in the Savanna biome have negative trends in mean NDVI throughout the study period (2001-2020) (Figure 4.2). The protected areas also have strong correlation with their respective buffers ranging from 0.985 to 1.000 (5 km) and 0.931 to 0.996 (20 km) (Table 4.1). The range of mean NDVI values inside Pilanesberg Nature Reserve (0.44 – 0.42) is higher

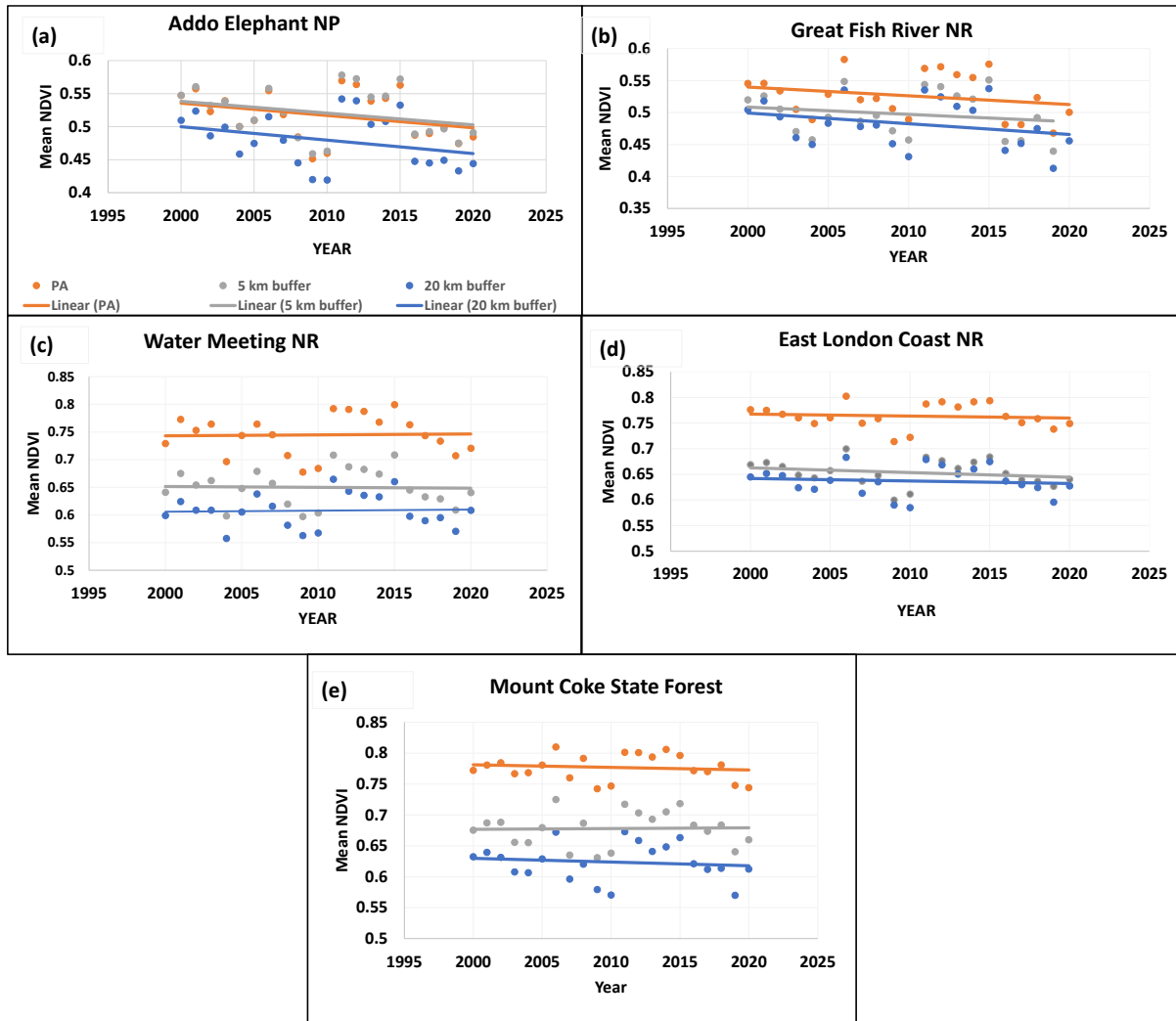
than its 5 km buffer (0.410 – 0.390) and 20 km buffer (0.405 – 0.39) while that of the Kruger National Park (0.43 – 0.40) is lower than its 5 km buffer (0.43 – 0.41) and 20 km buffer (0.44 – 0.42). Kahalari Gemsbok National Park and Marakele National Park have close mean NDVI with their buffers (0.20 – 0.19 and 0.45 – 0.43), while the range of mean NDVI values of Madikwe Nature Reserve is the same with its 5 km (0.43 – 0.38) and higher than the 20 km buffer (0.42 – 0.37).



**Figure 4.2:** Time series charts showing trendlines of mean NDVI values from 2001 to 2020 (20 years) for the protected areas and their respective buffers (5 km and 20 km) in the Savanna biome; (a) Kahalari Gemsbok National Park (NP), (b) Madikwe Nature Reserve (NR), (c) Kruger National Park (NP), (d) Marakele NP, and (e) Pilanesberg Nature Reserve (NR).

#### **4.1.3 Albany Thicket Biome**

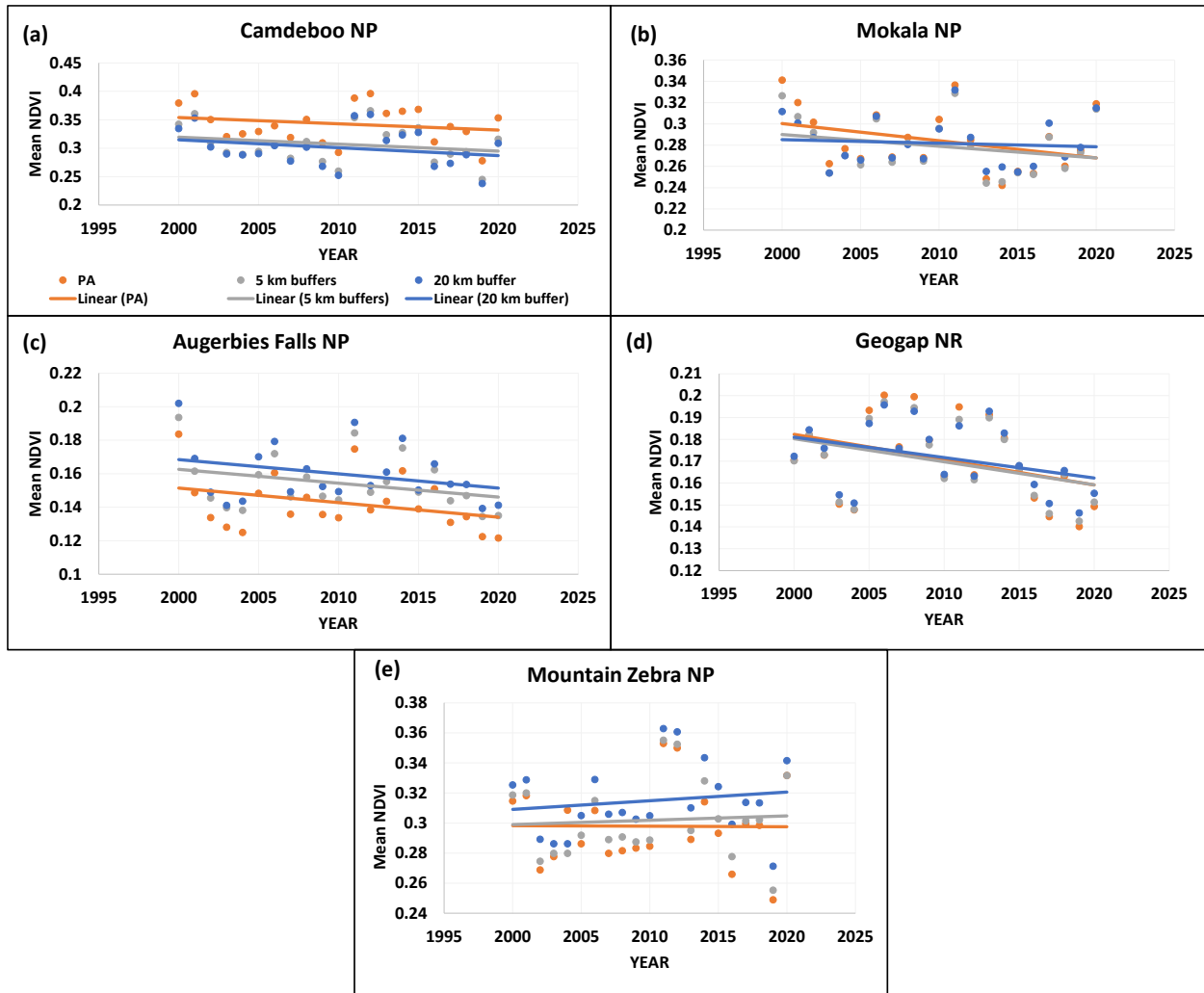
The protected areas and their buffers (5 km and 20 km) analyzed in this biome all have negative trends in mean NDVI over the 20 years period except the Water Meeting Nature Reserve where the mean NDVI values inside the PA and the 5 km buffer have positive trends and the 20 km buffer has negative trend (Figure 4.3). All the PAs in this biome have strong correlation with their respective biomes with 'r' values ranging from 0.932 to 0.996 (5 km) and 0.910 to 0.992 (20 km) (Table 4.1). The parks have higher ranges of mean NDVI values than their buffers except for the Addo Elephant National Park with the range of mean NDVI values (0.535 – 0.500) inside the park slightly lower than 5 km buffer (0.540 – 0.505) and higher than 20 km buffer (0.50 – 0.46).



**Figure 4.3:** Time series charts showing trendlines of mean NDVI values from 2001 to 2020 (20 years) for the protected areas and their respective buffers (5 km and 20 km) in the Albany Thicket biome; (a) Addo Elephant National Park (NP), (b) Great Fish River Nature Reserve (NR), (c) Water Meeting Nature Reserve (NR), (d) East London Coast Nature Reserve (NR), and (e) Mount Coke State Forest.

#### **4.1.4 Nama-Karoo Biome**

The protected areas and their buffers shown in Figure 4.4 displays negative trends except Mountain Zebra National Park which has a slight negative trend while the buffers have positive trends in mean NDVI. The parks have strong correlation values with their buffers ranging from 0.949 to 0.997 (5 km) and 0.897 to 0.978 (20 km) (Table 4.1). Mountain Zebra National Park and Augerbies Falls National Park range of mean NDVI values (0.31 – 0.30; 0.15 – 0.13) are lower than their respective 5 km buffers (0.31- 0.32; 0.16 – 0.15) and 20 km buffers (0.32 – 0.33; 0.170 – 0.155). The range of mean NDVI values inside Camdeboo National Park (0.35 – 0.33) is higher than the mean NDVI values of the buffers (0.32 – 0.30; 0.31 – 0.29). For Mokala National Park, the range of mean NDVI values inside the park (0.30 – 0.27) is higher than the buffers at the beginning of the study but declined rapidly towards the end of the study with values the same as those of the 5 km buffer (0.29 – 0.27) but lower than the mean NDVI values of 20 km buffer (0.280 – 0.275). Geogap Nature Reserve and its buffers approximately have the same mean NDVI values (0.18 – 0.16) giving them the same trends.

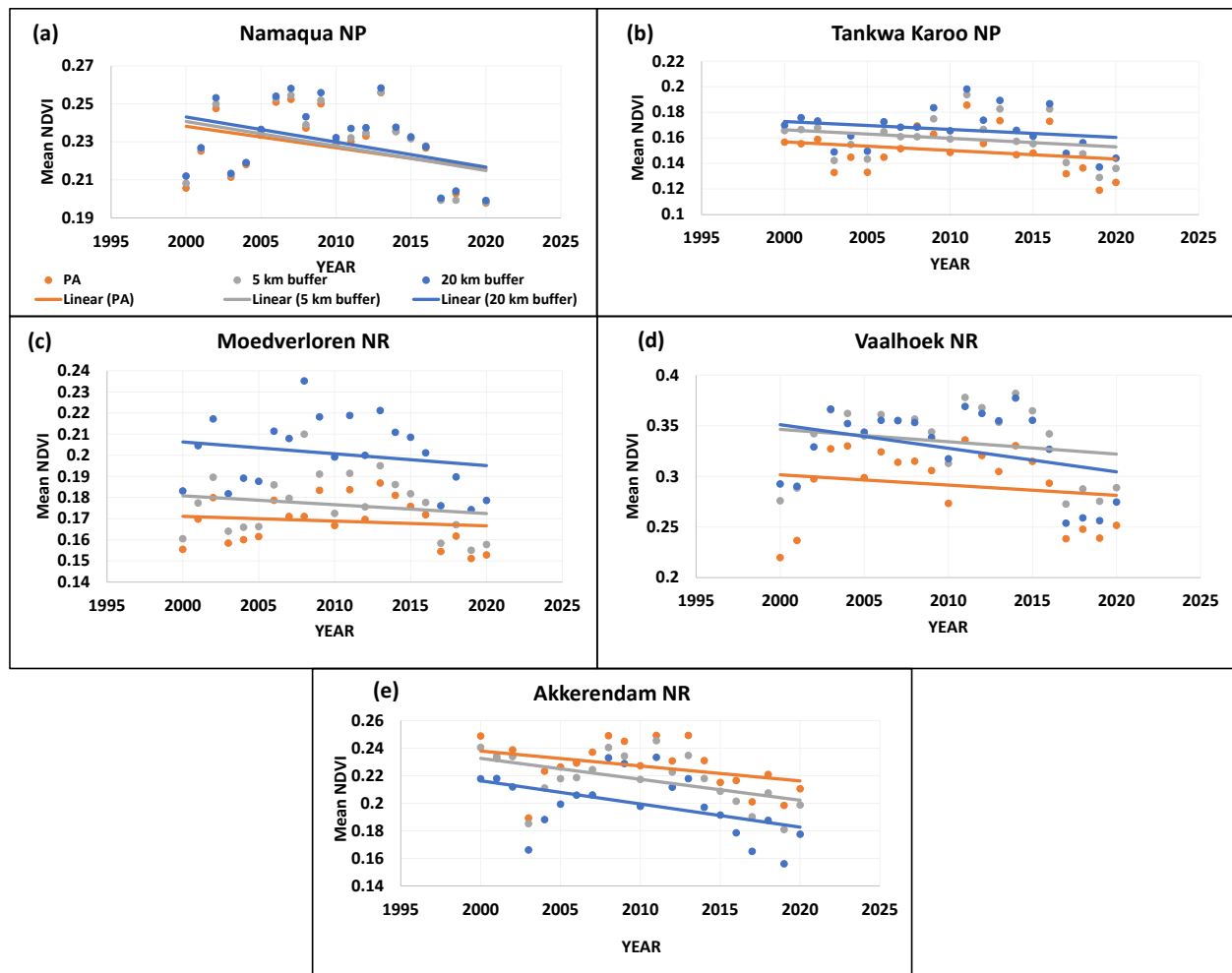


**Figure 4.4:** Time series charts showing trendlines of mean NDVI values from 2001 to 2020 (20 years) for the protected areas and their respective buffers (5 km and 20 km) in the Nama-Karoo biome; (a) Camdeboo National Park (NP), (b) Mokala National Park (NP), (c) Augerbies Falls National Park (NP), (d) Geogap Nature Reserve (NR), and (e) Mountain Zebra National Park (NP).

#### 4.1.6 Succulent Karoo Biome

In the Succulent Karoo biome, all the protected areas and their buffers have negative trends in mean NDVI (Figure 4.5). They also all have strong correlation values with their buffers with 'r' values ranging from 0.859 to 0.998 (5 km) and 0.885 to 0.984 (20 km) (Table 4.1). The ranges of mean NDVI in Tankwa Karoo National Park, Moedverlooren Nature Reserve, and Vaalhoek Nature Reserve (0.155 – 0.145; 0.170 – 0.165; 0.30 – 0.28) are lower than their 5 km buffers

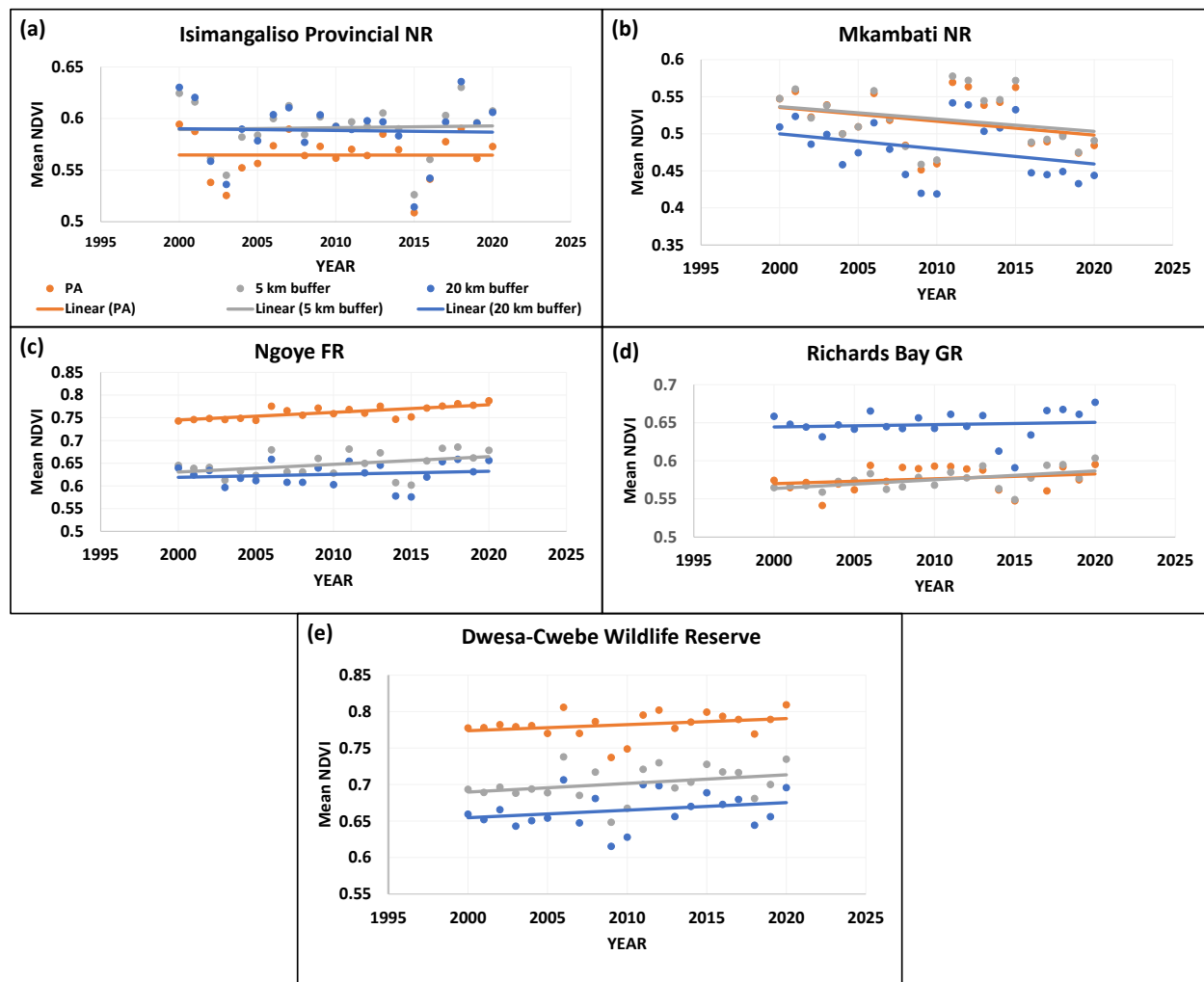
(0.17 – 0.15; 0.180 – 0.175; 0.35 – 0.33) and 20 km buffers (0.175 – 0.160; 0.205 – 0.175; 0.35 – 0.30) while that of Akkerendam Nature Reserve is higher than its buffers (0.23 – 0.20; 0.22 – 0.18). At the beginning of the study time, Namaqua National Park (0.235 – 0.215) and its buffers (0.240 – 0.215; 0.245 - 0.215) had slightly different mean NDVI values but by the end of the study they had the same values.



**Figure 4.5:** Time series charts showing trendlines of mean NDVI values of the protected areas and their respective buffers (5 km and 20 km) from 2001 to 2020 (20 years) in the Succulent Karoo biome; (a) Namaqua National Park (NP), (b) Tankwa Karoo National Park (NP), (c) Moedverloren Nature Reserve (NR), (d) Vaalhoek Nature Reserve (NR), and (e) Akkerendam Nature Reserve (NR).

#### 4.1.6 Indian Coast Biome

The PAs in this biome have positive trends in mean NDVI except for Mkambati Nature reserve with negative trends and Isimangaliso Provincial Nature Reserve with its 20 km buffer having negative trends and 5 km buffer has a positive trend (Figure 4.6). The parks all have a strong correlation with their buffers with 'r' values ranging from 0.600 to 0.996 (5 km) and 0.637 to 0.992 (20 km) (Table 4.1). The ranges of Mean NDVI values inside Ngoye Forest Reserve and Dwesa-Cwebe Wildlife Reserve (0.74 – 0.78; 0.77 – 0.80) are higher than their 5 km buffer (0.63 – 0.67; 0.69 – 0.72) and their 20 km buffers (0.62 – 0.64; 0.65 – 0.68) while Isimangaliso Provincial Nature Reserve (0.57 – 0.56) is lower than its buffers (0.585 – 0.590; 0.585 – 0.580). Mkambati Nature Reserve and Richards Bay Game Reserve mean NDVI values are approximately the same with their respective 5 km buffers (0.54 – 0.50; 0.57 – 0.59) but they are higher and lower respectively with their 20 km buffers (0.50 – 0.46; 0.64 – 0.65).

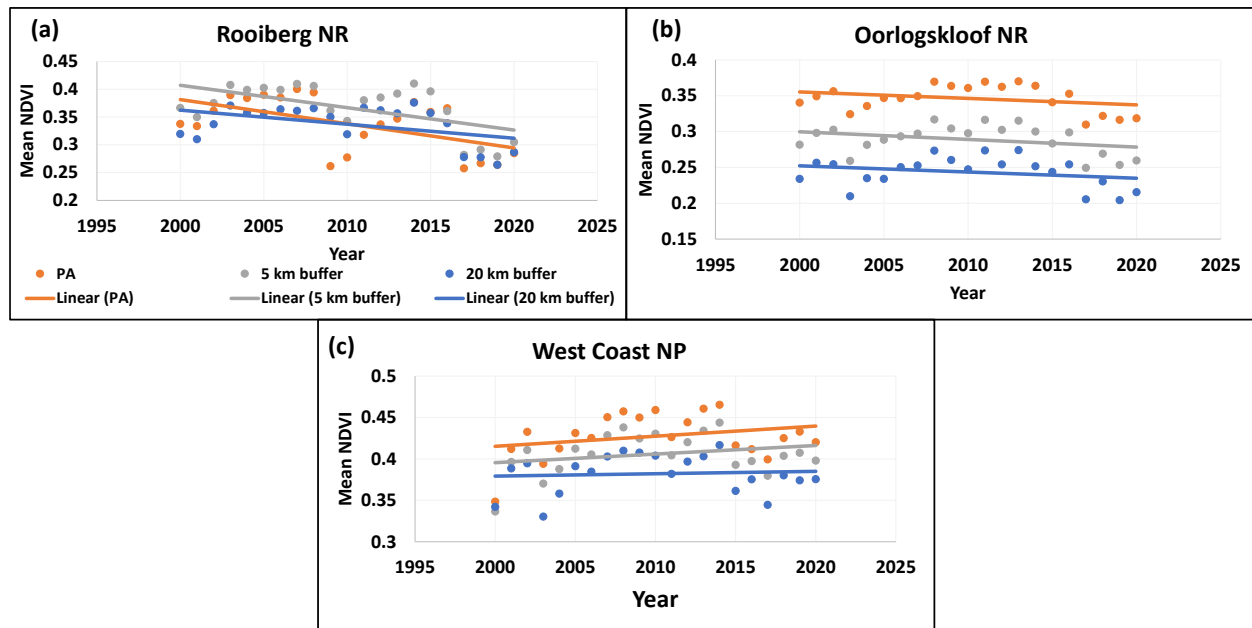


**Figure 4.6:** Time series charts showing trendlines of mean NDVI values of the protected areas and their respective buffers (5 km and 20 km) from 2001 to 2020 (20 years) in the Indian Coast biome; (a) Isimangaliso Provincial Nature Reserve (NR), (b) Mkambati Nature Reserve (NR), (c) Ngoye Forest Reserve (FR), (d) Richards Bay Game Reserve (GR), and (e) Dwesa-Cwebe Wildlife Reserve (WR).

#### 4.1.7 Fynbos Biome

In the Fynbos biome, Rooiberg Nature Reserve, and Oorlogskloof Nature Reserve with their buffers have negative trends in mean NDVI values while West Coast National Park has a positive trend in mean NDVI (Figure 4.7). All the PAs have strong correlation values with their respective biomes ranging from 0.876 to 0.979 (5 km) and 0.845 to 0.940 (20 km) (Table 4.1). The ranges of mean NDVI values inside Oorlogskloof Nature Reserve, and West Coast National Park (0.35 – 0.34; 0.42 – 0.44) are lower than their respective 5 km buffers' (0.30 - 0.27; 0.4 –

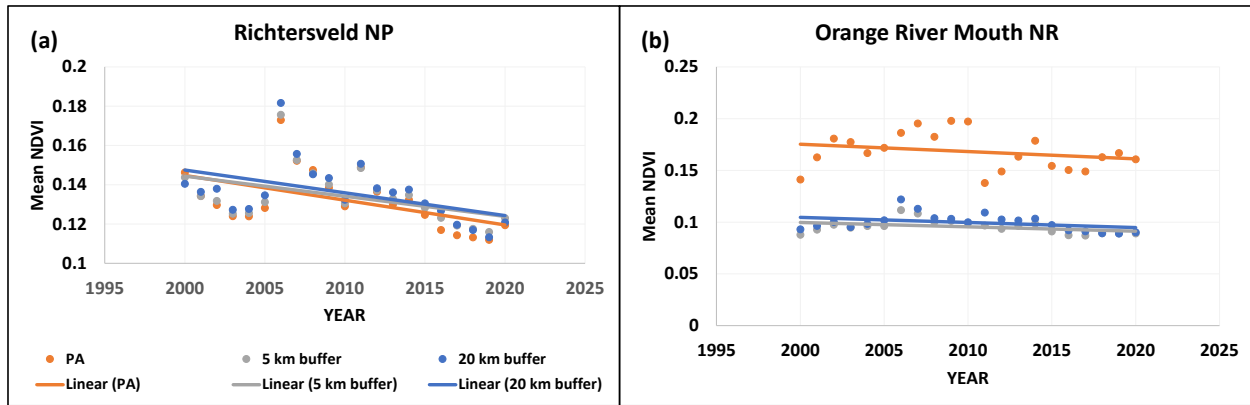
0.42) and 20 km buffers' (0.25 - 0.23; 0.380 – 0.385). At the beginning of the study time, the range of mean NDVI values inside Rooiberg Nature Reserve (0.38 – 0.30) is higher than its 20 km buffer (0.36 – 0.32) but lower than its 5 km buffer (0.41 – 0.33), and at the end of the study time, the values went below its buffers'.



**Figure 4.7:** Time series charts showing trendlines of mean NDVI values of the protected areas and their respective buffers (5 km and 20 km) from 2001 to 2020 (20 years) in the Fynbos biome; (a) Rooiberg Nature Reserve (NR), (b) Oorlogskloof Nature Reserve (NR), and (c) West Coast National Park (NP).

#### 4.1.8 Desert Biome

Both protected areas and their respective buffers have negative trend in mean NDVI in the Desert biome (Figure 4.8). The correlation between Orange River Mouth Nature Reserve and its 5km buffer is strong (0.706) and weak with its 20 km buffer (0.395) while the correlation between Richtersveld National Park and its buffers is strong  $r=0.994$  (5 km) and  $r=0.982$  (20 km) (Table 4.9). The range of mean NDVI inside the Orange River Mouth Nature Reserve (0.18 – 0.16) is higher than its buffers which are relatively the same (0.1 – 0.09), and the range of mean NDVI values in Richtersveld National Park (0.145 – 0.120) is slightly lower than its buffers which are also relatively the same (0.148 – 0.125).



**Figure 4.8:** Time series charts showing trendlines of mean NDVI values of the protected areas and their respective buffers (5 km and 20 km) from 2001 to 2020 (20 years) in the desert biome; (a) Richtersveld National Park (NP), and (b) Orange River Mouth Nature Reserve (NR).

#### 4.2 Vegetation cover change inside and outside the protected areas across South Africa from 2001 to 2020

In this section, the slope values of mean NDVI versus the years of the protected areas and their respective buffers (5 km and 20 km) which were calculated during the linear regression analysis are presented. To understand the vegetation cover change of each of the protected areas, the differences in the slope values of the protected areas and their buffers were calculated (i.e.: 5 km buffer minus PA, 20 km minus PA) and are presented in the Tables below (Table 4.1 – 4.8).

Slope differences with negative values means that there is a positive trend in vegetation cover change which indicates that the slope value of the PA is higher than that of the buffer which means that the PA is gaining vegetation faster or losing vegetation slower than its surrounding. Slope difference with positive values means there is a negative trend in vegetation cover change, and it shows that the slope value of the PA is lower than that of the buffer and this indicates that the vegetation cover inside the PA is increasing at a slower rate or declining at a faster rate than its surrounding. Having a slope difference value of 0 means that there is a flat trend in vegetation cover change which also means that the slope value of the PA is the same as that of the buffer.

#### 4.2.1 Grassland Biome

Ukahlamba- Drakensberg Park, Oviston Nature Reserve, and Motlase Crayon Nature Reserve have positive trends in vegetation cover change for both buffers as shown in Table 4.1. These parks experienced an increase in vegetation from 2001 to 2020 because the slope values inside the parks and around the parks are positive. Golden Gates Highlands National Park has a negative trend in vegetation cover change for both buffers. Songimvelo Game Reserve has a positive trend in vegetation cover change for 5 km buffer and a negative trend in vegetation cover change for 20 km buffer.

*Table 4.1: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Grassland biome including the slope differences between the PA and buffers.*

|   | Protected Area (PA)                  | Slope values  |             |              |                                        |                                         |
|---|--------------------------------------|---------------|-------------|--------------|----------------------------------------|-----------------------------------------|
|   |                                      | Inside the PA | 5 km buffer | 20 km buffer | Difference in slope (5 km buffer – PA) | Difference in slope (20 km buffer – PA) |
| 1 | Golden Gates Highlands National Park | -0.0013       | -0.001      | -0.001       | 0.0003                                 | 0.0003                                  |
| 2 | Ukahlamba- Drakensberg Park          | 0.0004        | 0.0002      | -0.000008    | -0.0002                                | -0.00041                                |
| 3 | Songimvelo Game Reserve              | 0.0003        | 0.00004     | 0.0005       | -0.00026                               | 0.0002                                  |
| 4 | Oviston Nature Reserve               | 0.0015        | 0.0009      | 0.0006       | -0.0006                                | -0.0009                                 |
| 5 | Motlase Crayon Nature Reserve        | 0.0008        | 0.0007      | 0.0006       | -0.0001                                | -0.0002                                 |

#### 4.2.2 Savanna Biome

Kruger National Park and Madikwe Game Reserve have negative trends with the 5 km and 20 km buffer. Marakele National Park have a positive vegetation cover change trends for both the 5 km and 20 km buffers. Kalahari Gemsbok National Park has a flat trend with the 5 km buffer and a negative trend with the 20 km buffer. Pilanesberg Game Reserve has a positive trend for the 5 km buffer and a negative trend for the 20 km buffer (Table 4.2).

*Table 4.2: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Savanna biome including the slope differences between the PA and buffers.*

|   | Protected Area                 | Slope values  |             |              |                                    |                              |
|---|--------------------------------|---------------|-------------|--------------|------------------------------------|------------------------------|
|   |                                | Inside the PA | 5 km buffer | 20 km buffer | Change in slope (5 km buffer – PA) | Change in slope (20 km – PA) |
| 1 | Kruger National Park           | -0.0027       | -0.0026     | -0.0022      | 0.0001                             | 0.0005                       |
| 2 | Kalahari Gemsbok National Park | -0.0001       | -0.0001     | -0.00003     | 0                                  | 0.00007                      |
| 3 | Marakele National Park         | -0.0006       | -0.0008     | -0.001       | -0.0002                            | -0.0004                      |
| 4 | Madikwe Game Reserve           | -0.0029       | -0.0026     | -0.0022      | 0.0003                             | 0.0007                       |
| 5 | Pilanesberg Game Reserve       | -0.0009       | -0.001      | -0.0007      | -0.0001                            | 0.0002                       |

### 4.2.3 Albany Thicket Biome

Addo Elephant National Park, Great Fish River Nature Reserve, and Mount Coke State Forest have experienced a negative vegetation cover change for 5 km buffer and positive vegetation cover change for 20 km buffer (Table 4.3). For East London Coast Nature Reserve, there is a positive trend in vegetation cover change for both 5 km and 20 km buffers. Water meeting Nature Reserve has a positive trend for 5 km buffer and a flat trend for 20 km buffer.

*Table 4.3: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Albany thicket biome including the slope differences between the PA and buffers.*

|   | Protected Area                   | Slope values  |             |              |                                    |                              |
|---|----------------------------------|---------------|-------------|--------------|------------------------------------|------------------------------|
|   |                                  | Inside the PA | 5 km buffer | 20 km buffer | Change in slope (5 km buffer – PA) | Change in slope (20 km – PA) |
| 1 | Addo Elephant National Park      | -0.0019       | -0.0018     | -0.002       | 0.0001                             | -0.0001                      |
| 2 | Great Fish River Nature Reserve  | -0.0014       | -0.0011     | -0.0017      | 0.0003                             | -0.0003                      |
| 3 | Water meeting Nature Reserve     | 0.0002        | -0.0002     | 0.0002       | -0.0004                            | 0                            |
| 4 | East London Coast Nature Reserve | -0.0004       | -0.0009     | -0.0005      | -0.0005                            | -0.0001                      |
| 5 | Mount coke State Forest          | -0.0004       | 0.0001      | -0.0006      | 0.0005                             | -0.0002                      |

#### 4.2.4 Nama-Karoo Biome

Mokala National Park, Geogap National Park, and Mountain Zebra National Park all experienced negative vegetation cover change for 5 km and 20 km buffers as shown in Table 4.4. Camdeboo National Park has positive trends for both buffers and Augrabies Falls National Park has a negative trend for 5 km and a flat trend for 20 km.

*Table 4.4: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Nama-Karoo biome including the slope differences between the PA and buffers.*

|   | Protected Area                | Slope values  |             |              |                                    |                              |
|---|-------------------------------|---------------|-------------|--------------|------------------------------------|------------------------------|
|   |                               | Inside the PA | 5 km buffer | 20 km buffer | Change in slope (5 km buffer – PA) | Change in slope (20 km – PA) |
| 1 | Camdeboo National Park        | -0.0011       | -0.0012     | -0.0014      | -0.0001                            | -0.0003                      |
| 2 | Mokala National Park          | -0.0016       | -0.0011     | -0.0003      | 0.0005                             | 0.0013                       |
|   | Augrabies Falls National Park | -0.0009       | -0.0008     | -0.0009      | 0.0001                             | 0                            |
| 4 | Geogap National Park          | -0.0012       | -0.0011     | -0.0009      | 0.0001                             | 0.0003                       |
| 5 | Mountain Zebra National Park  | -0.00004      | 0.0003      | 0.0006       | 0.00034                            | 0.00064                      |

#### 4.2.5 Succulent Karoo Biome

Moedverloren Nature Reserve, Vaalhoel Nature Reserve, and Akkerendam Nature Reserve have positive vegetation cover change trend (Table 4.5). Although the slope values inside the PAs are negative, they are not as low as those of the buffers. This shows that the rate of vegetation loss inside the PAs is not as rapid as their surroundings. Tankwa Karoo National Park and Namaqua National Park has a flat trend with the 5 km and 20 km buffer respectively and a negative trend with 20 km and 5 km buffer respectively.

*Table 4.5: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Succulent Karoo biome including the slope differences between the PA and buffers.*

|   | Protected Area              | Slope values  |             |              |                                    |                              |
|---|-----------------------------|---------------|-------------|--------------|------------------------------------|------------------------------|
|   |                             | Inside the PA | 5 km buffer | 20 km buffer | Change in slope (5 km buffer – PA) | Change in slope (20 km – PA) |
| 1 | Namaqua National Park       | -0.0013       | -0.0011     | -0.0013      | 0.0002                             | 0                            |
| 2 | Tankwa Karoo National Park  | -0.0007       | -0.0007     | -0.0006      | 0                                  | 0.0001                       |
| 3 | Moedverloren Nature Reserve | -0.0002       | -0.0004     | -0.0006      | -0.0002                            | -0.0004                      |
| 4 | Vaalhoel Nature Reserve     | -0.001        | -0.0012     | -0.0023      | -0.0002                            | -0.0013                      |

#### 4.2.6 Indian Coast Biome

All PAs experienced a negative and positive trend in vegetation cover change for 5 km and 20 km buffers respectively except Ngoye Forest Reserve which has flat trend for 5 km buffer and Dwesa-Cwebe Nature Reserve which has negative trend for 20 km instead (Table 4.6).

*Table 4.6: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Indian Coast biome including the slope differences between the PA and buffers.*

|   | Protected Area                         | Slope values  |             |              |                                    |                              |
|---|----------------------------------------|---------------|-------------|--------------|------------------------------------|------------------------------|
|   |                                        | Inside the PA | 5 km buffer | 20 km buffer | Change in slope (5 km buffer – PA) | Change in slope (20 km – PA) |
| 1 | Richards Bay Game Reserve              | 0.0006        | 0.0012      | 0.0003       | 0.0006                             | -0.0003                      |
| 2 | Ngoye Forest Reserve                   | 0.0017        | 0.0017      | 0.0007       | 0                                  | -0.001                       |
| 3 | Isimangaliso Provincial Nature Reserve | -0.000006     | 0.0002      | -0.0002      | 0.000206                           | -0.00019                     |
| 4 | Mkambati Nature Reserve                | -0.0019       | -0.0017     | -0.002       | 0.0002                             | -0.0001                      |
| 5 | Dwesa-Cwebe                            | 0.0008        | 0.0012      | 0.001        | 0.0004                             | 0.0002                       |

#### 4.2.7 Fynbos

West Coast National Park and Rooiberg Nature Reserve have positive and negative trends respectively while Oorlogskloof Nature Reserve has a positive trend for 5 km buffer and flat trend in 20 km buffer (Table 4.7).

*Table 4.7: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Fynbos biome including the slope differences between the PA and buffers.*

|   | Protected Area           | Slope values  |             |              |                                    |                              |
|---|--------------------------|---------------|-------------|--------------|------------------------------------|------------------------------|
|   |                          | Inside the PA | 5 km buffer | 20 km buffer | Change in slope (5 km buffer – PA) | Change in slope (20 km – PA) |
| 1 | Oorlogskloof             | -0.0009       | -0.0011     | -0.0009      | -0.0002                            | 0                            |
| 2 | Rooiberg Nature Reserve  | -0.0044       | -0.004      | -0.0025      | 0.0004                             | 0.0019                       |
| 3 | West Coast National Park | 0.0012        | 0.001       | 0.0003       | -0.0002                            | -0.0009                      |

#### 4.2.8 Desert Biome

All protected areas in the biome experienced a negative trend in vegetation cover change for both buffers (Table 4.8). The PAs experienced vegetation loss at a faster rate inside than their surroundings.

*Table 4.8: Slope values of selected protected areas (PA) and their respective buffers (5 km and 20 km) in the Desert biome including the slope differences between the PA and buffers.*

|   | Protected Area             | Slope values  |             |              |                                    |                              |
|---|----------------------------|---------------|-------------|--------------|------------------------------------|------------------------------|
|   |                            | Inside the PA | 5 km buffer | 20 km buffer | Change in slope (5 km buffer – PA) | Change in slope (20 km – PA) |
| 1 | Richtersveld National Park | -0.0013       | -0.001      | -0.0012      | 0.0003                             | 0.0001                       |
| 2 | Orange River Mount         | -0.0007       | -0.0004     | -0.0005      | 0.0003                             | 0.0002                       |

### 4.3 Correlation between Protected Areas in South Africa and their Buffers (5km and 20 km) from 2001 to 2020

From the analysis in Table 4.9 below, it can be observed that majority of the protected areas have high correlation values with their respective buffers. Kruger National Park has the highest correlation values of 1.000 (5 km buffer) and 0.996 (20 km) while Oviston Nature Reserve has the least correlation values of 0.571 (5 km buffer) and 0.234 (20 km buffer).

*Table 4.9: Pearson correlation values derived from the correlation of Mean NDVI values of various protected areas South Africa, and their buffers (5 km and 20 km).*

|    | Biome          | Protected Area (PA)                  | Correlation values between mean NDVI |              |
|----|----------------|--------------------------------------|--------------------------------------|--------------|
|    |                |                                      | PA and 5 km                          | PA and 20 km |
| 1  | Grassland      | Golden Gates Highlands National Park | 0.962                                | 0.881        |
| 2  |                | Ukahlamba- Drakensberg Park          | 0.962                                | 0.881        |
| 3  |                | Songimvelo Game Reserve              | 0.994                                | 0.974        |
| 4  |                | Oviston Nature Reserve               | 0.571                                | 0.234        |
| 5  |                | Motlase Crayon Nature Reserve        | 0.974                                | 0.946        |
| 6  | Savanna        | Kruger National Park                 | 1.000                                | 0.996        |
| 7  |                | Kalahari Gemsbok National Park       | 0.998                                | 0.984        |
| 8  |                | Marakele National Park               | 0.985                                | 0.931        |
| 9  |                | Madikwe Game Reserve                 | 0.998                                | 0.989        |
| 10 |                | Pilanesberg Game Reserve             | 0.994                                | 0.982        |
| 11 | Albany Thicket | Addo Elephant National Park          | 0.996                                | 0.992        |
| 12 |                | Great Fish River Nature Reserve      | 0.993                                | 0.977        |
| 13 |                | Water meeting Nature Reserve         | 0.958                                | 0.924        |
| 14 |                | East London Coast Nature Reserve     | 0.973                                | 0.967        |
| 15 |                | Mount coke State Forest              | 0.932                                | 0.910        |

|    |                 |                                        |       |       |
|----|-----------------|----------------------------------------|-------|-------|
| 16 | Succulent Karoo | Namaqua National Park                  | 0.998 | 0.984 |
| 17 |                 | Tankwa Karoo National Park             | 0.960 | 0.953 |
| 18 |                 | Moedverloren Nature Reserve            | 0.859 | 0.885 |
| 19 |                 | Vaalhoel Nature Reserve                | 0.987 | 0.963 |
| 20 |                 | Akkerendam Nature Reserve              | 0.970 | 0.950 |
| 21 | Nama-Karoo      | Camdeboo National Park                 | 0.992 | 0.975 |
| 22 |                 | Mokala National Park                   | 0.993 | 0.948 |
| 23 |                 | Augrabies Falls National Park          | 0.997 | 0.978 |
| 24 |                 | Geogap National Park                   | 0.997 | 0.988 |
| 25 |                 | Mountain Zebra National Park           | 0.949 | 0.897 |
| 26 | Indian Coast    | Richards Bay Game Reserve              | 0.600 | 0.637 |
| 27 |                 | Ngoye Forest Reserve                   | 0.855 | 0.738 |
| 28 |                 | Isimangaliso Provincial Nature Reserve | 0.977 | 0.938 |
| 29 |                 | Mkambati Nature Reserve                | 0.996 | 0.992 |
| 30 |                 | Dwesa-Cwebe Nature Reserve             | 0.968 | 0.923 |
| 31 | Fynbos          | Oorlogskloof Nature Reserve            | 0.979 | 0.940 |
| 32 |                 | Rooiberg Nature Reserve                | 0.876 | 0.779 |
| 33 |                 | West Coast National Park               | 0.897 | 0.845 |
| 34 | Desert          | Richtersveld National Park             | 0.994 | 0.982 |
| 35 |                 | Orange River Mount Nature Reserve      | 0.706 | 0.395 |

## 5. Discussion

Various researchers have studied vegetation cover change of biomes across South Africa using remote sensing and have predicted significant changes due to climate change and increasing atmospheric CO<sub>2</sub> (Okin 2007; Wegmann et al., 2014; Prevey et al., 2019). This study is aimed at investigating the rate and direction of change in NDVI from 2001 to 2020 inside and around protected areas in South Africa. The NDVI is used as a proxy to monitor vegetation cover change in the protected areas.

In this study, eight biomes of South Africa were examined and all protected areas I investigated in six of the biomes experienced negative trends in NDVI values from 2001 to 2020 (Savanna, Albany thicket, Nana-Karoo, Succulent karoo, Fynbos and Desert). The two biomes that experienced positive trends in NDVI values are the Grassland and Indian Coast biomes.

The Grassland biome of South Africa has experienced significant changes in vegetation cover over the years. According to the research carried out by Masubelele et al. (2015), there has been an evident increase in tall shrub and grass cover. As shown in Figure 4.1 (a, c-e), there is an increase in NDVI values with positive trends, which translates to an increase in grasses and tall shrubs. It has been reported that the Grassland biome is one of the least protected biomes in South Africa (Jewitt, 2018), and it has also been predicted that there would be an increase in aridification of the biome as a result of an increase in CO<sub>2</sub> and temperature and decrease in rainfall thereby leading to reduced vegetation (Driver et al., 2012). This prediction contradicts the data gathered and results obtained as four out of five protected areas examined had a positive trend in NDVI (Figure 4.2) which means that there has been an increase in vegetation cover. The increase in vegetation in the Grassland biome could be because of an increase in atmospheric CO<sub>2</sub>, which supports the findings of Higgins and Scheiter's (2012), adaptive Dynamic Global Vegetation Model (aDGVM). The result of the model shows that increased atmospheric CO<sub>2</sub> alongside increased temperatures favors grasses and tall shrubs. The aDGVM is supported by Morgan et al. (2011) and Leakey et al. (2012) experiments on grasslands in the United States. Their experiments proved that increased atmospheric CO<sub>2</sub> and temperature resulting in improved soil moisture conditions is an advantage for grasses leading to their increase (Bond, 2008). These conditions have been proven to exacerbate bush encroachment in grassland (Duker et al., 2015). On average, the trendlines of the mean NDVI values inside the protected areas in the Grassland

biome have steeper positive slope lines than their buffers (Table 4.1), which means that there is a faster rate of change and increase in vegetation cover inside the protected areas than their surroundings. The increase in vegetation cover may be attributed to an effective management plan in some protected areas such as culling of animals, fire management, and antipoaching activities (Mishra et al., 2015). In addition, the buffers of the protected areas may be experiencing a slower rate of vegetation growth because of human activities such as agriculture, animal grazing and land use change as observed by Jones et al. (2018).

The majority of protected areas in the Savanna and Albany Thicket biomes experienced negative trends in NDVI, as shown in Figure 4.2. This could be because of the extreme and severe drought which lasted from 2015 to 2018 in South Africa. The drought significantly impacted South Africa's vegetation as vegetation rapidly declined due to lack or inadequate rainfall. According to Scholes and Walker (1993), the availability of water in the savanna is an important factor that shapes the structure of the ecosystem. Although there are other factors like movement of water, soil condition, temperature, and plant type, that influence the functions and structure of the savanna ecology, availability of water is the dominant factor for the savanna ecology because savannas are semi-arid, and they rely on seasonal rainfall to function well. A faster rate of change occurred and in a negative direction inside most of the protected areas compared to their buffers in the Savanna biome (Table 4.2). This means that although vegetation is on the decline in these protected areas, it is declining faster inside the protected areas than in their surroundings. In the Albany thicket, most protected areas have a faster rate and positive trends in vegetation cover change compared with their 20 km buffers than 5 km buffers (Table 4.3) which may have resulted from human activities occurring 20 km away from the protected areas. Activities such as construction of buildings and roads, overexploitation of natural resources, and mining can result to fragmentation and land degradation, pollution, introduction of invasive species and wildlife diseases (Schulze et al., 2018).

The Protected areas in the Nama-Karoo and Succulent Karoo biomes experienced negative NDVI trends (Figure 4.4 and 4.5). Maestre et al. (2012) study supports this outcome and it is reported by the authors that the Karoo is experiencing enormous land degradation. A decrease in vegetation cover has been predicted to continue. It is expected that the area of the Karoos would increase in response to the projected increase in aridity as a result of the increasing impact of

climate change and anthropogenic activities, especially overgrazing (Schlaepfer et al., 2017). This expectation agrees with the projections made by Engelbrecht and Engelbrecht (2016) that the Karoo's aridity would increase, thereby expanding desert-like environments. Most of the Succulent Karoo biome's protected areas have positive trends in vegetation cover change between inside and around the protected areas (Table 4.5), unlike the Nama-Karoo biome (Table 4.4). These positive trends could be as a result of the increase in land set aside for conservation in the Succulent Karoo biome (Timm Hoffman et al., 2018) because the biome is widely known as a biodiversity hotspot which made it to be globally recognized (Myers et al., 2000) which is not the case with the Nama-Karoo.

The Indian Coast biome shows a positive trend in NDVI values. Three out of the five protected areas studied experienced positive trends alongside their buffers (Figure 4.6c-e). This shows that there had been an increase in vegetation cover during the study time. Most likely, the vegetation in the protected areas and buffers have access to water services provided by the nearest ocean and may have also adapted to the saltwater from the ocean (Mucina et al., 2006), making them less affected by the intense drought in South Africa between 2015 and 2018. While most of the protected areas have negative trends in vegetation cover change as compared with their respective 5 km buffers, they have positive trends in vegetation cover change compared with their 20 km buffers (Table 4.6). These trends explain that the vegetation in the protected areas is doing better than in their respective 20 km buffers but not as good as their 5 km buffers. Anthropogenic activities tend to happen far from protected areas which explains why these protected areas and their 5 km buffers have better vegetation cover than their 20 km buffers.

In the Fynbos, two out of the three protected areas experienced negative trends in mean NDVI values. Likewise, the two protected areas studied in the Desert biome also have negative trends in their mean NDVI values. The decline in vegetation might be as a result of the negative impacts of the extreme drought, climate change, and anthropogenic activities these biomes face.

In this study, 74% of the studied protected areas and their buffer had negative trends in NDVI, which means that vegetation cover has reduced inside and outside these protected areas, which has, in turn, reduced biodiversity from 2001 to 2020. Jones et al. (2018) explained that protected areas face significant threats that can reduce their function in conserving biodiversity, providing ecosystem services, and reducing the size of the protected areas. One of the threats highlighted

by King et al. (2015) is climate change, and its adverse effect on vegetation in South Africa has been on the increase. Protected areas also face threats from humans because these areas were formally their homelands which supported their livelihood (Garnett et al., 2018), and the increase in the human population and urbanization has significant effects on the biodiversity inside and outside protected areas (Richards & Friess, 2016; Barlow et al., 2016). Basommi (2016) elaborated in his study that there is a correlation between the increase in human activities around the protected areas (buffer) and the extinction rate of species. These activities are poaching, deforestation, land conversion, and urban settlement. The primary purpose of the buffer area is to give additional protection to the protected area and reduce conflicts between the local people surrounding the protected areas and the protected area by putting less restriction on the resources in the buffers (Hattter & Southworth, 2009).

On the other hand, Wells and Brandon (1992) disagree that providing benefits that are limited through the buffer zone to the people will change their attitude towards protected areas. The results of this study may support Wells and Brandon (1992) because most of the protected areas studied have lesser vegetation cover inside than their surroundings. According to McDonald et al. (2009), the average distance between protected areas and urban settlement is less than 50 km. This distance is reducing drastically, putting pressure on the protected areas. Guneralp and Seto (2013) predicted that between 2000 and 2030, urban settlements in a 50 km buffer of protected areas would be multiplied by three.

Nevertheless, some protected areas such as Marakele National Park, West Coast National Park, Motlase Crayon Nature Reserve and so on are not facing pressure from their surroundings. As a matter of fact, vegetation cover change is faster and in a positive direction in these protected areas. This may be because of some favorable practices carried out by the management of the protected areas, which improves vegetation growth. Such practices include but are not limited to the culling of animals, fire management, and antipoaching activities (Mishra et al., 2015). Culling of animals for example may have an impact of vegetation abundance. This brings a balance between the animals and available vegetation.

From the results (Table 4.1 – 4.8), it is deduced that 29% of the protected areas have a faster rate of vegetation cover change in a positive direction than both of their respective buffers. 40% and 49% of the protected areas studied have a faster rate of vegetation cover change in the positive

direction than their 5 km and 20 km buffers respectively. The percentages (40% and 49%) explain that vegetation is reducing more in the 20 km buffer than in the 5 km buffers. This difference is expected since 20 km away from the protected areas is closer to human settlements and exposes the area to human activities like agriculture, animal grazing, deforestation, and development. The study carried out by De La Fuente et al. (2020) shows that there are more infrastructures in areas surrounding protected areas than inside the protected areas. Although they studied 10 km away from the protected areas, their results can be related to what is happening in the 20 km buffers of this study.

Even though, according to De La Fuente et al. (2020), there are more infrastructures happening in areas surrounding the protected areas, the overall result of this study shows that vegetation is reducing faster in most of the protected areas than in their surroundings, especially the 5 km buffers. The faster rate of decline may be because the protected area experiences some level of development, especially for tourist satisfaction. Another reason may be the uncontrolled population growth of animals, which will negatively impact the protected area (Guldermond & van Aarde, 2008). As the population of animals in the park increases, since they directly or indirectly feed on plants, vegetation cover rapidly reduces if they are not given enough time to replenish (Young et al., 2009).

The correlation analysis done between the protected areas and their buffers (Table 4.9) shows that there are strong correlation values between them except for the Oviston Nature Reserve with correlation values of 0.571 (5 km) and 0.234 (20 km) and Orange River Mount Nature Reserve with a correlation value of 0.395 (20 km) (Table 4.9). It is assumed that protected areas with strong correlation values show that what is happening inside the protected area is also happening in the buffers. The protected areas with weak correlation values have little to no relationship between what is happening in the protected area and the buffers.

As earlier pointed out, this study expanded on the vegetation cover change study of Wegmann et al. (2014). While they examined protected areas across Africa, this study focused on protected areas across South Africa. The main aim of their study was to assess the habitat change of species in protected areas across Africa. An important method used was to get information on land cover change of the protected areas over time. In doing so, vegetation cover change of the protected areas was assessed from 1982 to 2006 with remote sensing and NDVI. They studied

the vegetation cover change inside and outside the protected areas using 17 km, 31 km, and 84 km buffers. Their results show that most of the protected areas in Africa, particularly in South Africa, have negative trends in vegetation cover change, i.e., vegetation is increasing or reducing slower in the buffer zones compared to within the protected areas. Wegmann et al. (2014) result is similar to the result of this study because most of the protected areas examined have negative trends in vegetation cover change.

## 6. Conclusion

Vegetation structure and composition in protected areas is faced with significant threats due to climate change and anthropogenic activities. Although various studies have been done to monitor vegetation cover change in protected areas and their buffers with the aid of remote sensing and NDVI, none has examined protected areas in different biomes across South Africa. This study extensively examined the trends in NDVI across protected areas with their buffers (5 km and 20 km) in South Africa. It expanded on the Wegmann et al. (2014) study of vegetation cover changes inside and outside protected areas from 2001 to 2020. This study was done with remote sensing in Google Earth Engine, and NDVI was used as a proxy to examine the vegetation cover change of the protected areas and their buffers (5 km and 20 km). A total of 35 protected areas were studied; it is reported that 26 out of the 35 protected areas have negative trends in NDVI, and 10 of the protected areas have a positive trend in vegetation cover change when compared to their buffers (5 km and 20 km).

The results of this study should be carefully used because even though NDVI is used as a proxy for vegetation and this study looked at NDVI trends to examine vegetation cover change, it is not entirely sufficient to determine the vegetation cover change of an area. Other variables that can influence vegetation cover change such as temperature, rainfall, soil condition, and human population must be examined in further research since it is not in the scope of this study. However, the NDVI trends give us an idea of how well vegetation in protected areas across South Africa is doing. Managers of protected areas can utilize the result of this study to guide them to areas and biomes that are vulnerable to the impacts of climate change and anthropogenic activities, thereby needing urgent attention. Managers of the protected areas with negative vegetation cover change should be aware that there is at least a condition in the protected area that is not favorable thereby practices like fire management, culling of animals, and antipoaching activities must be effectively done.

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