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Land use and climate change implications for biodiversity and habitat loss within the public and private reserves of the Southern Waterberg district, Limpopo

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I declare that the dissertation, which I hereby submit for the degree MSc Environmental Management (Coursework) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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ABSTRACT

The planet is facing a range of environmental issues related to and caused by anthropogenic activities. Biodiversity loss constitutes one of the most significant environmental tragedies of modern times. Climate change and land use changes may have severe consequences for biodiversity, ecosystem services, and habitat loss globally. The impacts of land use change and climate change may also differ between protected areas, and those areas surrounding protected areas. This can occur due to factors such as differences in management and conservation plans, as well as differing land use practices and development. Due to such factors, climate change and land use changes may cause the rate of biodiversity loss to be greater in areas surrounding protected areas, as opposed to within protected areas. The mountainous area known as the Waterberg Biosphere, located in the Southern Waterberg, has rich biodiversity, including more than 5,500 species of plants, 43% of which are endemic to South Africa. The dominant biome in the Southern Waterberg is the Savanna Biome. To investigate these impacts (land use and climate changes) in the Southern Waterberg, a range of mapping and visualisation methods have been implemented and used as well as statistical analysis (Chi-square analysis and linear regression). Two specific locations were the focus of this study, namely the Grootwater Nature Reserve (3.32 ha) and the Welgevonden Game Reserve (28.57 ha), which are located within the Waterberg Biosphere. The Grootwater Nature Reserve (an example of a public reserve), and the Welgevonden Game Reserve (an example of a private reserve) were compared in terms of the extent of habitat/vegetation loss within and surrounding the protected areas. Further, the extent of habitat/vegetation loss within the protected areas in comparison to the surrounding areas (5km buffer) was assessed between 1990 and 2020. Climatic changes (rainfall and temperature trends) were also assessed for the area from 1990 to 2020. Landcover maps (SANLC), Chi-square analysis, and linear regression analysis illustrated this comparison. Landcover data and maps were also used to illustrate the extent of land use changes in the study areas. Statistical analysis was then also introduced to confirm the difference in habitat and vegetation loss within and surrounding the two protected areas, as well as to gauge the relationship between the climatic changes in the area and habitat/vegetation loss within the study sites. The results indicated that both protected areas experienced habitat/vegetation loss to a lesser extent than the surrounding areas. Further, the Welgevonden Game Reserve experienced more habitat/vegetation loss than the Grootwater Nature Reserve. Trend analysis indicated that there was a general increase in average temperatures and decrease in average rainfall from 1990 to 2020 in the area. Statistical analysis suggested that habitat/vegetation loss was most likely due to climatic changes (particularly a decrease in total annual rainfall and increase in monthly maximum temperatures) rather than land use changes.

1. Introduction

The planet is facing a range of challenges in the modern era, but one of the most concerning issues is the rapidly increasing rate of biodiversity and habitat loss. Habitat loss is the greatest threat to global biodiversity through activities such as mining, deforestation, urban development, unsustainable agricultural practices, and other land use changes (Hansen *et al*, 2012; Thomas, 2021; IPBES, 2019). Biodiversity also faces threats other than habitat loss, however, including overharvesting and poaching, pollution, alien/invasive species, and climate change (Hanski, 2005; Thomas, 2021). With regards to terrestrial ecosystems, land use changes and climate changes will have the largest impacts on biodiversity loss in addition to habitat loss (Sala *et al*, 2000; Shackelford *et al*, 2018).

Global biodiversity and habitat loss is accelerating at a rapid rate (Ruckelshaus *et al*, 2020). Climate change, land use changes, and other impacts are hindering the ability of our natural world to sustainably support the human population and human wellbeing (Ruckelshaus *et al*, 2020; IPBES, 2019). Land use changes (human induced changes that negatively impact the natural environment) involve direct anthropogenic impacts on biodiversity and natural habitat and vegetation. Significant areas of natural habitat and vegetation have been subjected to conversion by human activities with the immediate impacts being the loss of native vegetation (Pardini *et al*, 2017).

Land use changes, particularly the expansion of cropland, does not only impact biodiversity and habitat loss directly through clearance of vegetation and mono agriculture, but it can also impact biodiversity and habitat loss indirectly (Molotoks *et al*, 2020). Cropland expansion further contributes to climate change, as it decreases the carbon storage capacity of the environment (Molotoks *et al*, 2020). Natural habitat and vegetation are more effective in terms of storing carbon and when disturbed, carbon may be released into the atmosphere. Under climate change, extreme weather events and natural disasters are also likely to increase (Bouwer, 2019). This may cause extensive damage to infrastructure and severely decrease food security and the availability of fresh water (Bouwer, 2019). This creates a greater need for the expansion of cropland and, more robust infrastructure and development which in turn can drive greater biodiversity loss. This will cause the carbon storing capacity of the planet to decrease further, as well as produce further emissions and land degradation (Molotoks *et al*, 2020).

Biodiversity, particularly natural habitat/vegetation, can act as a natural defence system against the impacts of climate change and the negative influences of land use changes (Pandit *et al*, 2021). However, with rapidly decreasing areas of natural habitat/vegetation and increasing global temperatures, biodiversity loss will start accelerating at a faster rate (Munang *et al*, 2013). It is important to understand the interactions and relationships regarding the impacts of land use changes and climatic changes on biodiversity loss and habitat loss. This will aid in both minimising habitat and biodiversity loss, as well as minimising the impacts of climate change and land use change through conserving biodiversity and natural ecosystems.

Climate change involves indirect anthropogenic impacts for biodiversity and natural habitat/vegetation. Climate change is a major threat to global biodiversity and natural habitat/vegetation but biodiversity, through ecosystem services, is one of the most effective natural defences to combat the impacts of climate change (Munang *et* *al*, 2013). South Africa is the third most biodiverse country on the planet and will experience a greater average temperature increase than the global average temperature increase caused by global warming (Gbetibouo, 2009; Kepe *et al*, 2005; Nyoni *et al*, 2021). South Africa has experienced a 1.2°C increase in average surface temperatures on average due to climate change and global warming to date (Ziervogel *et al*, 2022). South Africa also has a relatively high number of vulnerable ecosystems and habitats, many of which are key to the survival and livelihoods of the human population in many parts of the country (Ziervogel *et al*, 2022)

Limpopo Province, the province in which the Southern Waterberg is located, will experience higher rainfall variability and higher average temperatures due to climate change in comparison to current climatic conditions in the province (Rymer *et al*, 2013; Mbokodo *et al*, 2020). The primary type of natural habitat or biome that occurs in the Southern Waterberg is the savanna biome (Rutherford *et al*, 2006). The savanna biome is dependent on consistent temperature and rainfall patterns, and a change in either of the two could lead to ecosystem restructuring. The savanna biome is also dependent on other drivers that can be negatively impacted by a change in temperature and rainfall patterns such as fire and herbivory (Archibald *et al*, 2019). Climatic changes may cause herbivores to migrate and can change the fire regime in the area leading to other impacts such as bush encroachment and loss in species richness (Criado *et al*, 2020).

As already discussed, the consequences of land use change and climate change for biodiversity and habitat loss can be significant. Ecosystem services produce a range of benefits, such as greater food production through pollination and biological pest control, filtering out pollution and waste, provide mankind with medicine, purification of air and water, soil formation, and many more (Pimentel *et al*, 1997 and Pandit *et al*, 2021). However, if climate changes and land use changes were to persist, such natural services will decrease and even start to disappear (Hasan *et al*, 2020 and Scholes, 2016). This will have negative consequences on both the natural environment and human population.

The most common and effective way in which biodiversity and natural habitat/vegetation is protected, globally and in South Africa, is through the formation of protected areas which only constitute approximately 9.2% of the total land area of South Africa and roughly 1% of the total terrestrial surface area globally (Geldmann *et al*, 2019 and StatsSA, 2021). Protected areas provide a sanctuary for species, particularly in terms of protection from the influences of the human population. However, if protected areas are not managed properly, then the implications of land use change and climate change may have a significant effect due to the fact that a deteriorated habitat is more susceptible to change and the impacts of climate and land use changes (Pandit *et al*, 2021). The use of remote sensing and mapping can have significant value when illustrating the impacts of these factors in protected areas. The mapping of land use and landcover changes in these areas can provide insight into the impacts of climate change and land use change in protected areas. As mentioned earlier, the negative impacts of the human population may be occurring in the Southern Waterberg region, as this is an area where several conservation and protected areas are near both formal and informal settlements which have shown to have negative impacts on natural habitat within and alongside protected areas (Marcatelli, 2015).

This study focussed on the effects of climate change and land use change on the Grootwater Nature Reserve (public) and Welgevonden Game Reserve (private), as well as surrounding areas. These two protected areas are situated within the Waterberg Biosphere (Figure 1).

2. Literature review

2.1 Impacts of land use changes and climate changes:

As discussed earlier, one of the most common threats to biodiversity and habitat loss caused by land use changes is habitat fragmentation. Habitat fragmentation does not always have a negative influence on biodiversity and natural habitat/vegetation, and it could in fact be positive for various species as well as for local biodiversity and species populations in some cases (Lenore Fahrig *et al*, 2019). For example, species that reside on the edge of a particular habitat could experience population expansion as the habitat for these species expands due to the process known as edge effects (increase in fringe habitat) (Ewers and Didham, 2006). Different ecosystems and habitats are also impacted by habitat fragmentation differently and it is important to look at habitat fragmentation at an ecosystem or localised level when considering a small area of study (Fahrig *et al*, 2019). Further, the negative impacts of habitat fragmentation often are exacerbated by other factors and may not only impact biodiversity and the natural habitat in isolation, but it is also however a contributing factor to biodiversity loss and habitat/vegetation loss globally particularly when in combination with other negative impacts (Lenore Fahrig *et al*, 2019). It is also important to not only look at the different components of habitat fragmentation as singular forces (edge effects, fragment size, fragment shape etc.) but also to look at these factors as occurring together all at once (Haddad *et al*, 2015). Habitat fragmentation can segregate populations and cause a decline in the genetic diversity of species populations, as well as change the species dynamics and ecosystem structuring of the affected ecosystems or habitats (Ewers and Didham, 2006). This causes a loss in species richness within these fragmented habitats as a result of larger species and those species that reside within the central areas of a particular habitat, experiencing a population decline and those that reside on the edge of a particular habitat experiencing an increase in population. This change in species structure could severely impact the ecosystem services and ecosystem functioning of an area.

Overharvesting of both fauna and flora can result from land use changes, as the interactions between the natural environment and humans will becomes prevalent (Newbold *et al*, 2015). This is particularly the case when the intensity of land use increases in an area which impacts the species richness of fauna and flora (Newbold *et al*, 2015). Land use changes also create more homogenous landscapes through activities such as monocultural agriculture or urbanisation, which in turn may create secondary effects such as the alteration of local climates due to impacts such as the heat island effect (Zhao *et al*, 2006). Land use changes can also cause the deterioration of air and water quality in an area (Zhao *et al*, 2006). This causes a loss in ecosystem services and biodiversity through the destruction and replacement of natural habitat/vegetation with other land uses as well as pollution.

Climate change has a multitude of negative effects on biodiversity and habitat loss and is a key driver towards major biodiversity and habitat loss currently and in the future. The main effects that climate change can have on biodiversity and natural habitats/vegetation are: 1) Shifts in species ranges as well as a decline in many species ranges, 2) Increased drought frequency and rainfall variability which results in habitat loss due to impacts such as desertification, drought, and a loss in vegetation cover, 3) A possible increase in alien or invasive species and diseases which can affect the indigenous habitat and species due to competition for space and resources, and the fact that indigenous species will have less resistance to exotic diseases spread by these non-indigenous species, and 4) Species extinctions caused by a rapidly changing climate that is changing at a faster rate than species can adapt (Hannah *et al*, 2002; Hellmann *et al*, 2008).

It is important to understand how climate change impacts biodiversity and the natural habitat/vegetation, as this can help society to mitigate potentially harmful behaviour and activities. The IPCC reports, for example, outline important policies and identify the main causes of climate change such as those already mentioned (Pedersen *et al*, 2021; Pörtner *et al*, 2022). It is important for governments to take such reports into consideration to implement effective measures to reduce further climate change and to implement effective climate change adaptation measures.

However, the effects of climate change and global warming on biodiversity and natural habitat/vegetation frequently do not occur in isolation. There is often an interaction between climate change and land use changes in the process of causing biodiversity and habitat loss (Chazal and Rounsevell, 2009; Pandit *et al*, 2021). The impacts of land use change and climate change for biodiversity and habitat loss were found to be significantly greater when the drivers were considered to act in unison (Chazal and Rounsevell, 2009). An underestimation of biodiversity and habitat loss has often occurred when the effects of the two drivers were considered to occur individually (Chazal and Rounsevell, 2009). Thus, it is important to not only look at land use change and climate change as separate drivers of biodiversity and habitat loss, but also how these two drivers can combine to exacerbate the issue. This is particularly important in a country such as South Africa that, as mentioned earlier, has high biodiversity, and is predicted to be affected by climate change and global warming to a large extent.

Examples of how land use change and climate change can operate in tandem can be seen in agricultural activities and urbanisation. As climate change continues, food production becomes more difficult. This is due to less favourable climatic conditions such as increased drought frequency and rainfall variability which will force farmers to use more water, particularly groundwater, and possibly methods such as using genetically modified organism (GMOs). It is possible that GMOs can pose a significant threat to biodiversity as well as the natural habitat as they compete with native species for space and resources and decrease the genetic diversity of indigenous populations through hybridization (Trakhtenbrot *et al*, 2005; Prakash *et al*, 2011). However, in protected areas and surrounding areas such as the study sites it is more likely that the use of GMOs will be prohibited. Other factors such as increased urbanisation and urban development bring about greater environmental degradation and habitat destruction as well as the alteration of local climates (Zhao *et al*, 2006; Nuissl and Siedentop, 2021). Factors such as these will bring about greater biodiversity and habitat loss, and this may accelerate in a developing country such as South Africa.

2.2 Protected areas (study sites) and other possible impacts:

An important factor to consider is that nature and pollution do not respect boundaries that humans have put in place. It is, thus, not only important to protect and manage protected areas themselves, but also areas surrounding and outside of protected areas.

In South Africa, buffer zones are put in place around protected areas to manage land use (National Environmental Management: Protected Areas Act 57, 2003). However, it is sometimes the case that these areas are subjected to mismanagement, which leads to environmental degradation, commonly caused by land use change. For example, overgrazing or uncontrolled urban development around a protected area, due to poor management, can cut of the nature corridors connecting different protected areas to one another. This can cause habitat fragmentation and a loss in species richness and natural habitat within and around the protected areas (Ewers and Didman, 2006).

Poor management and formation of protected areas can significantly exacerbate climate change impacts. This is particularly the case when shifts in species ranges and declining species ranges are considered (Hannah *et al*, 2002). As climate change continues, if protected and surrounding areas are managed poorly, then the species within these areas will not have adequate habitat to survive (Pandit *et al*, 2021). As the species ranges shift and the conditions within a protected area change, the area may become less suitable for their survival (Pandit *et al*, 2021). Due to a lack of planning and poor management involved with some protected and surrounding areas, the areas in which climatic conditions are now suitable will not be able to support adequate biodiversity and ecosystem services due to lack of protection and greater environmental degradation. Thus, under future climate change scenarios, it will become even more important to focus on areas outside of protected areas - not only current protected areas.

Another factor that influences biodiversity and habitat conservation and land use changes, particularly in South Africa, is land reform. Land reform started in South Africa when apartheid ended, to help and return land to those that experienced racial injustices during that time (Kepe *et al*, 2005). In many cases, particularly in areas that are co-managed between the conservation officials and the land reform recipients, there is conflict over how the land will be used (Kepe *et al*, 2005; Clements *et al,* 2021; Musavengane, 2019; Davis, 2019). In land reform projects that involve protected areas, this conflict can result in, in certain areas, the degradation of the natural environment and lack of biodiversity conservation as it is not considered a priority (Kepe *et al*, 2005; Davis, 2019). Limpopo Province has a high rate of land reform cases and land claims however it is unclear whether there are land reform projects taking place within and affecting the study areas - however this may still be an issue within the Southern Waterberg area and Limpopo Province currently and in the future.

The impacts of climate change and land use change may differ between government run and privately owned protected areas. Such differences may be the result of aspects such as monetary/funding differences, management or mismanagement, the influence of corruption, knowledge, and political will (De Vos *et al*, 2019; Wicander, 2015). It is sometimes the case, particularly (although not always) in developing countries such as South Africa, that public protected areas are mis-managed and have less funding and resources than privately owned protected areas (De Vos *et al*, 2019; Wicander, 2015). Public protected areas can suffer misallocation of resources, and many of those involved with protected areas often do not have the capacity to effectively to manage these protected areas (Wicander, 2015). This leads to the degradation of facilities, and a decline in the protection of the biodiversity and habitat in these areas. On the other hand, privately owned protected areas are often (although not always) managed more efficiently and have the resources to conserve the habitat within their boundaries - as they are often not hindered by issues such as lack of funding and misallocation of resources.

2.3 Other impacts

Soil fertility and agricultural suitability/potential of an area will influence where agricultural activities will take place (Briassoulis, 2009; Msofe *et al*, 2019). For example, if the area in which the Welgevonden Game Reserve is located is more suitable for agriculture than the area in which the Grootwater Nature Reserve is located, then it is more likely that there will be more intense agricultural activities in that area which will impact the local biodiversity and natural habitat/vegetation to a greater extent (Briassoulis, 2009; Msofe *et al*, 2019; Hansen *et al*, 2012; Thomas, 2021). For instance, the main soil types within and surrounding the Welgevonden Game Reserve are classified as red, yellow, and/or greyish soils with low to medium base status, and shallow soils with minimal development with or without intermittent diverse soils in which lime is rare or absent (Agricultural Research Institute for Soil, Climate and Water, 2004). The main soil types within and surrounding the Grootwater Nature Reserve are classified as red, yellow, and/or greyish soils with low to medium base status, and rock with limited soils (Agricultural Research Institute for Soil, Climate and Water, 2004). While both areas are dominated by soil types that are not particularly productive from an agricultural point of view (Cultivated soils within South Africa in general are low in organic matter and are prone to wind and water erosion requiring artificial assistance such as fertilisers to remain productive), the soil types within and around the Welgevonden Game Reserve are more productive than those within the Grootwater Nature Reserve (Agricultural Research Institute for Soil, Climate and Water, 2004). Therefore, there will be more agricultural activities/land uses that will impact the biodiversity and natural habitat/vegetation within and surrounding the Welgevonden Game Reserve than the Grootwater Nature Reserve.

A similar observation can be made regarding the geology and mineral composition in an area and the location and abundance of mining areas (Briassoulis, 2009). The topography of an area influences aspects such as accessibility to an area and the ability of people to construct on and cultivate an area (Briassoulis, 2009; Msofe *et al*, 2019). For example, if the area in which the Grootwater Nature Reserve is less accessible than the area where the Welgevonden Game Reserve is located, then there will be more human activities and alteration to the natural habitat/vegetation in the Welgevonden Game Reserve and surrounding areas (Briassoulis, 2009; Msofe *et al*, 2019). Proximity to larger urban areas and human populations can be a significant factor regarding natural habitat/vegetation and biodiversity loss. This is due to the fact that the area closer to larger human populations is more likely to experience the impacts that may result such as the heat island effect, overharvesting and poaching, land use changes/land conversion, and pollution to name a few (Hansen *et al*, 2012; Thomas, 2021). For example, the Welgevonden Game Reserve is closer to human settlements and human populations than the Grootwater Nature Reserve and therefore will be impacted by the impacts associated with these areas to a greater extent.

3. Research problem and questions

The Southern Waterberg region in Limpopo Province is experiencing habitat loss due to land use changes and climate change. It is thus crucial to monitor and understand how these two drivers are affecting the natural habitat/vegetation within and surrounding protected areas (public and private) in the Southern Waterberg. The following questions were raised to investigate whether the Southern Waterberg is experiencing habitat loss due to climate change and land use change:

1) What is the rate of habitat loss within protected areas, as opposed to outside of protected areas in the Southern Waterberg?
2) What is the extent of land use changes and climate changes in protected areas and surrounding areas in the Southern Waterberg?
3) How has climate change and land use change effect habitat loss in the Grootwater Nature Reserve (government run) and the Welgevonden Game Reserve (privately owned) and surrounding areas in the Southern Waterberg?

4. Research aims and objectives

Aim:

The aim of this study was to assess the impacts of climate and land use changes on the natural habitat/vegetation within the Welgevonden Game Reserve and Grootwater Nature Reserve, as well as surrounding areas. Further, this study will assess which of the factors, climate change or land use change, has a greater impact on habitat loss within the study areas. A comparison between the protected areas and the surrounding areas as well as between the two protected areas themselves in terms of habitat loss will also be investigated.

Objectives:

The following objectives were formulated to aid in the solution of the above-mentioned research questions and research aim.

- To determine the rate and extent of habitat loss in both protected and surrounding areas in the Southern Waterberg, predominantly using the loss and changes regarding vegetation cover.

- To determine the impacts of land use and climate change on natural habitat/vegetation in the area through analysing factors such as landcover changes and, temperature and rainfall variability.
- To determine if climatic and land use changes impact areas surrounding protected areas to a greater extent than within protected areas as well as if these factors impact public protected areas (Grootwater Nature Reserve) to a greater extent than private protected areas (Welgevonden Game Reserve).

5. Methodology

5.1 Study area:

The Waterberg Biosphere is located in the Southern Waterberg region of the southern parts of the Limpopo province (Figure 1). The Waterberg Biosphere covers approximately 654,033 ha and was established in 2001 in order to aid in the conservation of the natural environment, rich biodiversity, and ecosystems that are present in the area. The Waterberg Biosphere consists of over 5,500 plant species, 43% of which are endemic to South Africa (UNESCO, 2021). This makes the Waterberg Biosphere a biodiversity rich area, with high biological importance in the country. The predominant biome in the region is the savanna biome and the second most common land use behind conservation and protected areas is agriculture (both crops and livestock), tourism, and hunting. The largest landcover in the Waterberg Biosphere is sparse bush and open woodland partly illustrated in the results below.

Both the Welgevonden Game Reserve and Grootwater Nature reserve are located in the western parts of the Waterberg Biosphere (Figure 1). The Welgevonden Game Reserve covers approximately 36,000 ha and was established in 1993 and was declared by UNESCO in 2014. The Welgevonden Game Reserve is a private game reserve that was established for conservation and tourism. The Grootwater Nature Reserve covers approximately 3,500 ha and was established in the early 1990s (exact date unknown). The Grootwater Nature reserve is a public reserve and was also established for conservation and tourism purposes as well as recreational activities. These areas are sparsely developed with very few large urban areas.

The Limpopo Province is a relatively poor region with the Gross Domestic Product (GDP) of the region being R38,543.00 in 2018 with 46% of the Waterberg regions population being below the poverty line. Many of the inhabitants in the region rely on low-income jobs and subsistence agriculture to survive.

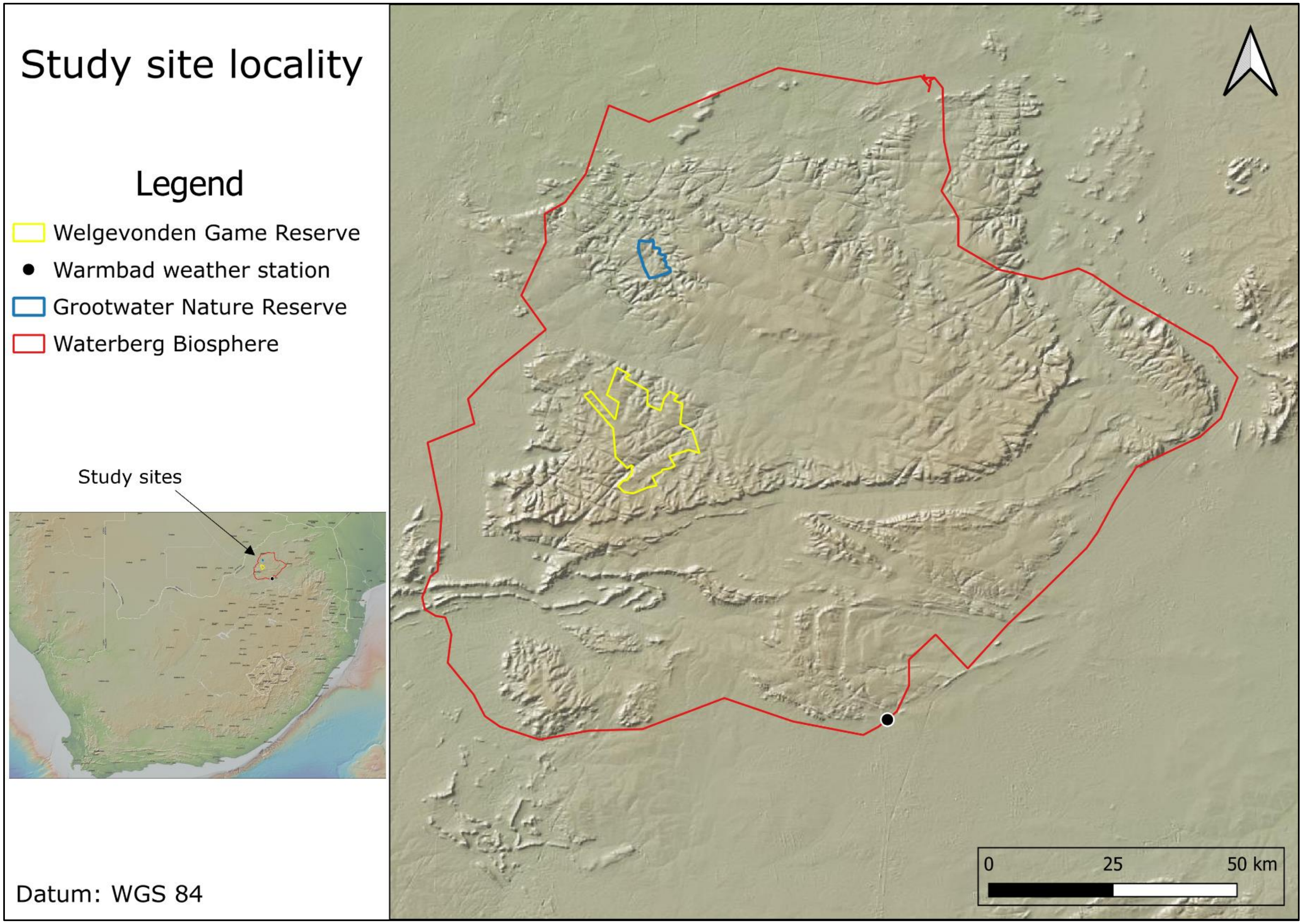

Figure 1: Locality of the Welgevonden Game Reserve, Grootwater Nature Reserve, and Waterberg Biosphere as well as the weather station used to obtain the climatic data in this study. This map also illustrates the locality of the Waterberg Biosphere in relation to the rest of the country (Google Earth Pro, 2022 and QGIS, 2023).

5.2 Data collection and data sources:

To address the above-mentioned research questions, a range of methods and data sources were utilised to gauge the rate of habitat/vegetation loss, and the effects of land use changes and climate changes in the Southern Waterberg region - within the Grootwater Nature Reserve and Welgevonden Game Reserve, as well as the areas surrounding these protected areas. These two reserves have not been studied to a large extent in comparison to others in the area particularly with regards to the impacts of climate changes and land use changes on vegetation loss and changes (habitat loss). A range of data sources and visualisation methods were used to achieve this including a literature review, statistical analysis, and linear and visual representations (graphs and maps), as well as suitable steps to effectively display and report the results.

The extent of the protected areas was extracted from the protected area dataset from the South African National Biodiversity Institute (SANBI), and Google Earth was also used to verify that this information was accurate (DFFE, 2021). Land cover maps of the two protected areas and surrounding areas in the Southern Waterberg were compiled using the SANLC datasets (Appendix 1). However, each year of the SANLC datasets were created using slightly different methodologies and slightly different classes (Appendix 4). Although the classes in the study area did not vary significantly between the different years and as illustrated in the methodologies and metadata of each year they were created using similar techniques, similar classes were merged and the data harmonised to create the new layers illustrated in the maps in Appendix 1. This also accounted for misclassifications in the datasets to a certain extent. This allowed for the identification of land use and landcover changes and represents how these changes are affecting the natural vegetation and natural habitat in these areas. This is important as vegetation is usually the first component of a habitat or ecosystem that is affected by land use changes (Pardini *et al*, 2017). The South African National Land Cover (SANLC) datasets were acquired from the Department of Fisheries, Forestry, and the Environment (DFFE) (DFFE, 2022). The software that was used to create these visual representations was the ArcMap Pro and ArcGIS Online software. The land cover and land use data were gathered over a suitable time period (SANLC: 1990, 2013/2014, 2018, 2020). It is important to use a time period that is long enough to observe significant change, as changes in a landscape or land use often occurs over a number of years. However, since the 1990, climate changes and land use changes have increased globally particularly in the last 10 years. Thus, it is important to analyse both differences over a long period of time as well as the differences between shorter time periods as the magnitude of climate change and land use changes increases. A 5km buffer was created around each of the protected areas using the ArcMap Pro software. The 5km distance was used as it was an adequate area in relation to the size of the study areas and is a suitable distance from the protected areas that can still influence the protected areas themselves. Areas further than the 5km buffer may not have a significant influence on the drivers within the protected areas. The SANLC data was then clipped to both the protected area polygons, as well as the 5km buffer surrounding the two protected areas to analyse and compare the change in land use and landcover in these study areas.

Rainfall and temperature data for the Southern Waterberg region was requested from the South African National Weather Service (SAWS) for three different weather stations however only data from the weather station in Warmbad was used as it was the most complete and accurate dataset for the region (SAWS, 2022). The average monthly rainfall as well as the total annual rainfall for the years 1990 to 2020 was extracted from this dataset. Similarly, average monthly minimum and maximum temperatures were extracted from the SAWS dataset.

5.3 Data analysis:

The land cover data and the extent of each land cover type was extracted from the attribute table for each year (1990, 2013/2014, 2018, 2020), and analysed in Microsoft Excel. The changes in both natural vegetation and natural areas (grassland, natural rivers, wetlands and water bodies, dense bush and forest, sparse bush and woodland, and low shrubland), and other land use changes (agriculture (plantations, cultivated crops), urban/mining/industrial, and barren and eroded land) within the study sites is represented using maps created in ArcMap Pro, and graphically. The changes in land cover are illustrated as the percentage of the study areas covered by the different land uses/land cover mentioned above. The percentage of each land cover category was extracted from the attribute table of the SANLC data. A Chi-square analysis was used to confirm whether there is a significant difference in habitat loss between the protected areas and the areas surrounding the protected areas (buffer zones). Chi-square analysis is a useful tool when comparing the relationship between variables in terms of the impact that they have on one another.

Additional methods were used to assess the climatic changes in the Southern Waterberg region, and the possible impacts of these climatic changes on habitat loss within the two protected areas and 5km buffers. A literature review of previous studies with the focus on the effects of climate change on biodiversity and habitat loss was used to interpret the data/results, particularly for the Southern Waterberg region.

Graphical representations were used to illustrate the change in rainfall and temperature in the Southern Waterberg region from 1990 to 2020, representing how the climate in the region may have shifted. The change in temperature of the region was also compared to the mean annual monthly temperature change of the country as a whole over the same time period (1990 to 2020) (World Bank Climate Change Knowledge Portal, 2021). It can also indicate periods of drought that have occurred in the region within that time period which was supported by the frequency of ENSO in the region as discussed in Section 7 below. Statistical analysis was incorporated to support the rainfall and temperature data trends illustrated in graphs (trend (linear regression model)) and whether these trends had an influence on habitat loss in the study areas (Chi-square analysis). Together with the change in natural vegetation loss, this can help deduce how the changes in temperature and rainfall patterns can impact the natural habitat/vegetation in an area. The use of use of other regression analysis techniques was also explored regarding the relationships between climate changes and land use changes on natural vegetation as well as the differences between landcover changes within the study areas. However, Chi-square analysis was the most effective statistical analysis technique as there were not enough sample points for other statistical analysis methods to be effective.

5.4 Study limitation and recommendations:

Study limitations

There are a few limitations and areas to build on in terms of the methods used and subjects analysed in this study. Firstly, only one public protected area and one private protected area included in this study (n=1). Secondly, the SANLC data that was used and analysed had slight variations in methodology in calculating each class between the years and each year had a slightly different number of classes. Further, the SANLC data does not illustrate vegetation and ecosystem health and does not display the vegetation composition or structure as accurately as other methods such as remote sensing. This study also used case study research as part of the methodology which can have some limitations such as the lack of site-specific conditions as it can be relatively broad particularly for site that have not been studied and researched extensively.

Study recommendations for future research

The following recommendations are made regarding further research regarding this study and the study areas:

- More than one (n=1) private and public protected area should be used to get a better understanding of how the drivers analysed in this study impact these protected areas.
- Use other types of datasets and remote sensing techniques such as vegetation datasets and Landsat/AVHRR to obtain more accurate results in terms of vegetation composition and illuminating possible errors due to methodology changes in datasets.
- Incorporate analyses to illustrate vegetation health in the study areas.
- The use of the actual area covered by the different landcover types could also be used instead of the percentage of the land covered by each landcover types in the study areas.

6. Results

Temperature and rainfall:

The results illustrated below in Figures 2 to 5 indicate the change in temperature and rainfall patterns in the Southern Waterberg from the year 1990 to 2020 (also see Appendix 3).

Both the average monthly maximum and average monthly minimum temperatures in the Southern Waterberg have increased from 1990 to 2020 (Figure 4 and 5), as indicated by the trend analysis that illustrates that both factors have a positive gradient (slope= 0.1128 and 0.0209 respectively) or show a general increase in temperature (Table 1). The average monthly minimum temperature has increased by approximately 0.3°C from 1990 to 2020 in terms of the linear/trendline average, while average monthly maximum temperatures have increased by approximately 2.5°C 1990 to 2020 in terms of the linear/trendline average. The increase in average monthly maximum temperatures shows a strong positive relationship ($R^2=0.525$) - however, both maximum and minimum average monthly temperature increases from 1990 to 2020 are deemed not significant ($F>0.05$ and $P>0.05$). This illustrates that there is an increase in monthly average temperatures - it is not, however, a significant increase. When comparing the temperature increase to the national mean average monthly temperature increase from 1990 to 2020, South Africa experienced a 1°C increase in mean annual temperature increase from 1990 to 2020 while the Southern Waterberg region experienced a higher mean annual monthly temperature increase of 2.2 °C from 1990 to 2020 (World Bank Climate Change Knowledge Portal, 2021).

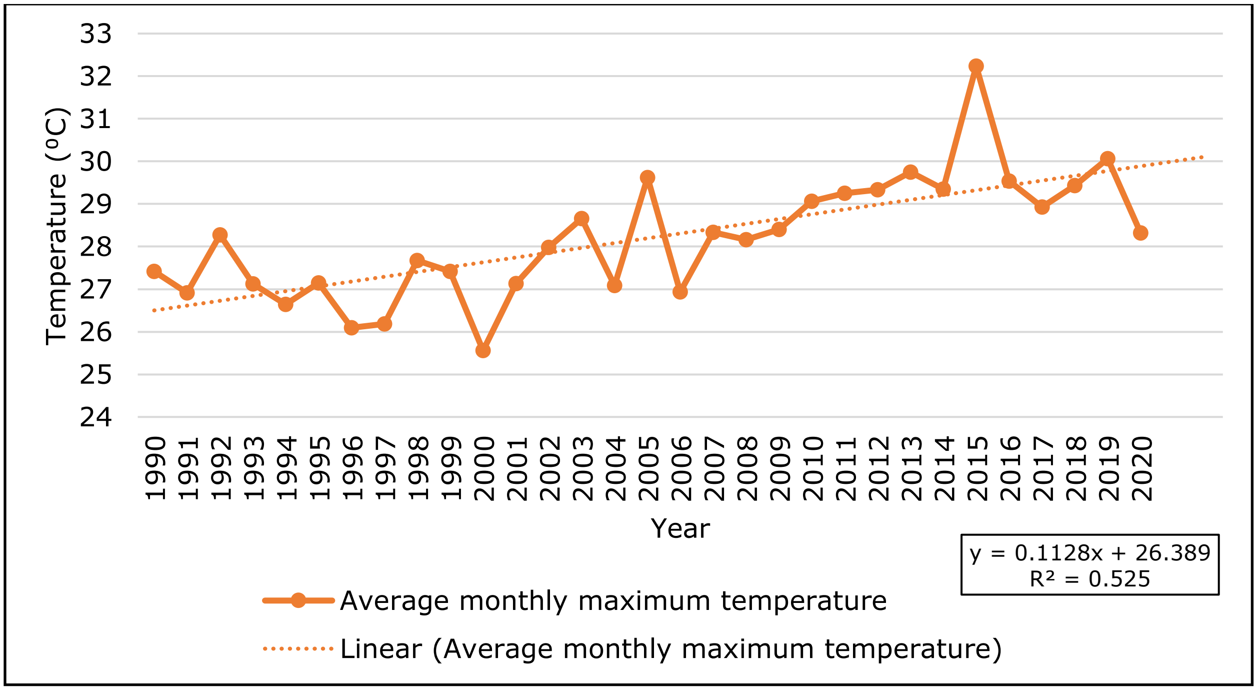

Figure 2: Average monthly maximum temperatures from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

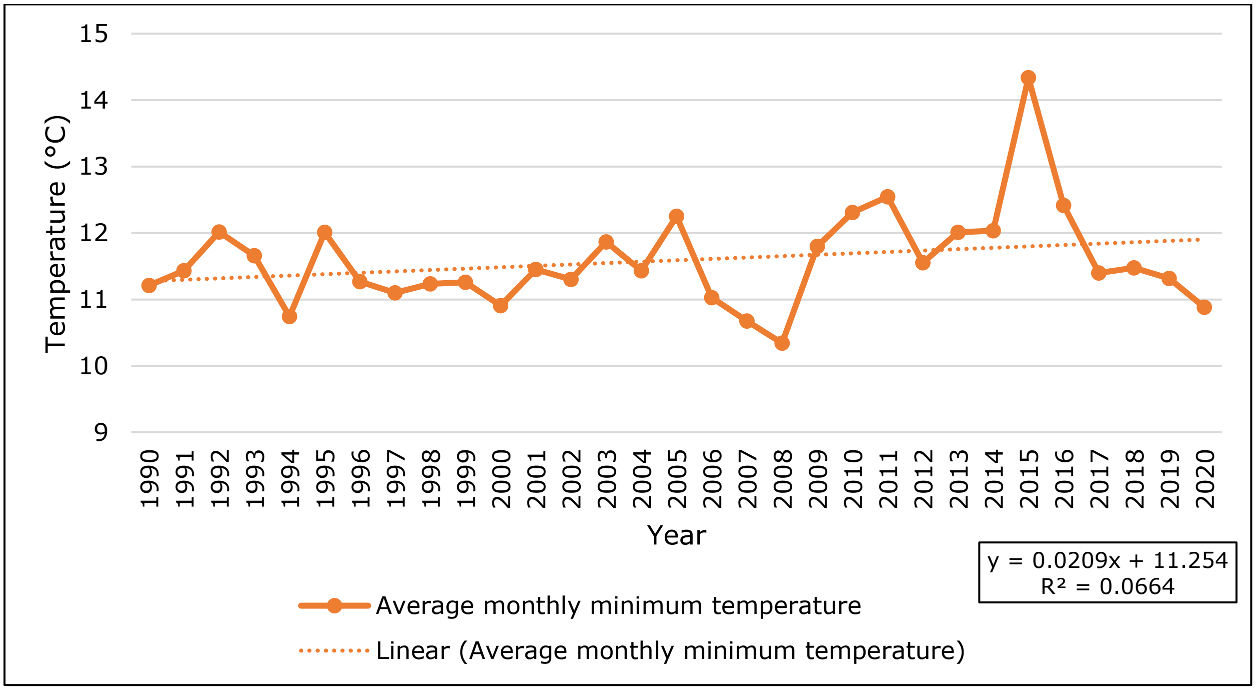

Figure 3: Average monthly maximum temperatures from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

Table 1: Trend analysis results for the average monthly minimum and maximum temperatures from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

Regression analysis	**Average monthly maximum temperatures**	**Average monthly minimum temperatures**
Significance (F)	F>0.05	F>0.05
R²	0.525	0.0664
P-Value (p)	p>0.05	p>0.05

Figures 7 and 8 indicates that both average monthly rainfall and total annual rainfall have decreased in the Southern Waterberg region, as indicated by the trend analysis that illustrates that both factors show a negative gradient (slope=-4.1168 and -0.2733 respectively) or general decrease from 1990 to 2020 (Table 2). Average monthly rainfall has decreased by approximately 2.5 mm from 1990 to 2020 in terms of the linear/trendline average, while the total annual rainfall has decreased by approximately 130 mm from 1990 to 2020 in terms of the linear/trendline average in the Southern Waterberg region. This decrease in both the average monthly rainfall and total annual rainfall is not significant (F>0.05 and p>0.05).

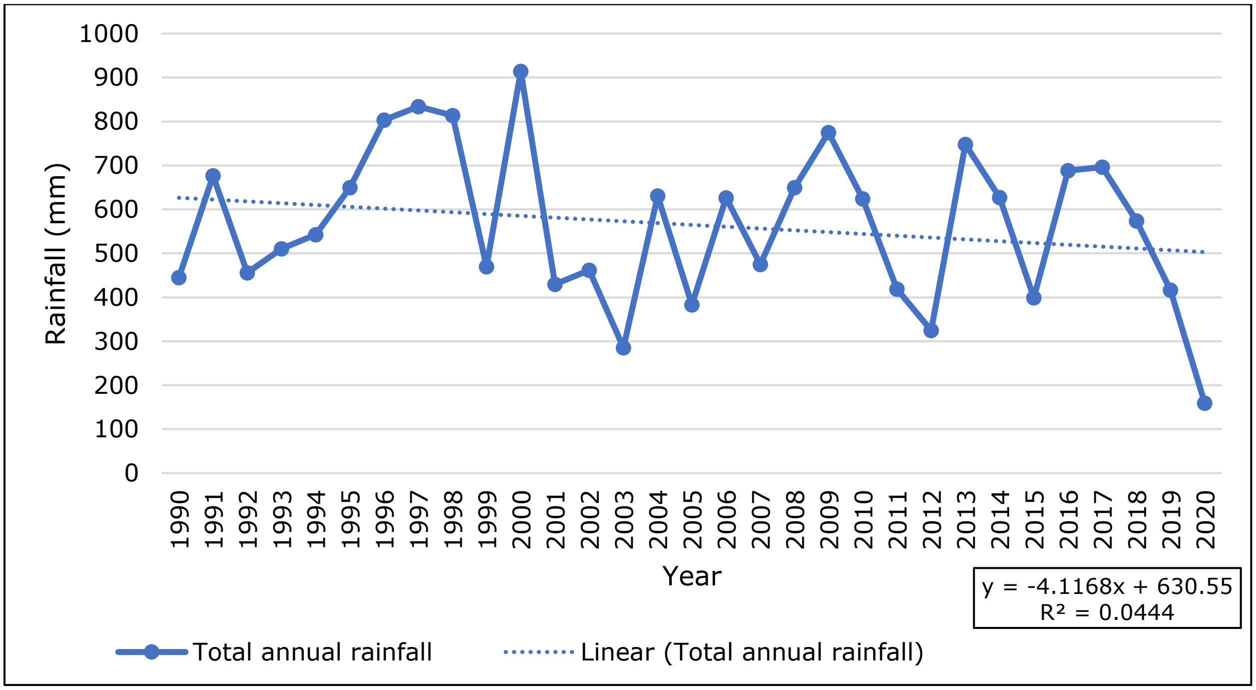

Figure 4: Total annual rainfall from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

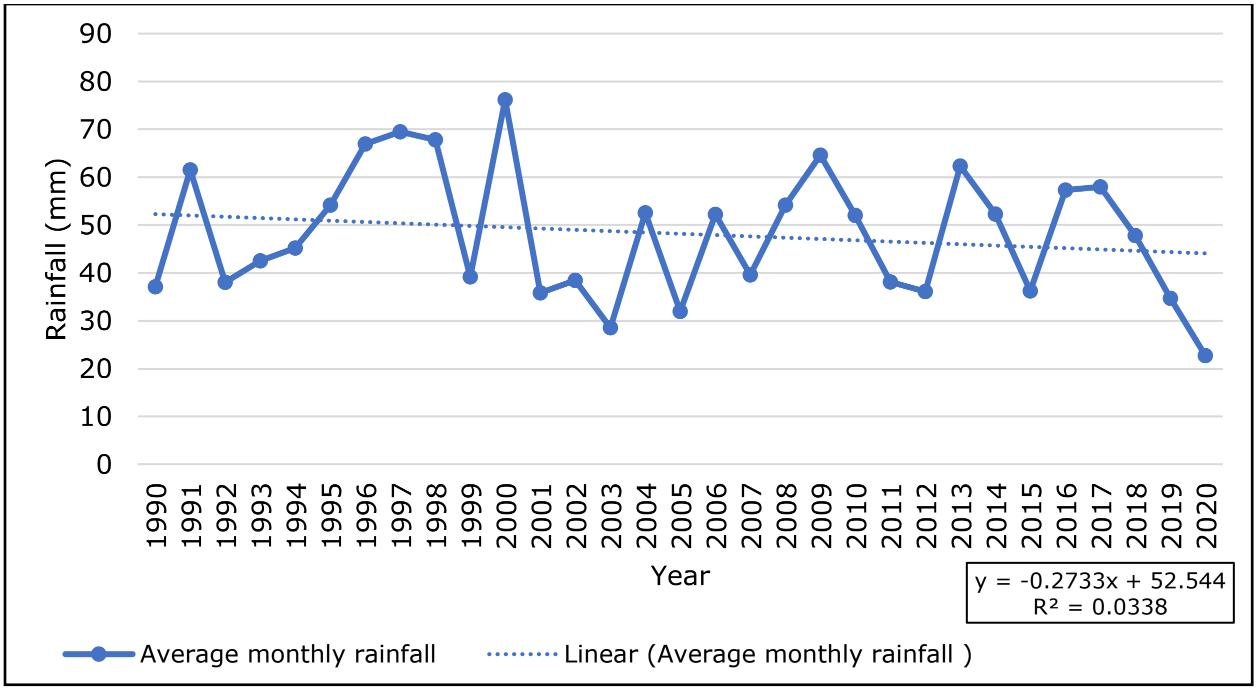

Figure 5: Average monthly rainfall from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

Table 2: Trend analysis results for the average monthly rainfall and total annual rainfall from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

Regression analysis	**Average monthly rainfall**	**Total annual rainfall**
Significance (F)	F>0.05	F>0.05
R^2	0.0444	0.0338
P-Value (p)	p>0.05	p>0.05

Land use changes:

The following results (Table 6 to Table 7 and Figure 6 to Figure 9) illustrate the changes in land use/land cover (excluding natural habitat and natural vegetation to illustrate the changes that could cause natural habitat and natural vegetation loss), and represent land conversion in the Grootwater Nature Reserve, Welgevonden Game Reserve, and the areas within the 5km buffers surrounding these two protected areas (also see Appendix 1 and Appendix 2).

Agricultural activities in the Grootwater Nature reserve increased by the largest margin (0.17%), while barren and eroded land increased by 0.13% from 1990 to

2020. Urban, mining, and industrial activities decreased by 0.02% from 1990 to 2020.

In contrast, the area surrounding the Grootwater Nature Reserve (5km buffer) showed a larger increase in barren and eroded land (0.59%) than both agricultural activities (0.27%) and urban, mining, and industrial activities (0.05%) combined.

The total percentage of land that experienced land use change and landcover conversion was greater in the areas surrounding the Grootwater Nature Reserve (0.91%) than within the protected area (0.3%).

Agricultural activities (0.07% increase) and urban, mining, and industrial activities (0.05% increase) did not change by a substantial margin within the Welgevonden Game Reserve. The largest percentage of land that was converted or experienced a significant change was barren and eroded land which increased by 1.52%.

The areas surrounding the Welgevonden Game Reserve (5km buffer) followed a similar trend whereby barren and eroded land increased by a much larger margin, increasing by 3.17%, than agricultural activities (0.83%) and urban, mining, and industrial activities (0.15%) combined.

Land use and land cover conversion or changes, similar to the Grootwater Nature Reserve and Grootwater Nature Reserve buffer area, was higher in the areas surrounding the Welgevonden Game Reserve (4.15%) than within the Welgevonden Game Reserve (1.64%).

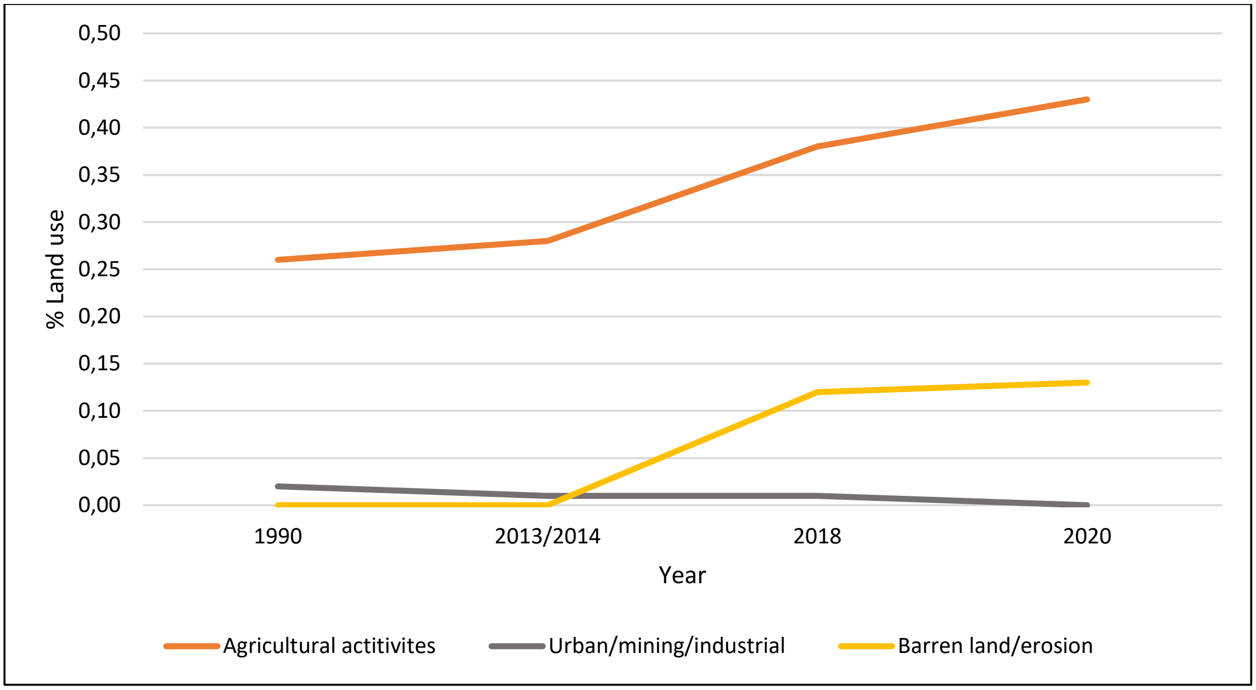

Figure 6: Land use changes in the Grootwater Nature Reserve from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

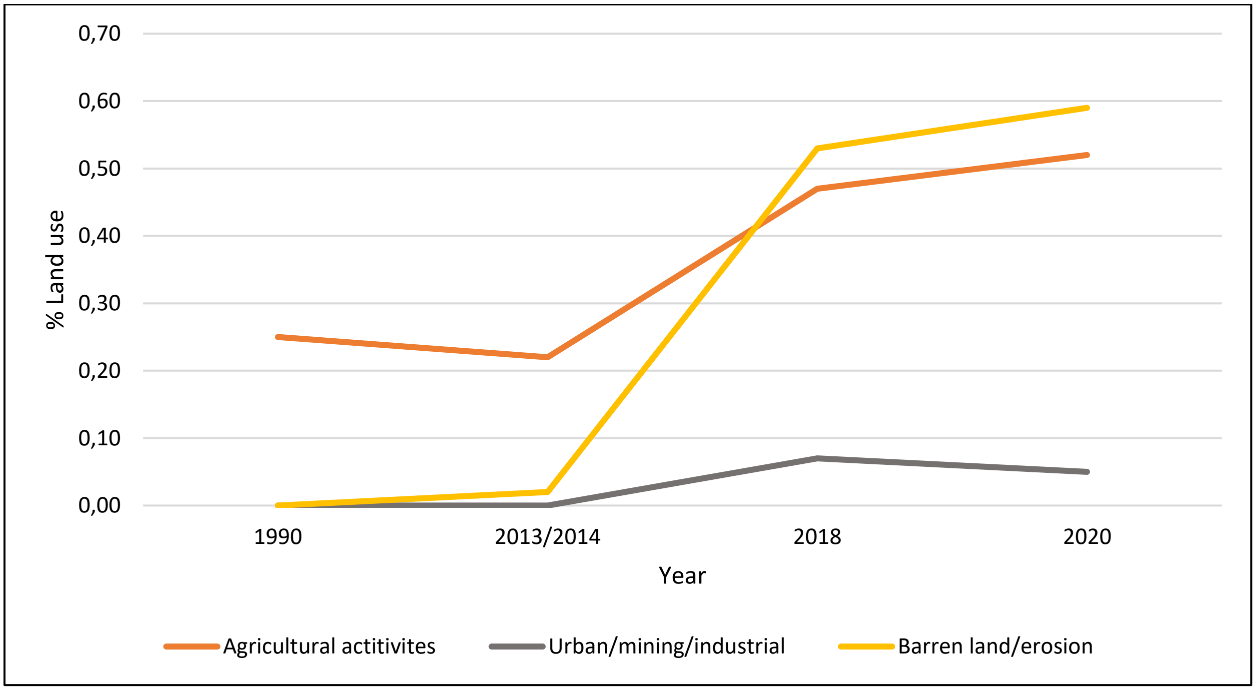

Figure 7: Land use changes in the areas surrounding the Grootwater Nature Reserve from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

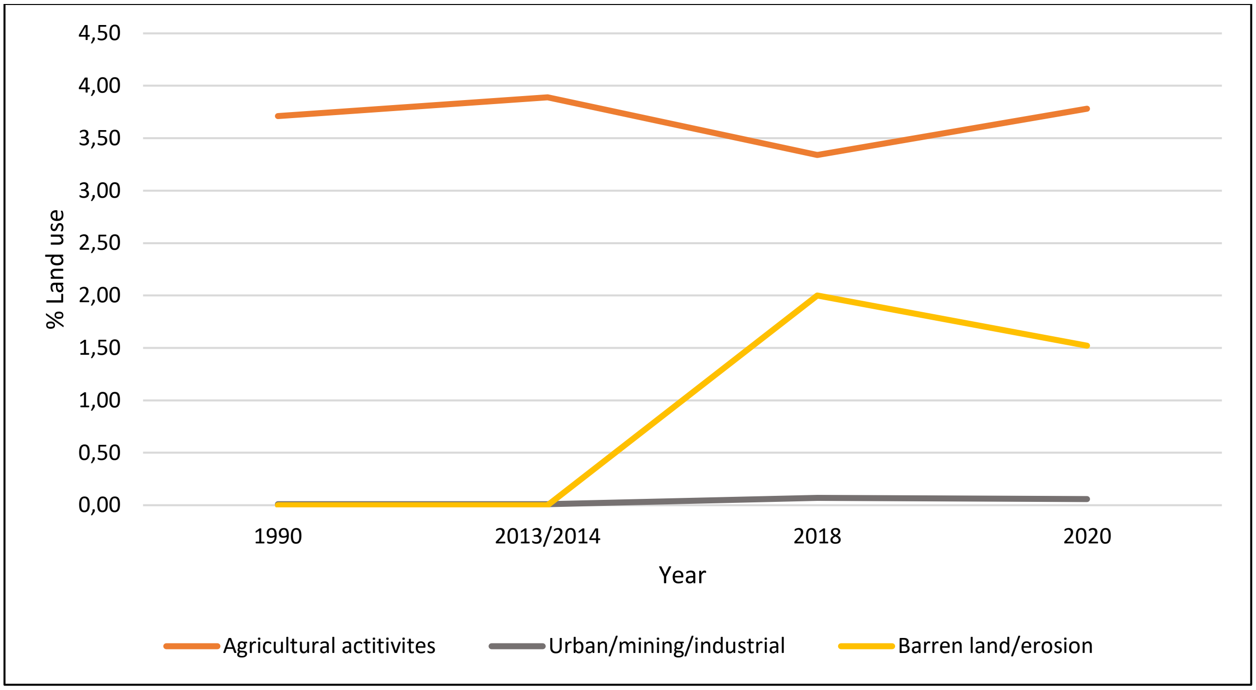

Figure 8: Land use changes in the Welgevonden Game Reserve from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

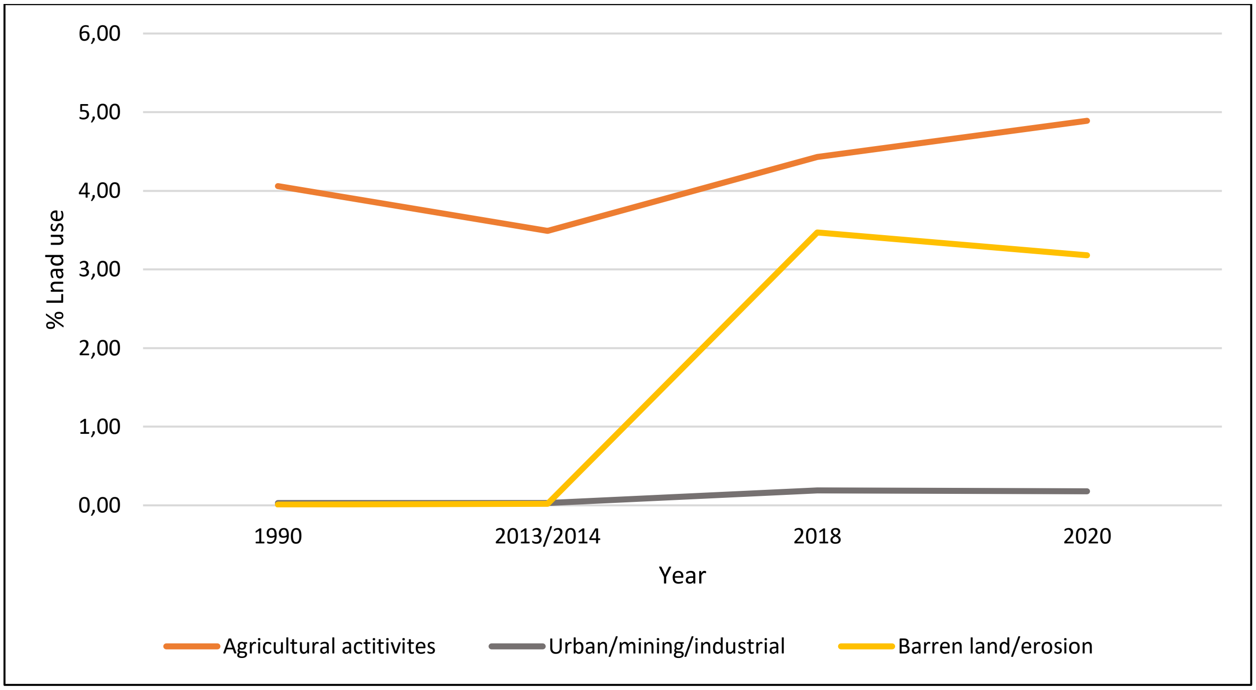

Figure 9: Land use changes in the areas surrounding the Welgevonden Game Reserve from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

Natural vegetation and natural habitat loss:

The analysis below (Table 3, Table 4, Table 6, and Table 7, and Figure 10, and Figure 11) indicates the natural vegetation and natural habitat loss within the Welgevonden Game Reserve and Grootwater Nature Reserve, as well as the areas surrounding these protected areas within the 5km buffer areas (also see Appendix 1 and Appendix 2).

The Grootwater Nature Reserve experienced an absolute decline of 0.28% in natural habitat and natural vegetation from 1990 to 2020. Natural habitat and natural vegetation loss was greater in the areas surrounding the Grootwater Nature Reserve, as natural habitat and vegetation experienced an absolute decline of 0.91%. Despite this difference, Chi-square analysis indicated that the relationship between the habitat/vegetation loss in the two areas is not significant ($p>0.05$).

The absolute natural habitat and natural vegetation loss in the Welgevonden Game Reserve was 1.64%. The areas surrounding the Welgevonden Game Reserve experienced an absolute decline of 4.15% in natural habitat and natural vegetation which is markedly higher than within the protected area from 1990 to 2020. Despite this difference, Chi-square analysis indicated that the relationship between the habitat/vegetation loss in the two areas is not significant ($p>0.05$).

The results above indicate that natural vegetation and natural habitat loss is greater in areas surrounding protected areas that within protected areas however the changes were not significant. Further, natural vegetation and natural habitat loss was greater within the Welgevonden Game Reserve (1.64%) than within the Grootwater Nature Reserve (0.28%).

The Chi-square analysis (Table 5) illustrates the relationship between climatic changes and habitat/vegetation loss within the study areas. The analysis indicates that habitat/vegetation loss is independent to the increase in minimum average temperatures and decrease in monthly average rainfall variables and there is no significant impact ($p>0.05$). This indicates that these climatic variables most likely have limited to no influence on habitat loss in the study areas. The analysis also indicated that the increase in average maximum temperatures may also not have an influence on habitat/vegetation loss ($p>0.05$), however the analysis shows that in the Grootwater Nature Reserve, habitat loss could be caused by increasing average monthly temperatures as the analysis indicated that the variables are dependent on one another ($p<0.05$). The analysis also indicated that decreasing total annual rainfall may have an influence on habitat/vegetation loss as it showed that habitat loss in all the study areas is dependent on the decrease in total annual rainfall ($p<0.05$).

Table 3: Natural habitat and natural vegetation loss in the Grootwater Nature Reserve and surrounding areas from 1990 to 2020

Natural habitat and vegetation loss in the Grootwater Nature Reserve and surrounding areas		
Year	Grootwater Nature Reserve (%)	Grootwater Nature Reserve Buffer (5km) (%)
1990	99.72	99.75
2013/2014	99.71	99.76
2018	99.49	98.93
2020	99.44	98.84

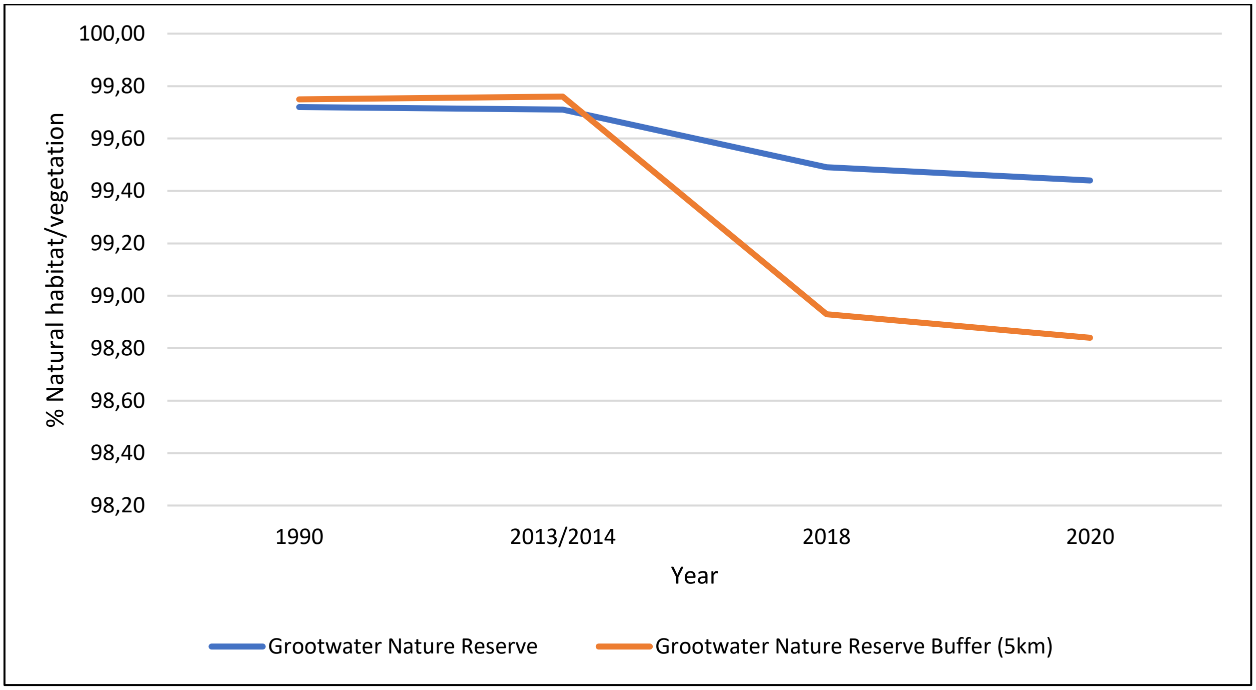

Figure 10: Natural habitat and natural vegetation loss in the Grootwater Nature Reserve and surrounding areas from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

Table 4: Natural habitat and natural vegetation loss in the Welgevonden Game Reserve from 1990 to 2020

Natural habitat and vegetation loss in the Welgevonden Game Reserve and surrounding areas		
Year	Welgevonden Game Reserve (%)	Welgevonden Game Reserve Buffer (5km) (%)
1990	96.28	95.90
2013/2014	96.10	96.46
2018	94.59	91.91
2020	94.64	91.75

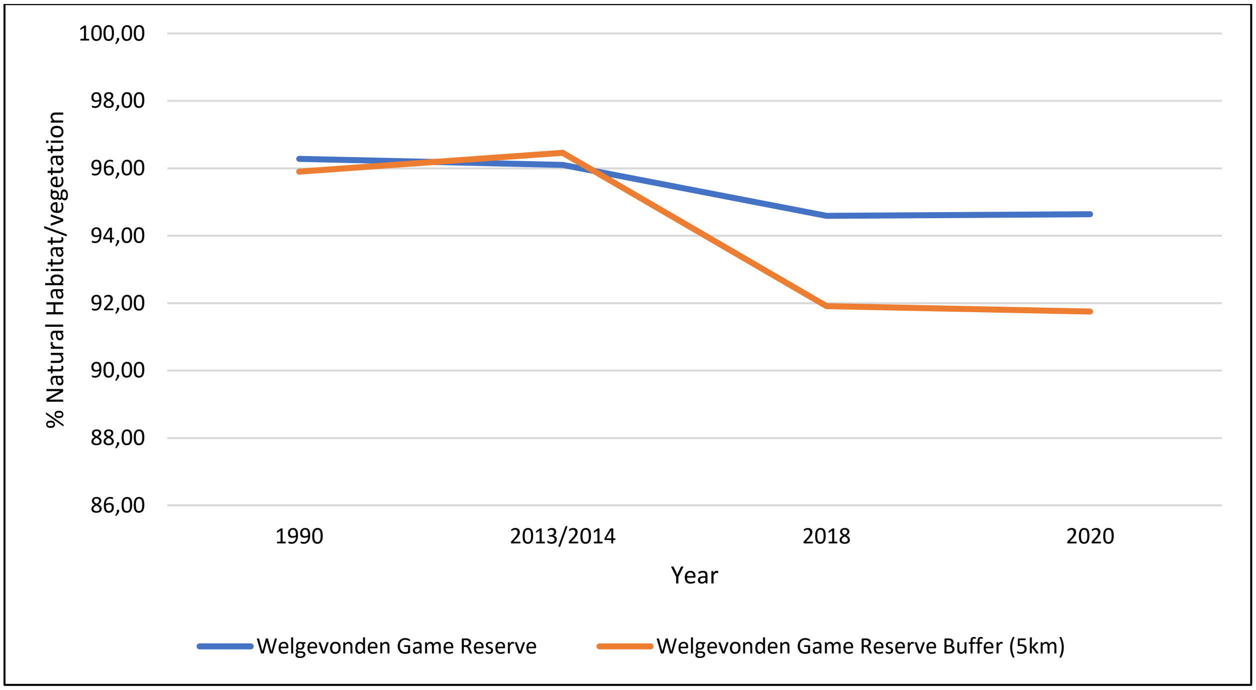

Figure 11: Natural habitat and natural vegetation loss in the Welgevonden Game Reserve and surrounding areas from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa

Table 5: Chi-square analysis comparing the impact of temperature and rainfall trends from 1990 to 2020 on the natural habitat/vegetation loss within the Welgevonden Game Reserve, Grootwater Nature Reserve, and surrounding areas from 1990 to 2020 for the Southern Waterberg, Limpopo Province, South Africa.

Chi-square analysis	**Welgevonden Game Reserve**	**Welgevonden Game Reserve Buffer (5km)**	**Grootwater Nature Reserve**	**Grootwater Nature Reserve Buffer (5km)**
P-value (Increase in maximum average temperatures)	$p>0.05$	$p>0.05$	$P<0.05$	$p>0.05$
P-value (Increase in minimum average temperatures)	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$
P-value (Decease in total annual rainfall)	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$
P-value (Decrease in average monthly rainfall)	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$

7. Discussion

The results illustrated above show that the conversion of land and land use/land cover changes in the areas surrounding protected areas is greater than within protected areas. The analysis also shows that land conversion in the Welgevonden Game Reserve (private protected area) is greater than in the Grootwater Nature Reserve (public protected area). This is a relatively surprising result, as it contrasts comparison the literature review above discussing the possible differences between public and private protected areas.

The most common anthropogenic land use or activity that was analysed in the findings above within the study sites, apart from barren and eroded land, is agriculture. Impacts that are more site specific such as overharvesting, vegetation clearance, and habitat fragmentation can all result from the identified agricultural activities. However, these impacts occur within or in close proximity to an agricultural activity and the impact of agricultural activities was deemed not significant ($p>0.05$). Agricultural activities also have wider ranging impacts including the overuse of pesticides and fertilisers (inorganic and organic) and, surface and groundwater depletion being the major impacts although these methods may not be used by all of the farmers in the study sites. The spraying of pesticides can impact local species significant distances from where they are being sprayed and implemented as they can travel through the lower atmosphere during windy conditions as well as waterways via runoff (Dubey and Sudhakar, 2021). These pesticides can also be passed through the food chain if they are consumed by species that are low in the food chain within the ecosystem, known as bioaccumulation (Dubey and Sudhakar, 2021). This causes loss in biodiversity, particularly fauna, and ecosystem services large distances from the source of the pesticide use (Dubey and Sudhakar, 2021). The overuse of both organic and inorganic fertilisers can also travel significant distances, particularly through the waterways in an area (Kumar et al, 2019). The increase in nutrients within these waterways can cause eutrophication, which leads to a loss in biodiversity and ecosystem services within the waterways (Kumar *et al,* 2019). This in turn can influence terrestrial biodiversity due to a decline in overall ecosystem services and key species (Kumar et al, 2019).

Depletion of both groundwater and surface water can result from agricultural activities, particularly the cultivation of crops using centre pivot and other largescale irrigation systems (Giordano *et al*, 2019; Perret and Payen, 2020). This can cause a decline in aquatic biodiversity, through habitat loss and concentration of potential pollutants, and can negatively impact terrestrial and aquatic biodiversity by exacerbating the potential and identified impact of drought conditions in the area as well as water quality (Giordano *et al*, 2019; Perret and Payen, 2020). As stipulated in the results above, there has been very little increase in agricultural activities in the area, and impacts such as pesticide use, and groundwater depletion would need to be investigated further to assess the possible impacts of these factors. However, despite the small changes in agricultural activities in the study areas, these factors can still have an impact both from within the study areas and areas surrounding the study areas. It is also important to note that a major form of agricultural activities performed by local people in rural areas in Limpopo Province, including the Southern

Waterberg and Waterberg Biosphere, like in many other developing countries is the small-scale farming of livestock and subsistence agriculture (Phokele and Sylvester, 2012; Rankoana, 2016; Zhou *et al*, 2022). The livestock in many rural communities are able to roam relatively freely through natural areas, particularly in municipal and tribal lands and substance agriculture uses land and natural resources often in or around protected areas (Rankoana, 2016; Zhou *et al*, 2022). If not controlled or carried out sustainably this could lead to overgrazing, loss of natural vegetation and natural habitat, spread of diseases as well as conflict between local people and local fauna due to predation of livestock and competition for grazing/food leading to a decrease in biodiversity (Thompson *et al*, 2013; Andersson *et al*, 2017). This could be a reason for the apparent decrease in dense bush and increase in barren/eroded land indicated in the maps below (Appendix 1) and results above. The data sets used in this study did not consider this form of agriculture and it could possibly be a contributing factor to the increase in barren and eroded land, and loss of natural habitat/vegetation from 1990 to 2020 within the areas of study. However, further research specifically analysing subsistence livestock farming and grazing in the area needs to be carried out to confirm this theory.

There are very few to no large built-up areas within the Welgevonden Game reserve, Grootwater Nature Reserve, and areas surrounding these protected areas - therefore the impact of urban and industrial activities in the area such as the heat island effect and increased runoff will be minimal and was shown to be not significant ($p>0.05$). Mining is also not a common land use within the study areas - however, mining can also have far reaching impacts in addition to impacts within or in close proximity to the mining area (Jhariya *et al*, 2016). Acid mine drainage and erosion are common impacts of mining operations (Jhariya et al, 2016). Acid mine drainage and erosion/siltation pollute both groundwater and surface water significant distances from the mining area (Jhariya *et al*, 2016). This can negatively impact biodiversity and the quality of the natural habitat and ecosystems over a wide area however the methodology used above cannot determine these specific impacts effectively.

The climate in the Southern Waterberg where the Welgevonden Game Reserve and Grootwater Nature Reserve are located has changed slightly between the years 1990 and 2020. Average monthly minimum and maximum temperatures have increased, and average monthly and total annual rainfall has decreased. Although the increase in average temperatures was deemed not significant ($p>0.05$), even a slight increase in average temperatures can result in severe impacts on habitat loss and biodiversity, particularly natural vegetation cover in the Southern Waterberg region, where the Grootwater Nature Reserve and Welgevonden Game Reserve are located. The decrease in both average monthly and total annual rainfall was also deemed not significant ($p>0.05$) in the results however, even a slight decrease in rainfall or increase in rainfall variability could potentially have a multitude of negative consequences for the fauna and flora in the region.

As mentioned previously, the main biome in the Southern Waterberg region is the Savanna Biome which requires relatively consistent rainfall and temperature conditions (Criado *et al*, 2020). The results above indicate that there is in increase in rainfall variability and drought conditions, indicating that the loss in natural habitat/vegetation is most likely as a result of the changing climatic conditions in the area. Further, statistical analysis indicates that a decrease in total annual rainfall and to a lesser extent, an increase in maximum monthly temperatures can negatively impact the natural habitat/vegetation in the area ($P<0.05$). The Savanna Biome is also reliant of the fire regime of the region which is also impacted by a change in rainfall and the frequency of drought conditions (Archibald *et al*, 2019). Further, ENSO cycles may also have had an influence on short term drought events in the region. For example, the country experienced an El Nino cycle from in 2015/2016 and 2019/2020 which caused a decrease in rainfall and significant increase in temperatures which would have contributed to the drought conditions in the region during that time period (Figure 2, Figure 3, Figure 4, and Figure 5) (Shikwambana *et al*, 2023; Alemaw, 2022). This type of event can cause short term changes in climatic conditions and contribute to an increase in rainfall variability if it occurs more frequently due to climate change (Hao *et al* 2020). However, although ENSO can cause a decrease in rainfall over a short time period, it is unlikely that this type of short-term event had a significant impact on the steady decrease in rainfall in the Southern Waterberg from 1990 to 2020 as for example, the region experienced lower temperatures and relatively high rainfall during the La Nina event in 2010/2011 (Shikwambana *et al*, 2023).

It can be seen in the findings above and the landcover maps below (Appendix 1) that there are changes in vegetation type and cover surrounding the land use areas such as agriculture and mining areas. However, there is also a loss in dense bush and change in species composition in areas that are not in close proximity to human activities, which indicates that a changing climate may be the most likely cause of habitat and vegetation loss in the area (Appendix 1). Another deduction can be made from this analysis regarding the natural habitat and natural vegetation loss within the protected areas, and the areas surrounding the protected areas. While there was an increase in land use changes such as agricultural activities and urban, mining, and industrial activities from 1990 to 2020, the majority of the change was in the form of land being converted or changing to barren and eroded land. This indicates that the majority of the land where the loss in natural vegetation and natural habitat is occurring is being transformed to barren and eroded land. Further, the loss in natural habitat and natural vegetation follows the changes in rainfall and temperature patterns. From the year 2013/2014 onwards, natural vegetation loss decreased at a faster rate to the year 2018 and 2020 however still not significant ($p>0.05$). During this period, the region experienced longer periods of drought-like conditions illustrated by the accelerating maximum average monthly temperatures and lower total annual rainfall. Further, the relatively high vegetation and natural habitat cover in 2013/2104 dataset may have been offset by the high rainfall that occurred during that time period (Figure 4 and 5). The ENSO cycle that the region experienced in 2015/2016 further indicates the regions dependence on steady climatic conditions and supports the results that indicate that a change in climate is the most likely cause of habitat/vegetation decreases within the study sites as during this time period natural habitat/vegetation begun to decline (Figure 10 and Figure 11).

The temperature and rainfall patterns above can be used to aid in identifying potential drought patterns in the area. For example, from the year 2009 to 2020, there was a general increase in average monthly temperatures, and a general decrease in rainfall (with the exception of outlier years such as the high rainfall recorded in the year

2013 (La Nina)). Due to the general decrease in average rainfall and increase in average temperatures from 2009 to 2020, the Southern Waterberg region would have experienced drought conditions for a large majority of that time period. Further, El Nino cycles appeared to have increased in intensity and frequency during this time period as they occurred in 2015/2016 and then again in 2019/2020 which correlated to the higher temperatures, lower rainfall, and decrease in natural habitat/vegetation in the region during those time periods (Figure, Figure, Figure 10 and Figure 11).

In addition, the landcover maps (Appendix 1) indicate that dense bush and forest cover decreased from 1990 to 2020 in both study areas - even in areas that did not experience any land use changes. The landcover maps also indicate shifts in both grassland and sparse bush habitat in areas that did not experience any land use changes. This indicates that the natural vegetation in the area is highly dependent on the climatic conditions in the region. Chi-square analysis further indicated that increasing average monthly temperatures and decreasing total annual rainfall are possibly causing habitat loss in the study areas ($p<0.05$). Therefore, if climatic conditions and land use changes continue to change in this manner and along the same trend, it can be said that climatic changes are having a greater impact on natural vegetation and natural habitat loss than land use changes in the Southern Waterberg region.

Under future climate change scenarios, it will become even more important to focus on areas outside of protected areas - not only current protected areas. This is illustrated by the results above when comparing the protected areas (Welgevonden Game Reserve and Grootwater Nature Reserve) and the areas surrounding the protected areas (5km buffer areas). The areas surrounding the protected areas experienced greater vegetation and habitat loss than the protected areas from the year 1990 to 2020. The buffer areas also experienced more land use changes and greater land conversion than the protected areas, further highlighting the importance of conserving both protected areas and areas surrounding protected areas.

In many documented cases privately run protected areas experience less degradation and loss of natural habitat than public protected areas (De Vos *et al*, 2019; Wicander, 2015). However, this does not appear to be the case with the Welgevonden Game

Reserve (privately run) and the Grootwater Nature Reserve (government run (public)). The results of the study indicate that the Welgevonden Game Reserve experienced greater land use changes and, natural vegetation and habitat loss than the Grootwater Nature Reserve due to climatic changes and land use changes. This can be an indication that the government run protected area (Grootwater Nature Reserve) is managed more efficiently that the privately run protected area (Welgevonden Game Reserve). However, there are other factors that also need to be considered when comparing two different study sites - including but not limited, to soil fertility and agricultural suitability/potential, proximity to larger urban areas and human populations, topography, and geology of an area (Briassoulis, 2009). Again, this is an unexpected result, and contrasts the literature review and assumptions made in this study, as the public protected area has a lower rate of natural vegetation and natural habitat loss than the privately owned protected area.

8. Conclusion

Global biodiversity loss is increasing rapidly due to both direct and indirect anthropogenic drivers. Two of the largest drivers of biodiversity loss globally are land use changes and climate changes. Land use changes, particularly habitat loss, have detrimental effects on biodiversity and ecosystem services. As mankind encroaches further into natural habitats, the loss of biodiversity and natural habitat/vegetation increases. Changing climatic conditions also have significant impacts on biodiversity loss through factors such as increased rainfall variability and drought frequency. South Africa’s average temperature increases caused by climate change are believed to be higher than the global average temperature increase. South Africa also one of the most biodiverse countries globally, making protected areas important in protecting biodiversity against both climate changes and land use changes. It is evident that these two drivers can have an impact on biodiversity and habitat loss in the Southern Waterberg, Limpopo, South Africa specifically the Grootwater Nature Reserve and Welgevonden Game Reserve as opposed to surrounding areas. However, even though these impacts may not be significant the smallest changes in climate and land use can create major problems for biodiversity and natural habitat.

The results indicated that both the Welgevonden Game Reserve and Grootwater Nature Reserve and surrounding areas experienced a loss in natural vegetation and habitat from 1990 to 2020. Natural habitat/vegetation loss in areas surrounding the Welgevonden and Grootwater Nature Reserve experienced a greater loss in natural vegetation and habitat and, a larger increase in land use changes than within the protected areas from 1990 to 2020. Further, the Welgevonden Game Reserve experienced a greater loss in natural vegetation and habitat than the Grootwater Nature Reserve from 1990 to 2020. However, these changes were shown to not be significant.

Average monthly temperatures, particularly average monthly maximum temperatures, increased from 1990 to 2020 in the Southern Waterberg region. Average monthly and total annual rainfall also decreased from 1990 to 2020 in the Southern Waterberg region. As changes in land use within the study areas were not substantial or significant ($p>0.05$) and there is evidence of the loss in dense bush as well as a change in natural vegetation type in areas that are not adjacent to human activities, one could deduce that the climatic changes in the area are the primary cause of the natural vegetation and habitat loss in the study sites. Further, in the Grootwater Nature Reserve, habitat loss could be caused by increasing average monthly temperatures as the Chi-square analysis indicated that the impact was significant ($p<0.05$). The analysis also indicated that decreasing total annual rainfall may have an influence on habitat/vegetation loss as it showed that habitat loss in all the study areas is dependent on the decrease in total annual rainfall ($p<0.05$).

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South African Weather Service

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Appendix 1: Land cover maps

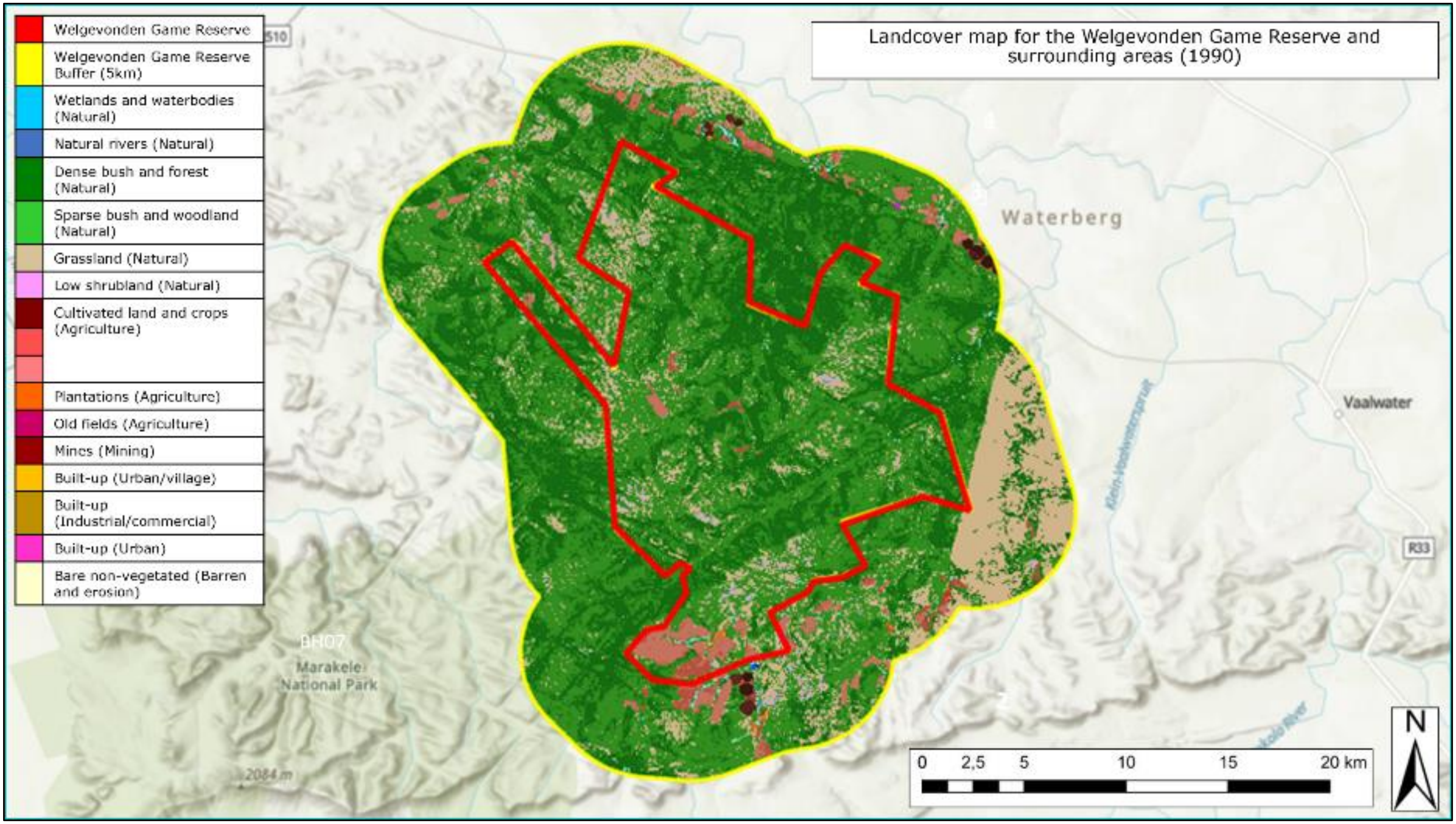

Figure 12: Landcover map of the Welgevonden Game Reserve and surrounding areas (1990)

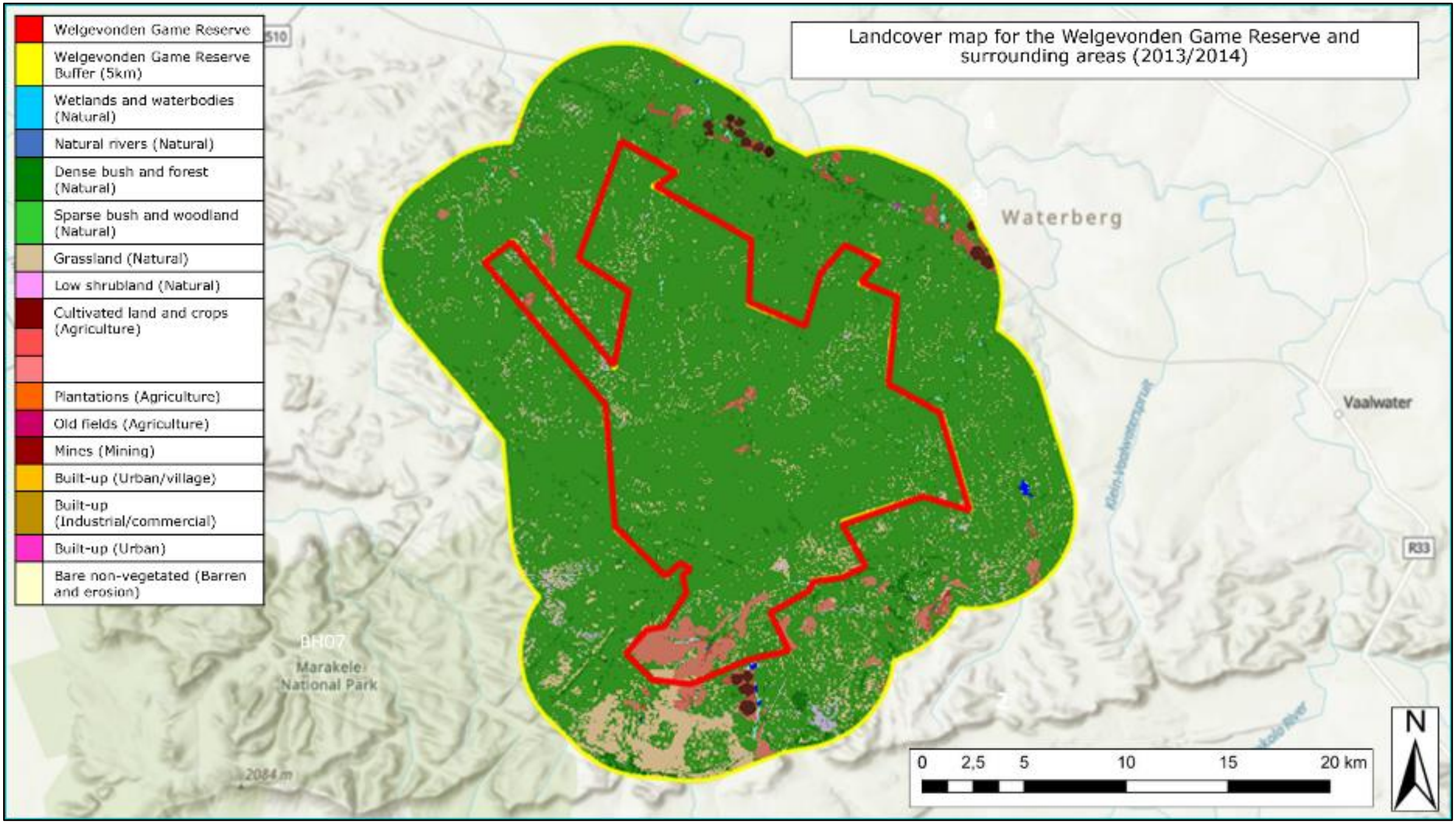

Figure 13: Landcover map of the Welgevonden Game Reserve and surrounding areas (2013/2014)

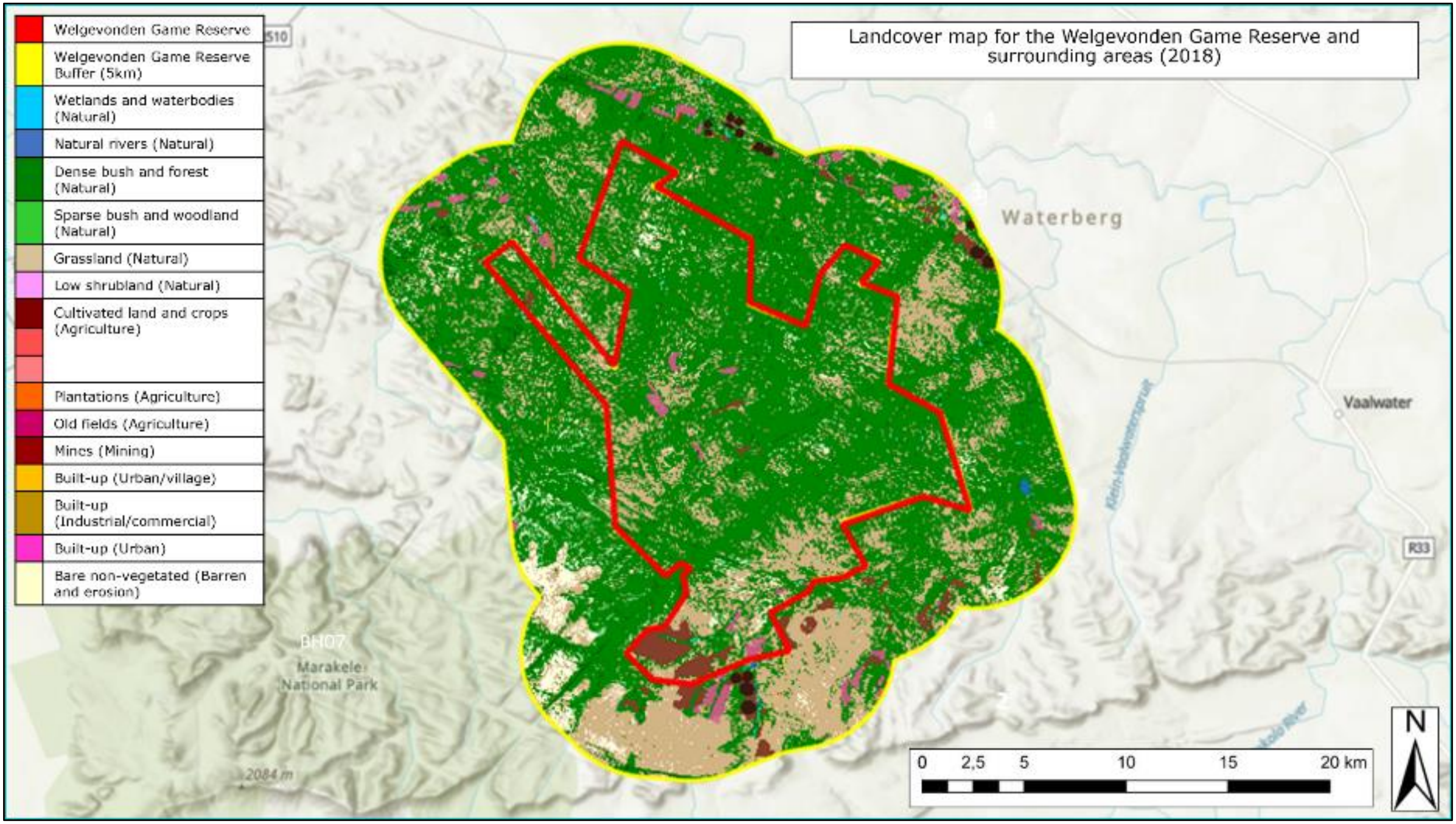

Figure 14: Landcover map of the Welgevonden Game Reserve and surrounding areas (2018)

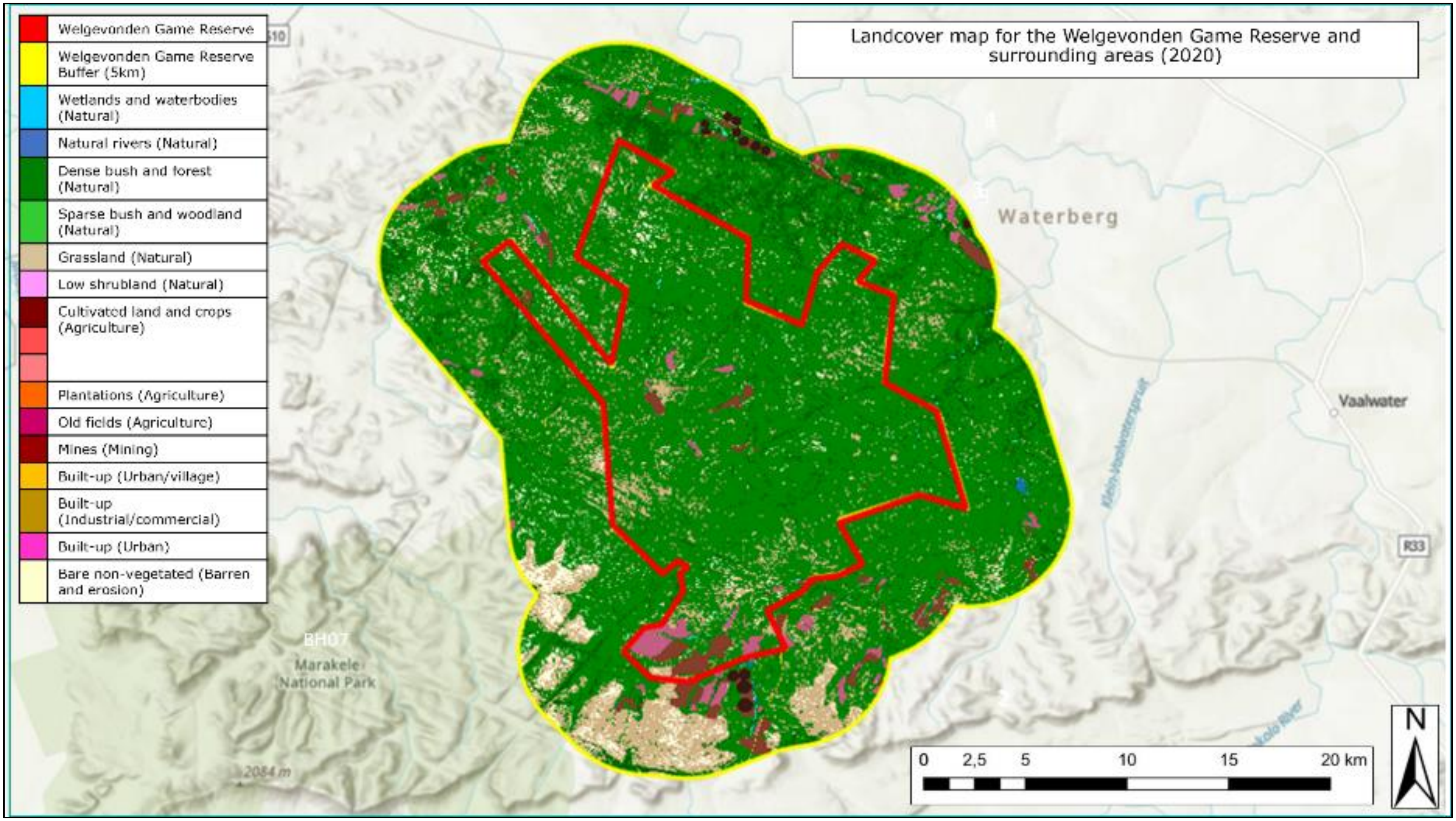

Figure 15: Landcover map of the Welgevonden Game Reserve and surrounding areas (2020)

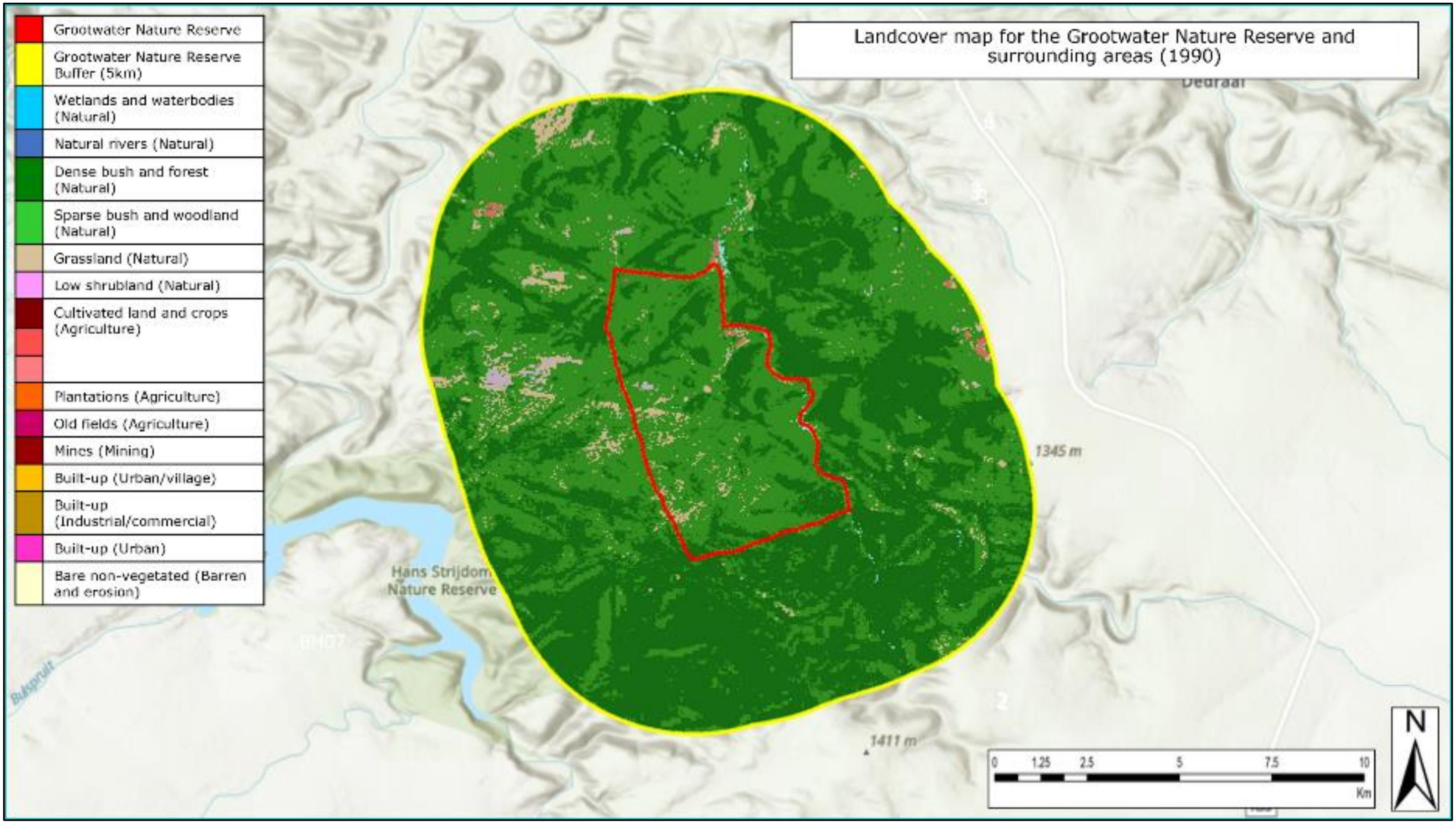

Figure 16: Landcover map of the Grootwater Nature Reserve and surrounding areas (1990)

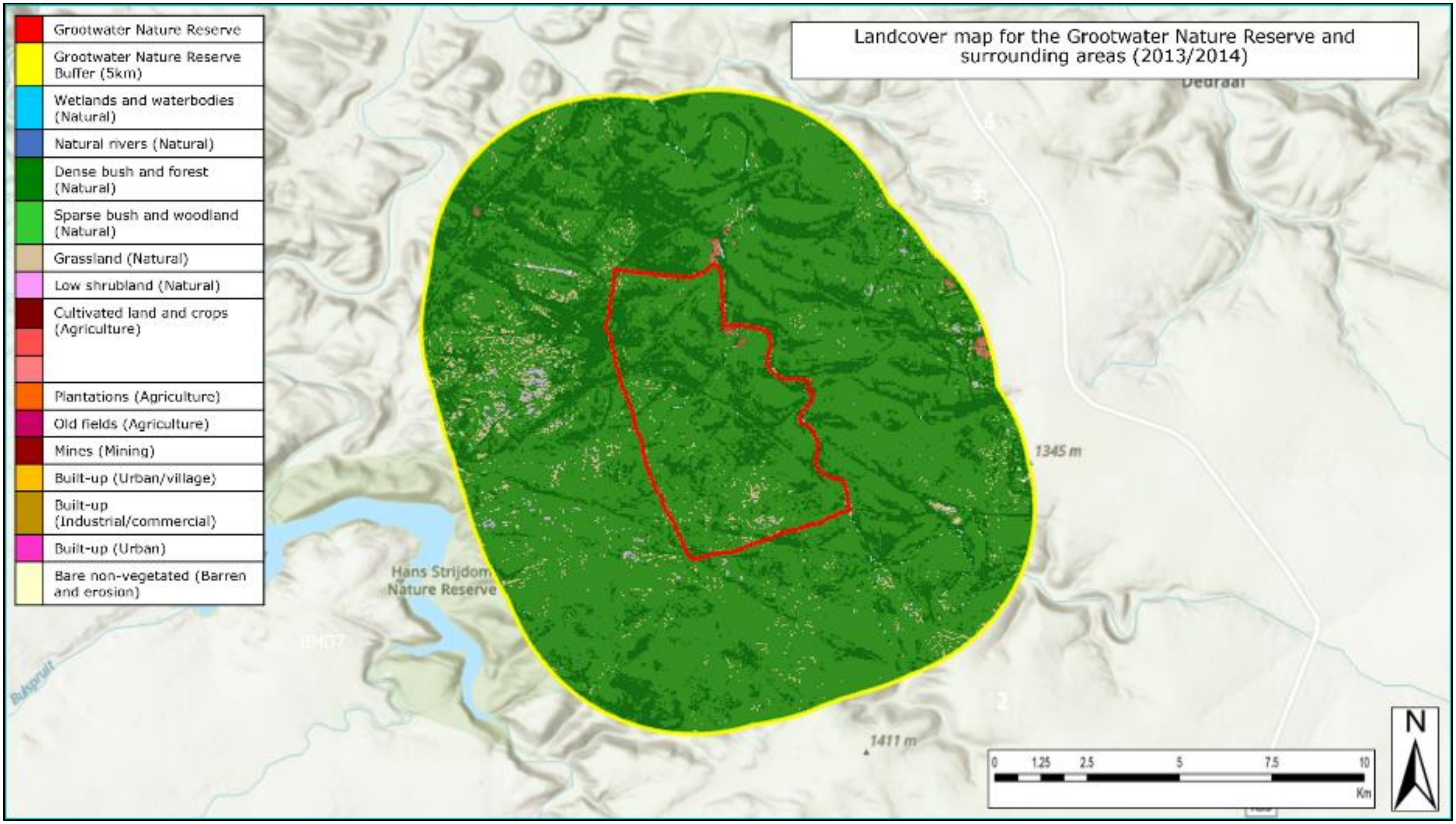

Figure 17: Landcover map of the Grootwater Nature Reserve and surrounding areas (2013/2014)

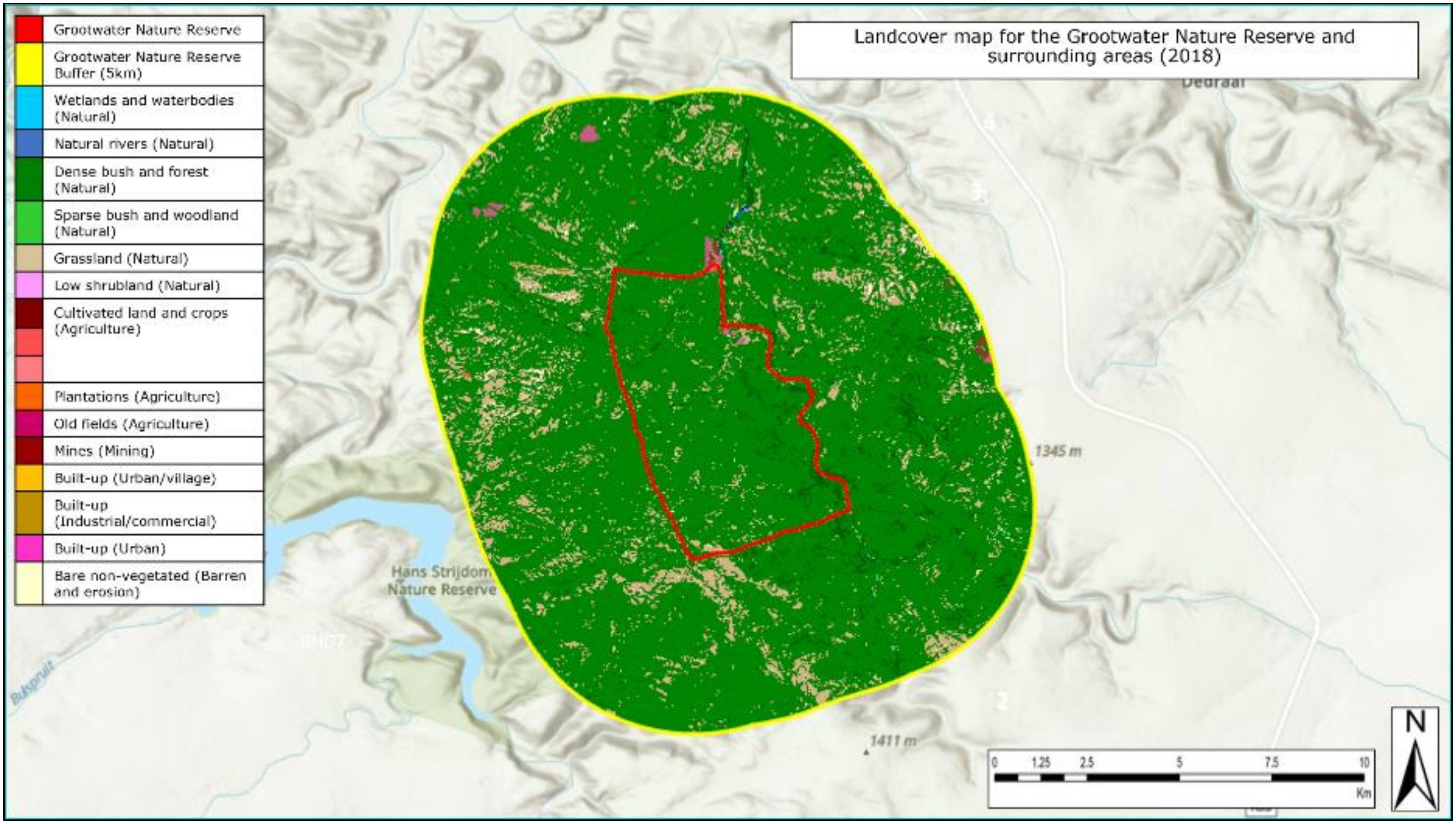

Figure 18: Landcover map of the Grootwater Nature Reserve and surrounding areas (2018)

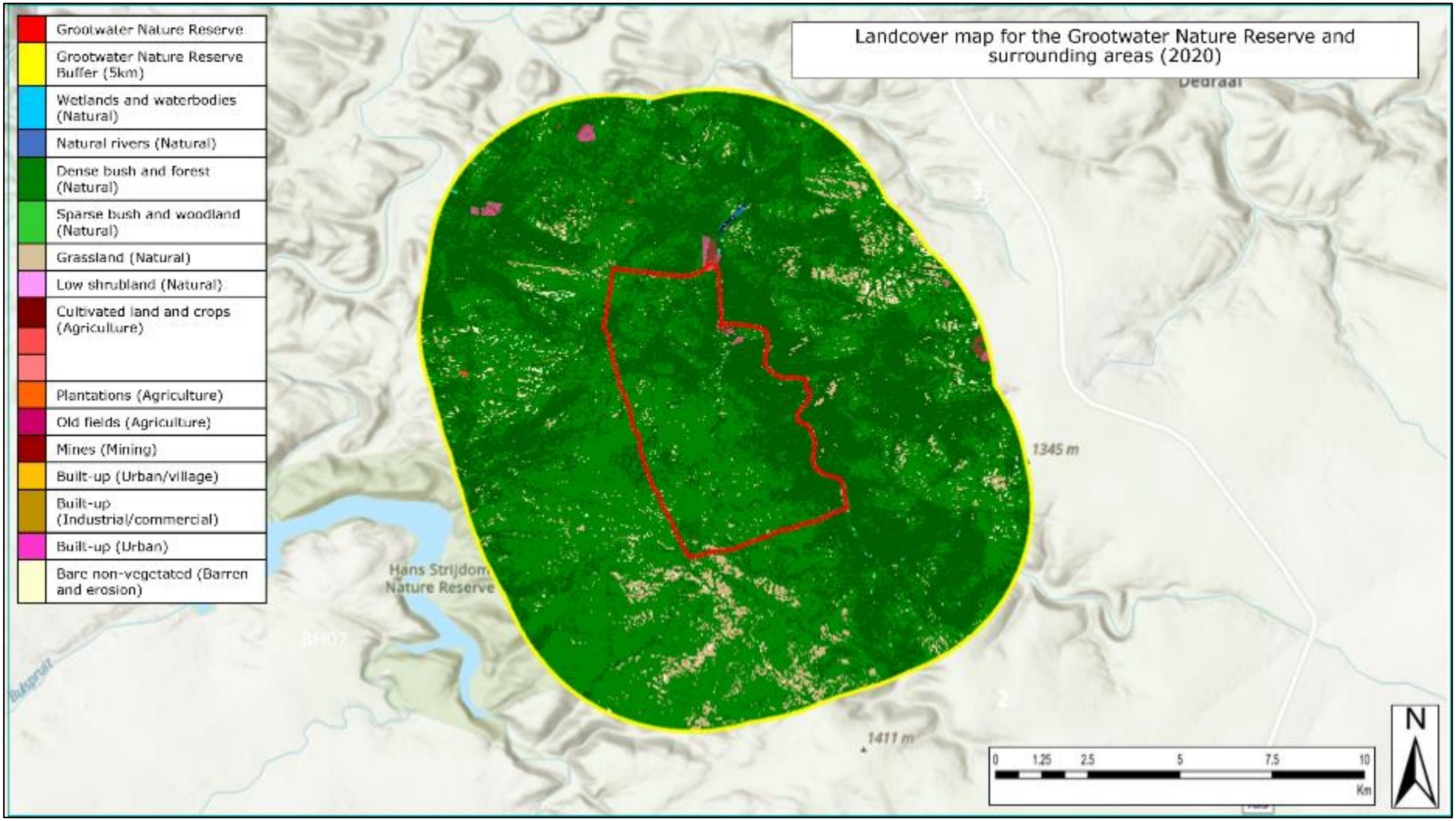

Figure 19: Landcover map of the Grootwater Nature Reserve and surrounding areas (2020)

Appendix 2: Land use/land cover changes

Table 6: Land use and landcover changes in the Grootwater Nature Reserve and surrounding areas (1990 – 2020)

Year	**Land use/Landcover**	**Grootwater Nature Reserve**	**Grootwater Nature Reserve Buffer (5km)**
1990	Natural habitat and vegetation	99.72%	99.75%
	Agricultural activities	0.26%	0.25%
	Urban/mining/industrial	0.02%	0%
	Barren land/erosion	0%	0%
2013/2014	Natural habitat and vegetation	99.71%	99.76%
	Agricultural activities	0.28%	0.22%
	Urban/mining/industrial	0.01%	0%
	Barren land/erosion	0%	0.02%
2018	Natural habitat and vegetation	99.49%	98.93%
	Agricultural activities	0.38%	0.47%
	Urban/mining/industrial	0.01%	0.07%
	Barren land/erosion	0.12%	0.53%
2020	Natural habitat and vegetation	99.44%	98.84%
	Agricultural activities	0.43%	0.52%
	Urban/mining/industrial	0%	0.05%
	Barren land/erosion	0.13%	0.59%

Table 7: Land use and landcover changes in the Welgevonden Game Reserve and surrounding areas (1990 – 2020)

Year	**Land use/Landcover**	**Welgevonden Game Reserve**	**Welgevonden Game Reserve Buffer (5km)**
1990	Natural habitat and vegetation	96.28%	95.90%
	Agricultural activities	3.71%	4.06%

	Urban/mining/industrial	0.01%	0.03%
	Barren land/erosion	0%	0.01%
2013/2014	Natural habitat and vegetation	96.10%	96.46%
	Agricultural activities	3.89%	3.49%
	Urban/mining/industrial	0.01%	0.03%
	Barren land/erosion	0.00%	0.02%
2018	Natural habitat and vegetation	94.59%	91.91%
	Agricultural activities	3.34%	4.43%
	Urban/mining/industrial	0.07%	0.19%
	Barren land/erosion	2%	3.47%
2020	Natural habitat and vegetation	94.64%	91.75%
	Agricultural activities	3.78%	4.89%
	Urban/mining/industrial	0.06%	0.18%
	Barren land/erosion	1.52%	3.18%

Appendix 3: Rainfall and temperature changes

Table 8: Average monthly minimum and maximum temperatures for the Southern Waterberg from 1990 to 2020

Year	**Average monthly maximum temperature (°C)**	**Average monthly minimum temperature (°C)**
1990	27.42	11.21
1991	26.92	11.43
1992	28.28	12.02
1993	27.13	11.66
1994	26.64	10.74
1995	27.15	12.01
1996	26.09	11.27
1997	26.18	11.10
1998	27.68	11.23

1999	27.42	11.26
2000	25.56	10.91
2001	27.13	11.45
2002	27.98	11.30
2003	28.66	11.87
2004	27.08	11.43
2005	29.62	12.25
2006	26.93	11.03
2007	28.33	10.68
2008	28.16	10.34
2009	28.40	11.80
2010	29.07	12.31
2011	29.25	12.55
2012	29.34	11.55
2013	29.75	12.01
2014	29.35	12.03
2015	32.24	14.34
2016	29.53	12.42
2017	28.93	11.40
2018	29.43	11.48
2019	30.07	11.32
2020	28.32	10.88

Table 9: Average monthly rainfall and total annual rainfall for the Southern Waterberg from 1990 to 2020

Year	Average monthly rainfall (mm)	Total annual rainfall (mm)
1990	37.08	445.00
1991	61.51	676.60
1992	38.01	456.10
1993	42.53	510.30
1994	45.18	542.20
1995	54.13	649.50
1996	66.95	803.40
1997	69.47	833.60
1998	67.80	813.60
1999	39.16	469.90
2000	76.19	914.30

2001	35.80	429.60
2002	38.44	461.30
2003	28.53	285.30
2004	52.56	630.70
2005	31.93	383.20
2006	52.19	626.30
2007	39.57	474.80
2008	54.15	649.80
2009	64.57	774.80
2010	52.00	624.00
2011	38.09	419.00
2012	36.11	325.00
2013	62.33	748.00
2014	52.27	627.20
2015	36.25	398.80
2016	57.33	688.00
2017	58.00	696.00
2018	47.80	573.60
2019	34.68	416.20
2020	22.71	159.00

Appendix 4: SANLC datasets methodology and metadata

SANLC 1990 (GeoTerraImage, 2016)

Methodology/data description

"The 1990 72 x class South African National Land-cover dataset produced by GEOTERRAIMAGE has been generated primarily from digital, multi-seasonal Landsat 5 multispectral imagery, acquired mainly between 1990 and 1991. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30x30m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. Each data cell contains a single code representing the dominant land-cover class (by area) within that 30x30m unit, as determined from analysis of the multi-date imagery acquired over that image frame. The original land-cover dataset was processed in UTM (north) / WGS84 map projection format based on the standard Landsat map projection format provided by the USGS2. The final product is available in UTM35(north) and (south), WGS84 map projections and Geographic Coordinates, WGS84."

Metadata

"Dataset title: 1990 GTI South African National Land-Cover(SA_Lcov_1990_GTI_utm35n_vs18.img)
Dataset reference date: April 1989 - October 1993
Dataset responsible party: Produced by GeoTerra Image (GTI) Pty Ltd, South Africa
Geographic location of the dataset. MBR:
West Bound Longitude: -717294.00 (Upper Left X)
East Bound Longitude: 1301256.00 (Lower Right X)
North Bound Longitude: -2239320.00 (Upper Left Y)
South Bound Longitude: -4046670.00 (Lower Right Y)
Projection coordinates: Based on Universal Transverse Mercator UTM 35 North, WGS84 (datum), meters.
Dataset language : "English" (eng)
Dataset character set: UTF8 (8-bit data)
Dataset topic category: 010 = Base Map earth coverage
Scale of the dataset: Land-cover mapped from 30 metre resolution Landsat satellite imagery, therefore recommended for ±1:75,000 - 1: 90,000 scale or coarse mapping & modelling applications.
Abstract describing the dataset: The 1990 South African National Land-cover dataset produced by GEOTERRAIMAGE as a commercial data product has been generated from digital, multi-seasonal Landsat 4/5 multispectral imagery, acquired between April 1989 and October 1993. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30x30m cells equivalent to the image resolution of the source Landsat 4/5 multi-spectral imagery. The dataset contains 72 x land-cover / use information classes, covering a wide range of natural and man-made landscape characteristics. The original

land-cover dataset was processed in UTM (north) / WGS84 map projection format based on the Landsat 4/5 standard map projection format as provided by the USGS.

Dataset format name: ERDAS Imagine *img raster formats

Dataset format version: version 01 (file # 22)

Additional extent information for the dataset: (vertical and temporal)

Vertical Extent: Minimum Value: n/a, Maximum Value: n/a, Unit Of Measure: n/a. Vertical Datum: n/a

Temporal Extent: Land-cover datasets generated in January 2015, based on April 1989 - October 1993 multi-seasonal Landsat 4 and 5 satellite imagery.

Reference system: Universal Transverse Mercator (UTM) 35 North

CRS:

Projection Used: Universal Transverse Mercator (UTM) 35 North

Spheroid used: WGS84

Datum used: WGS 84

Ellipsoid parameters**:** Ellipsoid semimajor axis, axis units, denominator of flattening ratio

Projection Parameters: UTM Zone: 35 (North), Standard parallel

Longitude of central meridian: 27:00:00.00 East

Latitude of projection origin: 00:00:00.00 East

False easting: 500000.00 meters

False northing: 0.00 meters

Scale factor at equator: 0.999600

Projection units: meters

Lineage statement: Land-cover dataset generated in-house by GeoTerraImage (Pretoria) in August 2015, based on primarily multi-date Landsat 4/5 imagery acquired between April 1989 and October 1993.

On-line resource: n/a

Metadata file identifier: n/a

Metadata standard name: SANS I878

Metadata standard version: version 01

Metadata language: English (eng)

Metadata character set: 021 (UsAscii)

Metadata point of contact:

Name: Mark Thompson

Position Name: Director Remote Sensing
Organisation Name: GeoTerraImage Pty Ltd
Physical Address: Grain Building (1st Floor), Witherite Street, Nr 477, Die Wilgers, Pretoria, 0041, Gauteng, South Africa
Postal Address: Box 295, Persequor Park, Pretoria, 0020, Gauteng, South Africa

Metadata time stamp: 20 August 2015"

SANLC 2013/2014 (GeoTerraImage, 2015)

Methodology/data description

"The 2013-14 South African National Land-cover dataset produced by GEOTERRAIMAGE as a commercial data product has been generated from digital, multi-seasonal Landsat 8 multispectral imagery, acquired between April 2013 and March 2014. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30x30m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. The dataset contains 72 x landcover / use information classes, covering a wide range of natural and man-made landscape characteristics. Each data cell contains a single code representing the dominant land-cover class (by area) within that 30x30m unit, as determined from analysis of the multi-date imagery acquired over that image frame. The original land-cover dataset was processed in UTM (north) / WGS84 map projection format based on the Landsat 8 standard map projection format as provided by the USGS3. The final product is available in UTM35(north) and (south), WGS84 map projections and Geographic Coordinates, WGS84."

Metadata

"**Dataset title**: 2013-14 GTI SA National Land-Cover (SA_Lcov_2013-14_GTI_utm35n_vs22b.img)

Dataset reference date: April 2013 - March 2014

Dataset responsible party: Produced by GeoTerra Image (GTI) Pty Ltd, South Africa

Geographic location of the dataset. MBR:

West Bound Longitude: -717294.00 (Upper Left X)

East Bound Longitude: 1301256.00 (Lower Right X)

North Bound Longitude: -2239230.00 (Upper Left Y)

South Bound Longitude: -4046670.00 (Lower Right Y)

Projection coordinates: Based on Universal Transverse Mercator UTM 35 North, WGS84 (datum), meters.

Dataset language: "English" (eng)

Dataset character set: UTF8 (8-bit data)

Dataset topic category: 010 = Base Map earth coverage

Scale of the dataset: Land-cover mapped from 30 metre resolution Landsat satellite imagery, therefore recommended for ±1:75,000 - 1: 90,000 scale or coarse mapping & modelling applications.

Abstract describing the dataset: The 2013-14 South African National Land-cover dataset produced by GEOTERRAIMAGE as a commercial data product has been generated from digital, multi-seasonal Landsat 8 multispectral imagery, acquired between April 2013 and March 2014. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30x30m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. The dataset contains 72 x land-cover / use information classes, covering a wide range of natural and man-made landscape characteristics. The original land-cover dataset was processed in UTM (north) / WGS84 map projection format based on the Landsat 8 standard map projection format as provided by the USGS. The data remains the property of GEOTERRAIMAGE, and is protected by copyright laws. All Intellectual Property rights pertaining to the data remain with GEOTERRAIMAGE at all times.

Dataset format name: ERDAS Imagine *img raster formats

Dataset format version: version 01 (file # 22)

Additional extent information for the dataset: (vertical and temporal)

Vertical Extent:

Minimum Value: n/a

Maximum Value: n/a

Unit Of Measure: n/a

Vertical Datum: n/a

Temporal Extent: Land-cover datasets generated in January 2015, based on April 2013 - March 2014 multi-seasonal Landsat 8 and 5 satellite imagery.

Reference system: Universal Transverse Mercator (UTM) 35 North

CRS:

Projection Used: Universal Transverse Mercator (UTM) 36 North

Spheroid used: WGS84

Datum used: WGS 84

Ellipsoid parameters: Ellipsoid semimajor axis, axis units, denominator of flattening ratio

Projection Parameters:

UTM Zone: 35 (North)

Standard parallel

Longitude of central meridian: 27:00:00.00 East

Latitude of projection origin: 00:00:00.00 East

False easting: 500000.00 meters

False northing: 0.00 meters

Scale factor at equator: 0.999600

Projection units: meters

Lineage statement: Land-cover dataset generated in-house by GeoTerraImage (Pretoria) in January 2015, based on primarily multi-date Landsat 8 imagery acquired between April 2013 and March 2014.

On-line resource: n/a

Metadata file identifier: n/a

Metadata standard name: SANS I878

Metadata standard version: version 01

Metadata language: English (eng)

Metadata character set: 021 (UsAscii)

Metadata point of contact:

Name: Mark Thompson

Position Name: Director Remote Sensing

Organisation Name: GeoTerraImage Pty Ltd

Physical Address: Grain Building (1st Floor), Witherite Street, Nr 477, Die Wilgers, Pretoria, 0041, Gauteng, South Africa

Postal Address : Box 295, Persequor Park, Pretoria, 0020, Gauteng, South Africa

Metadata time stamp: 04 February 2015"

SANLC 2018 (GeoTerraImage, 2019 and DFFE, 2019)

Methodology/data description

"The generation of automated land-cover data in the new, Sentinel 2 based procedure involves two separate, but sequential processing steps. Firstly fully automated image modelling procedures are used to generate what is referred to as the "spectrally-defined" *base land-cover* characteristics. These 'base' land-cover characteristics are the primary 'building blocks' which are used to describe the entire landscape in terms of primary cover characteristics such as woody vegetation, grass, bare or water dominated surfaces. No attempt is made at this stage to define additional detail such as whether the tree cover is a natural forest, or a managed forest plantation.

The conversion of these primary 'base' land-cover classes into more detailed sub-classes, such as natural versus man-planted forest, occurs during the second step. In the second step, ancillary spatial datasets, referred to as 'geographical masks', are used to convert the base land-cover classes into more detailed sub-classes. The geographical masks define specific, pre-determined areas-of interest within the South African landscape, within which the primary, spectrally-defined base classes are de-constructed into more specific land-cover and/or land-use sub-classes. In each case, a specific set of modification rules are used to either amalgamate, sub-divide or re-allocate the primary, base-level class(es) to the required sub-class detail. The primary objective and reason behind the use of these geographical masks is to facilitate the delineation of sub-classes that cannot be achieved using spectral data alone, since many unrelated sub-classes can often share similar spectral characteristics, e.g. river water versus water-in-pans, or non-vegetated mine dumps and some natural rock exposures, or coastal dunes and sand-roads etc.

The automated land-cover mapping models and associated procedures used in the production of the SANLC 2018 dataset utilise both cloud-based image archives and cloud-based geo-data computing capabilities; although the final compilation and merging of the different land-cover and land-use information components (i.e. water, mining extent, forest plantations etc), has been completed in a conventional desk-top environment, using automated modelling capabilities within proprietary, i.e. commercial mapping software.

This approach and design has been used in order that the entire workflow can eventually be migrated to cloud-based technologies, and become a fully automated process that will allow the SA Government to generate comparable South African National Land-Cover datasets in the future. This process (termed "CALC" for Computer Automated Land-Cover"), is currently being implemented in parallel with the production of the SANLC 2018 dataset. It is planned that CALC will generate a new, updated SANLC 2020 dataset in early 2021.

The models and algorithms used to generate the SANLC 2018 dataset are based on those used in the production of the SANLC 1990 and SANLC 2013-14 datasets, but have been modified and adapted to suit the enhanced spatial, spectral and temporal characteristics of 20m resolution Sentinel 2 imagery, as opposed to the 30m resolution Landsat imagery previously used. The overall concept and approach to land-cover and land-use modelling is however essentially the same as that used in the production of the previous SANLC 1990 and SANLC 2013/14 datasets."

Metadata

"Dataset title: SA_NLC_2018_GEO.img national land-cover (final release)

Dataset reference date: 2018

Dataset responsible party: Produced by GeoTerra Image (GTI) Pty Ltd (Mark Thompson, www.geoterraimage.com) for DEA, South Africa.

Geographic location of the dataset. MBR

West Bound Longitude: 16.3503263177878220(Upper Left X)

East Bound Longitude: 33.0456955362059330 (Lower Right X)

North Bound Longitude: -22.1241579749376310 (Upper Left Y)

South Bound Longitude: -34.9246117844703290 (Lower Right Y)

Projection coordinates: Based on Latitude & Longitude (Geographic), based on WGS84 Spheroid and Datum. Raster cell size is 0.00017966 degrees representing 20 x 20 meters.

Dataset language: "English" (eng)

Dataset character set: UTF8 (8-bit data)

Dataset topic category: 010 = Base Map earth coverage

Scale of the dataset: Land-cover mapped from 20m resolution Sentinel 2 imagery therefore recommended for ± 1:60,000 scale or coarse mapping & modelling applications.

Abstract describing the dataset: Raster-based land-cover dataset representing the full South African landscape for the full year 2018. Derived from 20m Sentinel

2 imagery acquired between 01 January 2018 and 31 December 2018. Land-cover information classes based on new Gazetted landcover standards and legend content used in 2013-14 national land-cover data. All land-cover and land-use classes generated using automated modelling procedures for full operational repeatability and change detection.

Dataset format name: ERDAS Imagine *img raster formats

Dataset format version: final release (no version number in name format).

Additional extent information for the dataset: (vertical and temporal)

Vertical Extent:

Minimum Value: n/a

Maximum Value: n/a

Unit Of Measure: n/a

Vertical Datum: n/a

Temporal Extent: Original dataset generated in March 2019, based on multiple Sentinel 2 imagery representing all seasonal conditions between January and December 2018.

Reference system: Geographic Coordinates (Lat / Lon), WGS84

CRS:

Projection Used: Geographic Coordinates (Lat / Lon)

Spheroid used: WGS84

Datum used: WGS 84

Ellipsoid parameters:

Ellipsoid semimajor axis: n/a, axis units: n/a, denominator of flattening ratio: n/a

Projection Parameters:

Standard parallel: n/a

Longitude of central meridian: East n/a

Latitude of projection origin: East n/a

False easting: meters n/a

False northing: meters n/a

Scale factor at equator: n/a

Projection units: degrees (0.00017966 degree raster, representing 20 x 20 meter units)

Lineage statement: Original land-cover dataset generated in-house by GeoTerraImage (Pretoria) in March 2019, based on full year 2018 coverage of 20m Sentinel 2 imagery. All original imagery sourced from Google Earth Engine cloud-archives, and used as-is in terms of the supplied Web Mercator projection format. An Albers Equal Area (20m resolution) projected version of the same has been generated from the original Geographic Coordinate format land-cover dataset.

On-line resource: n/a

Metadata file identifier: n/a

Metadata standard name: SANS I878

Metadata standard version: version 01

Metadata language: English (eng)

Metadata character set: 021 (UsAscii)

Metadata point of contact:

Name: Dr Zakariyyaa Oumar

Position Name: Chief GIS Professional

Organisation Name: Department of Environment, Forestry & Fishery

Physical Address: Environment House, Steve Biko, Nr 473, Arcadia, Pretoria, 0083, Gauteng, South Africa

Postal Address: Private Bag X447, Pretoria, Pretoria, 0001, Gauteng, South Africa

Metadata time stamp: 25 September 2019.”

SANLC 2020 (DFFE, 2021)

Methodology/data description

“The 20 m resolution, raster format South African National Land-Cover 2020 (SANLC 2020) dataset has been generated from automated mapping models (as opposed to conventional image classification procedures), using multi-seasonal 20 m resolution Sentinel 2 satellite imagery. The imagery used represents the full temporal range of available imagery acquired by Sentinel 2 during the period 01 January 2020 to 31 December 2020. The overall map accuracy for the SANLC 2020 dataset, calculated from 6835 reference points, is 85.47%.”

Metadata

“Dataset title: SA NLC 2020 GEO

Dataset reference date: 2020

Dataset responsible party: Produced with CALC (Computer Automated Land-Cover) System in Department of Environment, Forestry and Fisheries (DEFF), South Africa. Dr Zakariyyaa Oumar, +2712 399 9293, zoumar@environment.gov.za

Geographic location of the dataset. MBR

West Bound Longitude: 16.3503263177878220 (Upper Left X)

East Bound Longitude: 33.0456955362059330 (Lower Right X)

North Bound Longitude: -22.1241579749376310 (Upper Left Y)

South Bound Longitude: -34.9246117844703290 (Lower Right Y)

Projection coordinates: In degrees Latitude & Longitude (Geographic), based on WGS84 Spheroid and WGS84 Datum. Raster cell size is 0.00017966 degrees representing 20 × 20 meters.

Dataset language: English" (eng)

Dataset character set: UTF8 (8-bit data)

Dataset topic category: 010 = Base Map earth coverage

Scale of the dataset: Land-cover mapped from 20 m resolution Sentinel 2 imagery therefore recommended for ± 1:60,000 scale or coarse mapping & modelling applications.

Abstract describing the dataset: Raster-based land-cover dataset representing the full South African landscape for the full year 2020. Derived from 20 m Sentinel 2 imagery acquired between 01 January 2020 and 31 December 2020. Land-cover information classes based on new Gazetted land-cover standards and legend content used in 2013/14 national land-cover data. All land-cover and land-use classes generated using automated modelling procedures for full operational repeatability and change detection. The land-cover was produced with CALC (Computer Automated Land-Cover) system by DEFF.

Dataset format name: GeoTIFF (.tif) raster format

Dataset format version: version v1.0.4

Additional extent information for the dataset: (vertical and temporal)

Vertical Extent:

Minimum Value: n/a

Maximum Value: n/a

Unit Of Measure: n/a

Vertical Datum: n/a

Temporal Extent: 1 January to 31 December 2020.

Reference system:

Coordinate Reference System:

Projection Used: Geographic WGS84 Lat/Lon

Spheroid used: WGS84

Datum used: WGS 84

Ellipsoid parameters: Ellipsoid semimajor axis: 6378137.0 m, axis units: ‘degree’ 0.0174532925199432**8**, denominator of flattening ratio: 298.257223563

Projection Parameters:

EPSG: 4326

GEODCRS: WGS 84

DATUM: World Geodetic System 1984",

ELLIPSOID: WGS 84,6378137,298.257223563,

LENGTHUNIT: metre,1.0

CS: ellipsoidal,2

AXIS: “latitude”,north,ORDER[1]

AXIS: "longitude",east,ORDER[2]

ANGLEUNIT: "degree",0.01745329252

ID: "EPSG",4326]

1st Standard parallel: n/a

2nd Standard parallel: n/a

Longitude of central meridian: Greenwich 0◦ east

False easting: n/a

False northing: n/a

Scale factor at equator: n/a

Projection units: degrees

Lineage statement: Land-cover dataset for 2020 generated in-house by the Department of Environment, Forestry and Fisheries (DEFF) with the Computer Automated Land Cover system (CALC), based on full year 2020 coverage of 20 m Sentinel 2 imagery. All original imagery sourced and automatically processed on the Amazon Web Services (AWS) cloud platform. The land-cover classification consists of 73 classes at 20 m resolution and the product was exported as a Geographic Lat/Lon in a GeoTIFF format.

On-line resource: n/a

Metadata file identifier: n/a

Metadata standard name: SANS I878

Metadata standard version: version 01

Metadata language: English (eng)

Metadata character set: 021 (UsAscii)

Metadata point of contact:

Name: Dr Zakariyyaa Oumar

Position Name: Chief GIS Professional

Organisation Name: Department of Environment, Forestry & Fishery

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Physical Address: Environment House, Steve Biko Street, Nr 473, Arcadia, Pretoria, 0083, Gauteng, South Africa

Postal Address: Box X447, Arcadia, Pretoria, 0001, Gauteng. South Africa

Metadata time stamp: 14-03-2021.”