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Anthropogenic changes in the Ngorongoro Conservation Area.

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Abstract

Since the 1950s the Ngorongoro Conservation Area (NCA) has experienced several changes in land use policy. In the early 1990s the NCA's policy was changed for the last time and the area became considered an experimental multiple land use system. This has resulted in conflict between the government and conservationist groups, who argued that allowing people to reside within the protected area will cause damage to the functionality of the ecosystem. By mapping the land cover change within the NCA between 2000 and 2019 this report was able to determine the extent of degradation taking place.

The results of this paper show that agriculture and settlement now cover 2% of the area within the NCA with settlements being the dominant form of expansion. Whilst this development has taken place over the last 19 years, this paper also shows that population density in the districts surrounding the parks is increasing and may lead to population pressure and further degradation in the future. Through examining land cover changes surrounding the closest village to the NCA it was also possible to look for encroachment into the NCA. The results show that no encroachment is currently taking place but may do so as the town continues to expand.

Key Words: *land cover change*, *protected areas*, *encroachment*, *habitat fragmentation*

Contents

1.0 Introduction

The Ngorongoro Conservation Area (NCA) is a protected area that is part of the Greater Serengeti Ecosystem (GSE). The GSE is regarded as a UNESCO world heritage site as it hosts the world's largest unaltered ungulate migrations as well as the highest concentration of predators in the world (UNESCO 2019). It is made up of several protected areas, the largest two being Serengeti National Park and the NCA. During the early 1990s regulations on human habitation and cultivation within the NCA were lifted and the area became subjected to anthropogenic land use changes. The NCA has since been described as a long term experimental multiple use land system which aims towards meeting the needs of wildlife conservation within the park and economic development of the district (Niyobe 2010). Present land use within the NCA includes: the conservation of flora, fauna and natural resources; agricultural practices; livestock herding; tourism and research (Boone et al. 2006). The paradigm of combining human activities with conservation is thought by many to harm wildlife and conservation efforts (Bhola et al. 2012). It can be argued that if a balance is not maintained between people and the natural environment the structural integrity of the ecosystem may diminish and that the NCA will no longer be considered a protected area.

Growing human populations, increased demand for food and food scarcity are some prominent scenarios being faced in East Africa which have caused tremendous pressure to convert fertile land to agricultural land (Estes et al. 2012). The NCA in Tanzania first faced rapid population growth and the intensification of agriculture in the 1970s. The encroachment of people into protected areas, specifically regarding intensification of agricultural practices is well documented and often leads to a decline in the functionality and integrity of the ecosystem (Homewood et al. 2001; DeFries et al. 2007). Poor regulations and management within the NCA are cause for concern as the NCA has a variety of pull factors which have caused the area's population to rapidly increase (Kideghesho et al. 2013). Opportunities for jobs through tourism and an abundance of land have been the main attracting factors which have promoted immigration to the NCA. The issues associated with the encroachment of people into protected areas are well known and have had many negative results. These negative impacts often include: habitat fragmentation, invasion of exotic species, hunting of bushmeat and species decline (Estes et al. 2012). The issue of whether the NCA should continue to allow cultivation and settlement practices and to what extent is a source of debate and contention between the government and conservationist organizations (DeFries et al. 2007).

Previous studies done in the NCA have been strongly focused on the land cover /land use change and the effects on the ecosystem. That being said, the majority of these studies have been done by examining the change between 1950-2000. During this specific period there were several changes in land use policy within the NCA, which could be one possible reason for the limited development found in the area (Boone et al. 2006; Estes et al. 2012). This thesis will investigate the land use/ land cover changes between 2000 and 2019 with an added focus on the link between land cover change and population pressure. Given that the land use policy has remained unchanged since the early 1990s it is likely that a different result can be found. Since this thesis does have a period of overlap with earlier studies, comparisons in the results from this report will be compared and discussed at a later stage. Investigating the extent of change within the NCA and how it may change in the future can help to resolve the ongoing dispute between government and conservationists.

1.2 Thesis Aim and Objectives

The NCA provides an ideal representation of a commonly occurring phenomenon of land use conflict in and around conservation areas in Africa and one that is furthermore encouraged by changes in government policy. In order to examine the detrimental impacts of population pressure on converting natural habitats to agriculture, the thesis will aim to map the spread of agriculture and investigate the impact of population pressure in the NCA area and on the ecosystems occurring in the park. This will be done by examining the extent of the change historically in vegetation cover which has been altered by human practices in the NCA and relating the landcover to population variations over the same period of time. Thus, the specific objectives of this thesis are to:

- Map land cover change within the NCA from 2000-2019 with a strong focus on the anthropogenic changes
- Quantify trends in population changes for the same period of time in the area surrounding the park.

- Assess the linkage between land cover changes as a result of population pressure

Continuing ahead, this paper will first give a short description of the study area at hand followed by a brief history of policy changes relating to the management of the NCA. The next section will then describe the methodology used which will give a breakdown of the steps taken to achieve the objectives of this report. A results section will follow continuing onwards to the discussion and conclusion reached.

1.3 Study Area

Figure 1 shows the position of the NCA, which is located in the Northern part of Tanzania and is encompassed by the GSE on 3 sides. It borders the Serengeti National Park to the North, Maswa Game Reserve to the West, Loliondo Game Controlled Area to the East and urban and agricultural areas along the Southern border. The area is approximately $8300km^2$ large and can be divided into four different ecological zones: the Crater highlands; Salei plains; Gol Mountains and Eyasi escarpment (Niyobe 2010). The highlands that make up the southern region of the NCA are comprised of 9, inactive volcanoes. These volcanoes have shaped the landscape and have formed three calderas which include: the Olmoti Crater, Empakaai Crater dominated by a lake, and Ngorongoro Crater, one of the biggest tourist attractions in the area. The elevation formed by the volcanoes reaches up to 3640 meters above sea level and gives way to a unique vegetation dynamic in the region by creating areas of higher precipitation along the highlands and areas of low precipitation caused by a resulting rain shadow (Boone and BurnSilver 2002). The western slopes of the mountains, therefore, annually receive considerably less rainfall, approximately between 400-600 mm of rainfall annually whilst the eastern slopes can receive up to 1200mm of rainfall annually (Oates and Rees 2013). This has resulted in dense forest and bushlands on the eastern slopes and shrub and grasslands dominating the western slopes of the mountains. The NCA has multiple campsites and tourist accommodation as well as two villages, Endul and Nainokanoka located at 3°13'11.4"S 35°16'04.0"E and 3°01'47.6"S 35°41'10.3"E respectively.

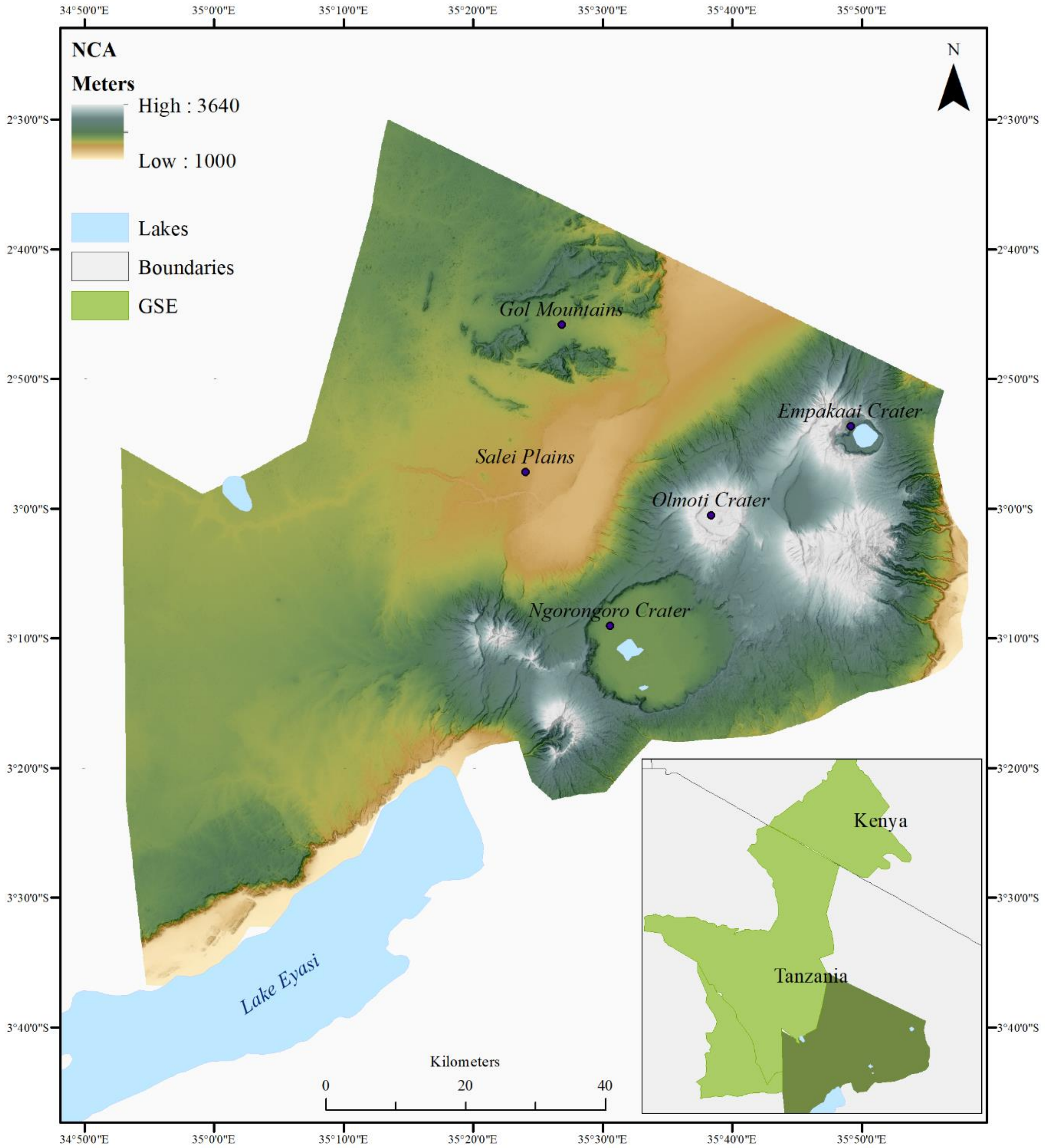

Figure 1- Study area of the NCA showing a digital elevation model of the area. The smaller inset map shows the NCA's position within the greater Serengeti ecosystem and a broader picture of where the ecosystem lies in in Tanzanian and Kenya.

1.4 Brief History

In the early 1940's the Serengeti National Park (SNP) established its borders under the Game Ordinance act of 1940, at that time the NCA was included within the SNP. This law prohibited the Maasai and other pastoralist groups to reside and use land within the park boundaries (Galvin et al. 2008). Being forced to move away from the area and abandon essential water resources the area offered, caused conflict between the Maasai and the Tanzanian government. This conflict resulted in the creation of the NCA boundaries in 1952 when the area became gazetted from the SNP, as a means of compromise to Maasai who were demanding compensation for the land and resources they lost (Galvin et al. 2008). The Maasai were allowed to continue their agro-pastoralist way until 1975 when concerns for the land degradation caused by the human activities became a great concern to the Tanzanian government which decided then to ban cultivation in the NCA (Boone et al. 2006). The ban lasted 16 years and was lifted in 1991 when the Maasai faced emergence food shortages. The current status of the NCA is that habitation and agricultural practices are allowed within the NCA, although there has been some discussion on reinstating the ban and relocating the NCA population to the Lilondo Game Controlled Area, North East of the NCA (McCabe 2003).

2.0 Methodology

This study relies primarily on remote sensing ad GIS techniques to meet the objectives set out in the beginning of the report. A combination of digitisation methods and supervised classification have been used to detect changes in landcover. Verification has been done for the two areas being examined through the use of Google Earth Pro to provide ground truth. Population data for the two decades has been analysed for regions and districts surrounding the NCA.

2.1 Data Acquisition

2.1.1. Satellite Data

The satellite data used to identify land cover change within the NCA was Landsat 7 Enhanced Thematic Mapper (ETM) and Sentinel2 for the years 2000 and 2019 respectively. This data was downloaded from United States Geological Survey website (USGS 2019). The Landsat 7 satellite images provided a resolution of 30 meters whilst the Sentinel2 data provided higher 10 meter resolution data. The tiles used for each year were restricted to the NCA peak rainy season which starts in January and ends in May and the tiles selected also prioritized cloud free conditions. This season was chosen as it gives the best result for examining the Normalized Difference Vegetation Index (NDVI) of the area. In the case of the Sentinel2 data some cloud cover could not be avoided but the tiles containing cloud cover had conditions of roughly 95% cloud free area. For the 2000 data a single tile was used but for the Sentinel2 data for 2019 multiple tiles were mosaicked together.

Ideally this thesis would have used population data from the same years as those being used to map land cover, however population data could only be found for years in which a census had been taken. Thus, the years 2002 and 2012 were the closest years to those being used for land cover.

2.1.2 Population data

The population data for the 2002 regions was given in a report by Madulu (2002), whilst the district level data was found in a report by National Bureau of Statistics Ministry of Planning (2006). The census data for 2012 along with the future projection for 2017 was downloaded from The World Bank (2019). The population data for the area surrounding the NCA was processed at both a regional and district level. Census data available for 2002 was only specific to each region and did not give district data. However, the 2012 census data was given at both regional and district level data, so the latter was chosen to display population density in the districts surrounding the NCA.

To create the population density map, the census data available for 2002, 2012 and the projections for 2017 were joined to a vector of the districts and regions around the NCA. The area of the regions and districts were then calculated so that the population density for each region could be calculated.

All maps produced in this report were standardized and used the: Datum: D Arc 1960 and the Projection: Transverse Mercator. Table 1 shows all GIS data used in this report and Table 2 shows all application methods used.

Table 1- GIS data and sources used to make maps within this report.

Data	Type	Source	Reference System
DEM	DEM	USGS (2006)	Arc 1960 UTM Zone 37S
Country Boundary	Vector	The Map Library (2019)	Arc 1960 UTM Zone 37S
Lakes	Vector	Diva-GIS (2019)	Arc 1960 UTM Zone 37S
GSE Boundary	Vector	UNEP-WCMC and IUCN (2019)	Arc 1960 UTM Zone 37S
Landsat 7	Satellite	NASA Landsat Program (2000)	Arc 1960 UTM Zone 37S
Sentinel2	Satellite	Copernicus Sentinel data (2019)	Arc 1960 UTM Zone 37S

Table 2- Applications used to process and make results in this report.

Applications	Source
Google Earth Pro	Google Earth 2019. Google Earth Pro. Version: 7.3.2.5776. Mountain view, CA: Google LLC
ArcGIS	ESRI 2018. ArcGIS Desktop: Release 10.6.1. Redlands, CA: Environmental Systems Research Institute
Microsoft Excel	Microsoft 2018. Microsoft Excel for Office. Desktop: 1904. Redmond, WA: Microsoft Corporation

2.2 Image Enhancement

For this study, two different image enhancement techniques were applied in ArcGIS. The first, is the NDVI which shows the difference between the near infrared and the chlorophyll reflectance divided by the sum of the two reflectance's. This can be seen in the equation below:

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

Where NDVI is the Normalized Difference Vegetation Index, NIR is the Near Infrared Bands and R is the Red Band. In the case of the 2000 Landsat 7 data the NIR is represented by band 5 and the red band is represented by band 4. In the 2019 Sentinel2 data the NIR band is given by band 8 and the red band is given by band 4.

The enhanced images were then used to create digitized land classes of the area. In the case of this thesis, where analysing anthropogenic change is key, digitization of the area was used as an alternative to a supervised classification method. As not many settlements could be found within the park, there was not enough training data to produce an accurate supervised classification of the area.

The second method used was the Tasselled cap function which supplies the greenness, wetness and brightness of the area. The greenness function of this tool was primarily used to help distinguish between the different densities of forest cover; densely vegetated areas appeared more vibrant with the greenness function applied. The wetness function was useful in distinguishing between the banks of waterbodies and the waterbodies themselves. The brightness function was not applied in any case to the classification process.

2.3 Classification

As no data on vegetation types could be collected in field this report used the classification method given by Niyobe (2010), who did a similar study in the area, measuring land cover change from 1975 to 2000. As the study performed by Niyobe (2010) was able to make field assessments of the main vegetation types the classification system provided was used in the current investigation. Table 3 gives a description of the appearance of vegetation from the NDVI of the Landsat7 images from 2000. The correlated land cover from Niyobe (2010) with the NDVI classes were the basis for digitizing the 2000 land cover map and later the 2019 land cover map.

Table 3- Description of land cover classes when the NDVI has been applied. This table has been taken from Niyobe (2010).

Land Cover/use Type	Identification Description of NDVI image	Code
Closed Forest	Deep red, speckled	11
Woodland Dense	Bright red, smooth	12
Woodland Open	Bright red, speckled	13
Shrubland	Pink smooth or speckled	14
Grassland	Pale blue-green	15
Intensive Cultivation	Bright Green, with distinctive boarders	16
Settlements	White speckles often with round shape	17
Water Bodies	Blue	18
Clouds	White	19
Riverine	Bright red, speckled	20
Bare soil	Pale green	21

Although the spatial resolution of the data for 2019 is much higher than that of 2000 the same classes were kept for the classification. Given that no data for a Digital Terrain Model (DTM) model could be found to help identify vegetation height, the vegetation classes remained broad.

To create the land cover map of the area outside of the NCA border, the supervised classification technique was used. This method was chosen over digitization in this case as the settlements and agriculture classes were larger in size and more easily detectable. To conduct the supervised classification, training data was produced for each class; these classes included: Settlements, Agriculture; Natural Vegetation; Bare Soil and Waterbodies. No less than 100 training samples were made for each of the classes, some classes such as the settlements and natural vegetation were given additional training samples due to their high spectral range. The number of samples between 2000 and 2019 also varied due to the coarse nature of the Landsat 7 data.

2.4 Verification

To verify the landcover classification of 2019, approximately 350 randomly stratified points were generated across the land cover map of 2019 with a minimum distance of 500 meters set between each point. Point's that fell on areas classified as clouds were then removed. The remaining points were then used as the ground truth points and verified using Google Earth Pro, which allowed for the most accurate way to verify the ground truth points given its very high resolution. Figure 2 shows how the validation points looked on the land cover map of 2019. A confusion matrix was then made to calculate the Producers Accuracy, Users Accuracy and Kappa Value. The Kappa Value also known as Cohen's Kappa is a statistical value that compares the observed accuracy to the expected accuracy. To calculate Cohen's Kappa the following equation was used:

$$K = \frac{P_o - P_e}{1 - P_e}$$

Where P_o is the observed agreement and P_e is the expected agreement.

The same method was used to verify land cover changes when looking at the development of anthropogenic changes close to the Western border of the NCA. No validation assessment for the year 2000 was done as no higher resolution data for the same time and area in 2000 could be found.

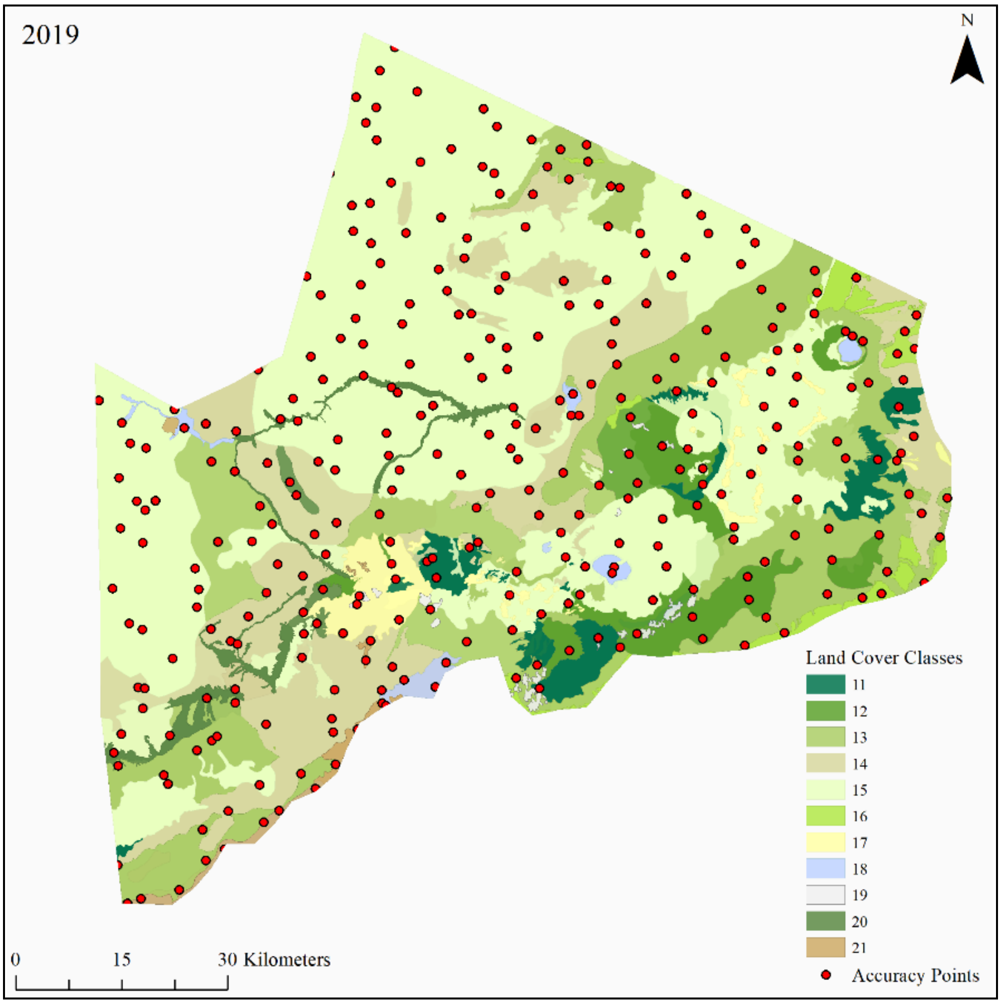

Figure 2- Randomly stratified points used for the accuracy assessment of land cover in 2019. 11-Closed Forest, 12-Dense Woodland, 13-Open Woodland, 14-Shrubland, 15-Grassland, 16-Agriculture, 17-Settlements, 18-Waterbodies,20-Riverine vegetation and 21-Bare soil.

3.0 Results

From the classifications made in Table 4 there is an overall accuracy of 81% given by the 0.75 Kappa value. Waterbodies had the lowest accuracy at 56% but was also the class with the lowest number of ground truth points. Dense woodlands had the highest accuracy at 94% but also had few ground truth points. Grasslands, which had the highest number of ground truth points received an accuracy of 84%. Of the 23 ground truth points that were misclassified in this class, 20 of them should have been classified as shrublands. Both open woodlands and shrublands have points which were wrongly classified as each other.

Table 4- Error matrix of a total of 325 classified points within the NCA. The classes given are codes representing the different land cover classes. 11-Closed Forest, 12-Dense Woodland, 13-Open Woodland, 14-Shrubland, 15-Grassland, 16-Agriculture, 17-Settlements, 18-

Waterbodies, 19-clouds, 20-Riverine vegetation and 21-Bare soil. The overall accuracy for the classifications is 81% which is given by the Kappa value.

Confusion Matrix												
Classified												
Ground Truth	11	12	13	14	15	16	17	18	20	21	**Total**	**U_Accuracy**
11	9	1	0	0	0	0	0	0	0	0	10	90%
12	0	15	0	0	1	0	0	0	0	0	16	94%
13	0	5	42	7	4	0	0	0	0	0	58	72%
14	0	1	6	39	4	0	0	0	0	0	50	78%
15	0	0	2	20	119	0	0	0	1	0	142	84%
16	0	0	0	0	0	8	2	0	0	0	10	80%
17	0	0	1	0	0	0	9	0	0	0	10	90%
18	0	0	2	2	0	0	0	5	0	0	9	56%
20	0	0	1	1	0	0	0	0	8	0	10	80%
21	0	0	0	0	0	0	0	1	0	9	10	90%
Total	9	22	54	69	128	8	11	6	9	9	325	
P_Accuracy	100%	68%	78%	57%	93%	100%	82%	83%	89%	100%	**Kappa: 0.75**	

3.1 Change in Land cover between 2000 and 2019 within the NCA

The result shown in Table 5 indicate that between 2000 and 2019 settlements had a 144km^2 net increase in area, which is an increase of 277% in land cover. This leads to it being the class with the largest relative but not the largest absolute change. This change came from grasslands which decreased by 748km^2 within the two decades. The second biggest change in net area was from open woodlands which gained an area of 600km^2. Excluding settlements, the net change from all other classes is less than 50km^2 in total. Given that settlement expanded by more than 200%, it is interesting to see that agricultural land experienced a decrease in area of 10%. Bare soil became the smallest class by area in 2019 after undergoing a shift in landcover causing a loss of approximately half of its original area in 2000.

Table 5- Landcover classes of the NCA from 2000-2019 including the net change in area and percentage for each land class.

Land Cover	Area Cover (km^2) 2000	Area Cover (km^2) 2019	Net Area Change (km^2) 2000-2019	Cover Change (%) 2000-2019
Closed Forest	268.2	257.6	-10.6	-4.0
Dense Woodland	395.8	418.9	23.0	5.8
Open Woodland	1083.2	1684.0	600.8	55.5
Shrubland	1408.6	1392.7	-16.0	-1.1
Grasslands	4630.6	3882.6	-748.0	-16.2
Agriculture	150.4	134.9	-15.5	-10.3
Settlements	52.3	196.9	144.6	276.7
Waterbodies	70.9	74.3	3.5	4.9
Riverine Vegetation	143.7	170.7	27.1	18.8
Bare Soil	97.4	52.2	-45.3	-46.5

Examining the tabulated intersection of the area in Table 6 shows that bare soil and water bodies are the two classes that have experienced the biggest conversion in land cover. Bare soil had a change of 36% to waterbodies and an approximately 20% change to open woodlands and shrublands. The change in land cover for water bodies was not as evenly distributed with 37% of its area being changing to waterbodies in 2019. Looking at the other end of the spectrum, closed forest, open woodland, settlements and riverine vegetation, these classes had less than 10% of their area in 2000 converting to other land use classes in 2019.

Table 6- The tabulated intersection for land cover was done between 2000 and 2019 to show where the changes occurred in each class. The numbers are given in percentage change for each class. The dashes have been used to indicate where no change has taken place. 11-Closed Forest, 12-Dense Woodland, 13-Open Woodland, 14-Shrubland, 15-Grassland, 16-Agriculture, 17-Settlements, 18-Waterbodies, 19-clouds, 20-Riverine vegetation and 21-Bare soil.

Tabulated Intersection										
	2000									
2019	11	12	13	14	15	16	17	18	20	21
11	92.3	1.4	-	0.2	-	-	2.3	-	-	-
12	3.3	84.2	0.5	0.2	1.5	-	-	-	-	-
13	-	0.7	94.6	13.1	9.0	14.8	2.8	-	7.9	19.4
14	1.2	-	3.2	68.6	7.7	8.1	1.0	-	-	19.9
15	1.6	11.6	0.1	5.5	80.7	-	2.4	4.7	-	10.4
16	-	-	0.3	1.7	-	72.0	-	-	-	-
17	0.6	-	0.1	8.9	0.4	4.7	91.4	-	-	-
18	-	-	-	-	0.1	-	-	58.4	-	30.7
19	1.0	2.0	1.0	0.2	0.1	0.4	-	-	-	-
20	-	-	0.2	1.4	0.4	-	-	-	92.1	-
21	-	-	-	0.2	0.1	-	-	36.9	-	19.6

In Figure 3, changes in land cover between 2000 and 2019 greater than 5% can be seen. As can be seen in Table 6, many of the changes in land cover have been relatively small, most of which were less than 1%. By displaying the larger changes in landcover it is easier to see where the most noteworthy changes have taken place. One of the most distinct areas is the change from 14, shrubland, to 17, settlements. This particular area was the largest anthropogenic change. In the nineteen year period it can be seen that the prominent change in vegetation was from grasslands to shrublands and open woodlands. Along the southern border some agriculture has been converted back to open woodland. Other noticeable changes include shifts from dense woodlands to grasslands and from grasslands to both shrubland and open woodland. In the north, along the start of the Gol Mountains, vegetation has changed from shrublands to open woodlands.

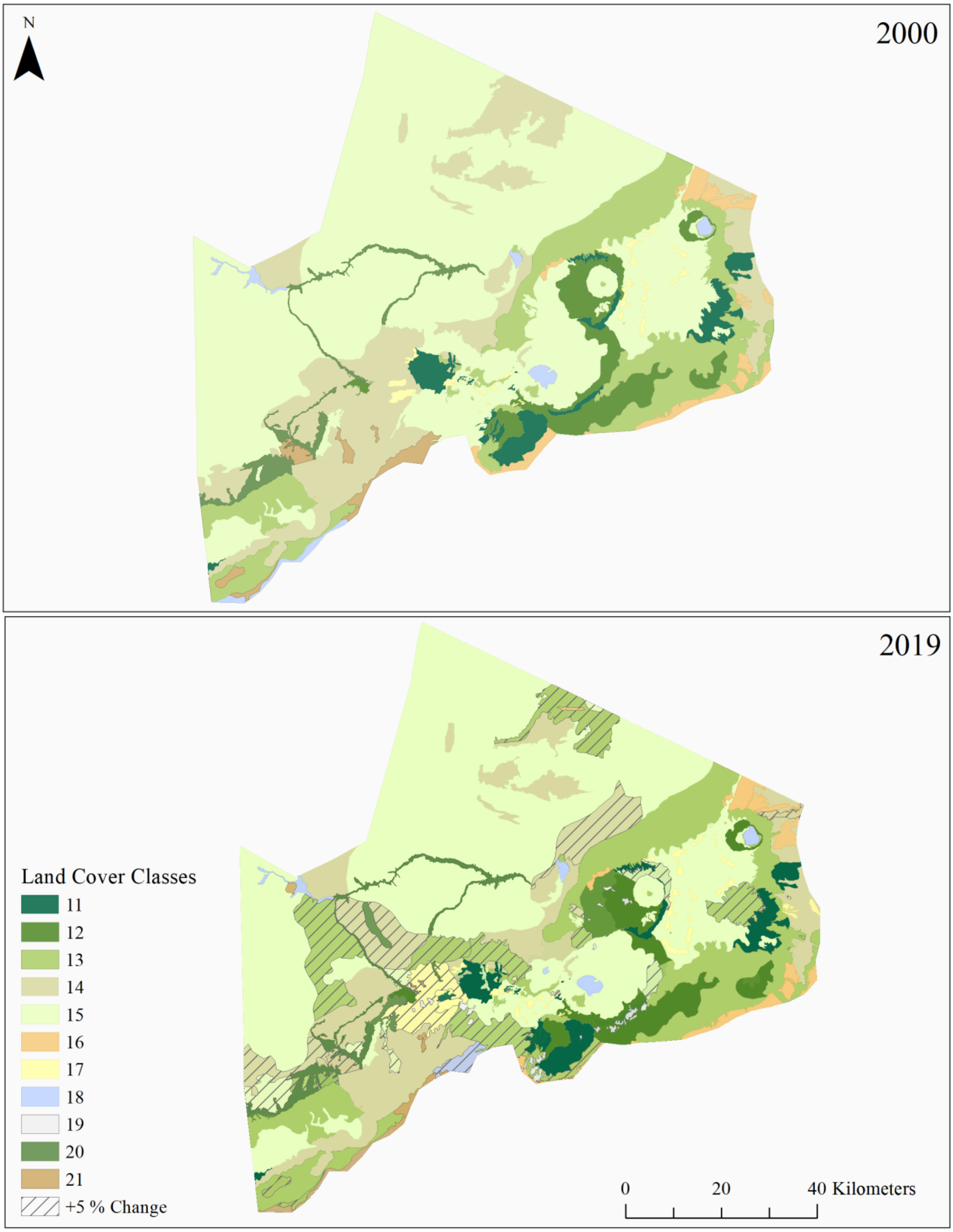

Figure 3- Area of land cover change between 2000 and 2019 showing changes greater than 5%. 11-Closed Forest, 12-Dense Woodland, 13-Open Woodland, 14-Shrubland, 15-Grassland, 16-Agriculture, 17-Settlements, 18-Waterbodies,20-Riverine vegetation and 21-Bare soil.

3.2 Population Data Analysis

The second objective of this report looks at population trends surrounding the NCA, this has been done at both region and district level to give a broader perspective of population density followed by a more in-depth review focusing on districts bordering the NCA. A map showing the regions bordering the NCA can be seen in Figure 4 ,Figure 5 illustrates the population density at the regional level whilst Figure 6 shows a district level, population density map for the years 2000, 2012 and 2017. The population density for the NCA and the regions surrounding it show that for all regions, excluding Mara, there has been an increase in the population density between the first census in 2002 and the second census in 2012. The region of Arusha has the most substantial increase of the regions between 2002 and 2012 with an increase of 10 people per km^2. Mara is the only region to have a decreasing population density between the two census', a decline of 24 people per km^2. The population projection from 2012 to 2017 shows an exponential trend for the growth of all regions which was calculated by The World Bank (2019).

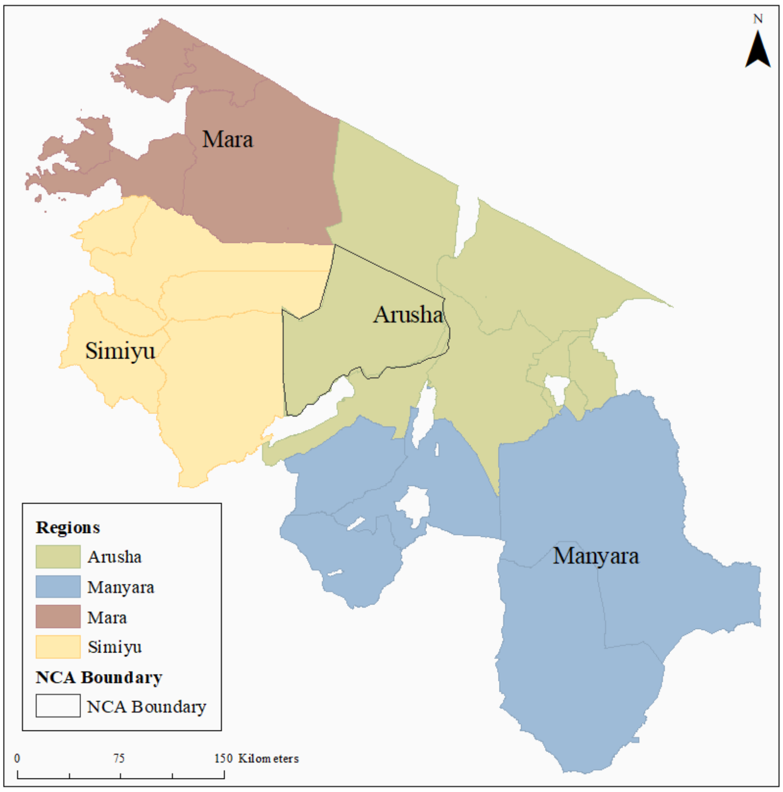

Figure 4- Regions surrounding the NCA, which in this figure is represented by the black boundary line.

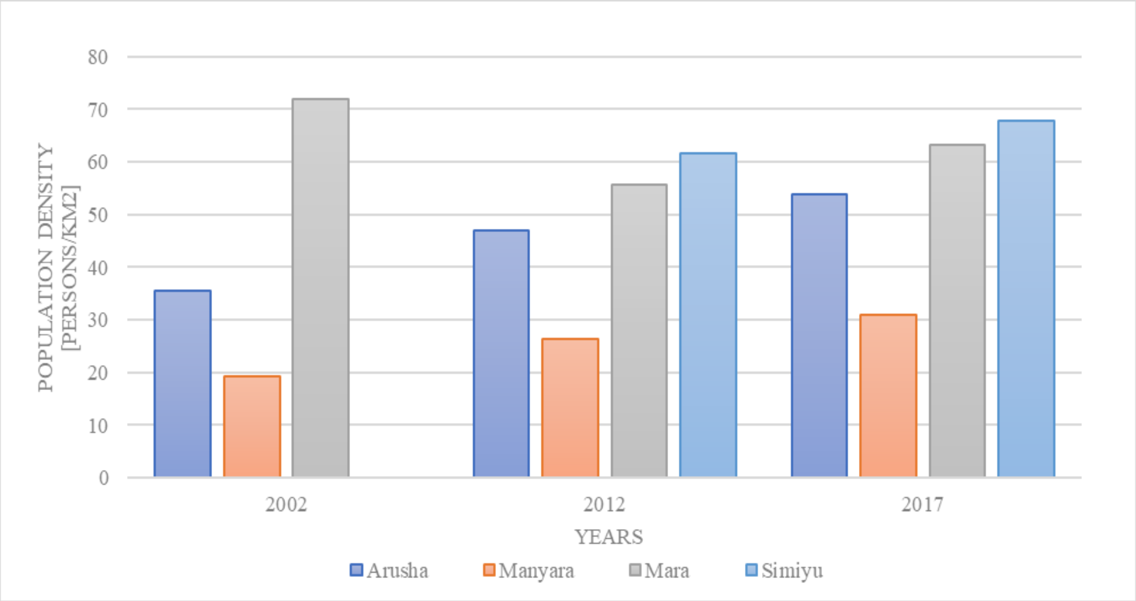

Figure 5- Population density of regions surrounding the NCA. Data from 2002 and 2012 shows data taken from census tracts whilst data for 2017 is a projection of population increase for each region based on the 2012 census. No data for the region of Simiyu could be found for the 2002 census.

For the 2002 census several districts were missing data, this did not impact the results as these regions were not directly bordering the NCA area. The districts with missing data can be seen in Figure 6. Mara was the most densely populated region with 50-70 people per square kilometre, followed by Arusha with 30-40 people per square kilometre and Manyara being the least densely populated with between 0-20 people per square kilometre. When looking at the population density for 2012 the NCA is sparely populated with only 1 to 23 people per square kilometre. The same pattern is present with the NCAs neighbouring districts to the North and North-East. Districts along the West and South of the NCA are slightly more populated with a density of between 24-72 people per km^2. The most densely populated districts in 2012 are; Arusha, Meru, Tarime, Musoma and Busega. These districts remain the most densely populated areas in 2017 with the addition of Roya. The projections for 2017 show that three districts along the NCA will increase in density to 73- 132 people per km^2, these districts are Karatu, Iltilima and Monduli.

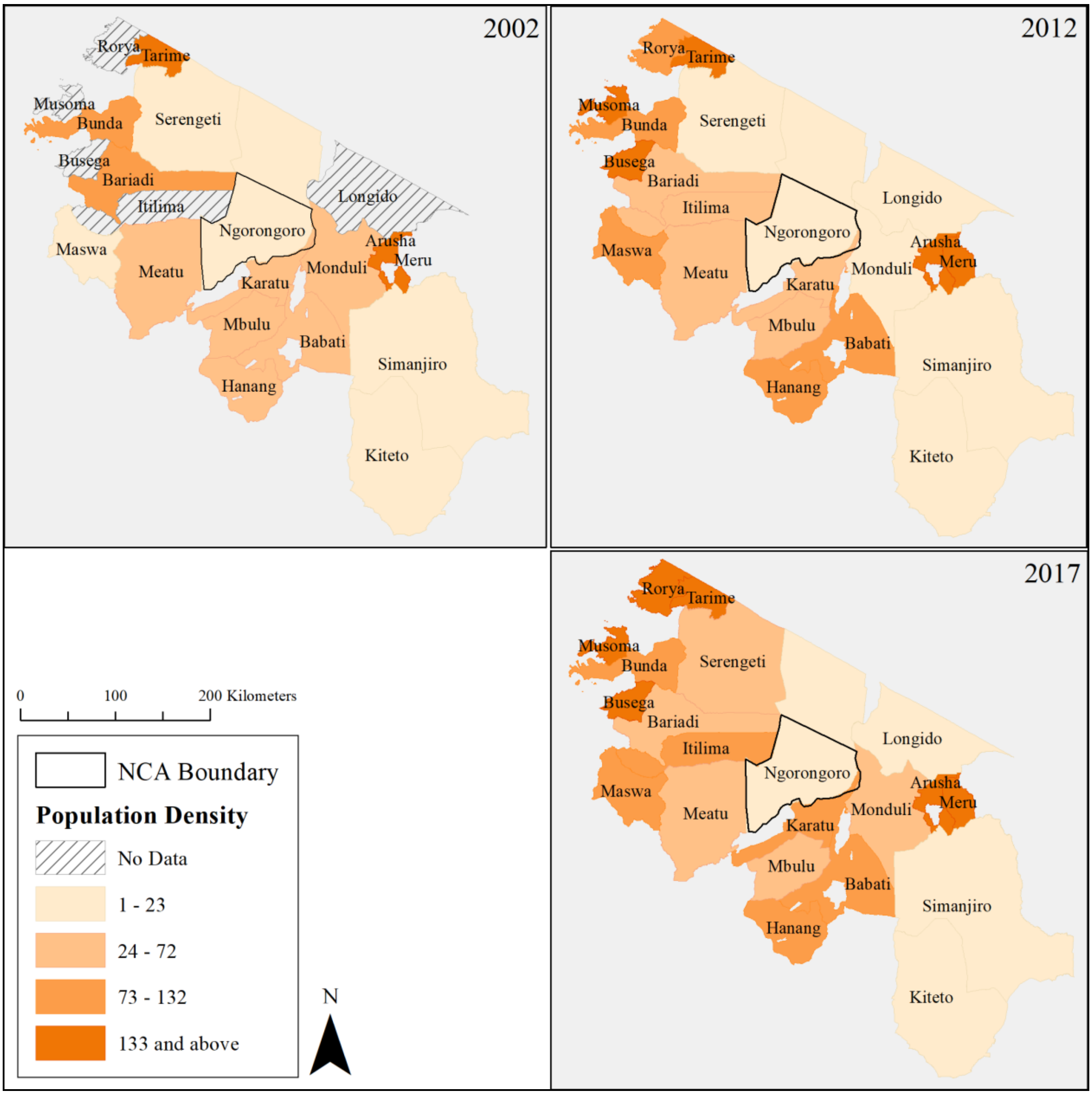

Figure 6- Population density from the years 2002, 2012 and 2017. The maps show the population density for several districts surrounding the NCA.

3.3 Assessment of land cover change in relation to population pressure

As it was found in Figure 3 that the area of highest population encroachment lies along the south eastern border of the NCA, an area which in Figure 6 can also be seen to be increasing in population density, this study will now exam a 15 km radius along the area of encroachment in the region of Karatu. This analysis relates to the last objective in this thesis which will look at assessing landcover changes as a result of population pressure. The buffer zones are included as a means of gauging the anthropogenic changes in this area in relation to how close they are to the NCA border.

By comparing 2000 to 2019 in Figure 7, the areas of settlement can be seen to have shifted away from the 2km buffer zone and more towards the 10 and 15km buffer zones. Particularly in the area alongside the bare soil zone towards the East and within it. Much of the area of agriculture remains the same or has reduced with an exception occurring within the 15km buffer section towards the south western edge of the buffer, here agriculture has replaced a large area of bare soil that was present in 2000. It can also be seen that above this area, there are less settlements and more natural vegetation in 2019.

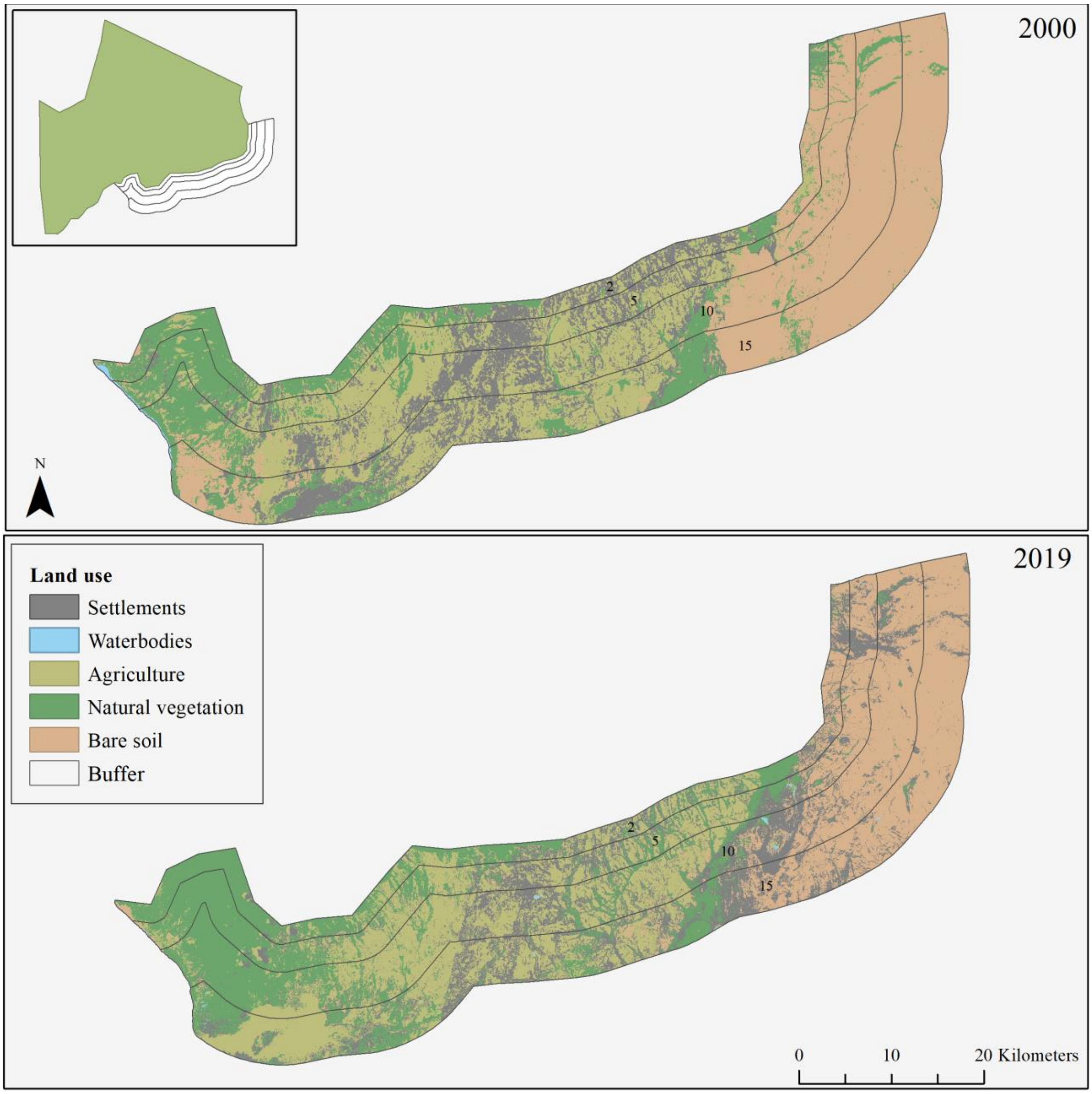

Figure 7- Land use change along the South Eastern border of the NCA at buffer intervals of 2,5,10 and 15 kilometres away from the border.

Changes in land use surrounding the southern border of the NCA show a similar pattern to that within the NCA. Agriculture has decreased slightly, and settlement and natural vegetation have increased. Agriculture has declined by -0.1%, a change that can be considered as negligible. Within the radius of development natural vegetation saw the biggest increase in land cover change by 0.8% followed by settlements which increased by 0.5%. The class which decreased the most in land use was bare soil which lost 1.3% of its area between 2000 and 2019. These results are presented in Table 7.

Table 7- Land use change within the 15km radius area outside of the NCA border. The cell size of the 2000 data has an area of 900m^2 and the 2019 data has a cell size of 100m^2

		2000		2019		
Code	**Land Cover**	**Count**	**Area (km^2)**	**Count**	**Area(km^2)**	**Cover Change (%)**
1	Settlement	319104	287.2	3388862	338.9	0.5
2	Waterbodies	3564	3.2	24681	2.5	0.0
3	Agriculture	504820	454.3	4486132	448.6	-0.1
4	Natural vegetation	351068	316.0	4000462	400.0	0.8
5	Bare Soil	647904	583.1	4538644	453.9	-1.3

The error matrix shown in Table 8 presents the verification of the data using supervised classification methods. The accuracy for this method was lower than that of the digitized method used earlier in this report. This classification method produced an accuracy of 71%. The class with the lowest accuracy was waterbodies where only 44% was classified correctly, though it should be noted that this is the class with the least ground truth points. Natural vegetation and bare soil were the two classes with the highest user’s accuracy, both scoring above 85% accuracy. Only two classes, agriculture and natural vegetation experience a misclassification of more than 10 points for a single land use. This was 12 points within natural vegetation that were misclassified as agriculture and 11 points within agriculture that were misclassified as settlements.

Table 8- Confusion Matrix depicting where land use change occurred. Code 1 shows Settlements, 2- Waterbodies, 3- Agriculture, 4- Natural Vegetation and 5-Bare Soil. The kappa is 0.7 which is an accuracy of 71%.

Confusion Matrix							
			Actual				
Ground Truth	1	2	3	4	5	**Total**	**U_Accuracy**
1	42	0	11	7	8	68	62%
2	0	4	0	2	3	9	44%
3	4	0	59	12	3	78	76%
4	1	0	6	63	2	72	88%
5	1	0	4	7	71	83	86%
Total	48	4	80	91	87	310	
P_Accuracy	88%	100%	74%	69%	82%		**Kappa: 0.7**

4.0 Discussion

4.1 Land cover change

The first objective of this report was to map land cover change within the NCA between 2000 and 2019 with a strong focus on anthropogenic changes. The results show that there was an increase in the area of settlement by 144km^2 and a decrease in agriculture by 16km^2 from 2000 to 2019. Figure 3 reveals that that the biggest change in settlements took place in the middle section of the NCA, which is a small village called Endul. As this is the biggest village within the park, expansion is likely to have occurred from the residents benefitting through the tourist industry within the park. Communities within the park receive up to 70% of their economy from the tourist industry with the NCA (Melita and Mendlinger 2013). The growth of the settlement area is likely due to the policy change that occurred in the 1990's allowing the Maasai communities to benefit from tourism (Galvin et al. 2008). The growth of this specific area and smaller settlements within the park defines the first stage of habitat fragmentation according to McGarigal (2005). This stage is known as perforation and describes the process of land being cleared and converted to fit a different purpose, which creates discontinuity within the vegetation and alters the spatial extent of the natural habitat.

Whilst the largest growth in settlements came from the town of Endul, changes in land use/ land cover could also be found around smaller settlements within the park. As the spatial resolution of the data used was not extremely high, it was not possible to distinguish between village settlements and tourist lodges. This is important to note as tourism can in some cases causes harm to the environment when it becomes a source of exploitation (Marion and Reid 2007).

Changes in landcover greater than 5% are more predominant in the mid-western section of the NCA. Many of the largest changes in vegetation cover lie close to the expanded city of Endul. Human influence could be one of the reasons for why this area has been more affected than other areas of the NCA. The most noticeable changes within the natural vegetation came from the conversion of grassland to shrubland and grassland to open woodlands, which can be seen in the tabulated intersection in Table 6. Research shows that there can be two main reasons for this change in habitat. The first is that over time the area has experienced a natural succession where through disturbances grasslands have become outcompeted to form stable shrub and woodland (Sebata 2017). The exact cause for this cannot be determined from satellite images alone and requires further investigation of the fauna and flora dynamics of the area. The second possibility of the apparent change is that due to the low resolution of the 2000 satellite data some areas of grassland were misclassified. Comparing the results of the land use found in 2000 with those found by Niyobe (2010) shows that area of grasslands within the park were the same as in the current study. This suggests that first scenario is more likely but should be investigated further.

The changes observed from the results showed that the growth of settlements in the parks is exceeding the expansion of agriculture, which has had a net area decrease in the last two decades. In a study done by Niyobe (2010), evaluating land cover change within the NCA between 1975-2000, there was an increasing trend in conversion of natural vegetation to agriculture. The study found that within the 25 year period agriculture increased to 175km^2. This report shows that in the year 2000, only 150km^2 of agriculture existed within the park and has since been decreasing. One reason that agriculture may have appeared to decrease could have been from the way settlements were classified. As the settlements were found in sparse clusters, they were not mapped as individual polygons but mapped as whole polygons, including the land in-between them, which, was often small-scale agricultural land. This method may be causing an over estimation in settlement areas and an underestimation of agricultural land.

4.2 Population change

The second objective of this report was to assess the population dynamics surrounding the parks. From the census data of 2002 and 2012 the population density within the NCA and districts directly bordering the NCA showed no change, apart from Baraidi, which in 2012 had decreased in population density. Given that its neighbouring district Busenga increased in population density, the shift could have been caused by migration. The more interesting results are presented in the projection map for 2017 where Karatu and Itilima increase in density to 73-132 people per square kilometre. The projection shows that many other regions also experience an increase in population density. This projection was done by The World Bank (2019), who used an exponential growth factor to project the population in 2017. Looking at population trends within Tanzania it can be seen that prior to 2002 more than 75% of the population has been living in rural areas. The 2012 census shows that there has been a further decrease to 70% (Finanace 2013).

Given that population development within the park appeared to be limited to the South Eastern border, this study went on to examine land cover changes of the town, Mbulumbulu, which borders the park area that had the most population encroachment. From the results it can be seen that the area of settlement has expanded within the past two decades and the majority of settlements were shifting away from the border and towards the south and east. This result is supported by Estes et al. (2012) whose study on land cover changes and population trends in the GSE showed a similar result in that settlements were expanding closest to the border in years 2000-2003 but the rate of annual conversion of land to agriculture has dropped from 0.9% in 1990 -1995 to 0.74% in 2000-2003. That being said there is still a possibility that once the natural resources in the bordering region have been depleted, people will encroach into the NCA to find more resources.

The overall results of this study indicate that anthropogenic changes within the NCA are limited and that currently encroachment and population pressure from surrounding districts do not pose a threat to the conservation of the NCA. Should the circumstances change in the future, it would be advisable to reinstate a policy whereby the NCA is converted back to an area reserved for wildlife.

4.3 Limitations

As this study relies on remote sensing, the changes observed are only from the canopy level and do not encompass all anthropogenic changes occurring within the NCA. For example, the understory changes in vegetation inflicted by people or grazing animals could be better observed from ground level. Grazing animals have been shown to have a strong impact on their surroundings, not only through the way they change the surrounding environment but also through competition with other grazers. A study by Boone et al. (2002) found that expanding agricultural/ grazing land to more than 5% of the total area in the NCA causes herbivore populations, excluding elephants, to decline in the area. Whilst this study does show that agriculture has not increased it is not possible to determine the extent of grazing land for domestic animals from the satellite imagery and the methods used in this study.

Given the coarse nature of the data and the sizeable area at hand this study did not map smaller anthropogenic changes such as roads and fences within the park. Although, this study did not map the road network with the NCA, it could be seen from the two satellite images that there has been development of the connectivity within the park. As pointed out by McGarigal (2005) the development of road networks creates an opportunity for future habitat loss which can lead to the second stage of habitat fragmentation, dissection. Whilst fencing could not be detected from the satellite images, a study by Lovschal et al. (2017) addressed concern for fencing causing ecosystem disruption further north in the GSE. A further limitation of the coarse resolution satellite data was related to classifying the vegetation. Whilst the accuracy was high for the digitized map of the NCA it was much lower for the area bordering the NCA, this was likely due to the number of small settlements which from the supervised classification method were more likely to be classified as agriculture or bare soil. Whilst the overall accuracy of this study was over 80% and thus relatively high, certain land classes had a higher classification accuracy than others; the best example of this can be seen in Table 5 where waterbodies had a much lower accuracy then the rest of the classes. The main reason for the poor classification result for waterbodies, which had an accuracy of 56%, was due to the fact that not all areas of the NCA showed up to date images in Google Earth Pro, and instead used imagery from 2017. This had a large effect on the waterbodies especially, as their borders shifts from year to year depending on the rains. Separating shallow waterbodies from the bank was difficult as they have similar spectral properties, this may have contributed to the low accuracy of the class.

One error to take into consideration for future studies should be to look at errors created by using two different satellite data sets with differing spatial resolutions and spectral bands. Both these factors related to the use of the Landsat7 and Sentinel2 images may have led to wrongly classifying certain classes within the landcover. Some of the smaller changes in landcover which were less than 1% could be a result of this.

5.0 Conclusion

The aim of this thesis was to examine the extent of anthropogenic changes within the NCA and the surrounding area. From the results of this report and the literature reviewed, a conclusion can be drawn that at the current time the extent of land use / land cover change does not make up more than 2% of the total area within the NCA. Population pressure from surrounding regions may play a larger role in environmental degradation and habitat fragmentation in the future but as can be seen from the closest bordering village of Mbulumbulu, expansion of settlements close to the NCA may not necessarily lead to encroachment. That being said the impacts of anthropogenic developments should also be examined at ground level to determine changes occurring under the canopy before a conclusion on the full extent of degradation can be made. To determine whether the NCA should continue to support both natural and anthropogenic uses, a more wholistic approach should be taken, whereby socio-economic factors are considered in conjunction with the biophysical properties of the area (Lambin et al. 2001). This conclusion can help in the policy conflict as it shows that within the period of the newest policy change the NCA has not suffered from extreme anthropogenic changes.

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