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Assessing the Spatial Drivers of Land Use and Land Cover Change in the Protected and Communal Areas of the Zambezi Region, Namibia

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Abstract: Understanding the patterns and drivers of land use and land cover (LULC) changes is fundamental for rational and specific planning for sustainable land management. Using remote sensing techniques, geographic information systems (GIS) and statistical modeling via multinomial logistic regression, we sought to identify spatial variables that determine LULC change and their extent over time in the protected and communal areas of the Zambezi Region, Namibia. Multi-temporal satellite imagery of the Landsat series was used to map changes over a period of twenty-six years, divided into three stages (1984–1991, 1991–2000 and 2000–2010). Post classification change detection methodologies were used to determine conversions between LULC classes. Additionally, socio-economic characteristics of the area were used to identify drivers of changes. Four spatial drivers of LULC change that we identified included the distance to the nearest road, distance to settlements, population density and fire return periods. Population density, distance to settlements and fire return period were significantly associated with conversion from crop/grass land to crop/grass land and forest land to crop/grass, forest land to bare land and forest land to forest land in the protected area. In communal areas, distance to the road was found to significantly influence conversion from crop/grass land to crop/grass land. The study concluded that the influence of these drivers is attributable to distinct political and agro-demographical differences during the study period. Policy makers and planners need to take these drivers into consideration together with their subsidiaries to respond and make sound decisions regarding undesirable changes in LULC.

Keywords: land use; land cover; spatial drivers; logistic regression; Zambezi

1. Introduction

Land use describes activities that take place on the land and represent the current use of property, while land cover describes the natural and anthropogenic activities that can be observed on the land [1,2]. Thus, land use goes deeper than cover by describing the actual use of the land. Remotely sensed data have been used to identify and derive land use through observations of land cover [3]. Changes in Land Use and Land Cover (LULC) may affect ecosystem services that sustain livelihoods and services such as food production, climate regulation, biodiversity maintenance and erosion control [4–6]. The drivers of LULC change are multifaceted and emanate from the interface between human-environment systems, socioeconomic, policy and institutional factors [7,8]. Considerable efforts have been undertaken to understand spatial drivers including distance to roads, distance to settlements, elevation, rainfall, population density and gross domestic product of LULC change [9–13]. These studies have been helpful in planning effective use of land and sustainable development, and they provide valuable insights to improve our understanding of the drivers of LULC change. However, knowledge regarding spatially explicit interactive effects of LULC change in the open savanna woodlands of Namibia including the Zambezi Region is limited. In addition, since the drivers of LULC change are dynamic in space and time, there is a need to further study these drivers in order to aid decision-making.

It has been widely argued that increased anthropogenic activities have altered LULC in the Zambezi Region before the region became part of the Kavango-Zambezi Transfrontier Conservation Area. These arguments are, however, little supported by quantitative data. Changes in LULC in the Zambezi Region continuously influence the extent as well as the nature of forest ecosystems, thus influencing the services provided by these. In effect therefore, the spatial driving factors are far from being thoroughly understood.

In this study, distances to the roads and settlements, population density and fire return periods were investigated as the variables that explain the spatial and temporal extent of LULC change in the study area. The distances to roads and settlements are correlated with improved access to land thus facilitating the utilization of the forest resource. On the other hand, population density has an impact on the clearance rate of forests for agriculture and the use of natural forests areas as the main sources of wood for fuel and construction [14]. Fire return period defined in this study as the average number of times an area was affected by fire. It was expected that these drivers might change over time, because of changes in socioeconomic and political conditions. Although these factors have previously been identified as determinants of LULC change, it is unclear if they are equally applicable in the open savanna woodlands of Namibia including the Zambezi Region to support regional LULC planning policy and practice.

It was within these contexts that we set out to (i) to quantify the impact of the spatial variables using current spatial modelling techniques; (ii) to compare the spatio-temporal variation of the effects of spatial drivers on LULC; and (iii) to prepare LULC conversion maps. Specifically, we attempted to examine the influential spatial drivers of LULC change of various LULC types in the protected and communal areas of the Zambezi Region. By understanding these, we hoped to provide new insights for guiding the sustainable land development of areas under similar socio-economic and environmental conditions.

2. Materials and Methods

2.1. Study Area

This study was undertaken in the Sibbinda Constituency of the Zambezi Region, Namibia (Figure 1). Sibbinda is a communal area, which extends over an area of about 188,000 ha, located to the south-west of Katima Mulilo, the regional capital of the Zambezi Region. The mean annual precipitation ranges from 650 mm in the western parts of the Zambezi Region to 1000 mm in the east, mostly falling between October and March, with a marked dry season between May and September.

Given the comparatively high rainfall, the area has potential for agriculture and forestry when compared to other parts of the country. The relatively high rainfall enables residents to practice dryland crop farming which supports a more sedentary standard of living compared to more arid areas. The soil is predominantly sandy-loam with isolated gravel hills. The vegetation is classified as woodland savanna and is predominantly comprised of *Baikiaea plurijuga*, *Guibourtia coleosperma*, *Pterocarpus angolensis*, *Burkea africana* and *Dialium engleranum*. The land cover is mostly made up of woodland, interspersed with swamps and wetlands [15].

The total population of Sibbinda constituency was 9190 in 2000 and increased to 10,182 in 2010, which represents an annual population growth rate of 1% [16]. The agricultural sector is dominated by small-scale mixed-crop and livestock farming and is the primary source of livelihood for these communities [14]. Land tenure is under a local traditional system headed by the "*Indunas*" who have rights under both customary and Namibian state laws [17]. Settlement clusters are found around the main settlements which are administered by the "*Induna Silalo*". Due to the relatively high rainfall, larger numbers of people are able to farm smaller parcels of land than in other areas of the country. Settlements are therefore relatively large with several satellite settlements. The road network is relatively dense, mainly comprising of dirt tracks and foot paths.
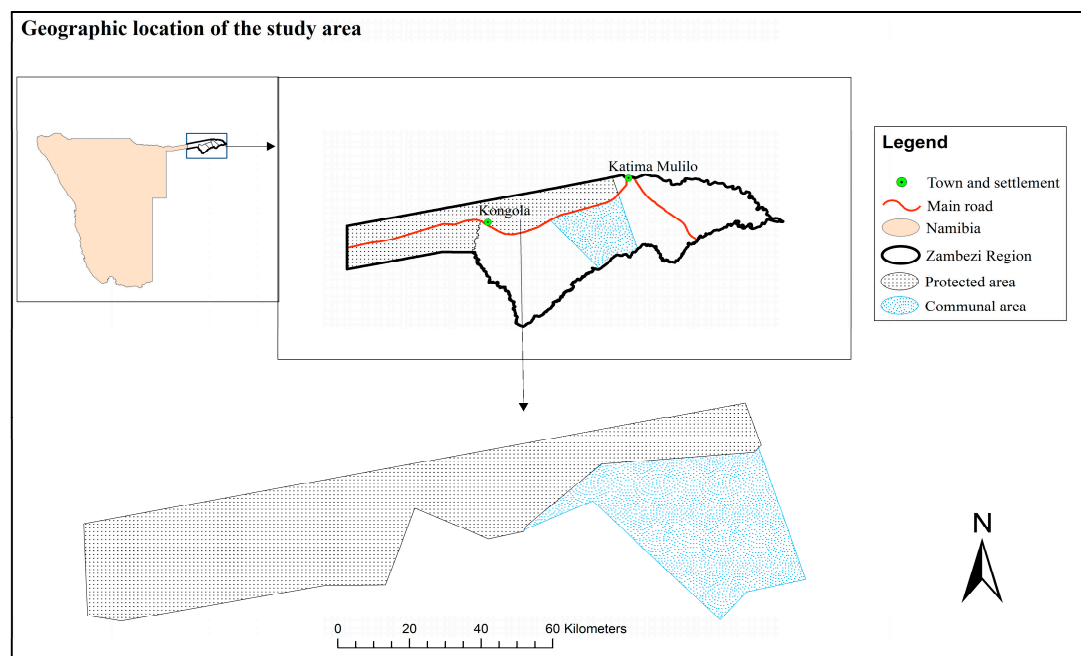
Figure 1. Location map of the study area (Source: [18]).

Since independence in 1990, and the end of Namibia's war of independence, the National Forestry Policy of 1992 as well as changes to the Nature Conservation Ordinance of 1975 contributed to the diversification of the region's economy to include wildlife-based tourism alongside agriculture. Supplementary, off-farm livelihood activities comprise of the gathering of non-timber forest products such as *Vangueria infausta* and *Grewia* fruits. Environmental degradation as a result of deforestation, land degradation, and illegal logging are now of great concern in the Zambezi Region.

2.2. Remote Sensing Analysis

Landsat TM and ETM images from 1984, 1991, 2000 and 2010 were downloaded from the University of Maryland's Global Land Cover Facility (GLCF) (http://glcapp.umiacs.umd.edu) and United States Geological Survey (USGS) Earth Resources Observation Systems (EROS) Data Center (EDC) (http://glovis.usgs.gov) [18]. The detailed description on the image specifications choice of image dates can be found in Ref. [18]. However, it is important to reiterate that before interpretation,

radiometric, geometric and atmospheric corrections were applied and the Root Mean Squared Error (RMSE) of geometric rectification was found to be less than 0.5 pixels. Moderate Resolution Imaging Spectroradiometer (Modis) with a spatial resolution of 250 m was used to map burned areas. MODIS images were downloaded from the MODIS web site (http://modis.gsfc.nasa.gov/).

*2.3. Image Classification and Accuracy Assessment*

A classification scheme to derive five LULC classes was based on Ref. [18]. (Table 1). The detailed account on ground truthing, accuracy assessment and change detection are depicted in Ref. [18].

Table 1. Description of land use and land cover classes.

Class Category	General Description
Forest land	Areas of closed and open canopy forests (with 20% or more crown cover) and wooded landscapes with trees higher than 3 m
Shrub land	Areas with combined cover of shrubs, bushes and occasional trees
Crop/grass land	Areas which are predominantly used for the production of food with isolated bushes and trees
Bare land	Areas which are predominantly bare in nature
Other land	Areas not classified as forest, shrub land, crop/grass land or bare land

2.4. Spatial Data Used

A systematic grid of 2 km by 2 km was superimposed on the study area to collect various factors on the 2000–2010 change map. A total of 926 survey pixels in the protected area and 402 in the communal area were evaluated (Figure 2). Since mapping was conducted using multiple spatial resolution images (Landsat and Modis) at different scales, field observations were collected at the corresponding resolutions to match image values in pixel sizes. Proximity analysis tools in ArcGIS were used to determine the distances from survey points to the nearest roads and settlements. Similarly, querying and selection techniques were employed to identify the fire return periods on the survey points and was used as an input into the multinomial logistic regression model. Distance variables were calculated based on digital base maps, all done by ArcGIS 9.3's near tool to determine the distances from random points to the nearest roads and settlements. The near distance was calculated by evaluating the shortest distance between the random points and near features such as roads or settlements. Image attributes of interest were extracted to the survey points through the spatial analyst extraction tools. The road network and settlement data were extracted from Namibian digital topographic maps produced by the Surveyor General's office in Namibia. Population density was extracted from the National Planning Commission of Namibia settlement distribution information system. Fire return period was extracted from a series of maps, which annually characterizes the temporal fire regimes from the MODIS fire scar maps.
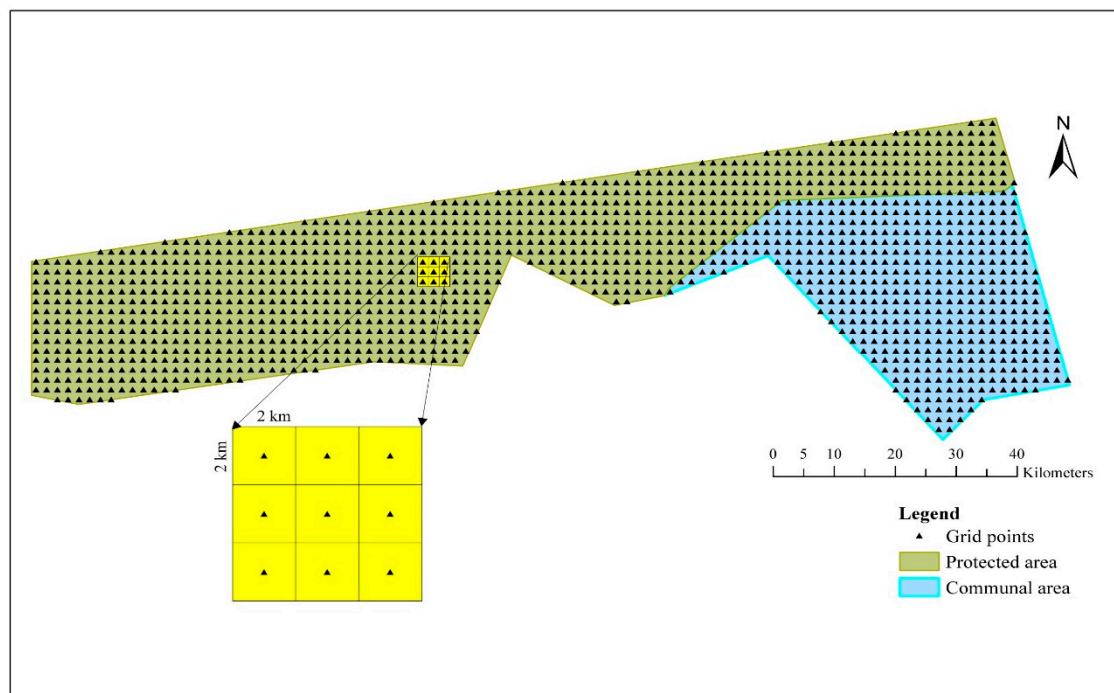
Figure 2. Distribution of surveyed points in the study area.

2.5. Multinomial Logistic Regression to Analyze the Spatial Drivers of LULC Change

Association between the derived spatial driver data and LULC change outcome was analyzed using the multinomial logistic regression. The multinomial logistic regression was used since the outcome variable (LULC change) had more than two outcome categories. We used the estimated odds ratios to measure the magnitude of strength of association between spatial explanatory variables and a particular LULC change. A *p*-value less than 0.05 was considered to denote a statistically significant association. A set of spatially explicit explanatory and dependent variables generated and assembled in a Geographic Information System are shown in Table 2. These were selected based on their representation of the processes believed to be driving LULC in the study area. Furthermore, the selection of explanatory variables was restricted by the availability of spatially explicit data in the study area. We are also aware that the spatial predictors may be collinear, which might cause problems in the estimation of regression coefficients. Informally, we used Pearson's correlation to evaluate the correlation between the spatially explanatory variables. Formally, Variance Inflation Factor (VIF) and tolerance (I/VIF) were calculated to measure the degree of collinearity among the spatial predictor variables, and used a rule of thumb to further investigate or eliminate predictors whose VIF is greater than 10 [19].

Table 2. Definition of explanatory factors used in the multinomial logistic regression model.

Factor	Description
Distance to the road	The distance (in km) from the middle of a pixel to the nearest road
Distance to the settlement	The distance (in km) from the middle of a pixel to the boundary of the nearest settlement
Population density	Corresponding population density (in square km)
Fire return period	Number of times a pixel was burned (in years)

Although these variables have been well studied in other areas as determinants of LULC change, they have not been investigated in the woodland areas of Namibia. These variables were used as predictors to fit a multinomial logistic regression model with each LULC class as dependent variable.

Other variables such as rainfall and soil conditions at field level are not available at the scale of the study. Table 3 shows the dependent variables used in the multinomial logistic regression analysis.

Table 3. List of dependent factors used in the multinomial logistic regression model.

Dependent Factors	
Forest land to forest land	Shrub land to forest land
Forest land to shrub land	Shrub land to crop/grass land
Forest land to other land	Shrub land to other land
Forest land to crop/grass land	Shrub land to bare land
Forest land to bare land	Bare land to bare land
Other land to forest land	Crop/grass land crop/grass land
Other land to shrub land	Crop/grass land to forest land

Several categories of LULC change described were considered very sparse and were excluded from the analysis. In the communal area, these included conversions of bare land to shrub land, bare land to crop/grass land, crop/grass land to shrub land, crop/grass land to other land, crop/grass land to bare land, other land to forest land, other land to other land, other land to shrub land shrub land to bare land and shrub land to other. In the protected area, categories which were sparse and excluded in the analysis were conversions of crop/grass land to forest land, crop/grass land to shrub land and crop/grass land to bare land.

The fitted model was then used to map the predicted probabilities of specific LULC change in the study area. The selection of explanatory variables was restricted by the availability of spatially explicit data in the study area. The variables used were selected based on their representation of the processes believed to be driving LULC in the study area. We mapped the predicted probabilities of occurrence to produce probability maps to underline spatial distribution of LULC with their respective relationship with the spatial variables. All regression models were determined using SPSS 16.0, after all data were standardized and normalized.

The schematic representation of the research design indicating steps used for producing probability of occurrence maps is provided in Figure 3.
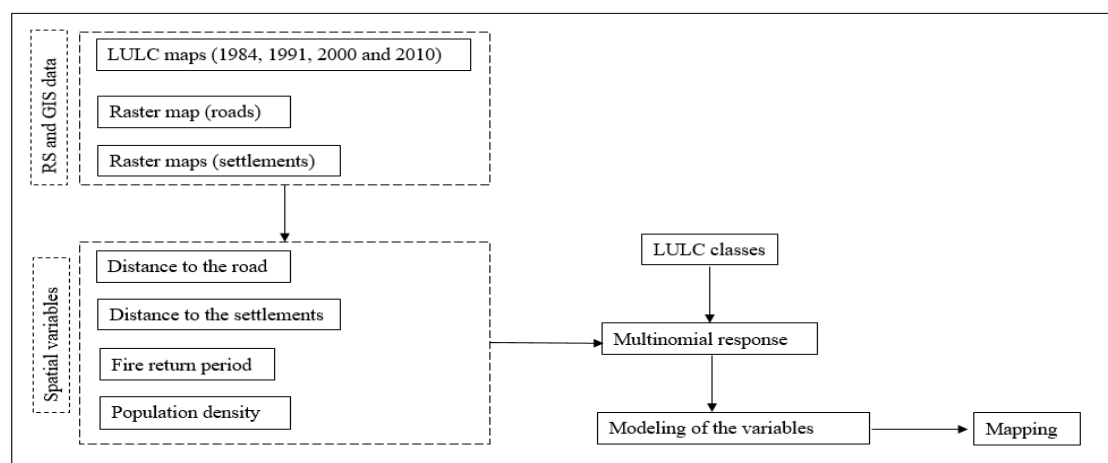
Figure 3. Steps used for the development of the probability maps for the occurrence of selected land use and land cover (LULC) change conversions in the protected and communal area.

3. Results

3.1. Land Use and Land Cover Change Assessment

The overall classification accuracy for 1984, 1991 and 2000 were respectively 79.6%, 75.5% and 80.6% [18]. In satellite-based classifications using Landsat imagery, most studies have claimed accuracy

of between 60% and 90% [20] implying that the accuracy of LULC maps used here are well within acceptable limits [18].

3.2. Land Use and Land Cover Changes

The results of the LULC classification for the time-series are presented in Table 4. Prominent changes under different LULC classes were that forest land increased in both protected and communal land after independence in 1991. However, shrub land reduced after independence in the protected area. In the communal area, shrub land reduced after independence in the protected area, there was a progressive marginal increase in crop/grass land. However, crop/grass land reduced after 1991 in the communal area. The detailed transition tables can be found in Ref. [18].

Table 4. Area statistics (ha) of the LULC classes (Source: Ref. [18]).

	Protected Area				Communal Area			
	1984	**1991**	**2000**	**2010**	**1984**	**1991**	**2000**	**2010**
Forest land	238,828	189,240	228,605	344,025	83,516	69,845	109,313	121,227
Shrub land	84,468	204,040	171,399	53,327	24,085	29,342	41,935	27,030
Crop/grass land	3542	9219	491	4248	6657	2611	1791	8448
Bare land	1245	1958	2011	212	23,584	3365	1909	6643
Other land	90,682	14,308	16,260	16,955	50,155	82,833	33,048	24,649

3.3. Modeling LULC

Table 5 shows that there is a negative correlation between population density and distance to the road and settlements in the communal area Fire return period recorded weak correlations with other spatial variables investigated in the communal area. As expected, distance to the road and settlement showed a strong correlation in the communal area.

Table 5. Correlation matrix for explanatory variables.

	Spatial Variable	**Distance to the Road (km)**	**Distance to the Settlement (km)**	**Population Density (km^2)**	**Fire Return Period (years)**
Communal area	Distance to the road (km)	1			
	Distance to the settlement (km)	0.353	1		
	Population density (km^2)	−0.361	−0.432	1	
	Fire return period (years)	0.020	0.027	0.197	1
Protected area	Distance to the road (km)	1			
	Distance to the settlement (km)	0.455	1		
	Population density (km^2)	−0.314	−0.557	1	
	Fire return period (years)	−0.054	−0.042	0.026	1

Tables 6 and 7 present effects of the variables affecting the change direction of LULC in the protected and communal areas, where odds ratios (ORs) (with 95 confidence intervals) are used to measure the effects. For multinomial LULC outcome, the conversion from shrub land to shrub land was taken as the reference category. In the protected area, population density was found to have a significant effect on crop/grass to crop/grass land compared to forest land to forest land and shrub land to shrub land ($p < 0.05$). Increasing distance to settlement significantly influenced the conversion of forest land to bare land, where the odds were 0.809 less likely with a unit increase in kilometer distance. Similarly, population density was found to have a significant effect on conversion from forest to crop/grass ($p < 0.05$) with the odds of 1.235, compared to forest land to shrub land. Fire return period was found to have a significant effect on forest land to forest land ($p < 0.05$) where the odds of 0.833 decreases with a unit increase in the number of years a pixel was burned, compared to shrub land to forest land (Table 6). The VIF values ranged between 1 and 1.562 (with a corresponding tolerance level

greater than 0.1), indicating multicollinearity is not a problem in estimating the predictor coefficients under the multinomial regression model.

Table 6. Factors affecting the LULC class/conversion in the protected area.

LULC Class/Conversion	Explanatory Variable	Odds Ratio	*p*-Value	Lower	Upper
Crop/grass to crop/grass	Distance to the road (km)	1.102	0.427	0.868	1.399
	Distance to the settlement (km)	1.037	0.692	0.868	1.238
	Population density (km^2)	1.344	0.001	1.129	1.601
	Fire return period (in years)	0.990	0.950	0.713	1.373
Forest to bare	Distance to the road (km)	1.069	0.635	0.811	1.410
	Distance to the settlement (km)	0.809	0.030	0.668	0.980
	Population density (km^2)	0.979	0.898	0.713	1.346
	Fire return period (in years)	0.819	0.218	0.596	1.126
Forest to crop/grass	Distance to the road (km)	0.983	0.865	0.805	1.200
	Distance to the settlement (km)	0.984	0.804	0.867	1.117
	Population density (km^2)	1.235	0.011	1.050	1.453
	Fire return period (in years)	0.938	0.621	0.728	1.209
Forest to forest	Distance to the road (km)	0.976	0.451	0.915	1.040
	Distance to the settlement (km)	1.038	0.167	0.985	1.094
	Population density (km^2)	1.139	0.070	0.989	1.312
	Fire return period (in years)	0.833	0.000	0.752	0.923
Forest to shrub	Distance to the road (km)	1.021	0.781	0.883	1.180
	Distance to the settlement (km)	0.936	0.266	0.833	1.051
	Population density (km^2)	0.974	0.865	0.715	1.325
	Fire return period (in years)	1.045	0.697	0.839	1.301
Shrub to crop/grass	Distance to the road (km)	0.943	0.460	0.807	1.102
	Distance to the settlement (km)	0.997	0.965	0.861	1.154
	Population density (km^2)	0.828	0.514	0.469	1.460
	Fire return period (in years)	0.899	0.396	0.702	1.150
Shrub to forest	Distance to the road (km)	0.955	0.179	0.893	1.021
	Distance to the settlement (km)	1.034	0.227	0.979	1.092
	Population density (km^2)	1.101	0.192	0.953	1.272
	Fire return period (in years)	0.925	0.154	0.831	1.030

Figure 4 shows the effect of spatial variables on various LULC conversions. The conversion from forest land to bare land is pronounced in areas closer to the settlements and along the roads. As expected, higher probabilities of converting forest land to crop/grass land and shrub land to forest land were found closer to settlements. However, moderate to high probabilities of converting forest land to shrub land were similar throughout the entire protected area.

In the communal area, distance to the road was found to have a significant effect on crop/grass land to crop/grass land ($p < 0.05$) where the odds reduced by a factor of 0.187 compared to crop/grass land to forest land and other LULC conversions (Table 7). The *p*-values of most of the LULC conversions are much higher than 0.05 meaning the effect of the respective explanatory is random. The VIF values ranged between 1 and 1.819 at a tolerance level of 1.
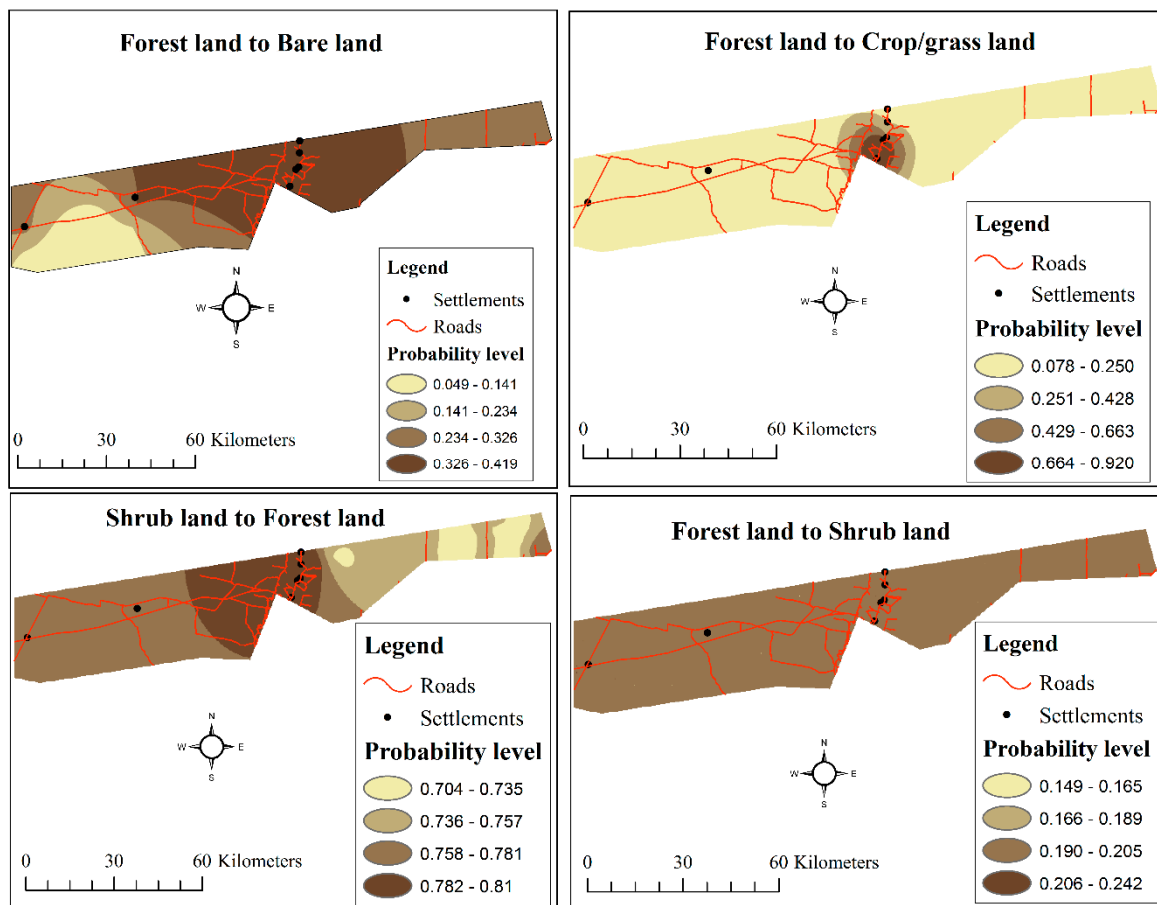
Figure 4. Probability of occurrence for the selected LULC conversions in the protected area.

Table 7. Factors affecting the LULC class/conversion in the communal area.

LULC Class/Conversion	Explanatory Variable	Odds Ratio	*p*-Value	Lower	Upper
Bare to bare	Distance to the road (km)	0.456	0.072	0.193	1.074
	Distance to the settlement (km)	1.307	0.339	0.755	2.263
	Population density (km^2)	1.082	0.414	0.895	1.308
	Fire return period (in years)	0.787	0.445	0.426	1.454
Crop/grass to crop/grass	Distance to the road (km)	0.187	0.000	0.081	0.433
	Distance to the settlement (km)	1.120	0.583	0.747	1.679
	Population density (km^2)	1.078	0.322	0.929	1.252
	Fire return period (in years)	1.129	0.562	0.750	1.700
Crop/grass to forest	Distance to the road (km)	0.931	0.734	0.617	1.405
	Distance to the settlement (km)	1.050	0.793	0.729	1.513
	Population density (km^2)	0.980	0.793	0.843	1.139
	Fire return period (in years)	0.978	0.894	0.700	1.365
Forest to bare	Distance to the road (km)	0.561	0.297	0.189	1.663
	Distance to the settlement (km)	0.745	0.390	0.381	1.457
	Population density (km^2)	0.890	0.432	0.665	1.191
	Fire return period (in years)	1.135	0.669	0.635	2.029
Forest to crop/grass	Distance to the road (km)	0.670	0.081	0.428	1.051
	Distance to the settlement (km)	0.995	0.978	0.687	1.440
	Population density (km^2)	0.977	0.758	0.844	1.131
	Fire return period (in years)	1.012	0.947	0.718	1.426

Table 7. *Cont.*

LULC Class/Conversion	Explanatory Variable	Odds Ratio	*p*-Value	Lower	Upper
Forest to forest	Distance to the road (km)	0.829	0.297	0.583	1.180
	Distance to the settlement (km)	1.328	0.078	0.969	1.822
	Population density (km^2)	0.989	0.870	0.871	1.124
	Fire return period (in years)	0.877	0.370	0.658	1.168
Forest to other	Distance to the road (km)	1.211	0.527	0.668	2.195
	Distance to the settlement (km)	1.103	0.732	0.628	1.939
	Population density (km^2)	1.020	0.889	0.773	1.346
	Fire return period (in years)	1.080	0.774	0.640	1.822
Forest to shrub	Distance to the road (km)	0.911	0.635	0.620	1.339
	Distance to the settlement (km)	1.179	0.349	0.835	1.666
	Population density (km^2)	1.016	0.820	0.885	1.166
	Fire return period (in years)	0.803	0.180	0.583	1.107
Shrub to crop/grass	Distance to the road (km)	0.743	0.227	0.459	1.203
	Distance to the settlement (km)	1.105	0.623	0.741	1.649
	Population density (km^2)	0.963	0.685	0.804	1.154
	Fire return period (in years)	1.166	0.439	0.790	1.722
Shrub to forest	Distance to the road (km)	0.905	0.605	0.621	1.319
	Distance to the settlement (km)	1.127	0.484	0.806	1.578
	Population density (km^2)	0.933	0.344	0.809	1.077
	Fire return period (in years)	0.902	0.511	0.662	1.228

Figure 5 shows the effect of spatial variables on various LULC conversions in the communal area. Moderate to high probabilities of converting crop/grass land to forest land and forest land to crop/grass land are found in areas closer to the roads and settlements. However, areas with low probabilities of converting crop/grass land to forest land and forest land to crop/grass land were found in areas further away from the settlements and roads. On the other hand, moderate probabilities of converting shrub land to forest land and forest land are found throughout the entire communal areas.
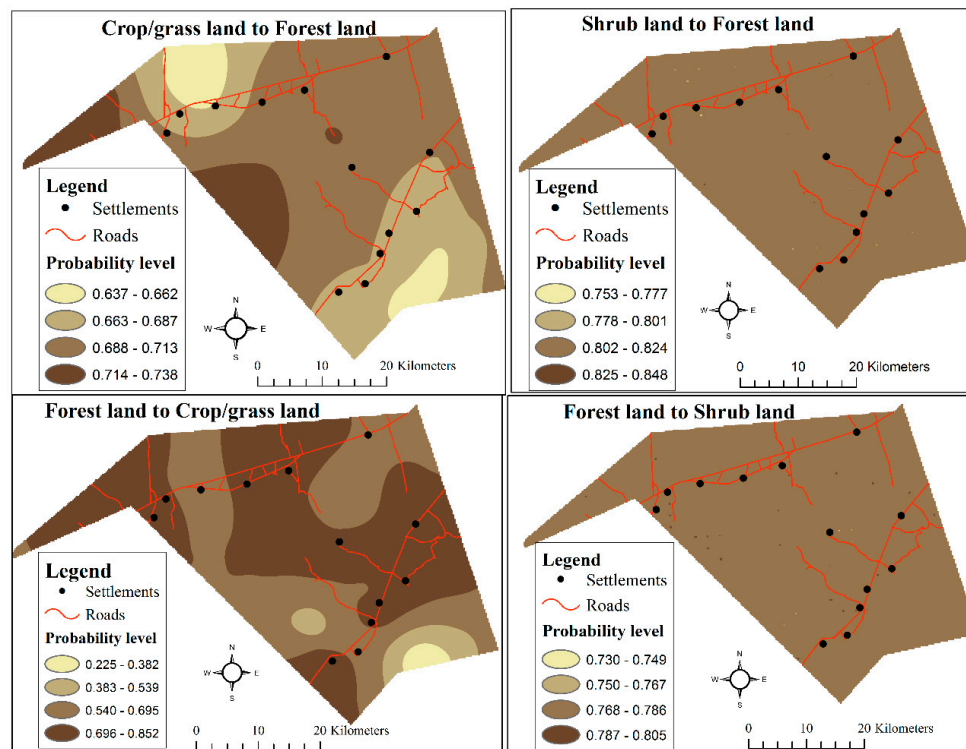

Figure 5. Probability of occurrence for the selected LULC conversions in the communal area.

4. Discussion

This study considered LULC change in the Zambezi Region, Namibia in periods of political and policy transition. Our analysis suggests that the factors affecting LULC change show different patterns for the two different near-decadal time periods (1984–1991 and 2000–2010). Overall, the main patterns in LULC occurring in the study area were summarized into 2 phases; (1) 1984–1991 represented high deforestation and gradual increase in shrub land; (2) 1991–2000 and 2000–2010 represented lower deforestation and slower agro-pastoral expansion [18]. The changes in forest land were consistent with the general increase in forest land observed in the field and from semi-structured interviews carried out in 2013 [14]. Two major LULC processes may have reduced crop/grasslands i.e., abandonment and intensification. Although there are no reliable data about the production of agricultural crops to estimate intensification of production, field visits showed that households had received fertilizer subsidies under the dryland cropping programs of the government.

Population density significantly influenced the retention of crop/grass land and conversions from forest land to crop/grass land with varying degrees to the observed LULC change dynamics in the protected area. A rather recent phenomenon in the protected area is demographic shrinkage since strict laws and regulations on resettlement have been passed. These developments call for increased detailed information on the types of households around the protected areas, to address differences in their preferences since they still derive their livelihoods from the protected area. Our models indicate that distance to the road affect the likelihood associated with crop/grass occurrence. It should be noted that there are numerous tracks in the study area that were not mapped and may affect the pattern showing the impact of the distance to the road and settlements.

Conversions of crop/grass land are driven by developments outside the agricultural sector, such as urbanization or nature development. The changes in agricultural production are driven by developments on the market for agricultural products, environmental regulations and technological innovations. The change towards multi-functional agricultural land is driven by regulations and subsidies for nature and landscape management, and by the attractiveness of different opportunities for subsistence farmers to increase their incomes. After independence in 1990, the benefits associated with the road network increased, such as access to health, education, employment and other opportunities, mainly along the major roads. This may have encouraged communities to move from remote areas (out-migration of 3.6%) of rural people was experienced between 2000 and 2010 to areas nearer the roads and towns, thus abandoning their inland croplands, and thereby reducing the land area under crops [14]. In comparison with other constituencies of the Zambezi Region, the labor force participation rates were the lowest in the Sibbinda constituency (29.2%) in 2010 [21]. Since agriculture is the main source of livelihoods, communities established crop fields in areas closer to their new settlements along the roads, hence the impact on the conversion of other LULC types to cropland near to the settlements.

Population density did not significantly influence the conversions of all the LULC types in the communal area. This is contrary to the findings of a study carried out in Sissili Province of Burkina Faso, which linked change in LULC to population density [22]. The lack of significance of population density in this study is counter-intuitive. However, the census tracts averaged out population densities over larger areas, making it difficult to identify a significant link. Other variables such as rainfall and soil conditions at field level were not available at the scale relevant to the study. This may have inflated the effect of spatial drivers. In addition, the low spatial resolution of Landsat images (30 m) used for this study and the mixed vegetation type (resulting in mixed pixel problems) may have influenced the patterns of LULC change that were detected. Increasing the spatial extent of the study area may permit the identification of other drivers of change (such as site conditions, economic and environmental factors). Nonetheless, the limited number of variables in a LULC change model is useful to understand the LULC phenomenon that involves complex processes [23], as carried out in this study. In addition, identifying the complex interaction between changes and their drivers in space and time is important to predict future developments, set decision making mechanisms and construct alternative scenarios.

5. Conclusions and Perspectives

The study concluded that prominent changes under different LULC classes were that forest land increased in both protected and communal land after independence in 1991. However, shrub land reduced after independence in the protected area. In the communal area, shrub land reduced after independence from 2000 to 2010. In the protected area, there was a progressive marginal increase in crop/grass land. However, crop/grass land reduced after 1991 in the communal area. Apart from the spatial driving forces investigated in this study, future land use may be strongly affected by existing patterns of land use and by policies in both the protected and communal areas of the Zambezi Region. Policies can affect land use directly (e.g., spatial policies) or via driving forces (e.g., subsidies and new technologies). Further, the likelihood that a land use change occurs at a location depends on the existing land use as demonstrated in this study. The information and models derived in the present study could be incorporated into an LULC framework for planning, environmental monitoring, scenario analysis and impact assessment at local government level. Moreover, many underlying factors, such as intensification of farming were difficult to establish using this quantitative approach due to data limitations. The same limitation might extend to population density as the population data obtained were based on the mean, thus, all areas or cells in an administration unit had the same numbers. However, the net of these less spatially distributed variables does not inevitably mean lower magnitude of these variables in reality. The problems of the non-spatial socio-economic drivers could be moderated through follow-up studies reflecting land use decisions. To do so, household surveys could be used to acquire socio-economic data and develop decision models for LULC. Otherwise, it is essential to develop methods for spatial disaggregation of statistical data in the Zambezi Region. Nonetheless, looking at isolated drivers of LULC change as carried out in this study may provide information on the spatial heterogeneity and dependence among LULC changes and the associated predisposing factors.

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