Chapter 3

Vegetation Changes in the Miombo Woodlands in Northwestern Zimbabwe: A Case Study of Nkayi District 1990 to 2017

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Additional information is available at the end of the chapter

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Abstract

The research applied Geographic Information Systems (GISs) and remote sensing tools in quantifying land cover changes in Nkayi District and assess the drivers for such changes. This was done to link the impacts of anthropogenic activities to change in the physical environment especially looking at ecosystem goods and services, which in turn reduce their productivity. Satellite images were analyzed for 1990, 2000, 2010, and 2017 in order to produce temporal land cover maps for Nkayi District and use them as tools for estimating the rates and the extent to which land cover has changed from 1990 to 2017. Four main land cover types were identified, namely woodland, deforested land, cultivated land, and water bodies. In 1990, woodland covered 58% of the total land area in Nkayi District, while deforested land, cultivated land, and water bodies covered 31, 11, and 0.2%, respectively. From 1990 to 2017, woodland declined to 47% in 2017, while deforested land and cultivated land increased to 14.9 and 36%, respectively. The major drivers of land cover changes were increase in household numbers, which were associated with woodland clearing for agriculture. The other drivers of land cover changes were soil infertility and overgrazing by livestock. The research was crucial in detecting the problems of forage shortages and poor rangeland conditions, mainly caused by expanding fields coupled with infertile Kalahari sands. The research highlighted the urgent need to manage the fragile miombo woodlands, which are being threatened by the increased demand for land for human settlements and cultivation. Alternatively, the research also highlights the need for farmers to produce more biomass in their fields in the form of high-value crop residues to cater for the loss of rangelands.

Keywords: miombo woodlands, vegetation, GIS, remote sensing, land cover change, participatory GIS

1. Introduction

Miombo woodland ecosystems are integral and crucial to biodiversity and human livelihoods for communities living across much of central and southern Africa stretching from Angola, Botswana, the Democratic Republic of Congo, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia, and Zimbabwe. The woodlands are vast ecosystems consisting of *Brachystegia* species, *Baikiaea plurijuga, Combretum, Terminalia*, and acacia species [1, 4] and offer a lot of benefits to the local communities in the form of rangelands, firewood, traditional medicines, and the general esthetic of the environment [16]. They are also home to a diverse range of wildlife that includes antelopes, giraffes, rhinos, lions, and some of the largest populations of elephants in Africa [5]. However, over the years, these ecosystems have experienced vast changes in their physical nature, which affect the roles they play as a result of land degradation caused by humans who clear land for cultivation [3]. Land degradation manifests itself in many forms, and the common way is through the transformation of the land from its natural state into man-made land use forms, e.g. from forest into farmlands. Management of the transitions and the new land cover forms creates chances for land degradation to occur. The miombo woodlands are affected by three main interacting disturbance factors namely people, wild fires, and wildlife. Anthropogenic activities center on the partial to complete clearance of woodland, conversion of woodland to cropland, excessive resource extraction and overgrazing, which lead to the modification or transformation of the ecosystem. Land cover change is a major driving force of habitat modification and has important implications for the distribution of savanna vegetation, ecology, and biodiversity [6–8]. Abrupt land cover change is continuously changing ecosystems, thus threatening sustainability of wildlife species, functionality of ecological system, and livelihoods [6, 7, 10]. This is the case for most communal areas in the semiarid areas of Zimbabwe.

Land use change is often the first consequence of population and economic growth, and it can be argued that low soil fertility, lack of infrastructure, and the presence of diseases have been the main factors preserving miombo [3, 7, 19]. However, due to increased demand for land for cultivation, a new dimension was created leading to massive land cover changes and degradation. In Zimbabwe, the demand for land can be traced back to the period of the 1950s and since then, the population has continuously increased, which in turn led to the clearing of land for farming and grazing of livestock.

These human activities have been happening in fragile miombo environments where the annual rainfall is below average (<600 mm per annum) and the soils are inherently infertile. The impact and extent of human activities on land in the miombo woodlands are not fully understood and have not been clearly investigated. This research, therefore, aims at using satellite images to quantify the land cover changes from 1990 to 2017 and through participatory GIS seeks to determine the drivers of these changes.

Vegetation cover change, change in species composition, and plant quality are often viewed as indicators of susceptibility to land degradation and its severity [17, 22, 27]. Causes of the land cover changes range from population increase, overgrazing, fuel wood extraction, timber extraction to wood cutting for the purposes of building [2, 5, 9, 10, 19]. Campbell and Mapaure [5] estimated the demand for firewood and calculated that 9,285,000 tonnes of wood are burnt in Zimbabwe every year, with an estimated 7,141,000 tonnes of wood consumed in communal areas only, representing 77% of the total firewood consumed in 1994. Campbell and Mapaure [5] also noted that the demand for firewood has been increasing over the period 1990–1996.

Several sensor systems operating in the visible and near-infrared (NIR) currently operational include the Landsat series, SPOT, AVHRR, and MODIS and these are extremely useful particularly for vegetation mapping [21]. The selection of the sensor data depends on a number of factors including spatial and temporal resolution as well as the cost of securing the data [18, 26]. For example, AVHRR data have a pixel resolution of 1 km × 1 km, which can be classified as coarse, but the images have a much higher re-visitation period that makes them useful in landscape-scale vegetation phenology studies [25–27]. Sabins [21] and Weng [26] used high-resolution Landsat satellite sensors for land cover characterization in different environments, and thus, they are widely adopted for that purpose. The very high spatial resolution images provide fine details on the ground and can be used as ground truth data, for example, Quick Bird images, IKONOS, and Hyperion data [14]. However, the cost of these images is prohibitive to cover large areas of study or for multi-temporal analysis [24]. As a result, Landsat images provide a balance between spatial resolution, temporal resolution, and cost, which make them popular with researchers. The application of remote sensing, with frequent repetitive image acquisition in multiple wavelengths and Geographic Information System (GIS) technologies, has been used as powerful tools to investigate, detect, and analyze habitat change [12, 21, 24, 26], where vegetation indices are the capstone of the field. Satellite imagery has, over the years, been used for land cover classification, land use monitoring, and assessment [19, 22, 26], through providing information on land features, their condition and distribution. Equally, it has proven to be valuable in qualitative and quantitative terrestrial land cover changes. Furthermore, applied in rangelands, remote sensing has the advantage of identifying early land degradation risks [13]. Its application is therefore essential in developing scientific principles that result in improved sound conclusions. GIS and remote sensing tools are used in conjunction with PGIS to understand the changes to the miombo woodlands as a result of increasing human and livestock populations.

1.1. Description of study area

The study was carried out in Nkayi District in Matabeleland North Province of Zimbabwe (see **Figure 1**). Nkayi District is located in Natural Region IV of Zimbabwe, which is characterized by low rainfall, high temperatures in the summer reaching up to 35°C, and infertile sandy soils. Rainfall ranges from 350 to 940 mm and averages 591 mm per annum. The district is subject to seasonal drought and long dry spells during the rainy season, which makes it unsuitable for rain-fed agriculture. The area can, however, support extensive livestock production. The natural vegetation of Nkayi District is typical dry Savanna dominated by the miombo woodland. Tree species are mainly *Brachystegia* species, *Baikiaea plurijuga, Julbernardia globiflora, Combretum* and *Terminalia* species, acacia species, *Peltophorum africanum, Albizia amara, Albizia harveyi, Euclea divinorum, Grewia* species, and *Kirkia acuminata*. The common grasses in natural woodlands include *Aristida* species, *Eragrostis* species, *Digitaria* species, *Cenchrus ciliaris, Enneapogon cenchroides, Pogonarthria squarrosa, Schmidtia pappophoroides*, and *Stipagrostis uniplumis* [7, 8].

1.2. Materials and methods

1.2.1. Satellite image preparation and pre-processing

A time series analysis of Landsat TM and ETM images was done in order to deduce land cover changes over time. Orthorectified satellite images path 171 row 73 covering region of study area

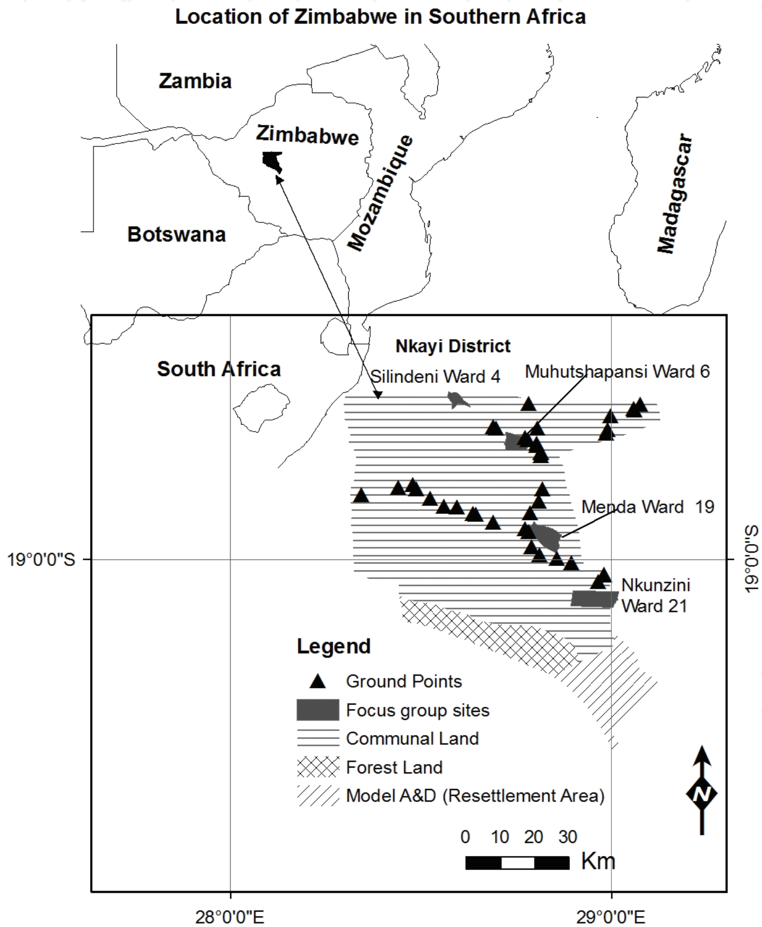

Figure 1. Location of Zimbabwe in southern Africa showing ground truth points in Nkayi District in Zimbabwe where the study was conducted.

(Nkayi District) were acquired from NASA, https://dds.cr.usgs.gov/. The satellite images were selected for the period toward the end of the vegetative growth from March up to beginning of May. This was done so that the contrast between vegetated areas and non-vegetated areas is clearly separable. The selected images had zero percent cloud cover, and were corrected for any geometric anomalies. The image for 2017 was georeferenced using Ground Control Points (GCPs) captured using Garmin Etrex 30, and the images for 2010, 2000, and 1990 were co-registered to the 2017 image in order to facilitate timeline comparison of land covers. In order to improve on the quality of the satellite images, the Digital Numbers (DNs) were converted to reflectance through a calibration process called normalization where Digital satellite numbers are converted to radiance and then radiance values are converted to sensor reflectance. This was done in order to correct for sun angle, sensor angle, and sensor height among other geometric distortions. The following formulas were used: $DN\ to\ Radiance\ =\ (Lmax - LMin)/255 * DN + LMIN$, and $Radiance\ to\ Reflectence\ =\ (d\pi * L\lambda * DN)/ESUN\lambda * Cos\Theta$.

where ρ is the planetary reflectance, L_λ is the spectral radiance at sensor's aperture, $ESUN_\lambda$ is the band-dependent mean solar exoatmospheric irradiance, θ is the solar zenith angle, and D is the earth-sun distance, in astronomical units.

1.2.2. Image classification

We used Envi 5.1 image analysis software to prepare and analyze the satellite images. Training data also known as end members in Spectral Angle Mapper used in the supervised classification technique were generated in the field using a GPS and then the Region of Interest polygons for each representative land cover was digitized on the image using the Regions of Interest (ROI) tool. The regions of interest that were digitized were woodlands, cultivated lands, disturbed woodlands which also included fallow lands, as well as water bodies. A supervised classification technique was employed to classify the land covers for each year. The classification was done using a combination of unsupervised K-Means, visual analysis, and the Spectral Angle Mapper algorithm. K-Means unsupervised classification was used to generate classes showing the general view of the area, which aided in training site selection. A supervised classification technique was applied in the form of the Spectral Angle Mapper (SAM), which is a physically based spectral classification technique that uses an n-dimensional angle to match pixels to reference spectra. This technique was used on calibrated reflectance data which is known to be relatively insensitive to illumination and albedo effects. The spectra for different classes were compared to typical spectra of known land features for the purpose of separating ambiguity features. In semiarid areas like Nkayi, it is difficult to use texture of the image because the land covers are always a mixture of different plant and grass species with distinct soil cover. At this point, visual interpretation techniques and prior knowledge were also employed to determine the features based on characteristics such as site, location, arrangement, and their shape.

1.2.3. Change detection analysis

After the supervised classification process, a land cover change matrix was calculated to show the direction of the changes. The land cover change matrix was calculated using the 1990 classified image as the input and the 2017 classified image as the output. The Change detection algorithm was used in Envi 5.1.

1.2.4. Participatory GIS analysis

The observed land cover changes were verified by the local communities through participatory GIS, as well as explaining the direction and causes of the land cover changes. The participatory GIS was carried out to verify the results of satellite image classification and also to explain the changes observed on satellite images. A stratified random sample was used to select four wards with two wards selected in the north while two wards were selected in the southern part of the district. In each ward, one village was selected for focus group discussions. On average, 35 participants were randomly selected from each village to participate in focus groups. Participants drew village resource maps for 1990 and for 2017 indicating the location of key resources within the villages. Plenary sessions were held during which the results from resource mapping and change pattern were further scrutinized and validated. The data sets from all the four focus groups were then collated, coded, and analyzed through use of Kenda matrices.

1.2.5. Accuracy assessment

The Kappa statistic and Google Earth Pro were used to assess the accuracy of the classification. The confusion matrix calculated from sampled points yielded an 88% Kappa while those sampled using Google Earth yielded a Kappa statistic of 91%.

2. Results

2.1. Spatial distribution of land covers and land cover change from 1990 to 2017

Land cover changes in Nkayi District were analyzed through the interpretation of Landsat TM and ETM images for 1990, 2000, 2010, and 2017. From the image classification process, four main land cover classes were identified. The classes were woodland, cultivated land, deforested/degraded land, and water bodies (**Figure 2**). Although the spatial extent of sand beds was limited, they were delineated by their high reflectance values. The spatial distribution of these land covers for each year is highlighted in **Figure 2**.

2.1.1. Distribution of miombo woodlands

Wooded areas were defined as a range of dense woody trees mixed with grass species. Woodland areas in Nkayi District were divided into three categories comprising the demarcated national forest land forming the Gwampa forest on the southwestern part of the district, the communally managed woodlands and those in the resettlement areas formerly known as commercial farms before the land reform program. Gwampa Demarcated Forest is managed

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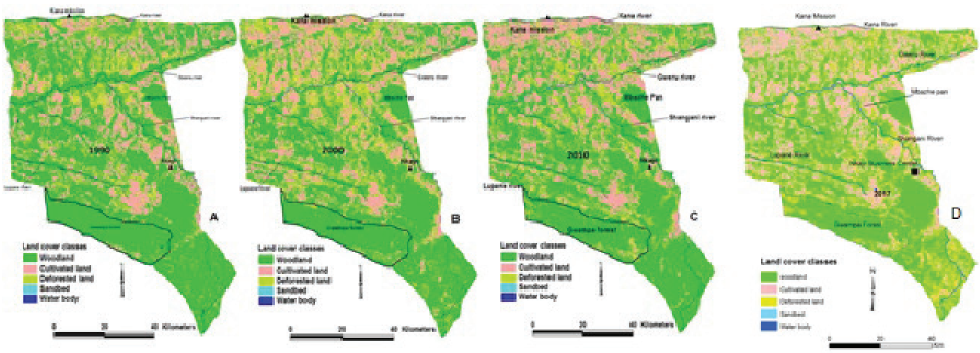

Figure 2. Distribution of land covers in Nkayi District from 1990 to 2017.

by the Forestry Commission under the Forestry Commission Act of 1996. Also found in the southern part of the district were resettlement farms. These were formerly commercial farms that were resettled to small-scale farms under the land reform models A2 and D. The rest of the district was occupied by communal woodlands stretching from the middle of the district up to the northern part of the district. Here, the fragmented woody cover of mainly *Brachystegia spp*. woodlands in uplands and mixed *Brachystegia spp*. and acacia toward the valleys is dominant. Woodlands were the dominant land cover by area/size in the whole of Nkayi District, covering 58% in 1990 before dropping to 50% and subsequently 47% in 2017 (**Table 1**). Communal areas had a very low proportion of woodlands comprising only 54% of the land area in 1990 before dropping to 44% in 2017. Land allocated to cultivation activities in communal areas was very high, 42% in 1990, and continues to increase as the demand increased. In contrast, woodlands in the resettlement areas occupied above 70% of the total land area in the same year. This indicates that the majority of the land in communal areas is allocated to cultivation (42%)-related activities, whereas in the resettlement areas, the majority of the land is woodland.

2.1.2. Spatial distribution of cultivated land

A large proportion of the land in Nkayi District is used for crop production during the rainy season between November and April and then becomes open for grazing after harvest time, between July and October. Livestock grazing is communal-based where unrestricted movement is permitted during the dry season. The total land under cultivation in the whole district in 1990 was 31% and increased to 36% in 2017 (**Table 1**). The majority (98%) of the cultivated lands were located in the communal areas, whereas only 2% were found in the resettlement area. Field observations showed that a very large proportion of these fields were on sandy soils, while in contrast, the proportion of the cultivated lands in the resettled areas were on clay soils that were highly fertile and suitable for crop production.

Land cover type	Total land cover (000 ha)				% of Land cover			
	1990	2000	2010	2017	1990	2000	2010	2017
Woodland	306	257	262	252	57.8	49.5	50	47
Cultivated land	164	167	186	193	31	31.8	35	36
Deforested land	58	97	81	84	11	18.5	14.9	16
Water	1	0.7	0.5	2	0.2	0.13	0.1	0.3

Table 1. Land cover change in Nkayi District: 1990-2017.

2.1.3. Distribution of deforested land

The deforested land consisted of open barren land, sparsely distributed woody and grass species, and abandoned fields which had not fully transitioned back to woodland. Most deforested lands were found close to cultivated lands in the form of fallow lands and also near homesteads where livestock graze during the planting season. Deforestation was also associated with areas around water points, as a result of trampling by livestock. During plowing, oxen used for ox-drawn plows graze in these areas. Together with fields and woodlands, deforested lands provided forage for the rest of the livestock and formed an important source of livestock feed. Since they were mainly close to homesteads, they were used as temporary grazing areas during the times of emergencies, as such were a crucial forage source for livestock. Up to 11% of the land was occupied by deforested lands in 1990 (**Table 1**) which translated to 58,000 hectares of land rising to 84,000 hectares in 2017. Of this, about 68% were found in the communal areas, while 32% were found in the resettled areas.

2.1.4. Water bodies

Water bodies such as dams, open wells, and boreholes were very scarce yet so vital in the district. Although they occupy much less than 1% (**Table 1**) of the land area in Nkayi, their availability and distribution play an important role in making optimal use of the land. They supply drinking water for domestic and livestock purposes and also used for irrigation services [11]. Three of the four surveyed villages had access to an open water source located within their villages. Access to water sources is a big challenge in the district, as witnessed by less than 1% of water sources available and there is huge competition for water between humans and livestock. This has limited the development of agricultural activities in the district. Agricultural extension officers also acknowledged that the scarcity of water sources in the district hindered the development of irrigation schemes. They stated that there were less than five operational irrigation schemes in the whole district. However, they revealed that small individual gardens were available along the major rivers such as Gweru, Shangani, and Kana rivers, and these were only enough to serve small local communities.

2.2. Spatial distribution of vegetation condition

Function and health of the miombo woodlands is critical for their survival and the life they support. Normalized Difference Vegetation Index (NDVI) for the district was calculated for 2017 to assess the distribution of vegetation healthiness across the districts. **Figure 3** shows the distribution of vegetation vigor across Nkayi District. High shades of red (0.4–0.62) depict healthy and dense vegetation, which were mainly woodlands inside the Gwampa forest and resettlement areas. Green shades represented sparse vegetation and grasslands with signs of degradation represented in yellow shades while severely degraded areas were represented in shades of light blue to light green and these marked the transitions from woodland to degraded land and from cultivated land to degraded land.

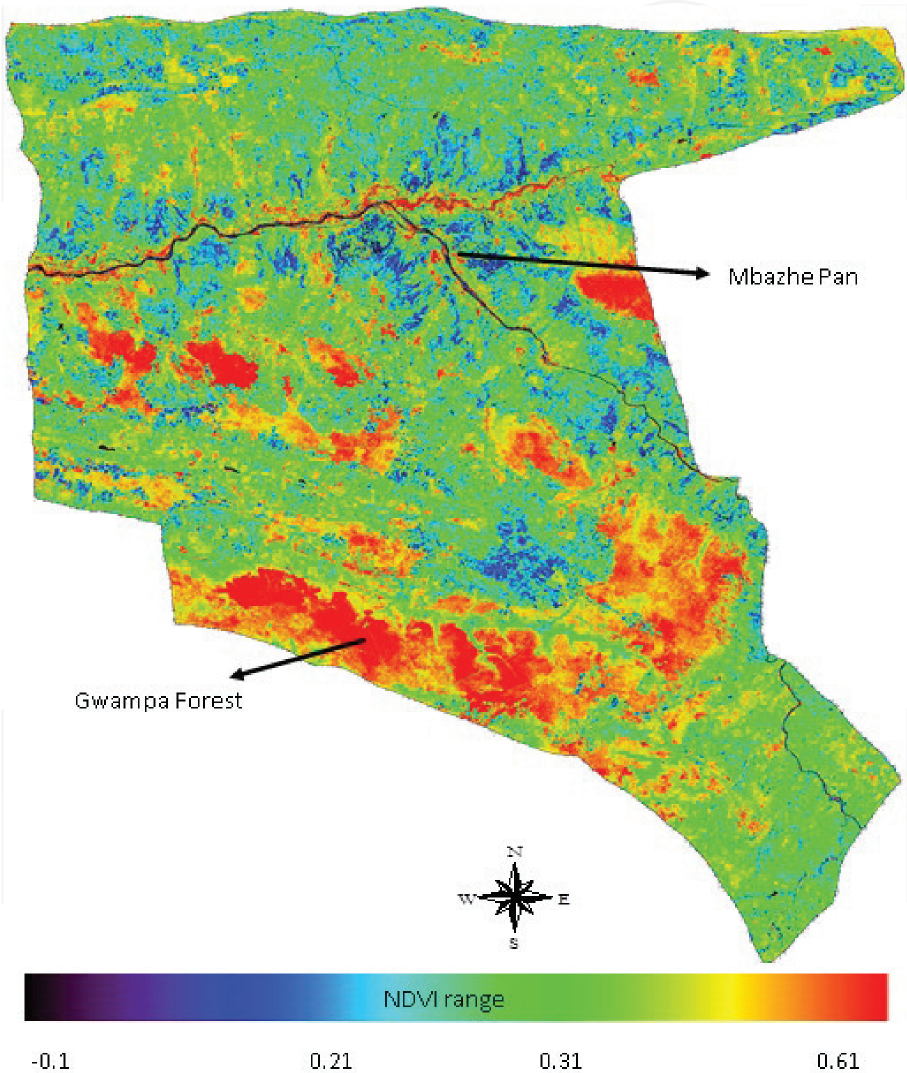

Figure 3. NDVI image showing degraded land in varying shades of blue while healthy woodland is shown in shades of red.

2.3. Magnitude and rate of land cover changes

The study showed widespread changes in land cover in Nkayi District during the last two and a half decades. This was evidenced by the widespread decrease of woodland in the communal areas and a visible increase of cultivated and deforested lands as shown in **Tables 1** and **2**.

Woodlands were decreasing at a rate of 0.76% per annum, translating to an average loss of 2300 ha per annum. On the other hand, cultivated land and deforested lands were increasing at the rates of 1.3 and 1.8% per annum, respectively (**Table 2**), which meant that they were increasing at 1800 and 800 ha per annum respectively. Considering the decrease in woodland against the increase in cultivated land and deforested land, it was clear that woodland declined because of expansion of cultivated land. There were also observed changes of deforested/degraded land being replaced by cultivated land especially between 2000 and 2010 images. This can be explained by the intricate shifting of cultivation by farmers whereby some lands left as fallow for some time were reclaimed after the ones being cultivated lost fertility, or as a result of inheritance of fallow lands by own children or relatives. Besides showing a general decrease in degraded/deforested lands, the overall trend showed that there were fluctuations in their extent from time to time.

2.4. Land cover change matrix 1990: 2017: Direction of change

Almost all the land cover classes went through some changes, with deforested and cultivated lands showing huge likelihood to changes. Twenty-two percent of the deforested lands remained unchanged between 1990 and 2017. Woodlands had the least likelihood to change as witnessed by 66% remaining unchanged between 1990 and 2017. Cultivated lands and water bodies had 55 and 40% of the areas unchanged. Only wooded areas showed a general decline of 11% in land covers during the study period, while cultivated lands, deforested land, and water bodies all showed an increase during the same period with deforested lands leading at 25% gain. Cultivated lands gained 31 and 13%, respectively, from woodlands and deforested land, while during the same period, fields lost 21 and 41% to woodlands and deforested areas,

Change detection statistics as percentages						
Land cover type	**Water**	**Forest**	**Deforested**	**field**	**Row total**	**Class total**
Water	**40**	0	1	0	98	100
Forest	28	**66**	28	31	100	100
Deforested	4	13	**22**	13	100	100
Field	27	21	49	**55**	100	100
Class total	100	100	100	100	0	0
Class changes	60	34	78	45	0	0
Image difference	87	−11	25	12	0	0

Table 2. Trade-offs among forest, cultivated land, field, and water bodies depicting direction of land change between 1990 and 2017.

respectively. Deforested land gained most of its land from cultivated lands in the form of fallowing, which was very common in the district. Regeneration was slow as witnessed by only 13% of deforested lands in 1990 detected as woodlands in 2017.

3. Discussion and conclusions

3.1. Understanding the direction of land cover changes

Analysis of satellite images revealed that there are complex and widespread land cover changes in Nkayi over the two and a half decades from 1990 to 2017. In general, there has been an increase in area under croplands and deforested lands. The increasing cultivated lands were mainly as a result of the conversion of woodland into croplands. As a result, 31% of woodlands were consumed by field lands since 1990. On the other hand, due to soil fertility challenges, some fields were being abandoned and left to regenerate back to woodlands. This resulted in 21% of cultivated lands detected as woodlands in 2017. During the fallowing periods, fallow lands were also being reclaimed for cultivation. These movements suggest that increase in cropland was through an intermediate conversion of woodlands into croplands and then deforested lands. In the process, old fields are created when cultivated lands are left uncultivated for a time long enough to regenerate into some sort of disturbed lands. As the old fields grow older, tree and grass species also grow, which turn the old field into woodland. Some old fields are also reclaimed back to croplands after being left for a couple of years as follows. There is also a direct movement from woodland to deforested land which is caused by direct impacts of overgrazing and wood extraction. During the first 10 years, farmers cleared a lot of woodland land and the decrease is closely matching that of increasing deforested land and cultivated land for crop production.

3.2. Drivers of land cover changes

Land cover changes have been noted all over the communal areas in Nkayi District, and the causes of these changes range from increase in household numbers and associated woodland clearing for agriculture, overgrazing by livestock, and soil infertility. The main driver for the expansion of croplands into forests appears to be the increase in household numbers. This is in contrast with the findings by Kamusoko and Aniya [15], Mapedza et al. [19], and Sibanda et al. [23] who cited population increase as the main factor in expansion of croplands in nearby Gokwe. Population increase did not necessarily result in increase in field sizes per se, but rather a new homestead is mandatorily allocated a field which basically means that a new area is opened up in the woodlands. In Nkayi, it was, however, noted that population increase was not a major factor as the number of people did not increase much, but the bigger change was noticed in household numbers. Population figures from the Zimbabwe National Census for the period 1992–2002 showed that household numbers increased from 110,161 to 111,118 because of the positive balance between births and deaths as well as immigration. Information from focus group discussions also indicates that these new immigrant households regularly clear land for establishing new crop fields and this led to an upsurge in area under cultivated land.

The other driver of land cover change is the impact of livestock on the rangelands (both forest land and degraded land). A decrease in forest land is closely related to a reduction in available rangeland. Feed shortages were the major setback for farmers in Nkayi District and elsewhere in miombo woodlands as reported by Hamandawana et al. [9] and Homann et al. [11]. The study also noted the same link between livestock feed shortages and shrinking of woodlands with the total livestock population remaining constant over the past 19 years, this means that livestock density increase as rangelands decrease. Woodlands' contribution to livestock feed, however, needs to be ascertained as more often, the quality of the grass species found there is of poor nutritional value. Also, increasing lands that are deforested highlight the decreasing amount of health rangelands available, i.e. changes in plant species composition.

Soil infertility is also noted in farmer discussions as another contributing driver of land cover changes. When farmers had worked in their fields since the1950s and through generations of use the fields became infertile and needed huge investments in soil fertility management to boost production. Faced with this problem, farmer group discussions indicated that they either cleared virgin land or extended their fields into the grazing areas. In the process, they clear vast lands for cultivation and the process starts again. On the other hand, old fields are then left as fallow lands. These, according to farmers, are left for the future generation and would be utilized and managed by the families concerned. Fallow lands are important in mitigating the impacts of wind erosion. They allow the soils to re-gain nutrients and provide an open space for cattle grazing. They are also used to grow thatching grass, fencing and building poles and as reserve grazing for the household's livestock only. They remain private and as such are not open for the whole community to utilize.

There are also, other socioeconomic factors which limit the ability of farmers to cope with the changing socioeconomic conditions and in a way contributing to land cover changes. People are relatively poor and are facing a number of challenges including costs of school fees, medical expenses, sourcing farming inputs and food to an extent that they are left with little or no resources to invest in productivity-enhancing technologies. This is forcing farmers to continue practicing unsustainable farming.

The decrease in forest land means that more land is exposed to heat, raindrop impact and runoff which increase the incidence of erosion. It also means that by reducing vegetation density on degraded lands, the loose topsoil is washed away easily, thereby increasing its loss. Eroded soils are deposited into rivers and dams which reduce their holding capacity and this contributes to dry season water shortages in the district. Again, reducing vegetation cover results in increased runoff and less infiltration of rainwater which also means that the groundwater recharge system is reduced therefore causing early drying up of wells and boreholes.

3.3. Vegetation healthy distribution

Woodlands, shown in different shades of red (**Figure 2**), were concentrated in the southern conservation area (Gwampa Demarcated Forest), and fragmented in the communal areas in the northern parts including the Mbazhe Pan area near the eastern boundary of the district. Gwampa Demarcated Forest Reserve has considerable health vegetation (high shades of red) because the area is reserved and is closer to Lake Alice, which is popular for its waterfowl and hence became part of the protected area [20]. The Mbazhe Pan also boasts of healthy vegetation because it was originally designated as a bird sanctuary in terms of the Parks and Wildlife Act (1975) (revised 1996). It is endowed with natural beautiful scenery, wetland and woodland habitats, bird life, and other biodiversity of importance [20]. Since the image was acquired during the post-harvest period (June), cultivated land and degraded rangelands had little or no photosynthetic activity as most of the crop residues and grasses had dried up or been removed by livestock resulting in bare surfaces hence low NDVI values of less than 0.2. Communities that surround Mbazhe Pan Sanctuary pose the greatest threat to the wetland through livestock grazing, siltation, erosion, and damage to infrastructure. As a result, the fence around the pan had been vandalized. Part of the wall had been destroyed and water drains into the Shangani River, which is less than a kilometer away. Signs of degradation and poor vegetation health were noticeable on the boundaries of the pan (**Figure 3**).

3.4. Conclusions

Integration of remote sensing and PGIS opened a better understanding of the drivers of land covers as there was a better way of interpreting the results by comparing classified images and people's perceptions. The study, therefore, concluded that the process of expanding croplands comes at the expense of forest and grazing lands. In terms of grazing land, the area available for grazing has decreased even though the herd size remained constant over the same period. This reduction has placed a lot of pressure on the ever-decreasing rangelands. The potential of the grazing land to offer enough goods and services such as high-quality biomass has been reduced. As a result, natural endowments of the land should be supplemented with sustainable inputs that improve the productivity of the land. The expanding crop fields must compensate for the loss of rangelands by producing equal or more biomass for feed as the rangelands did. Feed technologies, such as using crop residues as feed, using dual sweet sorghum cultivars, and intercropping conventional crops with fodder [1, 3], increase the productivity of the crop system to augment feed for livestock. Studies in the Philippines showed increased benefits in terms of feed quality and yield per hectare for intercropped sorghum and forage legumes, and they produce improved quality and quantity of sorghum fodder [1]. If these technologies are carefully practiced in semiarid regions, they can potentially free a lot of pressure on rangelands, by producing extra feed.

The study recommends that Sub-Saharan Africa needs to capture, store, and recycle land resources whenever possible to improve the production system of the land resources. Studies by United Nation Convention to Combat Desertification (UNCCD) in 2004 acknowledge that "Even though water and nutrients are scarce in dry lands, much is still wasted through runoff, unproductive livestock systems, and wasteful irrigation system". Fallow lands can present a good entry point in managing the rangelands. Fallow lands are reserved as private land as they are constantly linked to the occupiers as grazing reserves or fallow fields. In most cases, they are also found closer to homes and this would mean that they are easily accessible and manageable. In this case, it can be better if these are turned into feedlots with high palatable grass species such as *bana* grass grown. This might enhance the productivity of such lands and at the same time providing feeding for livestock.

The study also recommends that managing the herd size, age, and health is tantamount to reducing overgrazing. Sound livestock management practices such as timing the off-take of cattle economically improve the system in that an animal is moved out of the system through sale before it has eaten too much feed and/or is too old. In addition, money generated can be invested back in the system to improve the health of other animals, hence improving their productivity.

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