OSUN GEOGRAPHICAL REVIEW

Journal of the Department of Geography,
Osun State University, State of Osun, Nigeria

Volume 5, 2022

ISSN: 2695 - 1959

Published by the
Department of Geography, Osun State University,
State of Osun, Nigeria

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OSUN GEOGRAPHICAL REVIEW
Published by the Department of Geography, Osun State University, State of Osun, Nigeria
ISSN: 2695 - 1959 Volume 5, 2022; 113 - 120

GEOSPATIAL MONITORING OF VEGETATION VIGOUR IN KUYAMBANA GAME RESERVE, ZAMFARA STATE, NORTHWESTERN NIGERIA

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Abstract
Monitoring vegetation vigour is necessary to keep track of the status of an ecosystem and its ability to provide adequate and qualitative ecosystem goods and services. Vegetation vigour, to a considerable extent, determines the health, functions, and biological diversity in any ecosystem. However, the standard ground-based methods are labour and time expensive, making it impossible to assess vegetation vigour across large areas consistently. Therefore, this paper attempts to monitor the vegetation vigour in Kuyambana Game Reserve, Zamfara State, Nigeria, a vast forest region set aside by the government to preserve plants and animals, particularly endangered species. However, in addition to natural disturbances, armed banditry and cattle rustling in recent years constitute another type of disturbance that could harm the environment. From 2000 to 2020, the game reserve vegetation vigour was tracked using the Normalised Difference Vegetation Index (NDVI) produced by the Moderate-resolution Imaging Spectroradiometer (MODIS). The results showed a persistent drop in vegetation vigour (over 48%) that might be attributable to anthropogenic and natural sources. The study concluded that it is crucial to provide proper security and afforestation and enforce environmental regulations, among other steps, to protect the wildlife reserve and its ecosystem.

Keywords: Biological diversity, Monitoring, Vegetation vigour, Sustainable development.

Introduction

It is impossible to overstate the value of vegetation to the global environment. It is a connecting point between the earth's lithosphere, hydrosphere and atmosphere (Adepoju, Adelabu, & Fashae, 2019; Gabriele, Brumana, Previtali, & Cazzani, 2022; Jibrillah, Jaafar, & Choy, 2019). Vegetation dynamics, which are the main driver of primary production, heavily influence ecosystem structure and function as well as its capacity to produce both quantitative and qualitative products and services that support human subsistence and economic development (Ibañez-Alvarez et al., 2022; Jibrillah, Choy, & Jaafar, 2018; Jibrillah et al., 2019). Additionally, vegetation is essential for maintaining a stable climate system, preventing soil erosion and providing food and shelter for animal communities '–"(Adepoju et al., 2019; Chen et al., 2021; Jibrillah et al., 2019; Msoffe, Nauss, & Zeuss, 2020; Tang et al., 2015). Therefore, it is essential to regularly examine the condition of the vegetation to spot any unfavourable changes that can harm the ecosystem as a whole. Due to its fragility and people's excessive reliance on it for their livelihood, this is particularly crucial in the dryland ecology like that of the Kuyambana Game Reserve (Jibrillah et al., 2018, 2019).

However, this task might be challenging, time-consuming and resource intensive if standard land surveying methods were used. The issue is worsened because vegetation disturbance does not occur in a clear-cut, linear pattern. Undoubtedly, using remote sensing information from earth observation satellites like Landsat, Sentinel, and MODIS might be helpful. In recent years, remote sensing has developed into a powerful tool for tracking local, regional and global environmental problems. Data collected by remote sensing satellites is a reliable source of information for tracking and evaluating the kind, structure and condition of vegetation –(Bukar, Bukar, Bakari, & Mbaya, 2020; Jibrillah et al., 2018; Jonckheere et al., 2004; Pervez, Mcnally, Arsenault, & Budde, 2021; Rapport, Costanza, & McMichael, 1998; Vogelmann, Xian, Homer, & Tolk, 2012b).

This study uses the Normalised Difference Vegetation Index (NDVI) acquired by the Moderate Resolution Imaging Spectrometer (MODIS) on board the National Aeronautics and Space Administration (NASA) TERRA/AQUA Earth Observation Satellite as a substitute for vegetation productivity to track vegetation vigour in the Kuyambana Game reserve in Zamfara State Northwestern Nigeria. The Kuyambana Game Reserve is a sizable woodland area set aside by the government to protect plants and animals, particularly endangered species. However, in addition to the natural disruptions, the region has recently been severely disturbed by the action of armed bandits and cattle rustlers, making it nearly impossible to enter due to complicated security issues. This emphasises the necessity of monitoring and evaluating the vegetation state in the region to provide policymakers with factual data for effective intervention strategies.

One of the most important indications of the vegetation status in any given ecosystem is the vigour of the vegetation. It describes plants' dynamic, healthy, evenly distributed and vigorous growth. It is a crucial environmental quality index and one of the most important indicators of ecosystem health (Brandt et al., 2016; Fensholt et al., 2015; Higginbottom & Symeonakis, 2014). One of the key dryland ecosystem services for human needs is primary productivity, which is determined by vegetation vigour (MEA, 2005; Watson et al., 2005). Numerous studies have utilised NDVI as a substitute for vegetation productivity on land, which helps assess many aspects of plants, such as its vigour –'(Chen et al., 2021; Jibrillah et al., 2018; Pervez et al., 2021; Rapport, Gaudet, et al., 1998). Healthy vegetation absorbs more in the red and reflects more in the infrared region of the electromagnetic spectrum, and this ratio is used to characterised and monitor many characteristics of vegetation (Cao, Chen, Matsushita, & Imura, 2010; Z. Li, Xu, & Guo, 2014; McFeeters, 2013; Pettorelli et al., 2014).

Already, it has been established that there is a strong correlation between NDVI and vegetation vigour (Guo, Zhang, Wilmshurst, & Sissons, 2005; Jibrillah, 2018a; Jibrillah et al., 2018; B. Li, Ti, Zhao, & Yan, 2016; Mcdowell et al., 2014; Rapport, Costanza, et al., 1998; Zhou et al., 2017). Therefore, in this study, MODIS-NDVI is used to monitor the vegetation health in the study area.

Study Area

The Kuyambana Game Reserve (KGS) in Maru Local Government Area, Zamfara State, Nigeria, serves as the study's location. The game reserve is located roughly between latitudes 11^0 40' and 12^0 20' North of the equator and between longitudes 6^0 10' and 6^0 30' East of the Greenwich Meridian (Figure 1). Talata Mafara and Anka Local Government Areas to the West, Maradun Local Government to the North, Bungudu to the East and the remainder of Maru Local Government Area to the South are its neighbours.

The region is characterised by a tropical continental climate with alternating wet and dry seasons. Throughout the year, the temperatures are typically high and can reach as high as 40^0 Celsius, especially between April and June. Low and erratic rainfalls, both in terms of volume and duration. Most of the year's rainfall ranges from 600 to 700 mm from June to September (NIMET, 2015). The vegetation around the game reserve is a typical Sudan Savannah, with drought-resistant trees including baobab, acacia, tamarind, mahogany, shea butter and locust bean interspersed amongst the grasses and stunted thorny shrubs (Davis 1982).

The main economic activities of the inhabitants living close to the game reserve include crop cultivation, animal rearing and fishing along significant rivers and streams. The main crops grown in upland regions include grains like millet, maise, sorghum and legumes like beans and groundnut. Typically, irrigation farming is only practised in the flood plains and banks of the largest rivers, where crops like rice, tomatoes, onions and garlic are grown. Along the Sokoto and Rima rivers and several ephemeral streams and ponds, some locals also practice artisanal fishing. Many residents in the region have recently been forced to pursue certain off-farm activities as a way of income diversification throughout both wet and dry seasons due to diminishing agricultural output and the ensuing declining revenue from agriculture, animal husbandry and fishing (Iliya 1999).

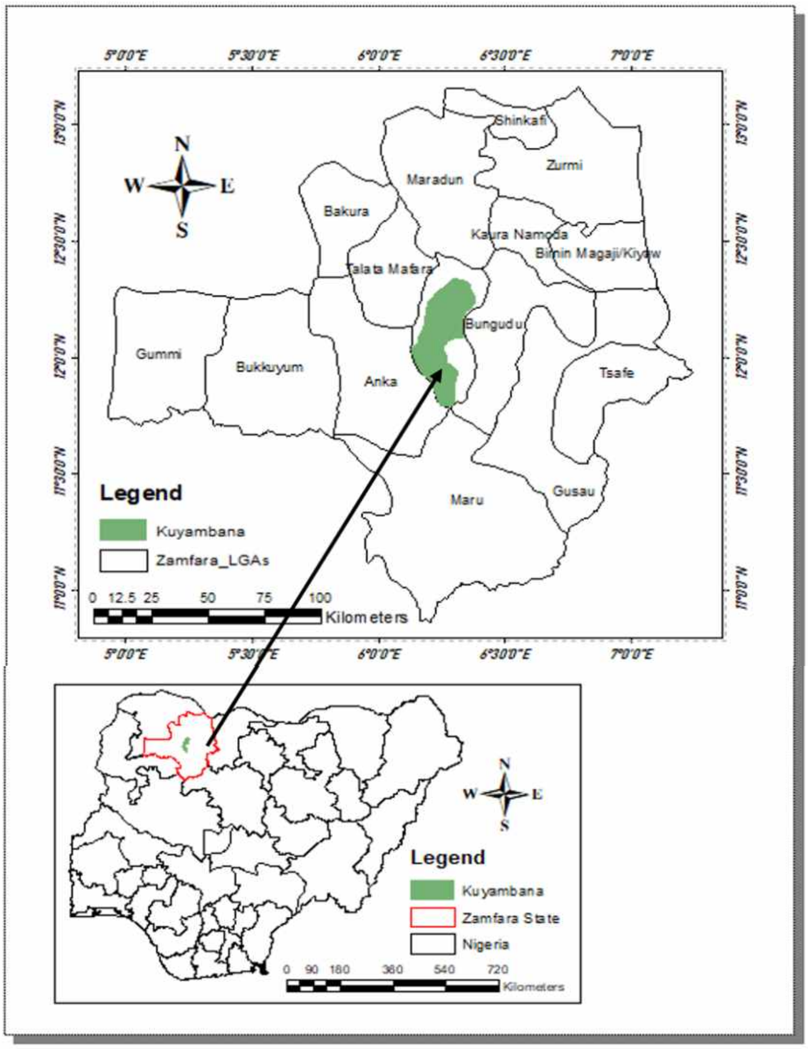

Figure 1: the Study Area.

Material and Methods

The main information used in this study was obtained from MODIS-NDVI satellite imageries (MOD13Q1V6) of the study area taken during 20 years (2001 - 2020) and downloaded from the United States Geological Survey (USGS) via Earth Explorer. The Moderate-resolution Imaging Spectroradiometer (MODIS) is a key earth observation sensor on NASA's Terra (EOS AM) and Aqua (EOS PM) satellite product MODIS-NDVI. By fussing the strength of AVHRR and Landsat sensors, MODIS-NDVI offers more effective worldwide monitoring of the earth's surface. One of the results of MODIS, the Normalised Difference Vegetation Index (NDVI), is intended to provide consistent spatial and temporal comparisons of vegetation status utilising blue, red and near-infrared reflectance centred at 469 nanometres, 645 nanometres and 858 nanometres respectively (Didan 2015). The information is derived from the atmospherically corrected bi-directional surface reflectance clean of water, clouds, heavy aerosols, and cloud shadows. Every 16 days, 250-meter spatially resolution MOD13Q1.V6 data are made available. Earth Explorer was used to downloading 460 images (23 per year), processed and used in this study. The images were obtained from the official United States Geological Survey (USGS) website and span the years 2001 to 2020. The fact that the data is frequently utilised for global monitoring of vegetation conditions and land cover changes influenced the selection of MOD 13Q1. V6. Additionally, the information can be used to model regional and local climate, global biogeochemical and hydrologic processes, and land surface biophysical characteristics and activities like primary production and land cover conversion (Didan 2015). The dataset is also appropriate for studying changes in the ecosystem's health, structure and functions

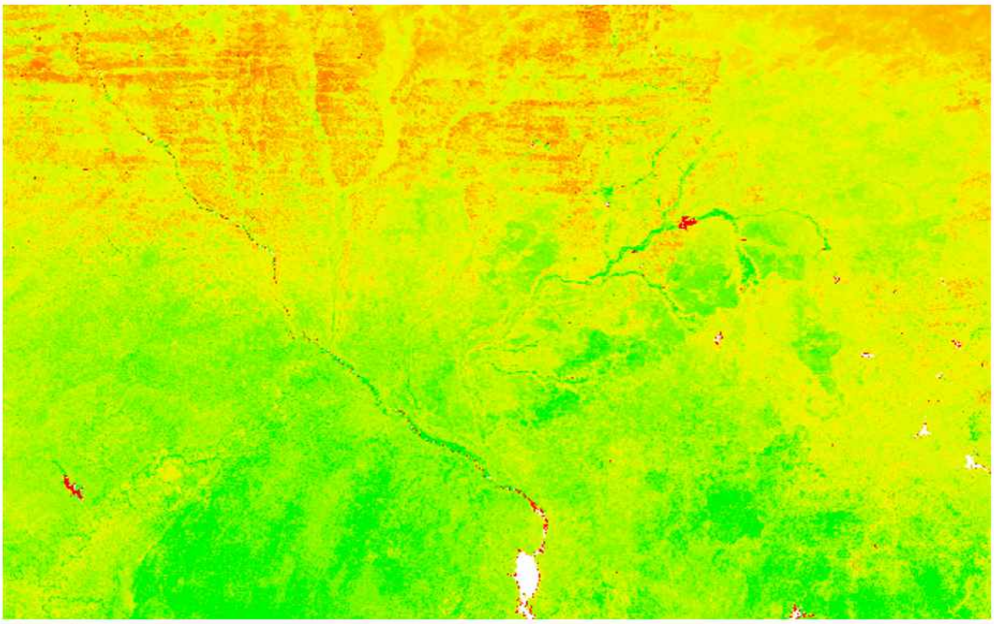

Figure 2: MOD13Q1. V6 MODIS-NDVI Image

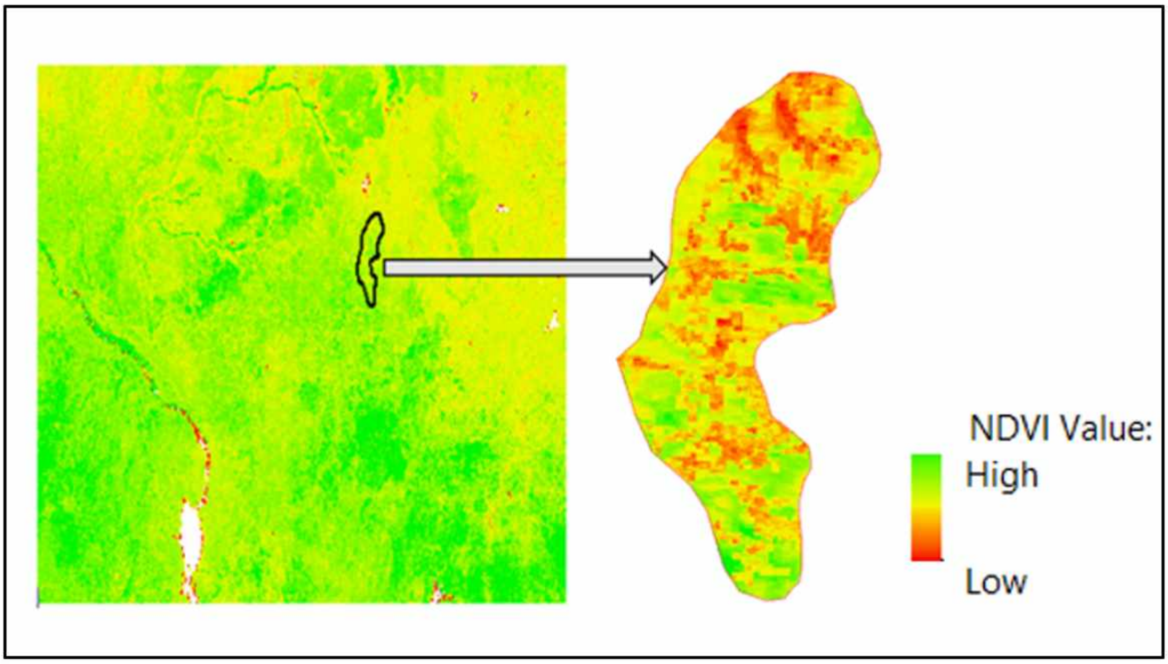

Figure 3: Sub-set Study Area

because of its 16-day temporal and 250-meter spatial resolution. A sample of MOD13Q1.V6 MODIS-NDVI data is shown in Figure 2. NDVI is thus calculated as NIR – RED / NIR + RED where NIR represent reflected near-infrared light and RED reflected red glow of the electromagnetic spectrum. The result is presented using values ranging from -1 to +1, with values from -1 to 0.1 representing different non-vegetative surfaces such as water bodies, bare soils and urban concrete surface, while values from 0.2 to 1 means a different shade of vegetative cover —'(Chauvenet, Reise, Kümpel, & Pettorelli, 2015; J. Chen et al., 2004).

The following image processing operations are performed on the acquired data: extraction of NDVI sub-dataset from the series of datasets contained in "MOD13Q1.V6" vegetation indices data; raster calculation to rescale the data range to the original NDVI range of -1000 to 1000 to the usual NDVI scale of "-1 to +1"; geometric transformation to re-project the original dataset from sinusoidal projection to WGS 84; data sub-setting to clip the study area.

ArcGIS 10.4 Software is used for all of these operations. A study area that was excised from the larger MOD13Q1.V6 sub-dataset is shown in Figure 3 below. The maximum NDVI value for the 32 images in a year was added, and their averages were taken to create $NDVI_{AL}$. This was used to illustrate the game reserve's annual vegetation vigour in the game reserve.

Results and Discussion

From 2001 to 2020, the estimated yearly vegetation vigour in Kuyambana Game reserve is shown in Table 1 and Figure 4. The result shows a downward tendency from more than 0.7 in 2001 to just about 0.4 in 2020. There is clear evidence of inter-annual variability and a slow loss of ecological vitality. The NDVI integral's depiction of the inter-annual variation in vegetation vigour reflects a variety of elements, including the annual variation in rainfall quantity and frequency as well as plant production from the previous year (Jibrillah, 2018b; Jonckheere et al., 2004; Paruelo, Epstein, Lauenroth, & Burke, 2013; Zhu et al., 2014).

Table 1: Vegetation Vigour in the Study Area

Year	Vegetation Vigour
2001	0.74
2002	0.70
2003	0.68
2004	0.67
2005	0.67
2006	0.66
2007	0.65
2008	0.63
2009	0.61
2010	0.63
2011	0.62
2012	0.60
2013	0.55
2014	0.53
2015	0.52
2016	0.52
2017	0.45
2018	0.44
2019	0.43
2020	0.40

The most critical concern, however, is the steady loss in vegetation vigour over time, as shown in Figure 4. This decline may destroy the ecosystem if quick action is not taken to stop it. Because an ecosystem is such a tightly knit system of living things in their environment, if one component is affected, a ripple effect can start that could eventually endanger the entire ecosystem. This is because vegetation is a quantifiable, vital and sensitive component and indicator of ecosystem health and functions (Casper, 2010). This scenario will have multiple implications for the area's ecosystem and inhabitants. Some of these implications may include increasing land degradation leading to decreased food and pasture production and poor production of other essential goods and services such as water and air purification, erosion and flood control, among others. This could also lead to increased pressure and competition on degrading resources such as agricultural land, grazing land and water, leading to conflicts and migrations.

This scenario is comparable to what Rapport et al. (1998) referred to as "Ecosystem Distress Syndrome" (EDS), which they said is common in both aquatic and terrestrial ecosystems. They also noted that many ecosystems worldwide are unhealthy, and this impairs their ability to support the delivery of goods and services essential to human existence and economic progress. These environmental changes are typically slow-moving and frequently go unnoticed unless deliberate efforts are made to study and monitor them. Still, their cumulative long-term effects could be extremely detrimental to the ecosystem and the way of life of the local population. The long-term interaction of several drivers of ecosystem changes in the study area, such as overgrazing, over-cultivation, infestation by pests and diseases, drought, flooding, natural successions and other climate change and human-induced modification of vegetation cover results in these typically subtle changes that occur within the state of vegetation communities and beyond the normal phenological cycles. Although this change occurs gradually, its cumulative long-term effects could have a significant impact on a variety of ecosystem processes and components, which could modify the carbon balance, biogeochemical cycles, microclimate and biodiversity (Lovett et al., 2007; Rose et al., 2015; Vogelmann, Xian, Homer, & Tolk, 2012a; Vogelmann et al., 2012b). In particular, vegetation protects soil from erosion, provides sources of domestic energy, pasture and habitat for livestock and other wild animals, as well as food, shelter, and raw materials for man. The vegetation's health greatly influences all ecological products and services. Therefore, a loss in these crucial ecosystem products and services would undoubtedly result from declining vegetation vigour in the Kuyambana Game Reserve.

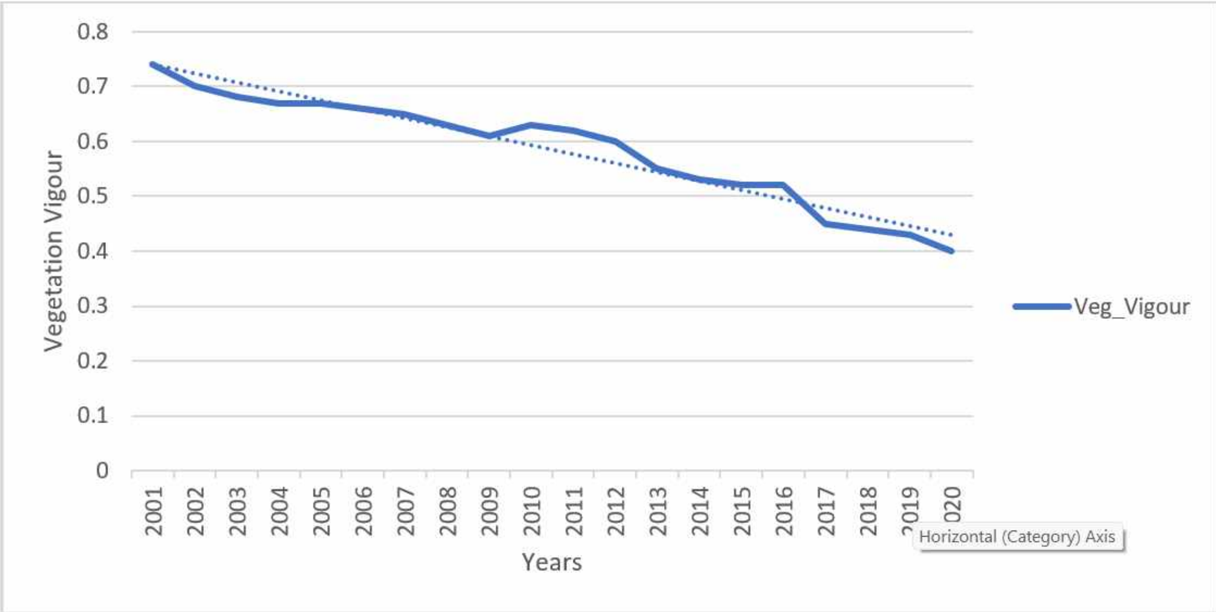

Figure 4: Ecosystem Vigour in Kuyambana Game Reserve

Conclusion and Recommendations

This study proved that the vegetation vigour has been declining in the Kuyambana Game Reserve, a condition known as Ecosystem Distress Syndrome that affects terrestrial and aquatic ecosystems. Vegetation vigour decreased by nearly 48% between 2001 and 2020, from 0.74 in 2001 to 0.40 in 2020. The recent upheavals brought on by the actions of armed bandits, and cattle rustlers are just one example of the anthropogenic and natural causes of this predicament. The ecosystem's capacity to deliver the essential services and goods required for human subsistence and economic growth is also affected. Some of the implications of this development would include increased land degradations such as soil erosion and desertification; reduction in food and pasture production; increasing pressure on land and its resources; food shortage and increased poverty; conflicts over land and its resource as well as migrations.

Effective intervention measures must be implemented by all parties to stop this terrible trend and maintain the game reserves rich in flora and fauna. This will require, among others: the provision of adequate and effective security within and around the game reserve to check the activities of armed bandits and cattle rustlers, which constate the significant source of anthropogenic disturbance in the game reserve in recent times. Regular and effective environmental monitoring and assessment. This will serve multiple purposes as it will help track the condition of the physical environment, detect negative changes in the structure and functions of the ecosystem, and assess the effectiveness of mitigation policies and programmes. Formulating and enforcing appropriate environmental protection policies and laws to check undesirable land management practices such as overgrazing, over-cultivation and indiscriminate cutting of trees for fuel and other domestic uses. Provision of alternative sources of energy and means of livelihood that are less dependent on the physical environment. This could be achieved by training the farmers around the game reserve to practice Agroforestry, involving the integration of crop farming, livestock and raising of trees to provide fuel, fruits, forage etc. These are practical measures for mitigating the impacts of climate change in the area. This will provide multiple socio-economic and environmental benefits in the area, including increased and diversified food production, increased income, improved living standard, soil conservation and improved soil quality, reduction of greenhouse gases concentration due to carbon sequestration, increased ecosystem health and biodiversity, flood mitigation and prevention of desert encroachment among others. Aggressive afforestation programmes should also be pursued through the collaborative efforts of state ministries of environment, forestry and natural resource, agriculture and other environmental protection agencies and parastatals. In addition, the agricultural and forest research institutes and universities in the country should develop improved varieties of trees that are adapted/adaptable to a changing climate.

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