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RESEARCH ARTICLE

DYNAMICS OF THE FOREST LANDSCAPE IN THE MIKEMBO SANCTUARY: 20 YEARS AFTER ITS CREATION AS A FLORA AND FAUNA CONSERVATION RESERVE, UPPER-KATANGA, DR CONGO

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ABSTRACT

Remote sensing is very important for conservation and biodiversity research and applications. For instance, it can be used for monitoring changes in ecosystems. **Objective**: The objective of this paper was to analyze the change in the forest landscape of Mikembo Sanctuary between 2002 and 2022 using satellite imagery. **Method**: Supervised classification by maximum likelihood algorithm was performed and helped to differentiate 3 land use classes. **Results**: The cartographic and statistical analysis show that land use dynamics of the study area are dominated by an increase in forest and a reduction in bare soil. The forest increases with 0.78 km² (18.04% of the study area) and therefore had a rate of change of more than 32.25%. **Conclusion**: It has been demonstrated that the Miombo woodland, specially Mikembo Sanctuary is capable of regenerating naturally or by assisted means. Encouraging people for using alternative solutions is necessary to ensure the sustainable forest management and utilization.

KEYWORDS

Ecological restoration, Regeneration, Remote sensing, Land use change, Miombo woodland

1. INTRODUCTION

Most of the Southeastern part of the Democratic Republic of Congo (DRC) is covered by a vast expanse of Miombo woodland under the Zambezian region of the greater Sudano- zambezian region (Duvigneaud, 1958). This ecosystem plays an important role in providing a wide range of ecosystem services among others non-timber forest products, charcoal and fuelwood, agriculture, local climate regulation and carbon sequestration for the local population and throughout the sub-region (Ryan et al., 2016; Gumbo, 2018).

In the miombo, the intense production of charcoal, wood and mining activities are identified today as major activities of deforestation, degradation, and disappearance of the forest cover (Bebroux et al., 2007; Munyemba et al., 2014; Khoji et al., 2022). Moreover, Useni et al., (2017), show that the Miombo is threatened by human activities in general. In this study on the deforestation radius around the city of Lubumbashi (Haut-Katanga, DRC), the authors show that there are four main causes of the regression of the miombo cover, and which would be supported by the accelerated population growth, namely agricultural development, charcoal production, city expansion and mining activities. Additionally, the miombo woodland is completely removed around the city of Lubumbashi within a radius of 100 km² and that intensity of deforestation would be -19.85 km² per year. Moreover, Khoji et al., (2022) show that the natural cover that dominated the landscape in 1979 has lost more than 60 % of its surface in 41 years (1979-2020) around four agglomerations in Southeastern Katanga (Lubumbashi, Likasi, Fungurume and Kolwezi) to agricultural and energy production.

These changes in land use and land cover, also known as land-use change, have severe consequences at several levels, notably on the capacity of forest ecosystems to adequately provide ecosystem services (Gillet, 2016, Ahononga et al., 2020). For instance, most of the non-timber forest products (NTFPs), such as honey, edible mushrooms, edible caterpillars, and wild edible fruits are gradually disappearing due to selective cutting of host plants (Gillet, 2016; Ahononga et al., 2020). This degradation also leads to a significant reduction in wildlife (Gillet, 2016) and decreased rainfall in some parts of the region (Ndehedehe and Agutu et al., 2022).

At the northeast of Lubumbashi, there is a private reserve "Mikembo" whose vocation is the conservation of biodiversity. This ecosystem also serves as a tourist site, as well as an educational support for schoolchildren from surrounding villages and for scientists from universities and research centres. For over ten years, several studies in the field of ecology have been conducted there (Kizila, 2012; Mushagalusa, 2012; Mushagalusa et al.,2014; Muledi et al., 2016; Bauman et al., 2016; Muledi et al., 2017, 2018; Muledi et al., 2020; Mushagalusa et al., 2020; Godlee et al., 2020; Kyalamakasha et al.,2021; Kasongo et al., 2021; Kaumbu et al., 2023). In addition, in remote sensing, Thibaut (2019) has attempted to explain the structure of the miombo open forest in the sanctuary using satellite imagery and photogrammetry; however, studies related to the spatial dynamics of vegetation within this reserve have not yet been conducted (Thibaut, 2019).

This study analyzes the dynamics of the forest landscape within the Mikembo Sanctuary, based on diachronic analyses of the forest cover between 2002 and 2022 using satellite imagery in order to clearly show the importance of sustainable forest conservation.

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2. Materials and Methods

2.1 Study Area

The study area is in the Upper-Katanga province, about 35 km Northeast of the city of Lubumbashi on National Road No. 5, in the Democratic Republic of the Congo (Figure 1). The entire domain covers approximately 800 ha (Muledi et al., 2016; Thibaut, 2019), but this one in this study has a total area of 442 ha. The reserve was established in 2003, but land acquisition had begun in 2002, and since then it has been protected from bushfire and wood cutting. The area includes three villages, a camp, and a river that runs through it. The sanctuary is characterized by Miombo woodland vegetation found on the Lubumbashi plain (Muledi et al, 2016). Its dry tropical climate is characterized by a rainy season from November to March and a dry season from May to September; April and October are transitional months between these two seasons. The average annual values of precipitation, temperature, and relative humidity are about 1270 mm, 20°C, and 66% respectively (Campbell, 1996; Malaisse, 2010). Prevailing winds are predominantly southeast to northwest with slight oscillations (Bruneau & Pain, 1990; Leteinturier et al., 1999). Agriculture, charcoal burning, residential livestock raising, and small-scale commerce remain the most common activities in the villages near the reserve. Mikembo Sanctuary is between 11°28′57″ - 11°29′5″ South latitude, 27°40′12″- 27°40′28″ East longitude; at 1200 m above sea level (Muledi et al., 2016). There are also about thirteen freely roaming ungulates as amongst others *Alcephalus buselaphus, Sylvicapra grimmia, Kobus ellipsiprymnus, Tragelaphus oryx, Giraffa camelopardalis, Tragelaphus strepsiceros, Tragelaphus scriptus, Equus burchelli.*

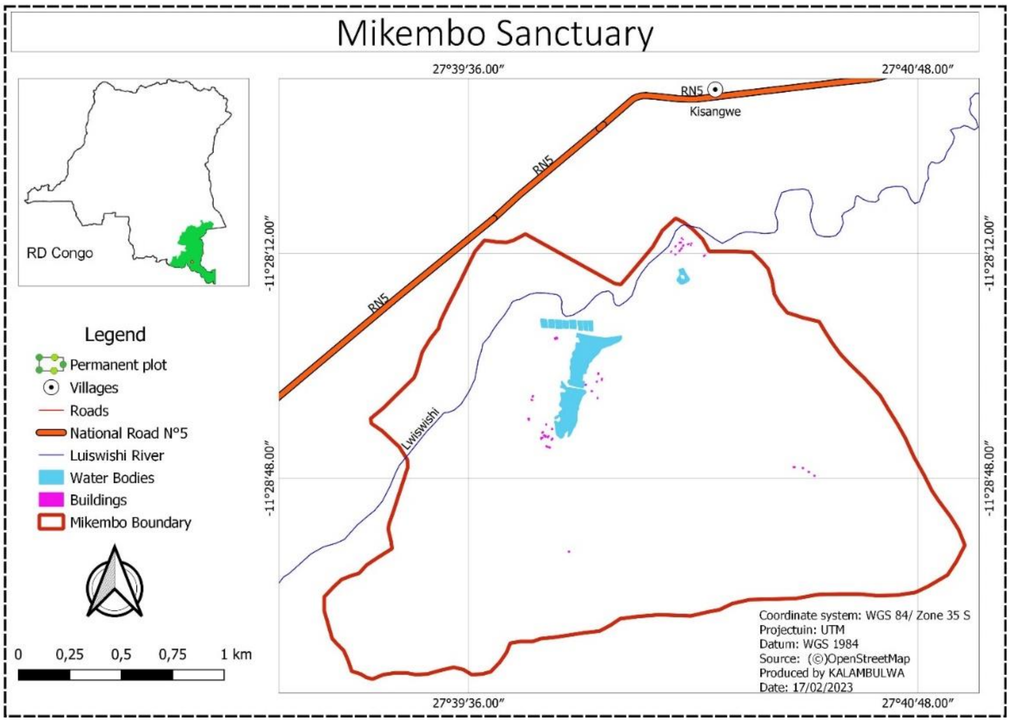

Figure 1: Location map of the study area (Source: Kalambulwa Credit, 2023)

2.2 Description of The Data

Landsat satellite images were downloaded on the USGS Earth Explorer platform of the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). Two LANDSAT 7 and 9 images of 30 m resolution in multispectral and 15 m in panchromatic were used. The spectral domains were the visible, near infrared and mid-range radiometric bands. They were acquired at different dates (04.05.2002 and 11.05.2022) during the dry season (Table 1). This period corresponds to the dry season in Southeastern DRC where there is less cloud cover in the sky.

Moreover, the time step is explained by observing medium- and long-term changes and not short-term changes related to vegetation phenology (seasonal landscape changes) (Okanga-Guay et al., 2018).

2.3 Data Processing

The processing of satellite images was facilitated by the Google Earth Pro image which allowed the identification of land cover types and their spectral response on the Landsat image. The results obtained were previously validated in the field using GPS. The validated data obtained and those collected in situ were integrated into a Geographic Information System for spatial analysis and the production of land use maps using ArcGIS 10.4 interface.

Four indices(Table 2) have been calculated to contribute to a better identification of the classes : NDVI (Normalized Difference Vegetation Index) to highlight the presence of vegetation (Rouse et al., 1974) ; SAVI (Soil-Adjusted Vegetation Index) to minimize the influences of soil brightness using a soil brightness correction factor (Huete, 1988); NDWI (Normalized Difference Water Index) for delineating water bodies, as it maximizes water reflectance using green wavelengths and SI (Soil Index) for distinguishing water-vegetation-built/bare soil, as it separates soil from vegetation (Gao, 1996).

The classification by the Maximum Likelihood algorithm was then performed, which is a parametric method based on probability laws. The probability of each pixel of the image to belong to a class is calculated from the data collected in the field. The pixel is assigned to the class for which the probability is the highest. This statistically based approach achieves a minimal error rate (Bonn and Rochon, 1992). Finally, three land cover classes were selected: (i) "Forest", (ii) "Bare soil" and (iii) "Water". Then, the "Bare soil" class takes into account all areas without woody vegetation and containing various constructions (housing, roads, periodically flooded areas, etc.).

Table 1: Characteristics of The Satellite Images Used.

Label	Features				
	Sensor	Collection and Level	Projection system	Resolution	Year
LE07_L2SP_173068_20020504	Landsat 7 ETM+.	C 2 L2	WGS 84 / UTM zone 35 S	30 m	2002
LC09_L2SP_173068_20220511	Landsat 9 OLI/TRS	C2 L2	WGS 84 / UTM zone 35S	30 m	2022

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Table 2: Index Values Used.

Index	Values	
	2002	2022
NDVI	0.36682 to 0.353245	0.365809 to -0.0541321
SAVI	0.529858 to 0.247602	0.457257 to -0.0676641
NDWI	-	0.182038 to -0.10337
SI	21714.4 to 15775.5	21620 to 11276.5

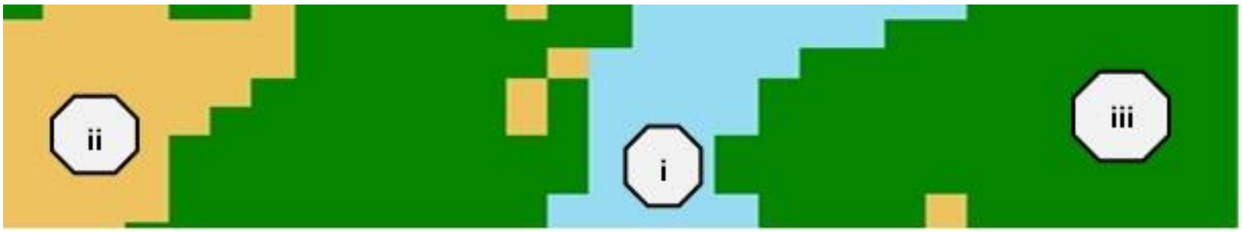

Figure 2: Different classes highlighted (Source: Kalambulwa, 2023).

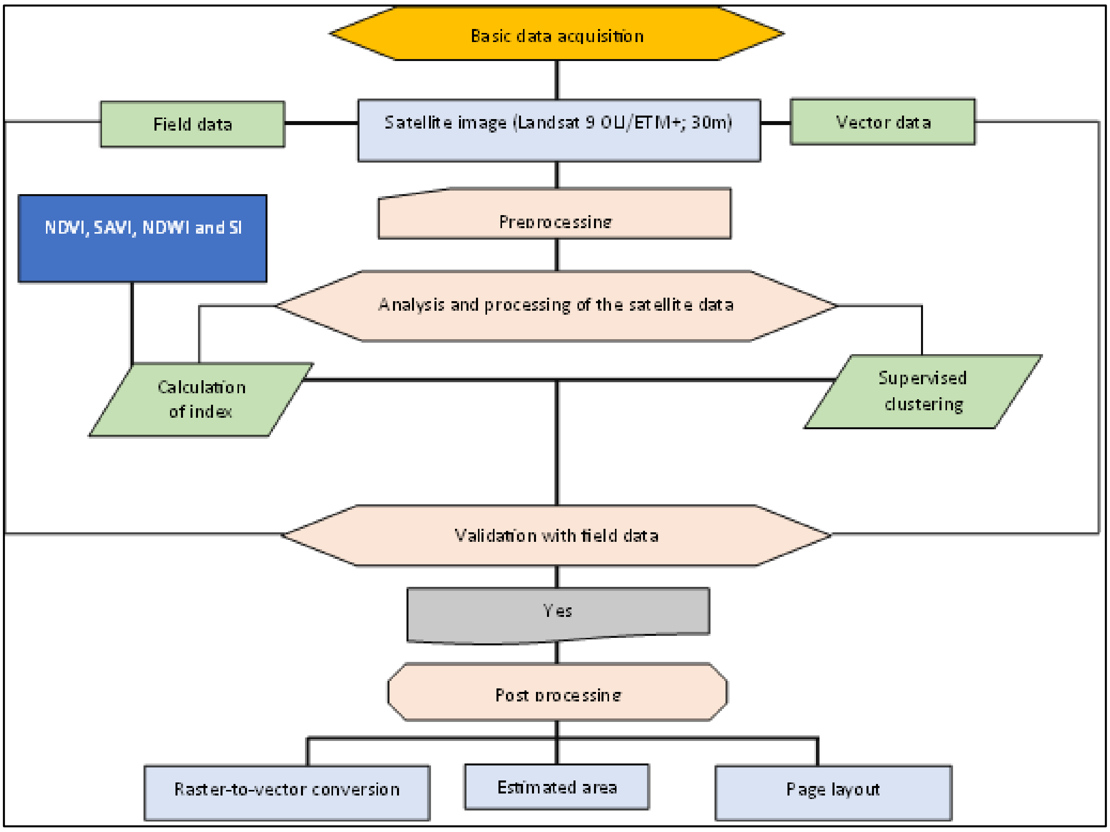

Figure 3: Methodological diagram of classification

Some points (30 minimum) were pre-sampled in the field to verify the classification of land use; then the evaluation and validation of the classification quality of the satellite images were carried out by applying two different approaches which include the cartographic approach enhanced by the statistical approach (Okanga-Guay et al., 2018). The cartographic approach allows a quick visualization and appreciation of land use changes.

The multi-date analysis is conducted in three steps:

1. The first step is to compare the study area from the starting year to the ending year (at times t, t1 and t2). Studying an area at time *t* and time *t+* gives a global view of each of the study years. From a cartographic perspective, this translates into the production of "before" and "after" maps that, when compared to each other, show visible changes (Okanga-Guay et al., 2018).
2. The second step shows the evolution of land use patterns in a general way: spaces without change and with change. From a cartographic point of view, this translates into a juxtaposition of these spaces that shows the presence or absence of spatiotemporal variations in the territory. It therefore refers to a degradation, modification, or loss of areas of land use units, or an absence of ecosystem modifications. It can be accompanied by "before" and "after" maps showing land use on the modified areas (Okanga-Guay et al., 2018).
3. The third step identifies in a more detailed manner the plots which have evolved. It is derived from the intersection of statistical analysis of land use changes and exogenous data (socioeconomic, demographic, geographic information, etc.) that influence territorial dynamics (Okanga-Guay et al., 2018).

The dynamics of land use accounts for the spatiotemporal variations of land use classes. The changes are assessed according to four cases :

•Progression: gain in land use class areas,

•Regression: loss of land use unit area,

•Stagnation: these are classes that have not undergone any changes,

•The conversion: passage of a class (or a part) of occupation to another.

The statistical approach quantifies the changes in land use. Initially, the statistical reliability of the classifications, which was obtained after calculating the area of each class during the conversion of raster data to vector. The detection of changes in land cover is then carried out using the following formula:

$$C = S2 - S1$$

Where C= area of change, S1 = area year 1 and S2 = area year 2.

The variable considered here is the area of change (C). Positive values represent an increase in the class during the period analyzed and negative values indicate the loss of area between the two dates. Values near zero indicate that the class remains relatively stable between the two dates.

The rate of change (Tc) is calculated according to the formula (Toyi et al., 2013):

$$TC = \frac{(S2 - S1)}{S1} * 100$$

Positive values indicate progress, zero values indicate stagnation and negative values indicate regression.

2.4 Data Analysis

The pre-processing and classification of the images was done using Arcgis 10.4. While the post-processing (raster files into vector files and the different page layaut) was done with ArgGis 10.4 and Qgis 3.16. Finally, the calculation of areas for each class and the construction of tables were done with Excel 2019.

3. Results

3.1 Land Use Mapping

The analysis of satellite images reveals the evolution of the land use configuration in the study area with an increase in forest (Figure 3).

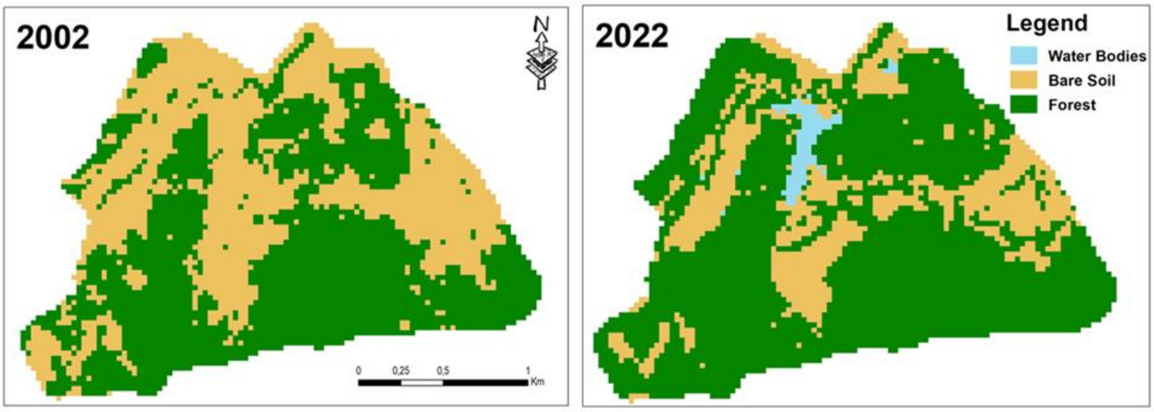

Figure 4: Land use maps from 2002 and 2022 (Source: Kalambulwa Credit, 2023).

In 2002, the land use is dominated by the "Forest" class (Table 3). Forest occupies 2.43 km^2, which represents 55.92%. The surface of bare soil, concentrated mainly in the Northeast and Northwest covers 1.92 km^2. These two classes represent respectively 100% of the study area in 2002. In addition, the classification of the image (Figure 4) shows an increase in the forest area (3.21Km^2) in 2022, which represents 73.96%, while the bare soil areas decreased of 1.04 Km^2. However, the emergence of a new class "Water" that occupies 0.09 Km^2, or 2.15% of space was observed over the period of observations. This class corresponds to the ponds and the water retention basin built on the site between 2005 and 2006.

Table 3: Rates of Change for 2002 And 2022. Values Are Expressed in Area (Km^2) And as A Percentage of The Area of The Land Cover Units.

Land use categories	2002		2022	
	Area		Area	
	$(Km)^2$	(%)	$(Km)^2$	(%)
Water Bodies	-	-	0.09	2.15
Bare Soil	1.92	44.08	1.04	23.89
Forest	2.43	55.92	3.21	73.96
Total	4.35	100.00	4.35	100.00

Table 4: Change in land use categories between 2002 and 2022

Land use categories	Area $(Km)^2$	Area $(Km)^2$	Evolution from 2002 to 2022 $(km)^2$	Rate of change (TC %)
	2002	2022		
Water Bodies	-	0.09	0.09	-
Bare Soil	1.92	1.04	-0.88	-45.82
Forest	2.43	3.21	0.78	32.25

3.2 Land Use Dynamics Between 2002 And 2020

The land use analysis between 2002 and 2022 is characterised by the significant changes in the study area (Figure 4). The overall trend indicates significant changes in the bare soil classes and forest (Table 4).

The forest class increased in area towards the Northeast and northwest part and bare soil decreased slightly. Of the total land cover type, the Bare soil class had the largest rate of change at -45.82%. Forest increased by 0.78 km^2, for a rate of change of 32.25%. The emergence of the "Water" class occupies a small area that was occupied by the "Bare Ground" class prior to site development. It has 0.09Km^2, or 4.69% of the bare soil area in 2002.

Analysis of the spatial pattern shows a class with the most significant change in area. The forest shows a much greater change in the Northeast and Northwest part of the study area (Figure 4). The central part of the area showed almost no change, as it is largely devoid of woody vegetation, but largely dominated by grassy vegetation that dries out completely in the dry season.

The photographic series 1 shows the activities of scientific research conducted in the permanent sampling plots (Figure 6) and in other parts of the reserve.

Series 2 photographs show the flora and fauna present in the study area (Figure 7). Thirteen species of ungulates have been reintroduced into the sanctuary. These are all species originally present in the area, except for giraffes. While the characteristic flora is composed of 8 communities classified according to structure*: Uapaca spp. thicket; Julbernardia paniculata* heterogeneous forest, *Pterocarpus tinctorius* old-growth forest, *Combretum acutifoliosum* and *Terminalia sp.* wooded savannah*; Julbernardia globiflora* heterogeneous forest, *Acacia spp* wooded savannah, *Acacia polyacantha wooded* savanna and *Brachystegia boehmii* heterogeneous forest.

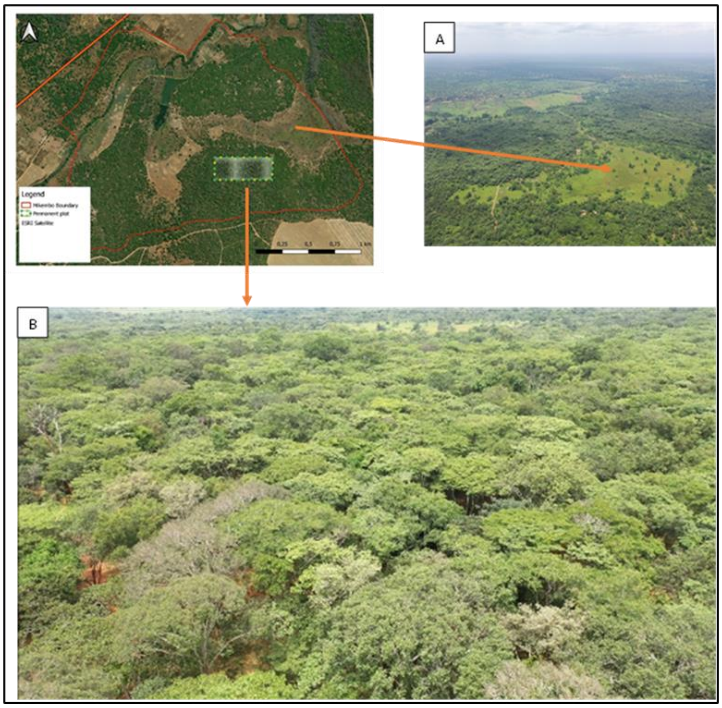

Figure 5: Top view of some patches taken with drone on field, empty space without woody vegetation (a) and dense vegetation in the area where the permanent sampling plots are installed (b).

Figure 6: Series of monitoring activities in the Mikembo Sanctuary permanent sampling plots.

Figure 7: Fauna and vegetation type present in the Mikembo sanctuary

4. Discussion

4.1 Land Use Dynamics Between 2002 and 2022

The evolution of land use within the Mikembo Sanctuary was visualized and analyzed respectively through Figure 3 and Table 3 from 2002 to 2022. It appears that during the two decades, the Forest class increased by 0.78 km^2 (18.04% of the study area), for a rate of change of 32.25%. However, a new class that did not previously exist has appeared in the study area. This is the Water class estimated at 0.09Km^2. Only the Bare Soil class has decreased, with a conversion of 0.88 km^2 or 20.19% of surface occupied by the study area, to other land use classes. Its high regression rate returns to 45.82% in 20 years.

Indeed, the positive evolution of the area occupied by forests attracted our attention because it is exceptional, compared to studies conducted by our predecessors where the land cover dynamics reveal in most cases a loss of forest cover over time (Munyemba et al., 2014; Useni et al., 2020; Mukenza et al., 2022; Khoji al., 2022).

In 2002, the Mikembo sanctuary was characterized by high anthropization. However, as shown in Figure 3, the sanctuary has undergone considerable restoration in 2022. Due to protective measures (fencing of the entire perimeter) and rigorous monitoring since the acquisition of this space, the vegetation is in full natural regeneration. In support of the results of this study, according to Muledi (2017) and Kyalamakasa et al., (2021), the growth dynamics of trees in Mikembo are explained by several factors. First, the growth of some species in the plot is influenced by edaphic factors of the environment, while some by local conditions, including competition between trees, assessed through the slenderness factor (Height/Diameter). Secondly, the annual mortality rate in the system is low, while the recruitment rate is higher than in most tropical forests. Finally, the authors conclude that the changes in demographic evolution place Mikembo Forest among the most dynamic stands, characterized by a good rate of diametral growth, low mortality, and high recruitment (Muledi et al., 2020).

In the same province where our study was conducted, there has been a rapid expansion of the built-up area, that has led to a regression of the vegetation (Munyemba et al., 2014; Useni et al., 2020). The liberalization of the mining sector in 2002 has led to a considerable loss of forest cover in mining sites and peripheries for more than two decades (Useni et al., 2020; Khoji et al., 2022; Cabala et al., 2022). In the western part of the province, in the Lufira Biosphere Reserve (LBR), a decrease in the Miombo woodland area is reported. The forested area has decreased from 85.3 km^2 in 1979 to 11.2 km^2 in 2018. The annual deforestation rate between 1979 and 2018 was 1.8%; nearly eight times the rate recorded at the country level (Useni et al., 2020).

At a time when forest areas are increasingly threatened and are declining in area and connectivity (Salomon et al., 2021). The Mikembo Sanctuary can constitute a conservation model to be followed, and popularized throughout the sub-region, because its policy is in line with contributing to the preservation of natural resources, the reconstitution of the vegetation cover, the improvement of soil fertilitý, the protection of land against erosion and the growth of wood and non-wood products.

5. Conclusion

This study analyzed the change observed in the forest landscape of Mikembo Sanctuary over the two decades since its acquisition. The combination of GIS tools, remote sensing and field observations shows the dynamics that have taken place in this reserve. Previous work in Upper Katanga and around Lubumbashi shows a drastic reduction in forest cover in the face of building and mining activities. However, the results found in this study show a significant progression of Miombo woodland in the Mikembo sanctuary between 2002 and 2022. The encouraging results of this research prove the effectiveness of the management model imposed on this reserve and demonstrate the pursuit of one of the objectives of the Mikembo ASBL, which is to protect the environment, which they call "priceless heritage" in southeastern Democratic Republic of the Congo. However, future studies should assess canopy dynamics in combination with dendrometric parameters to predict the Miombo woodland forest how many years more accurately is capable of regenerating. Then, same studies are very important in the local concession community forestry across the whole former Katanga province to assess the efforts made by indigenous people to contribute to the sustainable forest reconstitution and management.

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Authors' Contributions

Conceptualization: Kalambulwa N.A; Data collection: Kalambulwa N.A and Mumba T.U Data processing and analysis: Kalambulwa N.A; Kakule M.S; Lobho L.J; Manuscript writing: Kalambulwa N.A; Kakule M.S, Mumba T.U and Lobho L.J; Review: All authors.

References

Ahononga, F. C., Gouwakinnou, G. N., Biaou, S. S. H., Ahouandjinou, O., Biaou, S., & Sonounameto, R. C., 2020. Facteurs d'affectation des terres et effets sur les services écosystémiques et la biodiversité : Synthèse bibliographique. Bulletin de la Recherche Agronomique du Bénin (BRAB) Juin, Vol. 30(02), Pp. 1-9.

Bauman, D., Raspé,O., Meerts, P., Degreef, J., Muledi, I.J., Drouet, T., 2016. Multiscale assemblage of an ectomycorrhizal fungal community: the influence of host functional traits and soil properties in a 10-ha miombo forest, FEMS Microbiology Ecology, Volume 92, Issue 10, October 2016, fiw151, https://doi.org/10.1093/femsec/fiw151

Bonn F. J. Rochon G. & UREF., 1992. Précis de télédétection. Volume 1 principes et méthodes. Presses de l'Université du Québec. https://worldcat.org/en/title/30328235

Bruneau J.C. & Pain M., 1990. Atlas de Lubumbashi. Nanterre, France : Université Paris X, 133.

Cabala Kaleba, S., Useni Sikuzani, Y., Mwana Yamba A., Munyemba Kankumbi F., & Jan Bogaert, J., 2022. Activités anthropiques et dynamique des écosystèmes forestiers dans les zones territoriales de l'Arc Cuprifère Katangais (RD Congo). Tropicultura [En ligne], Volume 40 (2022), Numéro 3/4, URL : https://doi.org/10.25518/2295-8010.2100

Campbell, B. M., Angelsen, A., Cunningham, A., Katerere, Y., Sitoe, A., & Wunder, S., 2007. Miombo woodlands-opportunities and barriers to sustainable forest management. Center for International Forestry Research, Bogor, Indonesia.

Debroux, Laurent, Topa, Giuseppe, Hart, Terese, Kaimowitz, David, Karsenty, Alain, Abdon, Awono, Amsini, Fidele, Aveling, Conrad, Bertrand, Alain, Bekhechi, Mohammed, Bravi, Carlo, Chezeaux, Eric, Chomitz, Kenneth, Dewachter, Pauwel, d'Huart, Jean-Pierre, Diaw, Chimere, Dieterle, Gerhard, Dijire, Abderhamane, Dupain, Jef, Erdlenbruch, Katrin, Fauvet, Nicolas, Forni, Eric, Hall, Jefferson S., Kakinda, Joseph, Kalambay, Gaston et al., eds. 2007. Forests in post-conflict Democratic Republic of Congo: Analysis of a priority agenda. Bogor, Indonesia: World Bank, Center for International Forestry Research (CIFOR), Centre International de Recherche Agronomique pour le Développement (CIRAD), African Wildlife Foundation (AWF), Conseil National des ONG de Développement du Congo (CNONGD). https://repository.si.edu/handle/10088/11848.

Duvigneaud P.1958. The vegetation of Katanga and its metalliferous soils. Bulletin de la Société Royale de Botanique Belge, 90, Pp. 127-286.

Gao, B.C. A., 1996. normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment, no. 58, 257-266. https://doi.org/10.1016/S0034-4257(96)00067-3

Gillet, P. 2016. L'Afrique centrale : entre traditions et transitions. La mutation des socio-écosystèmes en Afrique centrale, Thèse de doctorat soutenue à l'Université de Liège https://hdl.handle.net/2268/203695.

Godlee, J.L., Gonçalves, F.M., Tchamba, J.J., Chisingui, A.V., Muledi, J.I., Shutcha, M.N., Ryan, C.M., Brade, T.K., Dexter, K.G., 2020. Diversity and Structure of an Arid Woodland in Southwest Angola, with Comparison to the Wider Miombo Ecoregion. Diversity 2020, 12, 140. https://doi.org/10.3390/d12040140

Gumbo, D.J., Dumas-Johansen, M., Muir, G., Boerstler, F., and Zuzhang, X. 2018. Sustainable management of Miombo woodlands: food security, nutrition and wood energy. FAO. ISBN:978-92-5-130423-5. https://agris.fao.org/agris-search/search.do?recordID=XF2018001617

Huete, A.R., 1988. A Soil - Adjusted Vegetation Index (SAVI). Remote Sensing of Environment. No. 25, 295-309. https://doi.org/10.1016/0034-4257(88)90106-X

Kambale N.N., Dramani R., Mulondi K.G., Muhindo S.W., Biaou S.S.H.2 & Natta K.A., 2021. Dynamique spatio-temporelle de l'occupation du sol et du couvert forestier dans les Hautes Terres Fraîches de Lubero (R.D. Congo), Geo-Eco-Trop., Vol. 45(4) : Pp. 641-658. https://geoecotrop.be/uploads/publications/pub_454_10

Khoji, M.H., N'Tambwe, D.-D., Malaisse, F., Waselin, S., Sambiéni, K.R., Cabala, S.S., Munyemba K.F., Bastin, J.-F., Bogaert, J., Useni S.Y., 2022. Quantificationand Simulation of LandscapeAnthropization around the MiningAgglomerations of SoutheasternKatanga (DR Congo) between 1979and 2090. Land 2022, 11, 850. https://doi.org/10.3390/land11060850

Kizila, W P., 2012. Caractérisation des communautés végétales du Miombo en lien aux paramètres physiques du sol. Réserve de Mikembo, Lubumbashi (RD.Congo), (Mémoire de Master inédit). Université de Lubumbashi, Facultés de Sciences Agronomiques. Pp. 58.

Kyalamakasa, J.M.K., Mulambi, M.M.M., Mukonzo, E.K.L., Shutcha, M.N., Tekeu, H., Nkombe, A.K., Khasa, D., 2021. Early Selection of Tree Species for Regeneration in Degraded Woodland of Southeastern Congo Basin. Forests 2021, 12, 117. https://doi.org/10.3390/f12020117

Kyalamakasa, J.M.K., Sene, G., Stefani, F., & Khasa, D. P., 2023. Characterization of the arbuscular mycorrhizal fungal community associated with rosewood (Pterocarpus tinctorius Welw.) in Miombo forests, Democratic Republic of Congo. https://doi.org/10.21203/rs.3.rs-2583352/v1

Leteinturier B., Baker A.J.M. & Malaisse F., 1999. Early stages of natural revegetation of metalliferous mine workings in South Central Africa: a preliminary survey. Biotechnol. Agron. Soc. Environ., 3(1), 28-41. https://popups.uliege.be/1780-4507/index.php?id=15734

Malaisse F., 2010. How to live and survive in Zambezian open forest (Miombo ecoregion). Gembloux, Belgium: Les Presses agronomiques de Gembloux.

Mukenza, M. M., Muteya, H. K., Nghonda, D. D. N. T., Sambiéni, K. R., Malaisse, F., Kaleba, S. C., ... & Sikuzani, Y. U., 2022. Uncontrolled Exploitation of Pterocarpus tinctorius Welw. and Associated Landscape Dynamics in the Kasenga Territory: Case of the Rural Area of Kasomeno (DR Congo). Land, 11(9), 1541. https://doi.org/10.3390/land11091541

Muledi, I.J., Bauman, D., Drouet, T., Vleminckx, J., Jacobs, A., Lejoly, J., Meerts, P., and Shutcha, NM., 2017. Fine-scale habitats influence tree species assemblage in a miombo forest, Journal of Plant Ecology, Vol. 10(6), December 2017, Pp. 958-969, https://doi.org/10.1093/jpe/rtw104

Muledi, J. I., Drouet, T., Lejoly, J., Luhembwe, M. N., Shutcha, M. N., & Meerts, P., 2018. Les dispositifs permanents du « Sanctuaire Mikembo » (Haut-Katanga), des outils pour le monitoring de la forêt claire katangaise anthropisée. Bogaert J., Colinet G. & Mahy G., Anthropisation des paysages katangais. Gembloux, Belgique, Presses Universitaires de Liège–Agronomie-Gembloux, Pp. 101-109.

Muledi, J., 2017. Ecologie fonctionnelle et dendroécologie d'une forêt claire de la Plaine de Lubumbashi (Haut-Katanga ; République Démocratique du Congo), Thèse de doctorat présentée à l'Université de Lubumbashi.

Muledi, J., Bauman D., Jacobs, A., Meerts, P., Shutcha, M., Drouet, T., 2020. Tree growth, recruitment, and survival in a tropical dry woodland: The importance of soil and functional identity of the neighbourhood, Forest Ecology and Management, Volume 460, 2020, 117894, ISSN 0378-1127, https://doi.org/10.1016/j.foreco.2020.117894

Munyemba Kankumbi, F., & Bogaert, J., 2014. Anthropization and spatiotemporal dynamics of land use in the Lubumbashi region between 1956 and 2009. E-revue Unilu, 1. https://orbi.uliege.be/bitstream/2268/288476/1/munyemba_eunilu_2014.pdf

Mushagalusa C.F., 2012. Etude de la régénération des espèces arborescentes de la forêt claire de Miombo en population naturelle, (Mémoire de Master inédit), Université de Lubumbashi, Facultés de Sciences Agronomiques. 56pp

Mushagalusa, C. F., Useni, S. Y., Nge, O. A., Munyemba, K. F., Ngoy, S. M., & Meerts, P., 2014. Interactions inter/intra stades de développement et régénération de Pterocarpus angolensis en population naturelle dans le miombo du Katanga méridional. Journal of Applied Biosciences, 73, 6020-6026.

Mushagalusa, C.F., Bauman, D., Shutcha, N.M., & Meerts, P., 2020. Trait divergence of woody species in relation to affinity for termite mounds in Upper Katanga (DR Congo). Journal of Vegetation Science, Vol. 31(1), Pp. 162-172. https://doi.org/10.1111/jvs.12827

Ndehedehe, C.E., & Agutu, N. O., 2022. Historical changes in rainfall patterns over the Congo Basin and impacts on runoff (1903-2010). Congo Basin Hydrology, Climate and Biogeochemistry: A Foundation for the Future, 151-170. https://doi.org/10.1002/9781119842125.ch9

Okanga-Guay M., Mpie Simba C., Ndonghan Iyangui N., Moussavou G., Obiang Ebanega M., Biboutou A.S., Nkoumakali B., & Mintsa Nguema R., 2018. Transformations des paysages périurbains de Libreville (Gabon) : dynamiques d'occupation du sol par télédétection de la zone Bambouchine - Bikélé, 1990-2014. Revue canadienne de géographie tropicale/Jeuvre canadienne de géographie tropicale [En ligne], Vol. 5 (2). Mis en ligne le 25 décembre 2018, Pp. 25-33. URL : http://laurentian.ca/cjtg

Rouse, J.W., And Haas, R.H., 1973. Monitoring vegetation systems in the great plain with ERTS. Third ERTS Symposium, 1, 309-317. Washington DC: NASA. https://ntrs.nasa.gov/citations/19740022614

Ryan CM., Pritchard R., McNicol I., Owen M., Fisher JA., Lehmann C., 2016. Ecosystem services from southern Africanwoodlands and their future underglobal change.Phil. Trans. R. Soc. B371: 20150312. http://dx.doi.org/10.1098/rstb.2015.0312

Salomon, W., Sikuzani, Y. U., Kouakou, A. T. M., Barima, S. S., Theodat, J. M., & Bogaert, J., 2021. Monitoring of Anthropogenic Effects on Forest Ecosystems within the Municipality of Vallières in the Republic of Haiti from 1984 to 2019. Trees, Forests and People, 6, 100135. https://doi.org/10.1016/j.tfp.2021.100135

Salomon, W., Useni S.Y., Sambieni, K.R., Kouakou, A.T.M., Barima, Y.S.S., Théodat, J.M., Bogaert, J., 2022. Land Cover Dynamics along the Urban- Rural Gradient of the Port-au-Prince Agglomeration (Republic of Haiti) from 1986 to 2021. Land 2022, 11, 355. https://doi.org/10.3390/land11030355

Thibaut, Q., 2019. Structure d'une forêt claire de type miombo par imageries drone et satellitaire. (Mémoire de Master inédit). Université de Liège, Liège, Belgique. Consulté sur https://matheo.uliege.be/handle/2268.2/8266

Toyi, M. S., Barima, S., Mama, A., Andre, M., Bastin, J.-F., De Cannière, C., Sinsin, B., and Bogaert J., 2013. Tree plantation will not compensate natural woody vegetation cover loss in the Atlantic department of Southern Benin. Tropicultura, 31(1). (February 2013): Pp. 62-70. https://hdl.handle.net/2268/160471

Useni, S.Y., Boisson, S., Cabala, K.S., Nkuku, K.C., Malaisse, F., Halleux, J-M., Bogaert, J., Munyemba K.F., 2020. Land use dynamics around mining sites along the urban-rural gradient of the city of Lubumbashi, DR Congo, Biotechnology, Agronomy and Society and Environment. http://creativecommons.org/licenses/by/4.0/

Useni, S.Y., Khoji, H.M., Bogaert, J., 2020. Miombo woodland, an ecosystem at risk of disappearance in the Lufira Biosphere Reserve (Upper Katanga, DR Congo)? A 39-years analysis based on Landsat images. Global Ecology and Conservation 24 (2020) e01333. https://doi.org/10.1016/j.gecco. 2020.e01333

Useni, S.Y., Malaisse, F., Cabala, K.S., Munyemba, K.F., & Bogaert, J., 2017. The deforestation radius around the city of Lubumbashi (Haut-Katanga, D.R. Congo): a synthesis, Tropicultura [Online], Vol. 35(3), Pp. 215-221 URL: https://doi.org/10.25518/2295-8010.1277