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Anthropization and Spatio-Temporal Dynamics of Land use in Virunga National Park of the Democratic Republic of Congo

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***Abstract*—** *Virunga National Park (ViNP) is part of Democratic Republic of Congo's Network of Protected Areas, where human activities have led to widespread reduction of vegetation cover, wildlife and land degradation. This study aims to analyze the spatio-temporal dynamics of threats to biodiversity in relation to anthropogenic pressures in the ViNP. Landsat 2TM February 1980 and Landsat 8 OLI February 2020 satellite images and documentary techniques were used. The method of visual interpretation of the images and comparison of the results was used to highlight the occupation units and calculate their rate of change. The results revealed that biodiversity has considerable decline in recent time. The lowland forest has reduced from 34.9% in 1980 to 12% in 2020. The savannah grass lands has increased within these periods from 8,3% in 1980 to 33.7% in 2020. The loss of wildlife in Virunga National park is worrying for hippos, buffalos and elephants between 1981 and 2017. The annual loss rate for buffalo is 7.8%, followed by hippos 6.7%, elephants 3% and Gorillas 0.04% respectively. In conclusion there has been a significant loss in vegetation cover and wildlife resources in the study area. More efforts from all stakeholders is needed to reverse these declining trends in biodiversity loss so as conserve this pristine biosphere from extinction.*

Keywords*— *Dynamics, land use, Virunga National Park, biodiversity, protected area.

I. INTRODUCTION

Protected areas are territories that conserve biological diversity and contain natural and cultural values (Keenleyside et al., 2013). They include a variety of ecosystems, such as, National Park, Nature Reserve, Wilderness Area, and Wildlife Reserves (IUCN, 2012). In addition, they are tools for conserving biodiversity and ecosystem services at the national and international scales (UNEP-WCMC, 2016; Deshaies, 2018). Unfortunately, unsustainable recovery practices contribute to the loss of biodiversity in the territories that are supposed to protect them from threats, due to lack of means and sometimes inappropriate management methods. In addition, Africa's wildlife is facing anthropization due to fuel wood cutting, mining, deforestation, and poaching.

The vast network of protected areas in the Democratic Republic of Congo (DRC), which comprise 13% of the country's territory, is a victim of these threats. According to the International Union for Conservation of Nature (IUCN) and the Institut Congolais pour la Conservation de la Nature (ICCN), 4 out of 7 parks, or about 57% of the DRC's protected areas, such as Salonga National Park, Garamba, KahuziBiega and Virunga, are in an alarming state of degradation and are on the list of protected areas at risk. Virunga National Park, in particular, faces multiple threats. Indeed, poverty affects 40% of the inhabitants, illegal logging, poaching, agricultural pressure, demographic weight, weakened capacity of institutions in charge of protected areas, and an unstable security climate due to socio-political crises and armed conflicts in North Kivu, contribute to the fragility of the ecosystems (Bakerethi, 2015). Similarly, these problems degrade the park's natural resources, and biodiversity is highly threatened by anthropogenic activities. Agricultural expansion into food crops, industrial destroy about 60% of Africa's forests and protected forest areas (FAO, 2016).

Over the past four decades, threats to the biodiversity of ViNP have been greatly accentuated; three-quarters of the park has been destroyed and wildlife diversity has been reduced by half including Hippos, Elephants, Gorillas and Buffalos.

The relationship between the demographic evolution in and around the park and their multiform needs, then, allows us to pose the problem of land availability for this growing population. In the same way, the appreciation of the changes of states of the units of occupation of the ground of the ViNP and the alarming disappearance of the biodiversity in relation to this demographic evolution, prove to be necessary. Hence the objective of this study, which aims to contribute to better management of the park by characterizing the dynamics of land use in relation to anthropogenic pressures in the ViNP.

II. MATERIALS AND METHODS

2.1 Presentation of the study area

The Virunga National Park (ViNP) is one of the most important protected areas in Africa for its diversity of fauna and flora. It is located in the eastern part of the Democratic Republic of Congo (DRC) in the province of North Kivu on the border between the DRC and Uganda on the one hand and Rwanda on the other. It covers an area of 785,000 ha and is elongated over a distance of nearly 300 km with an average width rarely exceeding 50 km (Languy and Merode, 2006). It is located at 1°35' South latitude and between 29°01' and 30°01' East longitude (Delvingt*et al.*, 1990) (Figure 1).

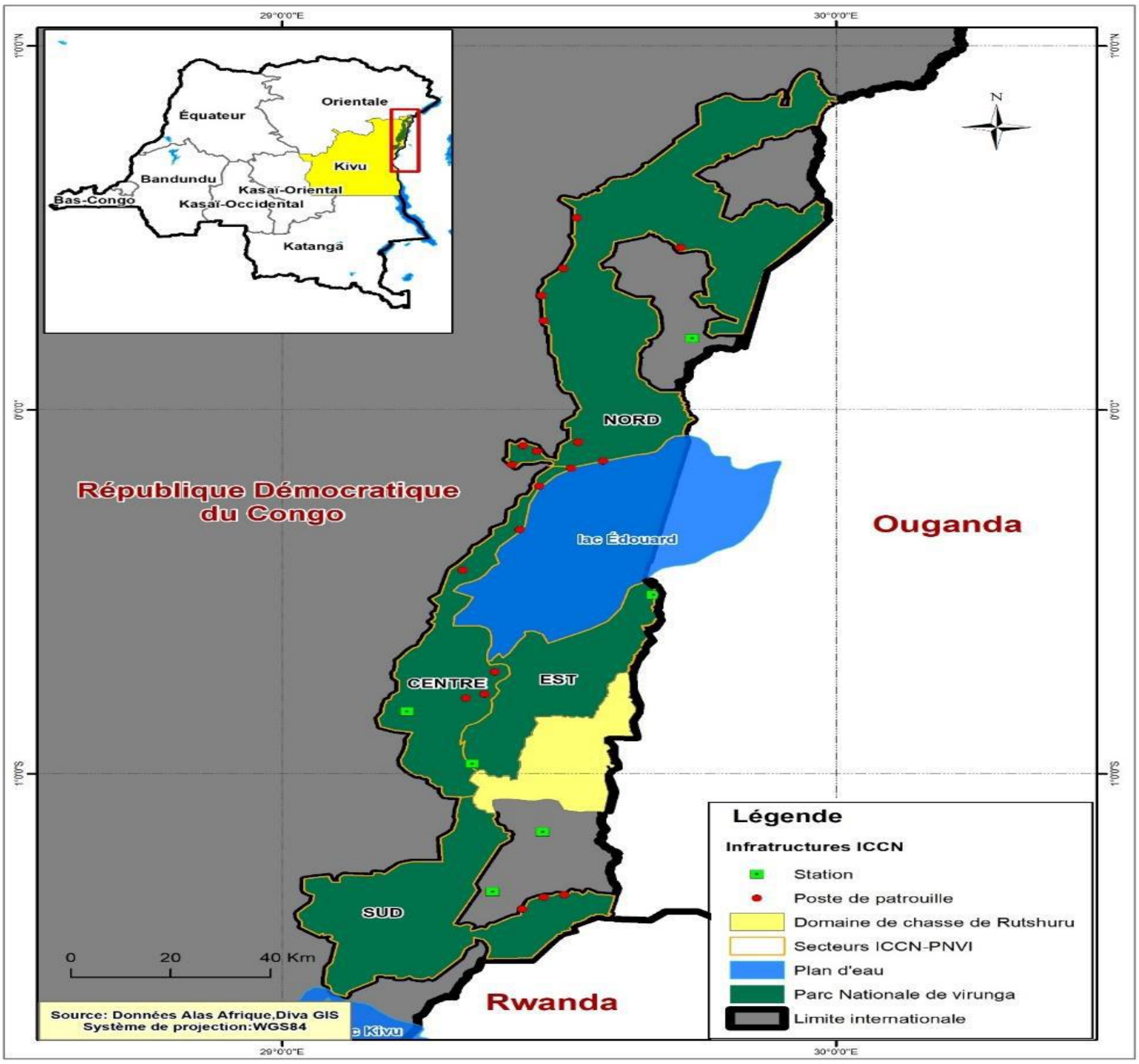


Fig.1: Map of ViNP

The average annual temperature is between 20° and 23° C. The landscape is located at an altitude of 680 to 2700 meters above sea level. Rainfall varies across the park. The savannahs immediately north and south of Lake Edouard are the least rainy areas, with an average of 30 to 40 mm of rain per month. ViNP has one of the world's most active volcanos.

The ViNP presents a remarkable floristic richness due to its great diversity of biotopes and natural habitats. This diversity of habitats covers an altitude ranging from 600 m to over 5000 m in the Ruwenzori Mountains. On particularly rich soils, more than 2000 higher plants grow, of which 10% are endemic (Plumptre*et al.*, 2003; Bulambo*et al.*, 2021). This exceptional specific diversity is due in part to the variety of ecosystems present. This variety of flora provides a specific habitat for a diverse fauna including 218 species of mammals (among them 22 species of primates including 3 great apes, endemic species such as the Okapi and the Red duiker), 706 species of birds, 109 species of reptiles and 78 species of amphibians. The park is home to elephants, buffaloes and Thomas's Cobs, in addition to the highest concentration of hippos in Africa with over 20,000 individuals. The demographic density around the ViNP is very high. It is over 300 inhabitants per km2 (Mulangala, 2004)

II.1 Methodology

Two Landsat image scenes, with a resolution of 30 m pixels, were used in this work to determine the dynamics of land use. These are a Landsat TM (Thematic Mapper) image acquired in February 1980 and a Landsat 8 OLI (Operational Land Imager) image of February 2020. These images were geo-reference using a 1st degree polynomial of the UTM system (Universal Transverse Mercator) zone 35 north. The processing of these satellite images was done in three steps: pre-processing, processing and post-processing. All processing was done using ENVI 5.3 software. The Digital Globe image with a resolution of 2.5 m was used to finalize the land use map. The final validation of the different land use maps was done using a pixel confusion matrix and data from field visits where a GARMIN GPS (Global Positioning System) handheld receiver was used to locate the position of the different control points. A camera was used to film important sites (forests, crop fields, savannahs, etc.).

The areas of the different land use classes were calculated using Arc Gis 10.1 software. This made it possible to carry out a diachronic study of the situations of the reference years in order to highlight the dynamics of the vegetation cover of the study area. The image classification focused on supervised classification and consisted in defining the nomenclature of the different land cover types based on the LCCS (Land Cover Classification System) model (Hussain*et al.*, 2013). Supervised classification using the maximum likelihood method was applied for each of the images.The formula below is use for the calculation of annual deforestation rate,

2.2 Data processing

Land cover mapping of the PNVi was performed on two dates: 1980 and 2020. The post-processing comparison method was used to determine the dynamics and rate of change by cover class during the study period (Hakan*et al.*, 2009). The analysis of wildlife dynamics within Virunga National Park was done using data obtained by consulting mission reports from UNESCO, the InstitutCongolais de la Conservation de la Nature (ICCN), and nature conservation NGOs. The missing data correspond to the time of political turbulence in Zaire before 1997 and in the Democratic Republic of Congo after 1997 with numerous wars.

For statistical analysis, the rate of stability, regression, or progression of landscape units is calculated from one year to the next. In order to determine the annual deforestation rate to observe the change, as well as the annual rate of loss of fauna in ViNP, the standardized Formula proposed by Puyravaud*et al.*, (2002) was used.

$$\mathbf{Tdfa} = -\frac{\mathbf{1}}{\mathbf{t_2 - t_1}}\mathbf{ln}\left(\frac{\mathbf{A_2}}{\mathbf{A_1}}\right) * \mathbf{100}$$

Where:

Tdfa= Annual deforestation rate,

A1= Initial year forest area,

A2 = Final year forest area,

t1 = Exact image acquisition date for initial year,

t2= Exact image acquisition date for final year.

This same formula was modified and uses to calculate annual rate of wildlife loss in the ViNP.

$$\mathbf{Tapf} = -\frac{\mathbf{1}}{\mathbf{t_2 - t_1}}\mathbf{ln}\left(\frac{\mathbf{A_2}}{\mathbf{A_1}}\right) * \mathbf{100}$$

Where:

Tapf= Annual rate of wildlife loss,

t1 = Initial year,

t2= Final year,

A1= Quantity of wildlife in initial year,

A2 = Quantity of wildlife in final year.

III. RESULTS

3.1 Land cover dynamics from 1980 to 2020

The processing of satellite images identified the following main land cover classes: lowland dense forest, mountain forest, water surface, grassy savannah, wooded savannah, crops, bare soil, volcanic lava and built-up areas. The results obtained show a significant change in land use during the study period. In 40 years, he observed an increase in the extent of fields, crops and built-up areas. Forests are decreasing in favour of grassy savannahs(Table1).

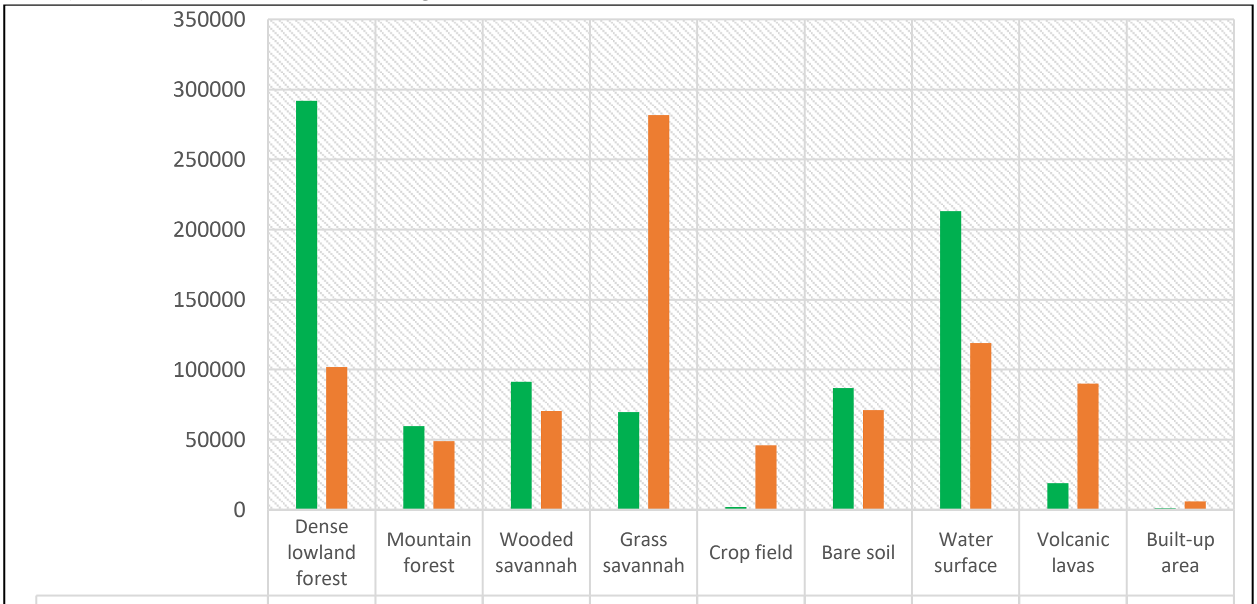
Table 1: Land use change between 1980 and 2020 in the ViNP

Land use	1980 (ha)	2020 (ha)	ARD (%)
Dense lowland forest	291929. 1 (34.9%)	101,819.4 (12%)	0,98
Mountain forest	59,614.11 (7%)	48,850.48 (5.8%)	0,40
Wood savannah	91,462.1 (10.9%)	70,717.63 (8.4%)	6,29
Grass savannah	69,740.7 (8.3%)	281,512.3 (33.7%)	2,35
Crop field	2,045 (0.2%)	45,840.21 (5.4%)	-
Bare soil	86,871.9 (10.4%)	71,128.33 (8.5%)	-
Water surface	213,121.6 (25.5%)	118,920.9 (14.2%)	-
Volcanic lavas	18,896.4 (2.2%)	90,100.56 (10.7%)	-
Built-up area	1,024.5 (0.1%)	5815.6 (0.6%)	-

*ARD= Annual rate deforestation

The analysis of the data in this table shows that in 1980 the park was more dominated in terms of plant formation by the dense forest of low altitude with an area of 291,929.1 (34.9%), the wooded savannah 91,462.1 (10.9%), the grassy savannah 69,740.7ha (8.3%) and the mountain forest with 59,614.11 ha (7%).

On the other hand it is shown that the bare soil was 86,871.9 (10.4%), which indicates the degradation. The water surface occupied by estimate 21, 3121.6 ha (25,5%). Crop fields of 2045 ha (0.2%) and built-up areas of 1024.5 ha (0.1%) and volcanic lava 18,896.4 (2.2%) are relatively low compared to other land use classes. This indicates a low anthropization of the ViNP.



	Dense lowland forest	Mountain forest	Wooded savannah	Grass savannah	Crop field	Bare soil	Water surface	Volcanic lavas	Built-up area
Surface area (ha) 1980	291929.1	59614.11	91462.1	69740.7	2045	86871.9	213121.6	18896.4	1024.5
Surface are (ha) 2020	101819.4	48850.48	70717.63	281512.3	45840.21	71128.33	118920.9	90100.56	5815.6

Fig.2: Altered areas in the park in ha from 1980 to 2020

The ecosystems of Virunga National Park over time have undergone disruptive changes in the past 4 decades. This shows the impact of human activities on the unsustainable use of natural resources in Virunga National Park.

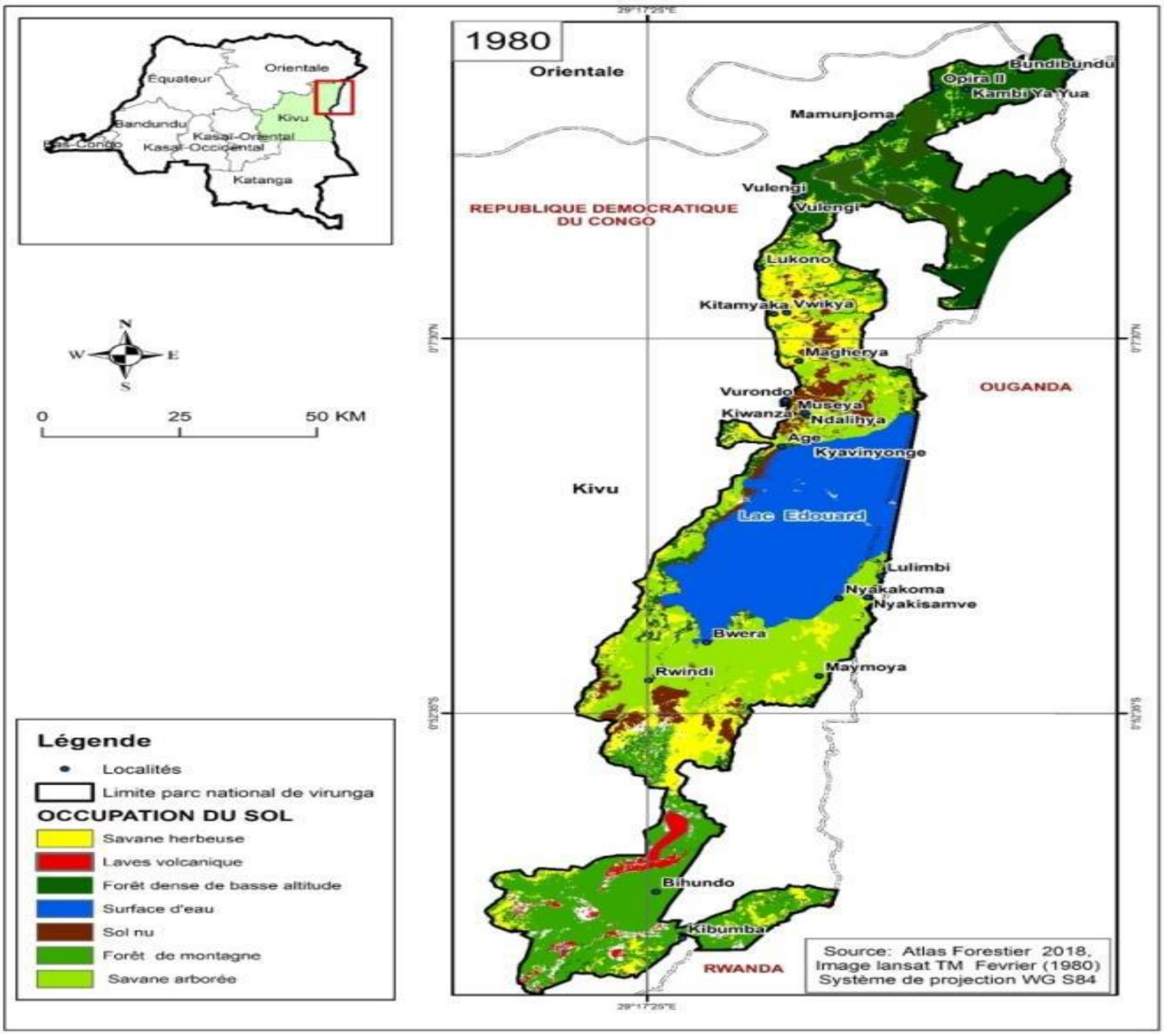


Fig.3: Land use in 1980

On the other hand, in 2020, the dense forests of low altitude represent 101,819.4ha (12%), the dense forests of the mountains 48,850.48 ha (5.8%). At the same time, the wooded savannahs have been reduced by 70,717.63 ha (8.4%) and transformed into grassy savannahs 281,512.3 ha (33.7%), which reflects a strong degradation of the protected area. However, the annual deforestation rate is higher (6.2%) in tree savannas than in grassy savannas (2.3%).

A strong modification of the forests with tree savannah and grassy savannah over the large area of the park whereas in 1980 were so dominated by the dense forests of low altitude and mountain. This testifies to the strong implication of anthropic activities in the destruction of the ViNP. In addition, crop fields were intensified in 2020 by occupying 45,840.21ha (5.4%). The bare soil decreased to 71,128.33 ha (8.5%), which can mean a slight improvement of the vegetation cover. The water surfaces decreased to 118,920.9 ha (14.2%), which is a consequence of climate change due to the deforestation of the park and its borders. Volcanic lava has increased to 90,100.56 ha (10.7%). Finally, the built-up areas have increased to 5,815.6 ha (0.6%).

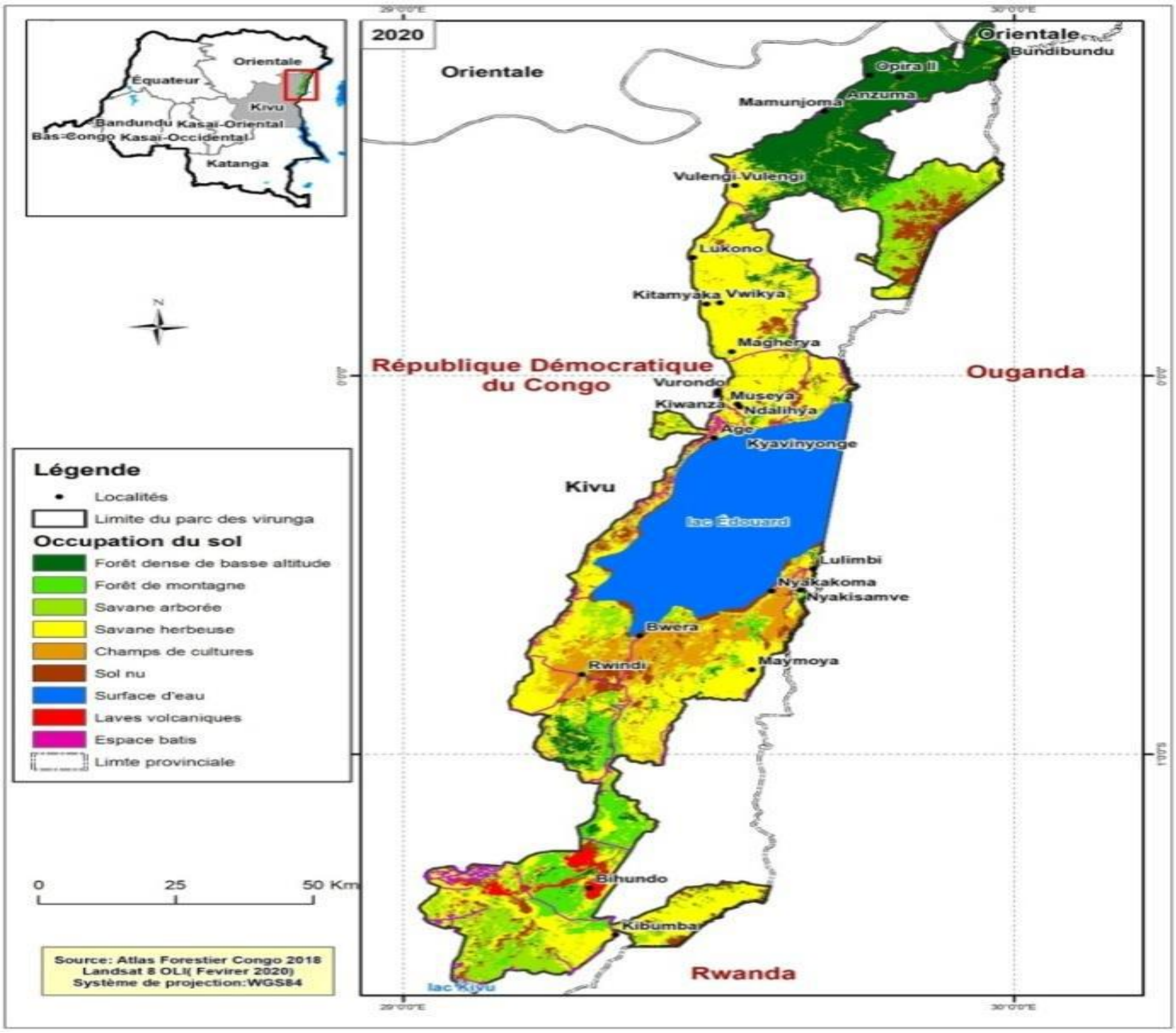


Fig.4: Land use in 2020

Over the past forty years, the forests have been degraded, giving way to savannah formations, particularly grassy and wooded savannahs, which are growing in size. The photo below shows the state of degradation and deforestation of the park in the extreme southern sector.

Fig.5: Grassland savanna of the Virunga National Park in the southern sector.

3.2 Wildlife dynamics in Virunga National Park from 1981 to 2017

Table 2: Wildlife population evolution between the period of 1981 and 2017

	Year					
	1981	2003	2006	2010	2017	ARWL
Hippopotamus	21,095	1399	629	753	1,850	6,76
Elephants	751	286	348	348	250	3,05
Gorillas	305	380	360	880	300	0,04
Buffalos	9,715	2292	3,822	2,154	586	7,80

*ARWL= Annual rate of wildlife loss

Source: Inventory reports (IUCN, 2018; ICCN, 2018)

Analysis of wildlife dynamics within Virunga National Park showed that large mammals have declined considerably in the period 1981 to 2017 (Table 2).The result shows a significant decline in all of the Park's emblematic species, indicating a major threat to biodiversity. In 1981, hippopotamuses were dominant in the Park with a population of 21,095 individuals. This number was considerably reduced between 2006 and 2017. Fortunately, in 2017 this number increased slightly to 1,850 individuals, thanks to the relative stability of the area and intensified surveillance. Elephants have also been reduced by more than half. They went from 751 individuals in 1981 to 250 individuals in 2017, with an estimated annual loss rate of about 3.05%, with slight stability between 2006 and 2010. This shows that elephant poaching has been intensified over the past four decades. In contrast, mountain gorilla populations have remained relatively stable, with only 5 gorillas lost in the past 40 years. From 305 individuals in 1981 to 300 individuals in 2017, an annual loss rate of 0.04%. Poaching of gorillas is low due to strong surveillance in the southern sector of the gorilla's ecological niche. In the end, buffalo were significantly reduced from9715 individuals in 1981 to 586 individuals in 2017, an estimated annual loss rate of 7.8%. More than three quarters of buffalo have been densely poached in the Park over the past forty years. This regressive trend in the wildlife of Virunga National Park is evidence of the extent of loss of wildlife diversity in Virunga National Park.

IV. DISCUSSION

In view of all this, land use in the ViNP is a very important and worrying dynamic from the point of view of conservation. Given that human activities have contributed significantly to the degradation of the entire territory of the protected area over the past forty years. The analysis that follows from Figures 3 and 4 is that in 2020 Virunga National Park (ViNP) has experienced unprecedented land use dynamics. Two land use classes in the park have experienced significant dynamics of progression. These are the classes of crops from 0.2% to 5.4% and built areas from 0.1% to 0.6%. On the other hand, other classes have known a dynamic in the direction of regression. In particular, mountain forests, wooded savannah, bare soil and water surface. The dense lowland forests in the north-western part of the park towards Beni have been destroyed by almost half. However, the wooded savannahs gave way to grassy areas, which in turn gave way to cultivated areas. Bare land has decreased slightly, while built-up areas have increased significantly in 2020. The deforestation rate is higher in tree savannas (6%) than in grassy savannas (2%). On the other hand, this rate is relatively low in the dense lowland and mountain forests (0.9% and 0.4%).

This forest loss exceeds the annual deforestation rate of 0.31 ± 0.042% in DRC between 1990 and 2010 (DIAF, 2015) cited by MECNDD-DRC (2016). But it is below the deforestation rate inside the park (10.6% (82,302 ha) found in 2019. It is therefore higher than the annual deforestation rate (0.39%) of the ViNP (Onfi, 2019). This reflects continued forest destruction through carbonization or overall by anthropogenic activities. These results corroborate those of the UNESCO commission castigating threats throughout the entire extent of the ViNP (IUCN, 2018), Kasolene et al. (2019),Dranginis (2016), showing that deforestation as is one of the causes of ecological disturbance in the Virunga National Park.

Several factors contribute to anthropogenic threats in Virunga National Park. These include the repeated use of bushfires to improve wildlife grazing, the unsustainable use of charcoal or firewood from VNP, and the expansion of cultivated areas and villages in the park. The Forces de Libération du Rwanda (FDLR) has been major actors of destruction for over 26 years operating in the park.

The estimated population increase of over three million in the landscape and poverty are negatively impacting the biodiversity of the park. There are similarities with those revealed in Virunga National Park by Ngongo (2015) and IUCN (2018) and (Bakerethi, 2015). The rate of area destroyed is the particularity addressed for a clarification of the magnitude of threats on this protected area.

The loss of more than three quarters of the fauna including hippos, buffaloes and elephants in Virunga National Park is linked to the political instability of the 1990s with repeated wars and armed conflicts in the region. However, thanks to the relative stability of the area and intensified monitoring through multiple efforts not only by the state, but also by NGOs and conservation organizations, this number has undergone a slight increase in 2017.

Buffalo, although not among the animals under strict protection in the DRC, have experienced a very worrying decline. The results are almost similar to those of the IUCN (2018) showing an alarming loss of buffalo, hippopotamus and elephants between 1990 and 2016. This loss of wildlife diversity is justified by the irrational use of natural resources (PAMEV-DRC, 2016). The armed groups designated in this haphazard harvesting contribute to the loss of biodiversity in Virunga National Park (Dranginis, 2016). The results of this study also note the relevance of the Democratic Republic of Congo to protect threatened wildlife including Hippopotamus (*Hippopotamus amphibius*), forest elephant (*Loxodonta Africana Cyclotis*) and Mountain Gorilla (*Gorilla berengeiberengei*), lowland gorilla (*Gorilla beringeigraueri)* (WWF-DRC, 2017).

The particular contribution of this work is the determination of the annual loss rate of wildlife in Virunga National Park. This rate being very high for buffalo (7.8%) followed by hippos (6.7%). Moreover, these results are consistent with those of Jane (2019) and Courchamp (2018) who have blasted the threats to African wildlife including lions, leopards, elephants, African buffalo and Rhinoceros. However, the anthropization of the Virunga National Park shows that the global approaches published in the summits of Stockohlm, Rio of 1992, the Convention on Biological Diversity of Rio+20, African convention on nature and natural resources and regional frameworks including the Commission for the Forests of Central Africa (COMIFAC), the Network of Protected Areas of Central Africa (RAPAC) are far from being reached. This calls for a new start in the management of the Virunga National Park in the perspective of sustainable development and the Aichi objectives.

V. CONCLUSION

Analysis of the spatio-temporal dynamics of threats to biodiversity in Virunga National Park shows that plant and wildlife formations have regressed significantly between 1980 and 2020. Grassland savannahs have increased in extent in the park in 2020, whereas dense lowland forest, tree savannah and dense mountain forest dominated in 1980. Crop expansion and village occupations in the park have increased in 2020 compared to 1980. This reflects the intensity of anthropization of the park. The majority of the emblematic biodiversity has been reduced by more than three quarters for hippos, gorillas and buffalo. Only elephants have been reduced by half. The loss of wildlife in Virunga National is alarming between 1981 and 2017 for hippos, buffaloes and elephants. It is appropriate to accept the hypothesis that over the past forty years more than three quarters of the park has undergone massive destruction, characterized by forest degradation, deforestation and the regression of the park's emblematic fauna. However, the establishment of alternatives for the sustainable use of natural resources in and around the Park is the major concern in the context of biodiversity conservation in this protected area.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTIONS

This work was conducted in collaboration with all authors. All authors have read and approved the final version of the manuscript.

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