Drivers and Impacts of Climate Change on Biodiversity and Ecosystem Services in the Greater Virunga Landscape

Final Report

Submitted to:

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EXECUTIVE SUMMARY

This study was undertaken under the Greater Virunga Transboundary Collaboration (GVTC) involving three partner states of Democratic Republic of Congo (DRC), Rwanda and Uganda. The collaborative transboundary framework of programs, plans and activities is aimed at conserving the network of Protected Areas (PAs) in the Greater Virunga Landscape (GVL). The GVL covers areas and communities around the PAs of Volcanoes National Park in Rwanda; Virunga National Park in DRC and five national parks (NP) in Uganda: Mgahinga Gorilla NP, Bwindi Impenetrable NP, Queen Elizabeth NP, Rwenzori Mountains NP, and Semliki NP. The landscape is unique and is a hot spot for biodiversity as it contains rare and charismatic species such as the Mountain Gorillas (*Gorilla beringei beringei*), chimpanzees and African elephants.

Climate change is perceived to be a major threat with long-term effects on the ecosystems and behaviour of wildlife. Climate Change is believed to exercise compounding effects, exacerbating the impacts of other threats to the biodiversity and ecosystem services within the GVL. In cases where climate change has resulted in habitat change, it is not clear what will happen to the plants and animals that survived in such sites.

Hence the GVTC Climate Change Strategy has the overall objective of *strengthening landscape-wide resilience to climate change and ensuring climate compatible conservation measures for sustainable livelihood in the GVL*. Implementing this strategy, required a baseline of the current effects of climate change on species, ecosystems, and ecological processes in order to understand how Ecosystem Services will be affected by future changes. It is also important to undertake forecast climatic conditions at high spatial resolution across the GVL to serve conservation planning needs. These forecasts need to be robust, taking account of exposure, adaptive capacity and sensitivity components. There is also a need to identify the tipping points of species, ecosystems, and ecological processes to stressors associated with climate change so that we can avoid crossing critical thresholds, beyond which it may be difficult and costly to restore or find substitutes for important Ecosystem Services. Similarly, there is a need to improve understanding of how current threatening processes such as invasive species, mining, land use, diseases of humans, livestock and wildlife will change under different climate change scenarios.

The overall purpose of the current consultancy, therefore, was to (i) strengthen the knowledge base in order to enhance common understanding of climate change risks and its impacts on biodiversity, ecosystems and associated services and the socio-economic system of the GVL; and (ii) propose appropriate actions for managing and mitigating negative changes in biodiversity and ecosystem services in the GVL. The current study specifically focussed on the following tasks:

i. Identifying the drivers of Climate Change in the in the GVL
ii. Describing how species, ecosystems, and ecological processes within the GVL are currently affected by climate change in order to understand how ecosystem services will be affected by future changes
iii. Undertaking a forecast of climatic conditions sufficiently robust and that take account of exposure, adaptive capacity and sensitivity components

iv. Describing how current threatening processes such as alien invasive species, mining, land use, diseases of human disease, livestock and wildlife will change under different climate change forecasts
v. Proposing appropriate actions for managing and mitigating negative changes in biodiversity and ecosystem services in the GVL

The methods for this study included a review of literature to establish the background knowledge about drivers and impacts of climate change on biodiversity and ecosystem services in the GVL. The WOCAT-LADA-DESIRE mapping tool was used to aid in identifying and assessing the drivers and impacts of climate change on biodiversity and ecosystem services. This was integrated with key informant interviews. Land Use Land Cover change and land degradation hotspots assessment was implemented to aid in identifying and assessing the drivers and impacts of climate change on biodiversity and ecosystem services climate modelling was carried out to generate projections for the GVL.

Drivers of Climate Change in the in the GVL: The study, as expected, shows that climate change is occurring in the GVL and is mainly driven by anthropogenic factors, especially increased land use intensity. This is driven by increased population growth and its associated demand for land for agriculture and settlement. In addition, there is unsustainable utilisation of natural resources.

Current effects of climate change on species, ecosystems, and ecological processes and potential future effects on ecosystem services: Climate change will negatively affect species, ecosystems and ecological processes in the GVL if appropriate mitigation and adaptation actions are not implemented.

Forecast of climatic conditions taking account of exposure, adaptive capacity and sensitivity: The GVL still provides a wide range of ecosystem services that vary spatially. The climate forecast for the GVL in the near future (2020-2039) under both RCP 4.5 and 8.5 generally shows an increase in both rainfall and temperature.

Changes in threatening processes under different climate change forecasts: The projected climatic conditions will thus affect several ecosystem services and processes in the GVL. These effects are more likely to occur in DRC and Uganda and under RCP 8.5 as compared to RCP 4.5.

The following actions are proposed for managing and mitigating negative changes in biodiversity and ecosystem services

1. Scaling up Sustainable Land Management (SLM)
2. Managing human population growth
3. Enhancing restoration of degraded ecosystems
4. Sustaining promising/successful interventions
5. Management Planning to emphasise climate change issues:
6. Planning around adaptation frameworks
7. Enhancing Research and Ecological Monitoring

TABLE OF CONTENTS

Content **Page**

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

GVTC	-	Greater Virunga Transboundary Conservation
GVL	-	Greater Virunga Landscape
DLG	-	District Local Government
FGD	-	Focused Group Discussion
GIS	-	Geographical Information System
MDAs	-	Ministries, Departments and Agencies
CBO	-	Community Based Organisations
HH	-	Household
KII	-	Key Informant Interview
NDVI	-	Normalized Difference Vegetation Index
NGO	-	Non-Governmental Organizations
PA	-	Project Area
NP	-	National Park
NPP	-	Net Primary Productivity
S/C	-	Sub-County
UWA	-	Uganda Wildlife Authority
NFA	-	National Forestry Authority
PAs	-	Protected Areas
PAAs	-	Protected Area Authorities

1. INTRODUCTION

1.1. Background to the Greater Virunga Landscape

The GVL covers areas and communities around the PAs of Volcanoes National Park in Rwanda; Virunga National Park in DRC and five national parks (NP) in Uganda: Mgahinga Gorilla NP, Bwindi Impenetrable NP, Queen Elizabeth NP, Rwenzori Mountains NP, and Semuliki NP. This landscape is unique and a hot spot for biodiversity as it contains rare and charismatic species such as the Mountain Gorillas, Chimpanzees and African Elephants. Other charismatic species include the Giant Lobelias and Dendrosenecios in the Afroalpine zone on the Mountains.

1.2. Context of the study

The GVL covers the central part of the Albertine Rift that straddles the borders of Democratic Republic of Congo, Rwanda and Uganda. It is one of the most diverse landscapes in the world and is known as a world's hotspot for biodiversity conservation (Figure 1). This region is also well endowed with other natural resources (water, fertile lands, minerals, oil, wood, etc.), though their spatial and seasonal distribution and accessibility varies. GVL is famous for its Mountain Gorillas (*Gorilla beringei beringei*) and other endangered flora and fauna. The biodiversity richness of GVL is threatened with species depletion from poaching, illegal timber harvesting, over fishing and habitat loss from exploration (and upcoming exploitation) of oil and gas. Climate Change is also believed to exercise compounding effects, exacerbating the observed impacts of these threats to the biodiversity and ecosystem services

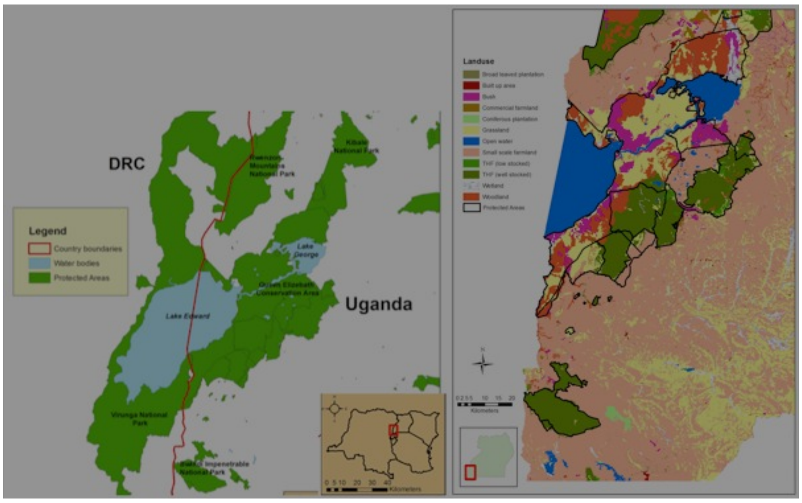


Figure 1: Location map of the study area (GVL) showing also land use and land cover

Climate change is perceived as an important phenomenon with long-term effects on the ecosystems and wildlife behaviour. In cases where climate change has resulted in habitat changes, what will happen to the plants and animals that survived in such sites is not clear. Other questions include, for example, how they would adjust to the changed. The extent to which climate change would influence the long-term behaviour of wildlife needs to be examined in-depth.

One impact of climate change is to create additional stress on habitats and ecosystems that are already threatened, which may result in a reduction of habitat leading to death or the migration of animals. The extent to which climate change would influence the long-term behaviour of wildlife has been examined in-depth e.g. Laurance *et al*. 2004. Pressures on ecosystems include high rates of change in land use and the conversion of land associated with agricultural expansion, pollution, population growth, civil wars, and the introduction of exotic species changing the integrity of ecosystems. Significant local and global extinctions of plant and animal species, many of which are important resources for people, are projected, and if they occur, would affect rural livelihoods, tourism and genetic resources (IPCC, 2007)

Because of the numerous ways that species and ecosystems can be affected by climate change, it is clear that the stocks and flows of Ecosystem Services will vary considerably with climate change, although the magnitude, rate and direction of changes are uncertain. Furthermore, the rapidly increasing human populations across much of the Greater Virunga Landscape, place considerable stress on many Ecosystem Services. The synergistic effects of combined threats complicate understandings of how Ecosystem Services will respond to climate change and other stressors.

The most important likely impacts of Climate Change to the human populations in the GVL include increased water stress and the often, associated changes in productivity and viability of agricultural practices. The population of Africa at risk from increased water stress alone is projected to be between 75–250 million and 350–600 million people by the 2020s and 2050s respectively (Boko *et al.* 2007), while agricultural productivity across the African continent is expected to decrease by 17–28% by the 2080s as a result of climate change (Cline 2007).

The GVTC Climate Change Strategy has an overall objective of *strengthening landscape - wide resilience to climate change and ensuring climate compatible conservation measures for sustainable livelihood in the GVL*. Its implementation requires a baseline of how species, ecosystems, and ecological processes within the GVL are currently affected by climate change to understand how Ecosystem Services will be affected by future changes. In addition, forecast climatic conditions at high spatial resolution across the GVL are required to serve conservation planning needs There is also a need to identify the tipping points of species, ecosystems, and ecological processes to stressors associated with climate change so that crossing critical thresholds (beyond which it may be difficult and costly to restore or find substitutes for important Ecosystem Services.) is avoided. Similarly, there is a need to improve understanding on how current threatening processes such as invasive species, mining, land use, diseases of humans, livestock and wildlife will change under different climate change scenarios.

1.3. Purpose and objectives of study

The overall purpose and purposed of the consultancy was to:

- Strengthen the knowledge base in order to enhance common understanding of climate change risks and its impacts on biodiversity, ecosystems and associated services and the socio-economic system of the GVL
- Propose appropriate actions for managing and mitigating negative changes in biodiversity and ecosystem services in the GVL

1.4. Tasks

The study specifically focussed on the following tasks:

i. Identifying the drivers of Climate Change in the in the GVL
ii. Describing how species, ecosystems, and ecological processes within the GVL are currently affected by climate change to understand how ecosystem services will be affected by future changes
iii. Undertaking a forecast of climatic conditions sufficiently robust and that take into account exposure, adaptive capacity and sensitivity components
iv. Describing how current threatening processes such as invasive species, mining, land use, diseases of humans, livestock and wildlife will change under different climate change forecasts.
v. Proposing appropriate actions for managing and mitigating negative changes in biodiversity and ecosystem services in the GVL

2. APPROACH AND METHODS

2.1. Approach

A four-phased approach was employed in carrying out this assignment: (i) Planning and inception; (ii) Data Collection; (iii) Data processing (analysis and synthesis), and (iv) Report writing and validation.

2.2. Methods

2.2.1 Overview

The methods for this study were derived from the overall purpose, the tasks and deliverables in the consultancy agreement, as well as experience in related assignments. Qualitative and quantitative methods were used. A review of literature was carried out to evaluate the background information about drivers and impacts of climate change on biodiversity and ecosystem services in the GVL. Among the literature reviewed was the WOCAT-LADA-DESIRE mapping tool (FAO 2011). Assessments of land use land cover change and land degradation hotspots of the GVL, was carried out to aid in identification and evaluation of drivers and impacts of climate change on biodiversity and ecosystem services. Key informant interviews were also utilised. Climate modelling was executed to generate projections for the GVL.

2.2.2. Review of literature

A desk-based review of documents was done to acquire background information while at the same time gaining an understanding of the drivers and impacts of climate change on biodiversity and ecosystem services in the GVL. The review was used as a basis for developing appropriate tools for collection of data but also discussion of the results. Focus was on learning from literature the various land use and land cover types in the GVL and how they have been changing, especially in this era of climate change with the possible drivers and impacts on biodiversity and ecosystem services. Issues of land degradation were also explored.

The WOCAT-LADA-DESIRE mapping tool (FAO 2011) was reviewed to aid in identifying and assessing the drivers and impacts of climate change on biodiversity and ecosystem services. This was because this tool was designed to comprehensively deal with the effects of land use and land use practises on soil, biodiversity, and water resources. It also places emphasis on direct and socio-economic causes of these phenomena, including their impact on ecosystem services. It evaluates what type of land degradation is actually happening where and why and what is being done about it in terms of sustainable land management (SLM) in the form of a questionnaire. Focus was put on the WOCAT-LADA-DESIRE mapping tool manual (FAO 2011; Lindaque 2010) as it contains a checklist of direct drivers, state indicators, direct pressure indicators, indirect driver indicators, impact indicators and response indicators that acted as a guide for potential or expected outputs from the field.

An understanding was also sought about the climate forecasts for the GVL in the near future, mid-century and end of century. Several documents including project reports, General Management Plans of PAs in the GVL, previous Baseline studies in GVL and published work including journal articles were reviewed.

2.2.3. Land use/cover change assessment

Land use/cover change was determined through satellite image analysis of the targeted region. Satellite imagery covering the period 2003, 2012 and 2019 were downloaded from https://gisgeography.com. The images were analysed using the unsupervised classification approach and validated using existing maps and layers for the different locations within the study area. The classification was based on six broad classes including Forest, Agricultural land, wetlands, bushland, grassland and water bodies. Both the trend and change in land-use/cover were estimated. The trends were assessed using simple linear model, while a relative change in the area coverage of each land-use/cover between the 1996 and 2016 was determined.

2.2.4. Land degradation assessment

Land degradation hotspot assessment was carried out using the cloud-based Trends. Earth tool available from http://trends.earth/docs/en/ which is a recent platform for monitoring land change using an innovative desktop and cloud-based system. The tool uses NDVI as a surrogate estimator of Net Primary Productivity (NPP). The analysis considered the same period used in land-use/cover classification (2000, 2010 and 2015). The average NPP for each period was compared to that of the previous period; for the first period, the year 2000-2002 as the reference period for the comparison period 2009-2010. Additional comparison scenarios will be done between 2000-2002 and 2013-2015. MODIS (250 m resolution) images were used in this study.

Three parameters are computed in trends.earth namely the state, trajectory and trend. The state is measured difference in NDVI for a given period compared to the baseline. This difference is clustered into improved (increase NDVI/NPP), stable (no change in NDVI/NPP) and degraded (reduced NDVI/NPP). Trajectory measures the rate of change in primary productivity over time. It was computed through linear regression at the pixel level. A Mann-Kendall non-parametric significance test was then applied, considering only significant changes i.e. those that show a p-value ≤ 0.05 and $p<0.01$. Those with no significant trend ($p>0.05$) were categorized as stable. Positive significant trends in NDVI indicates potential improvement in land condition while negative significant trends indicate potential degradation.

2.2.5. Climate change projection

Climate change projection was done using 29 GCMs models for near future and for two Representative Concentration Pathways (RCP) and using the period 1980-2009 as the reference period. Climate change projection was done using statistical method. Climate data was obtained from the mandated institutions in the three countries. MERRA data was obtained from NASA and used for gap filling and replacing National Meteorological data in the case of non-existence of the data. The different GCMs outputs were plotted and 5 of them selected based on their prediction (Cool/dry, Cool/wet, Hot/wet, Hot/dry and the ensemble mean). These values were interpolated for the entire targeted region.

2.2.6. Key Informant Interviews and Focus Group Discussions

Consultative discussions were held with the representatives of the Protected Area Authorities (PAAs), institutions/ MDAs, Conservation Organizations, NGOS, CBOS and LGs identified in Table 1 through key informant interviews or Focus Group Discussions. A key informant interview /Focus group discussion guide was used to guide the discussions on the following aspects:

- Drivers and impacts of climate change on biodiversity and ecosystem services within the GVL
- How species, ecosystems and ecological processes within the GVL are currently affected by climate change to understand how ecosystem services will be affected by future changes.
- Their account of climatic conditions and how they have been as a guide to forecast of climate conditions
- How the current threatening processes such as invasive species, mining, land use, diseases of humans, livestock and wildlife will change under different climate change forecasts and what these changes mean for the future of the PAs in GVL;
- Key Recommendations/appropriate actions for managing and mitigating negative changes in biodiversity and ecosystem services in the GVL

Table 1: Category of key stakeholders targeted per level

#	Category	level/Jurisdiction	Methods/Tool
1	GVTC	Program Team	
2	MDAs	• UWA • NFA	Consultative discussions/meetings
3	LGs	• District Agriculture Officers. • District Production & Marketing Officer. • District Natural Resource Officers • District Forestry Officers. • District Environment Officers. • DCDOs/CDOs. • Lands Officers.	Consultative discussions/meetings using a KII guide
4	PAs	• Warden In charge, Warden Enforcement, Warden Community Conservation, Warden Research & Monitoring and Head of Rangers .	Consultative discussions/meetings using a KII guide.
5	Development partners & CSOs	• WWF, IUCN, CARE. • Mgahinga Conservation Trust. • International Gorilla Conservation Program (IGCP).	Consultative discussion using a KII guide
6	Community groups	• Resource user groups e.g. supported by the Protected Area Authorities (PAAs). • Former poachers, Craft groups, Tourism groups, Biodiversity Conservation groups women groups, etc	KII guide

Selection criteria for key informants
Key informants are people who are knowledgeable in the subject matter, experienced and have been directly involved in the biodiversity conservation activities or programming within the GVL. Subjective sampling was used to select the KIs based on documents reviewed and consultative discussion with GVTC, PAAs and LGs.

Criterion-based sampling was used to select the participants as follows:

i. The participants must be involved directly or indirectly with land degradation and SLM, the implementation of SLM principles, and/or they could be on the receiving end of land degradation processes
ii. The participants must have at least 3 years' experience in SLM and land degradation so as to draw on their experiences
iii. Participants have to be able to articulate their experiences and willing to give complete accounts of their experiences.

2.3. Analysis of data from KIIs and FGDs
Qualitative data obtained from KIIs and FGDs were typed in MS-Word 2013. Qualitative data were analysed using qualitative techniques, for example, thematic analysis (i.e. using radial diagrams to present main themes and sub themes, explanation building, and conclusions), discourse analysis technique and content analysis technique. Overall, the process involved data reduction, displaying data and drawing conclusions.

2.4. Quality assurance
The following measures were taken to ensure quality of data and deliverables to GVTC:

i. Using the most recent land use/land cover base map of GVL and those of the past (>10 years) to reflect the changes that have occurred.
ii. Providing a standard checklist of indicators for drivers, pressures, state, impacts and responses of land degradation to be used as a guide during the fieldwork.
iii. Verifying and triangulating information collected.
iv. Presenting preliminary findings in a validation workshop
v. Training research assistants on data collection tools and interview skills to minimize error, but also improve data quality.
vi. Pretesting and refining data collection tools
vii. Maintaining close communication with the GVTC/focal person to provide regular updates on progress of work

3. FINDINGS

3.1 Drivers of Climate Change

Global climate drivers of significance include both those associated with anthropogenic activity and to a lesser extent, those of natural origin.

i) Drivers of natural origin

The significant natural drivers of climate are changes in solar irradiance, volcanic eruptions and the El Nino-Southern Oscillation.

ii) Anthropogenic drivers

On the other hand, anthropogenic drivers are categorized into well-mixed greenhouse gases (WMGHGs), short-lived climate forcers (SLCF, which include methane, some hydrofluorocarbons [HFCs], ozone, and aerosols), contrails (or vapour trails are line-shaped clouds produced by aircraft engine exhaust or changes in air pressure, typically at aircraft cruise altitudes), and changes in albedo (e.g. land-use changes). This is currently the most important in the GVL.

The anthropogenic drivers are associated with processes that change the atmospheric abundance of the principal well-mixed Greenhouse gases (WMGHGs) i.e. carbon dioxide (CO_2, Methane (CH_4) and Nitrous Oxide (N_2O). CO_2 emission sources have primarily grown from fossil fuel combustion, cement manufacturing and land-use change from activities such as deforestation. CH_4 has a variety of natural and anthropogenic sources and its abundance is controlled by the global abundance of the hydroxyl radical (OH) which controls the methane atmospheric life time, changes in large–scale anthropogenic activities such as mining, natural gas extraction, animal husbandry, agricultural practices and natural wetland emissions. On the other hand, N_2O, in addition to being emitted in the Nitrogen cycle, has a variety of anthropogenic sources including the use of synthetic fertilizers in agriculture, motor vehicle exhaust and some manufacturing processes (Fahey *et.al.*, 2017).

Land use land cover change

Recognizing that land is a very important resource for human livelihoods, a land use and land cover change (LUCC) analysis of the GVL as an indicator of vegetation degradation arising from anthropogenic human activities, was carried out. Figures 2 - 4 and Table 2 show the distribution of land-use/cover in GVTC landscape for the time period of 2003, 2012 and 2019.

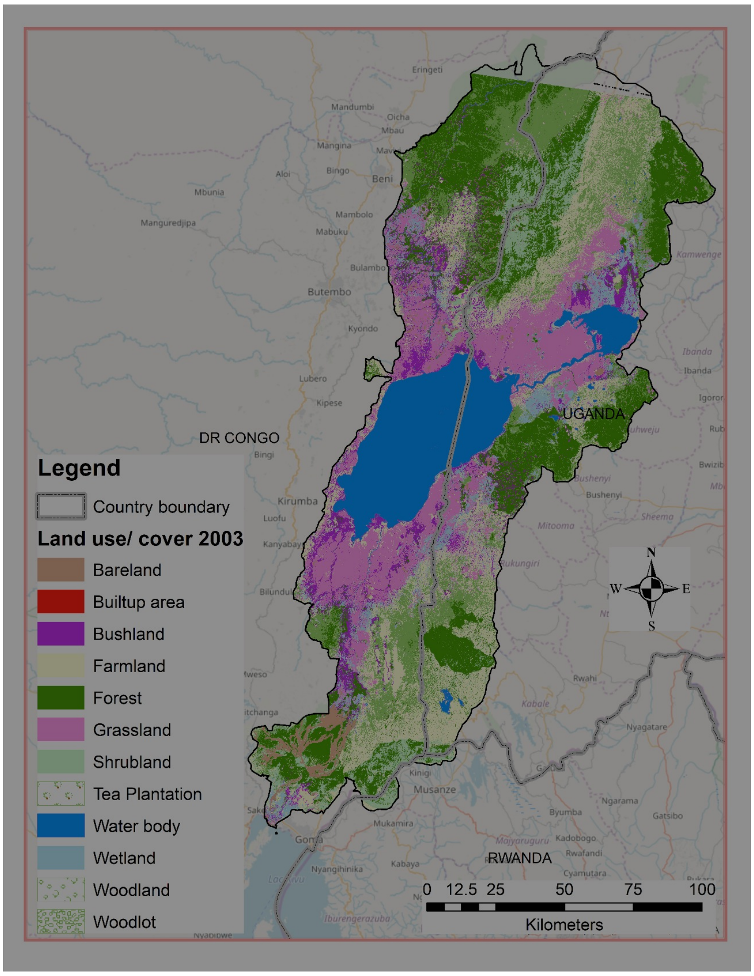


Figure 2: Land-use/cover of GVTC for the year 2003

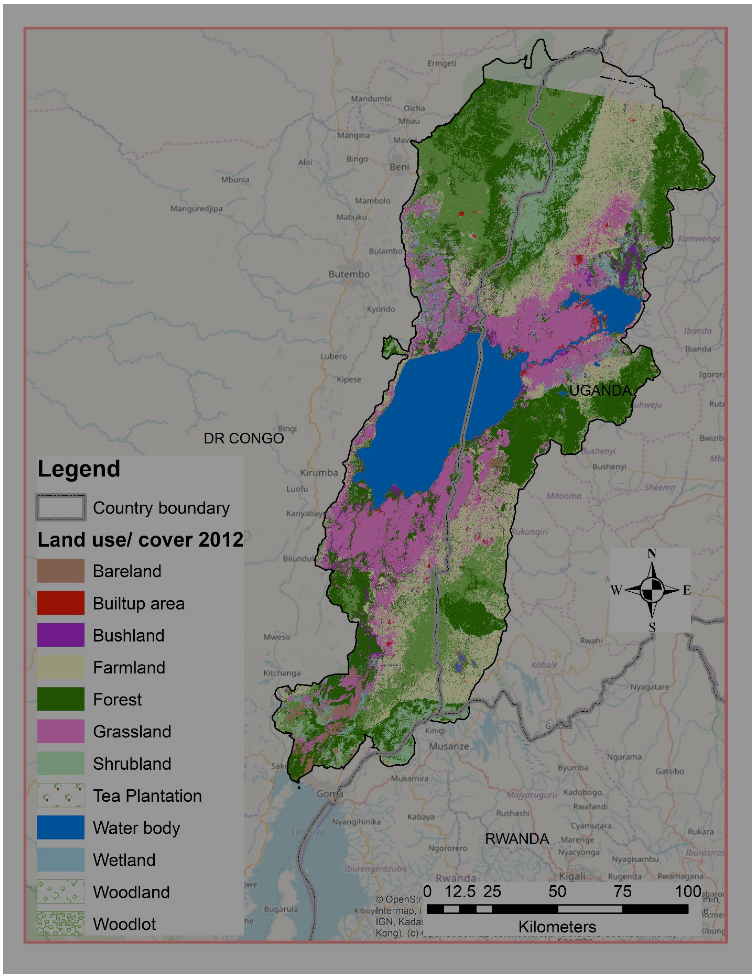


Figure 3: Land-use/cover of GVTC for the year 2012

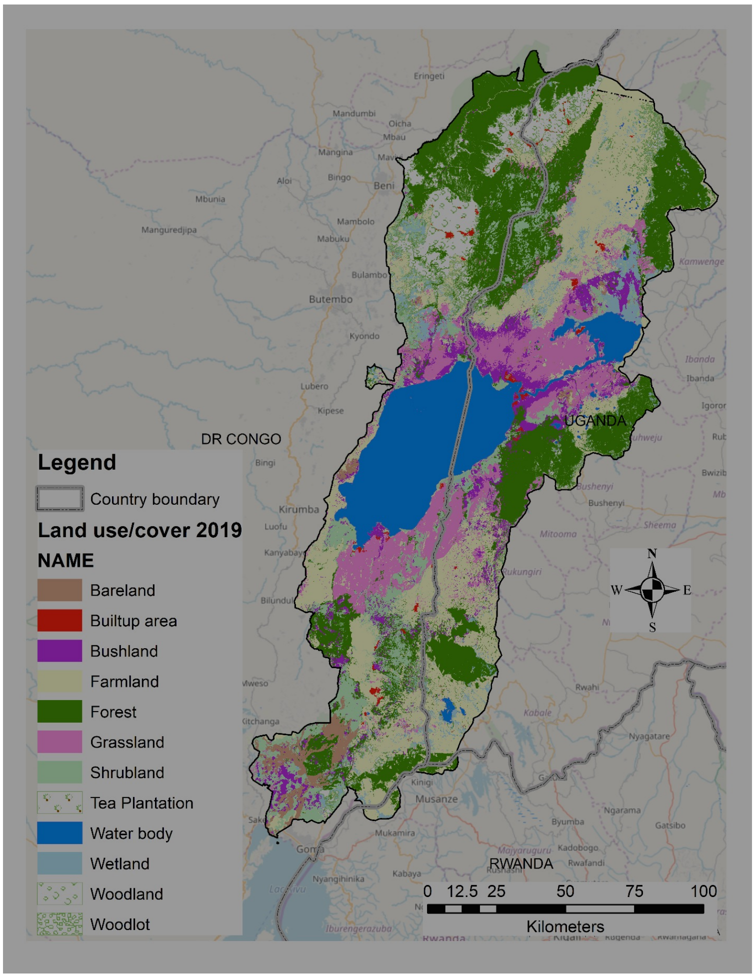


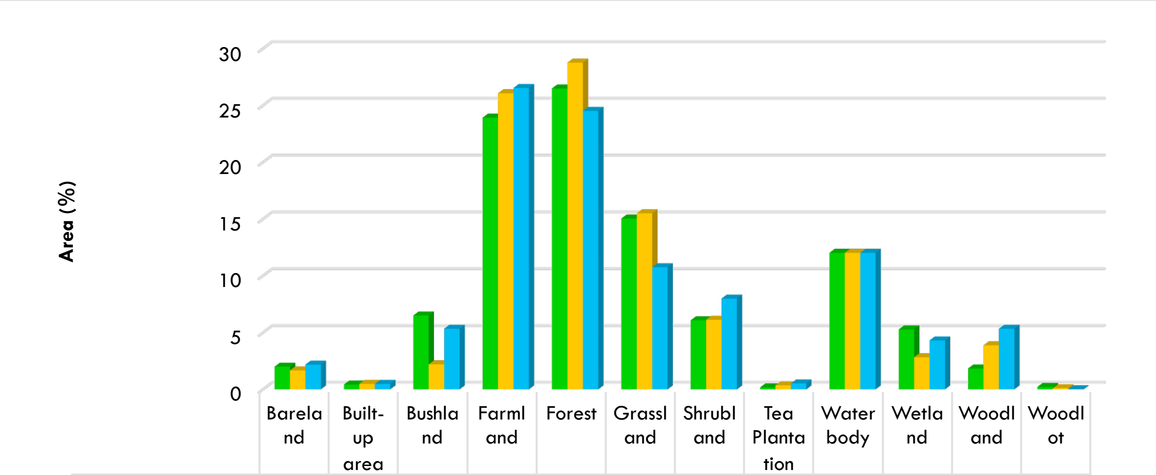
Figure 4: Land-use/cover of GVTC for the year 2019

Table 2: Land-use/cover of GVTC for the year 2003, 2012 &2019

CLASS_NAME	AREA 2003	AREA 2012	AREA 2019	Percentage area 2003	Percentage area 2012	Percentage area 2019
Bare land	430.82	360.89	471.29	2.00	1.67	2.18
Built-up area	93.25	103.90	104.62	0.43	0.48	0.48
Bushland	1403.74	474.47	1152.40	6.50	2.20	5.34
Farmland	5163.14	5623.53	5724.50	23.92	26.06	26.53
Forest	5716.42	6205.98	5292.35	26.49	28.76	24.52
Grassland	3245.99	3345.95	2319.20	15.04	15.50	10.75
Shrub land	1312.36	1321.96	1723.41	6.08	6.13	7.99
Tea Plantation	35.74	77.24	112.20	0.17	0.36	0.52
Water body	2595.02	2595.02	2595.02	12.02	12.02	12.02
Wetland	1138.48	610.12	931.18	5.28	2.83	4.31
Woodland	397.23	837.04	1151.37	1.84	3.88	5.34
Woodlot	48.44	24.53	3.08	0.22	0.11	0.01
Total	21580.63171	21580.63171	21580.63171	100	100	100

Forest, farmland, grassland and water bodies were the dominant land-use/cover in 2003 accounting for about 77.5% of the total area. Other land-use/cover included shrub land, bush land, wetland, bare land, woodland, built-up area, woodlot, and tea plantation. The area of the four dominant land-use/cover types has followed a quadratic trend for the last 16 years; with a peak around 2010. Among these dominant types, only farmland has increased linearly with time, forest and grassland slightly reduced in 2019, while water bodies remained constant. Other land-use/cover types which showed a significant increment in their coverage included woodland and tea plantation. Built up area had increased in 2012 and remained unchanged for 2019. The increment in the dominant land-use/cover in 2012 was to the expense of bushland, wetland and woodlots.

In 2003, grasslands were mainly located around the Lakes Edward and George. The Forested area occupied the northern part of the region, the southeastern part of the Lakes Edward and George, around Bwindi, and scattered in the east of Kitshanga. In 2012, the farmland expanded into the grassland areas particularly in the Ugandan and DRC side of the GVTC, particularly in the northern region and in the south of the Lake Edward. This expansion significantly increased in 2019 in this region moving towards the northeast, farther south of Lake Edward and to the western part of the Lake. Woodlands have mainly increased in the northern part of the region.



	Bareland	Built-up area	Bushland	Farmland	Forest	Grassland	Shrubland	Tea Plantation	Water body	Wetland	Woodland	Woodlot
Area in 2003 (%)	2	0.43	6.5	23.92	26.49	15.04	6.08	0.17	12.02	5.28	1.84	0.22
Area in 2012 (%)	1.67	0.48	2.2	26.06	28.76	15.5	6.13	0.36	12.02	2.83	3.88	0.11
Area in 2019 (%)	2.18	0.48	5.34	26.53	24.52	10.75	7.99	0.52	12.02	4.31	5.34	0.01

Figure 5: Percentage area of the different land-use/cover in GVTC for the year 2003, 2012 & 2019

The results show that farmland and woodland have been increasing since 2003 while forests, grasslands and wetlands have been declining in area coverage (Figure 5). These land use changes, that are anthropogenic in nature, are thus responsible for driving climate change in the GVL. These changes are associated with the ever-increasing population in the GVL as this region has very high annual population growth rates globally. For instance, Uganda, one of the countries in this study has an annual population growth rate of about 3.0% (UBOS, 2016). The high population is responsible for the increasing demanding for products and services, especially from the protected areas, thus leading to land degradation in the GVL, as manifested by the vegetation degradation through analysis of Net Primary Productivity.

The current state of the net primary productivity (NPP) in the GVL is shown in Figures 6 and 7 and the trajectory of the land degradation is shown in Figures 8 and 9. Generally, patches of land degradation are located in the north, south and eastern parts of the region. Larger patches of the major part of the landscape are degraded compared to the 2001 conditions. Patches of stable parts are scattered in the region. Most of the improved and stable parts of the region tend to occur inside the PAs (mainly National Parks).

Significant decreasing trends in NPP occur in the southern part of the region and the northern part of Lake Edward while a relative improvement in NPP is around all the Lakes and the northern part of Lake George. The status of degradation varies from one country to another. In Rwanda, the majority of the region is stable. Patches of improvement are scattered in the northern parts near the Kisoro district (Uganda) and the southwestern part of the country. In Uganda, there is a relatively high concentration of degraded patches in the western part of Kisoro, in Kanungu and Rukungiri districts, eastern part of Rubirizi and around the town of Fort portal. In DR Congo, degraded patches are located more in the southern part of Butembo, the south-eastern part of Lake Edward and in Rutshuru. Improved and stable patches are found around Beni and the southern part of Lake Edward.

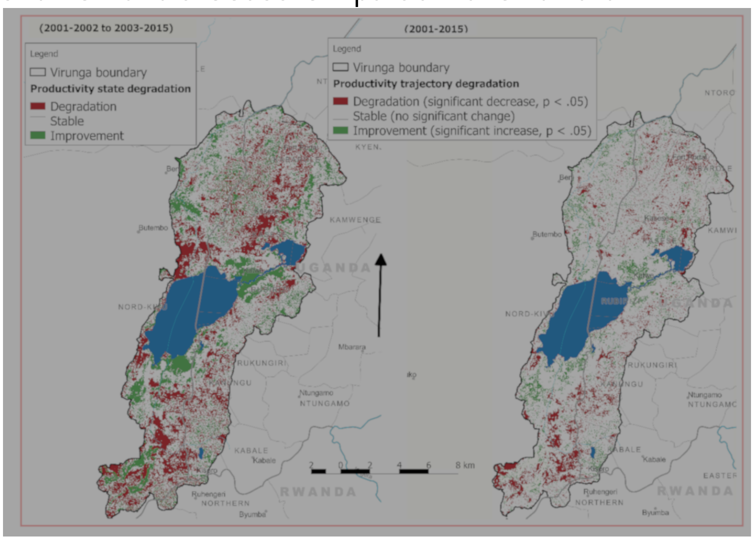


Figure 6: Vegetation degradation in Great Virunga Trans-boundary Landscape 2001-2015

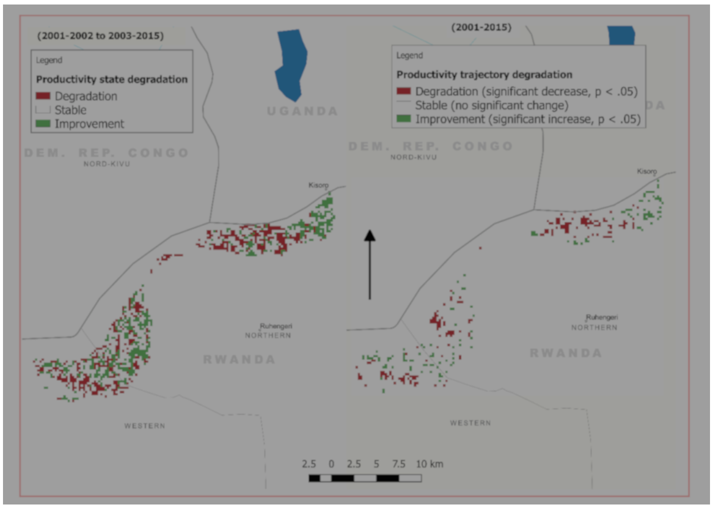


Figure 7: Vegetation degradation in Rwanda with the Virunga Trans-boundary Landscape 2001-2015

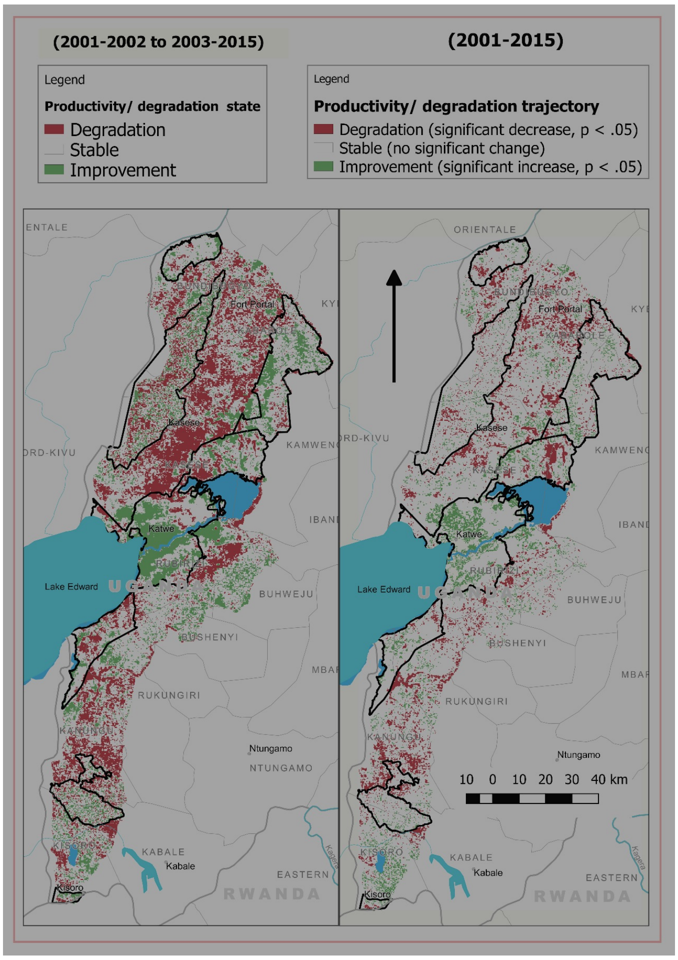


Figure 8: Vegetation degradation in Uganda within Great Virunga Trans-boundary Landscape, 2001-2015

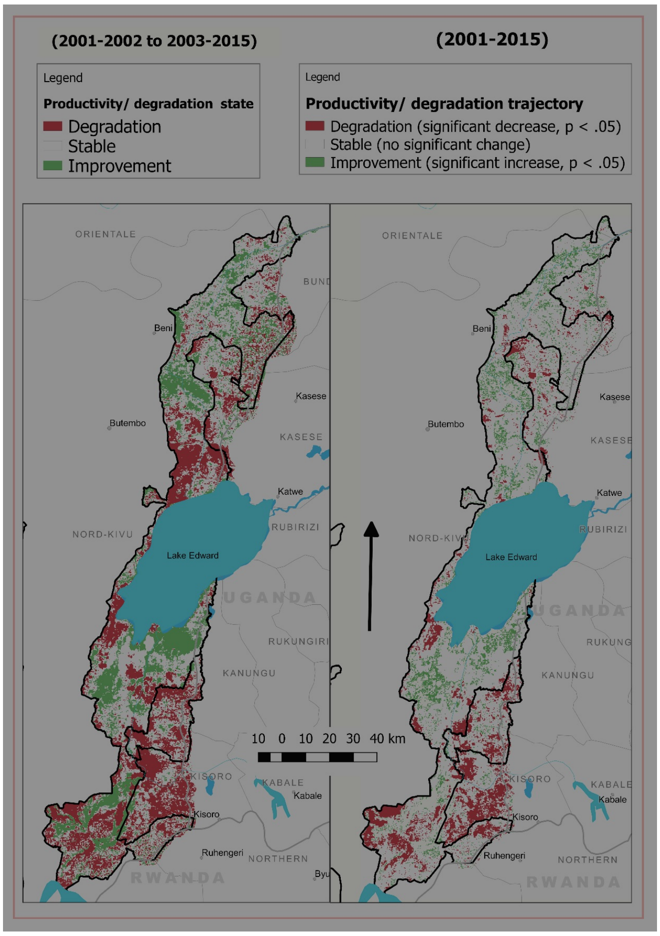


Figure 9: Vegetation degradation in D.R. Congo within the Great Virunga Trans-boundary Landscape 2001-2015

Figure 10 shows the state of NPP for the period 2001-2015. There is a higher density of degraded patches in the southeastern part of the region and around the northern and western parts of Bwindi National Park. More cases of stability and improvement are observed around the lakes and National Parks.

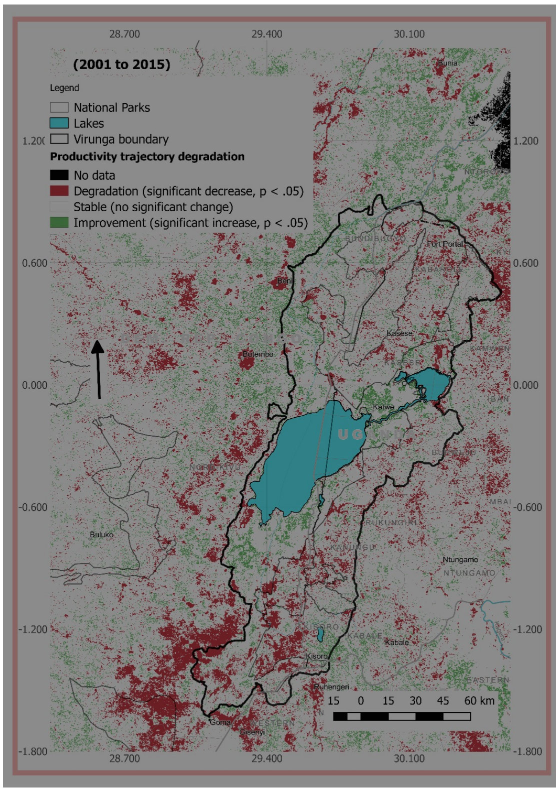


Figure 10: Productivity state in the GVL 2001-2015

Figure 11 shows the trend in productivity/degradation. In terms of status, stable and improved patches are located within the PAs (National Parks) and around the Lakes. Higher densities of degraded patches are located in the southwestern part of the landscape.

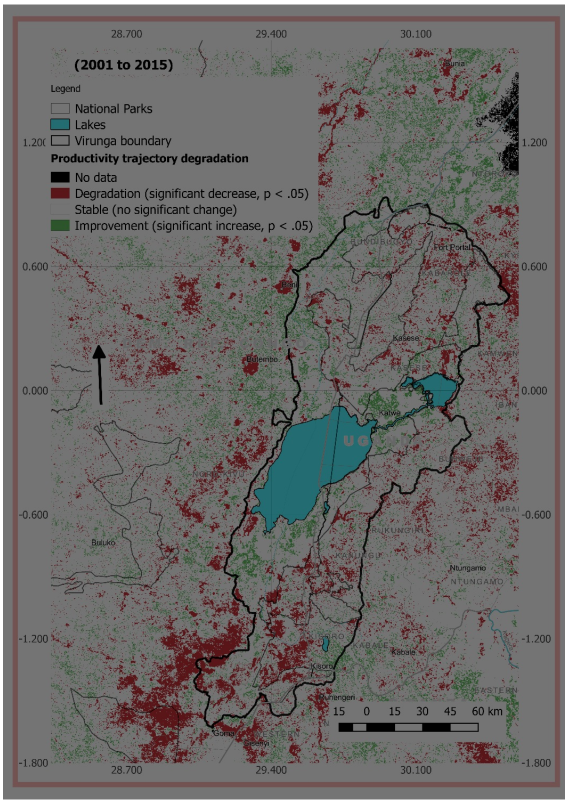


Figure 11: Productivity trends in the GVL 2001-2015

As already shown, human land degradation activities contribute significantly to climate change by contributing GHGs. Table 3 details some of the drivers of land degradation that contribute to climate change in the GVL.

Table 3: Direct and Indirect drivers of climate change in the GVL

Driving forces (Indirect causes of climate change)	Direct pressures (Direct causes of climate change	State (Type of land degradation	Impacts (on climate services)
Traditional tillage practices and lack of information on better options for nutrient enrichment	Nutrient enrichment	Burning of plant material (brush) during preparation of gardens for planting and opening up of new gardens	Release of GHG – Carbon dioxide (CO_2) – into the atmosphere
Poverty and lack of information on better tillage options other than traditional tillage practices	Tillage practice of using a hand-held hoe	Mechanical disturbance of surface soil	
Lack of knowledge on the use of agrochemicals and population pressure resulting land shortage	Nutrient mining due to continuous cultivation of same crop on same piece of land	Inappropriate application of fertilizers in crop production	Release of GHG - Nitrous oxide (N_2O) – into the atmosphere
	Fertility decline and reduction of organic matter and organic matter by water erosion	Cutting down of trees	
	Expansion of land for agriculture		
Land tenure – land fragmentation, land renting	Missing or insufficient soil conservation/runoff and erosion control measures	Deposition of sediments, flooding, siltation of valleys and wetlands	Release of GHG – CFCs, HCFs and HCFs – into the atmosphere
Population density, local politics and governance, lack of clarity on land tenure of wetlands	Conversion to agriculture	Loss of wetland vegetation, and exposure of peat	Release of GHG – methane (CH_4) – into the atmosphere Loss of carbon storage function and loss of micro-climate moderation and weather modification function
Demand for animal products like meat and milk and traditional source of income	Livestock rearing	Production of dung manure	Release of GHG – methane (CH_4) – into the atmosphere

Demand for fuelwood and lack of alternative source of energy	Overexploitation of woody biomass	Cutting down of trees	Loss of carbon storage function and loss of micro-climate moderation and weather modification function

3.2. Effects of climate change on species, ecosystems, and ecological processes

3.2.1. Historical climatic conditions of the GVL region

The average annual rainfall and temperature distributions are shown in Figures 12 and 13 respectively. Rainfall ranges between 600 mm and 1600 mm. The central part of the region receives 600-1000 mm annually. Rainfall tends to increase gradually from the Lakes (Edward and George) towards the north and southern part of the region.

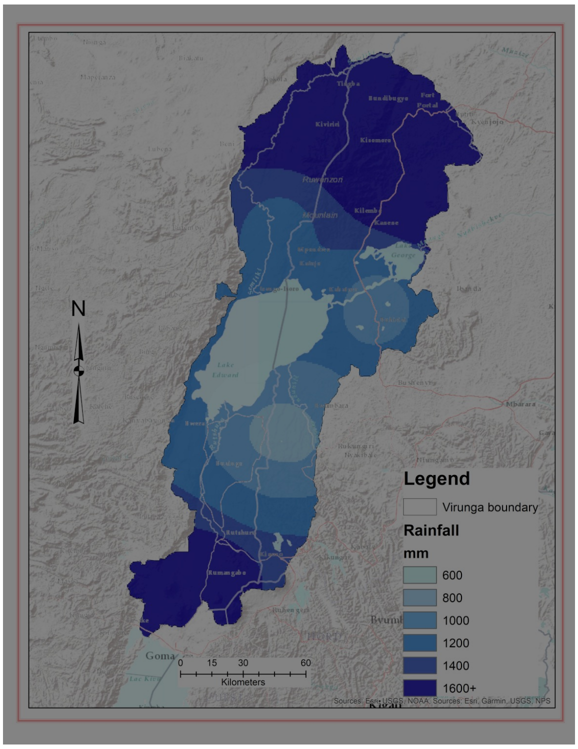


Figure 12: Baseline Average annual rainfall distribution in GVL (1980-2009)

The average annual temperature varied from 17 to over 23°C. The highest average annual temperature was experience in the southern part of Lake Edward and George and the north-eastern part of the region. A decreasing gradient was observed from Lake Edward towards the south of the region. The same declining trend was also observed in the north-eastern part of the region.

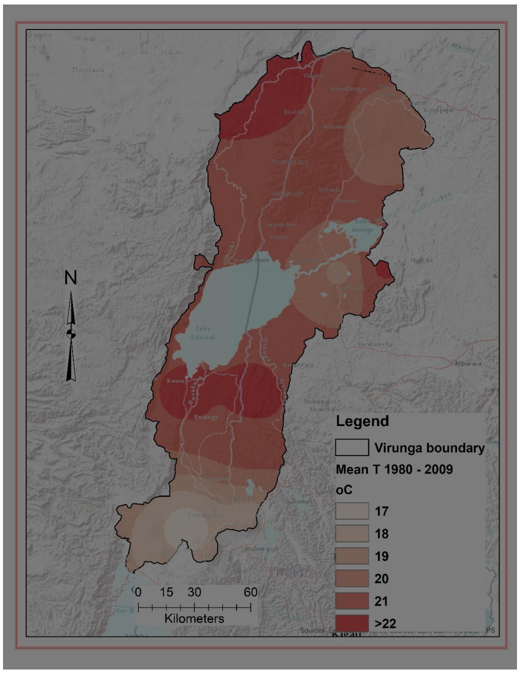


Figure 13: Baseline average annual temperature distribution in GVTC (1980-2009)

3.2.2. Ecosystem Services in the GVL

Table 4 shows the varied ecosystem services that a wide range of stakeholders, are benefiting from in the GVL and these range from non-wood and wood products. Under the current climatic conditions, these services and products are available. One of the services is power generation (Figure 14).

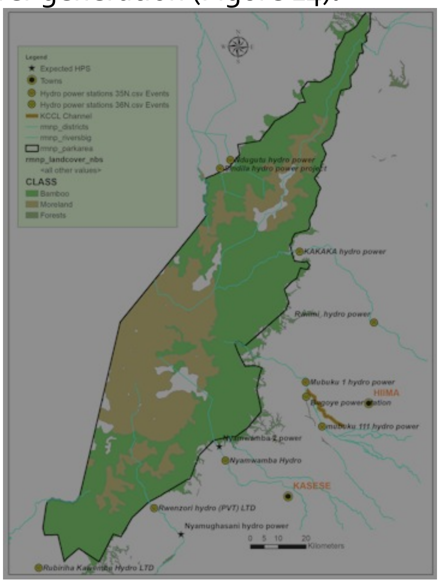


Figure 14: Location of hydropower stations around Rwenzori National Park, Uganda (Source: RMNP Field Monitoring Department, 2019)

Climate change effects on species, ecosystems and ecological processes

i) Shifts in vegetation belts: Climate change has had an effect on the species, ecosystems and ecological processes of importance to the local communities. Examples include shifts in vegetation belts and declining glaciers in the Rwenzori Mountains. There have been shifts in vegetation belts of the mountains, for instance in Rwenzori National Park, bamboo was initially found at 3000 meters but that has moved to 3200 metres above sea level. The giant lobelia is also undergoing a shift. Habitats for wildlife species continue to shift and warm temperatures are responsible for this.

The GVL has up to four taxa of Giant senecios (*Dendrosenecios*) that are endemic landmarks of the isolated sky islands in the region. These taxa have distinct altitudinal variation in morphology. They are found in the afro-alpine zone proper, i.e. above ~3500 m, but some of them also occur downwards into the transitional ericaceous zone and further into the montane forest zone. In addition, some taxa are restricted to lower altitudes, occurring in the forest zone down to 2600 m (Knox 2005). The plants have adaptations to enable them survive at the different altitudinal zones. The high-altitude plants typically have larger stems and leaves than low-altitude plants, and show stronger physiological adaptations to the harsh afro-alpine environment with their well-developed mechanisms for frost tolerance and avoidance (Hedberg 1964). Change in climate will definitely affect these species, some of them negatively.

Taxa of *Dendrosenecio* occurring in the GVL and their altitudinal range

Taxon	Altitudinal range (m)	F	E	A	Geographical range
1. *Dendrosenecio adnivalis* (Stapf) E.B.Knox ssp. *adnivalis*	3250-4500			X	Endemic to Mt Ruwenzori
2. *Dendrosenecio adnivalis* (Stapf) E.B.Knox ssp. *friesiorum* (Mildbr.) E.B.Knox	3900-4200			X	Endemic to Mt Ruwenzori
3. *Dendrosenecio erici-rosenii* (R.E.Fr. & T.C.E.Fr.) E.B.Knox ssp. *erici-rosenii*	2750-4200	X	X	X	Endemic to Virunga Mts, Mt Ruwenzori, Mt Muhi, Mt Kahuzi, Mt Nyiragongo
4. *Dendrosenecio erici-rosenii* (R.E.Fr. & T.C.E.Fr.) E.B.Knox ssp. *alticola* (Mildbr.) E.B.Knox	3400-4475			X	Endemic to Virunga Mts (Mt Muhavura, Mt Karisimbi, Mt Mikeno)

The vegetation zones in which the taxa occur (Knox, 2005) are denoted F - montane forest zone, E - ericaceous zone and A - alpine zone. *Adapted from Mugizi et al. (in prep)*

ii) Receding glaciers: Glaciers and snow on the mountain has drastically reduced in the past 25 years, a clear sign of climate change. It is projected that by 2025, there will be no glaciers on Mountain Rwenzori if climate change is not addressed. The melting of glaciers and snow on Mt Rwenzori is associated to increases in temperatures that continue to be recorded.

iii) Overharvesting in- park wildlife resources: The high demand and illegal harvesting of park resources has led to reductions in the quantities of resources, depletion of natural resources and of the ecosystems ecological functions. Over dependence on natural resources for survival by humans is one of the key drivers of climate change in the GVL.

iv) Proliferation of invasive species: Ecological processes such as the proliferation of invasive species in the GVL could be associated with the increasing degradation due to unsustainable utilisation of the resources in the GVL, and this trend is likely to continue as the human population is still on an increasing trajectory.

v) Increased incidences of dry spells and or floods: There have been noticeable increases in long dry spells followed by periods of increased rainfall intensity in the GVL, a manifestation of climatic changes, which have caused natural disasters. The evidence is in form of frequent flooding of Rivers Nyamwamba and Mobuku (Kasese District – Uganda), as well as Lugo and Kirumya in Bundibugyo District (Uganda) among others (Figure 15). Flooding of River Nyamwamba normally leaves behind serious devastation to both people and property vital infrastructures such as roads, health facilities, schools, bridges, and crops as well as serious silting of rivers. In 2015-2016, there were widespread Landslides and floods totalling to 19, which resulted in extensive destruction of property and lives where 20 deaths were reported especially in Ntandi village, Bundibugyo District. Constant floods and landslides have the potential to impact the socio-economic and physical welfare of communities living in risky areas. Response to the effects of floods is likely to result into new adaptive responses such as encroachment on naturally existing resources which has a possibility of affecting a broader environment.

Figure 15: Flooding of Rivers Kirumya (Left) and River Lugo (Right) that originates from Rwenzori National Park and drains Semliki River through Semliki National Park, Bundibugyo District

vi) Wild fires: Wild fires are a common phenomenon and are particularly caused by prolonged drought and increased human activities in the parks. More fire outbreaks will likely lead to changes in vegetation composition as certain plants become more competitive with increasing moisture and fire frequency which will in turn affect plants and animal distributions in the Great Virunga Landscape. For instance in 2010 there were more reports of increased wild fires that destroyed an area close to 15 hectares of Rwenzori National park land especially at higher altitudes. Uncontrolled fires constitute a serious threat to other PAs. Volcanoes National park has had incidences of fire. Fires are rare in some parks, but the effects are devastating. T

In addition to wild fires, bush burning for agricultural activities, poaching and honey harvesting activities are leading to increased fires, which destroy large parts of the

parks with all the associated biodiversity in these areas. January, February and March fires are very common and normally communities adjacent the park are particularly affected. The fires destroy plant and animal biodiversity, vital park infrastructures and negatively affect community livelihoods.
There are still challenges associated with accessing those ecosystem services as highlighted in Table 4 above. Of particular mention is that access to the diverse park resources and services is regulated by way of entering into Memoranda of Understanding (MoUs) between communities and park management to agree on sustainable resources harvesting.

3.3. Forecast of climatic conditions

3.3.1. Projected rainfall change for the near future for RCPs 4.5 and 8.5

Figure 16 shows the rainfall projections for the GVL. Under RCP 4.5, Rainfall is expected to range from 639 – 2505.49 mm in the region. The majority of the central part of the GVTC is likely to experience rainfall between 1.105- 1572.42 mm. The northern and southern parts of the region are likely to experience rainfall ranging from 1572.42-2039 m. The south-western part of Lake Edward and south-eastern part of Lake George are likely to receive less rainfall (648-957 mm). The highest amount of rainfall is likely to be experienced in the northern part of QENP. A similar pattern as for RCP 4.5 is likely to be experienced in the near future in terms of average annual rainfall distribution. However, the rainfall amount is likely to range from 648 mm to 2524.49 mm. The relative change in rainfall is expected to increase towards the central part of the region which had been experiencing relatively lower rainfall. Where up to 45% increment in rainfall amount is likely to be expected for both RCPs. It worthwhile to note that patched of <5% variation in rainfall are expected more in the northern region for RCP 8.5 compared to 4.5.

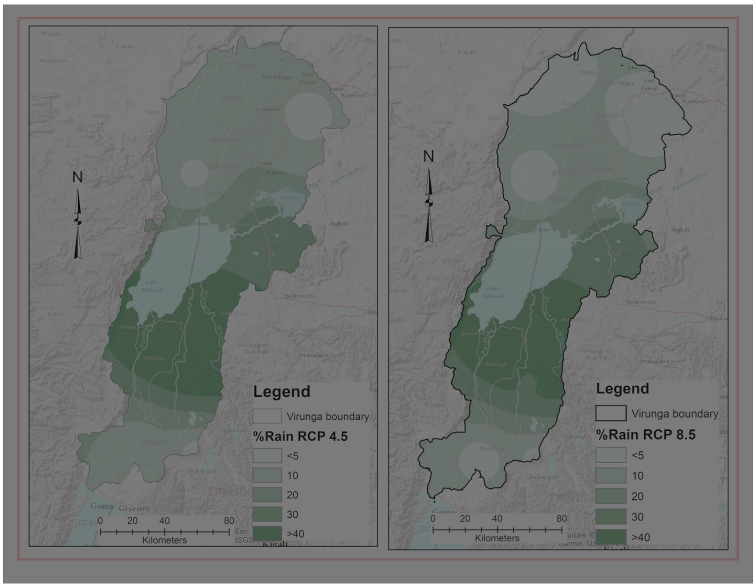


Figure 16: Projected rainfall change for the near future for RCPs 4.5 and 8.5

3.3.2. Projected temperature change for the near future for RCPs 4.5 and 8.5

In terms of temperature (Figure 17), the majority of the region is likely to experience an increment in average temperature ranging from 1-1.4°C. Some areas in the southern part of Lake George and eastern part of Lake Edward are likely to experience increment of 1.8-2.3°C. Small pockets in the north-east of Lake Kivu are likely to experience <1°C increment in average annual temperature for both RCPs. It is also necessary to note that there more patched which are likely to experience less than < 1°C of increment for RCP 4.5, particularly in the northern and southern part of the region.

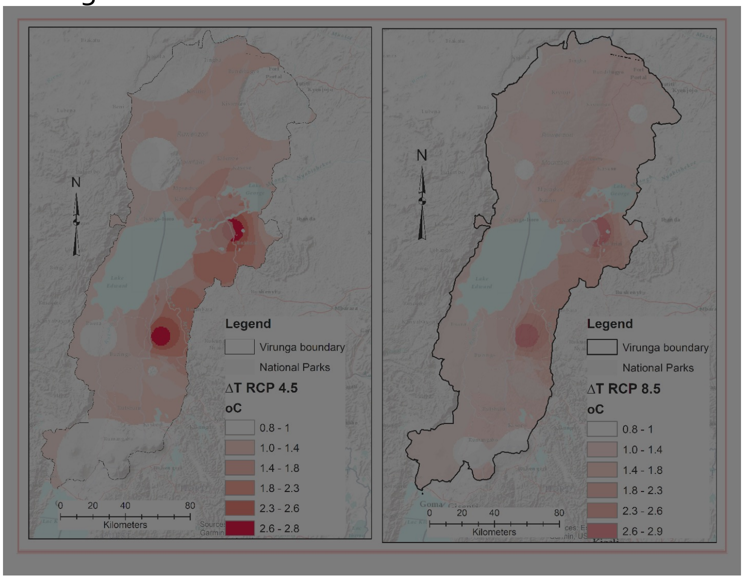


Figure 17: Change in average annual temperature in GVTC in the near future fir RCP 4.5 and 8.5

3.3.3. Climate projection across the GVL countries

Projected temperature and rainfall for the two RCPs is likely to vary across the landscape and from one country to another (Table 5). There is a likelihood that sites in Uganda experience relatively high increment in temperature compared to those in Rwanda and DRC. However, the relative rainfall increment will be highest in DRC, followed by Uganda.

Generally, the change in Tmin will tend to be higher compared to Tmax, and the gap is expected to increase under RCP 8.5 for the 2020-2040 periods. The northern and southern part of the region is also likely to experience <10% rainfall increment. This is likely to increase gradually from the south and north towards the Lakes Edward and George.

Table 4: Projected temperature and rainfall in GVTL (2020-2040) under RCP 4.5 and RCP 8.5

Part of the Landscape	RCP=4.5			RCP=8.5		
	ΔTmax	ΔTmin	Rainfall	ΔTmax	ΔTmin	Rainfall
	°C		(%)	°C		(%)
DR Congo	1.05	1.44	28.59	1.02	1.72	26.63
Rwanda	0.77	0.96	5.01	0.94	1.00	3.53
Uganda	1.05	1.51	12.62	1.21	1.59	11.36

3.4. Influence of different climate change forecasts on current threatening processes

3.4.1. Increasing temperature and rainfall

Although there are variations across the landscape and countries in terms of projected rainfall and temperature in the near future and the 2020-2040 period, it is generally projected that the GVL will receive more rainfall and experience higher temperatures. The projected climatic conditions will thus affect several ecosystem services and processes in the GVL. These effects are more likely to occur in DRC and Uganda and under RCP 8.5 as compared to RCP 4.5.

An increase in rainfall will exacerbate the already existing problem of natural disasters, especially landslides and floods. Floods will continue to have impacts on food security, as they will destroy agricultural fields, and thus negatively impacting livelihoods. Critical infrastructure such as roads and buildings with a possibility of loss of human lives will be destroyed.

3.4.2. Increasing human population

With the increasing population and the known dependency of humans on natural resources for livelihood needs, there will be an increase in land use and land cover dynamics with potential negative impacts. There is indeed an insatiable need for land to pave way for agricultural activities and settlements. The ever-increasing populations call for increased agricultural land coverage, a factor, which drives people towards parkland. Specifically, land degradation is projected to increase and this will negatively affect biodiversity conservation. Increasing land degradation will also put more pressure on the GVL, especially the protected areas, as those protected areas will be viewed as the remaining alternative source of survival for humans. In these desperate situations where agriculture is at stake, alternative income generating activities such as mining, although already being carried out, will have to increase with more people, especially the local communities, engaging in it. Poaching will also potentially increase.

3.4.3. Proliferation of alien invasive species

The projected change in climatic conditions will also lead to proliferation of invasive plant and animal species, some of which could lead to increasing incidences of diseases like malaria in humans. Changes are also expected in the abundance of some species, and since some of them are pests, incidences of pests and diseases will be on the rise.

3.4.4. Receding glaciers

Glaciers and snow on the mountain Rwenzori are expected to continue declining, a clear sign of climate change. Currently, the extent is reduced and crevices are evident on previously completely snow covered sites.

Reduced extent of Glaciers in some parts of the Rwenzori Mountains could be attributed to climate change *(Photo G. Eilu – July 2019)*.

3.4.5. Increase in occurrence of wild fires

Increasing temperatures will also exacerbate the incidence of fires in GVL. In 2012, wild fires ravaged an estimated 30-40 kilometres of vegetation cover at about 4600 metres above sea level in the Rwenzori Mountains National Park (Uganda). The fire caused damage to property such as a tented camp. Subsequently a fire plan was generated and is being operationalized, involving local participation in its implementation. Similarly, fires have been experienced in Queen Elizabeth National Park.

3.4.6. Increase in Anthropogenic activities

Anthropogenic activities such as agricultural activities, poaching and honey harvesting will increase and their association with fires implies that large parts of the GVL, especially the protected, will be at high risk of being burned. Such burning will lead to further destruction of biodiversity and associated ecosystems.

3.4.7. Degradation of fragile ecosystems

i. Lakes and wetlands

Under RCP4.5 and RCP8.5 scenarios, there is expected increase in annual precipitation. Under climate change conditions and due to the alteration of regional precipitation patterns, lakes and wetlands are exposed to greater nutrient loads, which can ultimately lead to water quality deterioration. Lake Mulehe in Kisoro district in Uganda has already experienced one eutrophication event, where the water turned green because of stimulated growth blue-green algae resulting in massive death of fish.

Intense extreme precipitation events are expected to occur and cause more erosion on the hill-slopes and re-suspension of sediments, ultimately resulting in higher concentrations of sediments and nutrients in the lakes and wetlands. These extreme events will increase contaminant discharge and affect non-point pollution by mobilizing them over agricultural land and increasing nutrient concentrations in receiving wetlands and lakes, consequently degrading the water quality.

In the event of less precipitation, there is still increased risk of eutrophication by lowering minimum flows. Less water volume will be available for dilution of pollutants. As a result, increased concentrations of contaminants can cause deoxygenation, by lowering dissolved oxygen concentration (DO) and increasing biochemical oxygen demand (BOD). Consequently, the risk of eutrophication, especially in water bodies with limited re-aeration capacity, will be increased.

Temperature of the region is likely to increase averagely by 1-1.4°C under RCPs 4.5 and 8.5 scenarios. Increasing air temperature will increase water temperature and lead to deterioration of water quality conditions by accelerating the eutrophication processes in water bodies, which can cause environmental and health-related issues.

Air temperature and temperature in water bodies are in equilibrium. Hence one of the immediate reactions to climate change is expected to be alterations in lake temperature. When water temperature and nutrient concentrations increase, algae growth is stimulated, leading to water eutrophication and algal blooms. As concentrations of phosphorus and nitrogen increase in lakes, cyanobacteria become increasingly dominant. Cyanobacteria are a group of bacteria that grow in any type of water and use sunlight to create food and survive. Because of their colour, they are commonly known as 'blue-green algae'. They grow quickly and bloom in warm, nutrient-rich environments. Once water temperature rises above 25°C, the growth of cyanobacteria accelerates.

As the inflow to a lake gets warmer as a result of higher temperature, the water column will stratify more intensely, decreasing nutrient availability in the surface water. In this case, cyanobacteria will obtain nutrients from deeper depths and accelerate nutrient release in water. Higher temperatures will accelerate microbial activity in the sediments at the bottom of the lake. In this case, the release rate of internal phosphorus will increase, and will contribute to a significant portion of the total nutrient load in the water. Therefore, under climate change conditions, the release of nutrient loadings from internal sources could still make water eutrophic, even if external sources of nutrients, such as non-point pollution from agricultural land are restrained.

Warming of both air and water temperature under climate change favours increasing survival and breeding of anopheles mosquitoes that are responsible for the spread of malaria. Environmental degradation, especially drainage of wetlands, has brought change in climate leading to areas that used to be cold and practically had no malaria to have severe malaria outbreaks. This, coupled with movements of people to and from areas with high malaria prevalence, like Kampala (Uganda), has propelled malaria to even higher levels. People living in areas with low malaria prevalence such as the highlands of Kigezi are prone to severe due to low immunity.

ii. Farmland

Climate change is likely to be exacerbating the land degradation problems in the area. For example, flash floods that occurred in Kirundo subcounty of Kisoro District (Uganda) killing 3 people, destroying 20 houses and several hectares of crops washed away in September 2011 while those that occurred in Muko subcounty of Rubanda District killed 17 people, destroyed 15 homes and crops in September 2017.

We are likely to witness more areas being degraded and becoming unsuitable for crop growing, especially on the hillslopes, due to extreme weather event like storms. However, even the valleys that are currently the main stay for agriculture are likely to be sedimented with unfertile or polluted soil. Frequent droughts are likely to drastically reduce crop yields, reduce water availability for human, livestock and plant use and increase wind erosion. Unpredictable and unreliable variability weather is likely to affect farmers greatly as they will not know when to plant crops. The present knowledge of synchronizing crop growing with weather events has been used for several generations so that it is now very difficult to change.

Conversion of natural habitat to agriculture in the GVL (as part of the Albertine Rift) has already claimed up to 38% of the suitable habitat of the average endemic species. Climate change is expected to worsen the situation by causing on average to a 75% loss of the remaining range of endemic species by 2080. Putting these two together means that on average only about 16% of species original suitable habitat would remain in 2080. Most of these areas of suitable habitat are predicted to shift upslope in the mountains.

However, on a positive note, there is likely to be significant overlap between the current and future suitable habitat for most species in the region, and nearly 68% of overlapping areas are already protected. This means that for these species the overlap will allow movement to new areas as well as species survival in the existing overlap areas. Up to 31 species are predicted to lose all or most suitable habitat by 2080, or do not have any overlap between current and future predicted ranges. These species will need more direct conservation action if they are to be conserved.

iii. Tropical montane forests

The tropical montane forests of the region (Bwindi, Mgahinga and Echuya) are all protected. They are often immersed in cloud. This cloud immersion affects every aspect very aspect of the forests from hydrological cycle to the species of plants and animals. This immersion makes the forests sensitive to climate. Changes in temperature and rainfall due to climate change makes altitude shifts in the climate optimum for mountain ecotones. This suggests complete replacement of high altitude alpine zones by lower altitude ecosystems, pushing the latter to near extinction. There is also expected to a reduction in low level cloudiness with the coming climate changes. The coming climate changes appear likely to upset the current dynamic equilibrium of the forests. Results will include biodiversity loss, altitude shifts in species' ranges and subsequent community reshuffling, and possibly forest death. Difficulties for montane forests species to survive in climateinduced migrations include no remaining location with a suitable climate, no pristine habitat to colonise, migration rates or establishment rates that cannot keep up with climate change rates and new species interactions. One example is study in the Volcanoes National Park (Musana and Mutuyeyezu 2011) showing that Mountain Gorillas depicted a seasonal use of vegetation zones. One group of gorillas had an altitudinal range of 2,400-2,600m while another ranged between 2,900-3,050m, but the two groups most commonly occupied the lower forest belt. Hence, the results showed that mountain gorillas had complicated seasonal movement patterns. Long-term data show a correlation between mountain gorilla movement and seasonal changes. This variation in use of vegetation zones can depend on the availability of food sources, which is a function of seasons and altitudinal climate zone.

Apart from changes in temperature, precipitation, and cloudiness, other changes include dry seasons, droughts and intense rain storms, all of which increase degradation to the forest. Because montane species occupy such small areas and tight ecological niches, they are not likely to colonize degraded sites. Fire, drought and non-native plant invasions are likely to increase the effects of any climate change damage in the montane forests. In terms of Hydrology, frequent contact of clouds on vegetation make vegetation gain an additional water source by stripping water out of passing clouds, either through direct contact or through condensation. This can be significant during the dry seasons or droughts. Also, frequent presence of clouds, reduce evapotranspiration, further reducing water stress. These forests provide additional water to normal rainfall. Reduction in the cloudiness due to climate change is therefore likely to result in changes in the hydrological regime like the lowering of water levels in montane wetlands. This is already detected in the swamps of MGNP.

iv. Impacts across habitat types

There are climate change related effects that are likely to affect more than one habitat type simultaneously. Examples include changes in the relative abundance of habitat types such as the encroachment on forested sites i.e. degraded versus intact habitat types.

v. Savannahs and Grasslands

The extent of savannahs and grasslands in terms of losses or gains to specific plant functional types, are likely to remain largely unchanged under climate change scenarios. However, there are complex interactions between plant functional types, fire and herbivores. Increase in atmospheric CO_2 favours typically woody C3 plants due to CO_2 fertilization, such effects may be counteracted by the benefits of increased temperature on C4 grasses (further complicated by interactions with water availability, water use efficiency, fire and herbivores.).

vi. Lakes and rivers

Climate change driven changes to freshwater ecosystems are likely to occur directly (from precipitation changes, rising temperatures and CO_2 concentrations, and indirectly, due to changes to upstream hydrological and precipitation regimes.

Increased freshwater inputs following heavy rains and rapid snowmelt may lead to increased sedimentation and nutrient loading in aquatic ecosystems. Reduction in runoff, particularly in the north of the GVL, may have important impacts on rivers and lakes such as Edward, George and Albert. This will affect runoff (64%), hydrology, erosion and siltation rates. The combination of increased runoff and greater evaporation is likely to result in large fluctuations in the size of water bodies in the area at seasonal and inter-annual time scales.

3.5. Proposed actions for managing and mitigating negative changes in biodiversity and ecosystem services

One of the recommended actions for managing and mitigating negative changes in biodiversity and ecosystem services in the GVL is adoption of Sustainable Land Management (SLM) practices. According to the WOCAT database, there are currently contains 129 SLM technologies reported for the LVB countries (Burundi, Kenya, Rwanda, Tanzania and Uganda). The major categories of SLM measures include grazing management (25 cases), agronomic measures (24 cases), cross-slope barriers (23 cases), water harvesting (18 cases), (agro-) forestry measures (17 cases), vegetative strips (14 cases) and gully/channel interventions (7 cases). Table 6 shows an overview of these categories and their main subcategories, as well as a qualitative assessment of the type of farming systems and environments where they can be applied, and the estimated potential impacts that can be obtained from their implementation.

Table 5: Overview of SLM (sub-) categories, their applicability and potential impacts

SLM		Farming system or environment where applicable	Potential impacts[2]			
Category	Subcategory		Biodiversity	Water availability	Erosion control	Socio-economic
Grazing management	Grazing control	Pastoralist	++	+	++	+
	Zero grazing	Intensive livestock/mixed	++	+	++	?
	Reseeding	Pastoralist/mixed	+	o	++	?
	Other	Livestock-based	o	o	+?	+
Agronomic measures	Crop rotation	Arable/mixed	+	+	+	?
	Tillage	Arable/mixed	+	++	++	+
	SFM[1]	Arable/mixed	o	++	++	+
Cross-slope barriers	Bunds	Arable/mixed (sloping)	+	++	++	o?
	Terraces	Arable/mixed (sloping)	+	++	++	-?
	Trenches	Arable/mixed (sloping)	o	++	++	+
Water harvesting	In situ	Arable/mixed	+	++	+	+
	Ex situ	Arable/pastoral/home	o	++	+	-?
	In-stream	None/vegetables	o	+	++	?
(Agro-) forestry	Woodlands /woodlots	Natural/Sylviculture	++	+	++	-?
	Agroforestry	Mixed/homegarden	++	+	++	?

Vegetative strips	Veg. barriers Riparian veg.	Arable/mixed Natural	++ ++	+ +	++ ++	-? ?
Runoff flow control		Natural/streambed	o	+	++	-?

[1]SFM = Soil fertility management; [2]Potential impacts estimated based on positive assumptions.

[Source: The WOCAT database of SLM technologies reported for the LVB countries (Burundi, Kenya, Rwanda, Tanzania and Uganda)].

Other actions, which could be considered for mitigating negative changes in biodiversity and ecosystem services, include:

- Developing and implement comprehensive fire management plans for all the protected areas. This will reduce incidences of unplanned fires and minimise the damage caused to biodiversity and entire ecosystems in case one breaks as it can easily be put out with proper preparedness and the right equipment.

- Developing land management plans to enable planned utilisation of land, water and related resources in a sustainable ways. This will reduce land degradation, through minimising vegetation clearance in landslide and flood prone areas.

- Restoring sensitive ecosystems that have been degraded. These include steep slopes on mountains that are prone to landslides and floods, water catchment areas, degraded wetlands that help to reduce the speed of the water as well as acting as water reservoirs and reduce flooding. Others include restoration of river banks and lake shores, forests and forest pockets as well as grassland land ecosystems. This will ensure that the ecosystems services that these natural resources were providing are restored.

- Renovating weather stations and establishing new ones where necessary to enable timely collection, analysis and dissemination of climate data and information. This will enable institutions and communities to better plan their activities and minimise the impacts of extreme climate occurrences like prolonged droughts and thunderstorms. These result in drying of crops, water bodies, grasses and plants, with losses to famers and also increasing the occurrences of unplanned fires in protected ecosystems. Prolonged rains, and storms result in landslides and floods that bring about a lot of destruction to farms, water, road and tourism infrastructure.

- Timely dissemination of climate information will enable proper planning and minimise damage from climate change related occurrences.

- Mainstreaming/Strengthening climate change in the planning process for both central and local governments managing the areas where these protected areas are located as well as the Management of the protected areas themselves. Actions for managing and mitigating negative impacts of climate change need to be planned and budgeted for within the general management plans of the protected areas.

- Mitigating impacts of climate change in planning for Water projects especially gravity flow schemes. This should involve catchment management to minimise landslides and or prolonged droughts that normally damage the infrastructure.

- Strengthening research and monitoring. These should form a major component of the management process for mitigating negative changes in biodiversity and ecosystem services.

4. CONCLUSION AND RECOMMENDATTIONS

4.1 Conclusion

The following conclusions are derived from the study:

- Climate change is definitely occurring in the GVL.
- Climate change in the GVL is mainly driven by anthropogenic factors
- Under current climatic conditions, GVL still provides a wide range of ecosystem services that vary spatially
- The climate forecast for the GVL in the near future (2020-2039) under both RCPs 4.5 and 8.5 generally shows an increase in both rainfall and temperature
- Based on the climatic conditions forecast, species, ecosystems and ecological processes in the GVL are likely to be in a worse situation than it is currently if appropriate mitigation and adaptation actions are not implemented.

4.2 Recommendations

The followed appropriate actions for managing and mitigating negative changes in biodiversity and ecosystem services in the GVL are proposed:

8. **Scaling up Sustainable Land Management (SLM):** Sustainable Land Management (SLM) should be scaled up towards a landscape effort to mitigate negative changes in biodiversity and ecosystem services. This will enable planned utilisation of land, water and related resources. Currently efforts are fragmented and disjointed and are unlikely to have a meaningful impact.
9. **Managing human populations:** Given that the anthropogenic activities stand out as major drivers of climate change, it is high time that managing human populations became a central theme of the conservation agenda in the Greater Virunga Landscape. This is a sensitive topic but bold steps have to be taken, linked to the gender related roles and livelihood issues.
10. **Enhancing restoration of degraded ecosystems:** It is necessary to enhance the ecological restoration of sensitive ecosystems that are degraded. Managing Alien Invasive Species would be a major component of the restoration programmes.
11. **Sustaining promising/successful interventions:** It is necessary to sustain efforts initiated by short-term projects (usually 3 – 4 years) beyond project lifespans. Hence exit strategies must be given prominence and project monitoring improved to identify trends and evaluate the efficacy of interventions. Transboundary organisations such as the GVTC are most suited for this role.
12. **Management Planning to emphasise climate change issues:** It is necessary to give climate change issues prominence in management planning for the Protected Areas in the Greater Virunga Landscape. This would include comprehensive fire management plans for all the protected areas.
13. **Planning around adaptation frameworks:** This may be achieved by using approaches that link threats and vulnerabilities to planning and actions.

Integrating direct and indirect impacts on species, ecosystems and people is essential. This recognizes that people are integral agents in conservation outcomes. One example is to consider mitigating impacts of climate change in planning for Water projects especially gravity flow schemes.

14. **Research and Ecological Monitoring:** Ensuring that research and monitoring are included as major components of management for mitigating negative changes in biodiversity. This would lead to developing predictions by Increasing engagement with the climate research and modelling communities to develop prediction products meeting conservation planning needs of PA management. This may include renovating existing weather stations and establishing new ones where necessary to enable timely collection, analysis and dissemination of climate data as well as capacity building.

REFERENCES

Ayebarea, S., A.J. Plumptre, D. Kujirakwinjaa, D. Segana (2018). Conservation of the endemic species of the Albertine Rift under future climate change. Biological Conservation 220 (2018) 67–75.

Carr, J.A., Outhwaite, W.E., Goodman, G.L., Oldfield, T.E.E. and Foden, W.B. 2013. Vital but vulnerable: Climate change vulnerability and human use of wildlife in Africa's Albertine Rift. Occasional Paper of the IUCN Species Survival Commission No. 48. IUCN, Gland, Switzerland and Cambridge, UK. xii + 224pp.

Fahey, D.W., S.J. Doherty, K.A. Hibbard, A. Romanou, and P.C. Taylor. 2017. Physical drivers of climate chang. In: climate Science Special Report: Fourth National Climate Assessment, Volume 1 [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B.C. Stewart, and T.K. Maycock (eds.). U.S. Global Change Research Program, Washington, D.C., USA, pp.73-113, doi: 10.7930/J0513WCR.

FAO 2011. Questionnaire for Mapping Land degradation and Sustainable Land Management (QM) v2. Food and Agriculture Organization of the United Nations, Rome, Italy.

Laurance, W. F. , Useche, D.C., et al., Eilu, G., et. al. (2011). Global warming, elevational ranges and the vulnerability of tropical biota. Biological Conservation 144: 548–557.

Lindeque, L. 2010. Training Manual for the Assessment of Land Degradation and Sustainable Land Management, based on the LADA/WOCAT mapping methodology. LADA field paper.

Mugizi, T.F., Gizaw, G., Gussarova, G., Nemomissa, S., Popp, M., Masao, C.A., Tigist Wondimu, Abdi, A.A., Mirré, V., Muwanika, V., Eilu, G., and Brochmann, C. (In prep). Afro-alpine flagships revisited: parallel adaptation, intermountain admixture and shallow genetic structuring in the giant senecios (Dendrosenecio).

Musana, A. and Mutuyeyezu, A. 2011. Impact of climate change and climate variability on altitudinal ranging movements of Mountain Gorillas in Volcanoes National Park, Rwanda. Unpublished Externship Report: Rwanda. The International START Secretariat, 2000 Florida Avenue NW, Suite 200, Washington DC 20009, USA in collaboration with: The Pan African START Secretariat, Institute of Resource Assessment, University of Dar es Salaam, Tanzania.

Plumptre, A. J., Davenport, T.R.B., Behangana, M., Kityo, R., Eilu, G. Ssegawa, P., Ewango, C., Meirte, D., Kahindo, C., Herremans, M., Peterhans, J.K., Pilgrim, J.D., Wilson, M., Languy, M. and Moyer, D. (2007) The Biodiversity of the Albertine Rift. Biological Conservation 134: 178–194.

Uganda Bureau of Statistics. 2016. The National Population and Housing Census 2014. Kampala, Uganda.