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Ecosystem Services and Land Degradation in Gishwati-Mukura Corridor, Rwanda: Cost-Benefit of Sustainable Land Management Practices

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Abstract

Gishwati and Mukura Forests are among the fragile ecosystems that face high rates of land degradation in terms of deforestation, loss of biodiversity, soil erosion and landslides because of intense agriculture and overgrazing, and mining activities. Sustainable land management practices are therefore needed for restoring ecosystem services within Gishwati-Mukura Corridor. Four scenarios that have been considered include (1) business as usual where costs and benefits of the current land use systems were analyzed; (2) landscape restoration by terracing, agroforestry, use of fertilizers and improved seeds; (3) restoration by planting and retaining exotic species (eucalyptus); and (4) restoration by planting and retaining indigenous species. Data were collected through the Focus Groups Discussions. Geographic Information Systems (GIS) analysis helped to calculate the land area for afforestation, grazing, and cropping. Google Earth image was also used to digitize and estimate the number of households to be compensated. A cost-benefit analysis was performed to compare the implementation costs of sustainable land management against its benefits. Sensitivity analysis was also carried out to determine how target variables are affected based on changes in other variables to know the most sensitive parameters and the land management option that provides the best Net Present Value (NPV). Results show that the restoration by exogenous species offers the highest economic and environmental benefits with a NPV of 40,690,477.7 USD. This is followed by the sustainable land management option with a NPV of 34,048,663.7 USD and the business-as-usual scenario with a NPV of 21,915,102.8 USD. The rehabilitation of the corridor by exogenous species is less profitable as it shows a NPV of -9494381.7 USD. Under all scenarios, the NPV is more influenced by changes in input and output than the discount rate. However, an increase in input prices leads to higher negative changes in NPV. Moreover, NPV is positively affected by an increase in output prices, implying high demands and high prices for food products (milk and Irish potatoes). Although maize cropping offers high economic returns to local communities, it requires however huge investments. Local communities can bear the costs of soil conservation and fertility improvement when there is a potential for an increased yield and good price of their agricultural products.

Keywords: *Net-Present Value, Landscape Restoration, Scenarios, Terracing, Indigenous specie, Gishwati and Mukura.*

1. Introduction

Goods and services provided by the functioning ecosystems contribute to human welfare and therefore represent a significant portion of the economic value of the landscapes (Wilson, Troy, and Costanza 2004). Four categories of ecosystem services were delineated by the Millennium Ecosystem Assessment (2005) as supporting, provisioning, regulating, and cultural services. These ecosystem services provide benefits to humans in the form of security, goods and materials, health and well-being. However, the ability to estimate the

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economic value of ecosystem services is recognized as a valuable tool in weighting trade-offs in environmental and land-use planning (Bingham et al. 1995). Overtime, there has been a continuous decline of ecosystem services in terms of size, arrangement and quality (Dobson et al. 2006; ELD-Initiative 2013), and in their ability to clean the atmosphere (Oliver et al. 2015). This decline of ecosystem services is also observed in aesthetically attractive landscapes and touristic destinations (ELD-Initiative 2013). This degradation results from anthropogenic factors such as poor management originating from poverty, limited knowledge and limited access to agricultural extension services, land cover changes, urbanisation and goods market access (Turner et al. 2016; MEA 2005).

Land degradation describes how land resources (soil, water, vegetation, rocks, air, climate, relief) have changed for the worse. It may take the form such as soil fertility decline; waterlogging; increase in salts (salinization); sedimentation; lowering of the water table; loss of vegetation cover; and increased stoniness and rock cover of the land. Land degradation is associated with the reduction or loss of the biological or economic productivity and complexity of cropland, pasture, forest and woodlands (Stocking and Murnaghan 2000).Outcomes of land degradation are ecologically, economically, and socially negative. Degradation disrupts ecosystem functions, processes, integrity, and services; diminishes food, livelihood, and income security; and undermines capacities to adapt to climate variability and other shocks and stresses (Dallimer et al. 2018). Overall, the continued degradation of ecosystem services reduces their capacity to support human well-being and to sustain human life (Tilman et al. 2011).

The impact of land degradation is mostly severe for poor rural populations (ELD-Initiative 2015). For instance, in Rwanda, over 72.1 % of the population lives in rural areas and 68.9 % of the workforce is employed in agriculture (NISR 2022). These populations are also affected by climate-related disasters exacerbated by unhealthy ecosystems (MIDIMAR 2015; NISR 2021). For example, the deforestation of Gishwati and Mukura Forests has increased the risk of flooding, landslides, soil erosion, decreasing soil fertility and water pollution. In Mukura forest, illegal mining activities are negatively affecting biodiversity and water streams of the already fragile landscape (Muhire et al. 2021). Streams and rivers are situated upstream and diverted for mining activities. Consequently, downstream water users suffer from water shortage or water quality, because of heavy sediment load from the upstream mining sites and uncontrolled soil erosion. Furthermore, rivers and wetlands are drying due to deforestation (Republic of Rwanda 2014). These hazards damage infrastructure, economic activities and disrupt the community's livelihoods and increase poverty. However, the linkages between poverty and ecosystem health are not yet well understood in Rwanda. As the country strives to end poverty, there is a need to assess the drivers of land degradation and the resulting impacts on human well-being and vice versa.

The National Forestry Policy in Rwanda recognises the need to manage forest resources to support the development goals for sustainable, low-carbon and climate-resilient growth to improve livelihoods (Republic of Rwanda 2018). The Biodiversity Policy in Rwanda considers the rehabilitation of degraded ecosystems as a key task requiring financial resources (Republic of Rwanda 2011). The National Land Policy stresses that agroforestry should be part of the agricultural landscape on hills to protect the soil and reduce erosion. The long-term forest policy target is to contribute to sustainable land use management by increasing the forest cover maintained at 30% and keeping the natural forest ecosystem at 10.25 %. This can be achieved by well-managed protected areas by using landscape restoration, especially on degraded land (Republic of Rwanda 2019). Forest landscape restoration activities include for example agriculture, agroforestry, improved fallow, ecological corridors, discrete areas of forests and woodlands, and river plants to protect waterways (Republic of Rwanda 2014). Despite the strong policy framework which protects ecosystems to achieve sustainability in natural resources management in Rwanda, the real value of the ecosystem services is yet to be assessed. Underestimation of ecosystem services and values results therefore in poor land management and degradation.

This study aims to assess the current land management practices and their effects on the ecosystem services of GMC. A cost-benefit analysis (CBA) of different scenarios of sustainable land management (SLM) practices from community perspective from a community perspective was performed. Scenarios that were taken into consideration are the following: 1) Business as usual (BAU) or status quo, where costs and benefits of current land use systems were analysed; 2) landscape restoration by terracing and improved soil fertility; 3) landscape restoration by exotic species; and 4) landscapes restoration by indigenous species. This study is aligned with the National Strategy for Transformation for Rwanda (NST1 2018-2024), which targets to achieve sustainable exploitation of natural resources and environmental protection in Rwanda (Ordway 2015). Findings from this study will help to raise the awareness of policymakers on sustainable land management and ecosystem services restoration in surrounding areas of GMC.

2. Geographical and Contextual Setting

2.1. Description of the study area

GMC extends on Gishwati and Mukura Natural Forests on the ridge Congo and Nile Divide, along the Albertine Rift in the northwest of Rwanda. The two residual forests touch 4 districts, Rutsiro and Rubavu in the West towards Lake Kivu and Ngororero and Nyabihu District in the East of the forests. GMC is a fragile landscape which is facing a high level of deforestation, land degradation, intense agriculture and overgrazing, and illegal mining. People around Mukura Forest Reserve mainly live in agriculture. Their livelihood is directly linked to cultivation and cattle rearing. However, in addition to these main activities, people in Mukura live on mining, logging, and beekeeping. Their crops include tea, potatoes (mainly Irish), maize, beans, etc. The artisanal mining focuses on coltan, cassiterite and wolfram. Activities that spoil the environment are related to the following: firewood, charcoal, mining, logging, water sources, sand and calcareous soil quarrying, fires, etc. The fires are caused by the need the expand the grazing land area. People neighbouring Gishwati forest also live on agriculture. They cultivate tea, potatoes (mainly Irish), maize, beans, etc. The majority of them are also cattle keepers. The activities that spoil the forest also include firewood, charcoal, mining, logging, water sources, sand and calcareous soil quarrying. The forest is also used for medicinal plants (Musabyimana 2014). Figure 1 shows the location of GMC in Gishwati-Mukura National Park (GMNP).

GMC is a fragile landscape which facing social-ecological change due to the encroachment of human activities on the forests (Ordway 2015). Due to high population pressure, unsustainable agricultural practices have led to decreasing crop yields and increasing pressure on natural forests (forest encroachment, poaching and illegal resource extraction). Since 1990s, inappropriate land use management policies, that were associated with the forestry industry alongside cattle ranching, have converted nearly 70% of the forest into agricultural land (Humphrey 2015). The socio-ecological and environmental changes have made GMC landscape one of the most environmentally sensitive areas in Rwanda which is very prone to severe land degradation in the form of deforestation, soil erosion, landslides, and flooding (Ordway 2015).

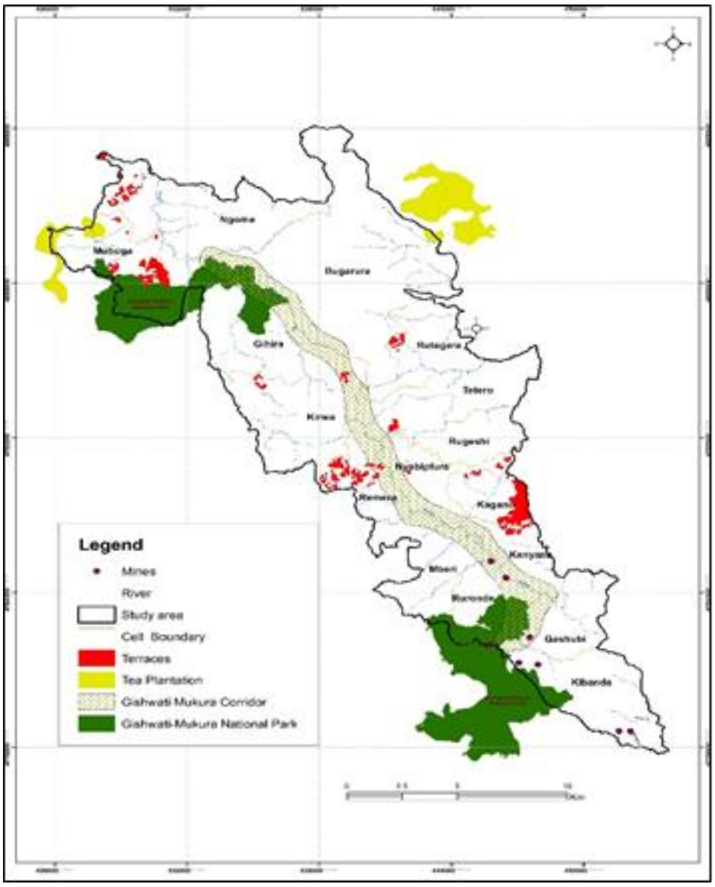

Figure 1: Location of GMC corridor in Gishwati-Mukura National Park

The deforestation resulted in biodiversity loss due to human activities such as human settlements, grazing land, cropland and tree plantations (RDB 2017). In some areas, these activities have led to habitat fragmentation, soil erosion, landslides and flooding (Musabyimana 2014). Connecting the protected areas with the biological corridors by using a land restoration approach can therefore provide an opportunity for increasing access to other areas of habitat and gene flow and population viability; enabling the regeneration of patches; and providing habitat for biodiversity (Bissonette and Krausman 1995).

This ecological corridor should be well managed to maintain or restore effective ecological connectivity (Hilty et al. 2020). GMC will allow free movement of animals, especially monkeys between two patches of the GMNP. GMC landscape restoration was supported by the Rwanda Environmental Management Authority (REMA) (Tashobya 2018). Under the LAFREC project, the focus was put on increasing the availability of native tree species in the landscape and enhancing biological connectivity. The highly vulnerable ridge-tops, steep slopes, and riparian buffers were set aside to comply with the national environmental regulations. Landscape restoration that combines agroforestry with native species offers the potential to increase biological connectivity, thus maintaining and enhancing the productive value of the landscape. In return, investments in land use intensification helped the local communities to restrict agriculture in the most vulnerable lands and protect the existing forests. A participatory approach to micro-watershed planning was adopted to identify sustainable land management investments with a particular emphasis on promoting agroforestry with native species and watershed rehabilitation by terracing (World Bank 2014). However, the high population density and agricultural conversion of the biological corridor make it difficult to re-establish the forest without dislocation of local communities.

Currently, land use and land management practices within and around GMNP are not yet sustainable. In other years, the forests were used by refugees resettling Rwandans and as resources for fuelwood and timber. Large agriculture zones are yet to be protected through terracing, which is an important land management strategy that can reduce soil erosion. Terracing is considered a suitable land management option for this area due to the very steep topography. The main land uses include farms, grazing lands, and forest and tea plantations. Around the GMNP, the provisioning and cultural ecosystem services are connected, and the majority of people are farmers who grow such as Irish potatoes, maize, peas, wheat and tea. The farming system is a complex polyculture producing different crops with different tolerances and timings. There are many plots with varied soils, slope, shade and moisture. This farming system is inseparable from the cultural meaning attached to land, livestock, agricultural inputs and human resources (Dawson and Martin 2015). These land management practices are intertwined with the culture and social systems, labour markets and trade patterns of people living in this mountainous landscape that have been developed over time to minimise the risk of food insecurity and response to extreme topography, climate change and variability (Pottier and Nkundabashaka 1992). Different manifestations of land degradation, including deforestation, soil erosion and loss, declining soil fertility, landslides and floods (MIDIMAR 2015; Rutsiro District 2018; Ngororero District 2018) are exacerbated by human activities and population pressure on fragile landscapes, construction of infrastructure and human settlements, intense agriculture, grazing and artisanal mining (Muhire et al. 2021).

Forest landscapes provide ecosystem services (provisioning, regulating cultural, and supporting services) and functions (regulation, production, habitats and information) that significantly contribute to human well-being and the national economy (Howe et al. 2014). Human well-being is strongly linked to ecosystem conditions and therefore environmental and ecosystem management should also deliver better outcomes for people (Duraiappah et al. 2005). Generally, the provisioning services of forest landscapes include timber, fuelwood, freshwater, and genetic resources. Forests also purify water, regulate the quick flow and runoff, control soil erosion, retain sediment retention, store and sequestrate the carbon from the atmosphere (Dyszynski, Cole, and Rutabingwa 2011). They also provide cultural services like cultural heritage, recreation, biodiversity and ecotourism, education and a sense of place. The supporting services from forest ecosystems include soil formation and nutrient cycling (Krieger 2001). Similarly, Gishwati-Mukura forest ecosystems provide different services that help to stabilise the climate, lessening extreme climatic events by slowing down water runoff and removing greenhouse gases from the atmosphere (Lal and Lorenz 2012). These forests moderate water and carbon cycles, retain and deliver nutrients to other organisms, and provide a source of clean water (Sun and Vose 2016). The value of the carbon sequestered in Gishwati Forest alone has been estimated to be US$3,000,000 per year (Humphrey 2015). Similarly, the carbon stored and sequestrated by Mukura Forest was estimated to be US$39,556 per year (Kakuru et al. 2014). The catchment and landscape protection, carbon storage and sequestration also benefit other people beyond Mukura-Gishwati landscapes (Kakuru et al. 2014).

GMNP provide habitat to endemic species and a rich biodiversity which attracts tourists (NISR 2018). Scattered trees and woodlots provide fuelwood, fruit and timber. They reduce the gap between fuelwood supply and demand while contributing to food security (Ndayambaje, Mugiraneza, and Mohren 2014; Kakuru et al. 2014). Agroforestry is one of the options for enhancing the share of forest cover and restoring the degraded landscape within Mukura-Gishwati watershed. Additionally, agroforestry stabilises agricultural landscapes through shade provision and wind control in farms. Many of the tree species used in

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agroforestry fix nitrogen and all support overall nutrient cycling, which reduces the need for fertiliser application. On very steep slopes, agroforestry reduces the soil erosion and enhances the water infiltration. Many agroforestry tree species provide fodder for animals (MINILAF 2017). Before deforestation, Gishwati and Mukura forests played a vital role in intercepting precipitation and channelling run-off, regulating the water flow that impacts the hydrological processes of the Sebeya and Satinstyi Rivers. The restoration of Mukura and Gishwati landscapes provides therefore an opportunity for ecosystem regulatory services that secure the operation of Rwanda's hydro-power plants. They protect waterways from heavy siltation caused by soil erosion and sedimentation. Multiple environmental, social and economic benefits from Mukura-Gishwati forests helps also to reduce the vulnerability to climate change and CO^2 emissions (Dyszynski et al. 2011).

Even though timber harvesting in the protected areas has been banned by the Government of Rwanda (GoR), firewood is one of the forest resources from Mukura-Gishwati that benefits local communities with insufficient trees and woodlots on their farms. As the population increases, the shortage of firewood supply will continue and should be used as an opportunity to promote tree planting (Kakuru et al. 2014). With the massive deforestation of Gishwati and Mukura, their ecosystem services have been lost locally, but the impacts are felt downstream through the sedimentation of the Sebeya River and the limited supply of hydroelectric in Rubavu City. During the rainy season, the water treatment plants are sometimes forced to close to allow the mud out of the equipment (Humphrey 2015).

2.2. Degradation of Gishwati and Mukura Forests

Gishwati and Mukura Forests have been subject to intense and gradual land degradation in the form of deforestation. In the 1970s, the Gishwati forest covered about an area of 28,000 ha. By 2001, only 550 ha of native forest remained and by 2005 the forest covered an estimated 600 ha (REMA 2015). Extensive deforestation of Gishwati began with the introduction of large-scale cattle ranching projects and the resettlement of new refugees after 1994. Encroachment of human settlements in Gishwati forest has led to cutting trees for timber, charcoal and fuel (Birdlife International 2012), cattle grazing within the forest, clearing for small-scale farming and establishment of plantations of non-native trees (Bizoza and Ndangiza 2013). The land-use and land cover change maps around GMC helped to quantify the spatial-temporal trends in forest loss using a multi-temporal Landsat raster dataset. The moderate and sparse forest areas declined from 88.2 to 931.5% between 1990 and 2015. This continues a long-term trend in Rwanda as more land has been brought under cultivation at the expense of remaining forested areas, potentially contributing to runoff and soil loss.

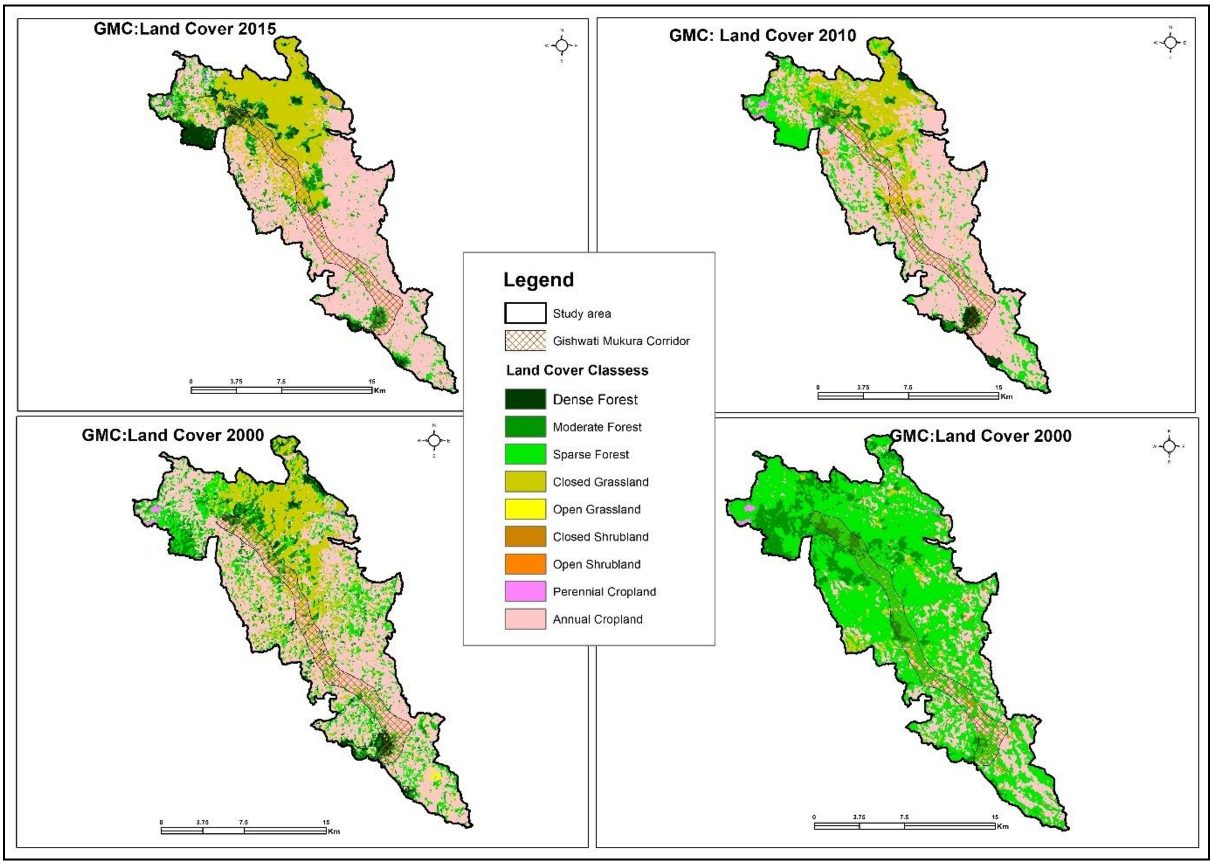

Figure 2: Spatial-temporal land cover around GMC

Conversely, the area of closed grassland and annual cropland has substantially increased from 1990 to 2015 (an increase of 90% and 68% respectively). Figure illustrates land cover changes around GMC between 1990 and 2015.

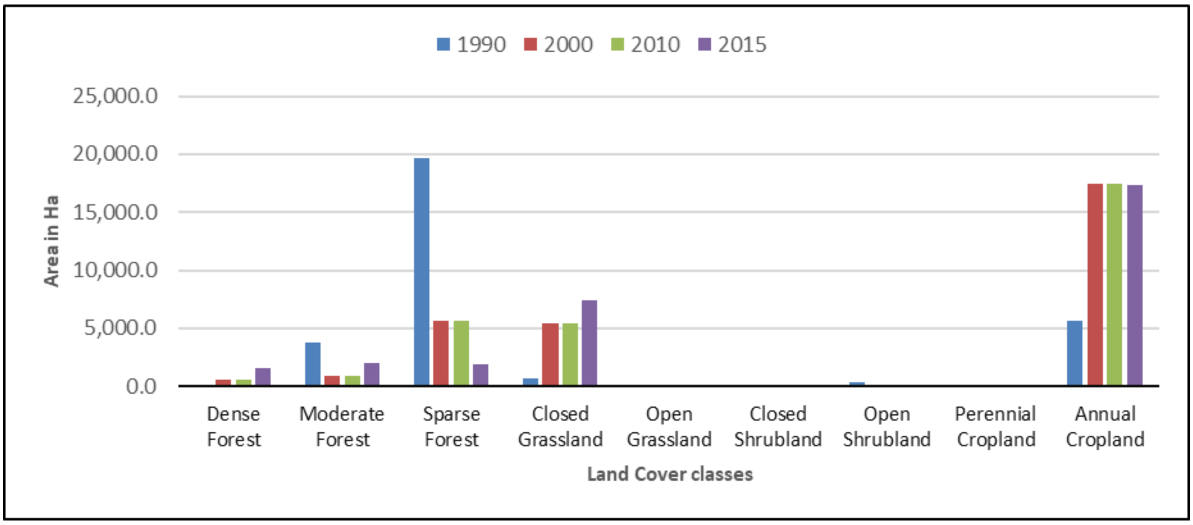

Figure 3: Land cover changes around the Gishwati-Mukura Corridor

A spatial and temporal change in forest cover indicated that GMC experienced massive deforestation where approximately 7617.1 ha (64.22%) of forest cover was completely cleared out, which implies an annual forest loss of 262.6 ha/year−1 (2.21%) between 1990 and 2019 (Uwiringiyimana and Choi 2022). Deforestation and grassland conversion into agricultural land use constitute a major threat to the soil and water conservation (Karamage,

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Shao, et al. 2016; Karamage et al. 2017). Ongoing forest losses and increasing isolation of natural forests pose significant threats to the biodiversity habitats and sustainable supply of ecosystem services in this densely populated, globally important biodiversity hotspot (Arakwiye, Rogan, and Eastman 2021). Equally, the extent of croplands in and around GMC results in an increasing rate of soil erosion especially in unsuitable croplands mostly distributed in the Congo Nile Ridge (Karamage, Zhang, et al. 2016). A recent study saw a decline in carbon storage from 1.14 to 1.08 MT from 1990 to 2000 reflecting forest loss (Bagstad et al. 2020; Ordway 2015), then an increase to 1.23 MT in 2015. Despite the low level of sediment export from the protected areas in Rwanda, a considerable increase in sediment export has occurred in GMNP. This was largely driven by deforestation in the 1990s (Ordway 2015).

The deforestation of Gishwati has also led to significant carbon losses (Verdoodt, Baert, and Van Ranst 2010). For instance, changing land use from forest to cultivated land reduced the organic matter, available nitrogen, soil moisture and porosity while the bulk density and pH increased significantly. The reduction of forestland and farmland are therefore highly sensitive to erosion with a declining soil fertility (Bizuhoraho et al. 2018). These results confirmed natural and anthropogenic processes (e.g., agricultural and built-up area expansions and road network development) caused forest fragmentation and degradation in the surrounding landscape of GMC. Therefore, land restoration is highly required in Gishwati-Mukura landscapes where land degradation negatively impacts crop productivity, water, food and nutrition security. Policy-makers should look at the new sustainable land management options and revise the existing natural resource conservation strategies to safeguard the remaining natural forests and degraded ecosystems.

2.3. Drivers of Land Degradation in GMC

Generally, drivers of land degradation are anthropogenic drivers such as population growth and poverty combined with natural drivers such as background soil erosion and climate change (Nkonya, Mirzabaev, and Von Braun 2016). The causes of land degradation in Rwanda include unsustainable farming and grazing practices, overexploitation of forests and woodlands, settlements and urbanization (Bizimana 2018). Furthermore, Rwanda has a high average population density of 503 people per km^2 (NISR 2022). Approximately 70% of land is devoted to subsistence agriculture, fuel wood and timber production for energy needs (NISR 2012). Land degradation including soil erosion, is driven by unsustainable agricultural practices on very steep slopes (Karamage, Zhang, et al. 2016). This is further execrated by intense rainfall events, resulting in increased rainfall erosivity (Rutebuka et al. 2020).

Gishwati and Mukura forests were gazetted as national forests since the 1930s and were placed by law under the jurisdiction of the colonial governance which prohibited their access to local populations. Nevertheless, these two natural forests faced continued deforestation because of population pressure, and lack of adequate protection and negligence in law enforcement (World Bank 1980). Subsistence agriculture and state investments in tea plantations and production have led to forest clearance (Von Braun, De Haen, and Blanken 1991). In the 1980s, large-scale development projects to enhance agricultural productivity and soil conservation were implemented in Gishwati under the World Bank's *Integrated Forestry and Livestock Development Project*. To protect biodiversity and promote economic growth, the Gishwati-Butare-Kigali (GBK) Project has focused on clearing the degraded forest patches to transform them into pastures and pine plantations in line with the objective of economies of scale in dairy and forestry while preventing small-scale grazing of cattle (World Bank 1991). The World Bank projects expanded the wood supply through industrial plantations and afforestation; enhanced the forest ecosystem values; and developed a high-productivity cattle industry. These projects also strengthened the capacity of institutions and agencies involved in forestry and livestock (World Bank 1996).

The socio-ecological solution required to remove the degraded forest; establish an industrial plantation of pine trees for timber and pasture on the degraded forest; and intensify the farming systems outside of the forest by planting forage. The cattle breeds have been improved through the construction of a milk processing centre. These proposed solutions reworked the subsistence production systems beyond the forest reserve's boundaries. Accordingly, they resulted in landscape degradation due to agricultural and economic development policy, natural resources management and demographic growth (Ford 1990). They negatively affected the socio-ecological externalities stemming from disruptive subsistence livelihoods and unpredictable biophysical environments (Clay 2019). Conflicts also erupted in surrounding buffer zones along the natural forests (Humphrey 2015). Despite being employed in project activities, local populations struggled to have their land expropriated and sometimes destroyed the buffer zones (World Bank 1996). Over the years, the populations living in surrounding villages of the natural forests have encroached on the area and grazed their cattle. This resulted in a gradual conversion of natural forests to pine plantations and pastures (Mukashema 2007; Nyandwi and Mukashema 2011). Moreover, high population density, steep slopes and abundant rainfall have made the task of erosion control more difficult for rural farmers (Clay and Lewis 1996; Clay, Reardon, and Kangasniemi 1998).

Since the 1990s, interventions for Gishwati-Mukura landscapes increased the risk of natural hazards such as landslide and flood (Byers 1992; Mupenzi et al. 2013; Nsengiyumva et al. 2018). These landscapes are fragile ecosystems which are naturally vulnerable to floods and landslides (Nahayo et al. 2017; Nahayo et al. 2019) owing to the steep slopes, land use changes and intense rainfall (Mind'je et al. 2019). The heavy rainfall clustered during two rainy seasons is the principal triggering factor of landslides in the landscape. The soils with a high percentage of clay content, originating from granite and quartzite, dominate the zones that are mostly affected by landslides (Fashaho et al. 2014). For instance, in September 2007, a heavy rain caused landslides in northeast Gishwati where GBK pastures and forest plantations had been concentrated (Clay 2019). Due to higher elevation and steep slopes, human settlements in bottoms-valley and floodplains block the water channels and intensify the localized floods (Asumadu-Sarkodie et al. 2015). The soil types that are conditioned by the topography and local climate contain medium to high plasticity clays and high infiltration rates. This allows a fast water flow into the deeper clay-rich soils and leads to water stagnation and slope failure (Bizimana and Sönmez 2015). Moreover, unsustainable mining activities have accelerated soil erosion and sedimentation into the rivers. They have also created new landforms around some mining sites. The physicochemical properties of mine tailings that are often scattered on mining sites are harmful to biodiversity. High metal concentrations from mines threaten both aquatic and terrestrial life as they may cause the extinction of vegetation species in mining areas (Muhire et al. 2021).

While landslides and floods result from interactions of economic and ecological processes in GMC, they are also exacerbated by climate change (Gebauer and Doevenspeck 2015). For example, the spatial-temporal trend of precipitation revealed that the mean rainfall was sharply increasing in most parts of Rwanda, especially around the Kivu Lake. At the same time, the wet highlands of North-Western Rwanda are becoming wetter and experiencing more floods and landslides (Muhire and Ahmed 2015; Muhire, Ahmed, and Abd 2015). Likewise, an increase in precipitation could increase the Dissolved Organic Carbon (DOC) in water percolation and streams. This increase in DOC negatively impacts the water quality of Sebeya and Satinstyi Rivers with severe implications for their ecological function (Rizinjirabake, Tenenbaum, and Pilesjö 2019).The heavy rain, the steep slopes, and the clay soils combine to amplify the susceptibility of the landscape to increased soil erosion that may associated with a reduction in yield and loss of income (REMA 2019). To respond impact of the global environment and climate change, climate change adaptation has proposed a promising solution. This was implemented in partnership with the United Nations Development Program(UNDP) project for *“Reducing Vulnerability to Climate Change by Establishing Early Warning and Disaster Preparedness Systems and Support for Integrated Watershed Management in Flood Prone Areas*” (UNDP 2011). Under this project, an integrated watershed management for Gishwati ecosystem services rehabilitation was proposed to reduce the vulnerability to flooding and landslides. This project focused on local communities engagement in ecosystem services restoration to manage the disaster risk; land use and settlement planning for enhancing the resilience of Gishwati-Mukura ecosystem to the impact of climate change (UNDP 2012). In return, rehabilitation of critical ecosystem services was seen as a key strategy for reducing the impact of climate change impact. Households living in floods and landslide-prone areas were relocated and resettled. The agriculture production was also intensified by constructing terraces (Gebauer and Doevenspeck 2015). In the lens of climate resilience, floods and landslides justify the rationality for promoting ecosystem services (Clay 2019). However, the costs and benefits of these attempts are not well understood or documented. This is a knowledge gap that needs to be addressed by this study.

Under the World Bank’s Project on “*Landscape Approach to Forest Restoration and Conservation*” (LAFREC), the overall vision of Gishwati is a landscape of refugees, a sanctuary of biodiversity and a source of ecosystem services that can benefit the downstream users (World Bank 2014). LAFREC project focused on the rehabilitation of forests and biodiversity, enhancement of sustainable land management and introduction of the silvo-pastoral approaches in existing rangelands (World Bank 2014). Forest landscape restoration is a planned process to recover ecological integrity and enhance human well-being in deforested or degraded landscapes. It aims to restore the degraded land, increase forest cover, provide access to clean water, improve management of woodlots, and introduce agroforestry. Specifically, the LAFREC project established protective forests on ridgetops and slopes. This project also reduced the exotic plantations in buffers around protected areas, preserved corridors between the protected areas, and eliminated row crop agriculture on steep slopes (Stanturf and Mansourian 2017). It is expected that the population will interact with the buffer zone of the corridor by getting non-timber products from the buffer zone that should be used as a barrier to abuse the corridor and to conciliate the interests of conservation and the needs of the local community (Gapusi 2007). The landscape restoration approach was a success story in protecting degraded lands and generating ecosystem benefits. It led to more sustainable natural resources management which addressed the frequent landslides, erosion and flooding while sustainably using land for the profit of local farmers in the livelihoods. It also helped to relocate people from high-risk zones to other safe places and build the capacities of farmers through farm-livestock cooperatives (Rutebuka 2021).

Land use planning interventions in Gishwati-Mukura landscapes aimed to enhance the biological connectivity of the two patches. This biological corridor provides a potential for recognition as a UNESCO Biosphere Reserve. This biosphere reserve can be used as a re-orientation of the local economy towards nature-based tourism (World Bank 2014). It will foster the conservation of landscapes, ecosystems, species and genetic variation (Committee 2005; Stoll-Kleemann, de la Vega-Leinert, and Schultz 2010). Enhanced environmental services would be provided by improved native biodiversity; increased carbon sequestration; enhanced watershed function, reduced sedimentation costs to downstream water infrastructure; and higher productivity and diversity of natural-resource-based livelihoods. Under LAFREC, climate resilience and climate adaptation components are intrinsic to sustainable land management and watershed rehabilitation. Additionally, climate resilience would be achieved through the diversification of livelihoods, targeting the most vulnerable populations, and improving the flood early warning (World Bank 2022). However, the landscape programs must be based on a comprehensive understanding of landscape dynamics and underlying drivers of social, economic and ecological change. They should be guided by scenarios agreed by key stakeholders. Their success will also require major changes in the behaviour of local people (Sayer, 2009).

2.4. Pressure of Land Degradation in GMC

Deforestation, an increase in cropland and settlement expansion in Gishwati-Mukura have limited the ability of this landscape to provide ecosystem services (Rukundo et al. 2018). Ecosystem services also changed in response to land use change with the declining carbon storage, increased soil loss and nutrients and growing use of fertiliser in agriculture. The water yield has also increased and the timing and quality of water are likely to change due to an increased runoff and quick flow and reduced evapotranspiration (Rukundo et al. 2018). The harvesting of forest resources, cropping practices, settlements and unsustainable mining activities have modified the land cover. Erosion on steep slopes of agricultural land reduces the soil fertility with additional costs of water provisioning and reduced production of hydropower facilities (Verdone 2015). Farmers either lose income due to lower crop yields or they need to offset the fertility loss with additional fertiliser purchases. The soil loss is also leading to pollution of downstream water bodies due to sedimentation and elevated application of fertiliser and pesticides. The soil erosion results in depositions on the land and sediment export to streams and wetlands. The exported sediments generate high financial costs in terms of poor water quality for consumers and sedimentation of critical infrastructure including roads and hydroelectricity supply dams. These sediments also elevate turbine erosion with the increasing energy generation costs. Consequently, the benefits associated with reduced soil erosion through sustainable land management practices can positively impact other sectors beyond agriculture.

3. Data and methods

3.1. Field data collection

Data used have been collected through the desk review, field visits, and interviews with local authorities and sellers of agricultural inputs. Focus Group Discussions (FGD) with farmers and pastoralists, tea growers were also organized. The corridor is still a settled area where people conduct various activities, including growing subsistence crops mostly Irish potatoes, maize and wheat, rearing cattle and tree planting mostly Eucalyptus. The main land uses within Gishwati-Mukura Corridor include human settlement, cropland (maize, Irish photos), terraces, woodlands, and tea plantations. These main land uses are important for comparing the cost and benefit of the four scenarios.

Within each sampled sector, a multistage cluster sampling method was used. Each sector touching or crossed by the GMC was considered as a cluster, several adjoining cells within one sector were considered as one cluster. The selection of people who participated in the FGD was not a straightforward process because the research team was not familiar with people from the study area. The meetings were organized with local authorities including agronomists who helped in the identification of persons or farmers to be involved in FGD. In collaboration with land managers at the sector level, a sample of 24 farmers having land in GMC or conducting some activities within the corridor was identified. and coming from different cells. From this sample, 12 farmers were randomly selected and invited to participate in FGD to reduce any bias from the proposals of local authorities.

The participants in FGD were farmers, pastoralists, tea growers, forest owners, miners, and beekeepers. The six FGDs that were organized in different sites involved 72 discussants. After each FGD at the cluster level, the data gaps related to the number of fertilizers used for different crops, the volume of trees harvested on an area of one hectare, the number of seedlings of native species per hectare and associated costs, and the labor needed to plough one hectare of land were noted. The data and information gaps were addressed by collecting other related secondary data from Districts and sector offices. The issue of data completeness was compensated with additional information received from the College of Agriculture and Veterinary Medicine of the University of Rwanda (UR CAVEM), Rwanda Agricultural Board (RAB), and from LAFREC Project in Rutsiro and Ngororero Districts.

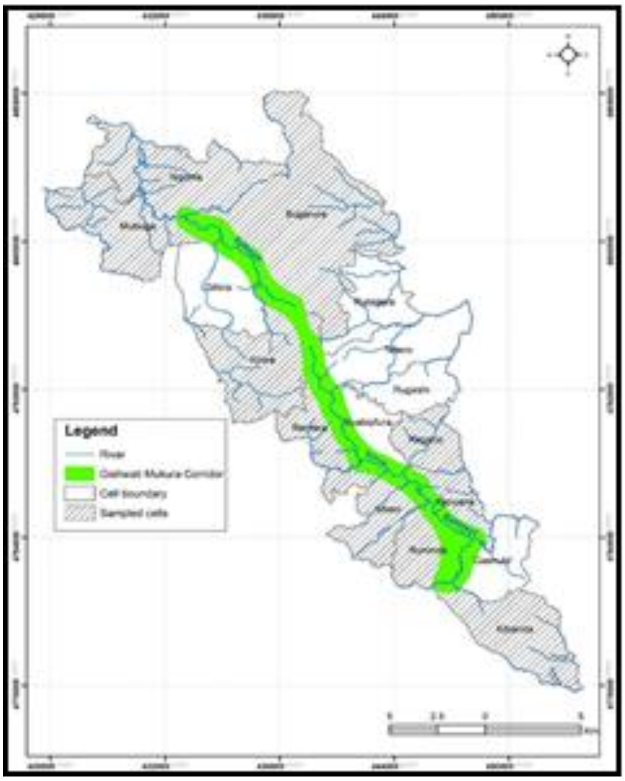

Figure 4: Sampled cell for FGD

3.2. GIS Analysis

GIS analysis was also used for visualizing and mapping the different land use types in the GMC and calculating the total area covered by each land use/land cover type. The land use and land cover data for 1990, 2000, 2010, and 2015 have been created by the Regional Centre for Mapping of Resources for Development (RCMRD)[1] in collaboration with the

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[1] *RCMRD, based in Kenya, was established as an inter-governmental Organization to supply spatial analysis and mapping and capacity-building services to member countries, including Rwanda. Its mission is to promote*

Government of Rwanda. These data are in the public domain and provide useful background analysis and information on long-term trends of land cover and land use changes. The Landsat TM and ETM scenes were acquired from the USGS site and pre-processed by RCMRD-SERVIR Africa for Rwanda. The on-screen digitizing was also used as an interactive process in which the location map of houses/buildings that were inside the GMC was created by using the Google Earth image. This process helped to estimate the number of households and houses to be relocated and compensated.

3.3. Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) is an assessment method that quantifies the monetary value of all policy and project consequences to the society (Tilahun 2007). The CBA is a commonly used planning tool that is suitable for comparing the costs of adopting a sustainable land management practice against the benefits derived from it. The main purpose of CBA is to provide a consistent procedure for evaluating decisions in terms of their consequences (Dallimer and Stringer 2018). Accordingly, the CBA can be extended for use related to economic valuation of positive and negative effects of sustainable land use management practices (Dallimer et al. 2018). Concerning sustainable land management practices, the CBA is commonly used to assess soil and water conservation and other natural resource use or conservation measures. For instance, Tilahun, (2007) used the CBA to determine and compare net benefits from closed and open *Boswellia papyrifera* forested land in Northern Ethiopia. Similarly, Balana *et al.* (2012) used the CBA to compare the major benefits and costs of different soil conservation measures in Northern Ethiopia (Tigray region). As a tool to assess the net benefits of soil resources management practice, the CBA uses the Net Present Value (NPV) for each management practice. In our case, we used the NPV criterion in comparing the economic benefits of different land management practices. NPV was defined as the difference between the sum of the present value of discounted benefit streams and discounted value cost streams over the project (Eq1).

$$NPV = \frac{\sum_{t=0}^{T} B_t}{(1+d)^t} - \frac{\sum_{t=0}^{T} C_t}{(1+d)^t} = \sum_{t=0}^{T} \left[(B_t - C_t)(1+d)^{-t} \right]$$

Where *NPV*: Net Present Value; *Bt:* Benefit at time ‘t’; C_t: Cost at time ‘t’; *d*: the discount rate; *t*: time in years (t=1,2, ...T) (Balana et al. 2012).

In the context of Rwanda, the CBA involved the comparison of unsustainable (BAU) land management and sustainable land management options. Sustainable land management practices were considered to reduce or remove land degradation pressures, while also contributing to the community's livelihoods through increased agricultural productivity. Data used were collected through FGD and analysis of Google Earth images. The surface area of afforestation, grazing land and cropland for each scenario was calculated through the mapping using Geographic Information System (GIS) software 10.8. The number of households to be compensated for scenarios 3 and 4 was digitized and quantified from Google Earth images. Information on the average cost of rural dwellings (in case of expropriation and resettlement of people settling in the corridor) was collected during the FGD.

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sustainable development in member States through the generation, application, and dissemination of geo-information and associated ICT technologies, products, and services.

The first scenario (BAU) consisted of cropland, eucalyptus, trees and ranch farming. For the cropland, the selected crops were Irish potatoes, maize and wheat. For cropland, the practice consists of rotation agriculture, in which the Irish potato crop is cultivated during two seasons, each lasting three months whereas maize and wheat are cultivated for one season. Ranching and eucalyptus constitute the permanent land uses. The costs of agricultural inputs such as labour, seeds manures or fertilizers were obtained through FGD and complemented by the NISR database. For the estimation of benefits, we used market prices. The collected data consisted of the prices of agricultural products such as maize, wheat, Irish potatoes, milk and meat. Data on these prices were obtained through either FGD or a visit to the nearby market. Specifically, a visit to the charcoal market in Rubavu Secondary City allowed us to obtain the estimation of market prices for charcoal.

In the second scenario of SLM practice, only the cropland area was considered because it is the driving factor of land degradation. For this scenario, we used the land area that was restored by terracing and adoption of agroforestry because the national policies in GMC are promoting rehabilitation by terracing and agroforestry. The implementation costs per hectare for this scenario were related to labour for terracing, seeds, fertilizers and pesticides, and seedlings for agro-forestry species. Data on these costs were obtained from FGD and interviews with local agronomists. For net benefits, the market value for crops such as wheat, maize and Irish potatoes was either obtained from FGD or visits to the market.

Both the third and fourth scenarios were hypothetical. They consisted of 1) landscape restoration with exogenous species especially the eucalyptus and 2) restoration by indigenous species. In the third scenario, the choice of eucalyptus was based on the fact that it is a tree species with high socio-economic value in terms of energy. Eucalyptus is used for firewood and charcoal production. Its branches are also used as support poles in the study area. In this regard, the data on costs consisted of labour, seedlings, and land compensation. Data for these costs were obtained from focus group discussions. For the benefits, in the case of the third scenario, market prices were used to estimate the benefits from the sale of charcoal and poles for bean supports. For the fourth scenario, we considered that the future of the corridor ecosystem’s services was eco-tourism, carbon storage and carbon sequestration. Data for these services were obtained from the existing literature on ecosystem services in Nyungwe National Park, which is located in the same ecological zone as Mukura Gishwati Corridor (Albertine Rift). In this perspective, we used the carbon storage market price per hectare that can be paid, if the corridor is fully restored by indigenous species as proposed by Masozera (2012). For every scenario, the study used the discount rate of 9.8%, which was the World Bank's average interest rate for 20 years. This allowed the calculation of the NPV and the annuity factor and annuity of each crop (land use) (Tilahun, Damnyag, and Anglaaere 2016).

3.4. Sensitivity Analysis

Sensitivity analysis is a financial model that determines how target variables are affected based on changes in other variables known as input variables. It is a way to predict the outcome of a decision given a certain range of variables. By creating a given set of variables, an analyst can determine how changes in one variable affect the outcome (Mangiero and Kraten 2017). For this study, the sensitivity analysis was carried out to know the most sensitive parameters and the SLM practices that provide the best Net Present Value result. This analysis assumes constant real discount rates, prices, and output levels. However, the real discount rate may change due to changes in either inflation or the nominal interest rates

(Tilahun, Damnyag, and Anglaaere 2016). The study applied different changes in parameters considered as the discount rate, input and out price.

Table 1: Variables and applied changes to sensitivity analysis

Variable	Applied changes				
Discount rate	25% decrease	25% increase	50% decrease	50% increase	100% increase
Input price	25% decrease	25% increase	50% decrease	50% increase	100% increase
Output price	25% decrease	25% increase	50% decrease	50% increase	100% increase

It is important to note that these changes were applied to every crop and land use considered in each scenario. Each of the factors that influence the NPV calculation represents an estimate. Some estimates can be established with a significant degree of precision, but other estimates can only be established within a relatively broad range (Mangiero and Kraten 2017).

4. Results and Discussions

4.1. Costs of Sustainable Land Management Practices

Results indicate that the costs of production in all land management practices include the purchase of seeds for cropland seedlings for forest and rehabilitation practice, and the introduction of calves in the calves in ranching land use, labor, fertilizers, and land and house compensation. Figure 10 shows that the cost of labor and fertilizers is lower than others. Their value is less than USD$5 million in each option. However, the cost of fertilizers increases in the SLM scenario due to the application of lime as a solution to reduce soil acidity in the terraces. The cost of terracing exists only in the scenario in the SLM scenario. Land and house compensation is the higher cost and is found in scenarios 3 and 4 as both involve the relocation of existing land uses for restoration of the corridor by either exogenous or indigenous species (Figure 5).

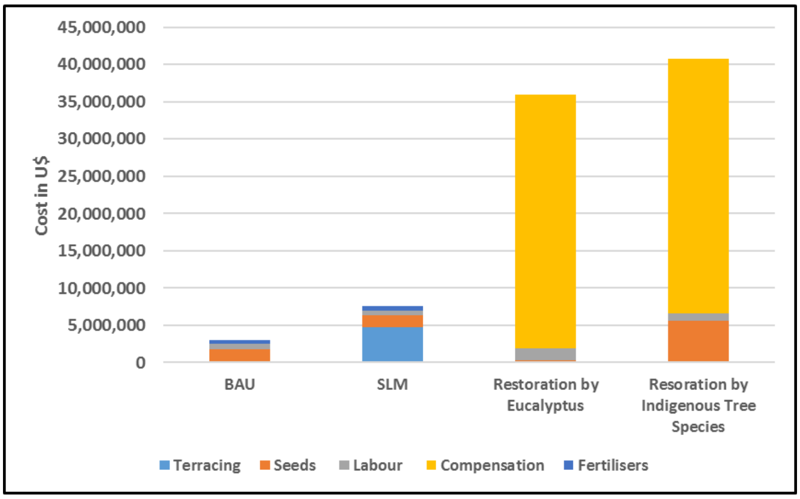

Figure 5: Costs in all Scenarios

Figure 5 offers a good comparison of annual total cost per hectare by showing that cropland, eucalyptus trees and ranching in the BAU scenario involve lower costs than other

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scenarios. The comparison shows a slight increase in cost for the SLM scenario because of the cost of terrace construction, agroforestry and application of lime, which is done every five years. Scenarios 4 and 3 record the high cost due to the land and house compensation.

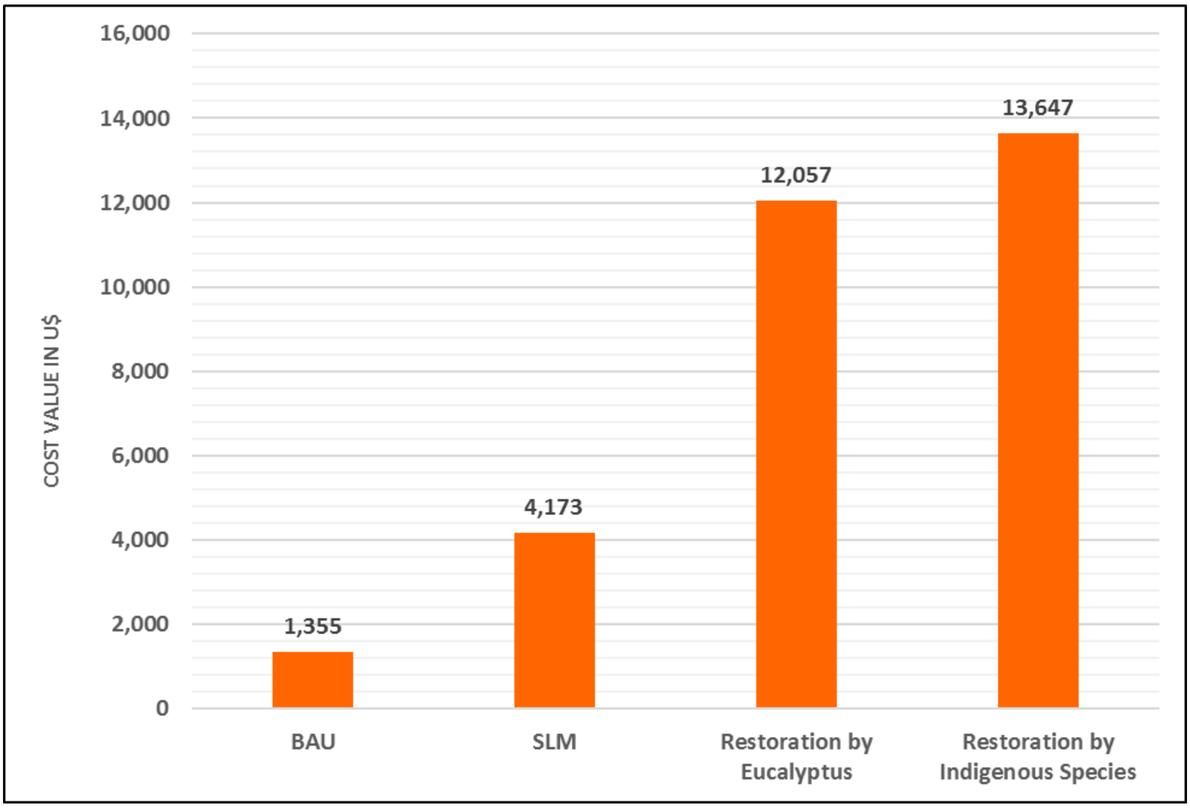

Figure 6: Annual cost per ha for all scenarios

During the study period, the maximum annual rainfall (1502 mm) was observed at the western rainfall gauge located close to the Nyungwe National Park. The minimum annual rainfall (1239mm) was observed in the center of rain gauging. The mean annual rainfall and, and the standard deviation

4.2. Cost-Benefits and Net Present Value

The results show that three scenarios show positive NPV. These are BAU, SLM and restoration by indigenous species. Only scenario 3 has recorded a negative NPV value. For BAU scenario, the reason for a higher value is due not only to the variety of land use on the total area (2036 ha) inside the GMC. In this scenario, the high NPV comes from Irish potatoes (U$50,279,157.57) and is followed by ranch farming for which the NPV is USD$3,850,629.23.

The second scenario in terms of high NPV is restoration by indigenous species. The NPV for this scenario amounts to USD$40,690,477.70. The area for this scenario is 2986.45 ha. This high NPV is attributable not only to the high area considered but also to the value of the benefits from carbon storage (USD$32,786,098 after eight years), ecotourism and carbon sequestration. NPV for scenario 3 on restoration by exogenous species is negative (Figure 7). The reasons for this are related to the cost of compensation and the lower value of its services. The latter includes the production of charcoal, firewood and bean support poles. The charcoal and wood are produced after 8 years whereas the beans' supports are harvested every five years.

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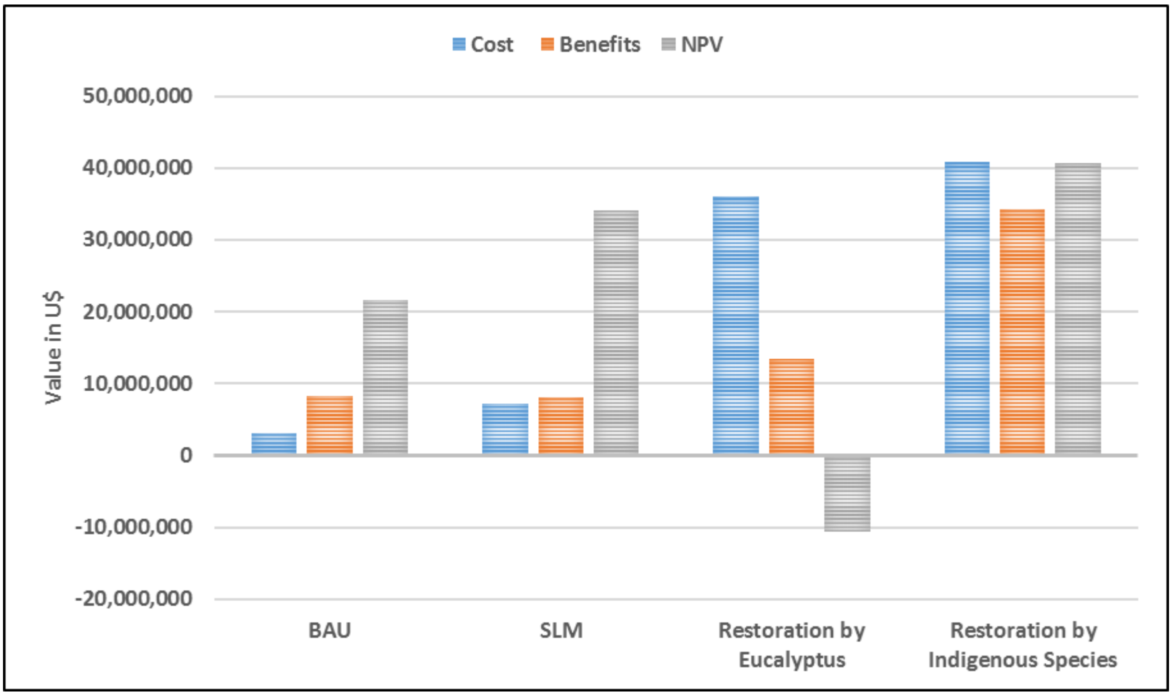

Figure 7: Costs, annual benefits and NPV in all scenarios

Considered crops such as Irish potatoes, maize, and wheat are farmed on a smaller surface area (1,719.33 ha) than that of BAU. Irish potatoes produce higher than other crops in two scenarios. Figure 8 shows that the average yield for Irish potatoes in the BAU scenario is 26,850 kg per hectare. Whereas in the SLM scenario, the average yield of Irish potatoes is 38,333 kg per hectare (Figure 8).

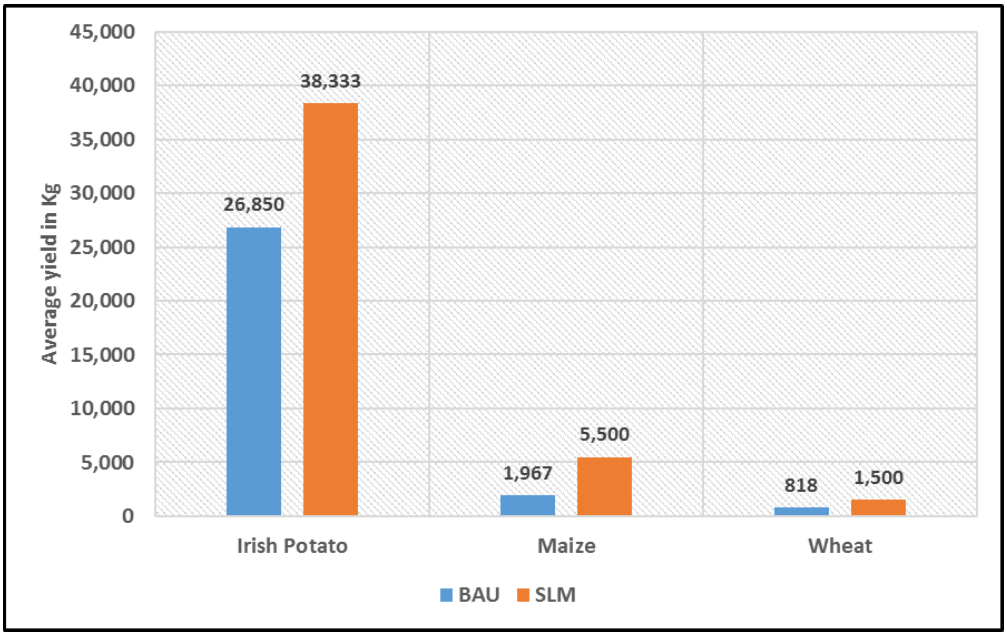

Figure 8: Annual average yield in Kg per crop and per ha

The NPV for SLM is higher than that of the BAU scenario as expected. This stems from higher investments in terracing and fertilizer application that reduce soil erosion and lead to

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high yield. However, a closer look at the crop practiced in both scenarios shows that the SLM scenario has a higher NPV than BAU for Irish potatoes and maize (Figure 10). Although the NPV for Irish potatoes in SLM is lower than in BAU, results on productivity show that the average yield (38,333 kg/ha) in SLM is higher than that of BAU (26,850 kg/ha).

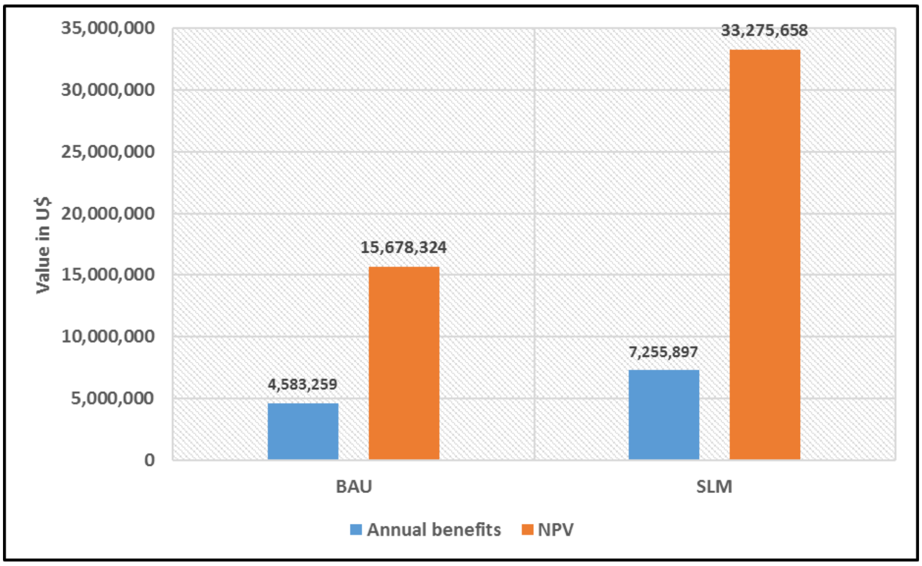

Figure 9: Annual benefits and NPV for Irish Potatoes in BAU and SLM scenarios

Results on maize production show a positive trend between BAU and SLM scenarios (Figure 10). As expected, both the annual benefits and NPV for the SLM scenario are higher than those of BAU. Despite the cost of fertilizers and terrace building, the productivity of maize almost doubles. This means that the cost of terracing in maize production is not of great importance. This positive trend results from the productivity which triples in the SLM scenario.

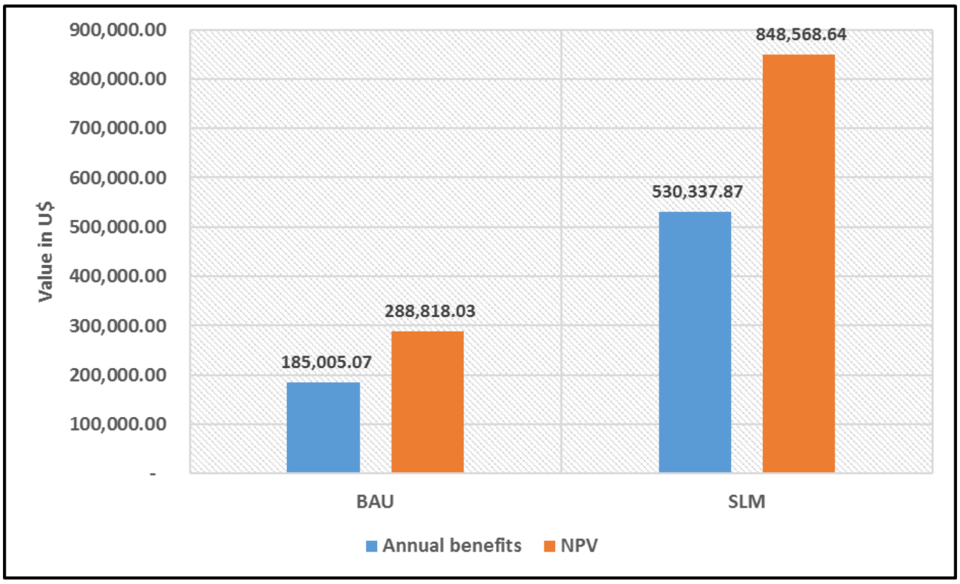

Figure 10: Annual benefits and NPV for Maize in BAU and SLM scenarios

The comparison of NPVs of wheat in the BAU and SLM scenarios shows that despite higher annual benefits in SLM, the NPV is negative. This negative value explains the importance of terracing construction.

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4.3. Sensitivity of all Scenarios

Under **BAU Scenario**, the change in discount rate does not lead to higher variation in NPV. For example, 25%t change in discount rate leads to 11% change in NPV whereas a 100% increase in discount rate leads to 29% reduction in NPV.

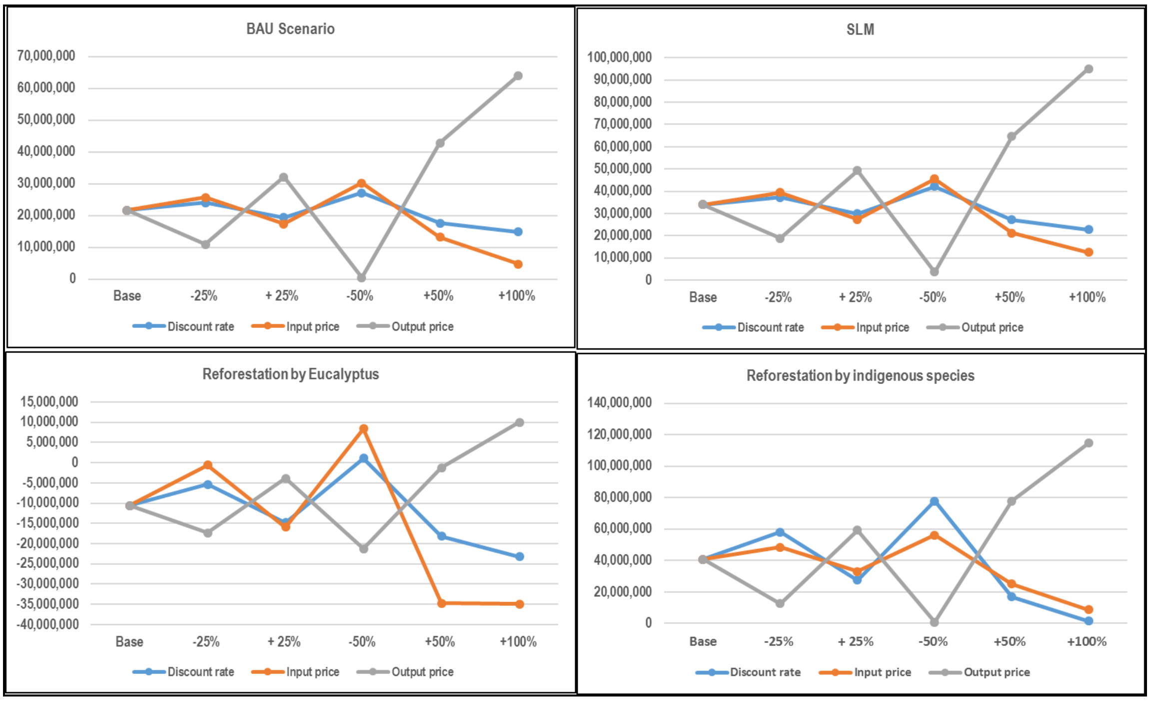

Figure 11: Sensitivity of all scenarios

The above figure shows that inflations and increases in interest rates will not have a higher positive or negative influence on community benefits. The most sensitive variable is the change in output price in which a 25% increase in the price contributes to the 176% increase in the NPV, and 100% contributes to 176 % increase in the NPV. However, one cannot ignore the importance of input price in the variation of NPV. For instance, the doubling of input price contributes to a negative 611% change in NPV. In some situations, an increase in input price can lead to an increase in NPV. Figure 21 on sensitivity of NPV for maize shows respectively that 50% and 100 % increase in input price leads to 55% and 111% positive change in NPV. However, an examination of NPV results reveals an average decrease in NPV though the percentages reveal positive trends.

In contrast to the Business-As-Usual scenario, a change in discount rate in the SLM scenario implies a major change in NPV. For instance, a 50% and 100 % increase in discount rates leads to 203% and 349% increase in NPV. However, positive change masks the negative trends in the real value of NPV. At a 50 % change in discount rate, the NPV of wheat changes from USD -$12,593 to -$36,270, whereas a 100 % increase in discount change leads the NPV to change from USD -$12,595 to -$53,350. The change trend is also the same for change input and output price though the NPV becomes more sensitive than in the case of discount rate.

Under the restoration by exotic species of Eucalyptus, change in all variables highly affects the NPV. Regarding changes in discount rates, for instance, 25% increase in discount rate leads to more negative outcomes in NPV at the rate of 306 %. This means that NPV changes from USD -$1,766,287.25 to $2,468,095.60. In addition, change in both input prices affects the NPV more than that of the output price. This is because, in this scenario, costs outweigh benefits both in baseline NPV and Sensitivity NPV. This trend results from the higher value of land and houses compensation which cannot be recovered from the benefits of charcoal production, firewood and beans support poles.

Under the restoration by indigenous species scenario, the effect of change in the discount rate is higher than that of the input price. As discussed earlier, the input prices for this scenario are labour, forest maintenance costs and compensation for relocation. However, a change in these costs does not affect the NPV at the same levels as that in output price as was observed in scenario 3. This is because there are many more benefits from this scenario with higher NPV. These benefits are ecotourism, carbon storage and sequestration. The higher effect of change in output price to NPV means that increased revenues from eco-tourism and the carbon market outweigh the cost of the corridor restoration.

5. Conclusions

The objective of this study was to assess the current land management and its effect on ecosystem services in GMC from the local community perspective. The study explored four scenarios of ecosystem services use and management. The comparison of all four scenarios shows that the scenario on the restoration of the corridor by indigenous tree species offers higher economic and environmental benefits than the other scenarios. The NPV for this scenario is USD 40,690,477.7. It is followed by the sustainable land management scenario whose NPV is USD 34,048,663.7. The third scenario is the Business-as-Usual Scenario with NPV amounting to USD 21,915,102.8. The last scenario is the rehabilitation of the corridor by exogenous species whose NPV is USD 9,494,381.7. Its economic benefits are related to charcoal, firewood and bean support poles.

These results support the importance of corridor restoration as championed by projects such as REMA/LAFREC. The analysis has shown that the economic and environmental benefits from this option are not negligible, particularly in terms of the economic benefits from ecotourism and environmental benefits from carbon sequestration and carbon storage. However, the cost of community land and assets relocation are exorbitant. Continued investment in soil protection by terracing and agroforestry is a practice to be encouraged since this scenario has proven to offer better economic services than others.

The sensitivity analysis has shown that in most cases, changes in input and output are higher than those in discount rates. Trend changes in discount are constant whereas those in input and output price are characterized by more variations especially the change in output price. This explains the increased value of the benefits due to their higher demands especially food products such as milk, Irish potatoes, and maize, which will offer high economic returns to the community. However, this requires investment in soil protection and fertilization. This confirms that local communities can bear the costs of soil conservation and fertility management when they perceive the sufficiency of the yield and good price of their agricultural products. The research findings from this study are useful for evaluating food security, economic development options and environmental sustainability goals set forth by the Rwandan government in GMC. The findings will inform the implementation of the National Strategy for Transformation of Rwanda which prioritizes the promotion of sustainable management of natural resources and environment to transition Rwanda towards a carbon-neutral economy. It is intended to be achieved through the increased sustainability and profitability of forest resources; increased energy security; sustainable land use and land management systems within GMC.

Although the study has provided a comprehensive snapshot of ecosystem services in Mukura Gishwati Corridor, there is a need to reveal its shortcomings. It was difficult to estimate the environmental benefits of soil protection especially erosion protection and nutrient supply, disaster reduction and carbon sequestration of different farming practices. In addition, it was difficult to estimate from the community perspective, the value of fodders and timber production from eucalyptus and pine trees.Farmers should continue to invest in sustainable land management practices using terrace actions because the SLM scenario has shown higher yields at low costs. They should be organized into cooperatives to be able to negotiate the price for their agricultural products by considering the investment cost. Agro-dealers should provide agricultural inputs (fertilizers, pesticides and veterinary medicines) at affordable prices because the change in input price has a substantial impact on NPV. There is also a need for agricultural input sellers to not take advantage of farmers' need for money by reducing the price of agricultural products. The Ministry of Agriculture should provide training to farmers on keeping records on investment and benefits from farming, ranching and agroforestry; and the required information to farmers on prices and market opportunities because the low prices are likely to influence the economic benefits of farmers. In the case of the restoration of GMC, the GoR should avoid using exotic species because not only they are suitable for biodiversity conservation but also their economic benefit is low.

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