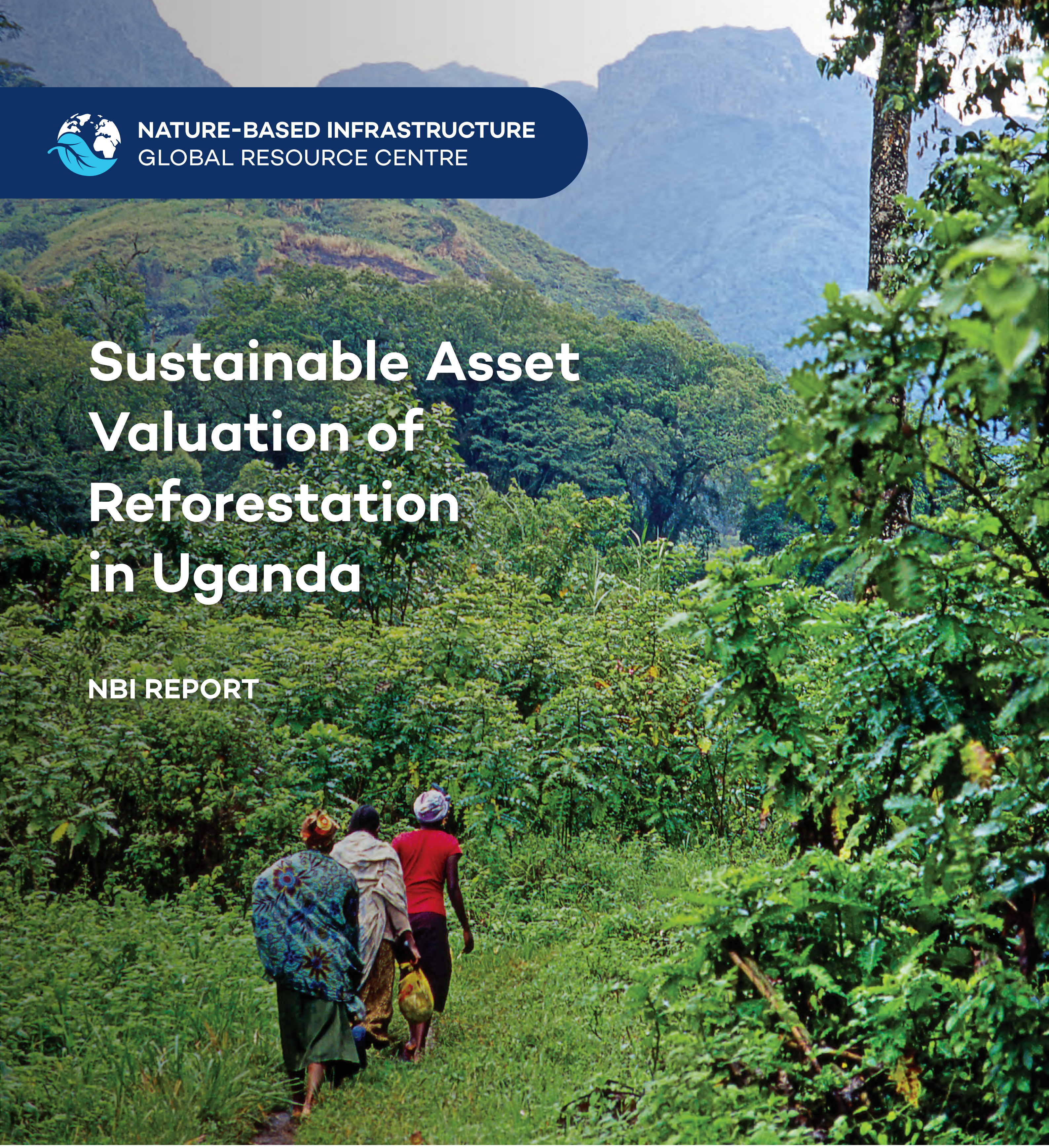

NATURE-BASED INFRASTRUCTURE
GLOBAL RESOURCE CENTRE

Sustainable Asset Valuation of Reforestation in Uganda

NBI REPORT

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International Institute for Sustainable Development

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The **Nature-Based Infrastructure (NBI) Global Resource Centre** aims to improve the track record of NBI to deliver infrastructure services and adapt to climate change while delivering other environmental, social, and economic benefits. We provide data, training, and customized valuations of NBI projects, based on the latest innovations in systems thinking and financial modelling.

The Centre is an initiative led by IISD, with the financial support of the Global Environment Facility (GEF) and the MAVA Foundation, in partnership with the United Nations Industrial Development Organization.

Sustainable Asset Valuation of Reforestation in Uganda

June 2024

Written by Ronja Bechauf, Henri Contor, and Marco Guzzetti

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Executive Summary

Kasese, a region in southwestern Uganda, faces increasing flood, landslide, and heat risks due to climate change and deforestation. While about 50% of the district is covered by forest, factors such as rapid population growth, a reliance on biomass for energy, and unregulated timber harvesting have put the ecosystem under pressure, leading to rapid forest loss. Deforestation, alongside increasingly intense rainfall from climate change, has contributed to devastating floods, soil erosion, and land degradation. In 2020, floods displaced over 10,000 people in Kasese District and severely damaged properties and infrastructure.

In response to these challenges, the municipality and district of Kasese have devised a comprehensive plan for reforestation and tree planting across 30,270 hectares of land that have already been identified in the District Forestry Plan (Mugume, 2022). The primary objective of this initiative is to mitigate flood risks by implementing agroforestry and reforestation measures in various critical areas throughout Kasese, including riverbanks, urban spaces, and nearby hills. By strategically placing trees along roads and in urban areas, the project enhances climate change resilience and reduces costly damage from floods. Furthermore, the planned nature-based infrastructure (NBI) interventions yield numerous additional benefits, such as carbon sequestration, improved habitat for biodiversity, soil revitalization, and additional revenues for local communities.

Kasese Municipality and the district of Kasese collaborated with the Covenant of Mayors of Sub-Saharan Africa to plan and secure funding for the project. With an estimated budget of USD 15 million, the initiative aims to restore 302 km^2 of forest over a decade and sensitize local communities about climate adaptation. The overall goal is to enhance the resilience of both local and national ecosystems and communities, benefiting about 1 million people living in the district.

For long-term sustainability, the municipality, in collaboration with the district, the National Forestry Authority, and the Ministry of Finance, Planning, and Economic Development, plans to explore the generation of carbon credits from the project. The revenue generated from the carbon offsets would be reinvested in sustaining the forests in Kasese. Successful implementation of this project could open doors for scaling up other NBI projects in Uganda using revenue from carbon finance.

The NBI Global Resource Centre was asked to apply the Sustainable Asset Valuation (SAVi) methodology to assess the economic, social, and environmental outcomes of implementing the reforestation project in Kasese. SAVi is based on systems thinking and uses a combination of spatial analysis, climate data, and Excel-based modelling to create an integrated cost-benefit analysis and estimate financial indicators. This economic analysis demonstrates the societal value of reforestation in Kasese and can help the municipality and district make a case for investing in the project and maintaining it in the long term.

As envisioned in the project plans (Mugume, 2022), we analyzed the following NBI activities:

- woodland interventions: restoring 20,000 ha of natural forest, establishing 1,000 ha of forest plantations and woodlots, and restoring 3,000 ha of degraded forest.
- agroforestry interventions: creating 3,000 ha of agroforestry systems, planting 3,200 ha of trees along roads, and growing 20 ha of trees in urban areas and 50 ha for aesthetic purposes.

Key Results

- The planned NBI interventions can play a vital role in supporting climate adaptation efforts in Kasese by enhancing water retention, reducing flood risks, and mitigating harmful erosion that affects agriculture. Climate data suggests that flood risks in Kasese will increase significantly in the future.
- The implementation of NBI generates a total net benefit of USD 69.1 million, including large benefits arising from carbon sequestration (USD 27.8 million), agroforestry revenues (USD 14.6 million), and avoided costs of damage to infrastructure amounting to USD 15.2 million (see Table ES1 for details and comparison between discounted and undiscounted values).
- Taking into account the social, economic, and environmental benefits, each dollar invested in Kasese's NBI activities yields USD 5.44 in returns for society. When applying discounted values, the results are 4.08 at a 3.5% discount rate and 2.68 at a 10% discount rate. This value could potentially grow even higher as the frequency and strength of extreme weather events increase with climate change.
- The integration of agroforestry, urban trees, and tree plantations is projected to generate net benefits of USD 69 million over the next 27 years. Moreover, it positively impacts health and food security in the region, as we estimate that the avoided value of life loss and health care is USD 12.2 million and that agroforestry and additional crop production generate USD 16.5 million in revenues.
- The municipality and district of Kasese could explore carbon offsets as a potential long-term financing strategy. The NBI could store 5.6 million tons of carbon dioxide, with an estimated value of USD 27.8 million.
- The diversity of benefits makes the NBI project economically viable. While construction costs could be covered through a partial monetization of carbon sequestration, operation and maintenance expenditures could be largely addressed through public tax revenue.

Table ES1. Cost-benefit analysis (2024 to 2050) (USD million)

Integrated cost-benefit analysis (2024–2050)	Undiscounted	Discounted (3.5%)	Discounted (10%)
Construction costs	14.3	11.6	8.2
Operation and maintenance (O&M) costs	1.2	0.8	0.4
Total costs	**15.6**	**12.4**	**8.6**
Avoided cost of damages to infrastructures	15.2	8.9	4.1
Avoided loss of life	7.1	3.8	1.4
Avoided health cost	5.1	2.7	1.0
Avoided loss in agriculture revenue	0.2	0.1	0.0
Total avoided cost/loss	**27.5**	**15.5**	**6.6**
Carbon sequestration	27.8	18.1	8.9
Agroforestry revenue	14.6	8.0	3.1
Timber plantation revenue	7.2	3.9	1.5
Additional crop production revenue	1.9	1.0	0.4
Total benefit of income creation	1.7	1.3	0.9
Additional public tax revenue	4.0	2.8	1.7
Total added benefits	**57.1**	**35.1**	**16.4**
Total benefits (avoided costs/loss + added benefits)	**84.6**	**50.5**	**23.0**
Total benefits	84.6	50.5	23.0
Total costs	15.6	12.4	8.6
Net benefit	**69.1**	**38.2**	**14.4**
Benefit-to-cost ratio (BCR)	**5.44**	**4.08**	**2.68**

Source: Authors.

As a next step, the district and municipality could explore various financing options available to support the project. This may include seeking funding from governmental sources, international organizations, and voluntary carbon markets. To prepare the project implementation, we also recommend that Kasese engage with local communities to undertake a technical feasibility study to identify the precise location and scope of the NBI interventions. By conducting the feasibility study and exploring financing avenues, Kasese can pave the way for successful implementation of the NBI interventions and ensure long-term sustainability of the project.

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Glossary

Discounting: A finance process to determine the present value of a future cash value.

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Program [UNEP], 2014).

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST): "A suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people" (Natural Capital Project, 2019).

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (UNEP, 2014).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net benefits: The cumulative monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Net present value: The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

1.0 Introduction

Kasese, a region in southwestern Uganda, faces increasing flood, landslide, and heat risks due to climate change and deforestation. While about 50% of the district is covered by forest, factors such as rapid population growth, a reliance on biomass for energy, and unregulated timber harvesting have put the ecosystem under pressure, leading to rapid forest loss (Mugume, 2022). Deforestation, alongside increasingly intense rainfall, has contributed to devastating floods, soil erosion, and land degradation. In 2020, floods displaced over 10,000 people in Kasese District and severely damaged properties and infrastructure.

Figure 1. Floods invaded homes in Kasese and displaced families

Photo by Evelyn Mugume

To address these challenges, the city and district of Kasese plan reforestation and tree planting on 30,270 ha of land. This project aims to reduce flood risks by implementing agroforestry and reforestation initiatives across both the municipality and district, planting in urban spaces, riverbanks, and hillsides. By strategically planting trees along the road network and in urban areas, the project aims to lower maintenance costs for infrastructure and improve climate change resilience. As part of the project, stakeholders plan to improve the management of existing forestry to prevent further destruction, improving water retention and reducing soil erosion, therefore reducing the need for grey infrastructure. The reforestation efforts provide several additional co-benefits, such as carbon sequestration, increased biodiversity, soil revitalization, and opportunities for revenue generation.

Kasese Municipality and the district of Kasese collaborated with the Covenant of Mayors of Sub-Saharan Africa (CoM SSA) to plan and secure funding for the project. With an estimated budget of USD 15 million, the initiative aims to restore 302 km^2 of forest over 10 years, as well as educate local communities on climate adaptation (Mugume, 2022). The overall goal is to enhance the resilience of both local and national ecosystems and communities, benefiting around 1 million people in total.

For long-term sustainability, the municipality, in collaboration with the district, the National Forestry Authority, and the Ministry of Finance, Planning, and Economic Development, plans to explore the generation of carbon credits from the project. The revenue generated from the carbon offsets would be reinvested in sustaining the forests in Kasese. Successful implementation of this project could open doors for scaling up NBI in Uganda, using revenue from carbon finance.

We used the SAVi methodology to assess the economic, social, and environmental outcomes of implementing the reforestation project in Kasese. As envisioned in the project plans, we analyzed the following set of NBI interventions related to woodlands and agroforestry that cover about 11% of Kasese District (Mugume, 2022):

Table 1. Overview of planned NBI interventions

NBI activities	Scope over 10 years (in ha)
Woodland interventions	
Restoration of natural forest	20,000
Creation of forest plantations and woodlots	1,000
Restoration of degraded forest lands	3,000
Agroforestry interventions	
Creation of agroforestry systems	3,000
Tree growing along roads	3,200
Tree growing in urban areas	20
Tree growing for aesthetic purposes	50
Total	**30,270**

Source: Authors.

Figure 2. Steep slopes where Kasese encourages landowners to practice agroforestry or establish woodlots with native trees

Photo by Evelyn Mugume

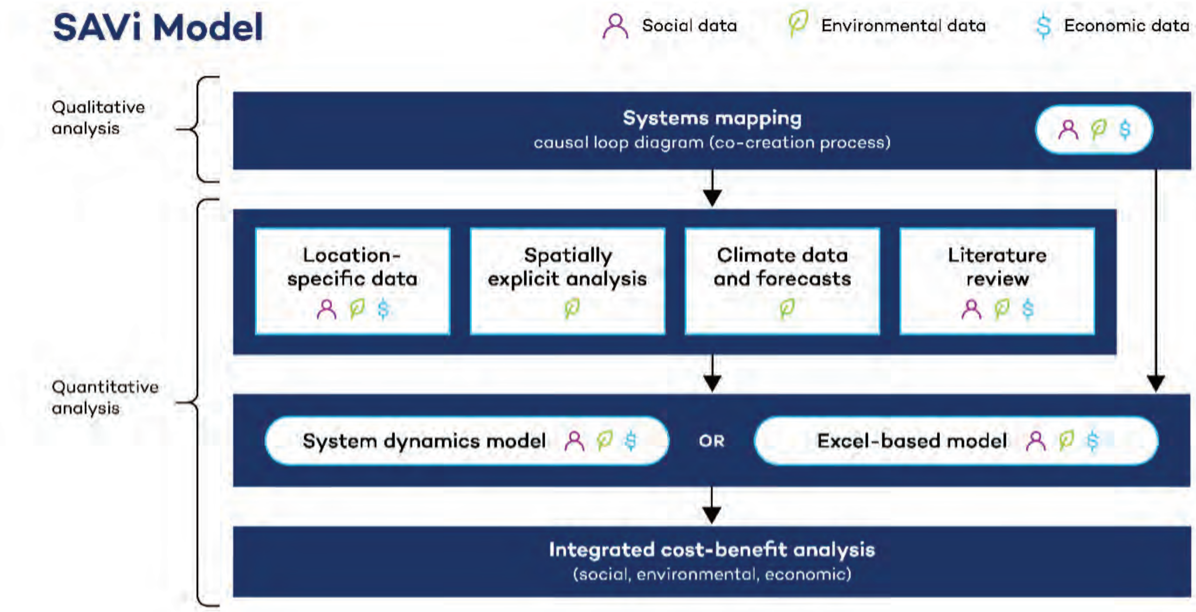
The integrated SAVi valuation demonstrates the societal value of reforestation in Kasese and can help the municipality and district make the case for investing in the project and long-term maintenance. By providing insights into potential revenue streams from carbon storage, the assessment helps to inform innovative financing strategies and scale up similar projects beyond Kasese.

The assessment also sheds some light on the gendered outcomes of NBI in Kasese. Due to the gendered division of labour, social norms, and disparities in land ownership, women in Kasese tend to be more affected by the impacts of floods and depend more on natural resources to complement their livelihoods, while the mainly male smallholder farmers might be more directly involved in the tree-planting efforts. To maximize the project's benefits for gender equality and women's empowerment, the municipality and district aim to involve all household members in the community sensitization component of the project (Mugume, 2022).

2.0 Sustainable Asset Valuation

Sustainable Asset Valuation (SAVi) is an assessment methodology that provides policy-makers and investors with a comprehensive life-cycle analysis of infrastructure projects, considering often-overlooked impacts. Combining systems thinking and project finance modelling, SAVi captures the full costs, including environmental, social, economic, and governance risks. It calculates the monetary value of externalities, offering a nuanced evaluation. This holistic approach enables investment decisions to align with regional development priorities, climate change adaptation, and the United Nations Sustainable Development Goals, ensuring a financially sound and sustainable outcome.

Figure 3. The SAVi methodology combines qualitative and quantitative tools to develop an integrated cost-benefit analysis of NBI projects



Source: IISD.

2.1 Importance of Systems Thinking

The SAVi approach relies on systems thinking. This holistic methodology considers the intricate connections linking various factors within a system and forms the first step of the SAVi methodology (see Figure 3). By employing this approach, our study explores how different indicators and variables within the system interact. It delves into the complex relationships and interdependencies among key indicators, including rainfall patterns, agricultural practices, infrastructure, and socio-economic aspects. Understanding these interconnections provides a more nuanced perspective, enabling us to identify the fundamental drivers and dynamics influencing the livelihoods of local communities. These drivers might include deforestation, population growth, urbanization, and policy frameworks, while dynamics encompass interactions and feedback loops shaping the system's behaviours or outcomes.

By unravelling these key drivers and dynamics, our study gains insights into the underlying causes and mechanisms that shape the current situation in Kasese. This method offers an integrated view, recognizing that changes in one aspect of the system can trigger cascading effects on others. This improved understanding facilitates a more accurate assessment of potential intervention impacts and the overall effectiveness of climate resilience strategies.

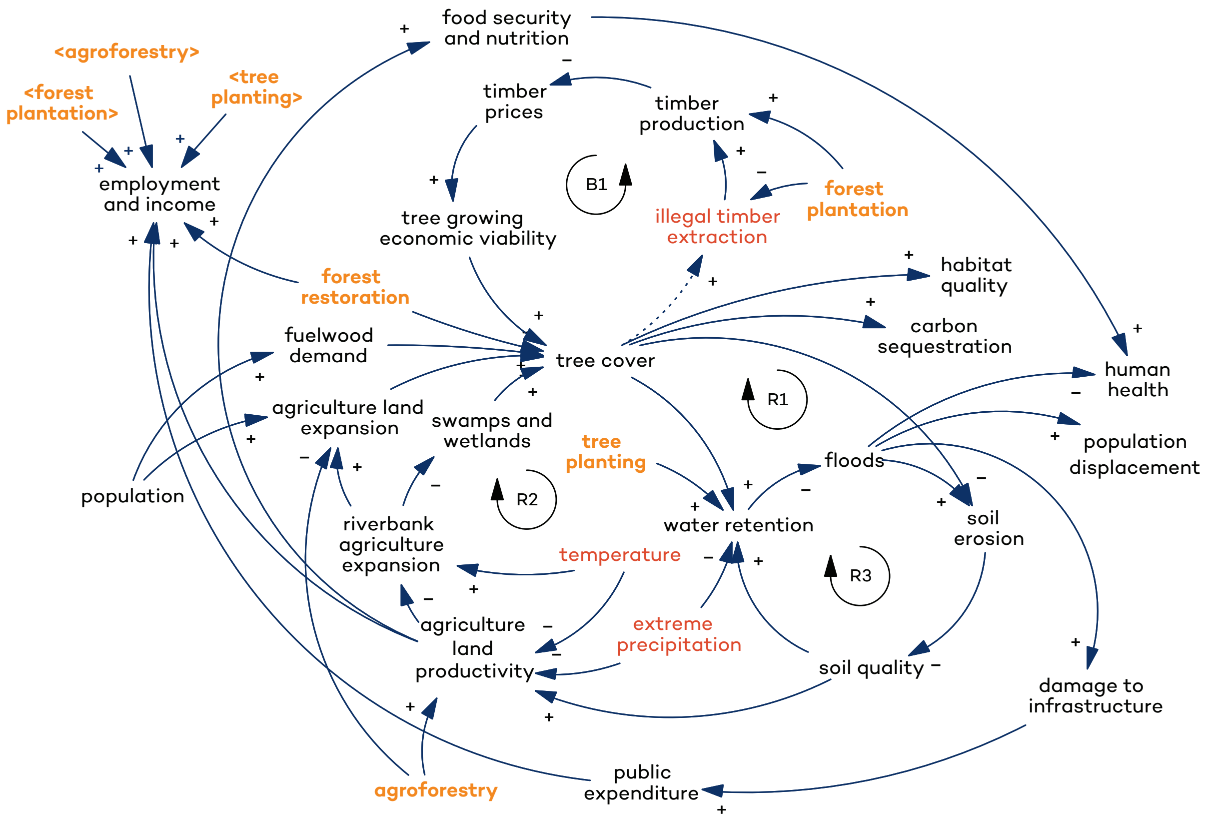
Systems thinking also aids in identifying policy entry points—specific areas or aspects within the system where interventions or policies can yield the greatest impact. A systemic understanding allows for a strategic approach to policy formulation by revealing leverage points and areas where interventions can be most effective. Policy-makers, armed with knowledge about these entry points, can prioritize and target their efforts, thereby maximizing the efficiency and effectiveness of policy interventions.

In summary, by applying systems thinking, our study achieves several key objectives: gaining a comprehensive understanding of the climate resilience system, recognizing the interconnectedness of key indicators, uncovering key drivers and dynamics, and discerning the most impactful policy entry points.

2.2 Causal Loop Diagram

We developed a causal loop diagram (CLD) to identify the main dynamics within the project context and to guide model development (see Figure 4). A CLD is a visual representation of key indicators and their interrelationships and can be regarded as the dynamic hypothesis of the system (Sterman, 2000). We validated the CLD with local stakeholders to ensure that all relevant aspects of the analysis are captured. The following section provides a summary of the most important insights identified in the CLD analysis.

Figure 4. Simplified CLD



Source: Authors.

Box 1. Reading a CLD

A CLD is a tool that supports systems thinking. It shows relations between components of a system. Arrows indicate causality, and plus and minus signs are used to show the direction of causality. A plus sign means that two variables change in the same direction (a positive correlation), while a negative sign means that they change in opposite directions (a negative correlation). Feedback loops are labelled as either reinforcing (R) or balancing (B). A reinforcing loop indicates that a change in one variable will lead to further change in the same direction, whereas a balancing loop dampens change.

In recent decades, Kasese has witnessed a significant reduction in **tree cover**, largely driven by the expansion of agricultural land and the increasing demand for fuel wood. Illegal **timber** extraction, fuelled by the region's abundant timber resources, has exacerbated this decline. The resulting oversupply of timber has led to a decrease in timber prices, negatively impacting the economic feasibility of legal timber production. This intricate dynamic creates a delicate balancing loop where the attractiveness of illegal timber extraction is tied to prevailing timber prices.

The consequences of forest loss extend beyond economic concerns. The district's trees play a crucial role in providing **ecosystem services**, including maintaining habitat quality for local biodiversity and sequestering carbon. Additionally, the natural vegetation acts as a stabilizer, preventing **soil erosion** during flood events. Over time, soil erosion leads to reduced soil quality as essential nutrients are washed away. This, coupled with the diminishing tree cover, reduces the natural water retention capacity during extreme precipitation events, resulting in increased runoff and more frequent floods.

Forest loss and increased erosion also affect **agricultural production**. Soil quality reductions, exacerbated by extreme weather events, strain yields. In an effort to counteract declining yields, riverbank areas are converted into cropland, perpetuating a destructive cycle by diminishing natural vegetation cover, intensifying soil erosion, and lowering water retention capacity. The expansion of agriculture onto riverbanks encroaches on swampy areas and natural wetlands, compounding pressures on overall tree cover and exacerbating the compromised ability to manage hydrological flows effectively.

The escalating frequency and severity of **floods** resulting from these interconnected dynamics cause infrastructure damages and increasingly displace people. Concurrently, reduced soil quality and agricultural productivity pose a threat to food security and nutrition, as diminished production may render it challenging to cultivate nutritious crops. This, in turn, has profound implications for human health. Beyond the direct impact on people, floods wreak havoc on infrastructure, necessitating increased public expenditure for reconstruction and diverting resources that could otherwise be invested more strategically.

Collectively, these multifaceted dynamics exert a profound influence on the **livelihoods** of the people in Kasese. The reductions in employment and income, particularly stemming from decreased agricultural yields, pose a significant threat to the district's inhabitants, given their substantial reliance on agriculture. Paradoxically, the increased public expenditure required for flood-related reconstruction generates a counteractive consequence, providing a temporary boost to employment and income but as a result of undesirable floods.

In understanding the intricate environmental dynamics of Kasese, four feedback loops play a pivotal role, each contributing to the complex interplay of factors shaping the region (see Figure 1). These loops, outlined below, shed light on the relationships between market forces, soil quality, agriculture expansion, water retention, floods, erosion, and crop yields.

1. **Balancing loop (B1): Market impact on illegal timber extraction**
    1. The amount of illegal timber extracted in Kasese is influenced by market dynamics.
    2. If the market is flooded with timber, driving prices down, the appeal of illegal extraction diminishes.
    3. Conversely, when timber is scarce and prices rise, the allure of illegal extraction increases again.

2. **Reinforcing loop (R1): Soil quality and agriculture expansion**
    1. Moving beyond market influences, the decline in soil quality triggers a ripple effect.
    2. This decline prompts agriculture to expand onto riverbanks and wetlands.
    3. As a result, the reduction in natural soil cover exacerbates the impacts of subsequent loops (R2-R3).
3. **Reinforcing loop (R2): Water retention and flood impact**
    1. Shifting focus to water dynamics, diminished water retention intensifies floods.
    2. These intensified floods, in turn, cause more soil erosion and further reduce crop yields.
    3. Importantly, the lower yields amplify the impacts of both soil degradation and flooding (R1-R3).
4. **Reinforcing loop (R3): Water retention, floods, and erosion**
    1. Lastly, the reduced ability to retain water heightens flood severity, leading to increased erosion.
    2. This erosion creates a harmful feedback loop, depleting soil quality and aggravating water retention issues.
    3. Altogether, these loops underscore the interconnected nature of environmental challenges in Kasese.

In tackling the environmental challenges in Kasese, the proposed **solutions** revolve around **reforestation** and **restoration** initiatives, as depicted by the orange indicators on the CLD (see Figure 4). Envisaged activities include forest restoration to increase tree cover, a measure designed to combat soil erosion and bolster water retention. By reducing peak water flow during flood events, these initiatives aim to alleviate both the socio-economic impacts, such as flood damages and displacement, and environmental impacts, like the loss of soil quality. Furthermore, urban tree planting is identified as a strategic approach to enhance water retention in localities. This targeted intervention plays a crucial role in diminishing flood severity and mitigating soil erosion, contributing to the overall resilience of affected communities. In parallel, the establishment of timber plantations is seen as a key element in sustainable resource management. Such plantations ensure a continuous supply of wood, helping maintain stable prices in the market. This equilibrium, in turn, diminishes the allure of illegal timber extraction, offering a robust solution to this environmental concern.

A significant benefit arising from these interventions is the generation of employment opportunities and income. This socio-economic impetus not only fosters local **livelihood** development but also serves as a deterrent, reducing incentives for engaging in illegal activities. Embracing this comprehensive set of interventions holds the potential to pave the way for a more resilient and sustainable future in Kasese, finding a harmonious balance between environmental conservation and socio-economic development.

2.3 Climate Data Analysis

Climate data and forecasts are a key input for the SAVi methodology (see Figure 3). They help us understand the long-term outcomes under different climate scenarios. In short, we find the following:

1. Under strong climate change scenarios, average temperatures by 2100 will increase by 3°C compared to 2000.
2. Precipitation patterns are expected to change, leading to wetter conditions in specific months of the year and increased flood risks.
3. Droughts are likely to decrease as the climate gets wetter.

The climate data underline the need for Kasese to build climate resilience. In our SAVi assessment, we consider these climate trends by assuming that floods will become more frequent in the future (see the assumptions in Section 2.5).

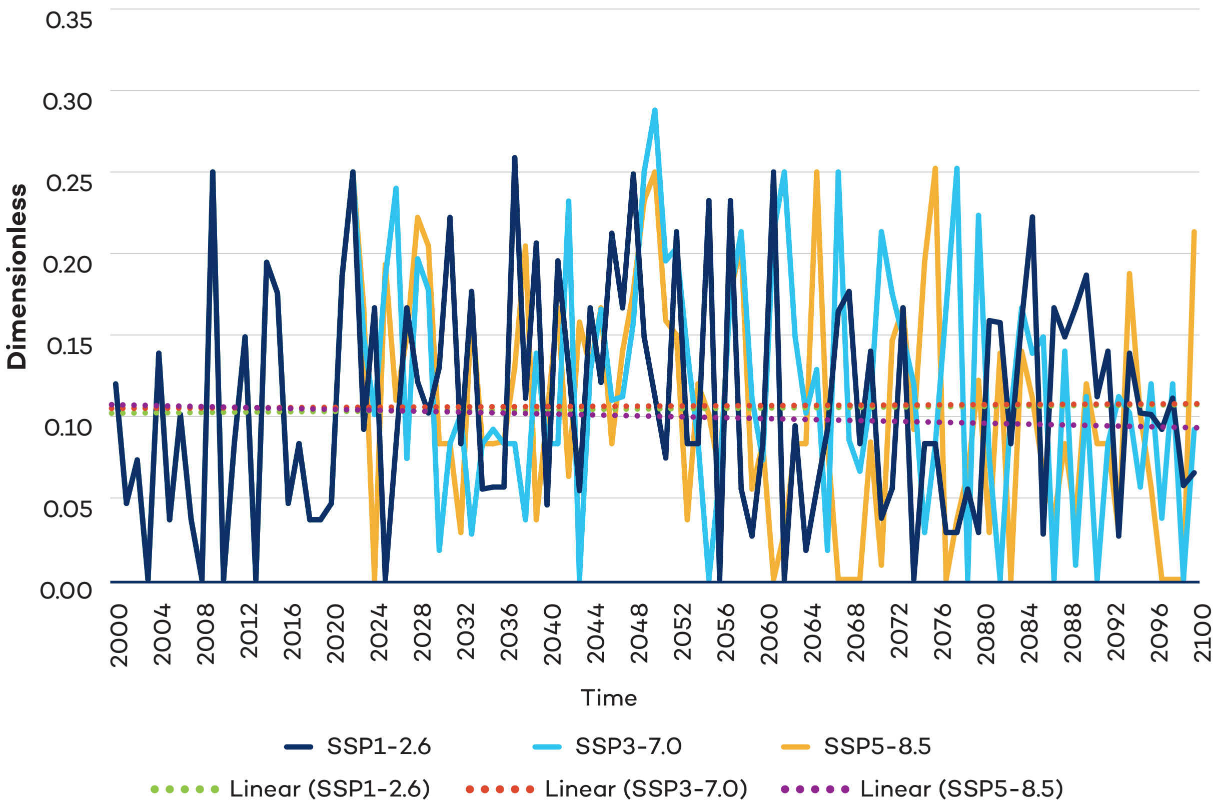
Climate data considered in this analysis are based on the shared socio-economic pathways (SSPs) scenarios. The SSPs define different baselines that might occur based on various underlying factors like population, technological, and economic growth, which may lead to different future greenhouse gas (GHG) emissions and warming outcomes (Hausfather, 2018). The SSPs are based on various narratives describing broad socio-economic trends that can shape future societies. Specifically, this study considers the following SSPs, as described by Meinshausen et al. (2020):

- SSP1-2.6 or "2°C scenario," approximately corresponds to the RCP2.6 scenario, where global temperatures are expected to increase by 2°C by 2100
- SSP3-7.0 is a medium-high reference scenario
- SSP5-8.5 correspond to a high reference scenario in a high-fossil-fuel-use world throughout the 21st century

Figure 5 shows the extreme dry percentile from 2000 to 2100 under different SSPs scenarios from 2000 to 2100. The climate data suggest that under the SSP5-8.5 scenario, the extreme dry percentile will decline compared to the SSP1.2-6 and SSP3.7-0 scenarios. This decrease indicates that the frequency and intensity of dry events will decline in the future.

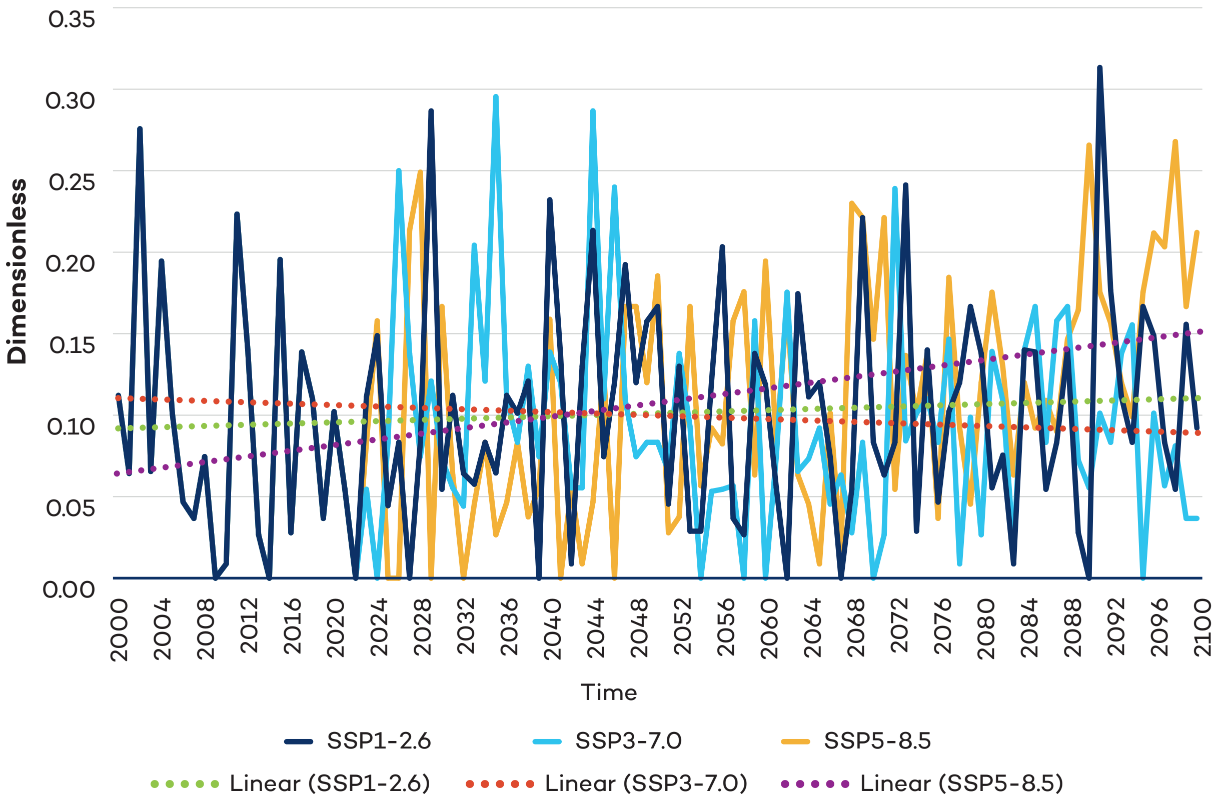
At the same time, Figure 6 shows the extreme wet percentile from 2000 to 2100 under the same SSPs scenarios from 2000 to 2100. Here, the SSP5-8.5 scenario shows an increase in wet conditions. This result further suggests that under this climate scenario, drier conditions will be less frequent, while wetter weather will be more common. Therefore, there is a higher chance that the frequency and intensity of flood risk will increase in the study area.

Figure 5. Extreme dry percentile (Kasese District)



Source: Authors.

Figure 6. Extreme wet percentile (Kasese District)

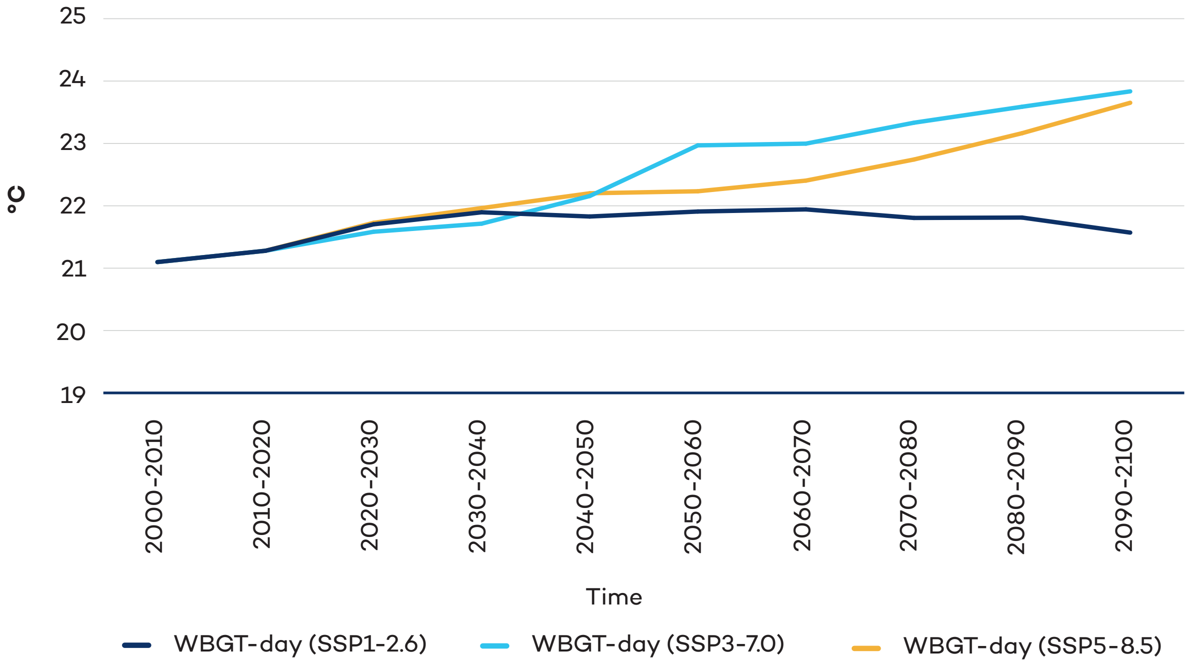


Source: Authors.

Figure 7 shows the average monthly temperature (°C) in the study area from 2000 to 2100 under the three different SSPs scenarios. The trends are similar under all three SSPs scenarios until 2050, after which they bifurcate. In the SSP1-2.6, monthly temperature remains constant throughout the decades between 2050 and 2100. In the SSP3-7.0 and SSP5-8.5 scenarios, average monthly temperature increases by roughly 1°C compared to 2050, or 3°C compared to 2000. The increase in temperature after 2050 could cause a decline in crop yields, given that air temperatures will increase further above the optimal temperature range for many crops. It may also increase the frequency and intensity of heatwaves, threatening human health.

The increase in wet conditions under the SSP5-8.5 scenario (as shown in Figure 6) may be counterintuitive, considering the expected increase in temperature under the same scenario. It may be possible that rainfall patterns, such as distribution, will change significantly in the future, leading to an overall increase in annual wet conditions while, at the same time, annual temperatures will also increase.

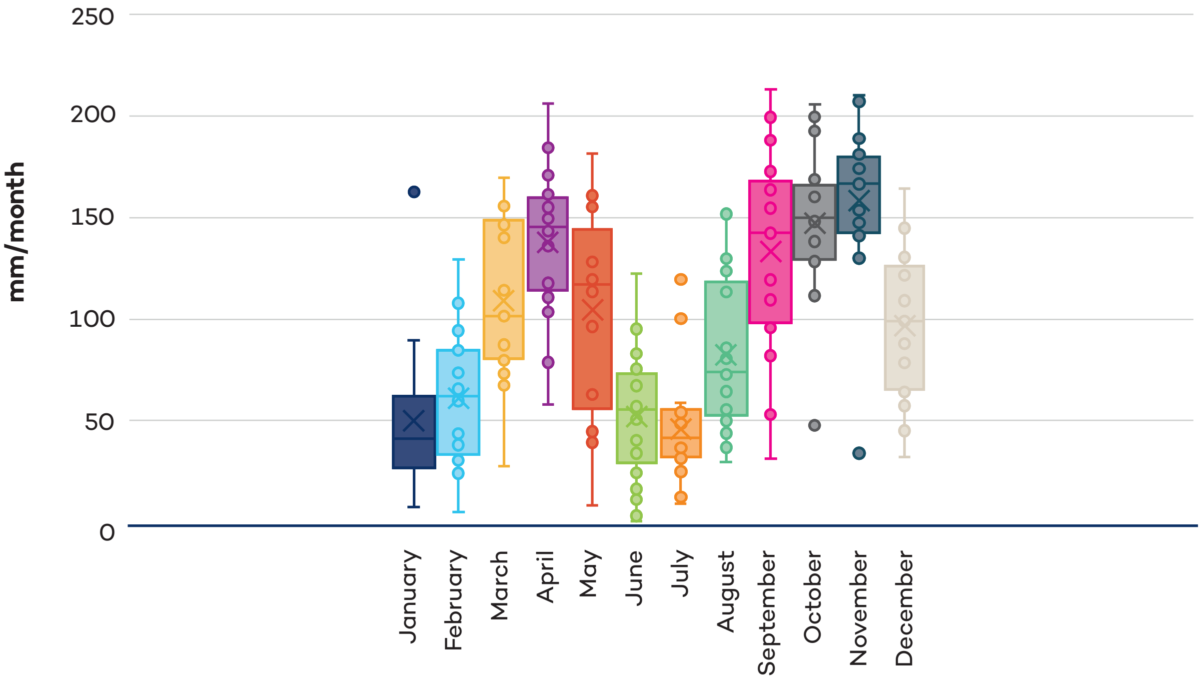
Figure 7. Average monthly temperature (Kasese District)



Source: Authors.

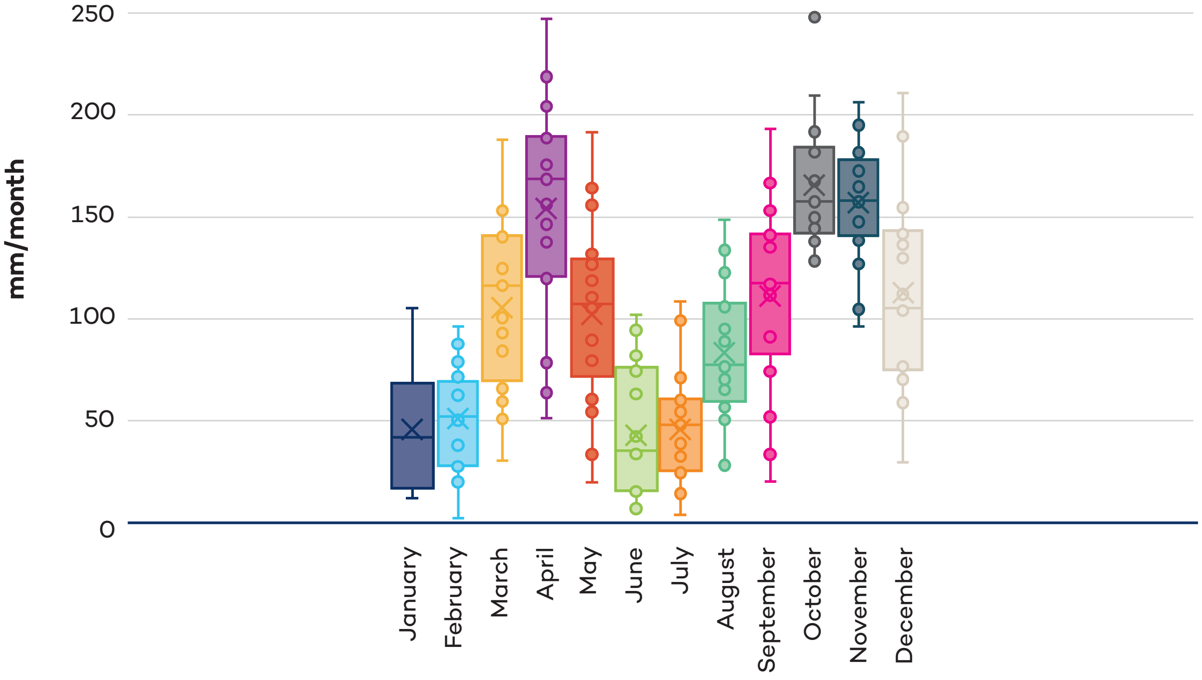
Figure 8 shows in a box plot the average precipitation (mm/month) in the study area for the period 2000 to 2020 under the SSP5-8.5 scenario, while Figure 9 shows the same variables but for the period 2040–2060. The results suggest that the average precipitation estimated for the period 2040 to 2060 during some months, like January, April, and June, is forecasted to increase. This means that precipitation patterns are expected to experience changes in the future, potentially leading to wetter conditions during specific months of the year.

Figure 8. Average precipitation (2000–2020)



Source: Authors.

Figure 9. Average precipitation (2040–2060)



Source: Authors.

2.4 Spatially Explicit Analysis

The SAVi methodology uses spatial analysis to quantify ecosystem services based on landcover maps, which are later monetized in the cost-benefit analysis (CBA) (see Figure 3). The spatially explicit analysis performed for this assessment relies on the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models.[1] These models, developed by the Natural Capital Project, use land-use/land cover (LULC) maps as input and quantify a wide range of ecosystem services.

2.4.1 Data Sources and Assumptions

For this assessment, we used the LULC map created by the Climate Change Initiative Land Cover team.[2] This is a prototype high-resolution LULC map at 20 m over Africa based on 1 year of Sentinel-2A observations from December 2015 to December 2016. The area of interest was extracted from this map, and its resolution was increased to 1 m in QGIS 3.8.0.

The legend of this map includes 10 generic land cover classes that appropriately describe the land surface at 20 m: "trees cover areas (1)," "shrubs cover areas (2)," "grassland (3)," "cropland (4)," "vegetation aquatic or regularly flooded (5)," "lichen and mosses/sparse vegetation (6)," "bare areas (7)," "built-up areas (8)," "snow and/or ice (9)," and "open water (10)." We also added the Nyamwamba River (20), downloaded from GeoFabrik.[3]

For each LULC, we considered the current landscape (business-as-usual [BAU] scenario) and a second option (restored scenario) that assumed the restoration interventions shown in Table 2. The LULC restored scenario was created in QGIS, where we replaced mainly agricultural land and shrubland with the interventions. Figure 10 and Figure 11 show the LULC BAU and LULC Restored scenarios, respectively.

Table 2. Restoration interventions by number of ha

Woodland	**Ha**
Natural forest restored	20,000
Forest plantation and woodlot established	1,000
Degraded forest lands restored	3,000
Agroforestry	**Ha**
Land under agroforest systems	3,000
Planted along roads	3,200
Trees grown and maintained in urban areas	20
Trees grown for aesthetic purposes	50

Source: Authors.

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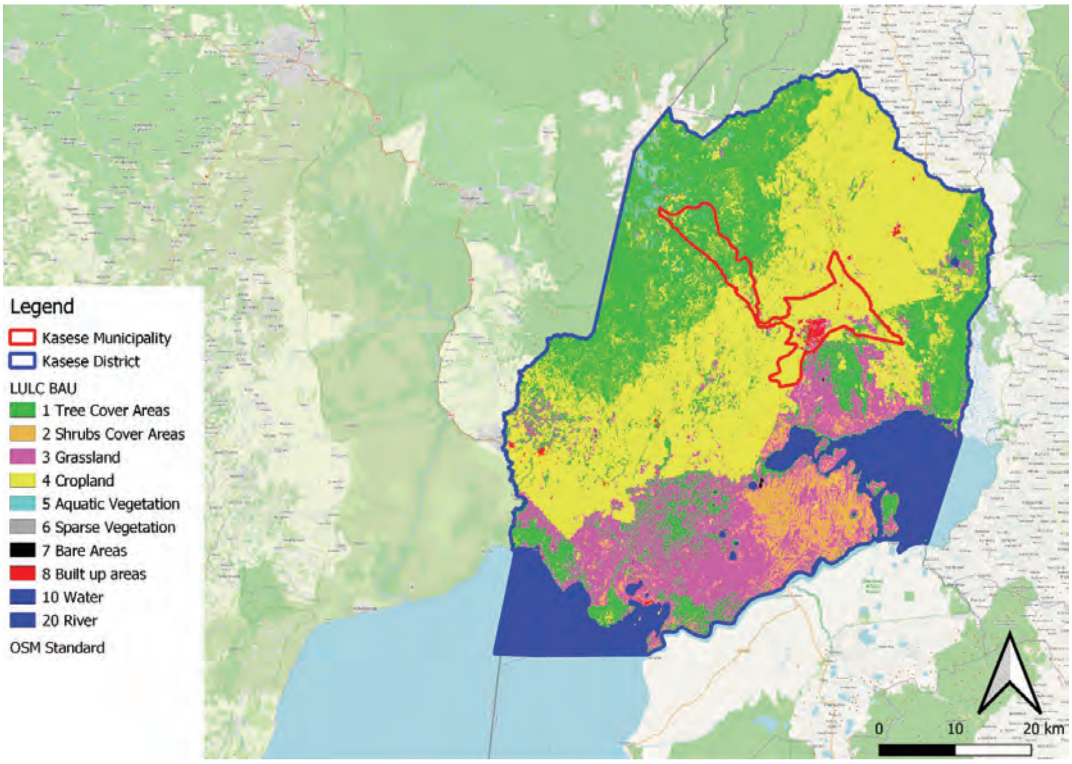
[1] https://naturalcapitalproject.stanford.edu/software/invest

[2] http://2016africalandcover20m.esrin.esa.int/

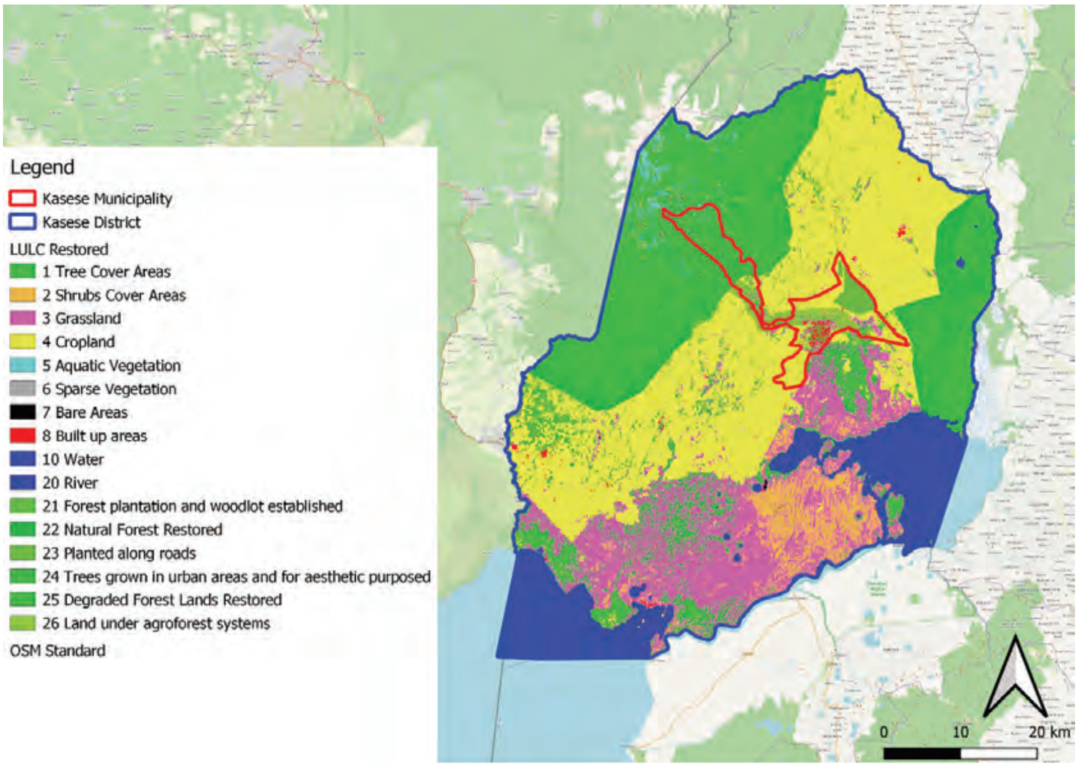
[3] https://download.geofabrik.de/

Figure 10. LULC BAU



Source: European Space Agency, 2016.

Figure 11. LULC restored



Source: Authors.

2.4.2 Results

The results of five InVEST models are presented. First, the carbon storage model calculates the amount of carbon stored in the landscape. Second, the urban flood risk mitigation calculates the runoff reduction, which is the amount of runoff retained per pixel compared to the storm volume, when land cover changes (i.e., in this case, when trees are planted). Third the habitat quality model estimates changes in disturbances to habitat, defined using a unitless index that ranges from 0 to 1, where 0 represents no habitat, and 1 is the highest quality habitat. Next, the sediment delivery ratio (SDR) model quantifies the sediment export in the landscape. Finally, the urban cooling model estimates the temperature reduction by vegetation.

Compared to the BAU scenario, carbon storage, runoff retention, and habitat quality are expected to increase in the restored scenario, while sediment export and temperature are expected to decrease, as illustrated in Table 3 and Table 4 which show the results within the whole municipality and within the district, respectively. These results suggest that landscape restoration not only increases carbon storage, habitat quality, and water quality but it also reduces the risk of flood (estimated via a reduction of stormwater runoff), damages from soil erosion, and heatwaves.

Table 3. Spatial analysis results summary (municipality)

LULC scenario	Carbon storage (tons)	Total runoff retention (m^3)	Mean of habitat quality	Sediment export (tons)	Average temperature value (°C)
BAU	1,687,882	7,561,143	0.0829	N/A	32.8695
Restored	2,326,542 (Change 37.84%)	8,534,914 (Change 12.88%)	0.1213 (Change 46.37%)	N/A	32.2520 (Change -1.88%)

Source: Authors.

Table 4. Spatial analysis results summary (district)

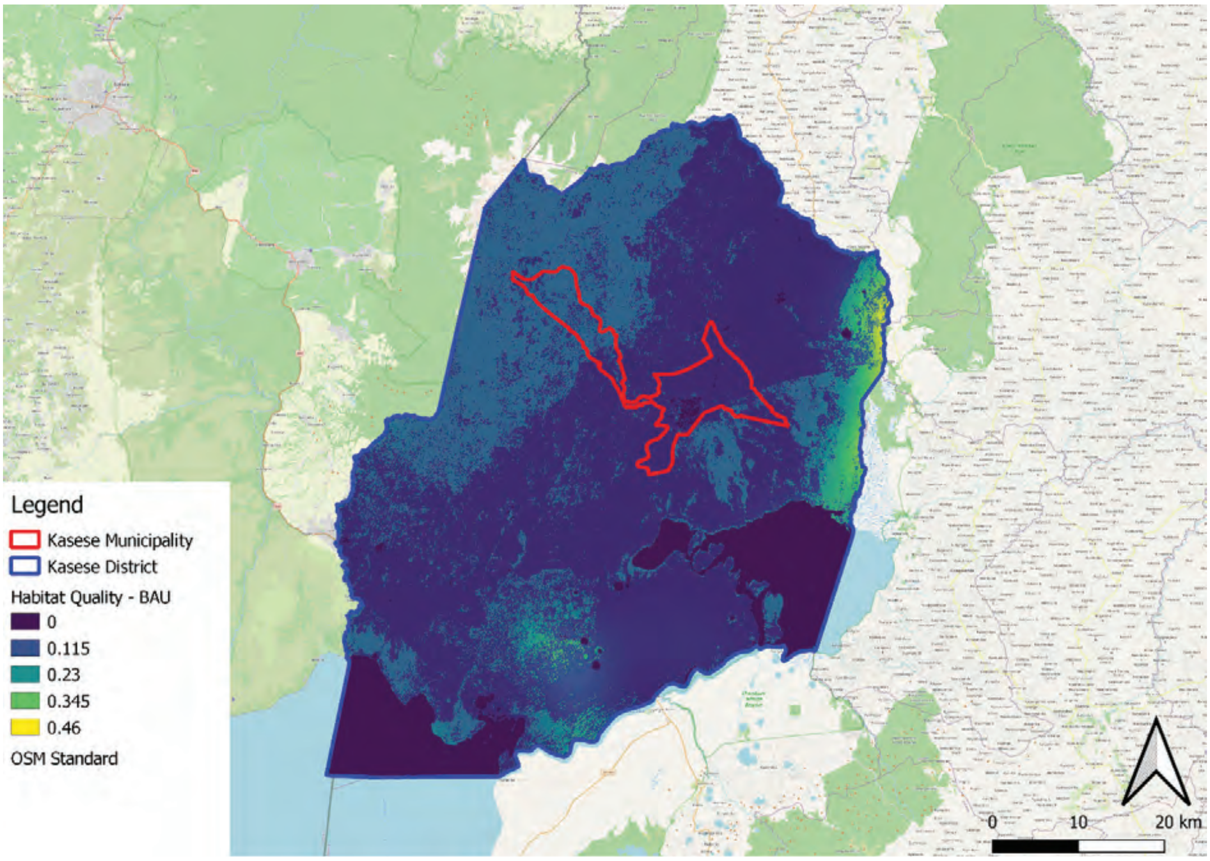
LULC scenario	Carbon storage (tons)	Total runoff retention (m^3)	Mean of habitat quality	Sediment export (tons)	Average temperature value (°C)
BAU	33,458,521	158,337,691	0.0877	33,054,106	32.7978
Restored	38,253,194 (Change 14.33%)	158,337,691 (Change 2.77%)	0.1034 (Change 17.88%)	25,888,327 (Change -21.68%)	32.5929 (Change -0.62%)

Source: Authors.

As can be seen in Table 4, the total sediment export (tons) is smaller in the restored scenario than in the BAU scenario, indicating a decrease of 21.68%. Moreover, Table 3 indicates that more water will be retained (12.88% increase in the municipality). These changes can be explained by the modification in land cover under the restored scenario. Sediment retention efficiency is the ability of vegetation to retain sediment flowing from upslope and is specific for every land class, with forest land having the highest efficiency (Terrado et al., 2014). Therefore, as forests replace cropland and shrubland, sediment export decreases and water retained increases as a consequence. These results of the spatial analysis indicate that the NBI can contribute to better water quality by avoiding erosion and nutrient pollution of water while also supporting water availability.

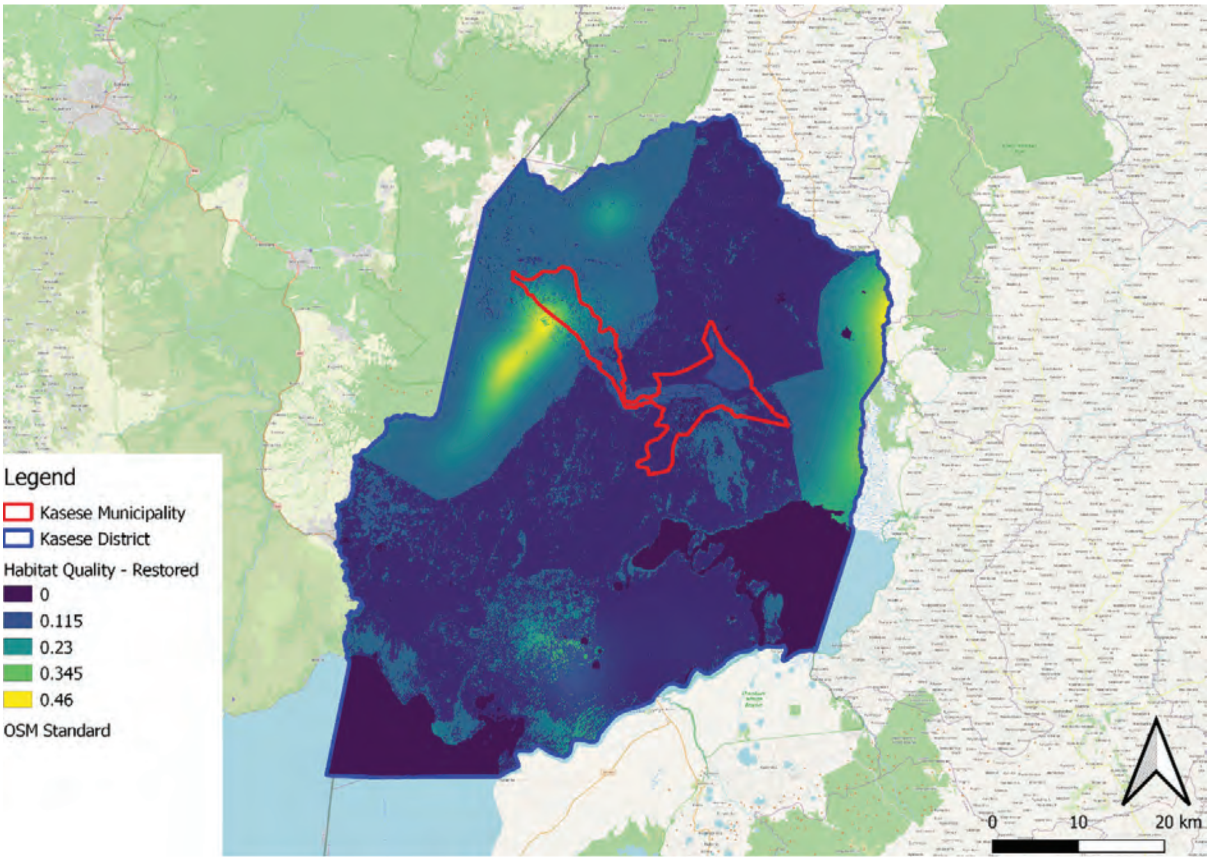
While detailed results are provided in Appendix A, we present below the spatial results of the habitat quality model: Figure 12 and Figure 13 show the relative level of habitat quality in the study areas considering the BAU and restored scenarios. Higher numbers indicate better habitat quality vis-à-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. The habitat scores values range from 0 to 1, where 1 indicates the highest habitat suitability. The results indicate that the mean of habitat quality is expected to increase in both the district and the municipality, since restored areas are expected to replace cropland, grassland, and other land cover classes. In the district, the mean of habitat quality is expected to increase by almost 18%, while in the municipality, it is expected to increase by more than 46%.

Figure 12. Habitat quality (BAU)



Source: Authors.

Figure 13. Habitat quality (restored)



Source: Authors.

2.5 Integrated Cost-Benefit Analysis

2.5.1 Methodology

The integrated CBA builds upon all elements of the SAVi methodology that were detailed previously: CLD and systems thinking, climate data analysis, and spatial analysis. For example, the CLD identified carbon sequestration as an important outcome of the NBI, the spatial analysis quantified how many additional tons of carbon will be stored, and the CBA assigns a monetary value to this carbon storage.

The CBA relies on the creation of an Excel-based model that integrates the results of these assessments. This user-friendly tool is designed to enhance accessibility and facilitate comprehensive assessments. Our Excel-based model considers not only the financial implications of NBI measures but also their broader ecological and socio-economic impacts. By including key indicators such as investment costs, ecosystem service valuation, additional revenues, and employment/income generation, the model provides a nuanced understanding of the overall effectiveness and sustainability of the proposed NBI strategies.

The model's initial structure benefits from the cumulative and collective knowledge that the NBI Centre has built over the years. We tailored the model to the project and partner's requirements in an iterative working pattern that mixes data collection, equation formulation, and results validation. Following the last iteration, we decided to use the following key indicators:

1. **Construction and maintenance costs:** The model incorporates a detailed assessment of the construction and maintenance costs associated with the various NBI interventions considered. This includes expenses related to forest plantation and restoration, and operation management.
2. **Value of ecosystem services:** An integral component of the model involves a robust evaluation of the value of ecosystem services (expressed in monetary terms). This encompasses a thorough analysis of avoided cost of damages to infrastructure, avoided loss of life, avoided health costs, avoided loss in agriculture revenue, as well as the quantification of carbon storage within the ecosystem.
3. **Additional revenues:** Recognizing the economic significance of sustainable land-use practices, the model incorporates an analysis of the additional revenues generated through the adoption of agroforestry and timber plantation. In addition, the model assesses the regeneration of soil quality, recognizing its pivotal role in sustaining local farming activities within communities.
4. **Employment and income generation:** To capture the socio-economic benefits of the NBI project, the model accounts for employment opportunities generated through the implementation of interventions. Furthermore, it assesses the additional income generation stemming from the needed operation and management activities.
5. **Public tax revenue:** As the NBI project generates new streams of economic activities, it also generates new sources of tax revenue, deepening the socio-economic benefits of the project as public authorities gain new financial means for regional development.

2.5.2 Data and Assumptions

Two types of data were used to build the model: quantitative and qualitative. The quantitative data serve as a core input to the model and can take the form of parameter values or time series collected through literature reviews, partner exchanges, and reliable online databases. The qualitative data is used to define the key indicators of interest and the equations that govern their development over time. Table 5 outlines the assumptions and data sources for each key indicator, offering transparency in our approach to the integrated CBA.

While our data compilation aims for accuracy, it's crucial to acknowledge inherent limitations. Quantitative data, reliant on literature and online databases, may carry a margin of error due to the localized context, impacting the precision of our model. This is particularly relevant for parameters with limited available data, where assumptions had to bridge gaps, such as unit damage of buildings, CO_2 price, average value of crop per ton, and average fruit plantation yield. The unit damage of buildings, a crucial factor in assessing avoided costs, relies on estimations derived from available literature and expert opinions. The dynamic nature of CO_2 pricing introduces an element of uncertainty, as market conditions and policy changes can significantly influence this key parameter. Similarly, assumptions about the average value of crops per ton and average fruit plantation yield are essential for projecting agricultural revenue, yet variations in climate conditions and agricultural practices may impact the accuracy of these estimates. Acknowledging these specific limitations is vital for a nuanced understanding of our model's results. Despite these challenges, our commitment to transparency and precision allows us to navigate these assumptions.

An inherent challenge in our spatial analysis stems from two key limitations, each bearing implications on the robustness of our findings. Firstly, the utilization of more recent land cover data would undoubtedly enhance the precision of our assessment. While we incorporated data from 2016, the dynamic nature of land cover necessitates frequent updates to accurately capture evolving environmental conditions. The reliance on historical data may introduce a degree of uncertainty, particularly in regions experiencing rapid land-use changes. Secondly, the exact geospatial locations of individual NBI activities would significantly augment the precision of our analysis. The effectiveness of nature-based interventions is intricately tied to their specific geographical context. Unfortunately, due to data constraints, we were compelled to employ an assumption-based approach, potentially leading to variations in the projected outcomes at finer spatial scales. Recognizing these limitations is crucial for a nuanced interpretation of our spatial analysis, and we recommend that future iterations incorporate the latest land cover data and precise geospatial information for a more granular and accurate assessment.

Table 5. Description of assumptions made and data used for the computation of results

Indicator	Computation description	Input name	Input value	Input unit	Input source
Construction costs	Construction costs captures the cost for the implementation of all interventions envisaged. The total cost by scenario is calculated based on the total ambition implemented and the average construction cost per hectare for the respective land-use systems. The cost assumptions come from the Bring Back Our Trees study (Mugume, 2022).	Total construction cost	14,340,989	USD	(Mugume, 2022)
		Construction time	10	Years	(Mugume, 2022)
Operations and maintenance (O&M) costs	The maintenance cost of the NBI systems is estimated based on the average maintenance cost per hectare and the total area that is implemented. The cost assumptions come from the Bring Back Our Trees study (Mugume, 2022).	O&M costs	45,104	USD/year	(Mugume, 2022)
		Time horizon	27	Years	(Mugume, 2022)
Avoided cost of damages to infrastructures	The cost of avoided flood and landslide infrastructure damages is calculated based on buildings and roads in the area, a flood damage multiplier per square metre of building and kilometre of road, along with the InVEST results for runoff retention. Information from flood damages was estimated based on a literature review. Note that the benefits of water retention increase as trees mature; therefore, average tree growth is also considered.	Number of floods	2 in 2022 3 in 2050	Flood/year	(Centre for Research on the Epidemiology of Disasters [CRED] & Université catholique de Louvain [UCLouvain], 2023)
		Building area at risk of flooding	130,000	m^2/Flood	(OpenStreetMap Foundation, 2023)

Indicator	Computation description	Input name	Input value	Input unit	Input source
Avoided cost of damages to infrastructures (continued)		Unit damage of buildings	5	USD/m^2	Assumption
		Roads at risk of flooding	100	km/year	(OpenStreetMap Foundation, 2023)
		Unit value of roads	25,000	USD/km	Partners
		Reduction in runoff from NBI project	13	%	Spatial analysis
		Average tree growth	17	Years	*Assumption*
Avoided loss of life	The cost of avoided loss of life is calculated based on the average number of deaths per flood, the statistical value of life multiplier, along with the InVEST results for runoff retention. Note that the benefits of water retention increase as trees mature; therefore, average tree growth is also considered.	Number of floods	2 in 2022 3 in 2050	Flood/year	(CRED & UCLouvain, 2023)
		Average number of deaths per flood	2.25	Death/ flood	(United Nations Disaster Risk Reduction, 2023)
		Value of statistical life	500,000	USD/death	(Markandya et al., 2015)
		Reduction in runoff from NBI project	13	%	Spatial Analysis
		Average tree growth	17	Years	*Assumption*

Indicator	Computation description	Input name	Input value	Input unit	Input source
Avoided health cost	The avoided health cost is calculated based on the average number of people needing health treatment per flood, the average health cost per person, along with the InVEST results for runoff retention. Note that the benefits of water retention increase as trees mature; therefore, average tree growth is also considered.	Number of floods	2 in 2022 3 in 2050	km/year	(CRED & UCLouvain, 2023)
		Average number of people needing health treatment per flood	25	People/ flood	(United Nations Disaster Risk Reduction, 2023)
		Average health cost per person	40 000	USD/ people	(Markandya et al., 2015)
		Reduction in runoff from NBI project	13	%	Spatial analysis
		Average tree growth	17	Years	*Assumption*
Carbon sequestration	The value of carbon storage is based on the additional amount of carbon sequestered in the landscape and an average value per ton of CO_2. Carbon sequestration is based on InVEST C stock results, while the average value per ton of CO_2e is assumed at around USD 5 per ton (Ecosystem Marketplace, 2021). Note that the benefits in carbon sequestration increases as trees mature, therefore the average tree growth is also considered.	Total CO_2 sequestrated	5,564,108	tCO_2	Spatial analysis
		CO_2 price	5	USD/tCO_2	*Assumption*
		Average tree growth	17	Years	*Assumption*

Indicator	Computation description	Input name	Input value	Input unit	Input source
Avoided loss in agriculture revenue	The avoided loss in agriculture revenue is calculated based on the potential revenue from the land and the avoided damage to the land achieved through tree planting water retention. The potential agricultural revenue is calculated based on the area impacted by floods, the average yield per hectare and the value of production. Finally, the reduction in runoff retention is computed through the InVEST model. Note that the benefits of water retention increase as trees mature; therefore, average tree growth is also considered.	Number of floods	2 in 2022 3 in 2050	Flood/year	(CRED & UCLouvain, 2023)
		Cropland area affected by flood	30	Ha	Assumption
		Average yield per hectare	3.8	Ton/ha/year	(Food and Agriculture Organization of the United Nations [FAO], 2023)
		Average value of crop per ton	100	USD/ton	*Assumption*
		Reduction in runoff from NBI project	13	%	Spatial Analysis
		Average tree growth	17	Years	*Assumption*
Agroforestry revenue	The agroforestry revenue is calculated based on the fruit and timber production that results from it. The disaggregated area of activity comes from the Bring Back Our Trees study (Mugume, 2022), which is then multiplied by the average yield and value of each product. Note that the benefits of production increase as trees mature; therefore, average tree growth is also considered.	Agroforestry area	3,000	Ha	(Mugume, 2022)
		Share of fruit plantation	70	%	(Mugume, 2022)
		Average fruit plantation yield	7	Ton/ha/year	*Assumption*
		Average timber plantation yield	7	m^3/ha/year	(FAO, 2023)
		Value of fruit production	30	USD/ton	Partners
		Value of timber production	55	USD/m^3	Partners
		Average tree growth	17	Years	*Assumption*

Indicator	Computation description	Input name	Input value	Input unit	Input source
Timber plantation revenue	The timber plantation revenue is calculated based on the total area of activity used in the Bring Back Our Trees study (Mugume, 2022), which is then multiplied by the average yield and value of timber products. Note that the benefits of production increase as trees mature; therefore, average tree growth is also considered.	Timber plantation area	1,000	Ha	(Mugume, 2022)
		Average timber plantation yield	7	m^3/ha/year	(FAO, 2023)
		Value of timber production	55	USD/m^3	Partners
		Average tree growth	17	Years	*Assumption*
Additional crop production revenue	The additional crop production revenue represents the benefits from higher soil quality. To compute this benefit, only the cropland near forest restoration is considered. The decrease in nutrient export from the InVEST analysis is then used along with the average yield and value of production to compute the total benefit. Note that the benefits of production increase as trees mature; therefore, average tree growth is also considered.	Average yield per hectare	3.8	Ton/ha/year	(FAO, 2023)
		Agriculture area benefiting from NBI	220	Ha	Spatial Analysis
		Percentage increase in yield from NBI	21.68	%	Spatial Analysis
		Average value of crop per ton	100	USD/ton	*Assumption*
		Average tree growth	17	Years	*Assumption*

Indicator	Computation description	Input name	Input value	Input unit	Input source
Total benefit of income creation	The benefits from income creation encompass the employment creation to implement and maintain the NBI project. To compute this benefit, both construction and operations activities are considered. Their respective time horizons are then used along with the percentage of income considered as a pure social benefit (consumption for leisure, sports, etc.).	Construction labour costs	4,772,062	USD	(Mugume, 2022)
		Construction time	10	Years	(Mugume, 2022)
		O&M costs	45,104	USD/year	(Mugume, 2022)
		Time horizon	27	Years	(Mugume, 2022)
		Percentage of income considered as benefit	30	%	(Numbeo, 2023)
Additional public tax revenue	The additional public tax revenue represents a new revenue stream for public authorities. It's computed based on all new production activities and a certain tax rate.	VAT rate	18	%	(Uganda Revenue Authority, 2022)

Source: Authors.

2.5.3 Results of the Integrated Cost-Benefit Analysis

The integrated CBA is shown in Table 6, indicating the following key results:

- The NBI project is economically viable, generating net benefits of USD 69.1 million by 2050. For each dollar invested, the forest-related interventions generate 5.44 dollars in economic, social, and environmental benefits (when using discounted values, the results are 4.08 dollars at 3.5% discounting and 2.68 dollars at 10% discounting).
- The largest benefits are carbon sequestration (USD 27.8 million), avoided damages to roads and buildings (USD 15.2 million), and additional agroforestry revenue (USD 14.6 million).
    - The avoided infrastructure damages (undiscounted) alone nearly make up for the construction and maintenance costs (USD 15.6 million), underlining the economic viability and climate adaptation benefits.
    - Carbon storage benefits are much larger than the construction and maintenance costs. Even if it is only possible to use a small portion of the 5.6 million tons of carbon dioxide that the project could store for carbon offsets, this would be enough to fund the long-term operation of the project.
- Establishing the woodlots and agroforestry systems can greatly improve people's health, food security, and livelihoods. On the one hand, the NBI can avoid flood-related health costs and fatalities of around USD 12.2 million. On the other hand, smallholder farmers stand to gain USD 14.6 million in agroforestry revenue, USD 7.2 million from timber production, USD 1.9 million from improved crop production, and USD 1.7 million from income for constructing the project.
- The results strongly depend on the discount rate chosen for the analysis. However, even with a high discount rate of 10%, the NBI project in Kasese remains economically viable, with net benefits of USD 14.3 million and a BCR of 2.68.

Table 6. Integrated CBA for landscape restoration (values in USD million)

Integrated CBA 2024–2050	Undiscounted	Discounted (3.5%)	Discounted (10%)
Project costs			
Construction costs	14.3	11.6	8.2
O&M costs	1.2	0.8	0.4
Total costs	**15.6**	**12.4**	**8.6**
Avoided cost/loss			
Avoided cost of damages to infrastructures	15.2	8.9	4.1
Avoided loss of life	7.1	3.8	1.4

Integrated CBA 2024–2050	Undiscounted	Discounted (3.5%)	Discounted (10%)
Avoided health cost	5.1	2.7	1.0
Avoided loss in agriculture revenue	0.2	0.1	0.0
Total avoided cost/loss	**27.5**	**15.5**	**6.6**
Added benefits			
Carbon sequestration	27.8	18.1	8.9
Agroforestry revenue	14.6	8.0	3.1
Timber plantation revenue	7.2	3.9	1.5
Additional crop production revenue	1.9	1.0	0.4
Total benefit of income creation	1.7	1.3	0.9
Additional public tax revenue	4.0	2.8	1.7
Total added benefits	**57.1**	**35.1**	**16.4**
Total benefits (avoided costs/loss + added benefits)	**84.6**	**50.5**	**23.0**
Net benefit			
Total benefits	**84.6**	**50.5**	**23.0**
Total costs	**15.6**	**12.4**	**8.6**
Net benefit	**69.1**	**38.2**	**14.4**
BCR	**5.44**	**4.08**	**2.68**

Source: Authors.

Following the Bring Back Our Trees study (Mugume, 2022), an initial investment of USD 14.3 million will be made over 10 years for project implementation. This financial commitment paves the way for the creation of NBI that provides long-term benefits for the region. In addition, USD 1.2 million in O&M costs are required to care for the woodlots and agroforestry systems until 2050.

These investments can provide economic, social, and environmental benefits for the people in Kasese. By 2050, the NBI yields benefits of USD 84.6 million, which far outweigh the costs. For each dollar invested, the forest-related interventions generate USD 5.44 in benefits by protecting local communities from floods and improving their livelihoods.

A 33% share of these benefits comes from averting potential flood damages. Stabilizing hillslopes and riverbanks with the new vegetation can save about USD 15.2 million related to avoided road and building costs. Moreover, the NBI helps protect people from the health impacts of floods, avoiding flood-related health costs and fatalities of around USD 12.2 million. The proactive approach of investing in NBI therefore not only saves resources but also contributes to the overall resilience of the community.

Creating the woodlots and agroforestry systems also contributes to mitigating climate change by storing about 5.6 million tons of carbon dioxide. By 2050, this carbon sequestration could yield USD 27.8 million through carbon offsets, making it the largest single benefit accrued from the NBI. More information about this financing option is provided below.

The CBA also highlights the vast benefits of the NBI for local livelihoods. Farmers in Kasese stand to gain USD 14.6 million in agroforestry revenue, USD 7.2 million from legal timber production, and 1.9 million from additional crop production. These revenue sources not only contribute to the project's economic viability but also promote a diversified and resilient local economy. By reducing erosion, the NBI also avoids agricultural losses of about USD 200,000.

In addition, creating and maintaining the project creates jobs and about USD 1.7 million in income, increasing prosperity in the community. The spending on construction and maintenance also boosts public tax revenue. Over the lifetime of the project, additional taxes of USD 4 million bolster community and regional fiscal health, indicating the broader positive economic impact of the project.

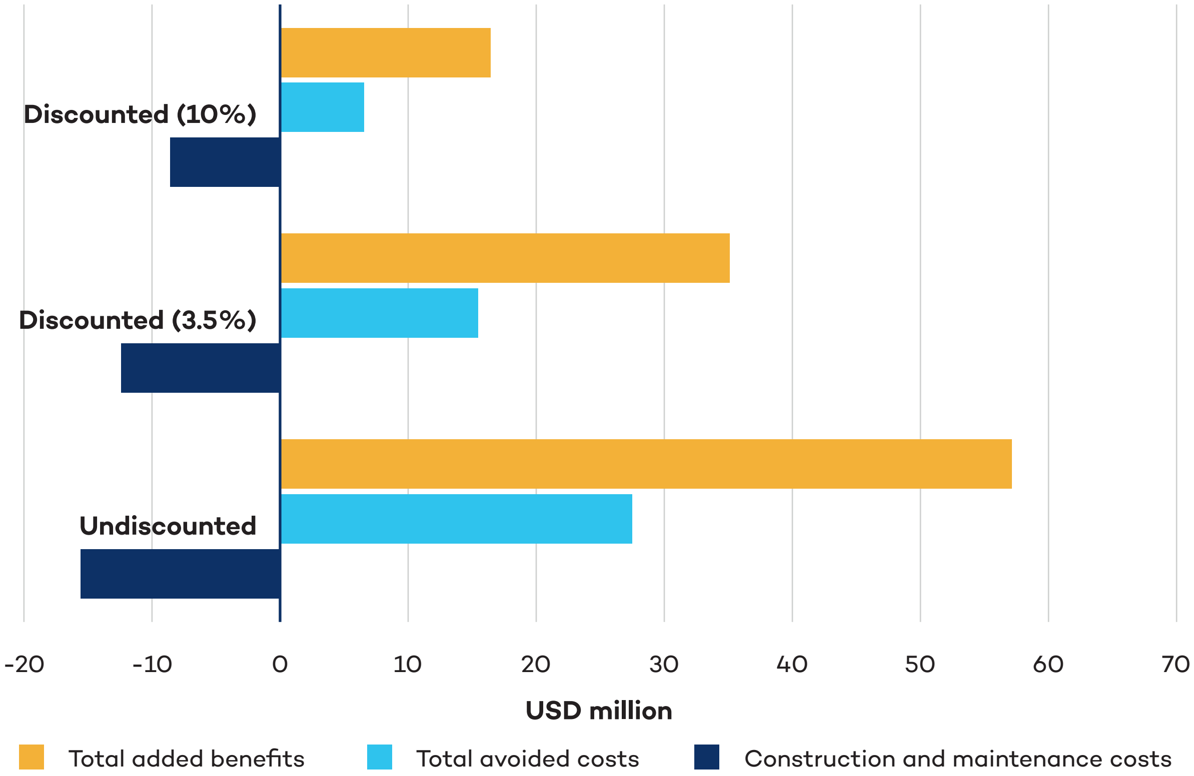
In sum, the CBA demonstrates the economic viability of the project but also emphasizes its far-reaching positive impacts, positioning it as a model for sustainable and impactful infrastructure development.

EFFECTS OF DISCOUNTING

Discounting is a crucial component of cost-benefit analyses for infrastructure projects, primarily driven by the time value of money. This concept acknowledges that a monetary amount today is inherently more valuable than the same amount in the future due to the potential for investment and earning returns over time (e.g., as a result of inflation). By discounting future costs and benefits to their present value, cost-benefit analyses ensure comparability and consistency, enabling decision-makers to assess the efficiency of various projects on a standardized basis. As shown in Table 6, we compiled the CBA for three scenarios: no discount rate, a low discount rate of 3.5% and a high discount rate of 10%.

In dissecting the distinct scenarios for our NBI project, the undiscounted scenario vividly portrays immediate and substantial benefits, with total benefits reaching USD 84.6 million, net benefits at USD 69.1 million, and a robust BCR of 5.44. This scenario serves as a testament to the project's potential for rapid positive impact. However, as we introduce discounting at 3.5% and 10% growth rates, a nuanced narrative unfolds. Using a 3.5% discount rate, the NBI delivers net benefits of USD 38.2 million and a BCR of 4.08, while the values decrease to net benefits of USD 14.4 million and a BCR of 2.68 when we apply a 10% discount rate (see Figure 14). This means that the project remains economically viable even with a high discount rate as long as we include its wider societal benefits in the analysis.

Figure 14. Undiscounted, discounted at 3.5%, and discounted at 10% bar plot comparison

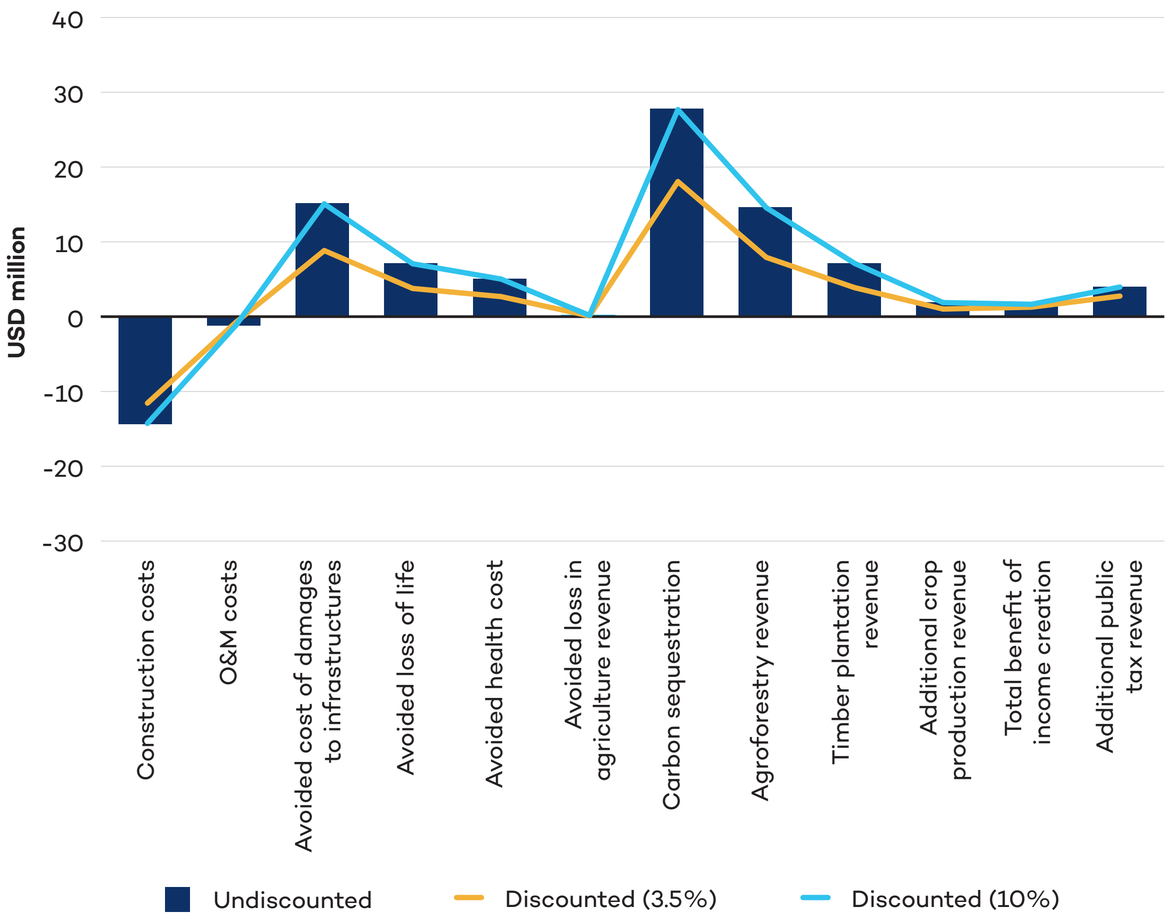


Source: Authors.

For policy-makers, this analysis prompts a strategic consideration of timing and financial prudence. While the undiscounted scenario showcases the project's potential for immediate positive outcomes, discounting introduces a reality check, emphasizing the inherent trade-off between immediate gains and future considerations. The decline in total benefits, net benefits, and BCR under discounting highlights the fiscal impact of delayed returns. Policy-makers should weigh this against the urgency of the project's goals and the imperative to balance near-term economic benefits with the financial realities of the long term.

DIVERSITY OF BENEFITS

Figure 15. Cost and benefits bar plot



Source: Authors.

The values for each indicator in Figure 15. present a rich and diverse array of outcomes for the NBI project. Examining the distribution of costs and benefits provides valuable insights into the multifaceted impacts of the project. Construction costs represent 92.2% of the total costs, signifying that most of the implementation cost is initial investment. In comparison, O&M accounts for around 7.8% of the total costs, reflecting the ongoing financial commitment essential for sustaining the project's effectiveness.

A significant portion of the benefits is attributed to avoided costs and losses, representing about 32.5% of the total benefits. This includes avoided damages to infrastructure, prevented loss of life, and reduced health costs. Notably, carbon sequestration emerges as a substantial benefit, representing 32.9% of the total benefits, highlighting the project's environmental significance. Revenue-generating activities, such as agroforestry, timber plantation, and additional crop production, contribute a combined total of USD 23.7 million, showcasing the potential for economic development and constituting around 28% of the total benefits. Additional public tax revenue and income creation collectively contribute USD 5.7 million, emphasizing the broader societal and economic impacts and accounting for approximately 6.7% of the total benefits. Overall, the diversified distribution of these numbers underscores the holistic approach of the NBI project, encompassing economic, environmental, and social dimensions.

VALUE OF CARBON SEQUESTRATION

When exploring future financial options for the project, it is worth considering the monetization of carbon sequestration as an initial step toward generating carbon credits. Pricing carbon sequestration is one of multiple factors that contribute to determine the issuing of carbon credits for the project. The revenue-generating potential of carbon sequestration can be considered an important factor for securing the long-term financial sustainability of this NBI project and aligns with the growing interest in using carbon credits as a financing solution to expand the implementation of NBI (Reber, 2022).

Nevertheless, acknowledging the uncertainties and challenges linked to carbon credit markets, particularly in terms of standardization, transparency, and integrity, it is wise to delve into alternative scenarios. To this end, we examined the net benefits and BCR without including the value of carbon sequestration in the CBA (see Table 7). In the absence of carbon sequestration revenue, the recalculated net benefits amount to USD 41.3 million, and the adjusted BCR stands at 3.65. This analysis offers insights into the project's viability without relying only on carbon-related income, thereby providing a more diversified perspective for strategic decision making.

Table 7. CBA comparison with and without carbon credits

		CBA with carbon sequestration			**CBA without carbon sequestration**		
		Undiscounted	**Discounted (3.5%)**	**Discounted (10%)**	**Undiscounted**	**Discounted (3.5%)**	**Discounted (10%)**
Total benefits	USD million	84.6	50.5	23.0	56.8	32.4	14.1
Total costs	USD million	15.6	12.4	8.6	15.6	12.4	8.6
Net benefit	**USD million**	**69.1**	**38.2**	**14.4**	**41.3**	**20.0**	**5.5**
BCR	**Ratio**	**5.44**	**4.08**	**2.68**	**3.65**	**2.62**	**1.64**

Source: Authors.

The strategy of internalizing benefits and avoided costs as additional revenue restream is commonly employed in financing mechanisms such as outcome-based financing. In such frameworks, these benefits and costs are converted into revenue streams to fund projects and yield returns for investors (Brand, 2021). The method of generating revenue from these benefits and avoided costs depends on the specific project context, for example, avoided costs to infrastructure and avoided loss in agriculture revenue can be considered as outcomes of the project implementation for which direct beneficiaries, such as farmers, are willing to contribute.

Another example of financing is tax increment, which is a financing mechanism that leverages increased tax revenue resulting from the project. In this case, governments can anticipate a growth in tax revenue linked to the value created by the project. For instance, through the execution of a substantial project, the local administration may foresee an uptick in tax revenue facilitated by an increase in property values in the surrounding area.

CLIMATE SENSITIVITY ANALYSIS

Because future climate projections entail some uncertainty, we conducted a sensitivity analysis of the results with varying assumptions of flood frequency, as illustrated in Table 8. If floods double or triple from the baseline of two floods per year, the project's benefits increase significantly. With four floods per year, benefits rise by 5.8%, and with six floods per year, benefits increase substantially by 15.6%. In contrast, if floods remain at the same frequency as in 2022 (two per year), the project's benefits decrease slightly—6.7% less for total benefits and BCR, and 8.3% less for net benefits compared to our earlier scenario, with three floods per year in 2050.

The sensitivity analysis indicates that even in the unlikely case that floods do not become more frequent, the NBI delivers large benefits to local communities and is economically viable. Under stronger climate change assumptions with more frequent floods, the woodlots and agroforestry generate higher benefits by avoiding larger infrastructure damages and health impacts. However, the analysis does not ascertain the NBI's capability to endure more frequent floods. To ensure that the NBI delivers long-term benefits, it may be important to swiftly repair potential damages from floods and landslides that may wash away immature trees.

Table 8. CBA results with changes in flood frequency (undiscounted values)

	Unit	**Two floods in 2050**	**Three floods in 2050**	**Four floods in 2050**	**Six floods in 2050**
Total benefits	USD million	79.3	84.6	89.8	100.3
Total costs	USD million	15.6	15.6	15.6	15.6
Net benefit	**USD million**	**63.8**	**69.1**	**74.2**	**84.7**
BCR	**Ratio**	**5.10**	**5.44**	**5.77**	**6.44**

Source: Authors.

3.0 Conclusions

Our analysis is the result of a synergistic and inclusive method, mixing knowledge from international expertise and local insight with a systemic and model-based approach. It builds upon the collective work done by the municipality of Kasese and its international partners,[4] which resulted in the conceptualization of a nature-based solution for climate change adaptation in Kasese. Multiple other sources of information were used and validated with local stakeholders to develop a thorough and contextually pertinent assessment that reflects the collective insights and prospects of stakeholders.

The NBI project in Kasese emerges as a multifaceted solution, with the potential to significantly enhance climate adaptation efforts in the region. By strategically leveraging natural systems, the NBI promises to bolster water retention, reduce flood risks, and combat erosive forces that impact local agriculture. Beyond environmental contributions, the project provides economic opportunities, with an estimated USD 84.6 million in benefits for local communities. This includes revenue from legal timber logging, heightened agricultural productivity, and positive impacts on health and food security. The robust BCR of 5.44 (when using discounted values, the results are 4.08 at 3.5% discounting and 2.68 at 10% discounting). underscores the societal returns on investment. Moreover, the integration of various components, such as agroforestry and urban trees, is projected to yield an overall net benefit of USD 69 million over the next 27 years.

Establishing the agroforestry systems and woodlots emerges as a path for fighting illegal timber extraction and protecting forest cover. As shown in the spatial analysis, the NBI also improves the habitat quality in Kasese indicating the potential for protecting and restoring biodiversity and opportunities for ecotourism.

The results derived from the analysis of the NBI project offer a wealth of strategic insights for various stakeholders in Kasese:

- Local policy-makers can leverage the economic benefits highlighted in the analysis, emphasizing the potential for job creation, avoided health impacts, enhanced food security, and climate adaptation. The CBA indicates that the additional tax revenue from creating the project far outweighs the long-term maintenance costs, creating an opportunity for public funding of the NBI.
- The municipality and district of Kasese, as well as owners of flood-prone homes, can benefit from the avoided flood damage that reduces the costly need to rebuild roads and buildings.
- Farmers and landowners stand to gain from increased crop production and timber revenue, improving their livelihoods and food security.

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[4] *Agence Française de Développement (AFD)*, Expertise France, Covenant of Mayors in Sub-Saharan Africa, Global Fund for Cities Development (FMDV), and Espelia.

- For environmental agencies and organizations, the demonstrated carbon sequestration potential underscores the project's climate mitigation contributions. Furthermore, international bodies and funding agencies may find the compelling BCR of 5.44 a persuasive indicator of the project's societal returns on investment. Environmental organizations can also promote the NBI as a way to fight illegal timber extraction and protect forest cover by creating alternative sources of income and wood.

As a note of caution, enhancing Kasese's flood resilience requires a multifaceted approach beyond investing in NBI. Policy-makers and planners can implement early warning systems that enable communities to evacuate or take preventive measures. Strategic land-use planning that avoids vulnerable uses in flood-prone areas represents another component of reducing flood risks. To support a swift recovery from floods, policy-makers should aim to allocate funds for immediate damage repair and recovery from floods. Additionally, fostering community engagement and participation in resilience-building initiatives empowers local populations to take ownership of the NBI and actively contribute to their safety and recovery.

As Kasese contemplates the implementation of the NBI, a prudent next step involves a comprehensive technical feasibility study. This study, enriched by meaningful stakeholder participation, will identify precise implementation locations and ensure a holistic consideration of diverse perspectives. Gender aspects should be given due attention to ensure that women are included in the decision-making process and that the project outcomes contribute to gender equality.

We suggest that policy-makers use this information to assess the project's resilience and explore a mix of financial instruments that align with the local realities. The focus here is on encouraging a strategic reflection. Policy-makers are prompted to envision a comprehensive financial strategy that aligns with the diverse revenue streams identified in the CBA. This strategic reflection encompasses the entire spectrum of possibilities, including but not limited to carbon credits. Public–private partnerships, grants, subsidies, and community-driven financing models emerge as potential avenues that can complement the project's multifaceted benefits. Based on this analysis, policy-makers can tailor financial instruments to maximize positive outcomes, ensuring a robust and sustainable financial strategy that effectively covers construction and maintenance costs while optimizing community and environmental impacts. Considering additional financial instruments is essential to diversify potential sources of financing and identify additional revenue streams that can be generated through ecosystem services. By undertaking these strategic steps, Kasese has the opportunity to realize the full potential of the NBI, fostering resilience, sustainability, and positive impacts for both the community and the environment.

4.0 References

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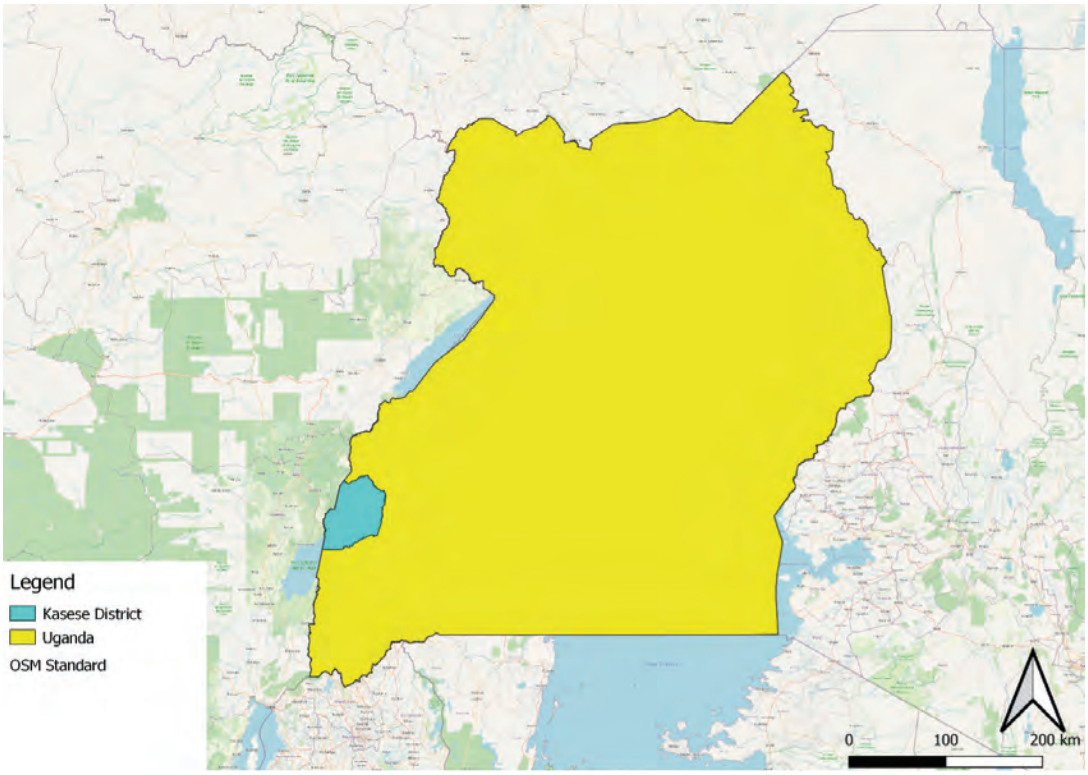
Appendix A. Spatial Analysis Report

Model Setup

Study Area

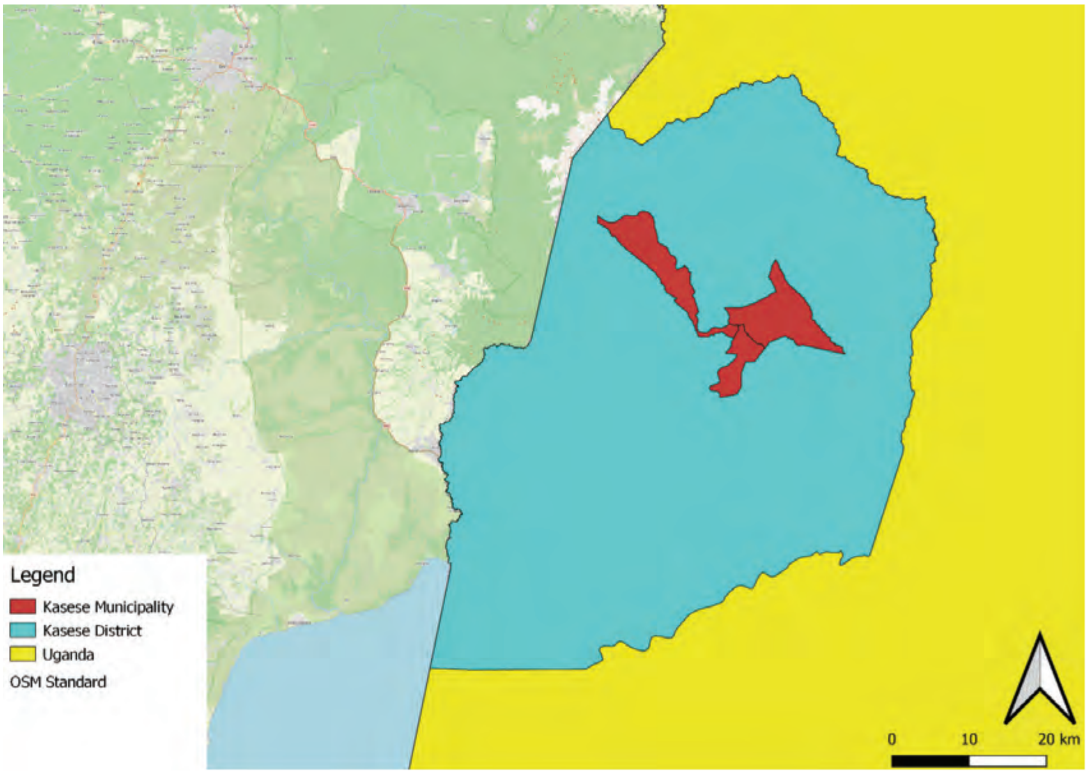
The regions considered in this NBI assessment are the Kasese District, shown in Figure A1, and the Kasese Municipality, found within the district, shown in Figure A2.

Figure A1. Kasese District



Source: Authors.

Figure A2. Kasese Municipality



Source: Authors.

Coordination System

Based on the world project coordinate system called “V WGS 84 / Pseudo-Mercator -- Spherical Mercator – ESPG: 3857”

Here is the detail of the coordinate system:

```
PROJCS["WGS 84 / Pseudo-Mercator",
   GEOGCS["WGS 84",
      DATUM["WGS_1984",
         SPHEROID["WGS 84",6378137,298.257223563,
            AUTHORITY["EPSG","7030"]],
         AUTHORITY["EPSG","6326"]],
      PRIMEM["Greenwich",0,
         AUTHORITY["EPSG","8901"]],
      UNIT["degree",0.0174532925199433,
         AUTHORITY["EPSG","9122"]],
      AUTHORITY["EPSG","4326"]],
   PROJECTION["Mercator_1SP"],
   PARAMETER["central_meridian",0],
   PARAMETER["scale_factor",1],
   PARAMETER["false_easting",0],
   PARAMETER["false_northing",0],
   UNIT["metre",1,
      AUTHORITY["EPSG","9001"]],
   AXIS["X",EAST],
   AXIS["Y",NORTH],
   EXTENSION["PROJ4","+proj=merc +a=6378137 +b=6378137 +lat_ts=0.0
+lon_0=0.0 +x_0=0.0 +y_0=0 +k=1.0 +units=m +nadgrids=@null +wktext  +no_
defs"],
   AUTHORITY["EPSG","3857"]]
```

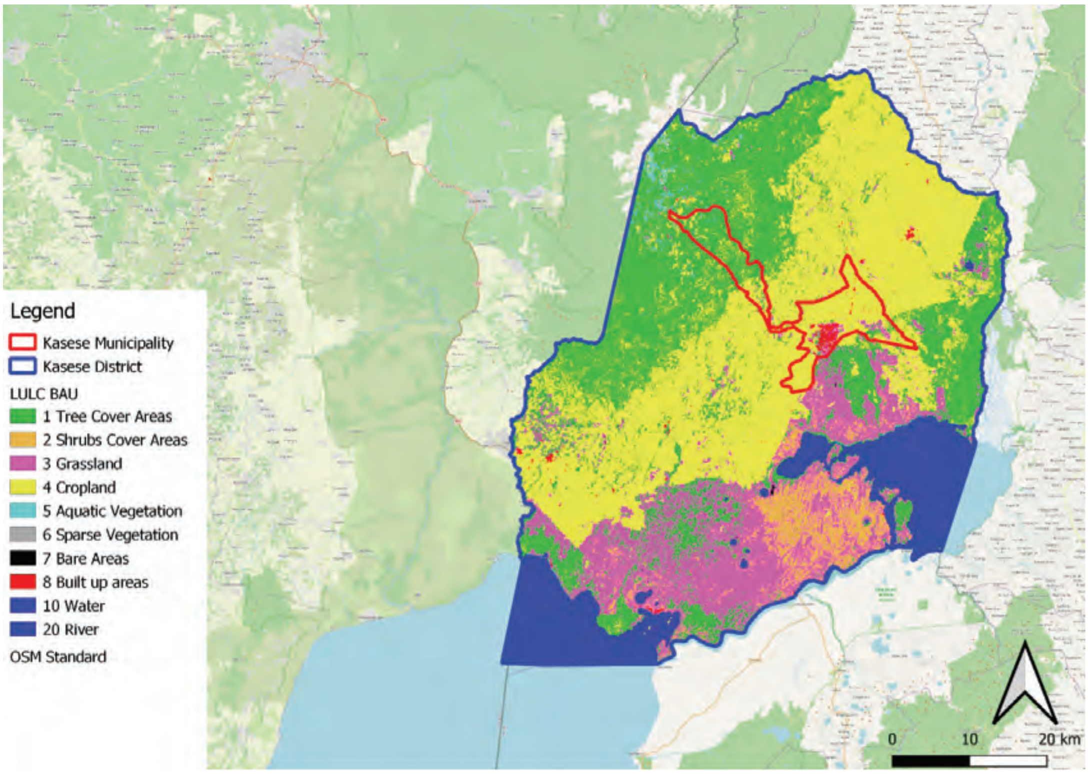
Current Land Cover Map

The LULC map created by the Climate Change Initiative Land Cover team was used for this analysis (http://2016africalandcover20m.esrin.esa.int/). This is a prototype high-resolution LULC map at 20 m over Africa based on 1 year of Sentinel-2A observations from December 2015 to December 2016.

The legend of this map includes 10 generic classes that appropriately describe the land surface at 20 m: "trees cover areas," "shrubs cover areas," "grassland," "cropland," "vegetation aquatic or regularly flooded," "lichen and mosses/sparse vegetation," "bare areas," "built-up areas," and "open water."

Figure A3 shows the current LULC (BAU), where we also added the Nyamwamba River.

Figure A3. LULC BAU



Source: European Space Agency, 2016.

Future Land Cover Map

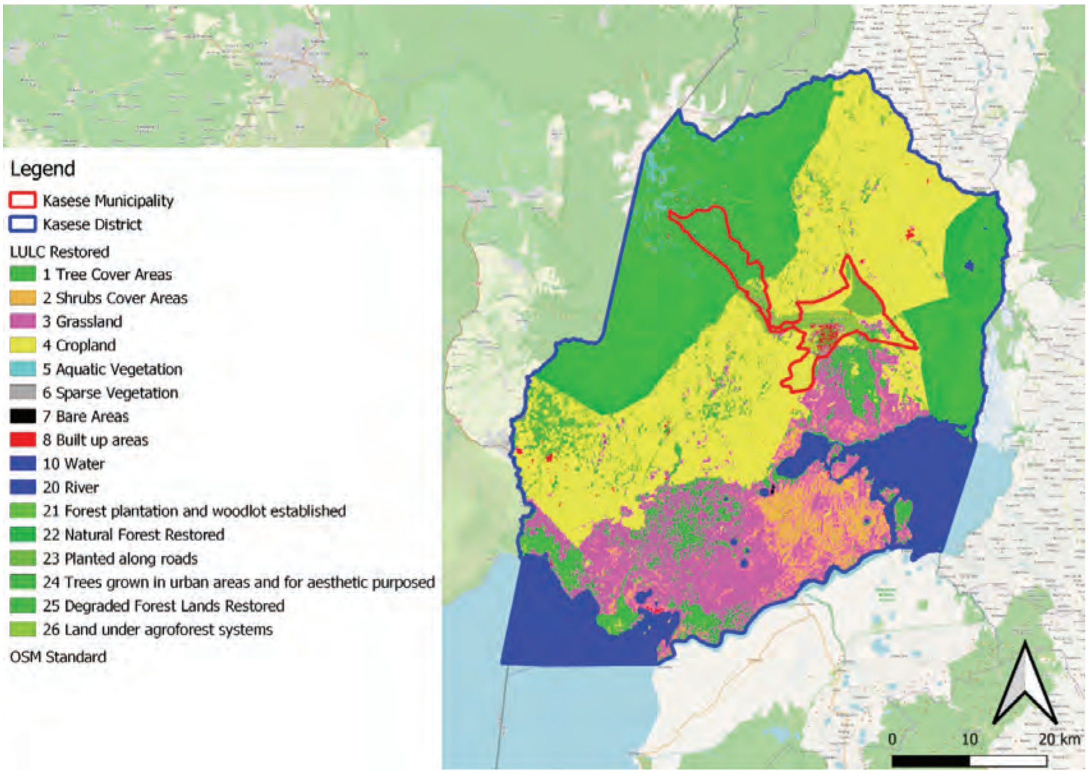
The restoration activities are shown in Table A1. Figure A4 shows the LULC under the restored scenario.

Table A1. Restoration activities by number of ha

Woodland	**Ha**
Natural forest restored	20,000
Forest plantation and woodlot established	1,000
Degraded forest lands restored	3,000
Agroforestry	**Ha**
Land under agroforest systems	3,000
Planted along roads	3,200
Trees grown and maintained in urban areas	20
Trees grown for aesthetic purposes	50

Source: Authors.

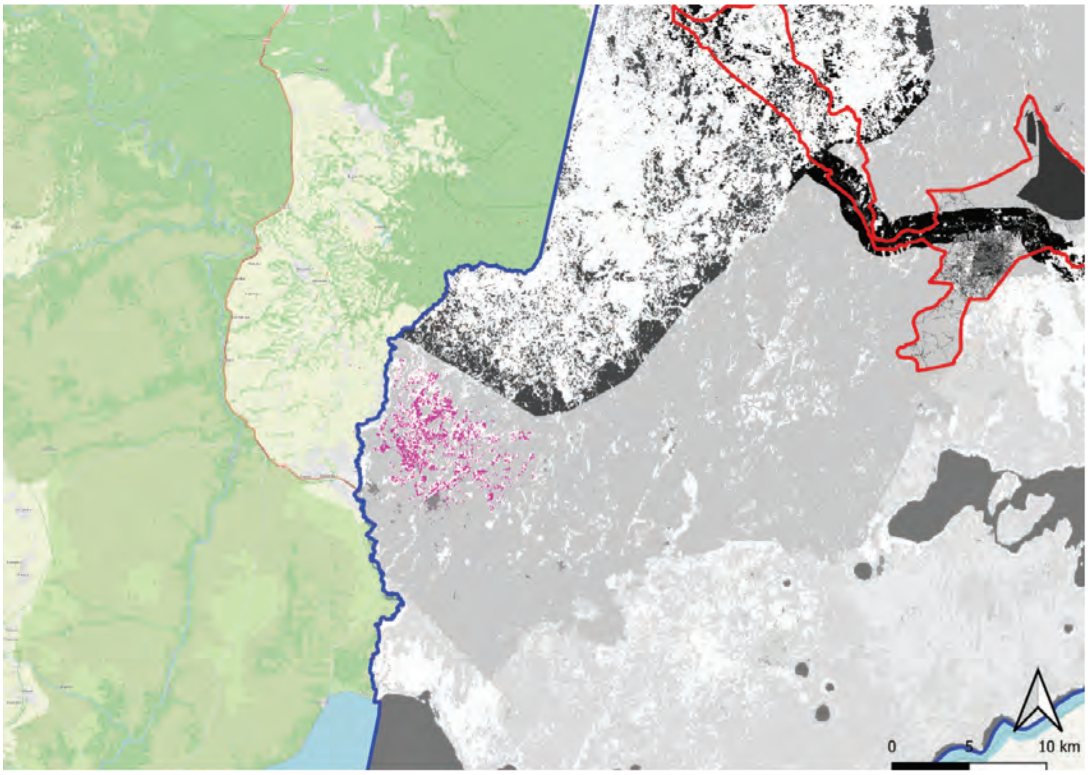
Figure A4. LULC restored



Source: Authors.

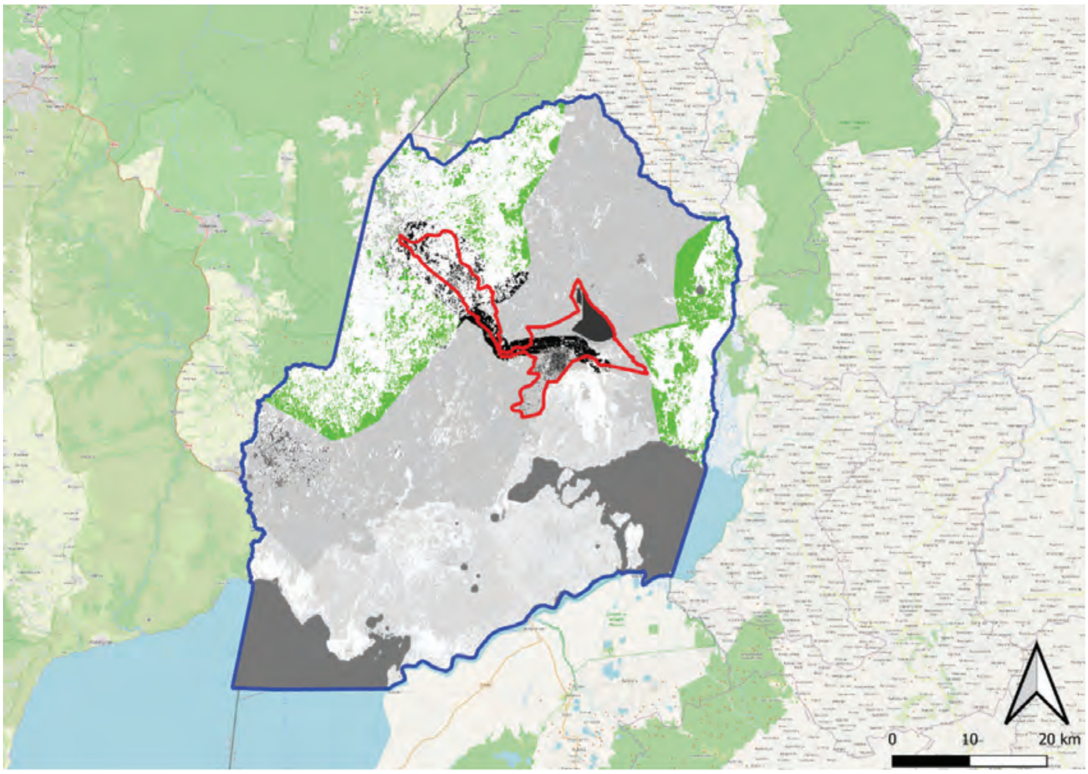
Next figures shows where the restored areas have been located. Figure A5 shows “forest plantation and woodlot established” (1,000ha). Figure A6 shows “natural forest restored” (20,000 ha). Figure A7 shows “planted along roads” (3,200 ha). Figure A8 shows “trees grown and maintained in urban areas” and “trees grown for aesthetic purposes” (70 ha). Figure A9 shows “degraded forest lands restored” (3,200 ha). Figure A10 shows “land under agroforest systems” (3,000 ha).

Figure A5. Forest plantation and woodlot established



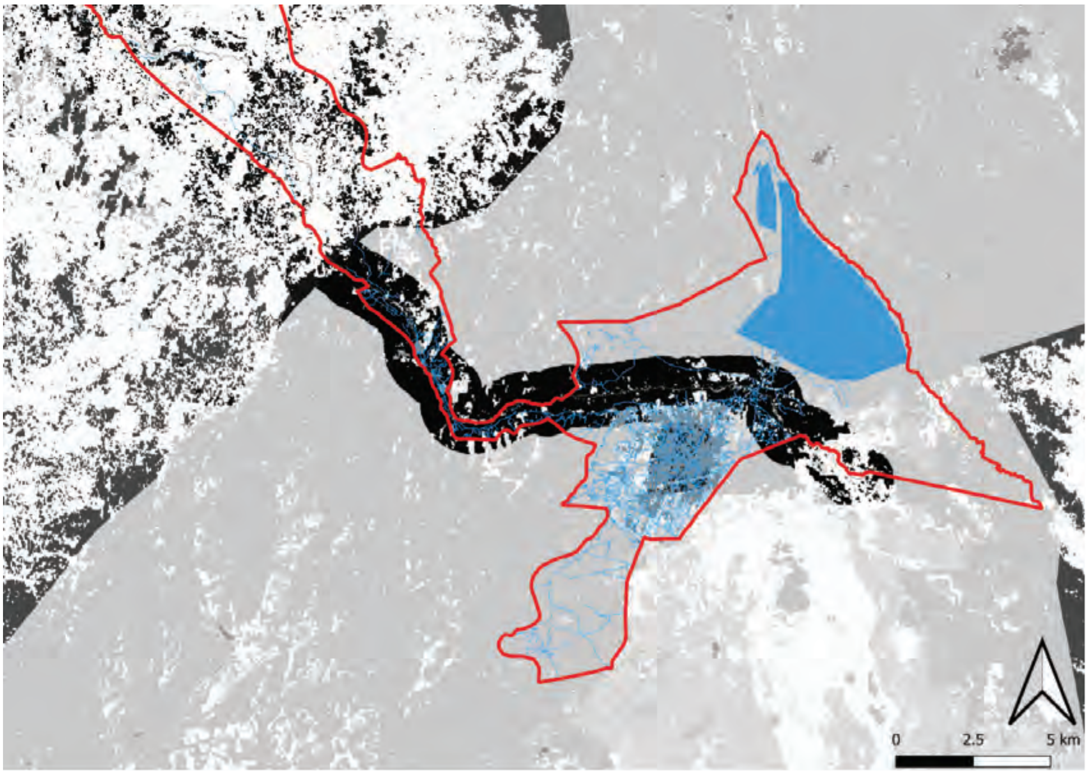
Source: Authors.

Figure A6. Natural forest restored



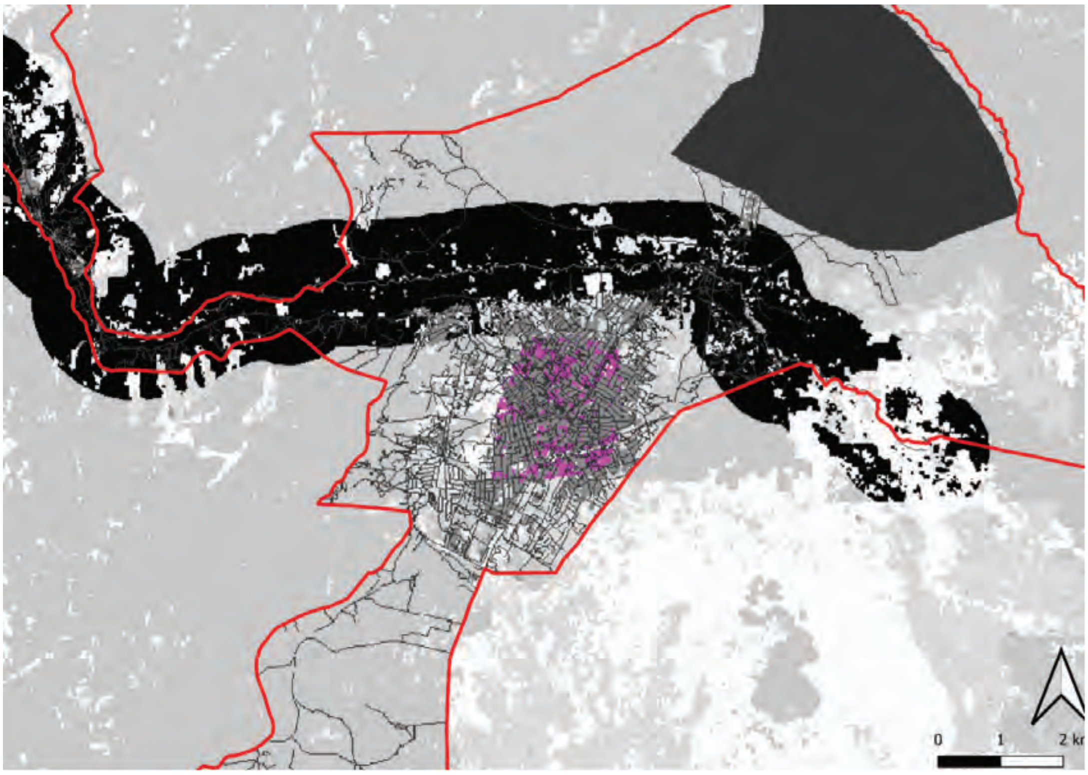
Source: Authors.

Figure A7. Planted along roads



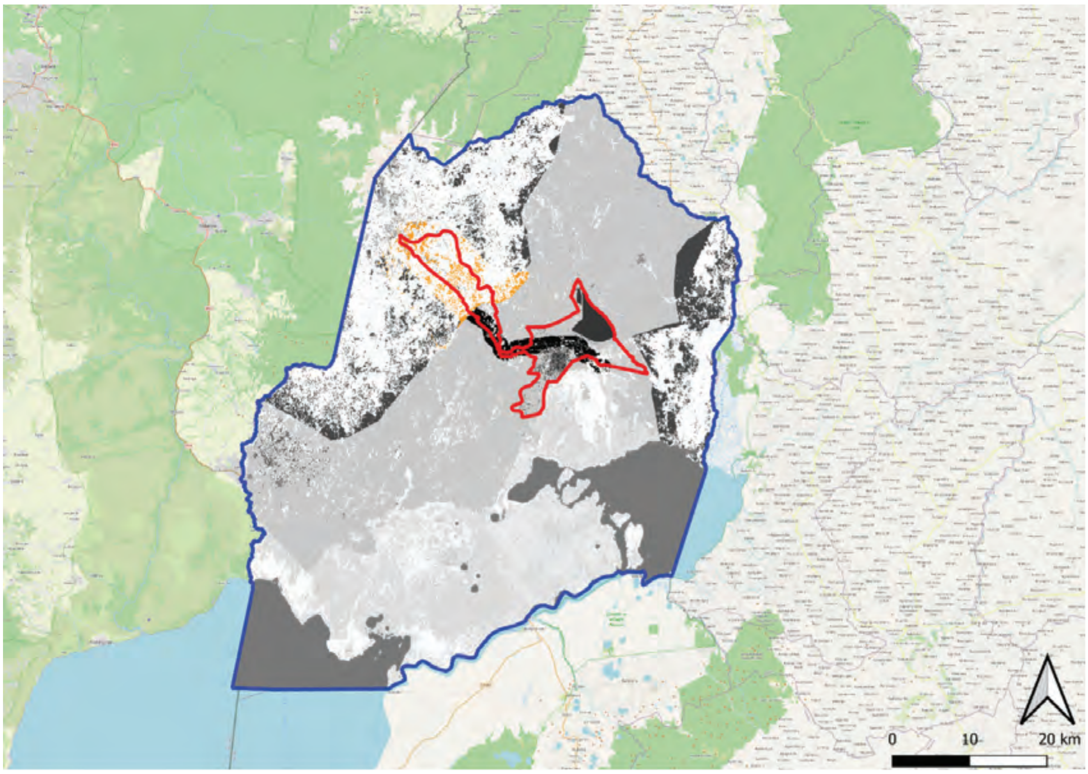
Source: Authors.

Figure A8. Trees grown and maintained in urban areas and trees grown for aesthetic purposes



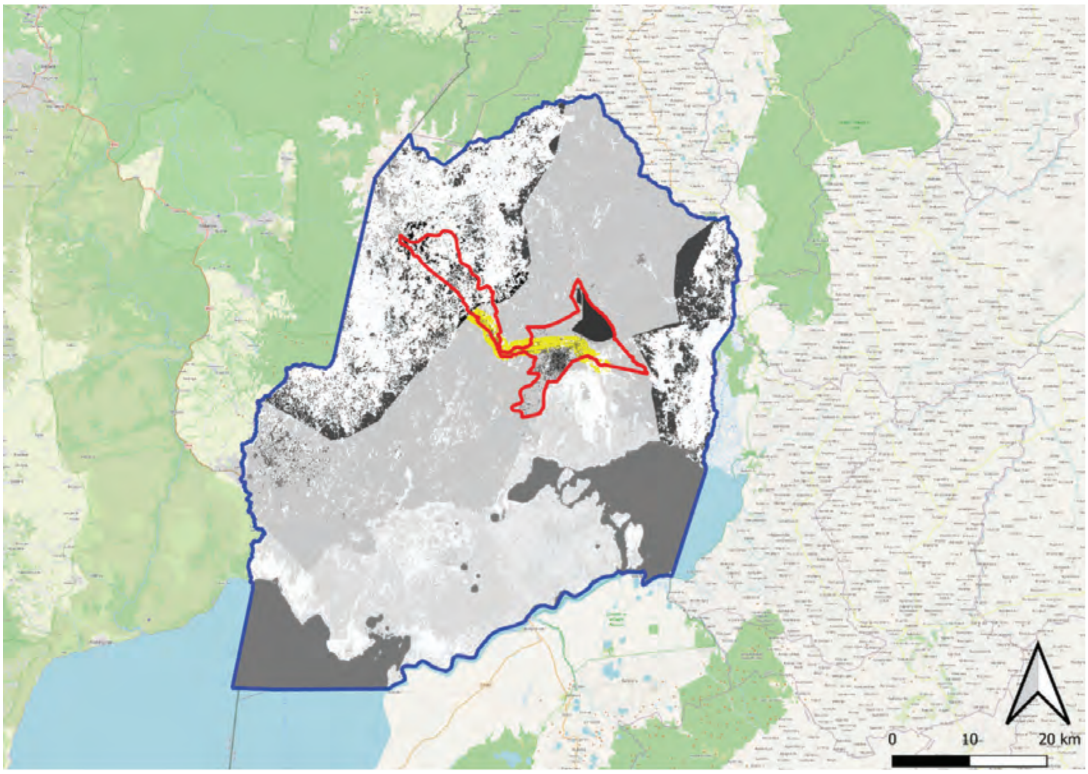
Source: Authors.

Figure A9. Degraded forest lands restored



Source: Authors.

Figure A10. Land under agroforest systems



Source: Authors.

Software and Simulation

The ecosystem services map simulation has been performed using InVEST Software V.3.9.0 (https://naturalcapitalproject.stanford.edu/invest/). The spatial data inputs for the InVEST model have been prepared utilizing QGIS-OSGeoW-3.4.2-1 (qgis.org/downloads/). The tabulated data will be managed and prepared in Microsoft Excel V. 2016.

Carbon Storage – Option 1

Input Data Preparation and Processing

1. **LULC map –** See Section 2.4.1.
2. **Carbon pools –** Table of LULC classes containing data on carbon stored in each of the four fundamental pools for each LULC class
    - carbon aboveground: The values of carbon density in aboveground mass (tons/ha) of each land-use type are shown in Table A2.
    - carbon belowground: The values of carbon density in belowground mass (tons/ha) of each land-use type are shown in Table A2.
    - carbon stored in organic matter: The values of carbon density in dead mass (tons/ha) of each land-use type are shown in Table A2.
    - carbon stored in soil: The values of carbon density in dead mass (tons/ha) of each land-use type are shown in Table A2.

The unit of measurement for these coefficients is tons/ha. Average carbon coefficient values have been found in the Intergovernmental Panel on Climate Change (2006) *Guidelines for National Greenhouse Gas Inventories* report, Chapter 4, Agriculture, Forestry, and Other Land Use. **Here, the assumption of "Option 1" is that part of forest restoration will take place in a natural park with very dense forest, and so this intervention will have the same carbon pools of natural forest**.

Table A2. Carbon pools

lucode	C_above	C_below	C_soil	C_dead
1	70.50	19.04	138.67	2.00
2	32.90	8.88	54.99	0.00
3	2.91	0.79	1.36	0.00
4	9.87	2.66	57.44	0.00
5	56.40	15.23	76.55	2.00
6	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00

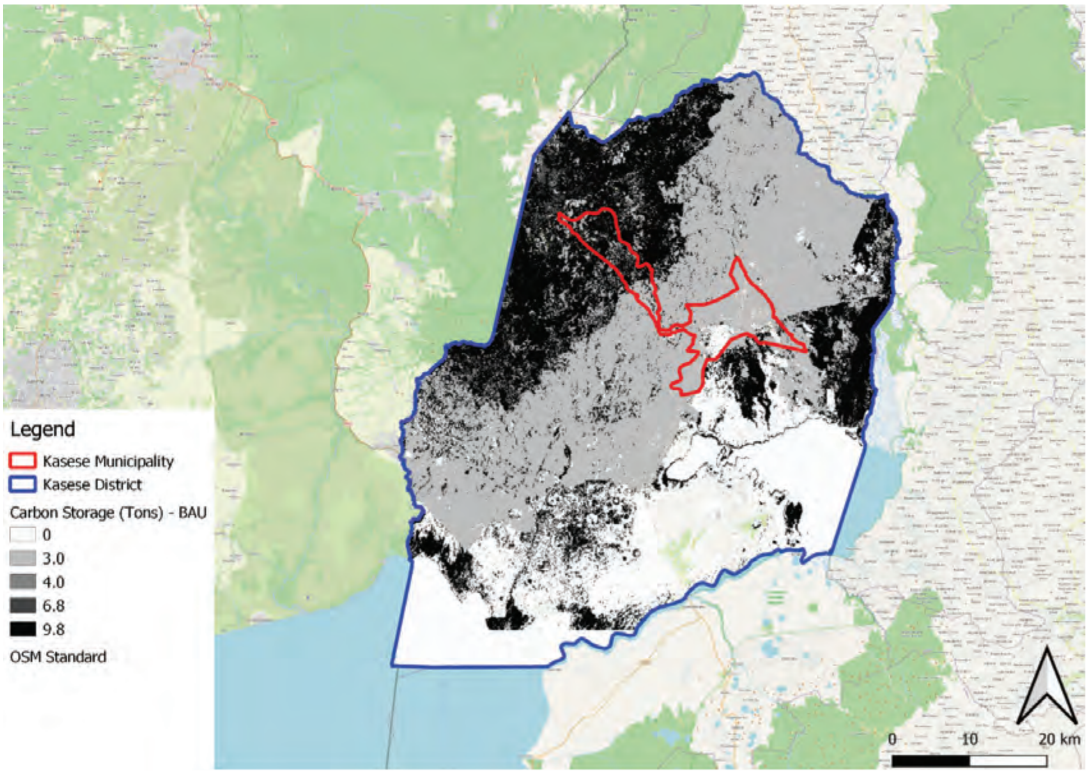
lucode	C_above	C_below	C_soil	C_dead
9	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
21	56.40	15.23	110.94	1.60
22	70.50	19.04	138.67	2.00
23	49.35	13.33	97.07	1.40
24	49.35	13.33	97.07	1.40
25	70.50	19.04	138.67	2.00
26	56.40	15.23	110.94	1.60

Source: Authors.

Results

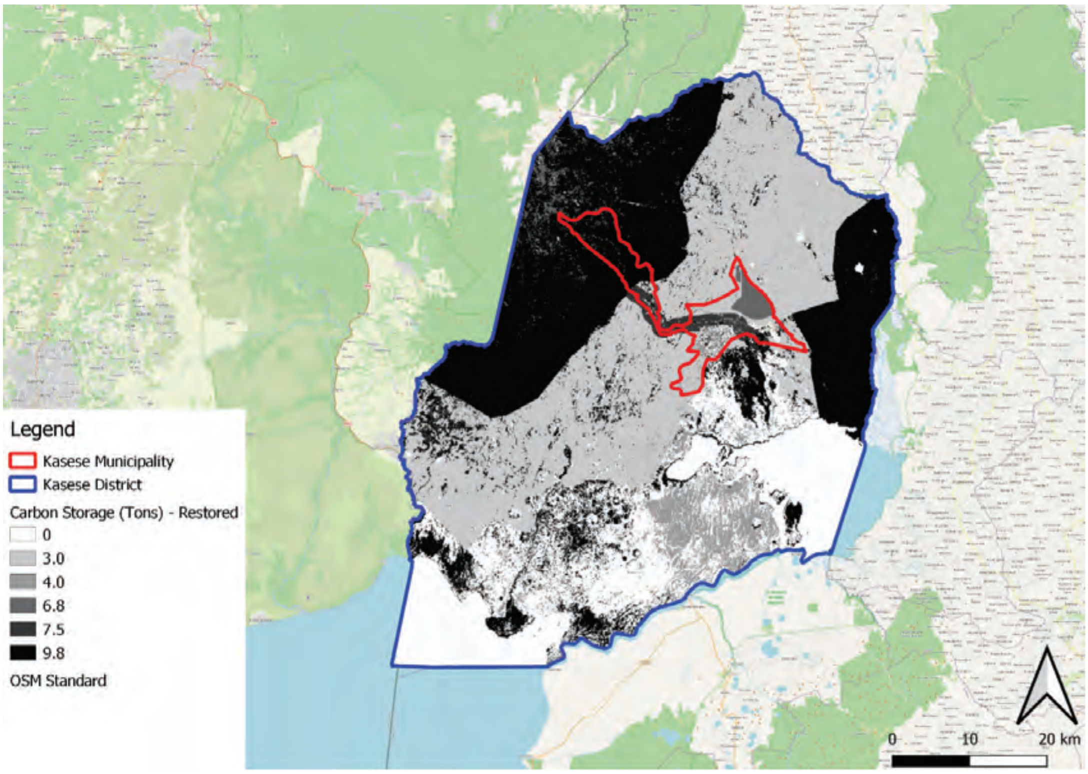
Figures A11 and A12 show the amount of carbon stored in tons in each pixel under the BAU and restored scenarios. They are a sum of all the carbon pools provided by the biophysical table.

Figure A11. Carbon model outputs (LULC BAU)



Source: Authors.

Figure A12. Carbon model outputs (LULC Restored)



Source: Authors.

Table A3. Carbon pool statistics

District

Scenario	Carbon stored (tons)	Change from BAU
BAU	33,458,521	
Restored	38,253,194	14.33%

Municipality

Scenario	Carbon stored (tons)	Change from BAU
BAU	1,687,882	
Restored	2,326,542	37.84%

Source: Authors.

As Table A3 shows, the carbon storage would increase by more than 14% and 37% in the district and municipality study areas respectively, from the BAU to the restored LULC scenario due to the replacement of cropland, grassland, and shrubland with the new ha of restored areas.

Carbon Storage – Option 2

Input Data Preparation and Processing

1. **LULC cover map –** See Section 2.4.1.
2. **Carbon Pools –** Table of LULC classes containing data on carbon stored in each of the four fundamental pools for each LULC class
    - carbon aboveground: The values of carbon density in aboveground mass (tons/ha) of each land-use type are shown in Table A4
    - carbon belowground: The values of carbon density in belowground mass (tons/ha) of each land-use type are shown in Table A4
    - carbon stored in organic matter: The values of carbon density in dead mass (tons/ha) of each land-use type are shown in Table A4
    - carbon stored in soil: The values of carbon density in dead mass (tons/ha) of each land-use type are shown in Table A4

The unit of measurement for these coefficients is tons/ha. Average carbon coefficient values have been found in the Intergovernmental Panel on Climate Change (2006) *Guidelines for National Greenhouse Gas Inventories* report, Chapter 4, Agriculture, Forestry, and Other Land Use. The assumption of "Option 1" is that part of forest restoration will take place in a natural park with very dense forest, and as a result, this intervention will have the same carbon pools as a natural forest. This justifies the high carbon pools. On the other hand, the assumption of "Option 2" is that the soil carbon pool of the first option is very high. Thus, if we plant trees in an existing forest, we will not increase the soil carbon storage by much. Therefore, we removed the additional carbon sequestration from the soil. For the land interventions related to forest plantation, given the lower density of trees, we used 50% of the carbon pool used for the forest. Similarly, for trees planted in urban areas, a smaller value was used, and we also did not consider the soil carbon impact because there is no vegetation on the ground (only concrete or unpaved roads) and a line of trees.

Table A4. Carbon pools

lucode	C_above	C_below	C_soil	C_dead
1	70.5	19.04	138.67	2
2	32.9	8.88	54.99	0
3	2.91	0.79	1.36	0
4	9.87	2.66	57.44	0
5	56.4	15.23	76.55	2
6	0	0	0	0
7	0	0	0	0

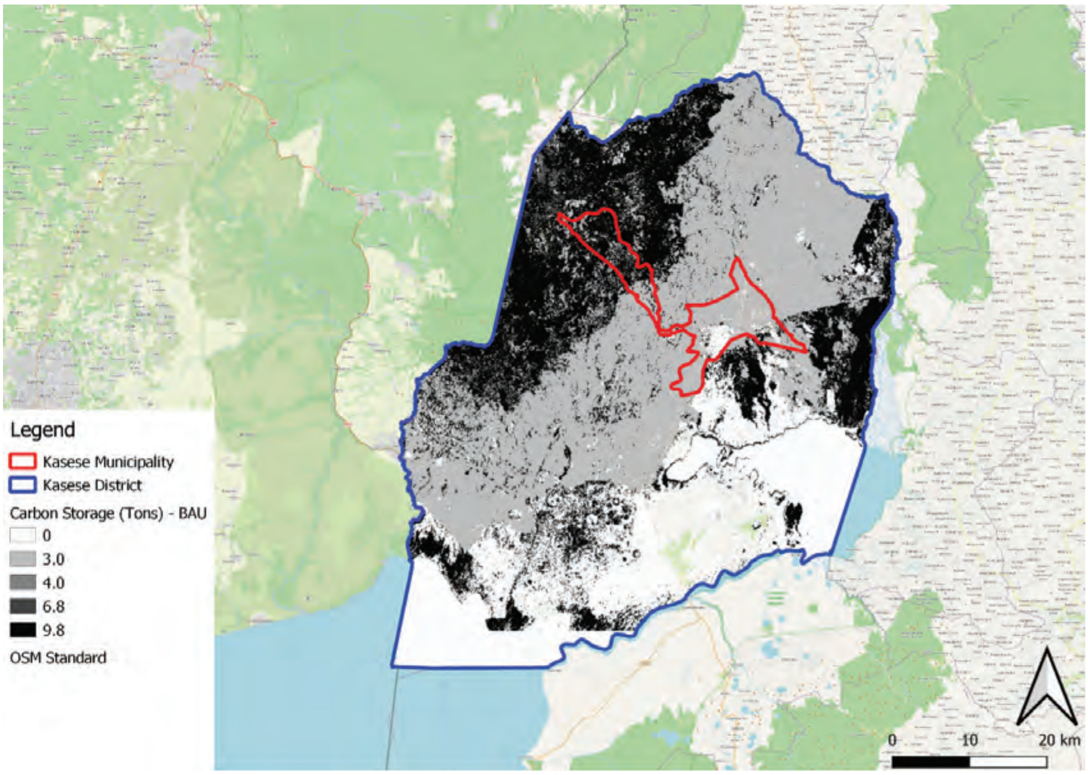
lucode	C_above	C_below	C_soil	C_dead
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
20	0	0	0	0
21	35.25	9.52	69.335	1
22	70.5	19.04	0	2
23	49.35	13.328	0	1.4
24	49.35	13.328	0	1.4
25	70.5	19.04	69.335	2
26	56.4	15.232	69.335	1.6

Source: Authors.

Results

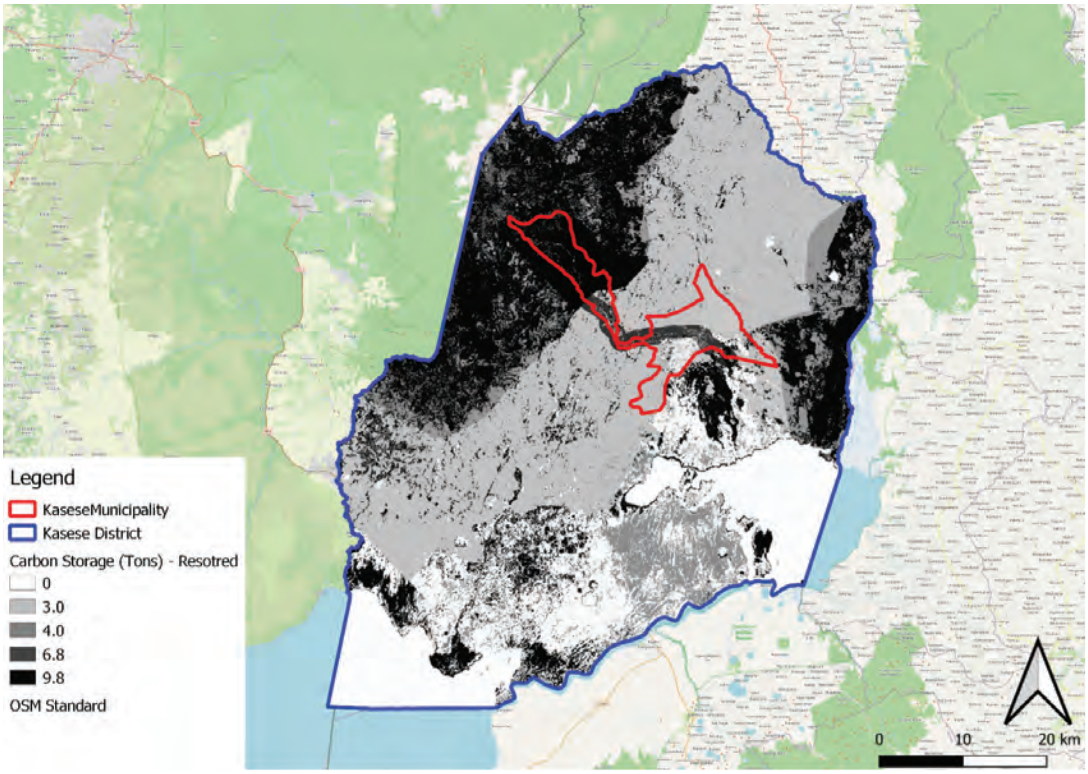
Figures A13 and A14 show the amount of carbon stored (in tons) in each pixel under the BAU and restored scenarios. They are a sum of all the carbon pools provided by the biophysical table.

Figure A13. Carbon model outputs (LULC BAU)



Source: Authors.

Figure A14. Carbon model outputs (LULC restored)



Source: Authors.

Table A5. Carbon pool statistics

District

Scenario	Carbon stored (tons)	Change from BAU
BAU	33,458,521	
Restored	34,976,005	4.54%

Municipality

Scenario	Carbon stored (tons)	Change from BAU
BAU	1,687,882	
Restored	2,002,414	18.63%

Source: Authors.

As Table A5 shows, the carbon storage would increase by roughly 5% and 19% in the district and municipality study areas respectively, from the BAU to the restored LULC scenario due to the replacement of cropland, grassland, and shrubland with the new ha of restored areas.

Annual Sediment Delivery Ratio

Input Data Preparation and Processing

1. **Digital elevation model (DEM) raster –** DEM: the hydrologically conditioned elevation dataset which is distributed by HydroSHEDS (https://www.hydrosheds.org/) was downloaded on June 1, 2023, for InVEST sediment model input. The data was prepared for hydrological model input purposes, mainly for flow direction, accumulation simulation, river network, and basin delineation. The data set was filled with missing data value and seeded inland sinks and depressions on original SRTM-3 and DTED-1 DEM. The original spatial resolution of the data set is 3 arc-seconds (approximately 90 m at the equator). The data is provided in geographic projection (latitude/longitude) referenced to the WGS84 horizontal datum and EGM96 vertical datum. Its elevation values are in metres.
2. **Rainfall erosivity index (R) raster –** A GIS raster data set containing erosivity index for each cell. This variable depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of the rainstorm, the higher the erosion potential. The erosivity index is widely used, but in case of its absence, there are methods and equations to help generate a grid using climatic data. Its value is MJ*mm*(ha*h*yr)-1. The R factor data set in spatial resolution of 25 km downloaded from https://www.nature.com/articles/s41467-017-02142-7 was employed for this study. The technical report of the data also can be found here: https://static-content.springer.com/esm/art%3A10.1038%2Fs41467-017-02142-7/MediaObjects/41467_2017_2142_MOESM1_ESM.pdf
3. **Soil erodibility (K) raster –** A raster data set of soil erodibility. It is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Its value is in T.ha.h.(ha.MJ.mm)-1. The spatial resolution of 25 km of soil erodibility downloaded from https://www.nature.com/articles/s41467-017-02142-7 was used in this study.
4. **LULC maps –** See Section 2.4.1.
5. **Biophysical table –** A table containing model information corresponding to each of the LULC types (see Table A6). The table has the following fields:
    - 5.1 **Lucode (land-use code) –** unique integer to identifier for each LULC class.
    - 5.2 **LULC_desc –** nominal name for each LULC class.
    - 5.3 **usle_c –** It refers to cover management factor, sometimes called cropping management factor (C factor) for the universal soil loss equation (USLE). This value is used to calculate the cover management in USLE. The C factor represents the effect of surface cover and roughness on soil erosion. The cover factor is the most common factor used to assess the impact of best management practices (BMPs) on reducing erosion because the C factor represents the effect of land use on soil erosion (Renard, 1997). Erosion control blankets and surface-applied BMPs such as blown straw are

represented as C factors within USLE. By definition, C = 1 under standard fallow conditions. As the surface cover is added to the soil, the C factor value approaches zero. For example, a C factor of 0.20 signifies that 20% of the amount of erosion will occur compared to continuous fallow conditions. C factors vary from region to region because they are strongly influenced by different rainfall erosivity indices (R factors) (Wischmeier & Smith, 1978). In the InVEST model, its value is stored in a float value ranging from 0 to 1.

5.4 **usle_p –** It refers to management practice, support, or conservation practice factor (P factor) in USLE. The P factor reflects the impact of support practices on the average annual erosion rate. P is the ratio of soil loss with a support factor to that with straight row farming up and down slope. Strip-cropping, contouring, and terracing are all activities that are considered support practices by USLE. The support factor is unitless, and its value is stored in a float value ranging from 0 to 1.

5.5 **sedret_eff –** the sediment retention factor for each LULC class. The column contains information in a float value ranging from 0 to 1. It refers to the capacity of each LULC class to retain sediment. This value is a percent per pixel area. A value of 1 for a LULC class means that the class contains the most natural vegetation (forest, natural pastures, wetlands, and prairie) in that class. The value of 0 means otherwise. The LULC class with a value of 0 should be pavement, roads, or urban areas.

Table A6. Biophysical table annual SDR

lucode	LULC_desc	LULC_veg	usle_c	usle_p	sedret_eff
1	lc_1	1	0.01	0.07	0.80
2	lc_2	1	0.15	0.15	0.60
3	lc_3	1	0.15	0.15	0.60
4	lc_4	1	0.50	0.40	0.25
5	lc_5	1	0.01	0.07	0.70
6	lc_6	1	0.80	0.25	0.25
7	lc_7	0	0.80	0.25	0.25
8	lc_8	0	0.50	0.10	0.05
9	lc_9	0	0.80	0.25	0.25
10	lc_10	0	0.00	0.01	0.60
20	lc_20	0	0.00	0.01	0.60
21	lc_21	1	0.01	0.08	0.72

lucode	LULC_desc	LULC_veg	usle_c	usle_p	sedret_eff
22	lc_22	1	0.01	0.07	0.80
23	lc_23	1	0.01	0.08	0.64
24	lc_24	1	0.01	0.08	0.64
25	lc_25	1	0.01	0.07	0.80
26	lc_26	1	0.01	0.07	0.72

Source: Authors.

6. **Threshold flow accumulation –** The number of upstream cells that must flow into a cell before it is considered part of a stream, which is used to classify streams from the DEM. This threshold directly affects the expression of hydrologic connectivity and the sediment export result: when a flow path reaches the stream, sediment deposition stops, and the sediment exported is assumed to reach the catchment outlet. It is important to choose this value carefully so modelled streams come as close to reality as possible. The default value of 1,000 was used for this simulation.
7. **Borseli K parameter (kb) and Borseli IC_0 parameter (IC_0) –** two calibration parameters that determine the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the SDR (percentage of soil loss that actually reaches the stream). The default values of kb=2 and $IC_0=0.5$ were used in the simulation.
8. **Max SDR value (SDRmax) –** the maximum SDR that a pixel can reach, which is a function of the soil texture. More specifically, it is defined as the fraction of topsoil particles finer than coarse sand. This parameter can be used for calibration in advanced studies. Its default value of 0.8 was used.

Results

Table A7. Sediment export statistics

District		
Scenario	**Sediment export (tons)**	**Change from BAU**
BAU	33,054,106	
Restored	25,888,327	-21.68%

Source: Authors.

Table A7 shows the total sediment export (tons) under both the BAU and restored LULC, indicating a decrease of 21.68%. This change can be explained by the modification in land cover under the restored scenario. Sediment retention efficiency is the ability of vegetation to retain sediment flowing into a pixel from upslope and is specific for every land class, with forest land having the highest efficiency (Terrado et al., 2014). Therefore, as forests replace cropland, sediment export decreases as a consequence.

Habitat Quality

Input Data Preparation and Processing

1. **LULC maps –** See Sections Section 2.4.1.
2. **Half-saturation constraint –** the default value of 0.5 was used.
3. **Threat data –** several major threats such as cropland areas, urban areas, and primary road networks have been identified as the threat sources to the natural habitat and biodiversity (see Table A8). See Table A10 for data sources.

Table A8. Table of threat (maximum distance, weighted value, and decay function) for InVEST simulation

THREAT	MAX_DIST	WEIGHT	DECAY
Cropland	4	0.7	Linear
Urban areas	7.1	0.7	Linear

Source: Authors.

4. **Sensitivity of land cover types to each threat –** Table A9 characterizes each LULC type to be habitat or non-habitat and the type's sensitivity to the threats (see Table A11). The table contains the following fields:
    - 4.1 **LULC –** codes identify each LULC class
    - 4.2 **Name –** abbreviation of each LULC class
    - 4.3 **Habitat –** score characterizing each LULC as habitat or non-habitat. The values of 0 and 1 are used for the purpose, in which 0 for non-habitat class and 1 for habitat class of LULC.
    - 4.4 **L_crop_4, L_urb_8, –** these are columns for the relative sensitivity of LULC classes to the threat. In this case, L_crop_4 contains the value for the sensitivity of each LULC class to "Cropland" threat, L_urb_8 sensitivity to "Urban areas."

Table A9. Table of sensitivity of land cover types to each threat for InVEST simulation

lulc	HABITAT	crop_4	urb_8
1	1	1	1
2	0.4	1	1
3	0.4	1	1
4	0.4	1	1
5	1	1	1
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
20	0	0	0
21	0.8	1	1
22	1	1	1
23	0.7	1	1
24	1	1	1
25	0.7	1	1
26	0.8	1	1

Source: Authors.

Table A10. Habitat quality model – references "threat table"

Threat	Max_ Distance	Max_ Distance adopted sources	Weighted value	Weight value Adopted sources	Decay function	Decay func. Adopted sources
Cropland	4 km	(Terrado, et al., 2016)	0.7	(Bhagabati, et al., 2012)	Linear	(Bhagabati, et al., 2012)
Urban areas	7.1 km	(Terrado, et al., 2016)	0.7	(Bhagabati, et al., 2012)	Linear	(Bhagabati, et al., 2012)

Source: Authors.

Table A11. Habitat quality model – references "threat-sensitivity table"

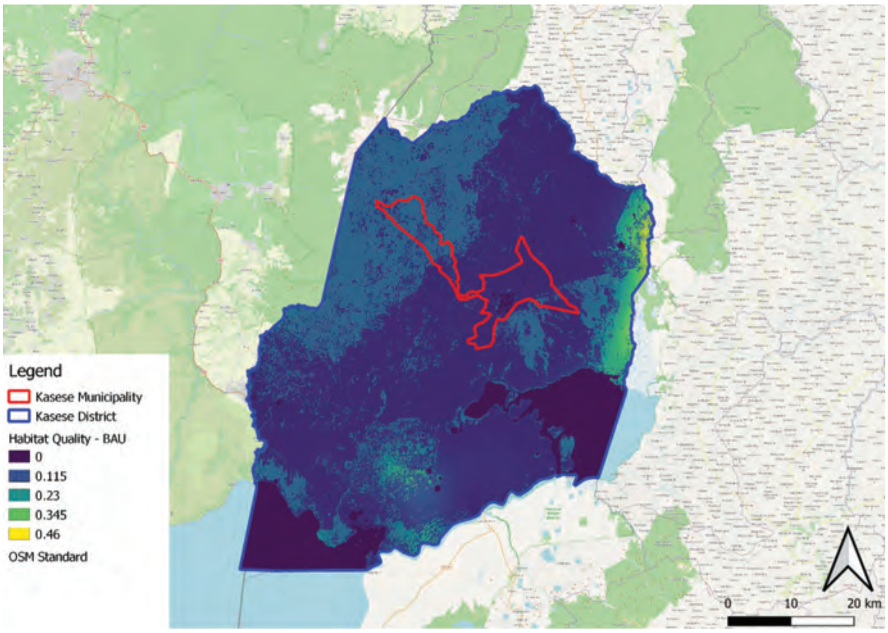
Value	Habitat	Habitat adopted sources	Sensitivity to agricultural source	Sensitivity to agricultural adopted sources	Sensitivity to urban areas sources	Sensitivity to urban area adopted sources
1	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
2	0.4	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
3	0.4	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
4	0.4	(Bhagabati, et al., 2012)	0.03	(Bhagabati, et al., 2012)	0.69	(Bhagabati, et al., 2012)
5	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
6	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
7	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
8	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
9	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
10	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
20	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
21	0.8	Assumed	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
22	1	Assumed	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
23	0.7	Assumed	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
24	1	Assumed	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
25	0.7	Assumed	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
26	0.8	Assumed	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)

Source: Authors.

Results

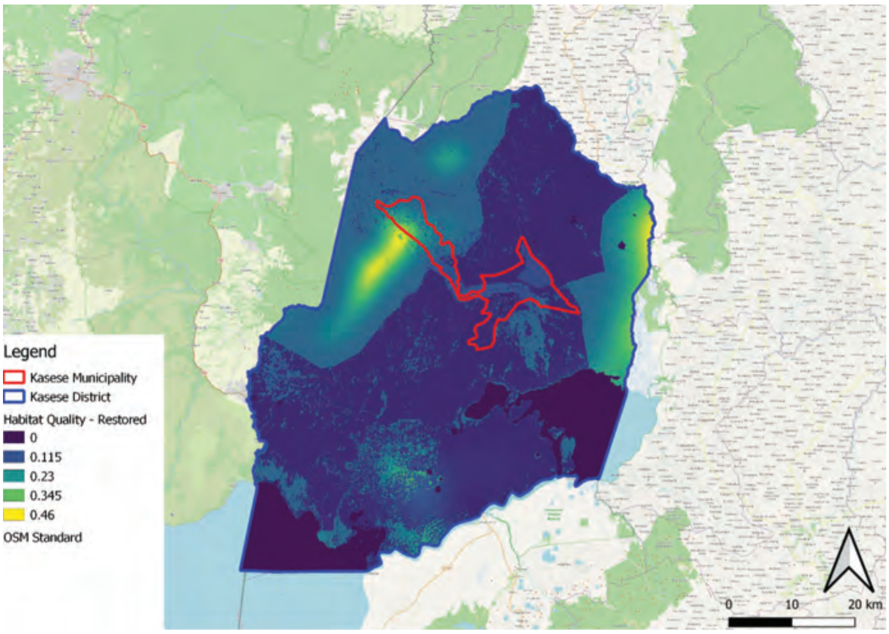
Figures A15 and A16 show the relative level of habitat quality in the study areas considering the BAU and restored scenarios. Higher numbers indicate better habitat quality vis-à-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. The habitat score values range from 0 to 1, where 1 indicates the highest habitat suitability.

Figure A15. Habitat quality (BAU)



Source: Authors.

Figure A16. Habitat quality (restored)



Source: Authors.

Table A12. Habitat quality statistics

District

Scenario	Mean	Change from BAU
BAU	0.0877	
Restored	0.1034	17.88%

Municipality

Scenario	Mean	Change from BAU
BAU	0.0829	
Restored	0.1213	46.37%

Source: Authors.

As Table A12 shows, the mean habitat quality is expected to increase in both the district and the municipality, as restored areas are anticipated to replace cropland, grassland, and other land cover classes. In the district, the mean habitat quality is expected to increase by almost 18%, while in the municipality, it is expected to increase by more than 46%.

Urban Flood Risk

Input Data Preparation and Processing

1. **LULC maps –** See Section 2.4.1.
2. **Depth of rainfall in mm –** For this analysis, we used 100 mm as a reference.
3. **Soil hydrological group raster –** Raster of categorical hydrological groups. Pixel values must be limited to 1, 2, 3, or 4, which correspond to soil hydrologic group A, B, C, or D, respectively (used to derive the curve number [CN]). The dataset can be requested by from Gijs Simons MSc - futurewater.eu/about-us/our-team/gijs-simons/
4. **Biophysical table –** A table containing model information corresponding to each of the land-use classes in the land cover map (Table A13). All LULC classes in the land cover raster must have corresponding values in this table. These values have been derived from sample data provided by InVEST. Each row is a LULC class, and columns must be named and defined as follows:
    - lucode: LULC class code. LULC codes must match the “value” column in the land cover map raster and must be integer or floating-point values, in consecutive order, and unique.
    - CN values for each LULC type and each hydrologic soil group. Column names should be CN_A, CN_B, CN_C, CN_D, which the letter suffix corresponding to the hydrologic soil group.

Table A13. Biophysical table

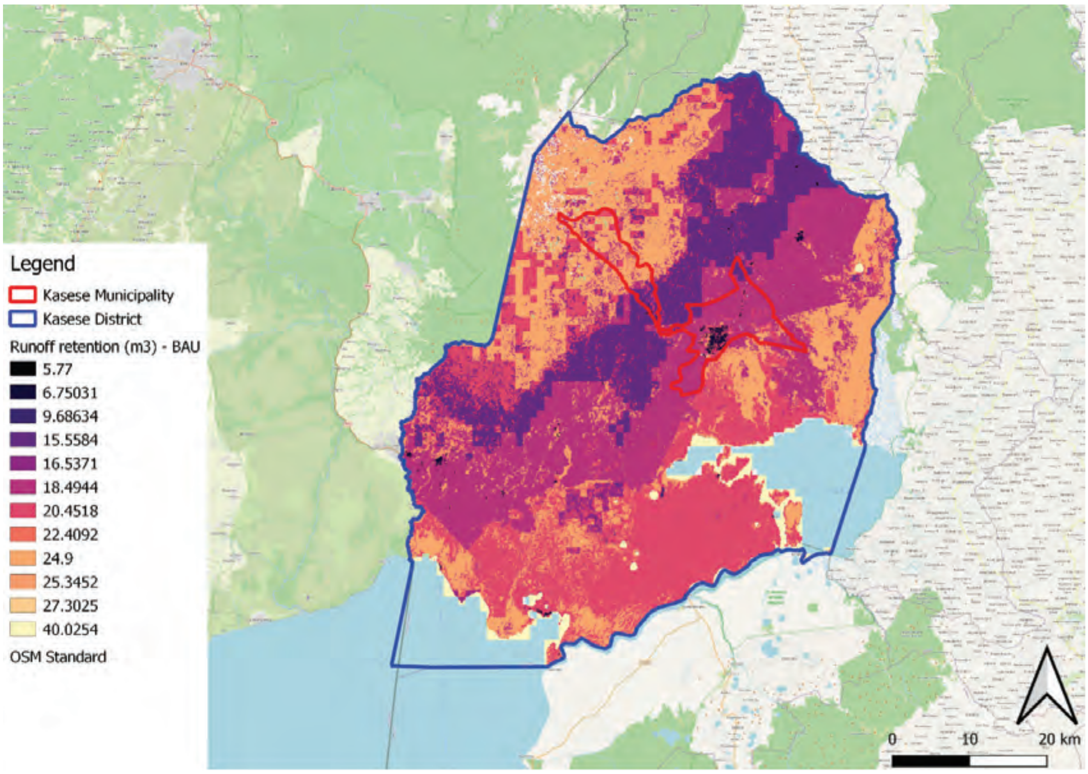
lucode	CN_A	CN_B	CN_C	CN_D
1	36	70	73	79
2	49	69	79	84
3	49	69	79	84
4	64	75	82	85
5	30	55	70	77
6	77	86	91	94
7	77	86	91	94
8	89	92	94	95
9	77	86	91	94
10	0.1	0.1	0.1	0.1
20	0.1	0.1	0.1	0.1
21	39.6	77	80.3	86.9
22	36	70	73	79
23	36	70	73	79
24	36	70	73	79
25	36	70	73	79
26	36	70	73	79

Source: Authors.

Results

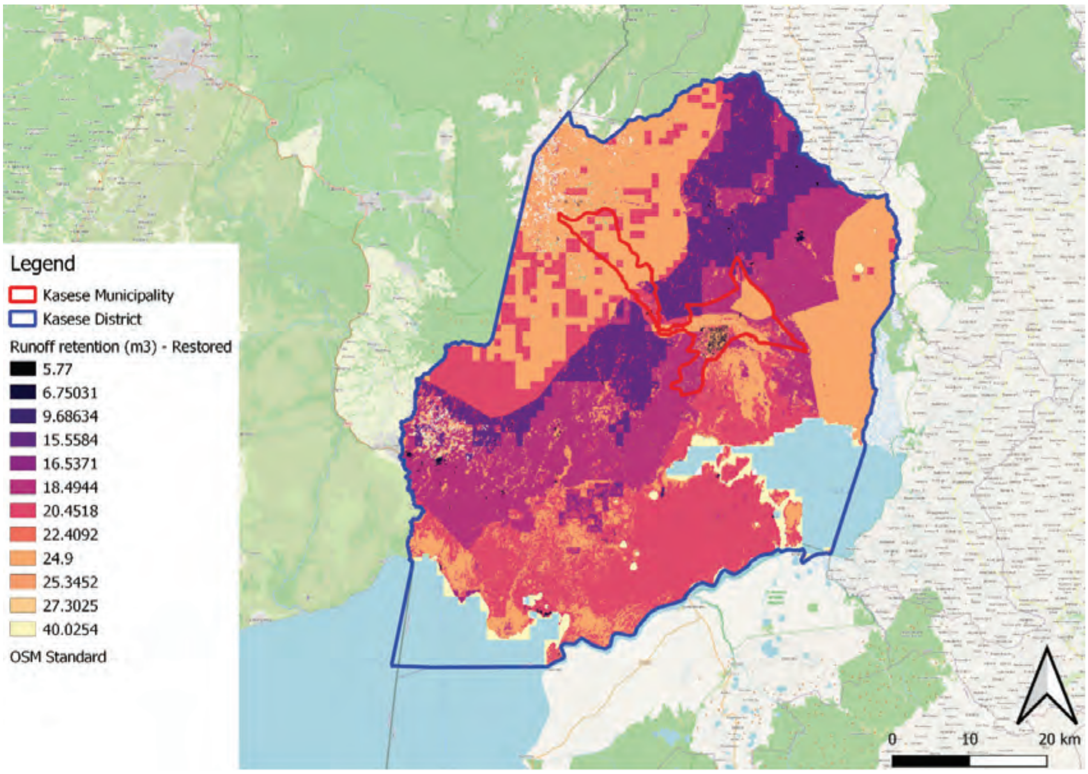
Figure A17 and Figure A18 show the runoff retention volumes (m^3) in the study areas under the BAU and restored scenarios.

Figure A17. Runoff retention values (m³) – (BAU)



Source: Authors.

Figure A18. Runoff retention values (m³) – (restored)



Source: Authors.

Table A14. Runoff retention statistics

District

Scenario	Runoff retention (m^3)	Change from BAU
BAU	158,337,691	
Restored	162,730,031	2.77%

Municipality

Scenario	Runoff retention (m^3)	Change from BAU
BAU	7,561,143	
Restored	8,534,914	12.88%

Source: Authors.

Urban Cooling

Input Data Preparation and Processing

1. **LULC maps –** See Section 2.4.1.
2. **Biophysical table –** A table containing model information corresponding to each of the land-use classes in the land cover map (Table A15). All LULC classes in the land cover raster must have corresponding values in this table. Each row is an LULC class and columns must be named and defined as follows:
    2.1 **lucode:** Required. LULC class code. LULC codes must match the "value" column in the land cover map raster and must be integer or floating-point values, in consecutive order, and unique.

    2.2 **Shade:** A value between 0 and 1, representing the proportion of tree cover (0 for no tree; 1 for full tree cover; with trees>2m). Required if using the weighted factor approach to cooling coefficient calculations.

    2.3 **Kc:** Required. Crop coefficient, a value between 0 and 1 (Allen, 1998).

    2.4 **Albedo:** A value between 0 and 1, representing the proportion of solar radiation directly reflected by the LULC type. Required if using the weighted factor approach to cooling coefficient calculations.

    2.5 **Green_area:** Required. A value of either 0 or 1, 1 meaning that the LULC is counted as a green area (green areas >2ha have an additional cooling effect), and 0 meaning that the LULC is not counted as a green area.

    The values of the biophysical table used in this study have been retrieved from Brocco (2021) and from the input samples of the InVEST package.

Table A15. Biophysical table – cooling model

lucode	Shade	Kc	Albedo	Green_area
1	1	1	0.15	1
2	0.3	0.2	0.1	1
3	0.3	0.2	0.1	1
4	0.3	0.2	0.1	1
5	0.45	1	0.2	1
6	0.45	1	0.2	1
7	0	0	0	0
8	0.05	0.37	0.18	0
9	0	0	0	0
10	0.05	0.37	0.18	0
20	0.05	0.37	0.18	0
21	0.9	0.9	0.15	1
22	1	1	0.15	1
23	0.8	0.8	0.15	1
24	0.8	0.8	0.15	1
25	1	1	0.15	1
26	0.9	0.9	0.15	1

Source: Authors.

3. **Reference evapotranspiration:** A GIS raster data set with an average evapotranspiration value for each cell in millimetres, for the month of March (the hottest month of the year in Ivory Coast). Reference evapotranspiration is the potential loss of water from the soil by both evaporation from the soil and transpiration by healthy alfalfa (or grass) if sufficient water is available. Its value is in millimetres. In this study, the global evapotranspiration of reference crops was adopted from “Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2.” The spatial resolution of the data is 30 arc-seconds (approximately 1 km at the equator). The dataset can be found here: (https://figshare.com/articles/Global_Aridity_Index_and_Potential_Evapotranspiration_ET0_Climate_Database_v2/7504448/3)
4. **Areas of interest:** the three study areas have been considered
5. **Green area maximum cooling distance:** 450 m, suggested by the developers of InVEST

6. **Reference air temperature:** 30°C[5]
7. **Magnitude of the urban heat island effect:** 4.5°C[6]
8. **Air temperature maximum blending distance:** 90 m (Gallay, 2023)
9. **Cooling capacity calculation method:** “Weighted Factors,” suggested by the developers of InVEST
10. **Shade:** Default value: 0.6
11. **Evapotranspiration index** and **albedo**: Default value: 0.2

Results

The following is a short description of the most important outputs from the urban cooling model:

1. **uhi_results_[Suffix].shp:** A copy of the input vector with areas of interest with the following additional fields:
    - “avg_tmp_v” - Average temperature value (degrees centigrade)
2. **hm_[Suffix].tif:** The calculated Heat Mitigation Index maps (spatial outputs)

The first outputs “uhi_results” are simple vectors and do not show any relevant spatial outputs. However, they indicate the “Average temperature value (degC)”. The second outputs are qualitative maps indicating the heat mitigation index from 0 to 1, where 0 is the lowest heat mitigation potential and 1 is the highest.

Table A16 shows the average temperature under the BAU and restored scenarios.

Table A16. Urban cooling statistics

District

Scenario	Average temperature value (degC)	Change from BAU
BAU	32.7978	
Restored	32.5929	-0.62%

Municipality

Scenario	Average temperature value (degC)	Change from BAU
BAU	32.8695	
Restored	32.2520	-1.88%

Source: Authors.

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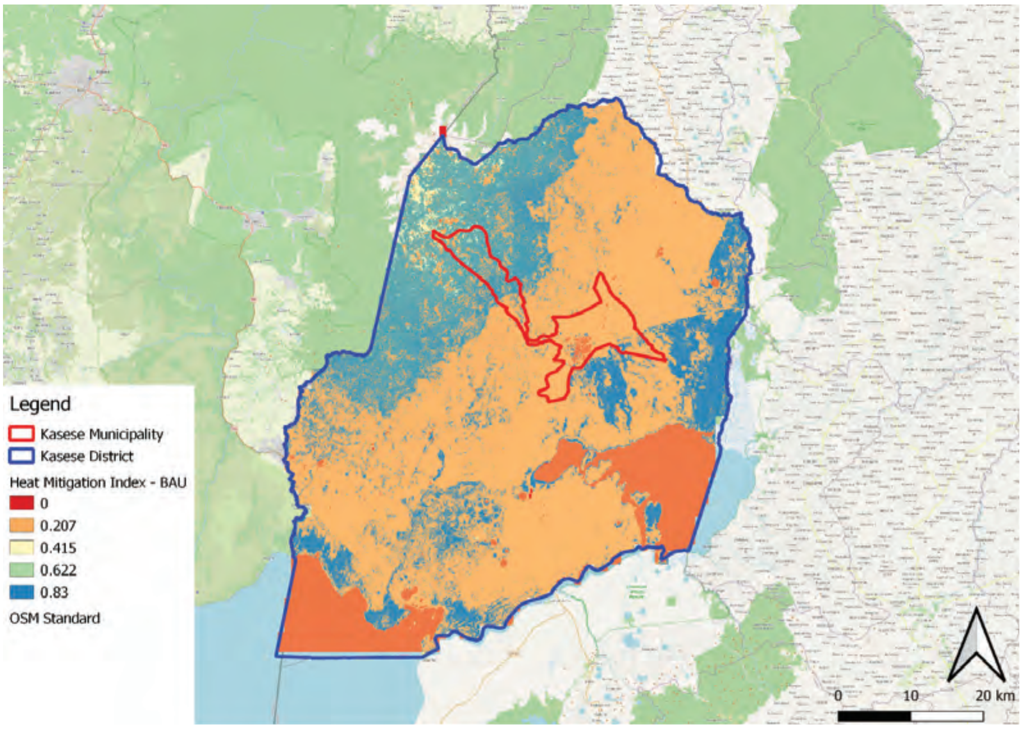
[5] https://www.climatestotravel.com/climate/uganda

[6] https://essay.utwente.nl/88923/1/ferrario.pdf

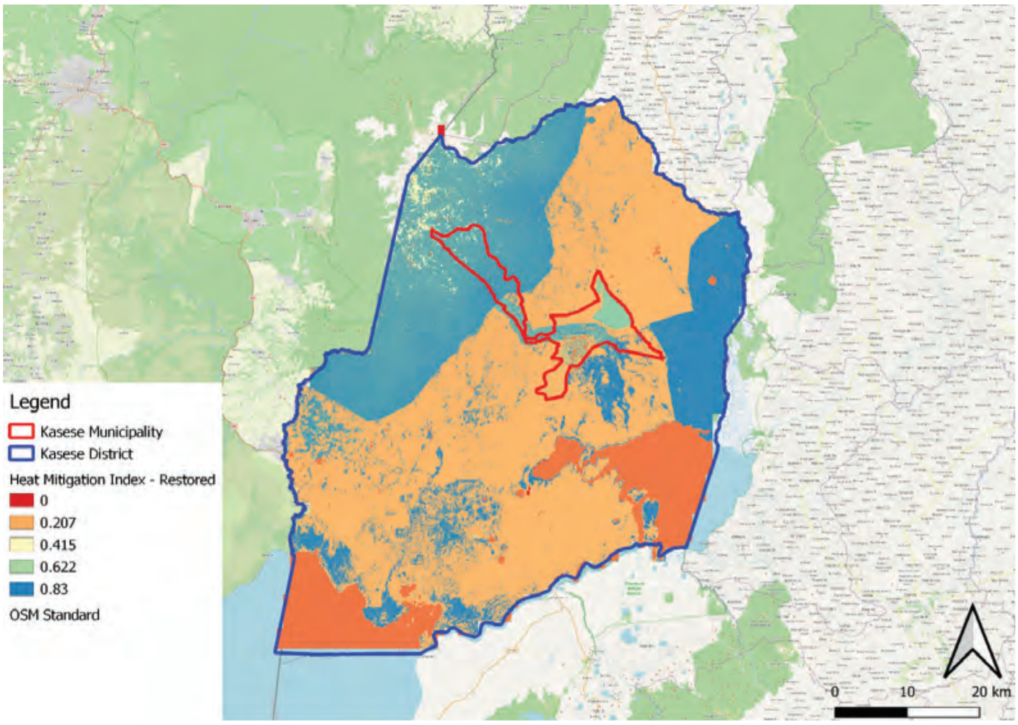
As Table A16 shows, the average temperature is expected to decrease in both the district and the municipality from the BAU to the restored scenario, due to the increased cover of natural vegetation replacing mainly cropland. Figures A19 and A20 show the calculated heat mitigation index maps using the LULCs under the BAU and restored scenarios.

Figure A19. Heat mitigation index (BAU)



Source: Authors.

Figure A20. Heat mitigation index (restored)



Source: Authors.

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