FOREST LANDSCAPE RESTORATION

Technical Packages for Rwanda

Leander RAES, Alain NDOLI, Ephrem IMANIRARBA, Salete CARVALHO, Charles KARAWANGA, and Joseph NJUE

International Union for Conservation of Nature

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Table of Content

1. Summary 1

2. Introduction 6

2.1. Forest landscape restoration as a sustainable land-management option in Rwanda 6

2.2. Restoration Opportunities Assessment Methodology in Rwanda 6

2.3. Restoration case study in two contrasting agro-ecologies of Rwanda 7

3. Presentation of Specific Forest Landscape Restoration Categories 9

3.1. Agroforestry systems in Rwanda 9

3.2. Description of land uses before restoration actions 11

3.3. Maize and beans production in Gicumbi and Gatsibo prior to restoration 11

3.4. Wheat and potato production in Gicumbi prior to restoration 12

4. Explanation of Forest Landscape Restoration Actions 14

4.1. Agroforestry with maize and beans in Gatsibo 14

4.1.1. Description of tree species in maize-bean agroforestry in Gatsibo 14

4.1.2. Agronomy of trees and crops in maize-bean agroforestry in Gatsibo 15

4.2. Agroforestry with maize, beans, and fodder in Gatsibo 15

4.2.1. Description of tree species in maize-bean-fodder agroforestry in Gatsibo 15

4.3. Agroforestry with maize, beans, and fodder in Gicumbi 17

4.3.1. Description of tree species in maize-bean-fodder agroforestry in Gicumbi 17

4.4. Agroforestry with wheat and potato in Gicumbi 18

4.4.1. Description of tree species in wheat-potato agroforestry in Gicumbi 18

4.5. Woodlot plantations in Gatsibo and Gicumbi 19

4.5.1. Description of tree species in woodlot plantations in Gatsibo and Gicumbi 19

4.6. Protective forests in Gatsibo (roadside) and Gicumbi (riverside) 20

4.6.1. Description of tree species in protective forests in Gatsibo and Gicumbi 20

5. Cost-Benefit Analysis 22

5.1. Introduction 22
5.2. Summary of previous land uses and forest landscape restoration actions 23
5.3. Cost-benefit analysis methodology 24
5.3.1. Costs considered 24
5.3.2. Benefit estimation 26
5.3.3. Data collection for costs and benefits 27
5.3.4. Financial indicators 29
5.3.5. Sensitivity analysis 31
5.4. Cost-benefit analysis results 31
5.4.1. Results of CBA agroforestry system with maize and beans in Gatsibo 31
5.4.2. Results of CBA agroforestry system with maize, beans and fodder in Gatsibo 32
5.4.3. Results of CBA traditional agriculture of beans and maize in Gatsibo 33
5.4.4. Results of CBA Eucalyptus plantation on public land in Gatsibo 36
5.4.5. Results of CBA Eucalyptus plantation on private land in Gatsibo 37
5.4.6. Results of CBA protective forest on roadsides in Gatsibo 39
5.4.7. Results of CBA agroforestry system with maize and beans in Gicumbi 40
5.4.8. Results of CBA agroforestry system with maize, beans and fodder in Gicumbi 41
5.4.9. Results of CBA traditional agricultural production of maize and beans in Gicumbi 42
5.4.10. Results of CBA agroforestry system with wheat and Irish potatoes in Gicumbi 45
5.4.11. Results of CBA traditional production system of wheat and Irish potatoes (previous agriculture practice) 46
5.4.12. Results of CBA Eucalyptus plantation on public land in Gicumbi 48
5.4.13. Results of CBA Eucalyptus woodlot on private land in Gicumbi . 49
5.4.14. Results of CBA protective forests in Gicumbi (riverside) 51
5.5. The effect of carbon sequestration on net present value 53
5.5.1. Monetary value from carbon dioxide removal 53
5.5.2. Carbon sequestration from FLR interventions 54
5.6. Discussion of the results 55
6. Restoration Stock Taking 58

7. InVEST Analysis Results 63

7.1. Introduction to InVEST 63

7.2. Spatial data inputs 65

7.3. Land uses with FLR potential 66

7.3.1. Agroforestry with annual crops 69

7.3.2. Agroforestry with perennial crops 70

7.3.3. Managed woodlots 71

7.3.4. Protective trees 71

7.4. Impact potential map 72

7.5. Soil erosion results 73

7.5.1. Impact potential maps 74

7.5.2. Agroforestry with perennial crops 76

7.5.3. Managed woodlots 78

7.5.4. Protective trees 80

7.6. InVEST conclusions 81

8. General Conclusions 82

9. References 84

List of Figures

Figure 1 – Summary results for CBA (NPV traditional system versus restored land use RWF/ha) 3

Figure 2 – Proportion of the impacted area and categorization by level of impact on soil erosion rate by combined FLR packages per district 4

Figure 3 – Rwanda administrative map with Gicumbi and Gatsibo districts of intervention highlighted 5

Figure 4 – Rwanda administrative map with Gicumbi and Gatsibo districts of intervention highlighted 8

Figure 5 – Tree cover transitions with agroforestry as a reinvestment in land restoration 10

Figure 6 – Tree arrangement in the agroforestry system of maize and beans in Gatsibo 15

Figure 7 – Tree arrangement in the agroforestry system with maize, beans, and fodder in Gatsibo 17

Figure 8 – Tree arrangement in agroforestry system with maize, beans, and fodder in Gicumbi 18

Figure 9 – Tree arrangement in agroforestry system with wheat and potato in Gicumbi 19

Figure 10 – Protective Forest – riverside plantation 20

Figure 11 – Protective Forest – roadside plantation ... 21
Figure 12 – Cost-benefit analysis of FLR actions in Gatsibo and Gicumbi ... 22
Figure 13 – Annual costs and benefits from the agroforestry system with maize and beans in Gatsibo District. Graph A depicts non-discounted annual costs and benefits; graph B depicts discounted annual costs and benefits. The red line represents the net benefit over time. ... 32
Figure 14 – Annual costs and benefits from an agroforestry system with maize, beans and fodder in Gatsibo District. Graph A depicts non-discounted annual costs; graph B depicts discounted annual costs. The blue line represents the net benefit over time. ... 33
Figure 15 – Annual costs and benefits from previous agricultural practice of maize and beans in Gatsibo ... 34
Figure 16 – Scenarios of annual net benefits of previous maize and beans production system in Gatsibo ... 35
Figure 17 – Annual costs and benefits of Eucalyptus forest plantation on public land in Gatsibo ... 37
Figure 19 – Annual costs and benefits of protective forest in Gatsibo ... 39
Figure 20 – Annual costs and benefits of agroforestry system with maize and beans in Gicumbi District ... 41
Figure 21 – Annual costs and benefits of agroforestry system with maize, beans and fodder in Gicumbi District ... 42
Figure 22 – Annual costs and benefits from previous agriculture practice of maize and beans without FLR in Gicumbi ... 43
Figure 23 – Scenarios of annual net benefits per hectare of previous agriculture practice in Gicumbi ... 44
Figure 24 – Annual costs and benefits of agroforestry system with wheat and Irish potatoes in Gicumbi District ... 46
Figure 25 – Annual costs and benefits from the production of wheat and Irish potatoes ... 47
Figure 26 – Scenarios of net benefits of previous agriculture practice considering soil loss and discount rate ... 47
Figure 27 – Annual costs and benefits from Eucalyptus woodlot on public land in Gicumbi ... 49
Figure 28 – Annual costs and benefits from Eucalyptus Forest plantation on private land in Gicumbi ... 50
Figure 29 – Annual costs and benefits for protective riverside forest in Gicumbi ... 52
Figure 30 – FLR project coverage by district (2011-2018) ... 58
Figure 31 – FLR project coverage by sector (2011-2018) ... 59
Figure 32 – Number of hectares restored in FLR projects by district (2011-2018) ... 59
Figure 33 – Number of hectares restored in FLR projects by sector (2011-2018) ... 60
Figure 34 – Amount invested in FLR projects by district (2011-2018) ... 61
Figure 35 – Amount invested in FLR projects by sector (2011-2018) ... 61
Figure 36 – Landover ... 65

Figure 37 – DEM 65
Figure 38 – Watersheds 66
Figure 39 – Soil Erodibility (k) 66
Figure 40 – Rainfall erosivity (R) 66
Figure 41 – Potential area for agroforestry with annual crops 67
Figure 42 – Potential area for agroforestry with perennial crops 67
Figure 43 – Potential area for woodlots 68
Figure 44 – Potential are for protective trees 68
Figure 45 – Total potential area per district and per type of restoration activity 69
Figure 46 – Development of impact potential map for FLR in Rwanda 72
Figure 47 – Soil erosion rate in Rwanda (t/ha/year 74
Figure 48 – Proportion of the impacted area and categorization by level of impact on soil erosion rate by agroforestry with annual crops per district 75
Figure 49 – Proportion of the impacted area and categorization by level of impact on soil erosion rate for agroforestry with perennial crops per district 77
Figure 50 – Proportion of the impacted area and categorization by level of impact on soil erosion rate by managed woodlots per district 79
Figure 51 – Districts with the highest area with highest reduction on soil erosion rate for protected trees by district 80

List of Tables

Table 1 – Average agricultural inputs for maize and bean production in both Gatsibo and Gicumbi districts in 2016 12
Table 2 – Average yields of annual crops in Gicumbi and Gatsibo districts prior to restoration 12
Table 3 – Average agricultural inputs for wheat and potato production in Gicumbi District in 2016 13
Table 4 – Forest landscape restoration (FLR) interventions 21
Table 5 – Restoration transition 23
Table 6 – Intervention maturity profile in percentage per year 25
Table 7 – Financial indicators of continuing the previous agricultural practice and implementing the corresponding agroforestry systems in Gatsibo 35
Table 8 – Sensitivity analysis for traditional agriculture and agroforestry systems in Gatsibo. All values are in RWF 36
Table 9 – Financial indicators of the implementation of woodlots on public and private land in Gatsibo 38
Table 10 – Sensitivity analysis of woodlots establishment in Gatsibo 39
Table 11 – Cost-benefit analysis of previous agriculture practice and protective forest in Gatsibo 40
Table 12 – Sensitivity analysis for protective forest in Gatsibo 40
Table 13 – Cost-benefit analysis of previous agriculture practice and agroforestry system in Gicumbi 44

Table 14 – Sensitivity analysis maize and beans agroforestry system in Gicumbi ... 45
Table 15 – Financial indicators of previous agriculture practice and agroforestry with wheat and Irish potatoes ... 48
Table 16 – Sensitivity analysis of the CBA of the agroforestry system with wheat and Irish potatoes in Gicumbi (RWF/0.5ha) ... 48
Table 17 – Cost-benefit analysis of previous agriculture practice and woodlots in Gicumbi ... 50
Table 18 – Sensitivity analysis for FLR woodlots in Gicumbi(RWF/ha) ... 51
Table 19 – Financial indicators protective riparian forest in Gicumbi ... 52
Table 20 – Sensitivity analysis of planting protective riparian forest in Gicumbi (RWF/ha) ... 53
Table 21 – Carbon dioxide sequestration capacity for FLR interventions ... 53
Table 22 – Carbon dioxide sequestration capacity for FLR interventions ... 53
Table 23 – Total contribution of FLR interventions in Gatsibo ... 54
Table 24 – Total contribution of FLR interventions in Gicumbi ... 55
Table 25 – Biophysical data for current land uses ... 64
Table 26 – Biophysical data for FLR actions ... 65
Table 27 – Number of hectares of potential area for the implementation of the restoration activities ... 67
Table 28 – Districts with highest percentage of potential area for the implementation of the restoration activities in relation to the district area ... 69
Table 29 – Districts with largest number of hectares of potential area for the implementation of agroforestry with annual crops ... 70
Table 30 – Districts with highest percentage of potential area for the implementation of agroforestry with annual crops in relation to the district area ... 70
Table 31 – Districts with largest number of hectares of potential area for the implementation of agroforestry with perennial crops ... 70
Table 32 – Districts with highest percentage of potential area for the implementation of agroforestry with annual crops in relation to the district area ... 71
Table 33 – Districts with the largest number of hectares of potential area for the implementation of managed woodlots ... 71
Table 34 – Districts with highest percentage of potential area for the implementation of managed woodlots in relation to the district area ... 71
Table 35 – Districts with largest number of hectares of potential area for the implementation of protective trees ... 72
Table 36 – Districts with highest percentage of potential area for the implementation of managed woodlots in relation to the district area ... 72
Table 37 – Reduction on soil erosion for agroforestry with annual crops ... 75
Table 38 – Districts with highest number of hectares categorised as highest priority for agroforestry with annual crops based on impact on soil erosion (hectares) ... 76
Table 39 – Districts with highest percentage of area categorised as highest priority for agroforestry with annual crops based on impact on soil erosion ... 76

Table 40 – Reduction on soil erosion for agroforestry with perennial crops 76
Table 41 – Districts with highest number of hectares categorised as highest priority for agroforestry with perennial crops based on impact on soil erosion ... 77
Table 42 – Districts with highest percentage of area categorised as highest priority for agroforestry with perennial crops based on impact on soil erosion ... 78
Table 43 – Reduction on soil erosion with managed woodlots 78
Table 44 – Districts with highest number of hectares categorised as highest priority for managed woodlots based on impact on soil erosion 79
Table 45 – Districts with highest percentage of area categorised as highest priority for managed woodlots based on impact on soil erosion 79
Table 46 – Reduction on soil erosion rate with protective trees 80
Table 47 – Districts with highest number of hectares categorised as highest priority for protective forests based on impact on soil erosion 81
Table 48 – Districts with highest percentage of area categorised as highest priority for protective forests based on impact on soil erosion 81

List of Annexes

Annexes 90

Annex 1 Example financial model 90

Annex 2 InVEST References Biophysical Table 92

Annex 3 Detailed results Chapter 6... 94

Annex 3.1.. Potential area (ha) and percentage of each restoration type by district 94

Annex 3.2. .... Methodology to create the impact potential maps 95

Annex 3.3... Additional SDR model result maps 96

Annex 3.4... Reduction classes per FLR action 96

Annex 3.5..... Detailed impact potential maps for erosion rate and sediment export rate.. 97

Annex 3.6............. Complete classification of districts according to area and percentage with highest potential impact.................................. 101

List of Annex Figures

Figure A1 – Total sediment export rate (per hectare and per year) in Rwanda........ 96

Figure A2 – Impact potential map on erosion rate for agroforestry system with annual crops 97
Figure A3 – Impact potential map on sediment export rate for agroforestry with annual crops.. 97

List of Annex Tables

Table A1 – Districts and number of hectares according to prioritisation category based on impact of agroforestry with annual crops on soil erosion 101
Table A2 – Districts and percentage of area according to prioritisation category for agroforestry with annual crops.. 102
Table A3 – Districts and number of hectares according to prioritisation category based on impact of agroforestry with perennial crops on soil erosion . 103
Table A4 – Districts and percentage of area according to prioritisation category for agroforestry with perennial crops... 104
Table A5 – Districts and number of hectares according to prioritisation category based on impact of planting managed woodlots on soil erosion.......... 105
Table A6 – Districts and percentage of area according to prioritisation category for managed woodlots 106
Table A7 – Districts and number of hectares according to prioritisation category based on impact of protective forests on soil erosion 107
Table A8 – Districts and percentage of area according to prioritisation category for protective forests 108

Acronyms

AER	Average Erosion Rate
AFR100	Africa Forest Landscape Restoration Initiative
BCR	Benefit cost ratio
CBA	Cost-benefit analysis
DAP	Diammonium phosphate
DEM	Digital Elevation Model
DM	Dry matter
FLR	Forest landscape restoration
ICRAF	World Agroforestry Centre
IMP	Intervention Maturity Profile
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IPR	Investment Packages for Rwanda
IRR	Internal Rate of Return
IUCN	International Union for Conservation of Nature
NPK	Nitrogen Phosphorus and Potassium
NPV	Net Present Value
NST1	National Strategy for Transformation
REDD+	Reduce Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
RNRA	Rwanda Natural Resources Authority
ROAM	Restoration Opportunities Assessment Methodology
ROI	Return on investment
RWF	Rwandan Franc
RWFA	Rwanda Water and Forestry Authority
SDR	Sediment delivery ratio

USLE	Universal Soil Equation
VTS	Value of Topsoil
WRI	World Resources Institute

1. SUMMARY

Delivering on the multiple benefits promise of forest landscape restoration (FLR) requires scaling appropriate technical packages in the suitable agro-ecological zone and should be supported by policies that enable its mainstreaming across all sectors in the development agenda. Rwanda's agenda for FLR is tangled with its socioeconomic transformation goals as presented in the National Strategy for Transformation (NST1) and in the Green Growth and Climate Resilience Strategy.

In 2011, the government of Rwanda made an ambitious commitment under The Bonn Challenge[1] of bringing 2 million ha under restoration by 2030. In 2014, the national Restoration Opportunities Assessment Methodology (ROAM)[2] was undertaken and identified four restoration transitions, including (i) agroforestry on steep sloping land, (ii) improved woodlot plantation, (iii) protective forests on riverbanks and (iv) natural forest rehabilitation.

The Bonn Challenge Barometer of Progress[3] showed that from 2010 to 2018, around 44 known projects brought 708,628 ha under restoration through an investment of US$ 530,762,526. One of the projects that piloted the landscape approach by implementing the mentioned restoration packages was entitled 'Piloting Multiple-Benefit Investment Packages through forest/landscape restoration and Reduce Emissions from Deforestation and forest Degradation (REDD+) and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries in Rwanda for scaling up in Africa', which was implemented by the International Union for Conservation of Nature (IUCN) in collaboration with the Ministry of Environment through Rwanda Water and Forestry Authority (RWFA). The project was implemented in two districts from two contrasting agro ecologies.

The first district was Gatsibo in the Eastern Savannah agro-ecological zone, located in the semi-arid relatively lower lands (1,200–1,400 m), while the second district was Gicumbi in the humid agro-ecology of Buberuka Highland (1,900–2,000 m). Through this project, 11 FLR technical packages were studied and analysed to understand the positive impact they can generate and to assess their potential for scaling up across the country. The current report highlights a financial cost-benefit analysis of implementing these FLR actions, their suitability mapping, carbon sequestration potential, and their quantified and mapped potential to reduce soil erosion across the country.

In Gatsibo, the five technical packages piloted were (i) agroforestry (*Markhamia lutea and Grevillea robusta*) with maize-bean; (ii) agroforestry (*M. lutea and G. robusta*) with maize, beans and fodder (*Calliandra sp.* and *Leucaena sp.*); (iii) Eucalyptus plantation on public land; (iv) Eucalyptus plantation on private land; and (v) protective forests on roadsides (*G. robusta*). In Gicumbi District, the six packages were (i) agroforestry

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[1] The Bonn Challenge is a global effort to bring 150 million hectares of the world's deforested and degraded land into restoration by 2020, and 350 million hectares by 2030.
[2] https://portals.iucn.org/library/sites/library/files/documents/2014-077.pdf
[3] https://infoflr.org/bonn-challenge-barometer/rwanda/2019/hectares

(*Alnus acuminata and G. robusta*) with maize and beans; (ii) agroforestry with maize and beans and fodder in Gicumbi (*Calliandra sp. and Leucaena sp.*); (iii) agroforestry (*A. acuminata and G. robusta*) with wheat and Irish potatoes; (iv) Eucalyptus plantation in public land; (v) Eucalyptus plantation in private land; and (vi) protective forests on riverside.

To assess the impact of FLR actions in the two districts, the study applied a cost-benefit analysis (CBA) to assess financial profitability of each of the above-mentioned technical packages. CBA was used to compare the estimated benefits and costs from FLR implementation, now and in the future.

To understand the profitability, CBA results compared the difference between continuing with the traditional agricultural systems with the implementation of FLR activities (with and without FLR scenarios). The costs considered were implementation costs, management costs and agriculture/forest production costs. In addition, for the scenario of continuing the traditional agricultural system, increased soil loss compared to implementing FLR was included. The benefits considered include sale/consumption of crops, timber, firewood, and other uses of wood products. Additionally, the potential benefits from carbon sequestration were considered. Net present value (NPV), benefit cost ratio (BCR) and return on investment (ROI) were used as indicators to understand the financial performance of the FLR packages.

The results show that most of the FLR packages are profitable and provide positive net benefits for the proposed rotation periods at a baseline discount rate of 13% (**Figure 1**). The analysis showed that the implementation costs of FLR activities is relatively small, compared to the benefits from restoration. In Gatsibo District, agroforestry systems with maize, beans and fodder provide the highest incremental value (12,825,294 RWF/ha more than the traditional system) after a 10-year rotation period, while in Gicumbi District the agroforestry system with wheat and Irish potatoes provides the highest incremental value (12,332,848 RWF/ha) after a period of 10-years.

Protective forests provide lower incremental values (894,668 RWF/ha and 913,587 RWF/ha in Gatsibo and Gicumbi, respectively) after a rotation period of 20 years. The packages have different NPV and ROI, and each FLR action is unique and provides its own benefits.

This study did not aim to identify the restoration intervention that provides the highest returns; rather, it assessed the contribution and the profitability of each of the interventions depending on previous agricultural practices and land-use. For example, agroforestry systems provide the highest returns from direct financial benefits (sales and consumption of crop products) while protective forests and woodlots provide higher indirect environmental benefits (increased carbon sequestration and improved erosion control). These results indicate that certain restoration activities (especially for woodlots and protective forests) would be more interesting for public investment whereas agroforestry would bring higher returns for private producers practising it.

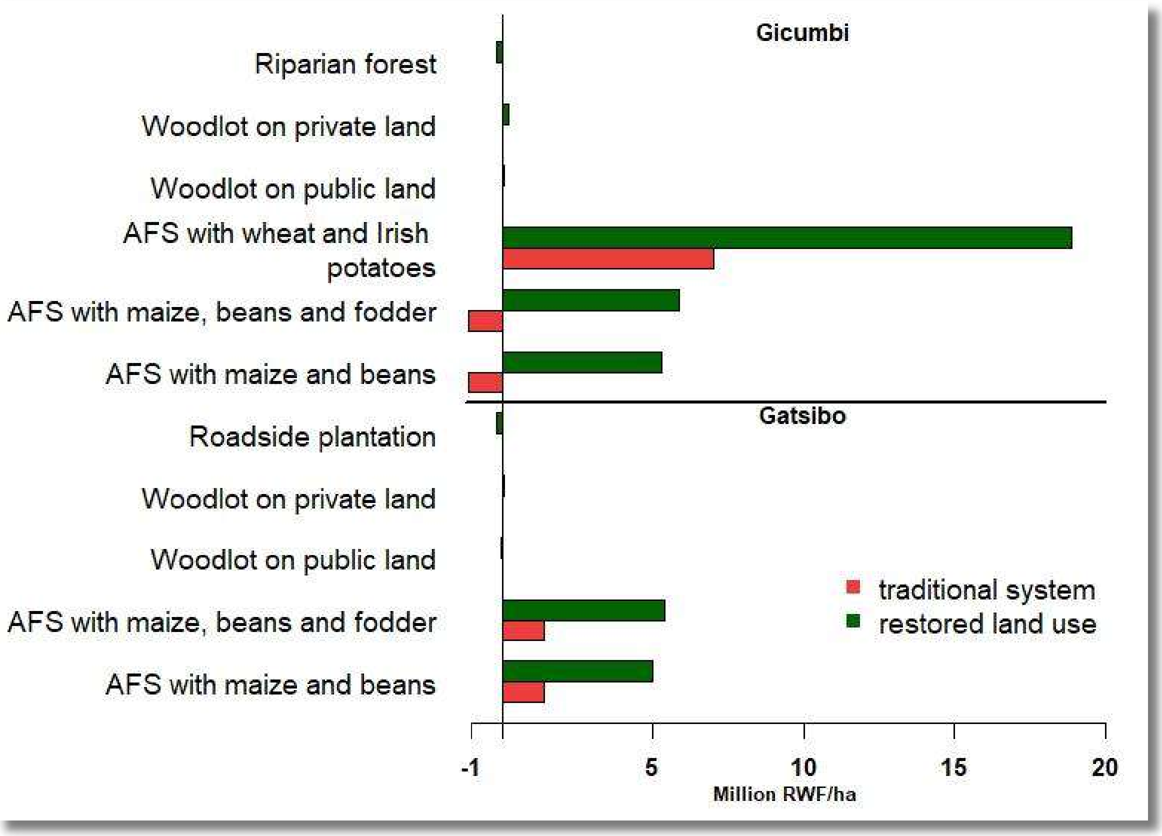


Figure 1 – Summary results for CBA
(NPV traditional system versus restored land use RWF/ha)

Based on the land cover map of 2015, the analysis showed that, not considering the 708,628 ha already restored since 2010, there are about 1,600,000 ha of land with potential for scaling up the implementation of the restoration packages considered in this study. About 79% of this potential area can be used for the implementation of agroforestry systems with annual crops. 16% of the total area with FLR potential for managed woodlots on land that currently contains sparse forest, and 2% for agroforestry systems with perennial crops, while the protective trees account for 3% of the total potential area of Rwanda.

Not including more than the 700,000 ha already restored in Rwanda, for agroforestry with annual crops, the districts with the greatest opportunities are by order Bugesera, Gatsibo, Gisagara, Kamonyi, and Nyanza. On the other hand, the top five districts with the highest potential for agroforestry with perennial crops are in the Eastern Province, starting with Kirehe followed by Kayonza, Ngoma, Rwamagana and Gatsibo. This is mainly because of the banana and agro-pastoral systems dominating in the Eastern Province.

For scaling the implementation of managed woodlots, the districts with the largest potential areas have between 19,000 and 22,000 ha, and those are Nyamagabe, Nyaruguru, Karongi and Gicumbi. For scaling protective trees, the highest potential areas suitable for these restoration types by district vary between 3,000 and 4,000 ha, with the highest area in Gisagara followed by Huye, Nyaruguru, Nyagatare and Nyanza.

To assess the potential impact of FLR actions on ecosystem services, the decrease in soil erosion was measured by estimating the difference between a scenario with and without the implementation of the restoration actions using the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) tool. The model results show a baseline average soil erosion rate of 65 t/ha/year, with values ranging from 0 to 380 t/ha/year across the country.

The FLR interventions showed high potential to reduce this annual soil loss due to erosion across the country. The district of Gakenke results indicate high potential for implementing agroforestry systems with annual crops and managed woodlots, based on the soil erosion reduction criteria. Other districts such as Ngororero, Rusizi, Rulindo, Karongi, Nyabihu, and Musanze also present high potential for restoration with high reduction on soil erosion coming from the implementation of agroforestry with annual crops and managed woodlots (**Figure 2** and **Figure 3**).

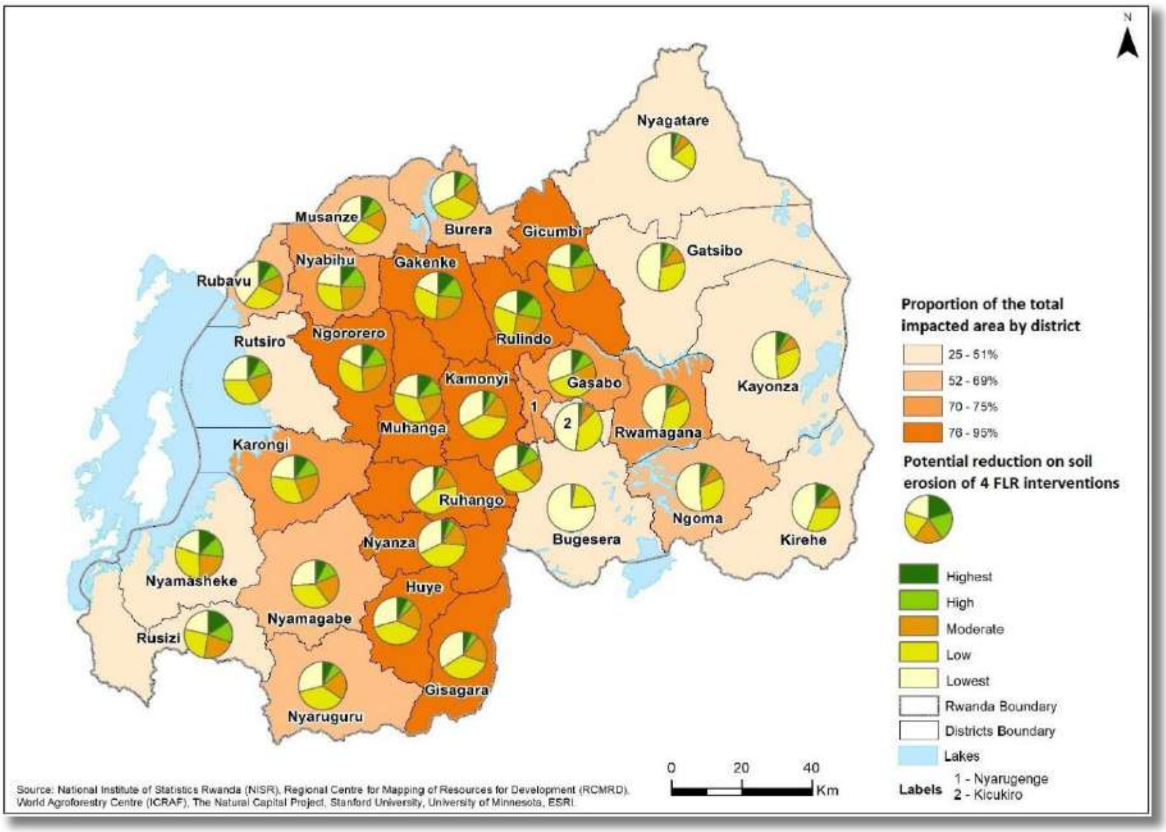


Figure 2 – Proportion of the impacted area and categorization by level of impact on soil erosion rate by combined FLR packages per district

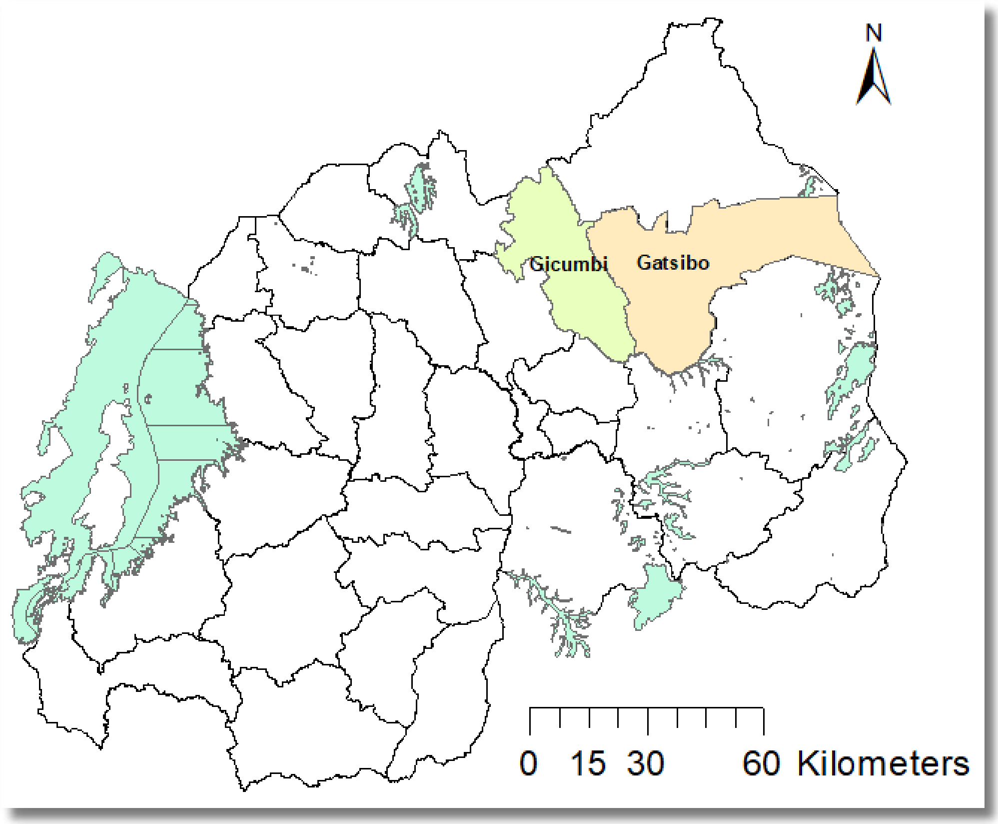


Figure 3 – Rwanda administrative map with Gicumbi and Gatsibo districts of intervention highlighted

The Investment Packages for Rwanda (IPR) project aimed to promote the restoration of a mosaic of forest landscapes and to enhance carbon stocks in Rwanda as well as deepen commitments to FLR across eastern Africa. It aimed to stimulate increased public and private investment in FLR at community, district, national and regional levels through policy and programmatic frameworks and pilot restoration of carbon intensive landscapes in two districts. The project started in June 2015 and by December 2018 it had brought under restoration 18,000 ha of degraded land. Restoration was implemented with more than 15,000 ha of agroforestry and 800 ha on new woodlots. Included in these new woodlots were 90 ha of indigenous trees with more than 20 indigenous tree species brought back into the landscapes. Around 130 ha of protective forests were established, and around 2,000 ha of existing forests were better managed with 100 ha restored through farmer-managed natural regeneration.

Beyond ground restoration, IPR has supported FLR policies and strategies such as:

i. Rwanda National Forestry Policy 2018,
ii. National Tree Reproductive Materials Strategy, and
iii. Forestry Research Strategy and Guidelines for Rwanda (2018–2024).

In the same efforts to influence policies, the project supported across-sectoral taskforce to catalyse coordination in FLR implementation and monitoring. The project reached 56,000 people during the implementation cycle and left a strong FLR legacy in the country especially in the two districts of intervention. The current document elaborates on lessons learned on FLR technical packages and reflects upon how they can be scaled up nationally.

2. INTRODUCTION

2.1. Forest landscape restoration as a sustainable land-management option in Rwanda

The Rwandan landscapes most vulnerable to climate change are those already affected by unsustainable land and water management, which have accelerated landscape degradation with multiple negative consequences on the population's livelihoods. The demand for tree products and the expansion of agricultural land in the highly populated country have led to deforestation and a shortage of tree products. Forest landscape restoration (FLR), which is the long-term process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes, presents high potential to reverse degradation trends while creating multiple benefits at the landscape level (IUCN & WRI, 2014).

In 2011, Rwanda made an ambitious pledge to the Bonn Challenge to restore 2 million ha of forest and agricultural land, establishing itself as a global leader in the restoration movement (MINIRENA, 2014). The country's National Strategy for Transformation (NST1), the green growth strategy, and the Sector Strategic Plan for Agriculture, among others highlight the political will to turn more than 80% of the country's land to productive landscapes for the national green economy. To achieve this, professionals from the Department of Forestry and Nature Conservation in Rwanda Water and Forestry Authority (RWFA) worked in partnership with International Union for Conservation of Nature (IUCN) and World Resources Institute (WRI) experts and alongside relevant governmental and non-governmental stakeholders to conduct the Restoration Opportunities Assessment Methodology (ROAM) in Rwanda. They identified priority areas for restoration as well as a brief list of feasible interventions that would restore degraded and deforested land (IUCN & WRI, 2014).

2.2. Restoration Opportunities Assessment Methodology in Rwanda

ROAM is a flexible framework for countries to rapidly assess FLR potential and locate specific areas of opportunity at national or sub-national levels. ROAM was developed by IUCN and WRI through a collective and collegial learning process that has involved a large number of organisations in Ghana, Mexico and Rwanda as well as local stakeholder groups in these countries (IUCN & WRI, 2014). IUCN has spearheaded ROAM applications across the globe and equipped decision makers and direct stakeholders with critical knowledge on where and how to implement restoration actions. There is a growing momentum to apply ROAM to assess the restoration opportunities in other countries, especially those committed to the Bonn Challenge and to Africa Forest Landscape Restoration Initiative (AFR100).

In Rwanda, a ROAM was undertaken in 2014 to rigorously assess and quantify restoration opportunities available for the implementation of Rwanda's "border to border" restoration commitment. The Department of Forestry and Nature Conservation professionals of RWFA (formerly RNRA), in partnership with IUCN and WRI experts, worked as a team to identify and map areas and landscapes with the most urgent restoration needs; where benefits are immediate and where success is more likely. More than one hundred district officials and other key stakeholders from civil society were involved.

Restoration transitions identified were:

i. Transforming agriculture to agroforestry mainly on steep-sloping land;
ii. Converting the poorly managed Eucalyptus woodlots and plantations into improved silviculture and rehabilitation of existing, sub-optimally managed woodlots, with spacing and erosion and fire-prevention best practices;
iii. Restoration of deforested land by protection and rehabilitation of existing areas of natural forests; and
iv. Restoration of deforested land through the establishment or improvement of protective forests on important and sensitive sites.

A total restoration opportunity area for these identified restoration transitions exceeded 1.5 million ha.

ROAM in Rwanda finally elaborated on the next steps to support FLR in the country, which are mainly to improve coordination among agencies and better align mandates, improve delivery of high-quality planting stock, match farmers' preferences to the FLR offer, and initiate early action in priority landscapes. Other required next steps were on the identification and mobilisation of innovative finance and resourcing packages. All these steps also require investments in education and outreach to communicate the value of restoration to the wide range of stakeholders who could be willing to participate in local, regional, or national restoration programs.

2.3. Restoration case study in two contrasting agro-ecologies of Rwanda

Rwanda is a hilly country with altitudes less than 1,500 m in the eastern plateau but rising higher than 2,000 m in the west and north. The variation in altitude affects rainfall and temperature patterns, which have influenced the farming systems and socio-economic characteristics, leading to six heterogeneous agro-ecological zones (Iiyama et al., 2018). The Bonn Challenge Barometer of Progress that IUCN piloted in Rwanda identified 44 projects/ programmes of FLR in the whole country, which had brought under restoration a total of 708,628 ha through an investment of almost USD 531 million from 2011 to 2018[4] (see Chapter 5 for more detail).

A restoration case study is derived from one of these projects, entitled 'Piloting Multiple-Benefit Investment Packages through forest landscape restoration and REDD+ in Rwanda for scaling up in Africa' which was implemented by IUCN in collaboration with RWFA in two districts from two contrasting agro-ecologies. The first district was Gatsibo in the Eastern Savannah agro-ecology, located in the semi-arid relatively lower lands (1,200–1,400 m), and the second district was Gicumbi in the humid agro-ecology of Buberuka Highland (1,900–2,000 m), see location in **Figure 4**. This project is abbreviated as IPR.

[4] https://infoflr.org/bonn-challenge-barometer/rwanda/2018/policies

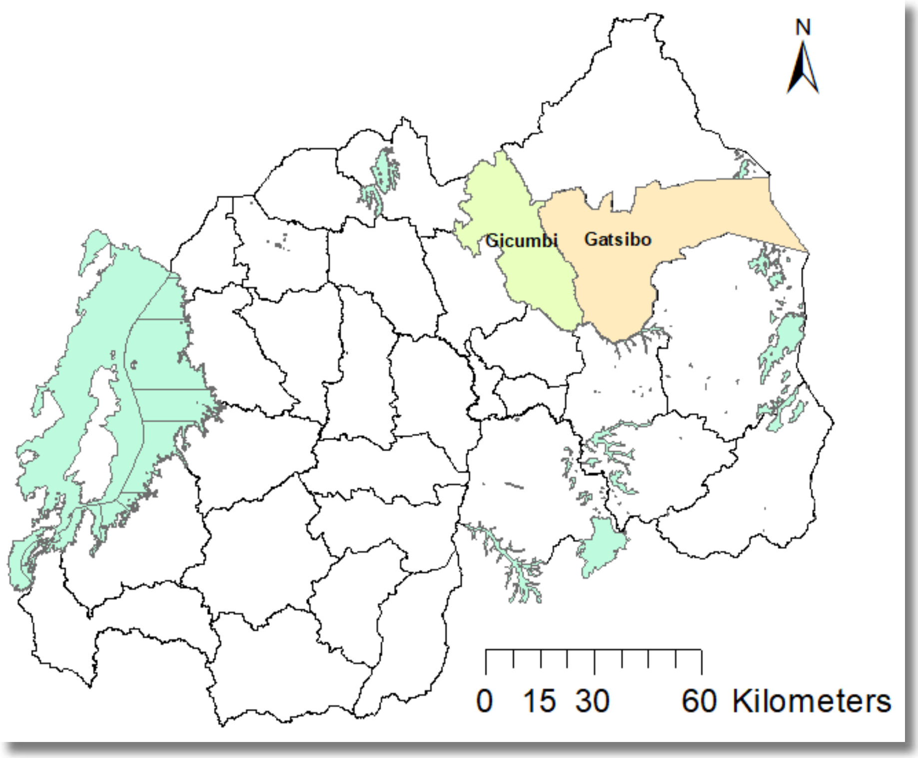


Figure 4 – Rwanda administrative map with Gicumbi and Gatsibo districts of intervention highlighted

The IPR project aimed to promote the restoration of a mosaic of forest landscapes and to enhance carbon stocks in Rwanda as well as deepen commitments to FLR across eastern Africa. It aimed to stimulate increased public and private investment in FLR at community, district, national and regional levels through policy and programmatic frameworks and pilot restoration of carbon intensive landscapes in two districts. The project started in June 2015 and by December 2018 it had brought under restoration 18,000 ha of degraded land. Restoration was implemented with more than 15,000 ha of agroforestry and 800 ha on new woodlots. Included in these new woodlots were 90 ha of indigenous trees with more than 20 indigenous tree species brought back into the landscapes. Around 130 ha of protective forests were established, and around 2,000 ha of existing forests were better managed with 100 ha restored through farmer-managed natural regeneration.

Beyond ground restoration, IPR has supported FLR policies and strategies such as:

i. Rwanda National Forestry Policy 2018,
ii. National Tree Reproductive Materials Strategy, and
iii. Forestry Research Strategy and Guidelines for Rwanda (2018–2024).

In the same efforts to influence policies, the project supported across-sectoral taskforce to catalyse coordination in FLR implementation and monitoring. The project reached 56,000 people during the implementation cycle and left a strong FLR legacy in the country especially in the two districts of intervention. The current document elaborates on lessons learned on FLR technical packages and reflects upon how they can be scaled up nationally.

3. PRESENTATION OF SPECIFIC FOREST LANDSCAPE RESTORATION CATEGORIES

3.1. AGROFORESTRY SYSTEMS IN RWANDA

Agroforestry is defined by the World Agroforestry Centre (ICRAF, 2016) as the practice and science of the interface and interactions between agriculture and forestry, involving farmers, livestock, trees, and forests at multiple scales. In agreement with ICRAF, international organisations, such as FAO (2015), define agroforestry as “a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals”. This agrees with IUCN’s definition that considers agroforestry as a land-use system in which woody perennials are grown for wood production alongside agricultural crops and with or without animal production.

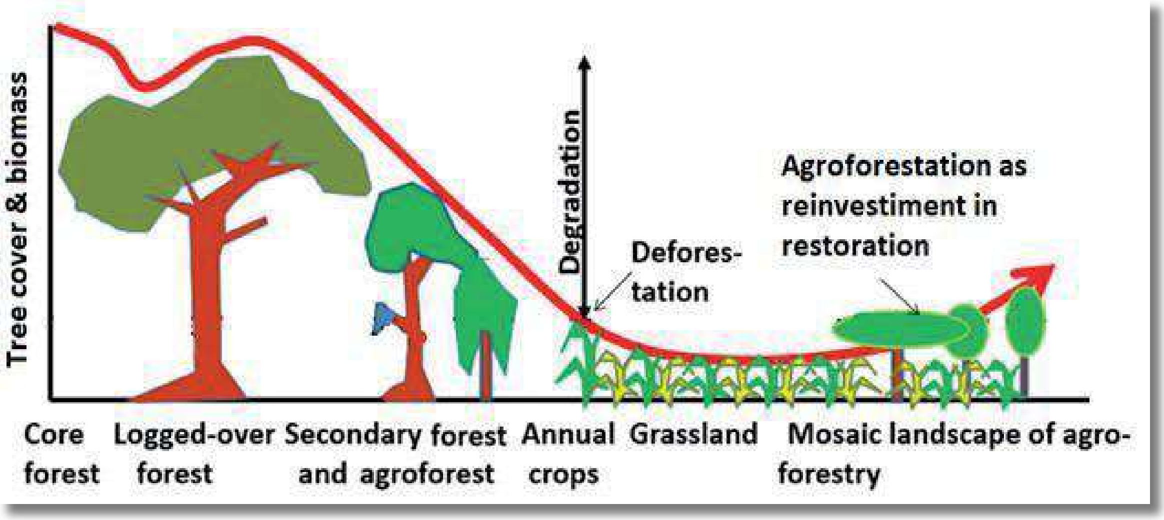
Agroforestry is an old practice around the world but relatively young as a branch of agricultural science. In Rwanda, some existing types of agroforestry are:

i. Slash and burn practices with tree-fallows
ii. Agroforestry home gardens
iii. Shade trees for coffee plantations
iv. Herding of animals in rangelands with trees

Based on agroforestry components, these practices can be classified in three broader categories the first being agrisilviculture (trees and crops), the second is silvopastoralism (trees and animals), and the third being the combination of the two in agrosilvopastoralism (tree, crops, and animals) (ICRAF, 2016) (see **Figure 5**). Based on time-structure, agroforestry can also be classified in simultaneous systems (e.g., alley cropping, savannah parklands, multi-story gardens) and sequential systems (e.g., the old shift cultivation, improved fallows, rotational woodlots).

Restored farmland in Gatsibo district by IUCN-Rwanda.

In many countries in the world, especially those constrained with land resources such as Rwanda, the replacement of natural forest by planted tree cover has occurred in a gradual process of agroforestry development. In Rwanda, agroforestry for land restoration is spreading mainly to control soil erosion on steep slopes, restore soil fertility and ensure a sustainable supply of fuel wood – the main source of cooking energy – and timber for various uses. Recent studies (Ndoli, 2018; Iiyama et al., 2018) found that the practice is becoming increasingly common with resource poor farmers and with limited access to larger forests.



Source: Adapted from Van Noordwijk et al. (1995) and Ndoli (2018).

Figure 5 – Tree cover transitions with agroforestry as a reinvestment in land restoration

3.2. DESCRIPTION OF LAND USES BEFORE RESTORATION ACTIONS

The land use of Rwanda has been affected by a steady period of growth in both population and economic development. Agriculture, in terms of crop production and livestock, is the principal economic activity in the country. At the onset of the IPR project in 2015, land use was and still is dominated by cropland (69%) with the remainder in forest (14%), grassland (7%), and wetlands and water bodies (9%). Land degradation in the country has been accelerated by direct drivers such as improper management of soil, deforestation, and over-exploitation of vegetation for domestic use, in addition to natural factors such as steep slopes vulnerable to erosion, landslides and flooding. Indirect drivers of degradation were mainly population pressure, poverty, low levels of education, and gaps in natural resource governance and policies (IUCN & WRI, 2014).

Before restoration in the IPR pilot districts (*Gatsibo* and Gicumbi), natural ecosystems were significantly altered. Large areas had been cleared for various farming practices. Almost all natural, indigenous vegetation (apart from small areas of freshwater swamps and grasslands influenced by soil types) had been converted to settlements or agro ecosystems in the pilot landscape sites. Large areas of bare soil existed within the districts. The land uses essentially consisted of farmlands (various crops) and exotic tree plantations (*Eucalyptu*s mostly). The latter ranged from formally managed to residual plantations that have been overharvested with evidence of tree coppicing. The farmlands were mainly cropped with maize and beans in Gatsibo District while in Gicumbi, farmers cropped maize, beans, wheat, and Irish potatoes.

3.3. MAIZE AND BEANS PRODUCTION IN GICUMBI AND GATSIBO PRIOR TO RESTORATION

Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) represent Rwandan subsistence rain fed agriculture. In 2014, around 84.9% of the population in Gatsibo and 90% in Gicumbi depended on agriculture for livelihoods. In these districts, maize and beans are major crops grown in rotational cropping systems because both crops share several climatic, landscape and soil requirements. Maize is somewhat more demanding – more sensitive to water shortages, low temperature, and low chemical soil fertility. In addition, extensionists advise this maize-bean rotation because beans can fix nitrogen in the soil, restoring fertility depleted by maize. In 2016, out of 16 crops, beans were grown on the second largest area (20%) following cassava (22%), while maize was ranked fourth, occupying 9.3% of the country's total arable land. In Gatsibo District, maize was grown in the largest area (49%). In this district, farmers had been experiencing significantly low yields due to unsustainable agricultural practices. Using the upper boundary of potential yield, gaps for maize yields were estimated at 60.7% and 71.7% for beans (MINAGRI, 2014). Yields of maize and beans prior to restoration are summarised in **Table 2**.

The agricultural sector employed the largest proportion of the Rwandan population with 68% workers at the national level and 76% in rural areas in 2014 (EICV, 2014). In addition, the proportion of females in agriculture was higher than males. In Gicumbi and Gatsibo districts, most agriculture operations in maize and bean production are done manually with in-house and hired labour. The national fertiliser policy (2014) highlights that fertiliser use increased from 4 kg/ha in 2006 to 30 kg/ha in 2013 with the target to reach 45 kg/ha in 2018. However, the usage of fertilisers was still relatively low (49.5% of farmers used fertilisers) when IPR started restoration in Gatsibo and Gicumbi. Statistics of agriculture inputs such as labour and fertiliser use for maize and bean production in Gicumbi and Gatsibo in 2016 are presented in **Table 1**.

Table 1 – Average agricultural inputs for maize and bean production in both Gatsibo and Gicumbi districts in 2016

Agricultural inputs	Values
Hired labour (days/ha/season)	11
House labour (days/ha/season)	99.5
Diammonium phosphate (kg/ha)	100
Urea (kg/ha)	50
Organic manure (t/ha)	10
Maize seeds (kg/ha)	24
Bean seeds (kg/ha)	50

3.4. Wheat and Potato Production in Gicumbi Prior to Restoration

Wheat (*Triticum aestivum L.*) and Irish potato (*Solanum tuberosum L.*) are important rain fed crops of the Rwandan highlands with large- and small-scale production (Nziguheba et al., 2016; Muhinyuza et al., 2015), but production is limited by unsustainable agricultural practices. In 2016, and among 16 crops, wheat was grown on the smallest area (0.5%) due to its limited niche in highlands, while potato was grown on 4.2% of the total arable land (MINAGRI-PSTA 4, 2018). National wheat and potato yield gaps were estimated at 46% and 76%, respectively, in 2014 (MINAGRI, 2014). Gicumbi District is in Buberuka Highlands, which is one of the few regions providing a conducive environment for wheat and potato production in the country. Farmers in Gicumbi traditionally rotate wheat with potato in their cropping patterns. Yields of wheat and potato prior to restoration are summarised in **Table 2**.

Table 2 – Average yields of annual crops in Gicumbi and Gatsibo districts prior to restoration

Crops	National (yield in t/ha)	Gicumbi (yield in t/ha)	Gatsibo (yield in t/ha)
Maize	1.6	2.6	3.4
Beans	1.2	1.6	2
Potatoes	8.2	14.88	-
Wheat	0.95	3.5	-

Source: National data are from PSTA4, 2018.

Fertilisers are commonly used for wheat and potato production in Rwanda, but rates of application are low, and the recommendations are generalised. The fertiliser recommendations for wheat are 250 kg/ha Nitrogen Phosphorus and Potassium (NPK 17-17-17) or 100 kg/ha Diammonium phosphate (DAP) and 10 t/ha organic fertiliser, and for potato it is 300 kg/ha NPK 17-17-17 and 20 t/ha organic fertiliser, but these rates are rarely applied. Potato generally receives higher amounts of fertilisers compared to wheat due to its high response to the applied nutrients and its greater market opportunities. Most of the activities in wheat and potato farming are done manually with hired and in-house labour. The figures on agricultural inputs, such as labour and fertiliser use, for wheat and potato production in Gicumbi District in 2016 are presented in **Table 3**.

Table 3 – Average agricultural inputs for wheat and potato production in Gicumbi District in 2016

Agricultural inputs	Values
Hired labour (days/ha/season)	11
House labour (days/ha/season)	99.5
Diammonium phosphate (kg/ha)	100
Urea (kg/ha)	50
NPK (kg/ha)	300
Organic fertilisers (t/ha)	10
Wheat seeds (kg/ha)	25
Potato seeds (kg/ha)	2,500

4. EXPLANATION OF FOREST LANDSCAPE RESTORATION ACTIONS

4.1. AGROFORESTRY WITH MAIZE AND BEANS IN GATSIBO

4.1.1. Description of tree species in maize-bean agroforestry in Gatsibo

A total of 8,545 ha of degraded farmlands were brought under restoration in Gatsibo District through planting of adapted and farmer-preferred agroforestry tree species. Around 7,690 ha of cropland were planted with one indigenous (*Markhamia lutea*) and one exotic (*Grevillea robusta*) tree species.

Markhamia lutea or Nile tulip is a tree species of the plant family Bignoniaceae, native to eastern Africa and found at elevations from 700–2,000 m. It is a small evergreen tree that grows 10–15 m in height with a narrow, irregular crown and long tap root. The tree is drought resistant but cannot withstand waterlogging. It prefers red loam soil but can tolerate well-drained, heavy, acidic, clay soils. It is propagated with seeds. In Rwanda, *M. lutea* products include firewood and medicinal leaves; and its wood, which is resistant to termites, is used for furniture, poles, posts, traditional tool handles and boat building. The ecosystem services provided by *M. lutea* are erosion control, shade, windbreaks, and soil improvements. In addition, it provides poles to support banana trees and can be used as an ornamental species or for boundary demarcation. *M. lutea* grows fast in good soil, and plants can attain growth rates of more than 2 m/year (Orwa et al., 2009).

Grevillea robusta is a highly successful Australian tree widely used in Africa with elevational ranges from 0 to 3,000 m. It is a semi-deciduous tree that grows to 20 m height or more with a straight trunk and angular branches. It grows on fairly well-drained and neutral to acidic soils but does not tolerate water logging or heavy clays. G. robusta was introduced to Rwanda in the early 20th century mainly for ornamental purposes and for shade in tea plantations (Kalinganire & Hall, 1993). It is one of the most widely planted upper-storey tree species in agroforestry systems in Rwanda having proved its adaptability under a range of conditions. It contributes to more than 10% of the total man-made forests in the country including the trees on farms (Kalinganire, 1996). In Rwanda, G. robusta is currently used as a multipurpose tree species mainly grown by farmers as a boundary tree, windbreak or shelterbelt, contour planting to control soil erosion, shade tree for tea and coffee, and among crops on farms to improve soil fertility. It provides good timber and firewood. In Rwanda, growth per year commonly achieved in routine plantings using locally produced seeds averages about 2 m in height and 2 cm diameter at breast height during the first 5-10 years (Kalinganire, 1996); however higher production is obtained in other countries with some species with Australian provenances (Kalinganire & Hall, 1993).

4.1.2. Agronomy of trees and crops in maize-bean agroforestry in Gatsibo

While layout and tree species varied, the agronomy of trees and crops was almost similar in all the FLR packages and is presented here to give an overview to the reader. It is therefore not repeated in the following packages.

Tree seeds for *G. robusta* and *M. lutea* were acquired from the national tree seed centre located in Huye District. High-quality seedlings were produced in the temporary and permanent nurseries close to water sources and feeder roads near the planting sites in Gatsibo District. Standard seedbed soil mixtures of 50% sieved topsoil, 50% sieved sand, and additional manure (around 10% of the mineral component) were used. Pot filling was done in polythene tubes with soil, pricking out and full shade for the first 2–3 weeks, then half shade accompanied by regular watering and weeding as appropriate. Whenever needed, root pruning was conducted to avoid the roots of the seedlings inter-twining. Hardening off was done by reducing the amount of irrigation water 3 to 4 weeks before seedlings were planted out in the field. Around 200 trees per hectare were planted by farmers in various niches, mainly on contour hedges, boundary planting and scattered within the fields (**Figure 6**).

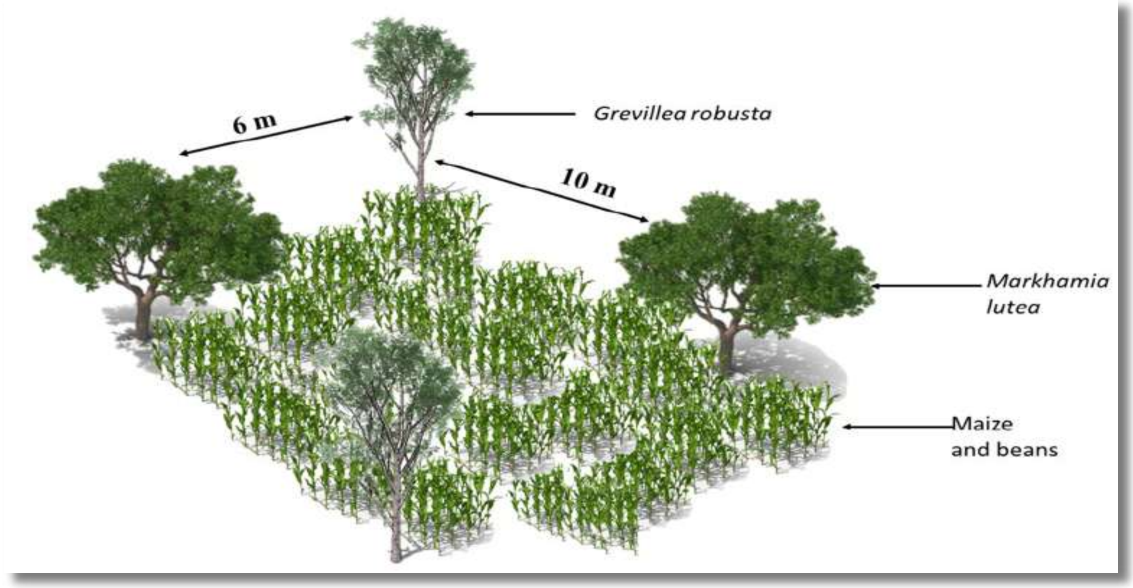


Figure 6 – Tree arrangement in the agroforestry system of maize and beans in Gatsibo

4.2. AGROFORESTRY WITH MAIZE, BEANS, AND FODDER IN GATSIBO

4.2.1. Description of tree species in maize-bean-fodder agroforestry in Gatsibo

In Gatsibo District, around 855 ha of farmland were planted with *M. lutea* and *G. robusta* in addition to fodder trees/shrubs namely Gliricidia sepium, Leucaena leucocephala, and Calliandra colothyrsus (see **Figure 7**). While *M. lutea* and *G. robusta* were described in the section above, the fodder trees are described and characterised in this section.

Gliricidia sepium is a fast growing, medium-size, leguminous (nitrogen-fixing) tree native to tropical dry forests in Mexico and Central America. It belongs to the family Fabaceae and grows 10 to 12 m in elevations ranging from 0 to 1,600 m. The drought-tolerant tree grows well in well-drained, acidic soils with sandy or clay texture and in slightly alkaline limestone soils. *G. sepium* is often used for fodder for large and small ruminants, firewood and charcoal production, stakes for climbing beans, and exceptionally durable and termite-resistant timber for various uses. It is used in hedgerows in alley cropping to suppress weed growth and control erosion and could be used as a shade tree for tea and coffee. Attributes contributing to its value as a fodder, stake and firewood source, and soil improver (fertiliser tree), are mainly its ability to withstand repeated pruning and to resprout vigorously (Stewart et al., 1996). Annual leaf dry matter (DM) production varies from 2–20 t/ha/year, depending on a wide range of factors. In fodder plots, annual yields of 5–16 t/ha of leaf DM or up to 43 t/ha fresh leaves have been obtained. Feeding levels have been 1–3% of body weight for cattle and goats, indicating a supplementation level of 30–100%, although a 20–40% level is more common. Increases in live weight gains of approximately 25% have been reported for steers grazing gliricidia-grass pastures, compared with steers grazing grass alone. Results from experiments with dairy cows reported similar or slightly increased milk yield and milk fat yield when concentrates were replaced by gliricidia forage up to about 25% of intake. When *G. sepium* is planted at a spacing of 2 m x 2 m (2,500 trees/ha) and cutting on a three-year cycle by coppicing all stems to 10–20 cm above ground level, the regime gives a mean annual increment of 2 to 5.3 t/ha dry weight (CATIE, 1991).

Leucaena leucocephala is a small, fast-growing, nitrogen-fixing mimosoid tree native to southern Mexico and northern Central America and is now naturalised throughout the tropics at altitudes of 1,500–2,100 m. *L. leucocephala* is used for a variety of purposes, such as firewood (high calorific value of 4,600 cal/kg), fibre, and livestock fodder. It is one of the highest qualities and most palatable fodder trees of the tropics, and its fodder results in a 70–100% increase in animal live weight gain compared with feeding on pure grass pasture. It is also used for soil erosion control, shade, live fencing, firebreaks, and as a soil improver. *L. leucocephala* is known to be intolerant of soils with low pH, low phosphorus, low calcium, high salinity, and high aluminium. It has been considered for biomass production because its reported yield of foliage corresponds to a dried mass of 2,000–20,000 kg/ha/year, and that of wood 30–40 m^3/ha/year, with up to twice those amounts in favourable climates. Young trees reach a height of more than 6 m in two to three years (Orwa et al., 2009).

Calliandra colothyrsus is a small, fast-growing, multipurpose legume (nitrogen-fixing) tree or large shrub in the Fabaceae family. It is native to the tropics of Central America and grows in altitudes ranging from 250 to 1,500 m. This tree is propagated by seeds, grows to about 5–12 m with a trunk diameter of 30 cm, and has flowers with a boss of prominent reddish-purple stamens. It is not very drought-tolerant, and the aboveground parts are short-lived but the roots regularly resprout. *C. colothyrsus* grows well on a wide range of soil types but prefers light textured, slightly acidic soils. It can tolerate infertile and compacted or poorly aerated soils but does not tolerate waterlogged and alkaline soils. It can be used to rehabilitate erosion-prone areas and recover land exhausted by agriculture, where it easily dominates undesired weeds. High leaf biomass production and high yields of protein leaf material on less fertile soils make it very suitable as a green manure and it is used in alley-cropping systems. It is good fodder with a protein content of 22% DM and annual fodder yield amounts to about 7–10 t/ha DM. The fodder can be given to all types of ruminants and fulfils 40–60% of their needs. *C. colothyrsus* is a good firewood species because it is fast growing, multi-stemmed, easy to regenerate and thornless. One year after planting, annual wood biomass yields have been reported in the order of 15–40 t/ha with annual coppice harvests continuing for 10–20 years.

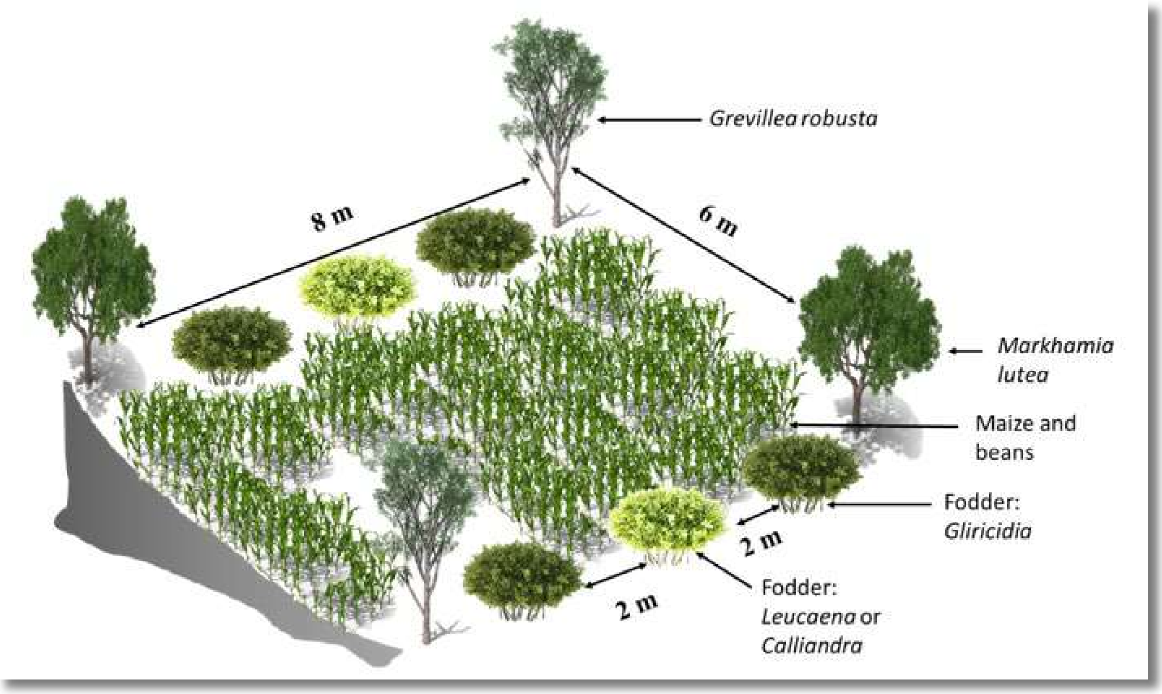


Figure 7 – Tree arrangement in the agroforestry system with maize, beans, and fodder in Gatsibo

4.3. Agroforestry with maize, beans, and fodder in Gicumbi

4.3.1. Description of tree species in maize-bean-fodder agroforestry in Gicumbi

Degraded farmlands of 5,722 ha were brought under restoration in Gicumbi District through plantings of adapted agroforestry tree species (see **Figure 8**). The indigenous tree species planted was *M. lutea* while the exotic species were *G. robusta* and *Alnus acuminata*. The fodder trees planted were *Leucaena leucocephala* and *Calliandra colothyrsus*. These tree species were described in the previous sections apart from *A. acuminata*, which is described here.

Alnus acuminata is a fast-growing, deciduous tree in the Betulaceae family originating in montane forests from Mexico to Argentina. It grows up to 30 m tall with a straight trunk of 50 cm diameter at breast height at 30 years of age and thrives in altitudes between 1,200 and 3,800 m. It tolerates poor soils and acidic conditions but prefers silty or sandy soils. The palatable, nitrogen-rich leaves make a useful source of emergency fodder. Reputed to be good for firewood, in a rotation of 20 years, the annual yield of wood for fuel is estimated at 10–15 m3/ha. A. acuminata is a pioneer species used for watershed protection and can be used for soil improvement because its root nodules fix nitrogen. A. acuminata is one of the main species that has been promoted in Rwandan highlands for its significant role in soil erosion control in steep and unstable soils and on radical terraces where it has proven to be a reliable source of stakes for climbing beans, the variety mainly grown in this region. Recent studies by Miyuki et al. (2018) have shown that A. acuminata was adopted by over 80% of the households in Bubureka Highland where Gicumbi District IPR sites are located.

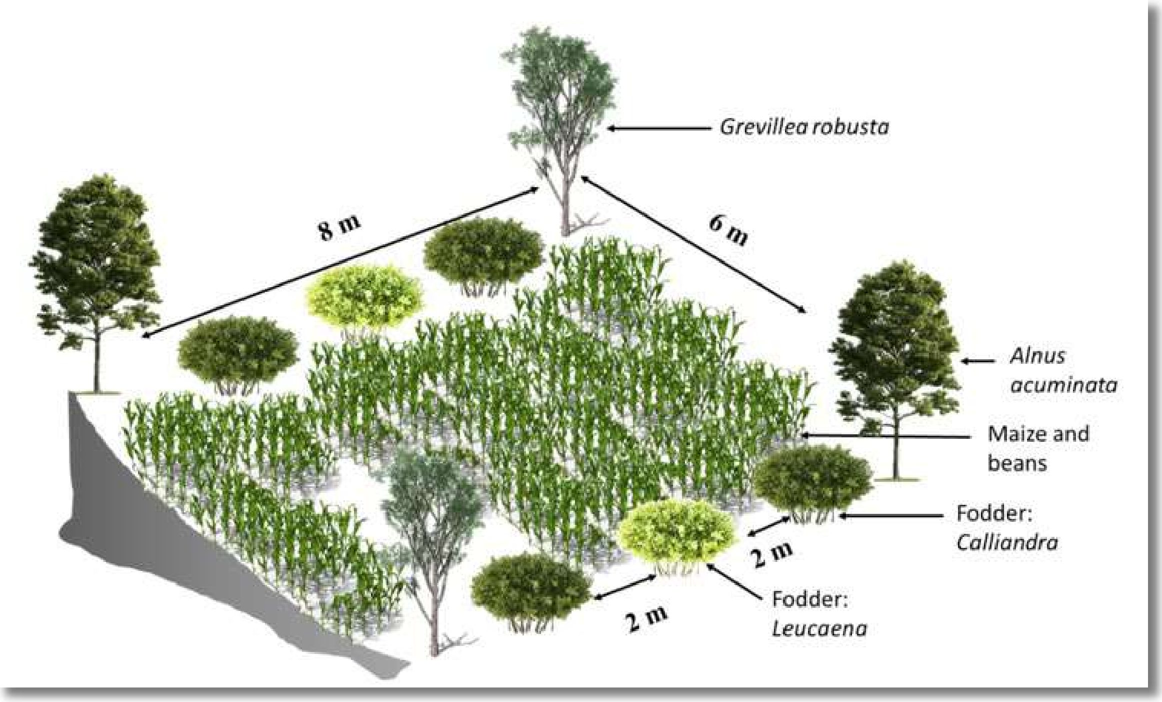


Figure 8 – Tree arrangement in agroforestry system with maize, beans, and fodder in Gicumbi

4.4. AGROFORESTRY WITH WHEAT AND POTATO IN GICUMBI

4.4.1. Description of tree species in wheat-potato agroforestry in Gicumbi

Around 1,270 ha of degraded farmlands in Gicumbi District were brought under restoration through planting of adapted agroforestry tree species (see **Figure 9**). The indigenous tree species planted was *M. lutea* while the exotic species were *G. robusta* and *A. acuminata*. These tree species were described in the previous sections.

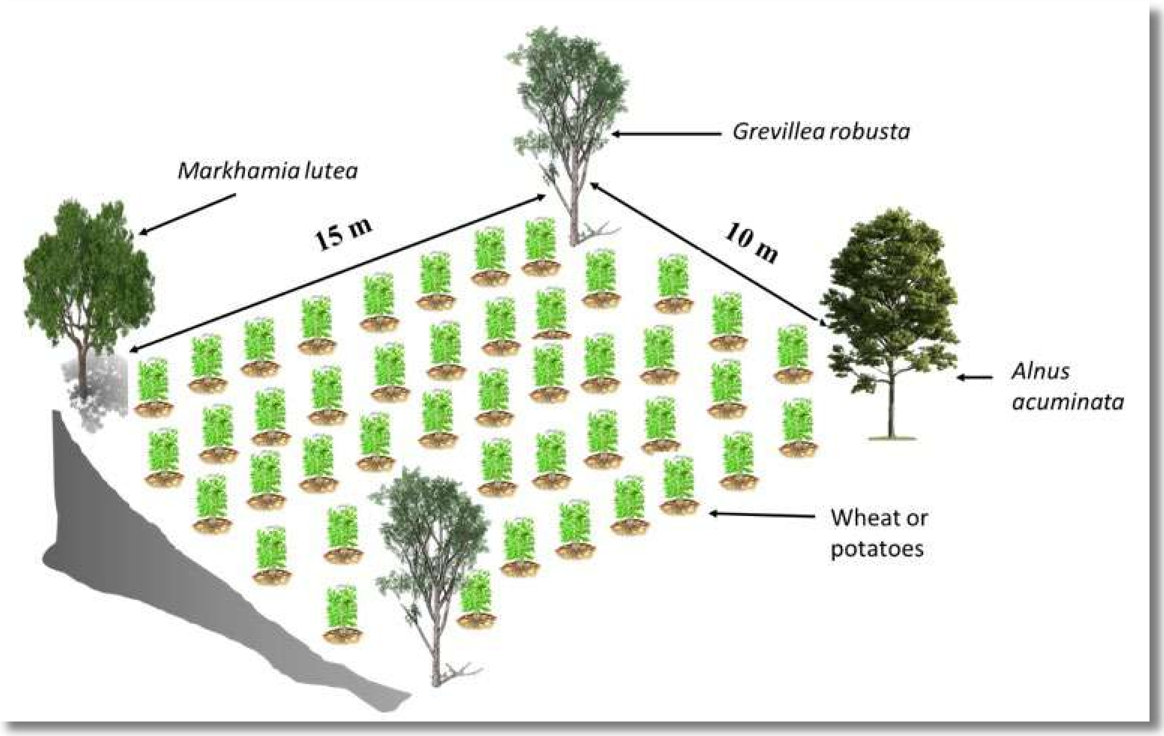


Figure 9 – Tree arrangement in agroforestry system with wheat and potato in Gicumbi

4.5. WOODLOT PLANTATIONS IN GATSIBO AND GICUMBI

4.5.1. Description of tree species in woodlot plantations in Gatsibo and Gicumbi

In Gatsibo District, 586 ha of degraded lands were planted with *Eucalyptus camaldulensis* in woodlots. Around 215 ha of degraded and bare lands in Gicumbi were also brought under restoration through woodlot plantations of *Eucalyptus microcorys*.

Eucalyptus camaldulensis, or river red gum, is one of around 800 species within the *Eucalyptus genus* that commonly grows to 20 m (occasionally reaching 50 m), has a trunk diameter of 1–2 m and thrives in altitudes of 0–1,500 m. It is a straight-growing tree but can develop a more twisted habit in drier conditions. This species grows best on deep, silty or loamy soils with a clay base and accessible water table. It tolerates waterlogging, periodic flooding and acidic soils. The speed of growth of the tree makes it a useful plantation timber; a reason why it is one of the most widely planted Eucalyptus in the world. *E. camaldulensis* is a major source of honey, producing high yields of nectar in good seasons. The firewood is suitable for industrial use in brick kilns but is not preferred for domestic use because it is too smoky and burns too fast. However, it makes good-quality charcoal. Because of its great strength and good durability, the wood is suitable for many structural applications. *E. camaldulensis* is widely planted for shade and shelter. While most Eucalyptus species severely compete and depress associated crops, *E. camaldulensis*, with its light crown, is suited for growing in arable fields. Intercropping maize with trees planted at 5 x 5 m in initial stages gives satisfactory yields (Orwa et al., 2009). Seedling growth may exceed 3 m per year for well-adapted provenances on favourable sites.

Eucalyptus microcorys, or tallowwood, is a eucalypt species native to Australia. A medium to tall evergreen tree growing to 40 m at fast rates, *E. microcorys* occasionally reaches heights of 70 m in mountainous or hilly countries. It is suitable for sandy, loamy and clay soils and prefers well-drained soils. It can grow in nutritionally poor acidic, neutral and alkaline soils but it cannot grow in the shade. It prefers dry, moist or wet soil and can tolerate drought. In Rwanda, the growth rates of *E. microcorys* are similar to the ones observed with *E. camaldulensis*.

4.6. PROTECTIVE FORESTS IN GATSIBO (ROADSIDE) AND GICUMBI (RIVERSIDE)

4.6.1. Description of tree species in protective forests in Gatsibo and Gicumbi

Protective forests were established on roadsides in Gatsibo District on 62 ha while in Gicumbi, protective forests were planted on riversides on 117 ha using *A. acuminata* and *M. lutea* tree species (see **Figures 10** and **11**). Detailed descriptions of these tree species are provided in previous sections.

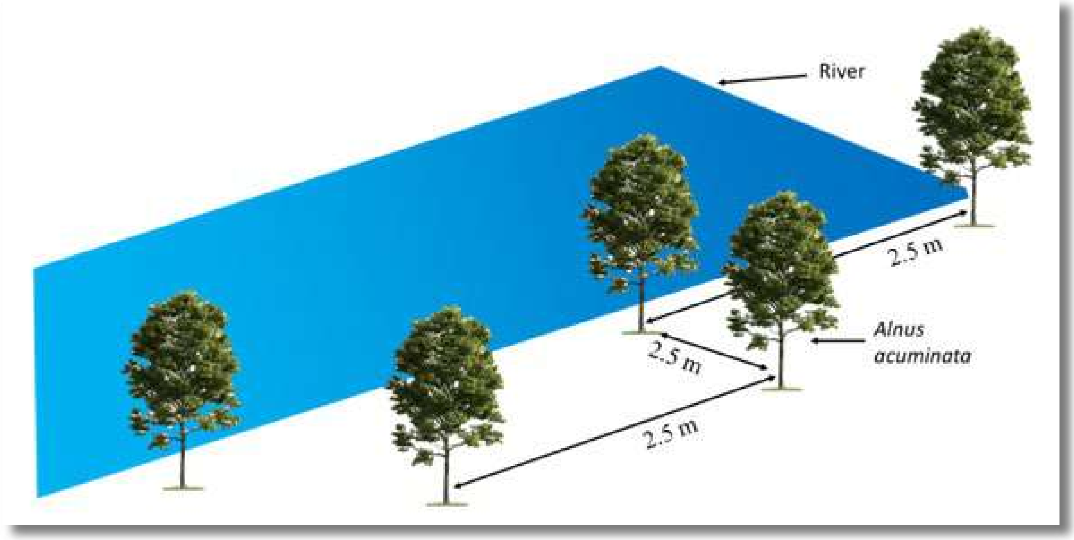


Figure 10 – Protective Forest – riverside plantation

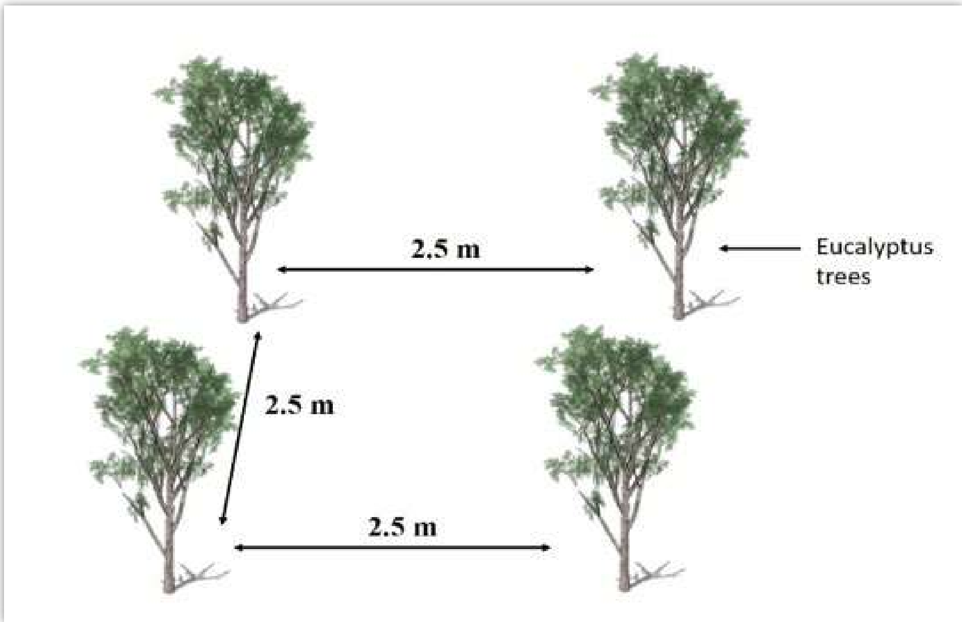


Figure 11 – Protective Forest – roadside plantation

The below **Table 4** presents the total area per forest landscape restoration category.

Table 4 – Forest landscape restoration (FLR) interventions

District/ Year	FLR interventions				
	Woodlots (ha)	Agroforestry (ha)	Protective forests (ha)	Management of forests (ha)	FMNR[5] (ha)
Gicumbi					
2016	115	2,752	64		100
2017	50	2,232	53	14	
2018	50	1,600		1,150	
Sub-total	215	6,584	117	1,164	100
Gatsibo					
2016	215	4,779			
2017	104	2,066	30	6	
2018	250	1,700		850	
Sub-total	569	8,545	30	856	-
Total	**784**	**15,129**	**147**	**2,020**	**100**

[5] FMNR: Farmer Managed Natural Regeneration.

5. COST-BENEFIT ANALYSIS

5.1. INTRODUCTION

To provide insights into the financial profitability of the different restoration actions, data related to costs and benefits of the forest landscape restoration actions were collected to develop financial flow models. A CBA was used to assess the profitability of the different interventions. Following the ROAM (IUCN & WRI, 2014) to understand the real profitability of the different actions, the CBA looked at the difference between having continued with the traditional agricultural production system or the degraded land and the implementation of the new agroforestry system or other restored (managed) land use. Additional costs due to a higher erosion rate were included in the analysis where pertinent. Finally, to assess the contribution of FLR interventions in storing carbon, the FLR Climate Impact Tool[6], developed by Winrock International, was used to estimate the average tons of carbon that will be requested. The CBA takes the following steps, **Figure 12** shows the flow of the calculations:

i. Define the period for analysis
ii. Define and estimate costs
iii. Define and estimate benefits
iv. Develop the financial flow model with costs and benefits over a specific period
v. Add the impact of erosion
vi. Apply the discount rate and calculate the NPV for both scenarios (with and without FLR)
vii. Calculate financial indicators and compare with and without FLR taking into consideration carbon sequestered from FLR interventions
viii. Carry out the sensitivity analysis
ix. Compare estimates

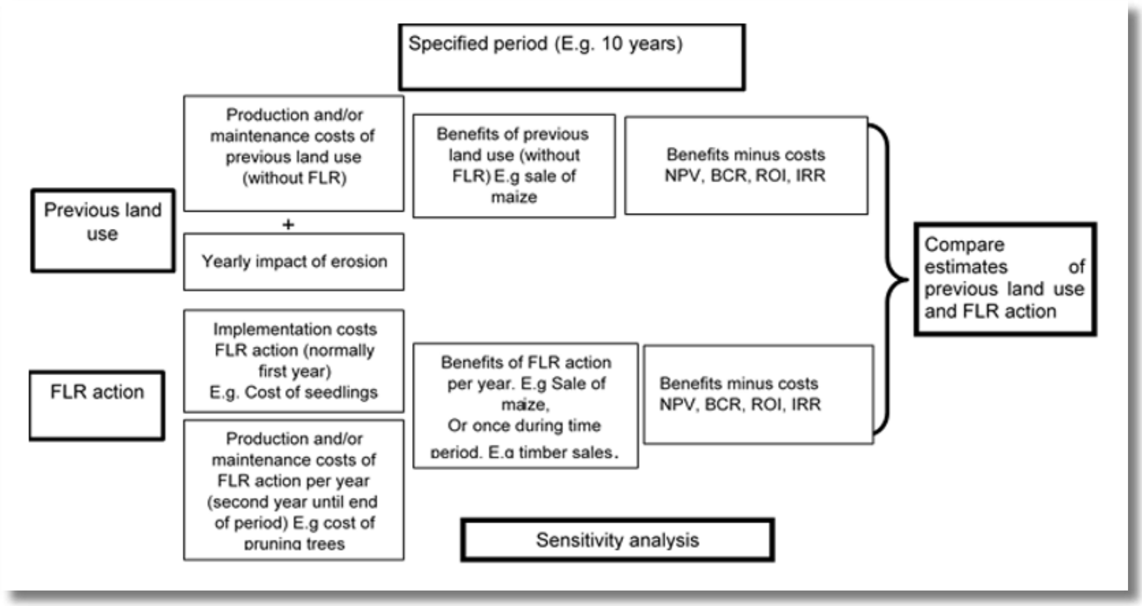


Figure 12 – Cost-benefit analysis of FLR actions in Gatsibo and Gicumbi

[6] https://www.winrock.org/document/forest-landscape-restoration-climate-impact-tool/

5.2. SUMMARY OF PREVIOUS LAND USES AND FOREST LANDSCAPE RESTORATION ACTIONS

The previous agricultural practices considered in Gatsibo and Gicumbi are traditional agriculture, poorly managed woodlots and deforested/degraded lands. Since 2016, FLR activities implemented by IUCN are mainly focused on the transition from traditional agriculture to agroforestry and from degraded lands to woodlots, roadside forest plantation and riverside forest plantation. **Table 5** provides a summary of the FLR actions described above and their respective previous agricultural practices considered for the CBA (**Chapter 2**).

Table 5 – Restoration transition

Land use	Assumptions
Protective forest	- All protective forests (both roadside and riverside) are established on deforested/degraded lands that generate no income - Protective forests are planted for protection of rivers and roads. After 20 years, they will be harvested to avoid accidents around the roads or rivers and sold as timber
Private woodlots	- Private woodlots are established on degraded private land that generates no income - Private woodlots are mainly planted for the provision of timber (e.g., for construction) and for bio-energy production - The rotation period is 29 years, but private farmers will be harvesting (Clear cutting) in years 8,15, 22 and finally in year 29 to provide income
Public woodlots	- Public woodlots are established on degraded public land that generates no income - Public woodlots are mainly planted for timber production - The rotation period is 29 years, but silviculture management can be done at years 8, 15 and 22 to provide energy and timber (for construction, electric poles, stakes, etc.)
Agroforestry	- Agroforestry is implemented on land that was previously used for traditional agriculture - The tree species most often used in agroforestry systems in Gatsibo and Gicumbi is Grevillea sp - Crops are rotated seasonally (maize in season A from September to February and beans in season B from March to June) - The rotation period for the entire system is 10 years, after which the trees will be harvested. From year 4 onwards, Grevillea trees will start generating income from pruning (e.g., sale of stakes, firewood) - Income will also be generated through the sale and use of crops and fodder

Restored landscape in Gatsibo (IUCN Rwanda).

5.3. COST-BENEFIT ANALYSIS METHODOLOGY

CBA is an economic evaluation method where benefits and costs of interventions are identified, measured (normally in monetary terms) and compared to determine whether the benefits of an intervention exceed its costs (Nurmi & Ahtiainen, 2018; Saarikoski et al., 2016; Quah & Haldane, 2007). CBA is used to determine whether an intervention is economically justified (Logar et al., 2019) and can be used either to rank projects or to choose the most appropriate option. The ranking or decision will be based on expected costs and benefits (DEAT, 2004). For this study, CBA provides information on the profitability of the different interventions of the IPR project. To assess the scenarios with and without interventions, all costs, and benefits before and after interventions are put into a financial flow model. This is a spreadsheet model detailing the costs and benefits from FLR intervention or the previous land uses to predict cash flows given the data.

5.3.1. Costs considered

The costs considered in this study are those related to the implementation and management of the FLR action and related agricultural or forestry production or those costs that would have been incurred if the previous agricultural production system had continued. Previous land use Costs include input and land preparation, labour, harvesting and costs related to soil erosion. Costs related to the FLR action can be costs related to on-farm (land preparation, inputs, labour) and off-farm (project administration, sensitisation) implementation, and costs related to production and maintenance of the restored land use after implementation.

Costs of continuing previous agriculture practice

The IUCN project baseline report was used to collect data on the inputs, land preparation, labour and harvesting costs of the traditional agriculture production of crops (maize, beans, wheat, and Irish potatoes) before the FLR actions were implemented (IUCN, 2016).

In addition to the costs directly related to the agricultural production system, like other studies such as Verdone & Seidl (2016), the costs related to erosion that would have occurred on the previous land-use without FLR actions were also considered. To estimate the cost of soil loss, this study used the results obtained through the application of the InVEST Sediment Delivery Ratio (SDR) model (see chapter 5 for a complete explanation of the model and its results). The InVEST SDR model provides an estimate of the average annual erosion rate for different FLR interventions in Gatsibo and Gicumbi for mature FLR systems[7]. This loss can be (partially) offset by an increased use of fertilisers or by the reestablishment of the lost soil. In Rwanda, a commercial market for topsoil exists. This market value is used as a proxy for the cost of offsetting soil loss. The average market value of topsoil in Rwanda is RWF 30,000/ton in all country districts except the districts of Kigali city (W4G, 2018). This value is multiplied by the estimated difference in tons of soil loss between the FLR action and the previous agriculture practice (see **Equation 1**). The **Table 6** presents the intervention maturity profile in percentage that was used to compare with and without FLR interventions.

Table 6 – Intervention maturity profile in percentage per year

Intervention	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Afforestation (%)	0.0	10	30	50	70	90	100	100	100	10
Agroforestry (%)	0.0	10	30	50	70	90	100	100	100	100
Riverside/Riparian (%)	0.0	10	30	50	70	90	100	100	100	100
Roadside (%)	0.0	10	30	50	70	90	100	100	100	10%

Source: Rwanda Water Forestry Authority-W4G_PES Study, 2018.

Cost of soil loss = IMP*VTS*AER (***equation 1***)

Where IMP is intervention maturity profile in percentage (W4G, 2018); VTS is value of topsoil (RWF 30,000/ha according to W4G, 2018); AER is average erosion rate t/ha/year.

FLR actions

The costs considered here are due to FLR implementation activities, including tree production, extension, agroforestry inputs, and management. The costs in this assessment are lower bound estimates of a restoration process and entail transaction costs (for example, costs related to project design, administration, legal and political activities, creating market access, among others), which go beyond the scope of this study. This study aims to evaluate the per hectare profitability of multiple FLR actions and compare these with the estimated profitability of the previous agriculture practices.

[7] An FLR system is considered mature when it provides maximum socio-economic and ecological benefits.

5.3.2. Benefit estimation

Benefits of continuing previous agriculture practice

The benefits of traditional agriculture practices were calculated from the production of maize, beans, wheat and Irish potatoes estimated using yields and market prices before FLR actions were implemented (IUCN, 2016).

FLR actions

The benefits of landscape restoration can provide both use and non-use value (Pearce, 2001; Krieger, 2001). Use values are derived from direct use and sale of products from the restoration intervention and these include timber, firewood, fodder, house construction, stakes, and yields of agriculture crops. Another source of use value is the indirect provision of services like erosion control and climate regulation through carbon sequestration. Non-use values, also called passive use values, are associated with the desire to protect ecosystem goods and services for future generations (Krieger, 2001). In this study, focusing on the potential financial flows related to the FLR action, the benefits considered are only direct and indirect use values. To estimate the benefits from direct use values, this study utilised market prices. The benefits are incomes from FLR actions, which are calculated from yields and their relative price per unit area (Benefit = Yield*Price). To estimate some of the indirect use values, the InVEST SDR model results and the FLR climate impact tool were used to provide an estimate of the impact of FLR on erosion and carbon sequestration.

To adjust all the prices considered in this study to the ‘current’ year, 2018, historical data on price were compounded using the annual inflation rate of Rwanda (data from World Bank[8]). The purpose of this adjustment is to have all historical prices expressed in a value of the same year. The procedure is to value all costs and benefits at the ruling price in the year of appraisal (OECD, 2006). To adjust the value of price from n year to n+1 year, the value price from n year is multiplied by the inflation rate of n+1 year.

Carbon sequestration

Deforestation and forest degradation, as well as forest landscape restoration activities, play a principal role in the global carbon cycle[9] (Wright, 2013; Pan et al., 2011). Preventable deforestation, sustainable forest management and natural regeneration of second-growth forests provide a low-cost mechanism that yields a high carbon-sequestration potential with multiple benefits for biodiversity and ecosystem services (Chazdon et al., 2016).

In collaboration with IUCN, Winrock International developed two comprehensive databases: (1) a global forest greenhouse gas emissions database and (2) a global FLR carbon dioxide removals database. These databases give information at both national and subnational scales on the greenhouse gas impacts that specific land-use

[8] https://data.worldbank.org/indicator, 15th June 2019
[9] https://infoflr.org/what-flr/global-emissions-and-removals-databases

activities have and thus provide a new resource to policy makers, donors, and researchers for science-based decision-making. The FLR Climate Impact Tool aims to support practitioners estimating and visualising the carbon dioxide impacts of past and planned FLR activities. The FLR removal calculation tool was developed using data from the global removals database (Bernal et al., 2018). The FLR Climate Impact Tool estimates tCO_2 per hectare based on the type of FLR, location and age of the plantation.

To add the carbon sequestration impact of FLR into the financial analysis, carbon sequestration must be expressed in monetary terms. There is no carbon price for Rwanda, but authors across the globe have been discussing and estimating the price of carbon as it is related to the type of carbon sequestration project in most cases. This price of carbon is used by policy makers to examine the benefits of climate policy in CBA analyses, and it reflects the damages incurred by emitting one tonne of carbon on current and future populations (Arnell et al., 2016). For example, the high-level commission on carbon price in 2017 estimated the required price range of USD 40–80/tCO_2 to achieve the goal of the Paris Agreement[10]. This price should rise to USD 50–90/tCO_2 by 2030, provided a supportive policy environment is in place (World Bank, 2017). Technical packages used the European Union allowable price of carbon of 2018, which is USD 16/tCO_2 to calculate the contribution of one tonne of carbon dioxide sequestered from interventions. This is approximately equal to RWF 13,900.7, using RWF 868.7951/USD, the average exchange rate for 2018.

5.3.3. Data collection for costs and benefits

To generate the financial flow models for the FLR actions and their respective previous agriculture practices, data on yield, growth rates, prices and costs were obtained through: (i) literature review, (ii) field visits, and (iii) interviews.

Document review

A document review was carried out to gather secondary data for the cost-benefit analysis.

The costs of continuing previous agriculture practices were gathered using the IUCN project baseline report. The costs of implementing FLR activities were gathered from IUCN project field reports, documents from 2016 to 2018 that were used in the implementation of the IPR project (e.g., bidding documents), and additional stated costs from farmers obtained through surveys (see below). In partnership with RWFA, IUCN has signed contracts with Rwanda Reserve Force as the service provider to implement FLR activities in both districts. The costs mentioned in the bidding documents and contracts were the ones used as references to estimate the restoration costs.

Market visits

The baseline report contained the crop price information from 2016 which was converted to 2018 values. The benefits from agriculture production were obtained by

[10] https://carbonmarketwatch.org/wp/wp-content/uploads/2017/09/CMW-PRICING-CARBON-TO-ACHIEVE-THE-PARIS-GOALS_Web_spread_FINAL.pdf.

multiplying price by yield. In addition to prices gathered through project documents, 2018 prices were gathered through market visits. From 5 to 7 September 2018, two local markets (Byumba and Manyagiro) in Gicumbi District and two in Gatsibo (Kabarore and Rwagitima) were visited to get the current price of maize, beans, Irish potatoes, wheat, firewood, timber and stakes. For each crop, the average price from diverse sources was used to estimate the benefits in each district.

Farm visits and interviews

To determine the estimated production yields from different agroforestry systems using the rapid appraisal method, twenty farmers and four agriculture cooperatives (see annex for complete list) adopting agroforestry in the regions were visited. The rapid appraisal method provides a tool to easily get information from a population about its condition and needs and provides understanding of a particular situation (Beebe, 1995). The method is used to evaluate the impact of development interventions. Rapid appraisal methods have several advantages such as being adaptable to different situations, having a low cost, and facilitating the exploration of topics not easily studied. However, this method presents some limitations like poor generalisation of findings and susceptibility to manipulation by informants (Bergeron, 1999).

A purposive sampling technique was used to select farmers who adopted FLR interventions. This non-probabilistic sampling technique is usually used when there is a specific group of people a researcher expects has the required information and is willing to share it (Kumar, 2014). Without underlying theories or a set number of participants, a researcher decides on the targeted information and selects people who will provide that information by virtue of knowledge or experience (Etikan et al., 2016). The selected farmers for these technical packages were some of the farmers who benefited from IPR project interventions from 2016 up to 2018. The farm visits and interviews provided information on agroforestry production systems compared to the previous production system. For example, farmers provided numbers of stakes and yields of maize, beans, Irish potatoes and wheat and timber production as well as their associated production costs.

By using a mini-survey, local farmers in both districts were surveyed and provided not only insights on additional management costs and the benefits from the FLR interventions, but also expressed their willingness toward the implementation of interventions. Through open questions focusing on adoption of agroforestry, farmers expressed the level of acceptability and their interest in continuing planting trees for landscape restoration.

Expert interviews

One-on-one interviews with key informants from RWFA (director of the Forest Management Unit and the head of the Forest Department) and district staff were conducted to validate the cost and benefit data related to the implementation of the FLR actions. The interviews with the forest and natural resources officer, district agriculture officer and district cash crop officer confirmed the information from market visits and added feedback from the technical team about the estimated benefits (production) from farmers adopting FLR interventions. The discussion with the head of the Forestry Department helped to determine the average rotation period for interventions mentioned in the technical packages.

5.3.4. Financial indicators

To evaluate FLR actions and their previous agriculture practices through a CBA, different indicators were used: NPV, BCR, ROI and internal rate of return (IRR).

Net present value

The NPV is the difference between the total of the present value of discounted benefits and the discounted value of costs over a specific period of a project or intervention (Balana et al., 2012). The first principle of NPV reflects the fact that usually people prefer to receive money in the present rather than in the future – this is the time value of money. Hence, future cash flows are discounted each year, and the discount rate represents the opportunity cost of the capital mobilised. The second principle of NPV is to consider all the future net cash flows linked to the project intervention opportunity. By contrast, some approaches like payback period and upfront investment consider only initial cash flow. The NPV is an economic valuation technique that consists of discounting all future cash flows (in and out-flow) resulting from project interventions with a given discount rate and summing them (Žižlavský, 2014).

The discount rates reflect the time value of money, which recognizes that money can be invested to generate profits or increase profits. Selecting the correct discount rate is important when evaluating impacts that occur many years in the future. The key issue in determining the discount rate is deciding on the weights that society should apply to costs and benefits that occur in future periods relative to the current period (Moore et al., 2004). The higher the rate, the more weight is given to present over future benefits. To give more consideration to future generations, analysts recommend using a lower or zero discount rate for environmental costs (Litman, 2009). Interventions with positive NPV are profitable, and interventions with negative NPV are not profitable. The formula for NPV is shown in **equation 2** below (Balana et al., 2012):

$$\left[NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}\right] \; (\boldsymbol{equation\ 2})$$

Where: NPV = net present value; B_t = benefit at time t; C_t = costs at time t; i = discount rate; t = time in years (1, 2, …n).

For Rwanda's ROAM, a 7% discount rate was used (MINIRENA, 2014), but this study used the public discount rate of 13% as requested by the Ministry of Environment, government of Rwanda.

a) Benefit-cost ratio

The benefit-cost ratio is the total discounted benefits divided by the total discounted costs. The BCR formula is shown in **equation 3** bellow (Campbell & Brown, 2003):

$$BCR = \sum_{t=0}^{n} \left(\frac{\frac{B_t}{(1+i)^t}}{\frac{C_t}{(1+i)^t}} \right) \quad (\boldsymbol{equation\ 3})$$

Where: B_t = the benefit at time t; C_t = the cost at time t; i = the discount rate; t = time in years; n = number of years over which the future costs or benefits are expected to occur (the current year t = 0).

The intervention with a benefit-cost ratio greater than 1 has higher benefits than costs. The higher the ratio, the greater the benefits relative to costs. If a project's BCR is less than 1, the project's costs outweigh the benefits (Lawrence & Mears, 2004).

b) Return on investment

ROI is a measure that investigates the amount of profits produced per unit of a certain investment. It can be used to compare different scenarios for investments. This ROI calculates the amount of value that was generated from every Rwandan franc invested in restoration transition, where the total cost in year 1 is considered the investment. The basic formula for ROI involves only two values: the cost of the investment and the gain from the investment. The formula is shown in equation 4 bellow (Kaminski & Lopes, 2009):

$$ROI = \frac{\left(\sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \right)}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \quad (\boldsymbol{equation\ 4})$$

c) Internal rate of return

IRR is the discount rate that makes the NPV equal to zero. IRR relies on the same formula as the NPV but instead of calculating the NPV, it solves for the discount rate to arrive at an NPV value of zero. IRR can be helpful when making an investment decision. If an IRR is greater than the cost of capital, then it is a profitable investment. The cost of capital represents the minimum desired rate of return, which is considered an opportunity cost of making a specific investment. If the IRR is lower than the cost of capital then it will be a loss-making investment (Campbell & Brown, 2003). It is also used to easily compare different alternatives, where the higher IRR will be more attractive. The IRR is calculated in **equation 5** below:

$$0 = CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \frac{CF_3}{(1+IRR)^3} + \cdots \frac{CF_t}{(1+IRR)^t} \quad (\boldsymbol{equation\ 5})$$

$$0 = NPV = \sum_{t=0}^{t} \frac{CF_t}{(1+IRR)^t} \quad (eq. 6)$$

Where: NPV = net present value; CF_t = cash flows; t = total number of periods; IRR = internal rate of return.

5.3.5. Sensitivity analysis

Sensitivity analysis is used to examine the results of changes of model parameters to assess the robustness of the analysis (Saarikoski et al., 2016). In a sensitivity analysis, critical components or inputs in the calculations should be changed and the results recalculated to determine how much the results vary, that is, how sensitive the results are to changes in these inputs (Phillips et al., 2003). Like other investments, investing in forest landscape restoration is not risk free. Investments are subject to changes in ecological and economic situations. Therefore, the cost and benefit streams of restoration transitions are subject to changes in variables such as market prices of crops or crop yields, as well as the discount rates. For the first NPV a 13%, which is the public discount rate, was used. To evaluate the sensitivity to the discount rate, rates of 3%, 7%, 15% and 25% were used to recalculate NPVs and assess how sensitive the results were to different discount rates. Furthermore, historical prices of crops from 2005 to 2018 (adjusted to inflation[11]) were used to determine the minimum and maximum prices to be used for price sensitivity analysis. Also included were the maximum and minimum yields from crops to assess how sensitive the results were to changes in yields. With these maximum and minimum prices and yields an optimistic (high price and high yield) and a pessimistic (low price and low yield) scenario were created to provide a range of NPV estimates for the sensitivity analysis.

5.4. COST-BENEFIT ANALYSIS RESULTS

In this chapter, the results from the cash flow analysis, scenarios showing the effect of soil loss and discount rate, results from sensitivity analyses and finally, the results/effect of carbon sequestration are presented. Both FLR actions and previous agriculture practices are presented. The previous agricultural practice is a traditional agricultural production system that is considered business as usual. Graphs from agroforestry systems show agricultural crops alternately in both agricultural seasons. CBA results of Gatsibo District will be presented first, then the results of CBA of Gicumbi District will follow.

5.4.1. Results of CBA agroforestry system with maize and beans in Gatsibo

The costs and benefits for the agroforestry system with maize and beans in Gatsibo District are represented in **Figure 13A** below. The analysis was focussed on an agroforestry system on a 0.5 ha unit, as this is the average area households use for maize and bean production. The figure shows both non-discounted and discounted annual costs, benefits, and net income from this FLR action. The implementation of this agroforestry system generates an annual positive net benefit throughout the rotation period for both discounted and non-discounted net benefit. As shown on **Figure 13B**, the benefits from this agroforestry system outweigh the cost of establishment, production and management.

The costs of planting trees are lower compared to their benefits when they are harvested. The income considered from timber is the price of a standing tree in the

[11] (Price 2016) * (1 + inflation 2016) = price 2017.

region at the end of the rotation. Additionally, this system provides an annual income from pruning trees for fuelwood production starting in year four up to the end of the rotation period. The income from beans and maize is generated from annual production throughout the rotation period.

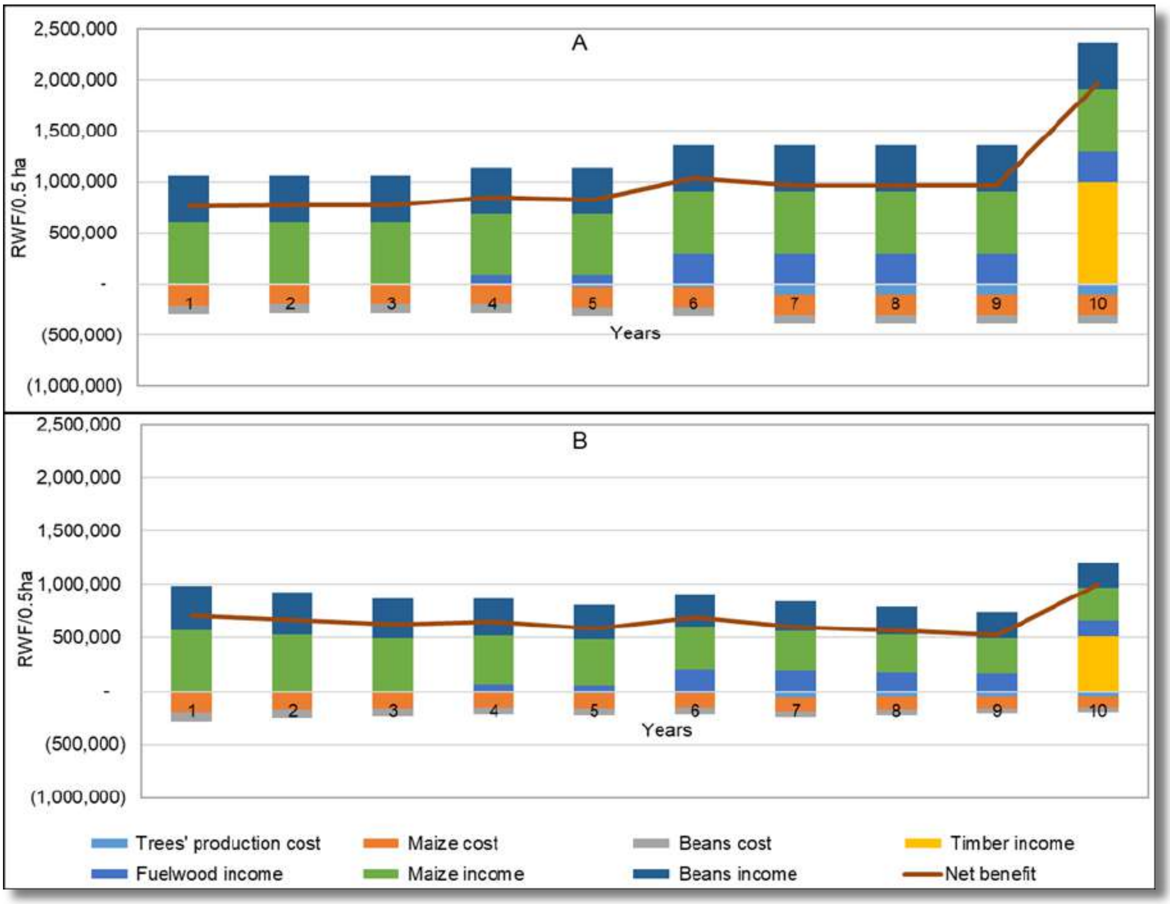


Figure 13 – Annual costs and benefits from the agroforestry system with maize and beans in Gatsibo District. Graph A depicts non-discounted annual costs and benefits; graph B depicts discounted annual costs and benefits. The red line represents the net benefit over time.

5.4.2. Results of CBA agroforestry system with maize, beans and fodder in Gatsibo

Figure 14 illustrates the estimated costs and benefits of the agroforestry system that consists of maize and beans mixed with trees (including fodder trees) in the Gatsibo District. This system produces fodder starting in the second year. Fodder products are sold to cattle ranchers, while timber income is generated at the end of the rotation period. The income from beans and maize is generated annually.

The annual income from fuelwood comes from selling pruned branches and starts in the fourth year up to the end of rotation, resulting in a steady increase of net income. Tree production costs are much smaller compared to the non-discounted benefits from timber. The total estimated costs are lower than the benefits from agroforestry, thus the annual net benefit from implementing agroforestry with maize and beans and fodder presents a positive result for the evaluation period.

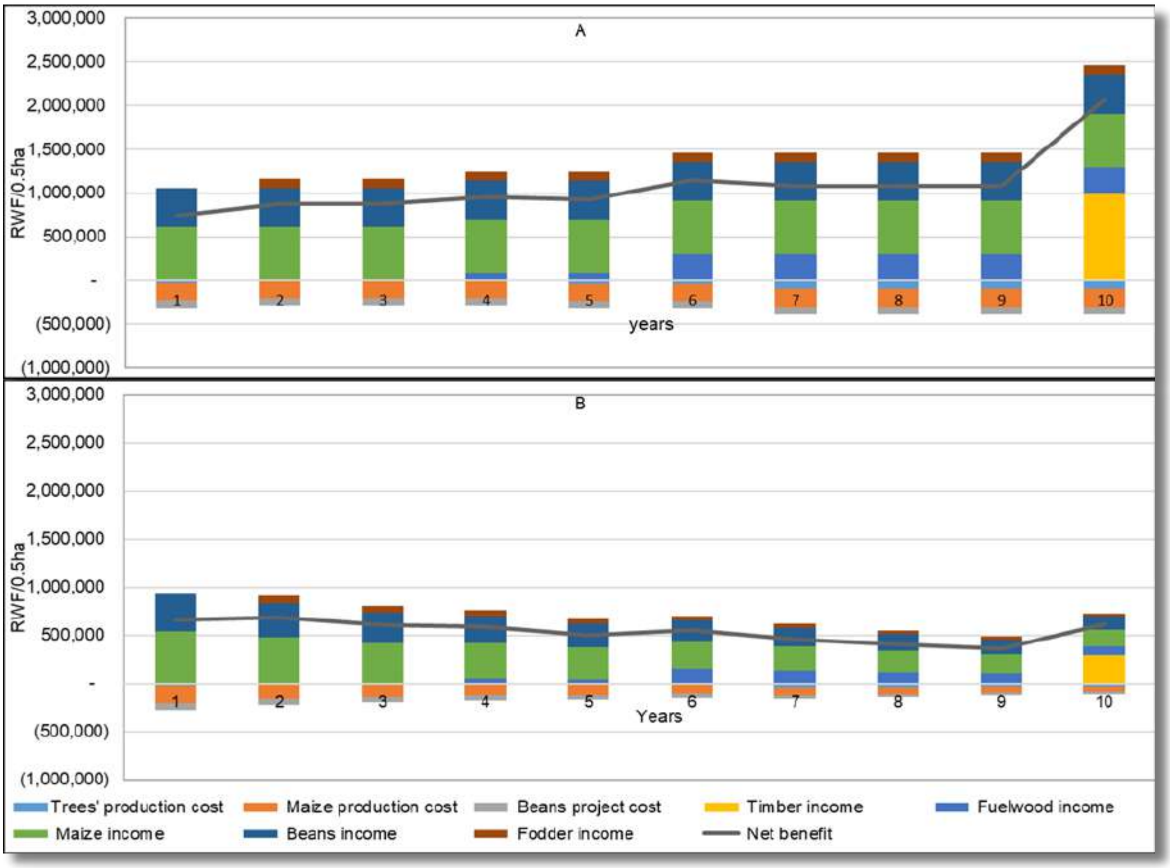


Figure 14 – Annual costs and benefits from an agroforestry system with maize, beans and fodder in Gatsibo District. Graph A depicts non-discounted annual costs; graph B depicts discounted annual costs. The blue line represents the net benefit over time.

5.4.3. Results of CBA traditional agriculture of beans and maize in Gatsibo

To be able to evaluate the profitability of an FLR action, whether this action is more profitable than what would have been generated by continuing with the previous agricultural land use, and the estimated costs and benefits related to the previous system provides a superb tool for comparing complex production systems. In comparison with the FLR actions presented previously, the following analysis provides net benefit estimates for a traditional agricultural production system of beans and maize. Results presented in **Figure 15** show lower net income, for both discounted and non-discounted scenarios, for one rotation period in Gatsibo District.

Graph **A** depicts non-discounted annual costs; graph **B** depicts discounted annual costs. The blue line represents the net benefit over time

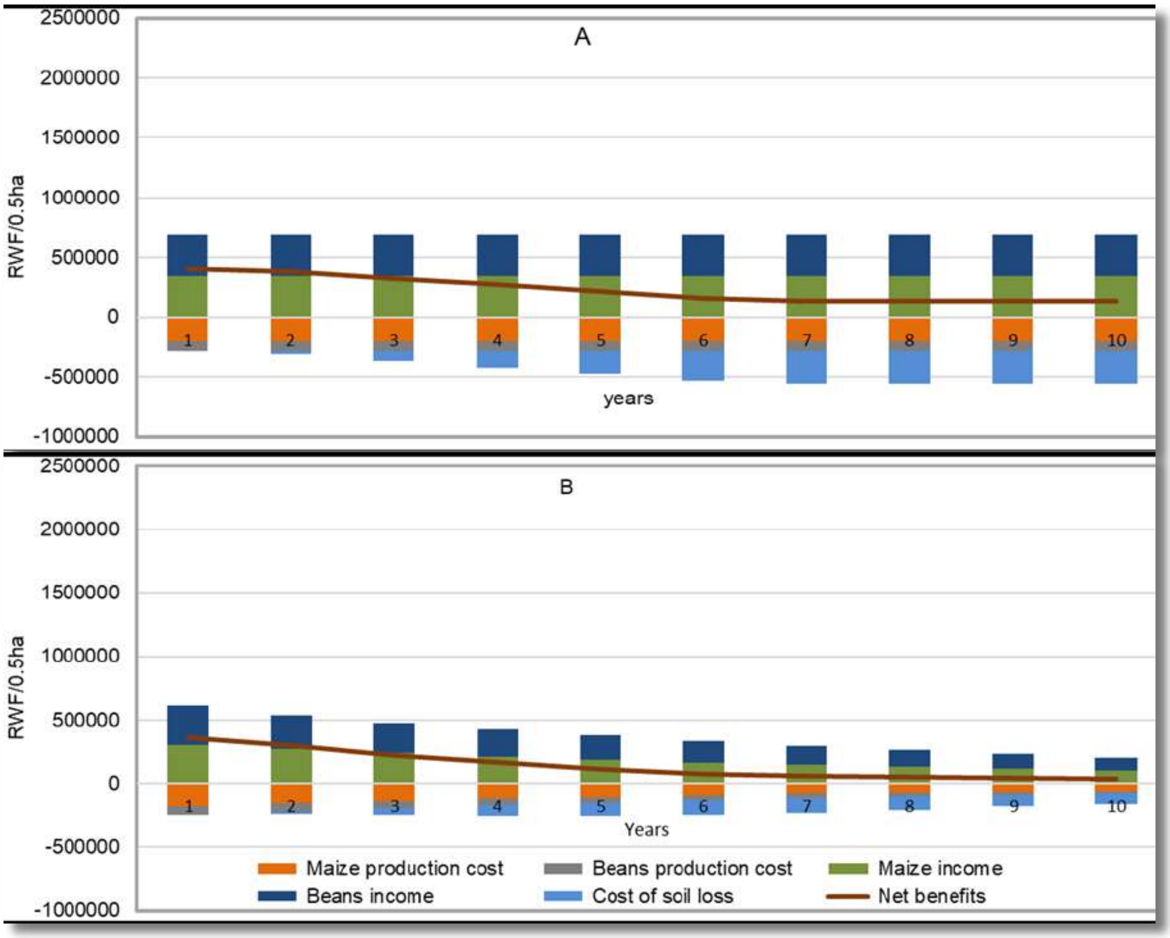


Figure 15 – Annual costs and benefits from previous agricultural practice of maize and beans in Gatsibo

In the next step in the CBA, the effect of reduced soil loss through the implementation of an FLR action, or conversely an increased annual soil loss from not implementing the FLR action, are considered in the scenario with the continuation of the previous agriculture system, maize, and beans, in Gatsibo. Erosion impact is included as an additional cost, based on the replacement cost of the lost soil. The intervention maturity profile of agroforestry is seven years. **Figure 16** presents different scenarios with and without the cost of soil loss and with and without the discount rate. Compared to the FLR action, there is a higher soil erosion rate and thus the soil replacement cost decreases the net benefit from traditional agricultural practice.

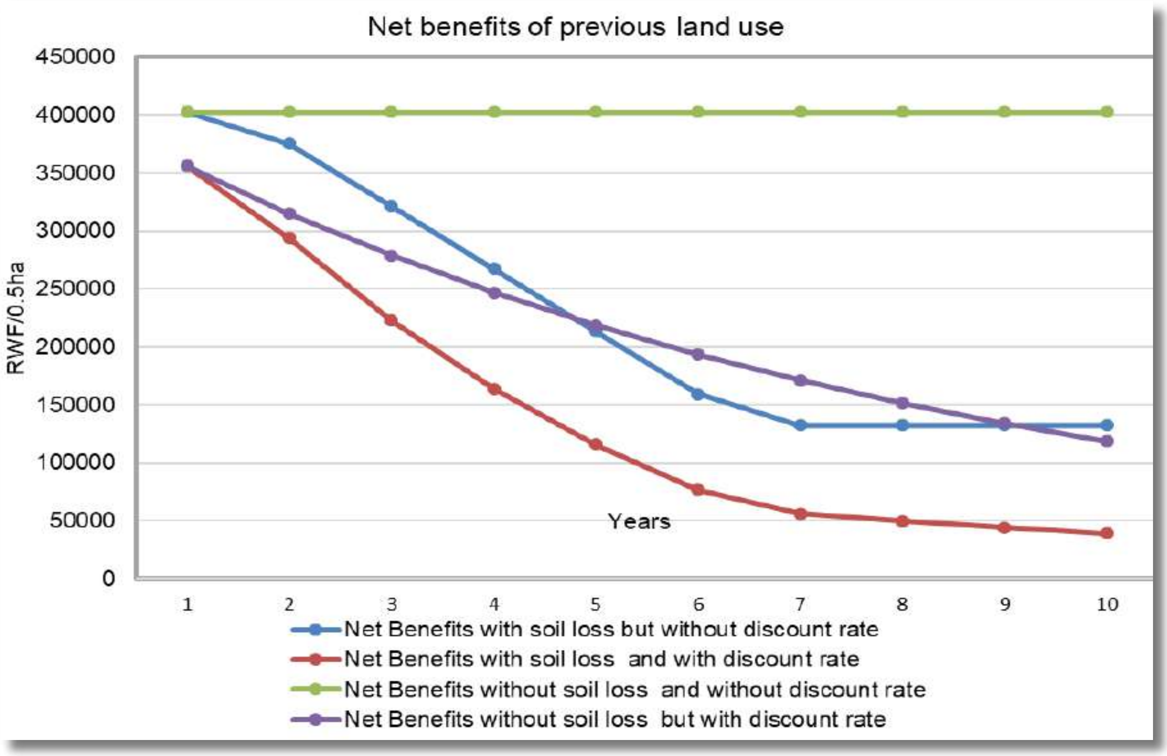


Figure 16 – Scenarios of annual net benefits of previous maize and beans production system in Gatsibo

Financial indicators

The agroforestry system with maize, beans and fodder shows a higher NPV compared to the agroforestry system with only maize and beans, due to additional income from fodder. The agroforestry systems both have a higher NPV than what would have been generated with the previous agricultural practice (**Table 7**). The BCR is positive for all three options but agroforestry with maize, beans and fodder has the highest BCR, and presents the highest ROI. Continuation of traditional agriculture of maize and beans has the lowest ROI and BCR. The financial indicators (NPV, BCR and ROI) of the traditional system are relatively lower compared to related agroforestry systems, indicating the contribution of FLR actions.

Table 7 – Financial indicators of continuing the previous agricultural practice and implementing the corresponding agroforestry systems in Gatsibo[12]

Land use	NPV 13% (RWF)	BCR	ROI	Increase of NPV from FLR
Traditional agriculture of maize and beans	1,418,665	1.55	0.61	-
Agroforestry system with maize and beans	4,953,957	4.00	2.84	3,535,292
Agroforestry system with maize, beans and fodder	5,416,455	4.08	3.08	5,997,790

As a last step for the evaluation of these FLR actions and the corresponding previous agricultural land use, a sensitivity analysis is carried out. **Table 8** shows outcomes for

[12] NPV: Net Present Value in RWF; BCR: Benefit Cost Ratio; ROI: Return on Investment.

different discount rates and changes in prices and yields. The agroforestry system with maize, beans and fodder continues to have the highest NPV in all scenarios. Only traditional agricultural practice shows a higher sensitivity to prices and crop yields as is shown by the negative NPV in the pessimistic scenario.

Table 8 – Sensitivity analysis for traditional agriculture and agroforestry systems in Gatsibo. All values are in RWF

Land use	NPV at 3%	NPV at 7%	NPV at 13%	NPV at 15%	NPV at 25%	Pessimistic scenario	Optimistic scenario
Traditional agriculture with maize and beans	2,006,403	1,727,870	1,418,665	1,336,663	1,030,117	-336,724	4,450,579
Agroforestry with maize and beans	8,263,661	6,633,390	4,953,957	4,535,552	3,091,013	862,798	6,315,347
Agroforestry with maize, beans and fodder	9,041,671	7,257,595	5,426,455	4,957,131	3,368,955	1,277,613	6,825,529

5.4.4. Results of CBA Eucalyptus plantation on public land in Gatsibo

The next FLR action analysed is the establishment of woodlots of Eucalyptus trees. Here the estimates are for an area of 1 ha. A rotation period of 29 years is considered. **Figure 17A** shows both the non-discounted and discounted annual costs, benefits and net benefit from the establishment, management and harvesting of a public forest plantation (woodlot) in the Gatsibo District. Public forests are mainly planted to provide timber, which is harvested at the end of the rotation period. Some other wood (product) incomes like charcoal and fuelwood are generated either during management practices (after 8, 16 and 24 years) or at the end of the rotation period.

In plantations, most income is generated at the end of the period, as this coincides with the year of the timber harvest. **Figure 17B** clearly illustrates the impact of the discount rate on income (sale of standing timber) generated in the distant future.

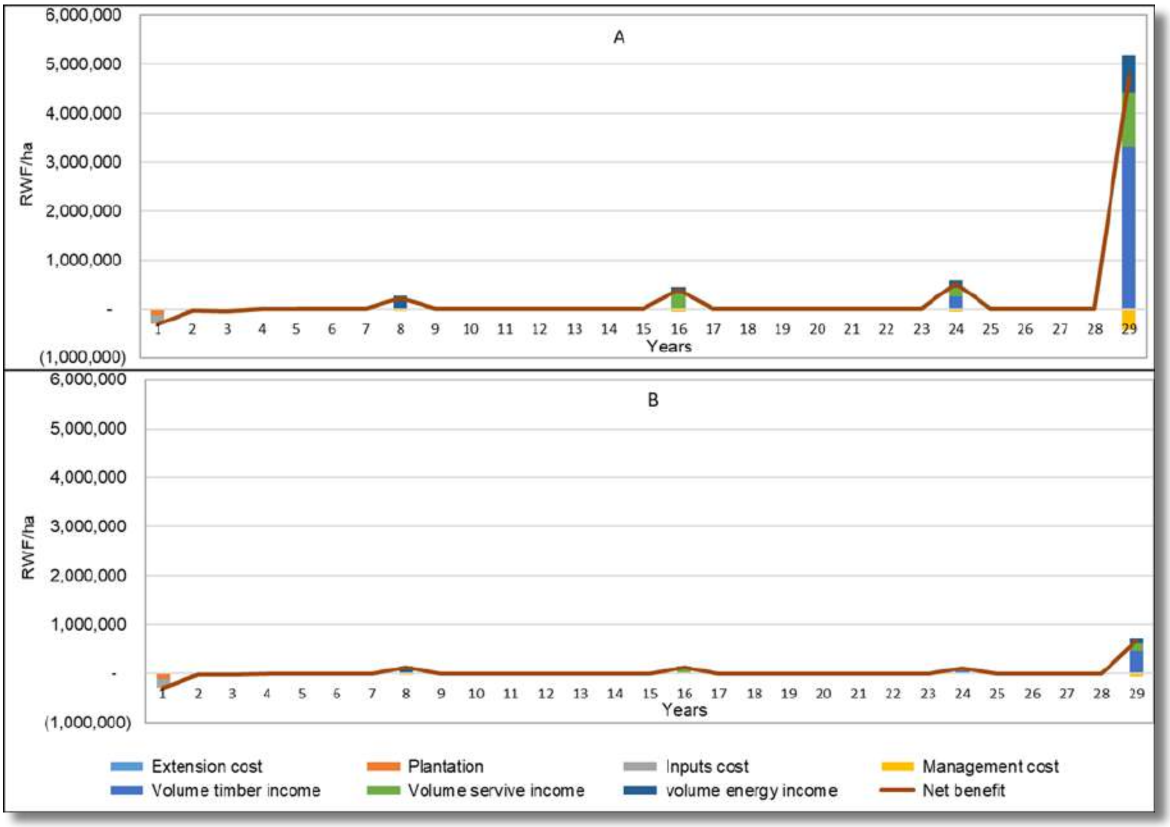


Figure 17 – Annual costs and benefits of Eucalyptus forest plantation on public land in Gatsibo

5.4.5. Results of CBA Eucalyptus plantation on private land in Gatsibo

This FLR action also evaluates the establishment of woodlots with Eucalyptus trees, but on private lands. Though the main purpose of this FLR action is the production of energy (fuelwood) and other wood products (timber for construction, stakes, electric poles, etc.), this system also produces timber at the end of the rotation period, depending on silviculture practices adopted by the forest owner. The woodlot is harvested in years 8, 15 and 22 to provide energy, wood products and timber (year 29). The results show a positive annual net income when products are sold and no income or costs in the years without any harvest taking place (see **Figure 18**).

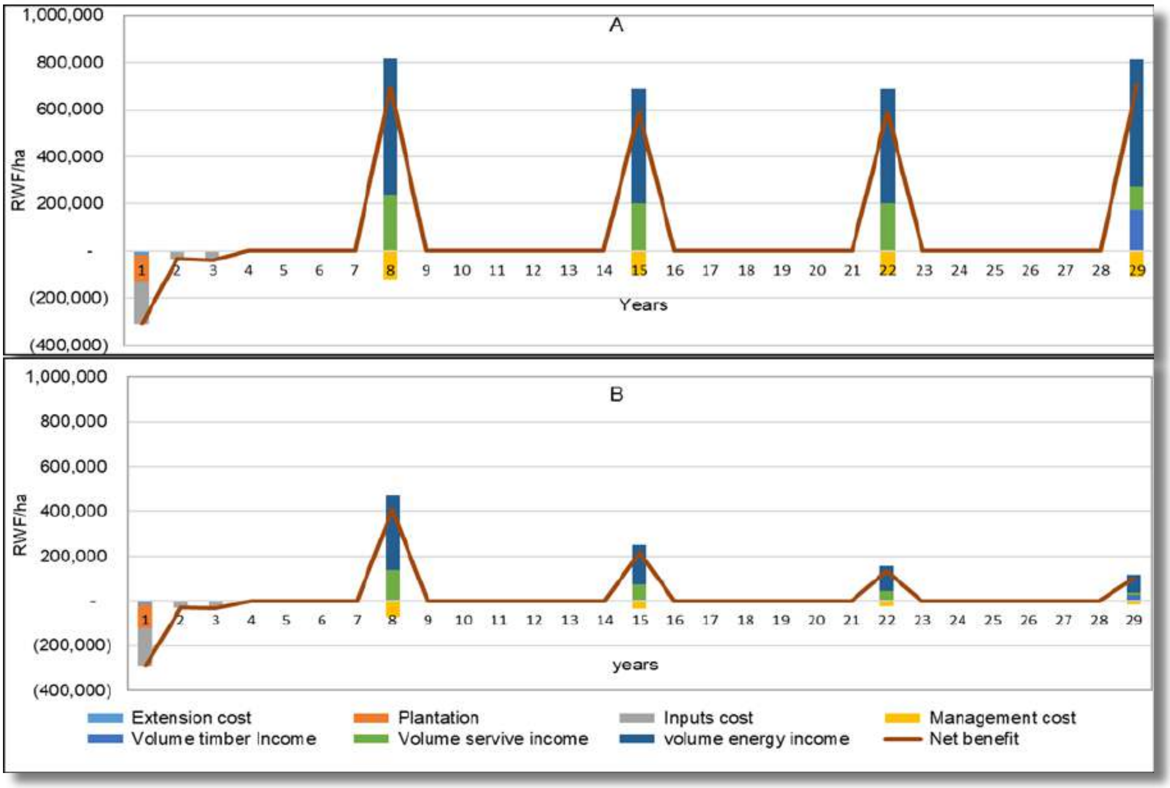


Figure 18 – Annual costs and benefits of Eucalyptus forest plantation on private land, Gatsibo

Financial indicators

Woodlots have been implemented on previously unproductive and degraded public and private lands. No costs or benefits are thus considered for the previous land use. **Table 9** presents the financial indicators of the establishment of woodlots on public and private land. The establishment of private woodlots has a positive NPV. BCR is higher than 1, however the ROI is smaller than 1 indicating that the return is less than the initial investment. By applying the discount rate of 13% for the NPV, the ROI for public woodlots establishment is negative. Furthermore, for every RWF invested, an additional 0.72 RWF is lost. Apart from additional benefits such as carbon sequestration and erosion control that reduces sediments in rivers and streams, the establishment of public woodlots to be harvested after 29 years is not profitable.

Table 9 – Financial indicators of the implementation of woodlots on public and private land in Gatsibo

Land use	NPV 13% (RWF)	BCR	ROI	Incremental NPV from FLR (RWF)
Degraded public and private land	-	-	-	-
Woodlot on public land	-21,711	0.28	-0.72	-21,711
Woodlot on private land	87,131	1.21	0.22	87,131

The results from the sensitivity analysis are shown in **Table 10**. With a discount rate of 25%, the NPV becomes negative for both private and public woodlots because most of the timber income occurs in year 29. Therefore, both public and private woodlots establishments are sensitive to long-term revenues and a decrease in timber yields.

Table 10 – Sensitivity analysis of woodlots establishment in Gatsibo

Land use (all values in RWF)	NPV at 3%	NPV at 7%	NPV at 13%	NPV at 15%	NPV at 25%	Pessimistic scenario	Optimistic scenario
Woodlot on public land	2,337,317	687,937	-21,711	-104,110	-231,609	-119,290	89,105
Woodlot on private land	1,164,687	498,269	87,131	17,187	-147,960	-87,358	261,325

5.4.6. Results of CBA protective forest on roadsides in Gatsibo

The next FLR action analysed, through the estimation of costs and benefits, was the establishment of tree plantations along roads. The cash flow model was developed for an area of 1 ha with a rotation period of 20 years. This period reflects the planted tree species, Grevillea robusta, which can be replaced after 20 years.

Figure 19 (**A** & **B**) shows both non-discounted and discounted net benefits from the roadside plantation in Gatsibo District. This restoration action has a protective role and can provide timber at the end of the period. The analysis shows in the beginning there is a negative annual benefit, and in the end a positive annual benefit for both non-discounted and discounted scenarios. The reason for this shift is due to costs incurred in the beginning and the sale of timber in the end of the period.

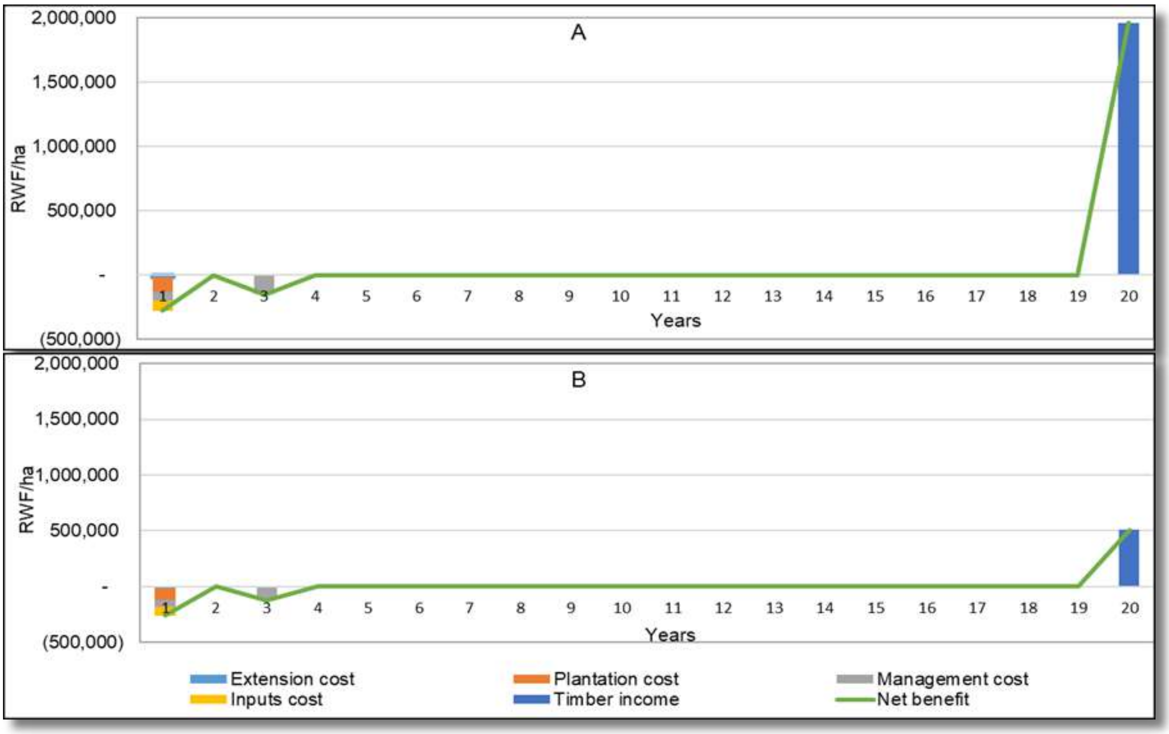


Figure 19 – Annual costs and benefits of protective forest in Gatsibo

Financial indicators

Table 11 presents the financial indicators for the transition from degraded land to the establishment of protective forest in the Gatsibo District. The protective forest was established on degraded lands that generated no revenue, so the NPV from previous land use equals zero. The establishment of protective forests as roadside plantations generate a negative NPV and ROI, and BCR is less than one. This means that the discounted benefits are less than discounted costs. Without considering other (environmental) benefits, the financial flow of the establishment of protective forests on roadsides, which generates income after 20 years, is not profitable.

Table 11 – Cost-benefit analysis of previous agriculture practice and protective forest in Gatsibo

Land use	NPV 13%	BCR	ROI	Incremental NPV from FLR
Degraded lands	-	-	-	-
Protective forest (roadside plantation)	-179,472	0.486	-0.51	-179,472

The sensitivity analysis of the CBA models of the establishment, maintenance, and harvest of protective forest (**Table 12**), shows a positive NPV at discount rate 3% and 7%, but a negative NPV at 13%, 15% and 25%, reflecting the relatively long time before revenues are generated. This FLR action also presents a negative NPV for the pessimistic and the optimistic scenarios. The establishment of roadside plantation is sensitive to having revenues in the long term, which cannot be offset by yield and price increases, considering a 13% discount rate.

Table 12 – Sensitivity analysis for protective forest in Gatsibo

Land use	NPV at 3%	NPV at 7%	NPV at 13%	NPV at 15%	NPV at 25%	Pessimistic scenario	Optimistic scenario
Protective forest (roadside plantation)	679,397	125,010	-179,472	-220,255	-276,366	-247,578	-79,203

5.4.7. Results of CBA agroforestry system with maize and beans in Gicumbi

This system – an agroforestry system consisting of maize and beans mixed with trees – is identical to the system implemented in Gatsibo. The CBA (**Figure 20**) was carried out for a production system on 0.5 ha with non-discounted (**A**) and discounted (**B**) annual costs, benefits, and net benefit. The agroforestry system with maize and beans in Gicumbi shows a positive annual net benefit throughout the rotation period, which indicates the impact of restoration activities (FLR actions) on local farmers. The cost of planting trees is relatively lower compared to its benefits in agroforestry systems of 0.5 ha. Timber income is only generated at the end of the rotation (year 10) as trees must reach a certain size before they can be sold.

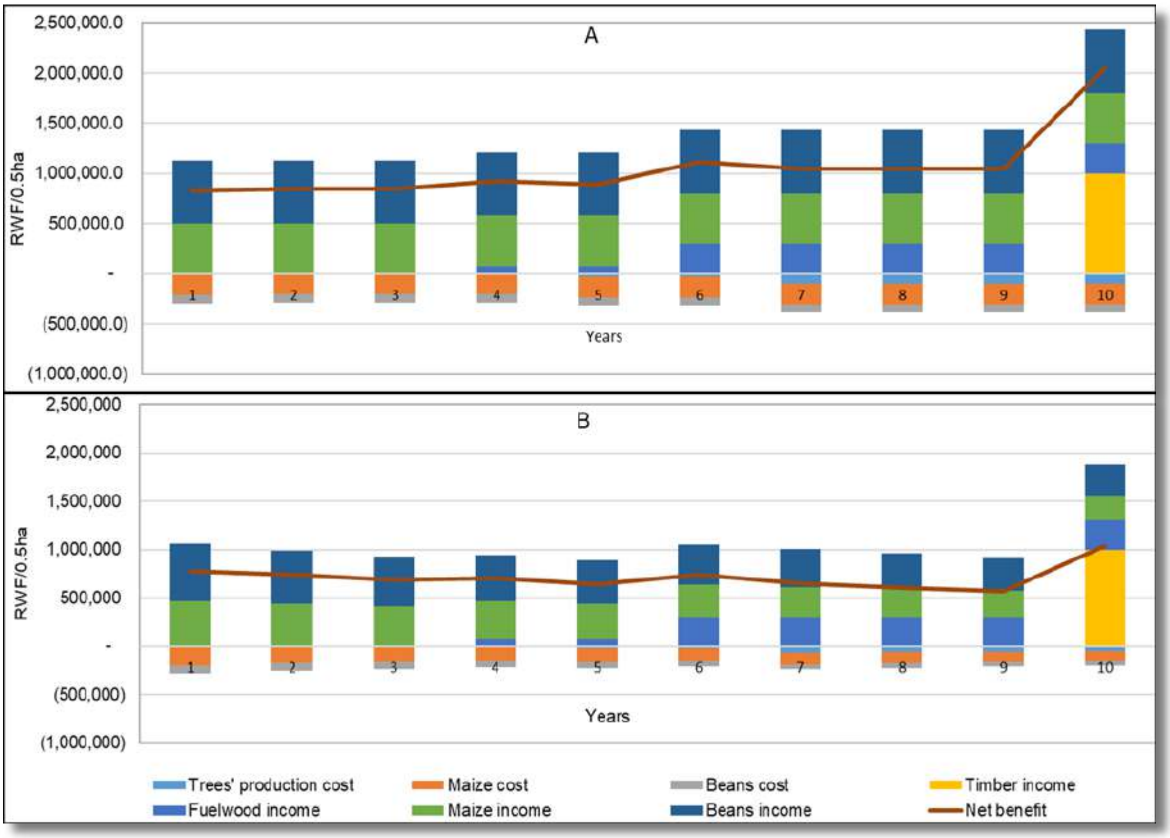


Figure 20 – Annual costs and benefits of agroforestry system with maize and beans in Gicumbi District

5.4.8. Results of CBA agroforestry system with maize, beans and fodder in Gicumbi

In comparison with the previously described CBAs of different agroforestry systems, in addition to the annual planting and harvesting of maize and beans, fodder trees are considered in a rotation period of 10 years for agroforestry systems. During the rotation period, fodder trees are harvested every year to feed animals or to be sold to other cattle ranchers; the agroforestry trees are harvested for timber at the end of the rotation period. Due to soil characteristics and the specific agro-ecological zone, the productivity of maize and beans is different in both districts (Gatsibo and Gicumbi). **Figure 21** presents the annual costs and benefits for both non-discounted (**A**) and discounted estimates (**B**). From year 4, agroforestry trees (grevillea) are pruned to provide fuelwood income, while timber income comes from selling mature agroforestry trees after 10 years.

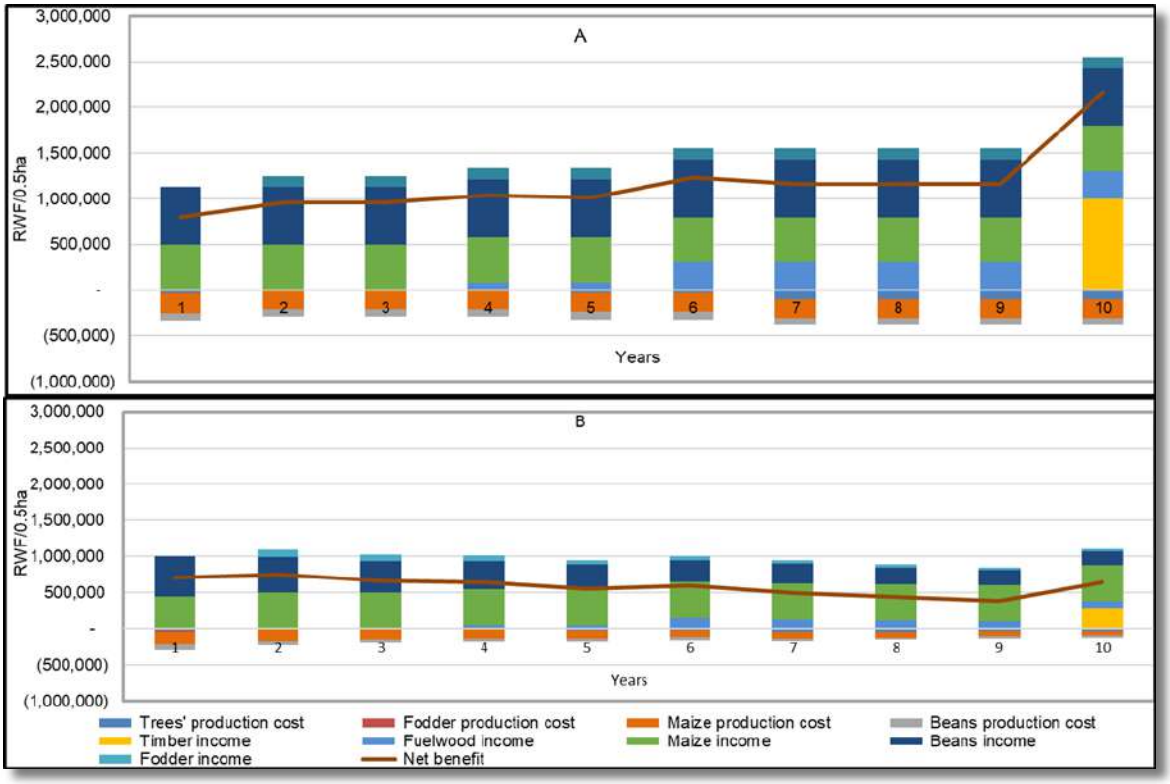


Figure 21 – Annual costs and benefits of agroforestry system with maize, beans and fodder in Gicumbi District

5.4.9. Results of CBA traditional agricultural production of maize and beans in Gicumbi

For the analysis of this land use, the same period (based on a rotation of 10 years) and the same area of 0.5 ha are considered. **Figure 22** presents the annual income from traditional agriculture – the income that would have been generated in a business-as-usual scenario. These first estimates do not consider the cost of soil loss.

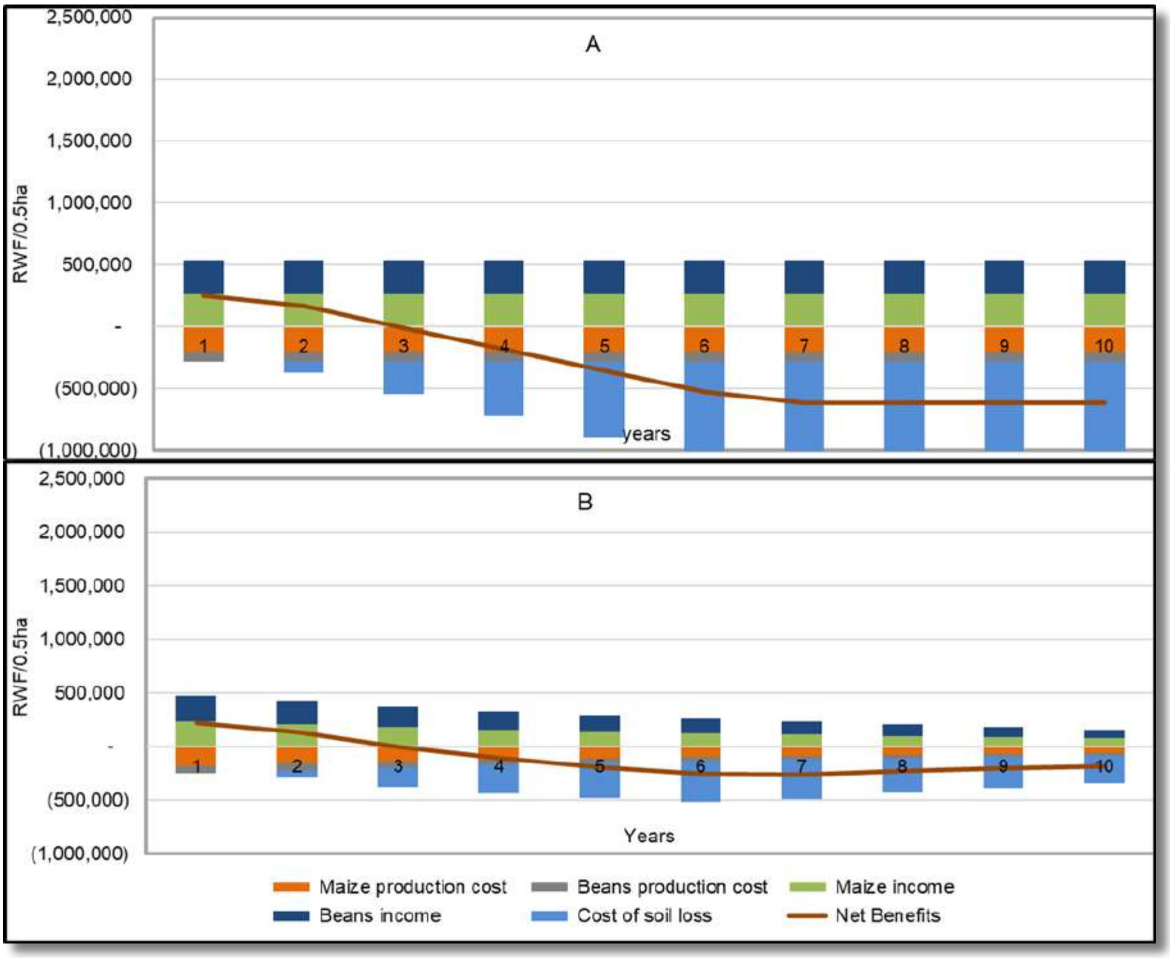


Figure 22 – Annual costs and benefits from previous agriculture practice of maize and beans without FLR in Gicumbi

Figure 23 presents the effect of considering soil loss and discount rate on annual net benefit of the previous agricultural practice. The effect of a higher annual erosion rate in the Gicumbi District from continuing the traditional agricultural production system with annual crops, compared to this system in Gatsibo, is shown by the blue line. Considering the soil loss, this production system is no longer profitable after year 3, both with and without applying the discount rate.

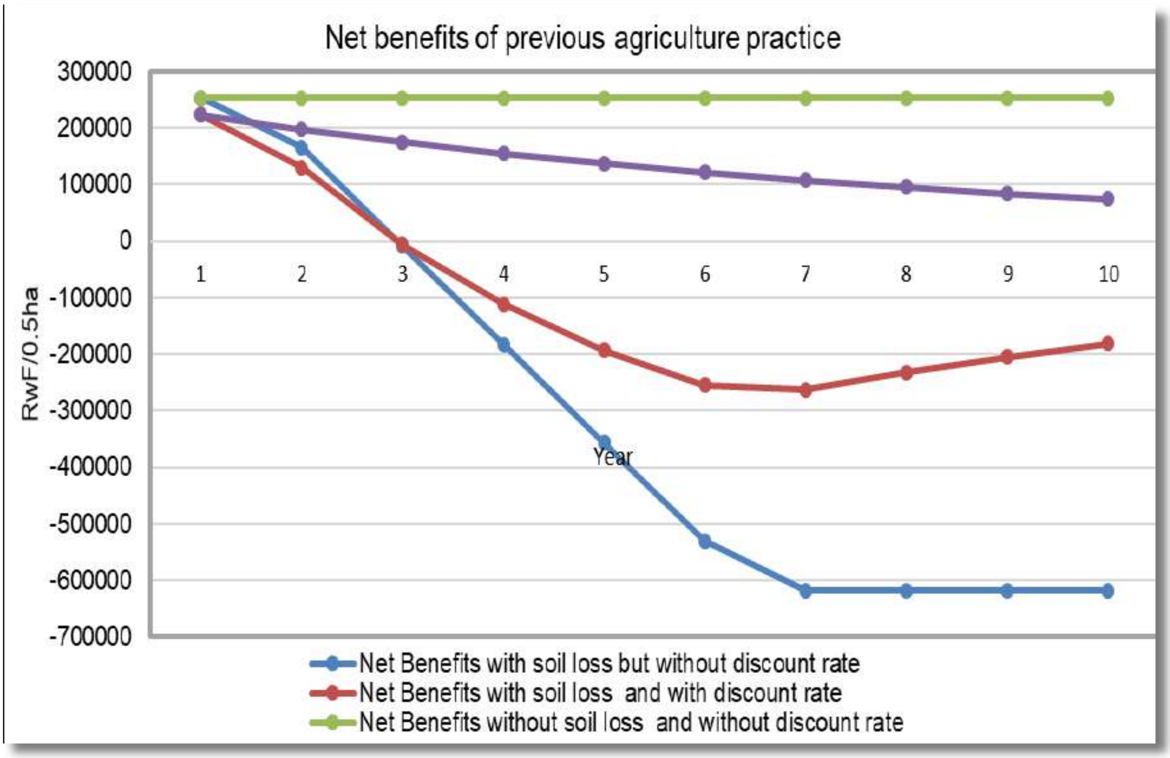


Figure 23 – Scenarios of annual net benefits per hectare of previous agriculture practice in Gicumbi

Financial indicators

Table 13 shows the financial indicators for traditional agriculture and the corresponding FLR actions. The negative figures of traditional agriculture imply that having continued with this system in Gicumbi District would not have been a profit-generating strategy.

Table 13 – Cost-benefit analysis of previous agriculture practice and agroforestry system in Gicumbi

Land use	NPV (at 13%) (RWF)	BCR	ROI	Incremental NPV from FLR (13%) RWF
Traditional agriculture, including costs of soil loss	-1,095,552	0.541	-6.42	-
Agroforestry with maize and beans	5,347,359	4.06	3.07	6,442,911
Agroforestry with maize, beans and fodder	5,877,977	4.34	3.34	9,973,529

From a financial perspective, the agroforestry system with maize, beans and fodder is the most interesting restoration intervention, as it has the highest NPV. In addition, the BCR and ROI illustrate the financial benefits of this system. The incremental NPV compared to the previous land-use of traditional agriculture is high compared to the Gatsibo District due to the excessive cost of replacing soil loss in the cost-benefit model for previous agricultural practice.

Sensitivity analysis of agroforestry with maize and beans in Gicumbi

Table 14 shows the results of the sensitivity analysis. The agroforestry system with maize, beans and fodder has the highest NPV in all scenarios. The sensitivity analysis of traditional agriculture is the most sensitive to changes in discount rates, prices and yields.

Table 14 – Sensitivity analysis maize and beans agroforestry system in Gicumbi

Land use	NPV with different discount rates (r)					Pessimistic scenario	Optimistic scenario
	r = 3%	*r = 7%*	*r = 13%*	*r = 15%*	*r = 25%*		
Traditional agriculture of maize and beans (with soil loss)	-2,443,299	-1,767,380	-1,095,552	-934,243	-409,5299	-1,846,002	6,110,499
Agroforestry system with maize and beans	8,882,110	7,142,600	5,347,359	4,899,412	3,349,874	1,053,802	9,675,548
Agroforestry system with maize, beans and fodder	9,773,501	7,858,139	5,877,977	5,383,230	3,669,374	1,529,925	10,246,326

5.4.10. Results of CBA agroforestry system with wheat and Irish potatoes in Gicumbi

The next agroforestry system for which a cost-benefit model was developed is an agroforestry production system of wheat and Irish potatoes mixed with trees in the Gicumbi District. **Figure 24** shows the estimated annual costs and benefits of implementing this agroforestry system over a period of 10 years on an area of 0.5 ha. Irish potatoes and wheat generate an annual income while the income from timber is generated at the end of the rotation period. The information from on-the-ground data collection shows high productivity of Irish potatoes in the Gicumbi District, and this crop provides the highest income compared to other components of the system as shown by the figure. The agroforestry system presents a positive annual net benefit for both discounted (**A**) and non-discounted (**B**) scenarios. The annual net benefit of this agroforestry system being positive throughout the rotation period is an indication of the potential future profitability of this FLR intervention to local farmers.

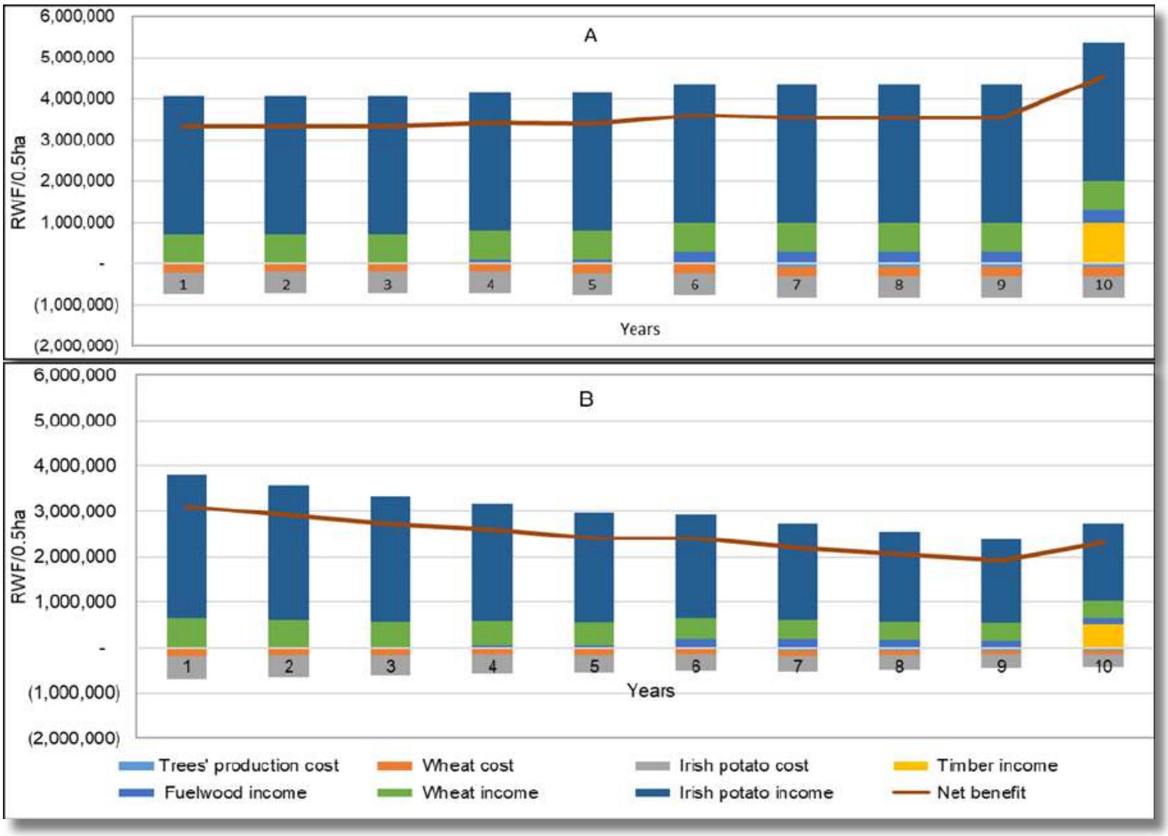


Figure 24 – Annual costs and benefits of agroforestry system with wheat and Irish potatoes in Gicumbi District

5.4.11. Results of CBA traditional production system of wheat and Irish potatoes (previous agriculture practice)

To estimate the incremental value of the agroforestry system discussed previously, it is compared with the costs and benefits that would have been generated through the previous agricultural practice. In **Figure 25**, the annual discounted (**A**) and non-discounted (**B**) net benefit from the production of Irish potatoes and wheat is positive for every year of the ten-year period.

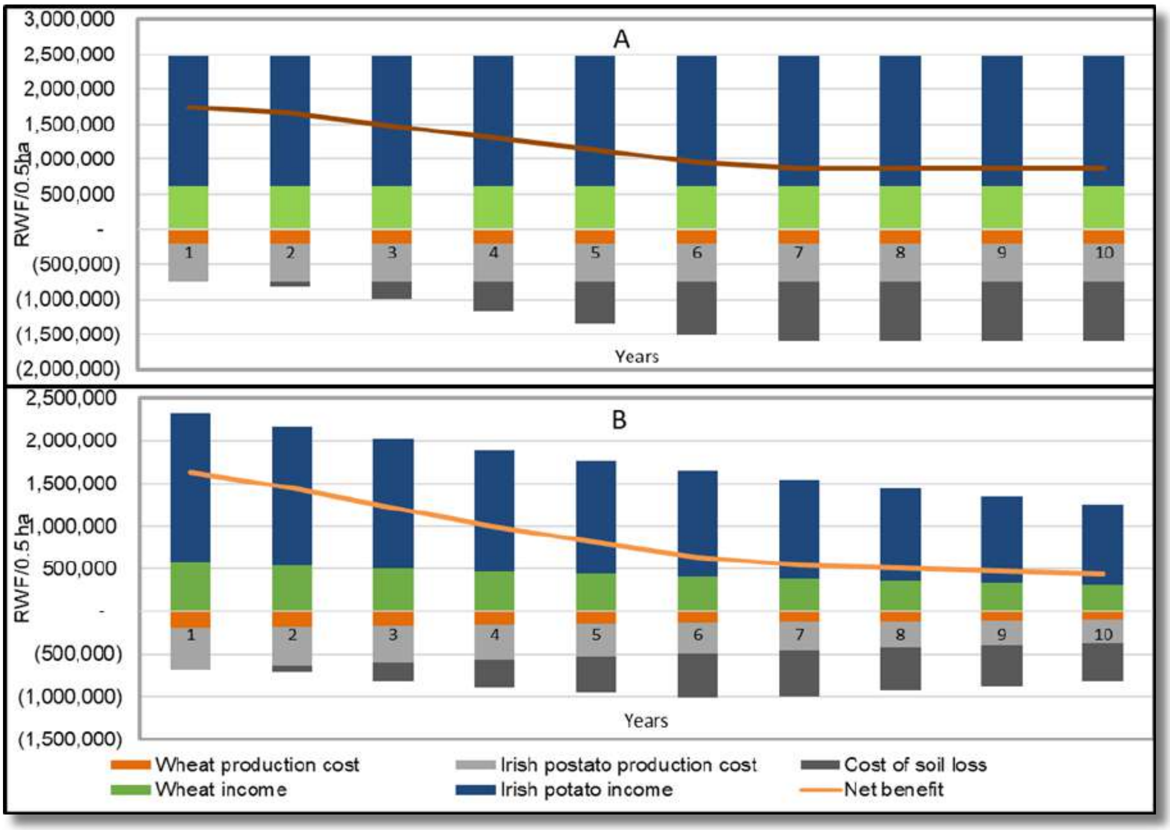


Figure 25 – Annual costs and benefits from the production of wheat and Irish potatoes

Figure 26 illustrates the effect of considering the difference in annual soil loss between the agroforestry system and the previous agriculture practice in Gicumbi. From the figure, soil loss negatively affects the annual net benefit from previous agriculture practice. The business-as-usual scenario will gradually reduce the projected net benefits while more and more soil is lost compared to the FLR action.

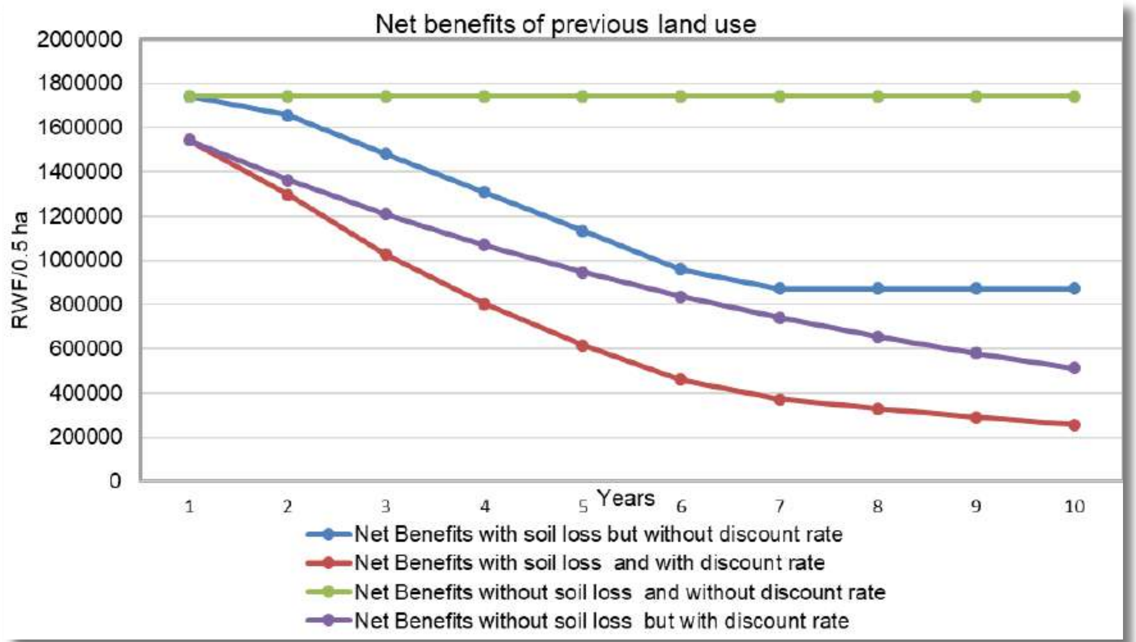


Figure 26 – Scenarios of net benefits of previous agriculture practice considering soil loss and discount rate

Financial indicators

The financial indicators of the agroforestry system with wheat and Irish potatoes and its previous agriculture practice are shown in **Table 15**. The agroforestry system presents a positive NPV and ROI, and the BCR is greater than 1. The positive marginal NPV shows that the benefits from implementing this restoration action surpass the costs, even if you include the opportunity cost of no longer continuing the previous land use.

Table 15 – Financial indicators of previous agriculture practice and agroforestry with wheat and Irish potatoes

Land use	NPV (13%) RWF/0.5ha	BCR	ROI	Increase of NPV from FLR (RWF)
Traditional production system of wheat and Irish potatoes	6,990,853	2.08	1.08	-
Agroforestry system of wheat and Irish potatoes	18,908,844	5.54	4.54	11,917,991

Sensitivity analysis of CBA of implementing an agroforestry system with wheat and Irish potatoes in Gicumbi

The sensitivity analysis of the estimation of the NPV shows positive values for all scenarios. From **Table 16** below it is understood that the profitability of the agroforestry system with wheat and Irish potatoes is not overly sensitive to changes in the discount rate, prices and yields.

Table 16 – Sensitivity analysis of the CBA of the agroforestry system with wheat and Irish potatoes in Gicumbi (RWF/0.5ha)

Land use	NPV with different discount rates (r)					Pessimistic scenario	Optimistic scenario
	r=3%	r=3%	r=3%	r=3%	r=3%		
Traditional production of wheat and Irish potatoes	10,268,751	8,699,442	6,990,853	6,544,927	4,911,378	4,547,090	18,651,850
Agroforestry system of wheat and Irish potatoes	30,201,134	24,696,215	18,908,844	17,442,519	12,273,419	7,446,893	22,216,899

5.4.12. Results of CBA Eucalyptus plantation on public land in Gicumbi

The FLR considered here is the establishment of a woodlot of Eucalyptus trees on an area of 1 ha with a rotation period of 29 years. These woodlots are established on public land, and the main purposes of plantations are protection and the provision of timber at the end of the cycle. The figure below presents the annual costs, benefits, and net benefits. **Figure 27 A** and **B** present non-discounted and discounted costs and benefits, respectively, and are both positive. However, the discounted net income is not extremely high due to the lengthy wait time until timber harvest.

Restored farmland in Gatsibo district (IUCN-Rwanda).

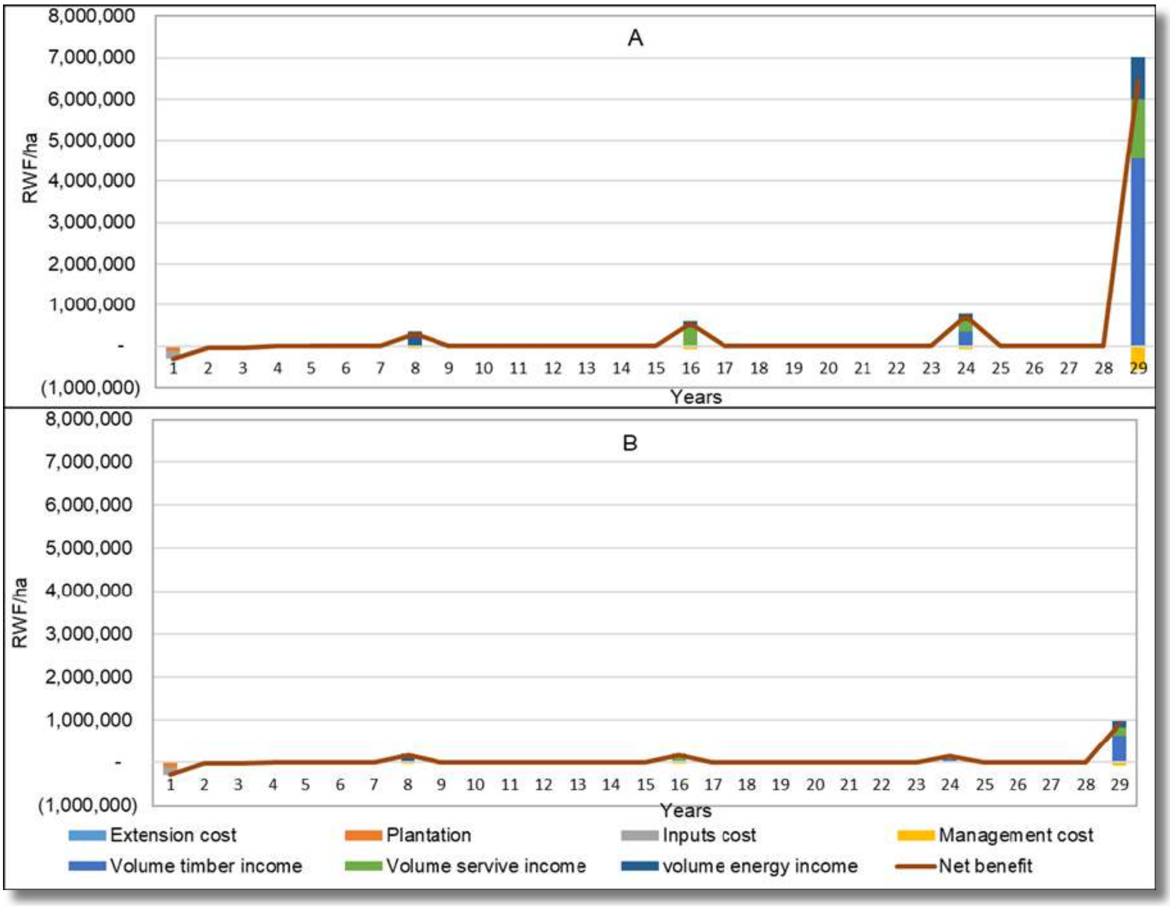


Figure 27 – Annual costs and benefits from Eucalyptus woodlot on public land in Gicumbi

5.4.13. Results of CBA Eucalyptus woodlot on private land in Gicumbi

The main purposes for the establishment of woodlots of Eucalyptus trees on private lands are the production of fuelwood and other wood products used for construction, stakes or electric poles. The analysis is also carried out for a period of 29 years. Private woodlots are cut in years 8, 15, 22 and 29. Timber income is only generated in year

29 as some trees are left uncut until the end of the rotation period for timber (see **Figure 28**).

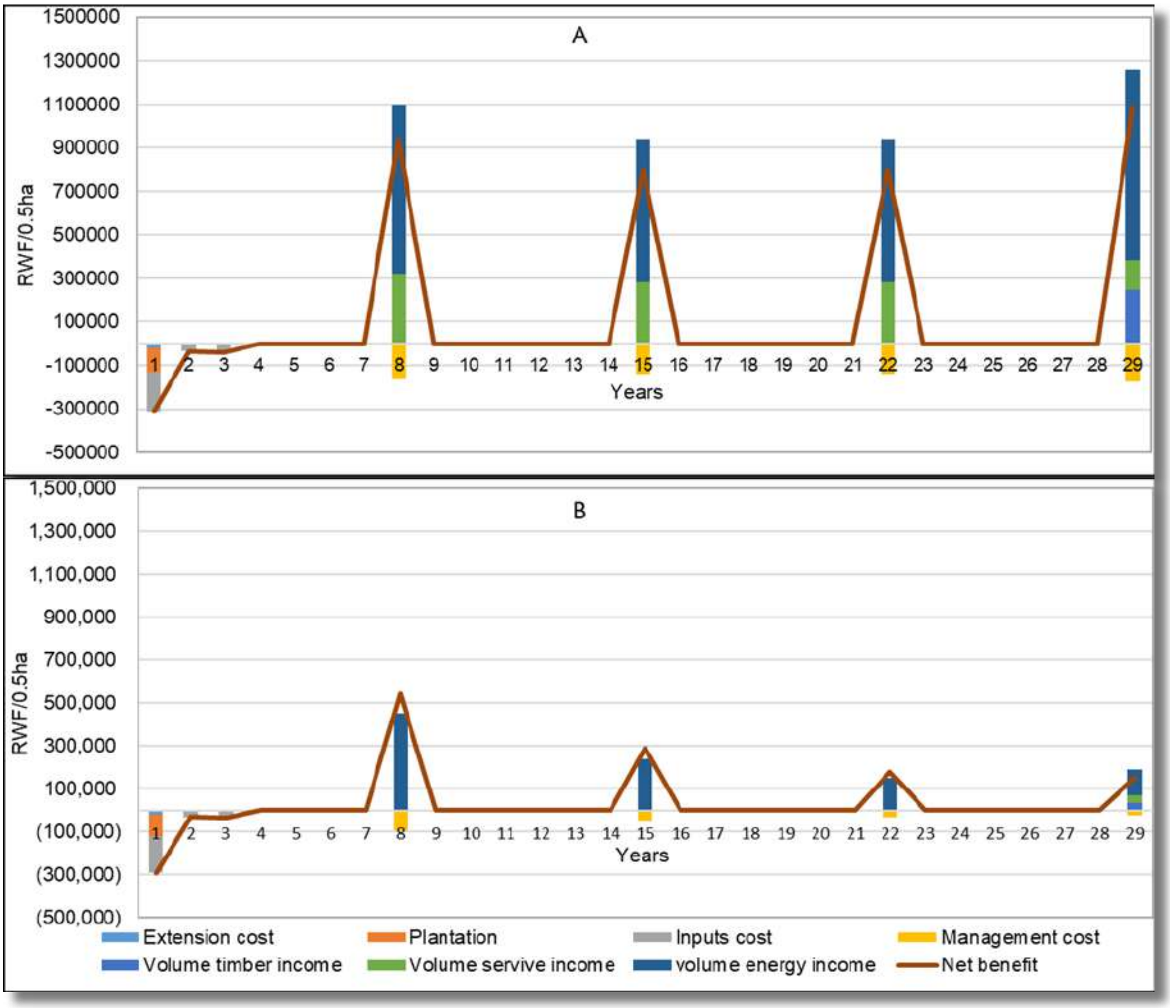


Figure 28 – Annual costs and benefits from Eucalyptus Forest plantation on private land in Gicumbi

Financial indicators

Table 17 presents the financial indicators of the CBA of both woodlots on public and private lands in Gicumbi District. Both woodlots on public and private land have positive NPV and ROI, and BCRs are greater than 1. A positive NPV shows that the discounted benefits outweigh the discounted costs, the same as when the BCR is greater than one. The ROI represents the proportion earned when investing 1 RWF in these two FLR actions (for example: 0.22 RWF for public land).

Table 17 – Cost-benefit analysis of previous agriculture practice and woodlots in Gicumbi

Land use	NPV at 13% RWF/ha	BCR	ROI	Incremental NPV from FLR (RWF)
Degraded public and private lands	-	-	-	-
Woodlot on public land	82,679	1.216	0.22	82,679
Woodlot on private land	237,502	1.556	0.56	237,502

Restored farmland in Gatsibo district (IUCN-Rwanda).

Sensitivity analysis

Table 18 presents the results from the sensitivity analysis. The discount rates of 3%, 7% and 13% make the NPV positive, but the discount rate of 25% makes the NPV negative for woodlots on public and private land. The establishment of woodlots on both public and private lands is sensitive to a higher discount rate, price and production of wood products. The pessimistic scenario considered minimum price and minimum yields/timber harvests. The public woodlot establishment shows a high sensitivity to changes in prices and yields.

Table 18 – Sensitivity analysis for FLR woodlots in Gicumbi(RWF/ha)

Land use	NPV with different discount rates (r)					Pessimistic scenario	Optimistic scenario
	r = 3%	r = 7%	r = 13%	r = 15%	r = 25%		
Woodlot on public land	3,285,318	1,048,911	82,679	-30,751	-212,503	-93,016	226,408
Woodlots on private land	1,764,541	817,500	237,502	138,780	-97,745	14,018	533,737

5.4.14. Results of CBA protective forests in Gicumbi (riverside)

This FLR action establishes tree plantations along the banks (riparian area) of rivers. The CBA is carried out for an area of 1 ha over a period of 20 years. **Figure 29** shows the results of the estimated costs and benefits of implementing a riverside plantation in the Gicumbi District. This restoration action serves a protective role and additionally provides timber at the end of the rotation period. The figure shows a positive net benefit from timber income at the end of the rotation period for the non-discounted scenario (**Figure 29A**). However, the costs of establishment and management in the first years for the discounted scenario (**Figure 29B**) are higher than the benefits provided at the end of the rotation period.

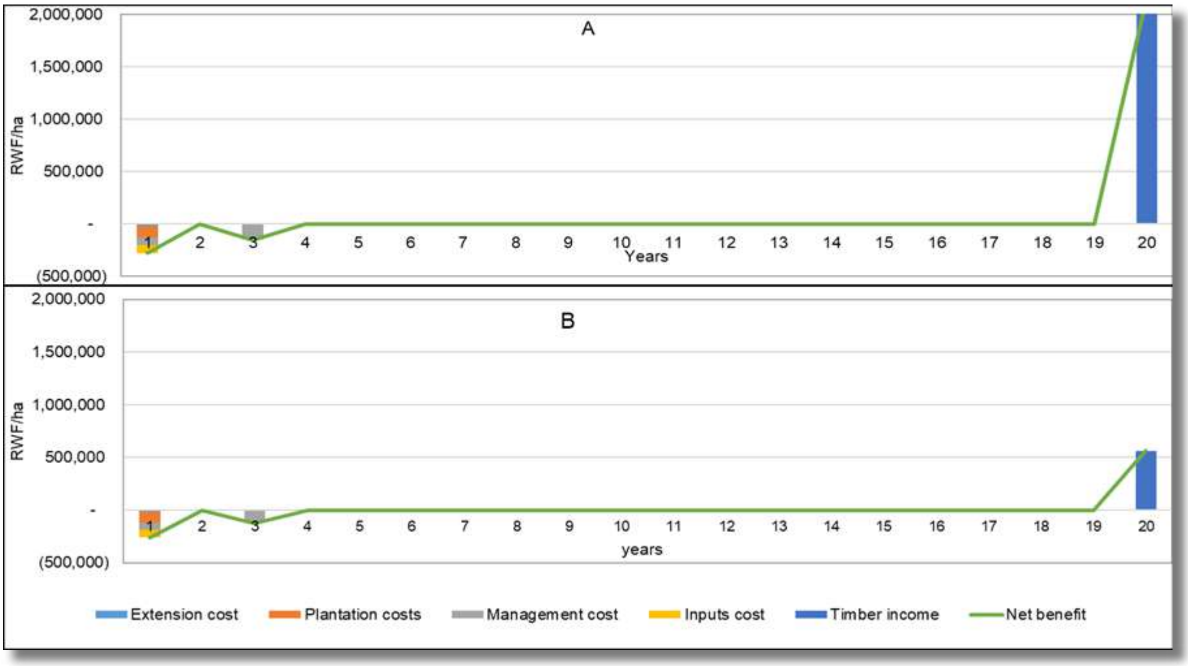


Figure 29 – Annual costs and benefits for protective riverside forest in Gicumbi

Financial indicators

As with the public and private woodlots, the riverside (riparian) plantation has been established on degraded lands that generate no income, thus the NPV of the scenario continuing the previous land use will be equal to zero. Riverside plantations are established for protective and environmental purposes including sequestering carbon; stabilising the riverbanks against sediments by slowing rainwater runoff; reducing flooding, erosion and pollution; recharging the aquifers; keeping the river cool and supporting fish populations. Without considering any additional environmental benefits, the results from the analysis (**Table 19**) show a negative NPV and ROI. Furthermore, the BCR is less than 1 at a 13% discount rate.

Table 19 – Financial indicators protective riparian forest in Gicumbi

Land use	NPV (r = 13) RWF/ha	BCR	ROI	Incremental NPV from FLR (RWF/ha)
Protective forests (riparian forest)	-160,553	0.54	-0.46	-160,553

Sensitivity analysis

The establishment of protective riparian forest shows a positive NPV at a discount rate of 3% and 7% and a negative NPV at 13%, 15% and 25% (**Table 20**). Thus, providing more weight to long-term timber income makes this FLR action a profitable one. Both pessimistic and optimistic scenarios present a negative NPV.

Table 20 – Sensitivity analysis of planting protective riparian forest in Gicumbi (RWF/ha)

Land use	NPV with different discount rates (r)					Pessimistic scenario	Optimistic scenario
	r = 3%	r = 7%	r = 13%	r = 15%	r = 25%		
Protective forest (riparian forest)	800,099	181,346	-160,553	-206,935	-273,852	-213,525	-37,583

5.5. THE EFFECT OF CARBON SEQUESTRATION ON NET PRESENT VALUE

5.5.1. Monetary value from carbon dioxide removal

The results from an analysis produced with the FLR Climate Impact Tool represent the quantity of carbon dioxide sequestered by FLR action from 2016 up to 2018. Depending on the type of tree species planted in both districts of intervention (Gicumbi and Gatsibo), the tool calculated the total tonnes of carbon dioxide that will be captured over 10 years for agroforestry, 20 years for protective forests and 29 years for woodlot plantations.

Table 21 below presents sequestration capacity of different FLR interventions.

Table 21 – Carbon dioxide sequestration capacity for FLR interventions

Technical packages	Carbon sequestration capacity t CO_2/ha/year	Rotation period (years)
Agroforestry	11	10
Riparian forest	11	20
Roadside plantation	11	20
Woodlot plantation	39	29

Table 22 presents the CO_2 sequestration capacity of FLR interventions according to their respective rotation period and the discounted benefits using the carbon price discussed previously. The discounted benefits for agroforestry are calculated at 0.5 ha; woodlot, riverside and roadside protective forests are calculated at 1 ha. Regarding benefits based on the type of tree species planted, Eucalyptus in woodlots has the highest sequestration capacity.

Table 22 – Carbon dioxide sequestration capacity for FLR interventions

Interventions	Sequestration capacity (tCO_2/year)	Period (years)	Discounted benefits (tCO_2)
Agroforestry	11	10	414,857.85
Woodlot	39	29	4,049,745.14
Riverside	11	20	1,074,140.28
Roadside	11	20	1,074,140.28

5.5.2. Carbon sequestration from FLR interventions

Table 23 presents the incremental NPV and the discounted carbon sequestration of interventions respective to their rotation period. The tree-based biomass or the contribution of agroforestry trees in farmland was considered for carbon sequestration, however, the calculation did not include emissions from agricultural fertilisers or cattle. The incremental NPV is the difference between NPV from FLR action and NPV from previous agricultural practice. The percentage increase represents the contribution from carbon sequestration compared to the contribution from agriculture or forest production. Considering the discounted carbon throughout the rotation period, all interventions show positive net benefits. Incremental NPV and carbon sequestration represent the total contribution of FLR interventions (private and public benefits respectively) in Rwandan Francs per unit area (0.5 ha for agroforestry and 1 ha for woodlot and protective forests).

Table 23 – Total contribution of FLR interventions in Gatsibo

Interventions in Gatsibo	Incremental NPV (RWF/unit area)	Carbon sequestration (RWF/unit area)	Incremental NPV + carbon value (RWF)	% Increase
Agroforestry, maize and beans	3,535,292	414,858	3,950,150	10.5
Agroforestry, maize, beans and fodder	5,997,790	414,858	6,412,648	6.5
Woodlot on public land	-21,711	4,049,745	4,028,034	100.5
Woodlot on private land	87,131	4,049,745	4,136,876	97.9
Protective forest (roadside plantation)	-179,472	1,074,140	894,668	120.1

Table 24 shows the total contribution of FLR interventions considering both NPV from financial flows and the discounted carbon sequestration value. Considering monetary value from carbon sequestration, all interventions show positive net benefits. The percentage increase represents the incremental NPV from carbon sequestration.

Table 24 – Total contribution of FLR interventions in Gicumbi

Interventions in Gicumbi	Incremental NPV (RWF/unit area)	Carbon sequestration (RWF/unit area)	Incremental NPV + carbon value (RWF)	% Increase
Agroforestry, maize and beans	6,442,911	414,858	6,857,769	6.0
Agroforestry, maize, beans and fodder	9,973,529	414,858	10,388,387	4.0
Agroforestry, wheat and Irish potatoes	11,917,991	414,858	12,332,849	4.0
Woodlot on public land	82,679	4,049,745	4,132,424	98
Woodlot on private land	237,502	4,049,745	4,287,247	94
Protective forests (riparian forest)	-160,553	1,074,140	913,587	118

5.6. Discussion of the Results

This study estimated the costs and benefits of a series of FLR interventions in two districts (Gatsibo and Gicumbi) of Rwanda. The study presented in this chapter showed the estimated NPV and other financial indicators (BCR, ROI) for the implementation of the FLR interventions. Without considering the value from carbon sequestration, most of the interventions provide a positive NPV and a favourable return on investment except for protective forests in both districts (riparian and roadside plantation) and Eucalyptus plantation on public lands in Gatsibo. Considering the economic value from carbon sequestration, all FLR interventions are profitable and provide positive net benefits for the proposed rotation periods at a discount rate of 13%. The analysis showed that the implementation costs of different agroforestry systems are relatively minor compared to the benefits they attain.

The results from agroforestry systems are positive and are similar to the results of MINIRENA (2014) and Kiyani et al. (2017) who estimated the incomes farmers could receive from adopting agroforestry. In these studies, adopting agroforestry shows positive income and is recommended as a key pillar for Rwanda FLR options to provide multiple benefits, both public and private. Verdone & Seidl (2016), Kiyani et al. (2017) and Stainback et al. (2012) also recommended that policy makers increase the adoption level of agroforestry and improve woodlot management as the preferred land uses to restore degraded lands.

The results from the financial analyses of agroforestry systems show greater NPVs compared to the findings of the ROAM assessment (MINIRENA, 2014), adjusted for inflation, because this study only focused on two districts while ROAM was conducted at the national level. This difference may also be due to factors like the use of improved varieties of seedlings provided to farmers and the adoption level of agroforestry systems using technical agriculture guidelines leading to increased production.

Additionally, MINIRENA (2014) calculated NPV from beans and maize separately while this assessment considered the rotation of maize and beans on one piece of land during seasons in A and B. Since 2010, the government of Rwanda initiated a programme to provide agriculture inputs like seeds and subsidised fertilisers, which gained attention from 2014 until now. This programme was also supported by the extension programme of Rwanda Agriculture Board that was decentralised at the district level.

With a discount rate of 13%, the NPV from forest woodlots on public land provides a relatively high NPV (4,132,424 RWF/ha in Gicumbi and 4,028,034 RWF/ha in Gatsibo) over 29 years, while MINIRENA (2014) found that the timber with erosion prevention would create a revenue of 386,896 RWF/ha in a rotation of 28 years. Furthermore, the establishment of woodlots generates higher net benefits compared to ROAM results despite the higher discount rate (13% instead of 7%), because the technical packages included the contribution from carbon sequestration throughout the rotation period.

The fact that the assessment of technical packages was conducted in two districts instead of a national assessment could also affect the differences between the two studies. The net benefits from protective forest plantations are RWF 913,587 (riverside plantations) and RWF 894,668 (roadside plantation) in Gicumbi and Gatsibo, respectively, at 13%. This is quite different from the ROAM analysis that found an NPV of -608,224 RWF/ha for protective forests in general at 7%. The difference in results can partially be understood based on two reasons: (1) because the technical packages study assumes that after 20 years of plantation, trees planted on roadsides or riversides will be replaced by new plantations and sold as fuelwood to avoid accidents that might occur with older trees; and (2) technical packages considered the contribution (value) of carbon sequestration.

Although the FLR interventions have different NPV and ROI, each restoration transition is unique and provides its own benefits. This study was not assessing the restoration intervention that provides the highest returns; rather, it was assessing the contribution and the profitability of each of the interventions depending on previous agriculture practice or previous use of land. Each restoration intervention provides both direct benefits (timber, yields, fodder, and erosion control) and indirect benefits (carbon sequestration).

MINIRENA's (2014) assessment placed these benefits into two categories: public benefits which measure the off-site goods and services from restoration (e.g., carbon sequestration), and private benefits which are received by the landowner like fuelwood, yields, timber production and reduced costs of soil loss.

Though agroforestry systems provided the highest returns from direct benefits, the establishment of protective forests and woodlots provided higher gains in terms of indirect benefits. The roadside plantations (*G. robusta*), agroforestry and riparian forests remove an average of 11 tCO_2/ha/year, while the Eucalyptus woodlots remove an average of 39 tCO_2/ha/year. These results are closer to the estimated carbon removal rates from FLR activities of Bernal et al. (2018), where woodlots were found to have the highest CO_2 removal rate ranging from 4.5 to 40.7 t/ha/year while the range of CO_2 removal rate for agroforestry is from 10.8–15.6 t/ha/year globally. Carbon sequestration rates used in this study are greater than the ones used by Verdone et al. (2017) as that study used the value transfer of carbon sequestration rates from Myneni et al. (2001), which provided an average value for biomass carbon capacity from different countries using the biome-average datasets.

The total net benefits calculated (**Table 23** and **Table 24**) are the contributions of interventions throughout the rotation periods. All FLR actions studied in these technical packages are profitable at 7%, the reference discount rate used in ROAM and in the IPR baseline report. The net benefit calculated provides both public and private benefits and this brings attention to different stakeholders involved in FLR activities.

The use of a discount rate of 13% (as requested by the Ministry of Environment) has reduced the overall net benefits and the calculation of NPV without considering the monetary value of carbon dioxide sequestration at 13% has made public woodlots and protective forest plantations unprofitable. Thus, a low discount rate would be interesting to attract investors in restoration activities.

The analysis showed that the establishment of agroforestry systems requires less money than other interventions, but the contribution of each of the interventions is unique for both public and private benefits. It was remarked that the trends of agriculture production have increased in agroforestry systems compared to the production from previous land use.

For unit area, the net gain (benefits) from adopting agroforestry is greater than woodlot and riverside and roadside plantations. However, woodlots and protective forest plantations generate more environmental benefits than agroforestry. Therefore, private investors are potentially more suited to investments in agroforestry systems to improve livelihoods income while public investment should focus on woodlot establishment and protective forests to align with national climate change plans. As all interventions are profitable, scaling up the same interventions to the other districts would be advantageous for both farmers and the people in general.

Restoration is not a new topic in Rwanda. Restoration has been happening for decades, and the momentum was enhanced by the country’s commitment to the Bonn Challenge in 2011. The next chapters, 5 and 6, will present the status of restoration activities, potential contributions of further implementing FLR actions on ecosystem services and prioritisation of areas, actions, or restoration opportunities across the country.

6. RESTORATION STOCK TAKING

In addition to restoration in Gatsibo and Gicumbi, Rwanda has been implementing FLR actions all over the country as part of its commitment to the Bonn Challenge. In 2015 Rwanda conducted the first inventory of FLR initiatives in the country, which was updated in 2018. This study was guided by IUCN in collaboration with the Rwanda Water and Forestry Authority (RWFA)[13]. According to this study, between 2011 and 2018, 44 FLR projects/programmes were identified across the country. Considering that each project has several intervention areas, the study revealed that these projects were implemented in more than 1,700 areas, totalling more than 708,629 ha under restoration with around USD 531 million invested.

Bugesera, Rulindo, Gatsibo and Nyamagabe are the districts (**Figure 30**) with the highest number of project interventions. The distribution of these interventions in each district is represented in **Figure 31** and per sector in **Figure 32**.

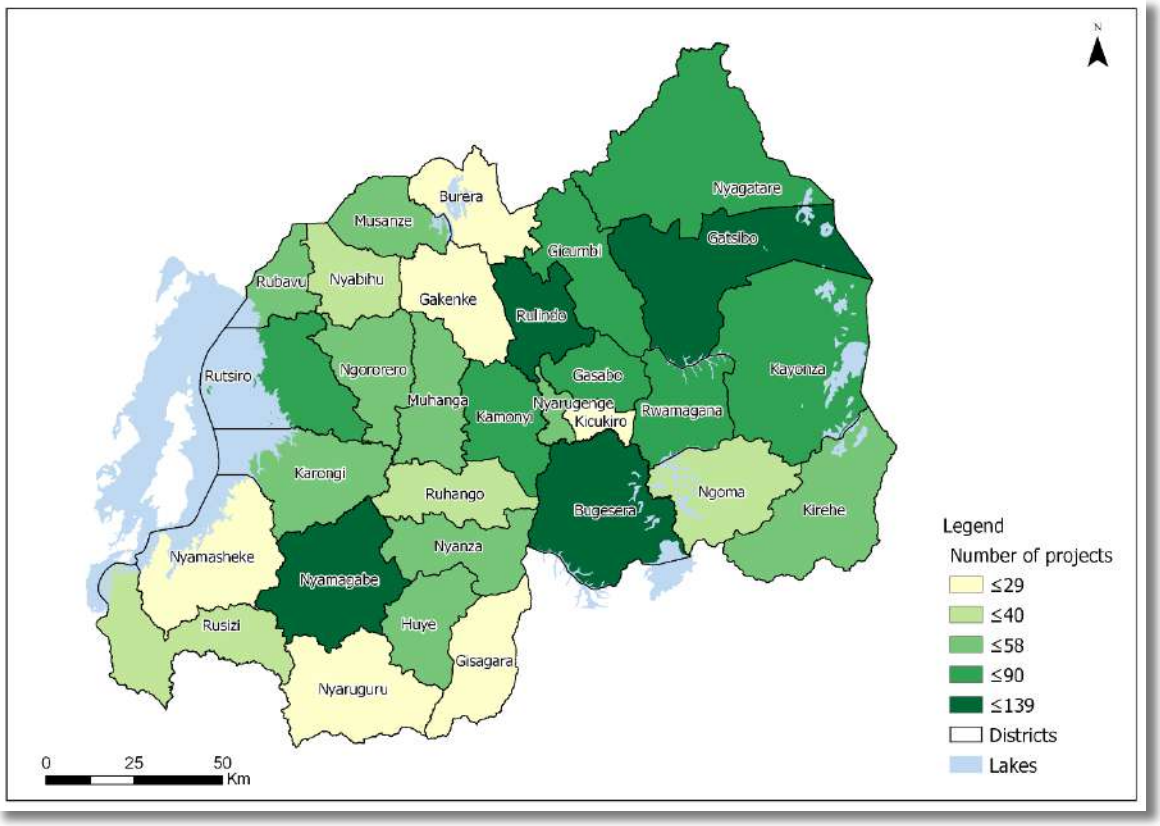


Figure 30 – FLR project coverage by district (2011-2018)

[13] Dave, R., Saint-Laurent, C., Murray, L., Antunes Daldegan, G., Brouwer, R., de Mattos Scaramuzza, C.A., Raes, L., Simonit, S., Catapan, M., García Contreras, G., Ndoli, A., Karangwa, C., Perera, N., Hingorani, S. and Pearson, T. (2019). 'Second Bonn Challenge progress report'. *Application of the Barometer in 2018*. Gland, Switzerland: IUCN. xii + 80pp.

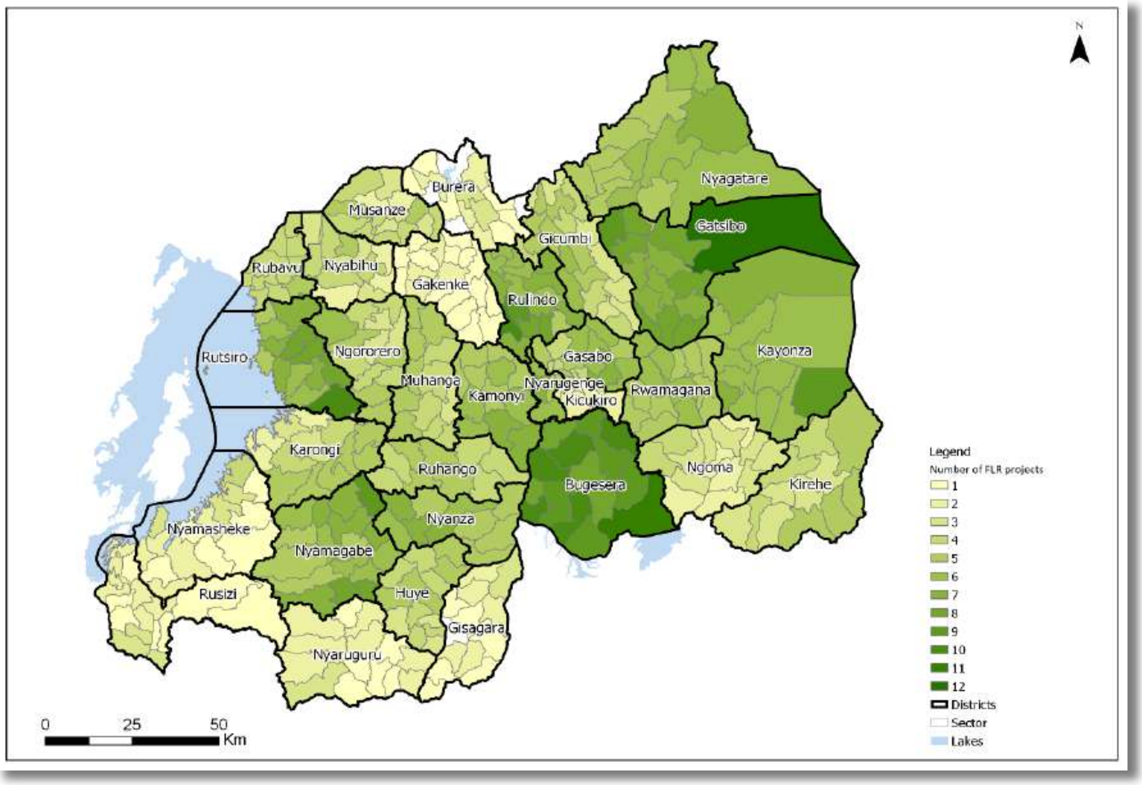


Figure 31 – FLR project coverage by sector (2011-2018)

Figure 32 shows the number of hectares restored by district between 2011-2018.

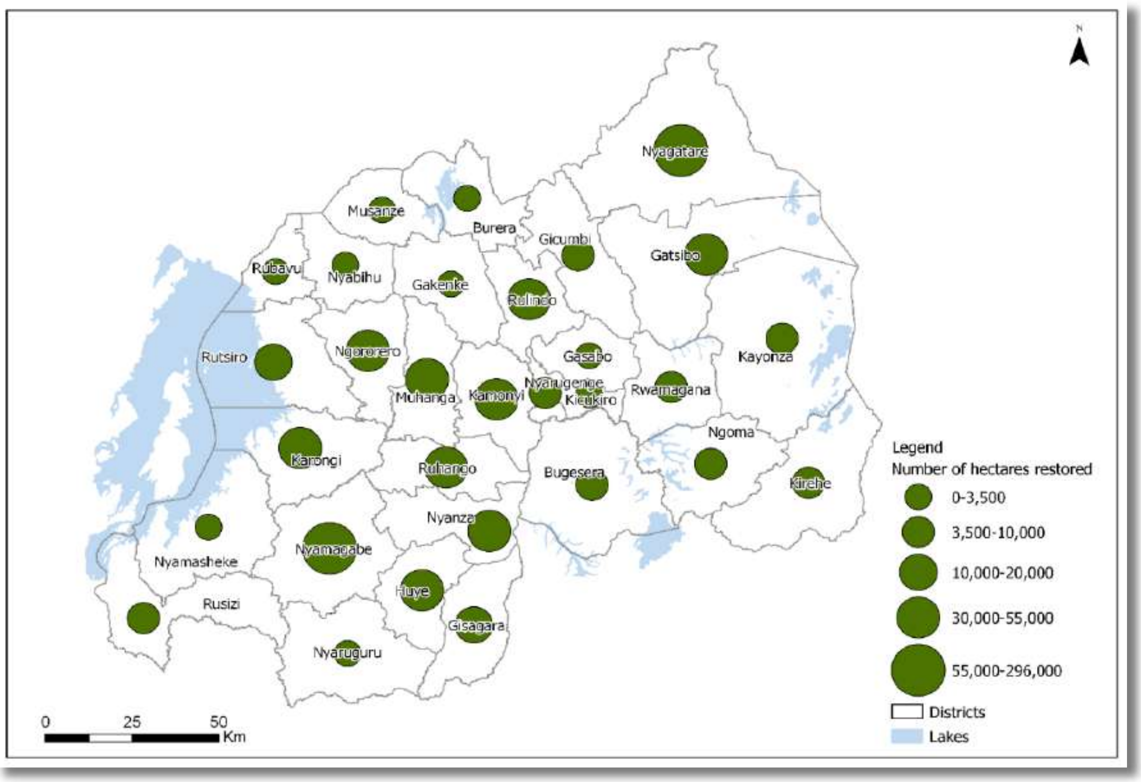


Figure 32 – Number of hectares restored in FLR projects by district (2011-2018)

Figure 33 presents the number of hectares restored in FLR projects by Sector between 2011-2018.

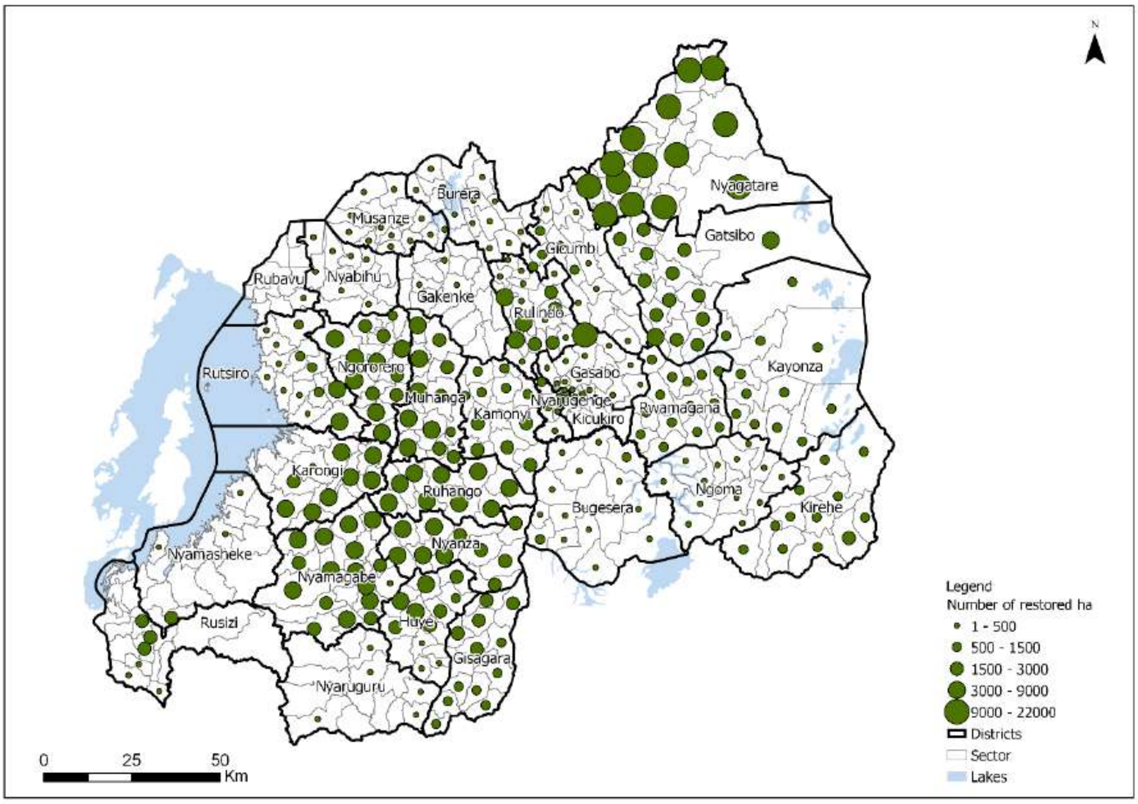


Figure 33 – Number of hectares restored in FLR projects by sector (2011-2018)

The monetary amount invested in FLR projects is represented in **Figure 34**. Rutsiro is the district with the highest amount invested in FLR with the main objective to reduce the landslides that have been taking human lives and their property every year. There is no project with a budget disaggregated by sector. To estimate the amount of investment of each project in each sector, the total budget of each project was divided by the number of sectors each project has covered (**Figure 35**).

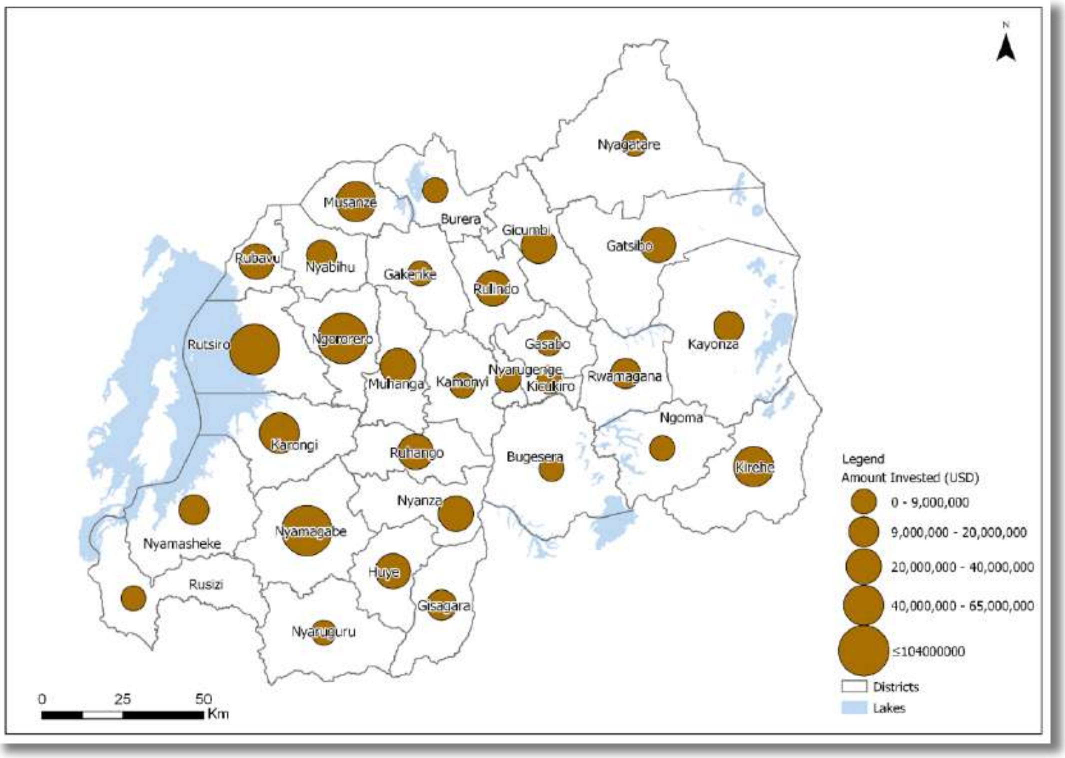


Figure 34 – Amount invested in FLR projects by district (2011-2018)

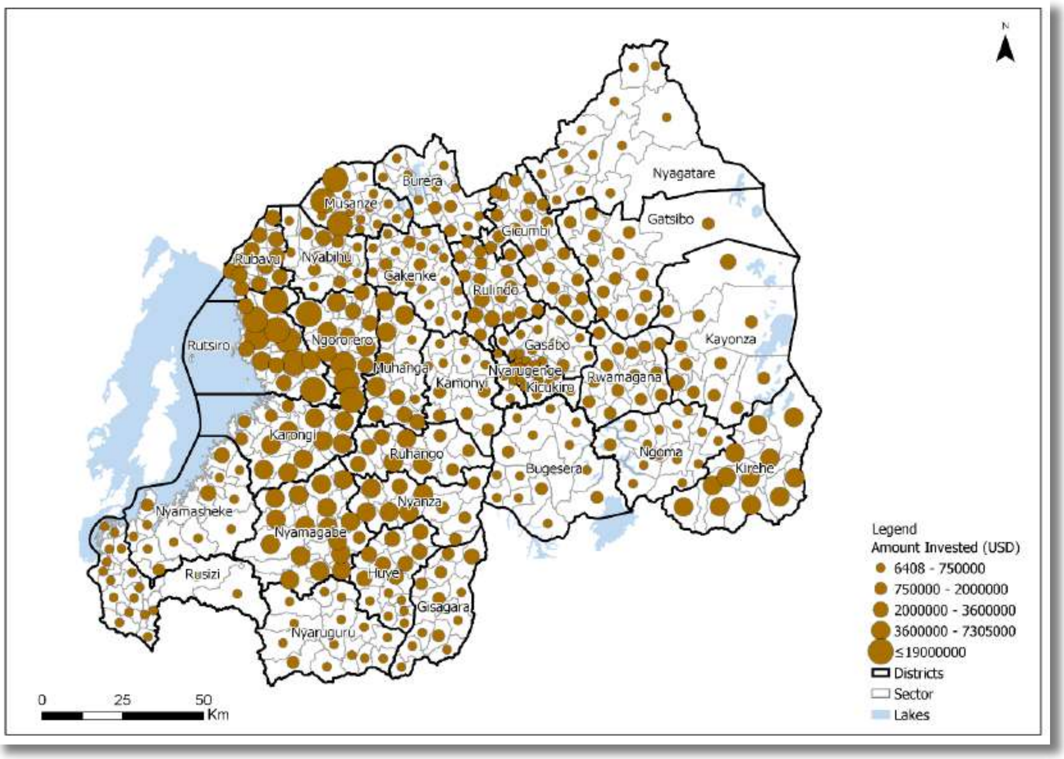


Figure 35 – Amount invested in FLR projects by sector (2011-2018)

As this chapter illustrates, Rwanda has already made noteworthy progress in restoration in the period 2011–2018. Rwanda also continues to be committed to restore its landscapes. As a new step towards further implementation of FLR in Rwanda, a first potential impact assessment was carried out. This impact study assessed which districts have the highest potential impact related to the reduction in annual erosion if the FLR actions implemented in Gatsibo and Gicumbi would be implemented on a national level. The next chapter will provide the methodology and results of this exercise. As no precise mapping of the area restored in Rwanda was available at the time of this study, the area already restored was not included in the analysis. A correction for areas already restored will be needed to use the results of the next chapter in a national prioritisation of FLR actions and areas and to increase the number of potential impacts of FLR beyond the reduction of annual erosion rates.

7. INVEST ANALYSIS RESULTS

7.1. INTRODUCTION TO INVEST

One of the fundamental issues in the FLR process is the identification of areas that should be considered a priority for intervention (Vallauri et al., 2005). The selection of priority areas is dependent on the objectives of the restoration action. This task is complex as it is typically a multi-objective process, and diverse types of variables should be considered. This part of the study proposes a preliminary prioritisation based on the assessment of the potential impact on the annual soil erosion rate, which can be used as an input for a broader spatial prioritisation considering multiple objectives (for example, as part of the financial analysis done previously or through the inclusion of a broader range of ecosystem services). To provide a first indication of the areas with high potential for future FLR actions, an assessment was carried out on the possible impact of implementing different FLR actions on erosion control. Soil erosion was measured by estimating the difference between a scenario with and without the implementation of the restoration actions. The two scenarios allow an estimate of the potential difference in erosion rate before and after the implementation of the restoration actions (see **Figure 46** later in this chapter).

To measure the impacts on this ecosystem service (erosion control and sediment retention[14]) the InVEST tool version 3.6.0 was used. This tool is designed to estimate a range of ecosystem services (Sharp et al., 2018). To measure the effects on erosion control and on sediment export – the export of sediments is a product of erosion; the InVEST SDR model was used. The objective of the SDR is to map the generation and delivery of terrestrial sediments to water currents (Sharp et al., 2018). The 'retention of sediment' service may improve soil fertility, can have a positive impact on water quality and can decrease efforts related to the dredging of sediments of rivers and reservoirs (Hamel et al., 2015; Vigiak et al., 2012; Solís et al., 2007). The SDR model is based on the revised universal soil equation (Vogl et al., 2016).

The model calculates the sediment discharges from terrestrial areas, and it does obviate the formation of uneven terrain that prevents the passage of sediment or other sources of sediment, for example the impact of ravines or landslides, among others (Sharp et al., 2018). The model first calculates the amount of annual erosion for each pixel of the spatial data input (the reference map for pixel size is the digital elevation model(DEM)), and as a product of this soil loss it determines an estimate of the amount of soil that will reach the streams, SDR corresponds to the proportion of soil loss that reaches the stream (Hamel et al., 2015; Borselli et al., 2008). The soil erosion rate map based on the universal soil equation is an intermediate result of the SDR model, while the sediment export map, which represents the contribution to sediment yield on a per-pixel level, is a final model result (Sharp et al., 2018; Hamel et al., 2015). Sharp et al. (2018) and Hamel et al. (2015) provide more details about the model. Beatty et al. (2018) give examples of how InVEST models can be applied in FLR prioritisation analyses.

[14] Erosion rate is an intermediary result of the InVEST model estimating sediment retention capacity of different land uses.

To evaluate the impact of the four restoration techniques, the SDR model requires two biophysical inputs for the different land uses: the cover-management factor (C-factor) and the support practice factor (P-factor). Because the main aim of this assessment was to rank areas according to the impact of the FLR actions on annual erosion and sediment export reduction and to prioritise areas for the future implementation of FLR actions, the model was not calibrated (Hamel et al., 2015). The basis of this spatial assessment is Rwanda's land use map (RCMRD, 2015). The model was run twice to assess the potential impact of a specific restoration action on erosion and sediment export – once with C and P factors for the current land-use (**Table 25**) and then again adjusting these factors for a specific land use or multiple land uses with the corresponding factors with FLR potential (**Table 26** and **Figure 41** to **Figure 44**).

Table 25 – Biophysical data for current land uses

Land use	C-factor	P-factor
Dense forest	0.001[1,2,3]	1[13,14]
Moderate forest	0.021[3,4,5,6]	1[13,14]
Sparse forest	0.150[7]	1[13,14]
Sparse forest with potential for protective forest in riparian buffers	0.150[7]	1[13,14]
Sparse forest with potential for protective forest in buffers of wetlands	0.150[7]	1[13,14]
Sparse forest with potential protective forest in buffers of roads	0.150[7]	1[13,14]
Woodland	0.207[8]	1[13,14]
Closed grassland	0.129[3,6,9,10]	1[13,14]
Closed grassland with potential for protective forest in riparian buffers	0.129[3,6,9,10]	1[13,14]
Closed grassland with potential for protective forest in buffers of wetlands	0.129[3,6,9,10]	1[13,14]
Open Grassland	0.253[2,3,5,6,8,10]	1[13,14]
Open grassland with potential for protective forest in riparian buffers	0.253[2,3,5,6,8,10]	1[13,14]
Open grassland with potential protective forest in buffers of wetlands	0.253[2,3,5,6,8,10]	1[13,14]
Closed shrubland	0.011[2,6,9]	1[13,14]
Open shrubland	0.233[2,6,8]	1[13,14]
Open shrubland with potential for protective forest in riparian buffers	0.233[2,6,8]	1[13,14]
Open shrubland with potential for protective forest in buffers of wetlands	0.233[2,6,8]	1[13,14]
Open shrubland with potential protective forest in buffers of roads	0.233[2,6,8]	1[13,14]
Perennial cropland	0.041[1,2]	1[13,14]
Perennial cropland with potential for protective forest in riparian buffers	0.041[1,2]	1[13,14]
Perennial cropland with potential for protective forest in buffers of wetlands	0.041[1,2]	1[13,14]
Annual cropland	0.402[1,2,75,6]	1[13,14]
Annual cropland with potential for protective forest in riparian buffers	0.402[1,2,75,6]	1[13,14]
Annual cropland with potential for protective forest in buffers of wetlands	0.402[1,2,75,6]	1[13,14]
Wetland	0.001[6]	1[13,14]
Water body	0.001[6]	1[13,14]

Land use	C-factor	P-factor
Settlement	0.1[11,12]	1[13,14]
Other land	0.000[13]	1[13,14]

() References biophysical data.

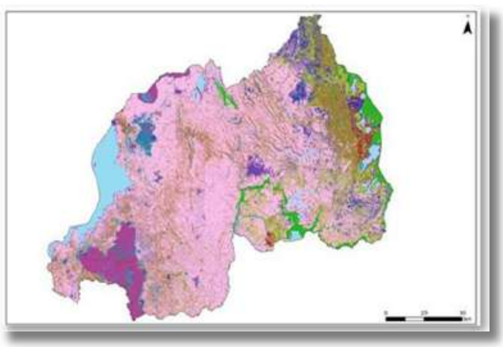
Table 26 – Biophysical data for FLR actions

Land use	C-factor	P-factor
Managed woodlots on sparse forest	0.155[6,7,8]	0.8[15]
Protective forest in riparian buffers on spare forest	0.027[4,5,6]	0.71[2]
Protective forest in buffers of wetlands on spare forest	0.027[4,5,6]	0.71[2]
Protective forest in buffers of roads on spare forest	0.027[4,5,6]	0.71[2]
Protective forest in riparian buffers on closed grassland	0.027[4,5,6]	0.71[2]
Protective forest in buffers of wetlands on closed grassland	0.027[4,5,6]	0.71[2]
Protective forest in riparian buffers on open grassland	0.027[4,5,6]	0.71[2]
Protective forest in buffers of wetlands on open grassland	0.027[4,5,6]	0.71[2]
Protective forest in riparian buffers on open shrubland	0.027[4,5,6]	0.71[2]
Protective forest in buffers of wetlands on open shrubland	0.027[4,5,6]	0.71[2]
Protective forest in buffers of roads on open shrubland	0.027[4,5,6]	0.71[2]
Agroforestry with perennial cropland	0.006[1]	1[13,14]
Protective forest in riparian buffers on perennial cropland	0.027[4,5,6]	0.71[2]
Protective forest in buffers of wetlands on perennial cropland	0.027[4,5,6]	0.71[2]
Agroforestry with annual cropland	0.1[1,7]	1[13,14]
Protective forest in riparian buffers on annual cropland	0.027[4,5,6]	0.71[2]
Protective forest in buffers of wetlands on annual cropland	0.027[4,5,6]	0.71[2]

() References biophysical data.

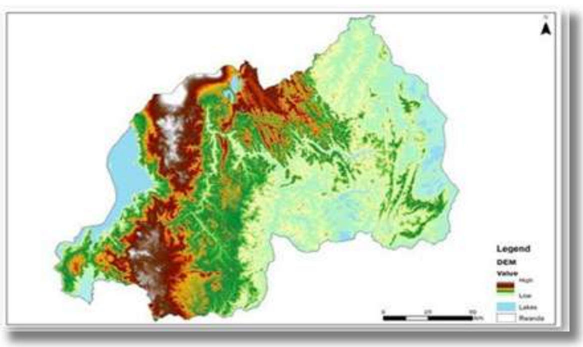
In addition to the biophysical data, the model uses spatially explicit data. The maps presented in the next section (land cover, DEM for slopes, location of watersheds, soil erodibility and rainfall erosivity) show the spatial data used to generate the model (**Figure 36** to **Figure 40**). For the other indicators, the model's default values were used (see Sharp et al., 2018).

7.2. SPATIAL DATA INPUTS



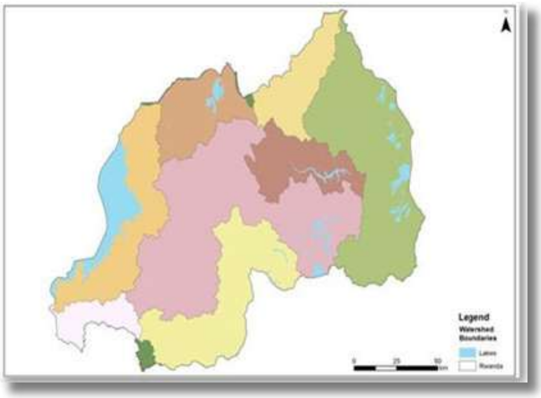
Source: RCMRD, 2015.

Figure 36 – Landover



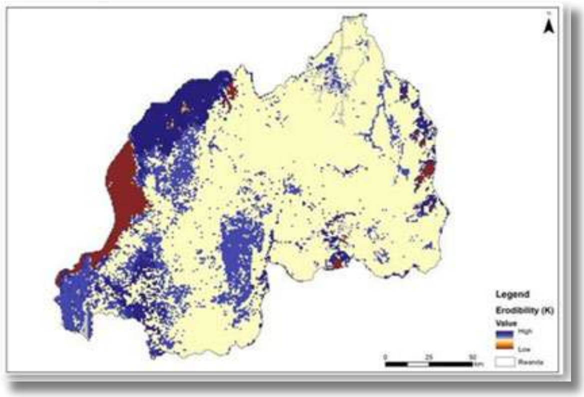
Source: RCMRD, 2015.

Figure 37 – DEM



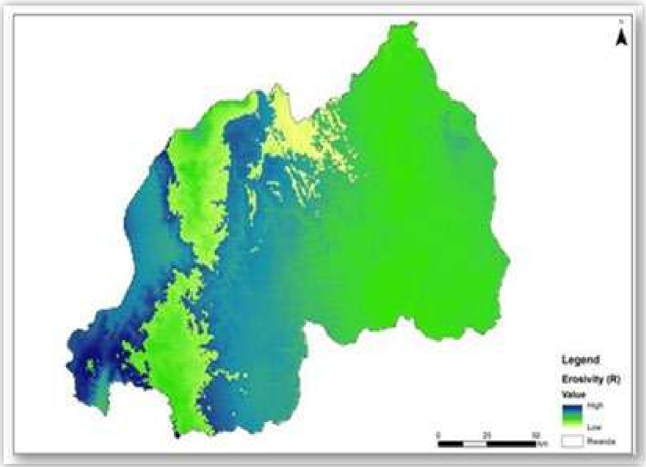
Source: ICRAF, 2016.

Figure 38 – Watersheds



Source: Johnson, J. Natural Capital Projects. Unpublished.

Figure 39 – Soil Erodibility (k)



Source: Johnson, J. Natural Capital Project. Unpublished.

Figure 40 – Rainfall erosivity (R)

7.3. LAND USES WITH FLR POTENTIAL

The analysis is based on Rwanda's 2015 land cover map, and the areas identified having potential for the further implementation of the four FLR actions are considered here. As was mentioned earlier, the 2015 map did not yet include the areas restored since 2011, so it is to be expected that part of the area with a potential for further restoration have already been restored. There are about 1,600,000 ha of land with potential for implementation of the restoration activities considered in this study (**Table 27**). About 79% of this area can potentially be used for the implementation of the agroforestry system with annual crops. The potential area for managed woodlots on land that currently contains sparse forest accounts for 16% of the total area with FLR potential, agroforestry systems with perennial crops account for about 2% and the protective trees account for 3% (**Figure 41** to **Figure 44**).

Table 27 – Number of hectares of potential area for the implementation of the restoration activities

Current land use (2015)	FLR action (see also previous chapters)	Potential area (ha)
Annual cropland	Agroforestry system with annual crops	1,256,273
Perennial cropland	Agroforestry system with perennial crops	32,622
Sparse forest	Managed woodlots	257,897
Buffers on roads: • sector roads: 10 m • district roads: 15 m • national roads: buffers on rivers (20 m), buffers on wetlands (50 m)	Protective trees in buffers on sparse forest, closed and open grassland, open shrubland, annual and perennial crops	50,865

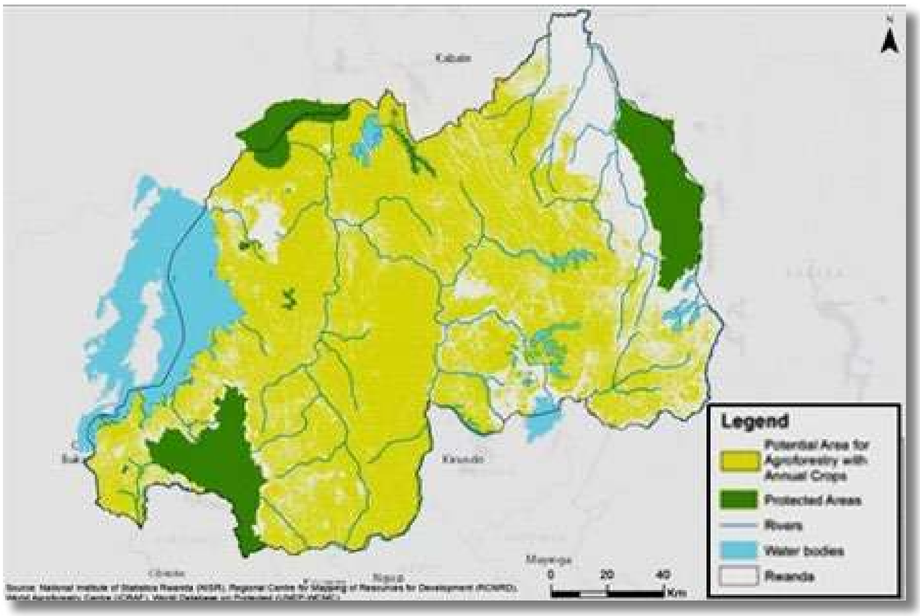


Figure 41 – Potential area for agroforestry with annual crops

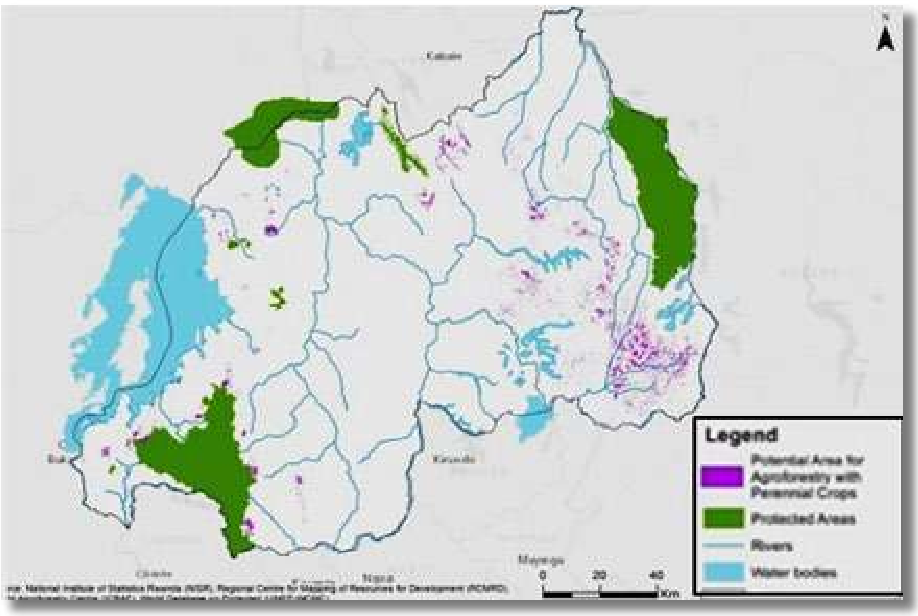


Figure 42 – Potential area for agroforestry with perennial crops

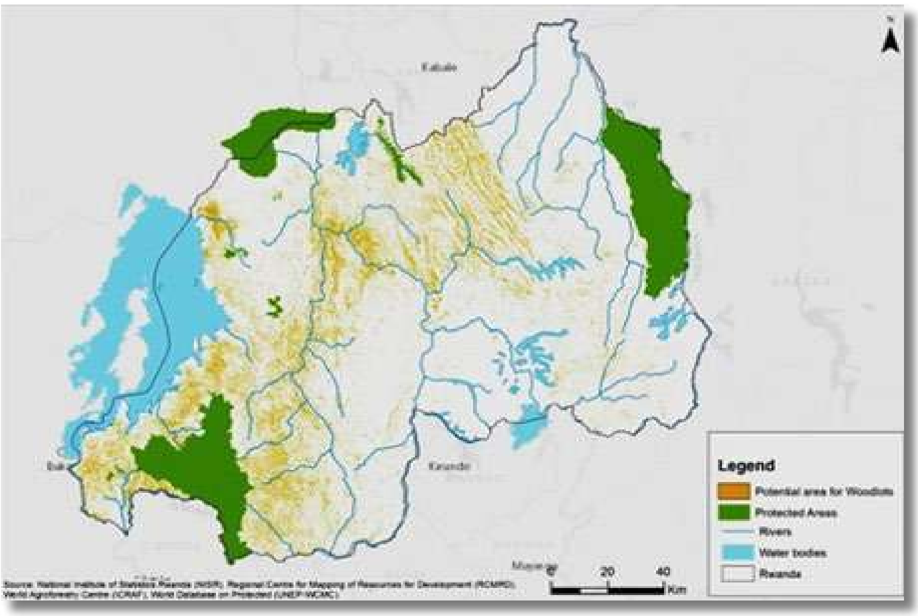


Figure 43 – Potential area for woodlots

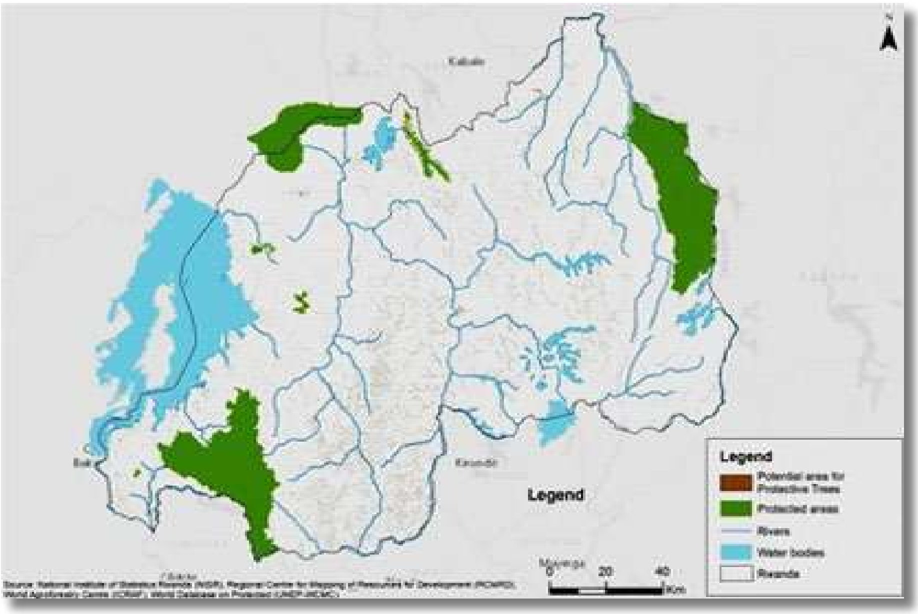


Figure 44 – Potential are for protective trees

This potential area is slightly different from the 1.5 million hectares of FLR opportunity identified through the ROAM assessment. This is because the FLR actions considered here are those that have been implemented in Gatsibo and Gicumbi, which are not completely the same as the FLR actions evaluated with ROAM (The Ministry of Natural Resources – Rwanda, 2014). We use the term “potential” as some of the areas considered may already have implemented the FLR actions. The map in **Figure 45** shows by district, the total potential number of hectares for the implementation of the four restoration actions identified. It also represents the distribution of these areas per type of restoration action. **Annex 2** contains the overview of all the districts in Rwanda and respective potential area per type of restoration action.

Figure 45 shows the districts with the largest number of hectares with potential for the implementation of the four restoration activities. The percentage of potential area per district ranges from 25% to 95%. The six districts with the highest potential area account for 27% of the total potential area in the country – Gicumbi, Nyamagabe, Karongi, Gatsibo, Nyaruguru and Gakenke.

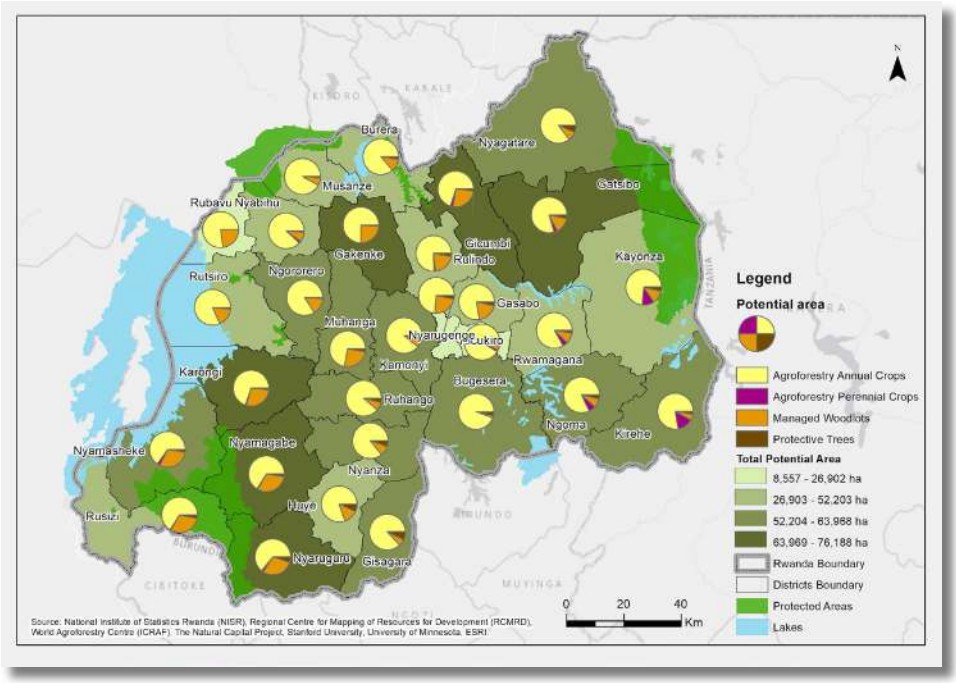


Figure 45 – Total potential area per district and per type of restoration activity

Table 28 shows the districts with the highest percentage of potential area.

Table 28 – Districts with highest percentage of potential area for the implementation of the restoration activities in relation to the district area

District	Total district area (ha)	Total potential	
		District area (ha)	% of the district area
Ruhango	63,106	60,355	96
Gakenke	70,929	67,770	96
Muhanga	65,172	61,394	94
Gisagara	68,611	63,968	93
Nyanza	67,753	62,825	93

7.3.1. Agroforestry with annual crops

The agroforestry system with annual crops is the restoration action with the largest potential area in all districts (**Figure 45** and **Annex 2**). There are nine districts where the agroforestry with annual crops systems could be implemented further in an area potentially larger than 50,000 ha (Bugesera, Gatsibo, Gisagara, Kamonyi, Nyanza, Ruhango, Gicumbi, Gakenke and Ngorero). These nine districts account for 39% of the total potential area for agroforestry with annual crops in the country (**Table 29**). Considering the potential area in relation to the area of the district, there are three districts in which the potential area for agroforestry in annual crops occupies more than 80% of the total district area (i.e., Ruhango, Kamonyi and Gisagara). There are also four districts where the implementation of this restoration type represents more than 70% of the districts' area (i.e., Nyanza, Ngororero, Gakenke and Huye) (see **Table 30**).

Table 29 – Districts with largest number of hectares of potential area for the implementation of agroforestry with annual crops

District	Total district area (ha)	Potential area for agroforestry with annual crops	
		District area (ha)	% of the district area
Bugesera	130,410	59,850	46
Gatsibo	159,617	55,893	35
Gisagara	68,611	55,729	81
Kamonyi	66,508	54,905	83
Nyanza	67,753	53,840	79

Table 30 – Districts with highest percentage of potential area for the implementation of agroforestry with annual crops in relation to the district area

District	Total district area (ha)	Potential area for agroforestry with annual crops	
		District area (ha)	% of the district area
Ruhango	63,106	53,591	85
Kamonyi	66,508	54,905	83
Gisagara	68,611	55,729	81
Nyanza	67,753	53,840	79
Ngororero	68,177	50,062	73

7.3.2. Agroforestry with perennial crops

As referred to previously, the restoration type with lowest total potential area for further expansion of FLR is the agroforestry with perennial crops. The analyses of the data by district found that Kirehe is the district with the highest potential area in number of hectares (8,738 ha) and highest percentage (7%) of potential area relative to the district area (**Table 31** and **Table 32**). This restoration type represents less than 2% of the area in most districts (**Annex 2**).

Table 31 – Districts with largest number of hectares of potential area for the implementation of agroforestry with perennial crops

District	Total district area (ha)	Potential area for agroforestry with perennial crops	
		District area (ha)	% of the district area
Kirehe	119,852	8,738	7
Kayonza	194,694	5,313	3
Ngoma	87,568	3,507	4
Rwamagana	68,613	2,337	3
Gatsibo	159,617	2,225	1

Table 32 – Districts with highest percentage of potential area for the implementation of agroforestry with annual crops in relation to the district area

District	Total district area (ha)	Potential area for agroforestry with perennial crops	
		District area (ha)	% of the district area
Kirehe	119,852	8,738	7
Ngoma	87,568	3,507	4
Rwamagana	68,613	2,337	3
Kayonza	194,694	5,313	3
Gicumbi	83,483	1,998	2

7.3.3. Managed woodlots

For continuing the implementation of managed woodlots, the districts with the largest potential areas have areas between 19,000 and 22,000 ha, and those are namely Nyamagabe, Nyaruguru, Karongi and Gicumbi. Proportion-wise (potential woodlot area per total district size), districts with the highest percentage of area with potential for managed woodlots range from 20% to 24% of the district area, and those are Muhanga, Gicumbi, Gakenke, Nyamagabe and Karongi (**Table 33** and **Table 34**).

Table 33 – Districts with the largest number of hectares of potential area for the implementation of managed woodlots

District	Total district area (ha)	Potential area for managed woodlots	
		District area (ha)	% of the district area
Nyamagabe	110,031	22,515	20
Nyaruguru	102,022	19,668	19
Karongi	99,712	19,503	20
Gicumbi	83,483	19,319	23
Nyamasheke	118,108	17,171	15

Table 34 – Districts with highest percentage of potential area for the implementation of managed woodlots in relation to the district area

District	Total district area (ha)	Potential area for managed woodlots	
		District area (ha)	% of the district area
Muhanga	65,172	15,595	24
Gicumbi	83,483	19,319	23
Gakenke	70,929	16,058	23
Nyamagabe	110,031	22,515	20
Karongi	99,712	19,503	20

7.3.4. Protective trees

For planting protective trees, the highest potential areas suitable for these restoration types by district vary between 3,000 and 4,000 ha (Gisagara, Huye, Nyaruguru, Nyagatare and Nyanza). Gisagara and Huye have the highest percentage of potential area, in relation to the district area, for the implementation of the protective trees (7% and 6%, respectively) (**Table 35** and **Table 36**).

Table 35 – Districts with largest number of hectares of potential area for the implementation of protective trees

District	Total district area (ha)	Potential area for protective trees	
		District area (ha)	% of the district area
Gisagara	68,611	4,472	7
Huye	58,611	3,550	6
Nyaruguru	102,022	3,489	3
Nyagatare	193,208	3,405	2
Nyanza	67,753	3,353	5

Table 36 – Districts with highest percentage of potential area for the implementation of managed woodlots in relation to the district area

District	Total district area (ha)	Potential area for protective trees	
		District area (ha)	% of the district area
Gisagara	68,611	4,472	7
Huye	58,611	3,550	6
Nyanza	67,753	3,353	5
Ruhango	63,106	2,209	4
Nyaruguru	102,022	3,489	3

The above data show the heterogeneous distribution of the potential areas among the districts, but also among the diverse types of restoration actions. In the next step, to define priority areas for the implementation of these restoration actions, the assessment of the potential impact of these areas on the annual soil erosion rate was carried out.

7.4. IMPACT POTENTIAL MAP

In total, the SDR model was run five times: once to obtain estimates of the current situation and then four more times to adjust the values in the biophysical table with the coefficients of a given FLR action (see previous section). To obtain the spatial results as maps that show the potential impact on erosion reduction of implementing the proposed restoration actions, the spatial results of the current state of agriculture are subtracted from the spatial results of each of the models that include the biophysical values corresponding to FLR actions (**Figure 46**). The resulting impact potential maps provide an estimate of the overall potential impact of each of the FLR actions on erosion rate and on the sediment export rate. To create the impact maps, the Esri ArcMap 10.6 software was used (see **Annex 2** for detailed methodology).

Figure 46 – Development of impact potential map for FLR in Rwanda

7.5. Soil erosion results

The InVEST SDR model assessed the implementation impact of the four restoration actions on erosion (intermediate model result) and sediment export (final model result).

Before discussing the impact potential results, the results of the SDR model, specifically soil erosion rate, will be discussed. The results of the potential impact of FLR actions on sediment export can be found in the annex. These results will not be discussed here but can be used for further prioritisation, for example by linking the reduction of sediment export with the location of reservoirs for drinking water or the production of hydroelectricity. This step is not considered in this chapter of the study; the focus will be on the spatial impact of FLR on the reduction of the erosion rate.

Figure 47 shows the soil erosion rate estimates across the country using three classes of soil erosion. These classes were created using the natural breaks classification of ArcGIS, with the purpose of facilitating map visualisation. The following analyses were conducted five with classes created by using natural breaks classification (from lowest to highest values). Some of the figures presented below contain less classes.

In this case some of the classes are an aggregation of the highest and high values to create one high class in the map, and the low class is comprised of the lowest and low class[15].

The model results show an average soil erosion rate of 65 t/ha/year, with soil erosion rates ranging from 0 to 380 t/ha/year across the country. The model estimated that 46% of the land in Rwanda has erosion rates between 0 and 36 t/ha/year, and approximately 27% of the land shows soil erosion rates between 37 and 94 t/ha/year. These two classes are represented in our map as the low rates.

The moderate soil erosion rate lies between 95 and 176 t/ha/year, which represents about 15% of the country's land. Finally, about 7% of the land in Rwanda has a soil loss rate between 1,77 and 291 t/ha/year, and approximately 5% of the land in Rwanda showed soil loss rates between 292 and 380 t/ha/year.

As mentioned previously, the SDR model has not been calibrated with the use of field observations or adjusted to default values for the threshold flow accumulation, Borselli k and IC0 parameters, and maximum SDR value. The model is based on existing data and a literature review to obtain data for the biophysical tables (C- and P-factors). However, previous studies in Rwanda provided similar findings to the model results of this study.

Mugabo (2005) highlights that the soil erosion in Rwanda, depending on the location, could change between 50 and 400 t/ha/year. Nyesheja et al. (2018) estimated that in the region of the Congo Nile Ridge of Rwanda, the soil loss averaged 63.62 t/ha/year. Kabirigi et al. (2017) estimated the average soil loss in the Nyamyumba and Mukamira

[15] As classes are used for visualisation only, they are not related to international classifications that classify erosion rates according to the severity of annual erosion.

watershed was 32 t/ha/year, whereas Kagabo et al. (2013) observed mean annual soil losses of around 40 t/ha/year in their study on plots in the Northern Province.

Nyamulinda (1991) in a study focusing on parcels without anti-erosion structures in the Gakenke District, also in the Northern Province of Rwanda, observed soil erosion rates between 35 and 240 t/ha/year. Finally, Roose and Ndayizigiye (1997) detected an annual soil loss in the Southern Province from 450 t/ha/year on bare plots to 27 t/ha/year for cropped and hedged plots.

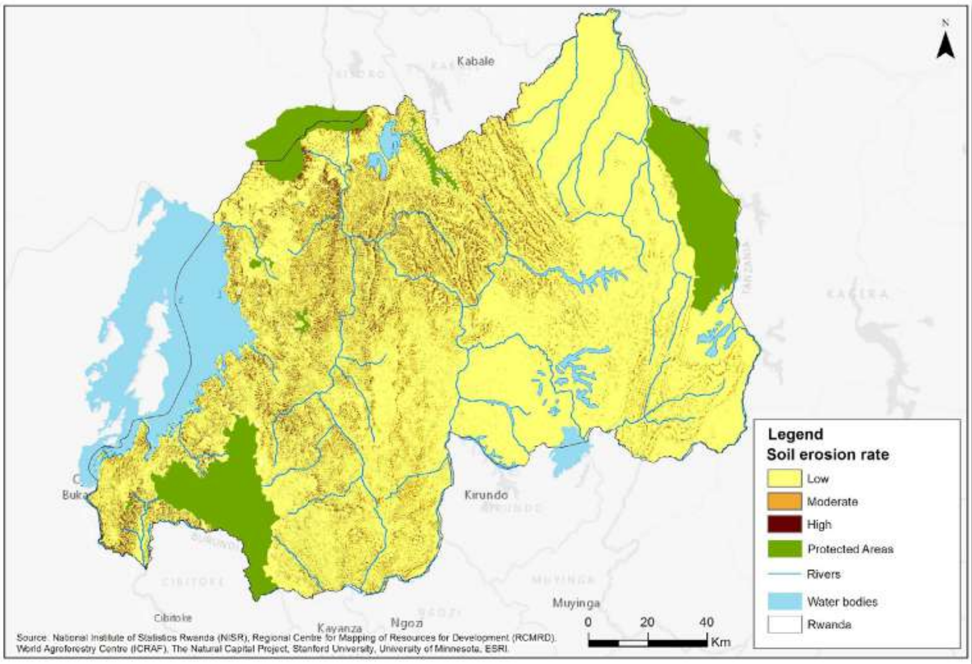


Figure 47 – Soil erosion rate in Rwanda (t/ha/year [16]

7.5.1. Impact potential maps

Impact potential maps for each restoration action were developed to assess the impact of implementation on soil erosion and sediment export. These maps function as tools to prioritise future areas for FLR implementation (**Figure 48** and **Figure 49**). The maps show classifications according to the potential contribution of these restoration activities in decreasing soil erosion (see annex for maps of sediment export rates). For the ease of representation, only three impact potential categories were used, but the tables throughout the text provide more detailed data using five categories (see also Annex for more detailed impact potential maps and tables). As referred previously, the low class in the map was represented by the low and lowest classes in the table, and the highest and high classes in the table correspond to the high class on the map. The moderate class remains the same.

Agroforestry with annual crops

The impact potential map for agroforestry systems with annual crops on soil erosion rate is shown in **Figure 48** and reveals those areas where the impact on soil loss

[16] The figure of the estimated annual sediment export in Rwanda can be found in the Annex.

reduction is significant (see **Table 37**). The implementation of an agroforestry system with annual crops has the highest reduction in soil losses in about 3% of the total potential area. The number of hectares with potential impact increases as the degree of impact decreases, so the area with lowest reduction on soil losses represents 39% of the total area with impact (**Figure 41**).

Table 37 – Reduction on soil erosion for agroforestry with annual crops

	Number of hectares with impact potential on soil erosion					
	Highest reduction area	High reduction	Moderate reduction	Low reduction	Lowest reduction	Total impact
Number of hectares	37,542	86,707	211,574	423,279	483,039	1,242,141
%	3	7	17	34	39	100

The distribution of the impacted area by district and the categorisation by level of impact on soil erosion rate for implementing an agroforestry system with annual crops is shown in **Figure 48** and **Table 38** and **Table 39**. The districts with the highest proportion of impacted areas are in the centre of Rwanda. In most of these areas, the FLR action has a potential impact that is classified as low or lowest impact on the annual soil erosion rate.

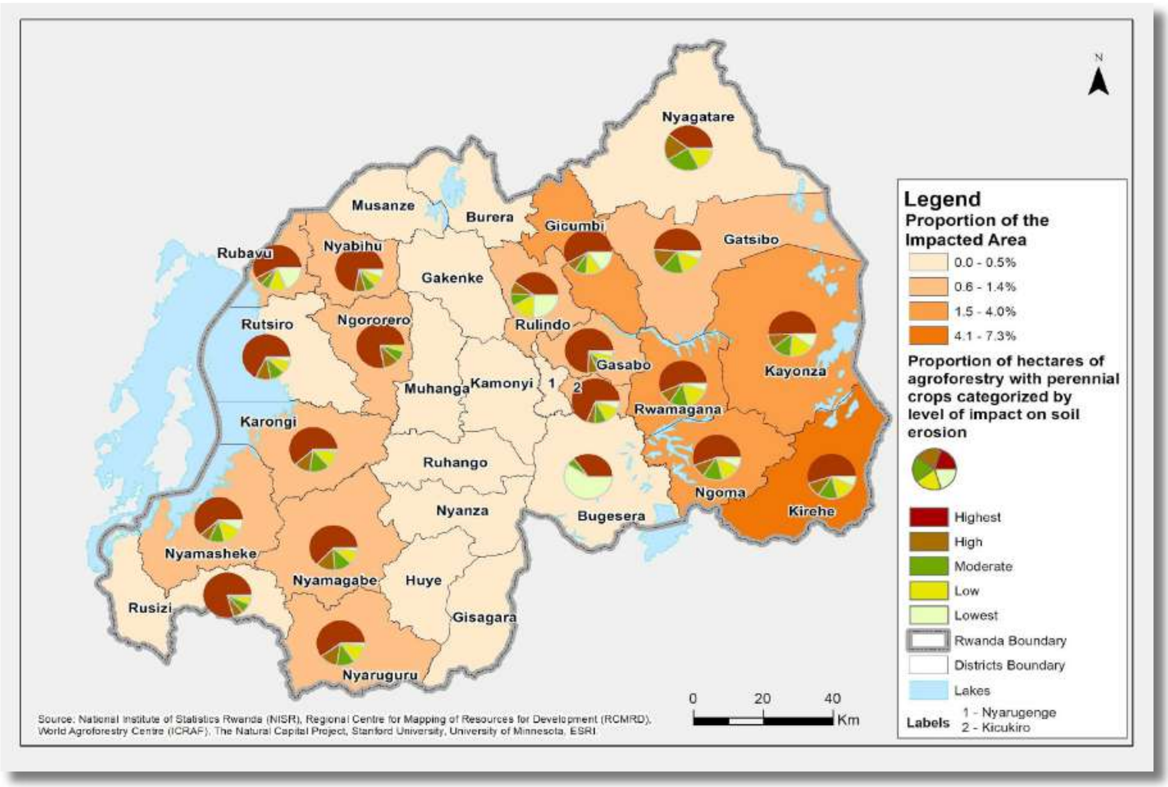


Figure 48 – Proportion of the impacted area and categorization by level of impact on soil erosion rate by agroforestry with annual crops per district

The impacted area represents the total area of the district that could have a reduction in soil erosion rate due to the implementation of the specific activity considered. This area is calculated as a percentage of the total area of the district (impacted area = sum of highest, high, moderate, low, lowest impact/ district area*100). The potential area for agroforestry with annual crops covers about 37,000 ha of land estimated to have the highest potential reduction on soil erosion. About 38% of this land is located in five districts, namely Gakenke, Ngororero, Rusizi, Rulindo and Karongi (**Table 38**). All of these districts have over 2,000 ha with the highest estimated impact on the annual soil erosion rate. When the focus is on highest percentage of district area categorised as highest priority for an agroforestry system with annual crops considering potential impact on annual erosion rates, three of the same districts are found among the five with the highest percentage (Rulindo, Gakenke, Ngororero), and two are new (Nyabihu, Musanze) (**Table 39**).

Table 38 – Districts with highest number of hectares categorised as highest priority for agroforestry with annual crops based on impact on soil erosion (hectares)

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gakenke	70,929	3,202	6,758	12,817	16,833	10,825
Ngororero	68,177	2,966	6,476	13,785	16,799	9,698
Rusizi	96,858	2,824	4,535	7,381	8,738	8,452
Rulindo	57,166	2,723	5,768	9,949	11,987	8,727
Karongi	99,712	2,650	5,507	11,381	16,812	12,596

Table 39 – Districts with highest percentage of area categorised as highest priority for agroforestry with annual crops based on impact on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Rulindo	70,929	4.76	10.09	17.40	20.97	15.27
Nyabihu	68,177	4.66	9.19	15.84	19.33	15.22
Gakenke	96,858	4.51	9.53	18.07	23.73	15.26
Ngororero	57,166	4.35	9.50	20.22	24.64	14.22
Musanze	99,712	3.97	5.80	10.20	18.94	24.76

7.5.2. Agroforestry with perennial crops

Figure 48 is an impact potential map on soil erosion through the implementation of the agroforestry system with perennial crops (the annex provides more detailed impact potential maps for both reduction in erosion rate and in sediment export).

As discussed previously, the potential area occupied by this restoration type is lower than for other FLR actions. Contrary to the results from agroforestry systems with annual crops, for perennial crops the area with highest impact represents about 56% of the total area with potential impact (**Table 40**).

Table 40 – Reduction on soil erosion for agroforestry with perennial crops

	Area with impact potential on soil erosion					
	Highest reduction	Highest reduction	Highest reduction	Highest reduction	Highest reduction	Highest reduction
Number of hectares	17,983	17,983	17,983	17,983	17,983	17,983
%	56	56	56	56	56	56

Figure 49 shows the impact potential for agroforestry systems with perennial crops. For districts with an impacted area less than 10 ha, representing less than 0.5% of the total potentially impacted area, the pie charts were not given.

The presence of agroforestry with perennial crops is most important in the southeast of the country. However, the highest proportion of impacted areas is only about 7% of the districts. Concerning the level of impact, the map reveals that this type of restoration action may have, in general, a highest or high potential impact on the reduction of the annual soil erosion rate.

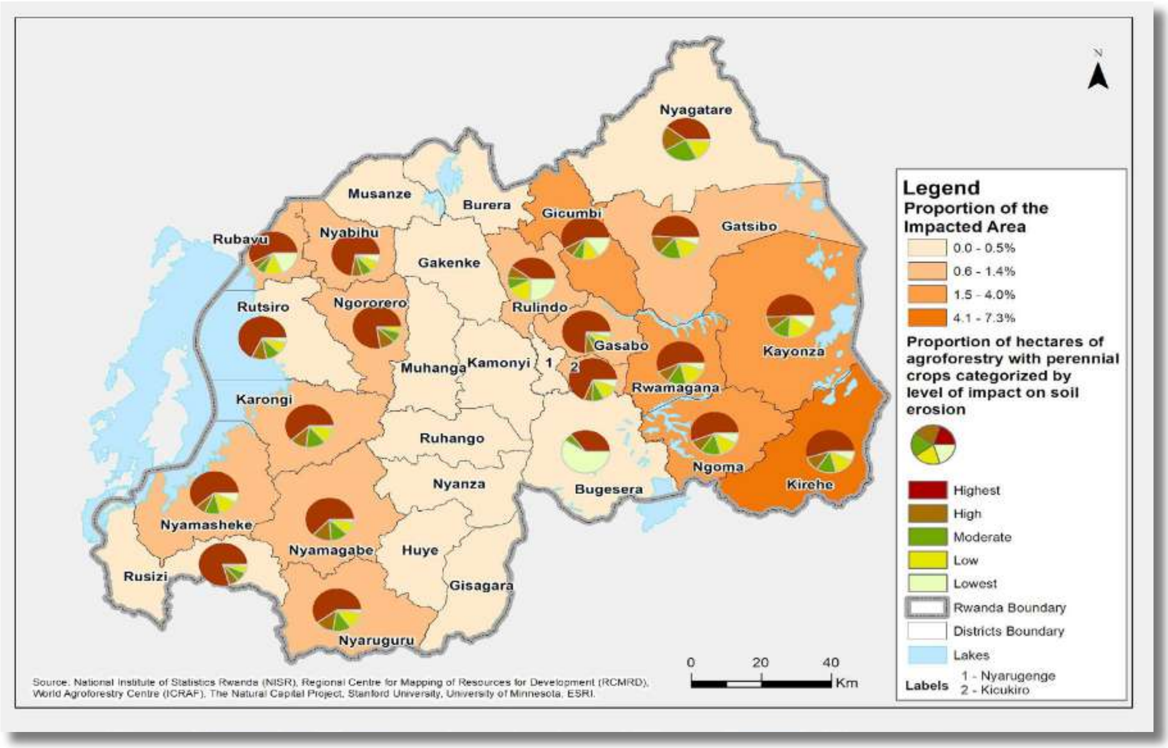


Figure 49 – Proportion of the impacted area and categorization by level of impact on soil erosion rate for agroforestry with perennial crops per district

For the area with potential for agroforestry with perennial crops, there are about 17,000 ha that are classified as having potentially the highest impact on soil erosion reduction. More than 65% of this area is distributed across five districts: Kirehe, Kayonza, Ngoma, Rwamagana and Gicumbi (**Table 41**). The same districts, although in a slightly different order, are also those with the highest percentage area with the highest priority for an agroforestry system with perennial crops (**Table 42**).

Table 41 – Districts with highest number of hectares categorised as highest priority for agroforestry with perennial crops based on impact on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Kirehe	119,852	4,773	934	1,179	1,206	610
Kayonza	194,694	2,644	530	684	842	523
Ngoma	87,568	1,941	341	472	470	264
Rwamagana	68,613	1,337	220	300	337	125
Gicumbi	83,483	1,126	146	152	217	292

Table 42 – Districts with highest percentage of area categorised as highest priority for agroforestry with perennial crops based on impact on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Kirehe	119,852	3.98	0.78	0.98	1.01	0.51
Ngoma	87,568	2.22	0.39	0.54	0.54	0.30
Rwamagana	68,613	1.95	0.32	0.44	0.49	0.18
Kayonza	194,694	1.36	0.27	0.35	0.43	0.27
Gicumbi	83,483	1.35	0.17	0.18	0.26	0.35

7.5.3. Managed woodlots

Planting managed woodlots is the restoration activity with the second highest potential area after the implementation of agroforestry systems with annual crops.

The number of hectares classified according to their impact potential on the annual soil erosion rate is even across classes (see **Table 43**), but most of the area has a relatively low reduction impact on the soil erosion rate.

Table 43 – Reduction on soil erosion with managed woodlots

	Area with impact potential on soil erosion					
	Highest reduction	Highest reduction	Highest reduction	Highest reduction	Highest reduction	Highest reduction
Number of hectares	36,282	35,341	56,642	77,928	43,549	249,742
%	15	14	23	31	17	100

Figure 50 represents the impacted area after the planting of managed woodlots. The proportion of the impacted area in hectares is higher in the Congo/Nile watershed districts.

The highest proportion is found in Muhanga (24%). As can be observed, the proportion of hectares by level of impact on soil erosion is, in these districts, remarkably similar among the distinct categories.

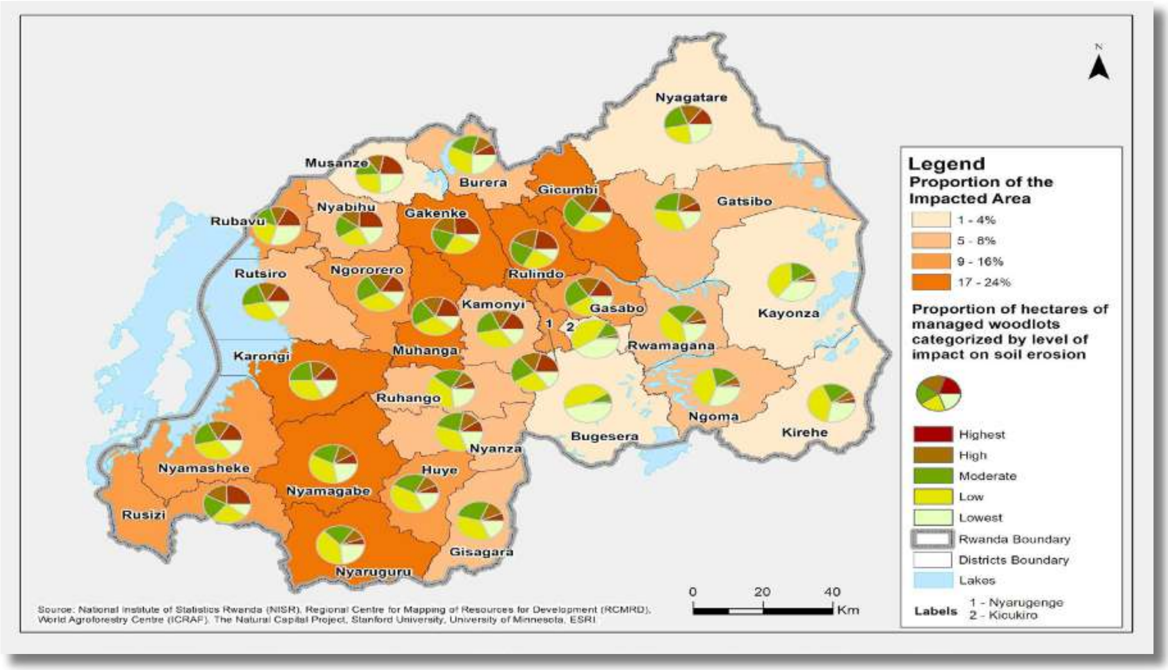


Figure 50 – Proportion of the impacted area and categorization by level of impact on soil erosion rate by managed woodlots per district

For the managed woodlots, the districts with the highest number of hectares with highest reduction impact on soil erosion are Gakenke, Rusizi, Gicumbi, Muhanga and Nyamasheke. Totalling around 17,000 ha, these districts represent about 45% of the total area with highest reduction in soil erosion for this type of restoration action (36,000 ha) (**Table 44**). When considering districts with the highest percentage of area with highest priority for the planting of woodlots, the five leading districts are Gakenke, Muhanga, Rulindo, Gicumbi and Rusizi (**Table 45**).

Table 44 – Districts with highest number of hectares categorised as highest priority for managed woodlots based on impact on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gakenke	70,929	4,087	3,040	3,574	3,895	1,325
Rusizi	96,858	3,502	2,286	2,991	3,398	1,512
Gicumbi	83,483	3,299	3,736	5,470	4,791	1,881
Muhanga	65,172	3,003	2,401	3,600	4,632	1,783
Nyamasheke	118,108	2,786	2,486	3,600	5,086	2,457

Table 45 – Districts with highest percentage of area categorised as highest priority for managed woodlots based on impact on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gakenke	70,929	5.76	4.29	5.04	5.49	1.87
Muhanga	65,172	4.61	3.68	5.52	7.11	2.74
Rulindo	57,166	4.20	3.80	4.51	4.22	1.87
Gicumbi	83,483	3.95	4.48	6.55	5.74	2.25
Rusizi	96,858	3.62	2.36	3.09	3.51	1.56

7.5.4. Protective trees

The impact on the reduction of the annual soil erosion rate through the planting of protective trees in the buffers of rivers and roads is shown in **Figure 50**. About 66% of the potential total impact area is classified as having the highest comparative reduction in soil erosion rate (**Table 46**).

Table 46 – Reduction on soil erosion rate with protective trees

	Area with impact potential on soil erosion					
	Highest reduction	Highest reduction	Highest reduction	Highest reduction	Highest reduction	Highest reduction
Number of hectares	31,510	3,842	4,372	4,677	3,205	47,607
%	66	8	9	10	7	100

The area impacted by planting protective forests is shown in **Figure 51**. The highest proportion of the affected area is 6% in Gisagara. As the pie charts in the map show, this type of restoration option could have an important contribution to reducing soil erosion. The highest level of impact is well represented in most of the districts.

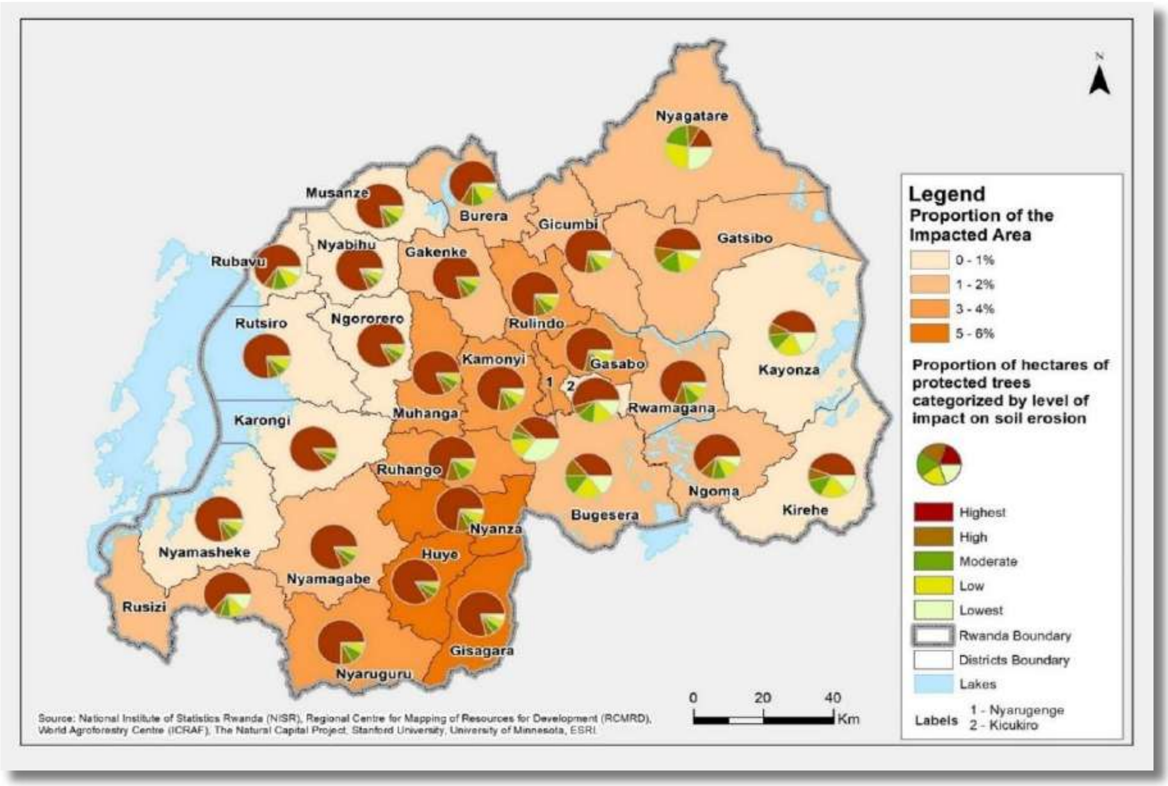


Figure 51 – Districts with the highest area with highest reduction on soil erosion rate for protected trees by district

The districts with the largest area with highest reduction impact on soil erosion rate are Gisagara, Huye, Nyaruguru, Nyanza and Ruhango, totalling about 12,500 ha. This accounts for 39% of the potential area with highest reduction in soil erosion through the planting of protective forests (**Table 47**). The same districts also have the highest percentage of their area categorised as the highest priority for the implementation of protective forests, based on the potential impact on soil erosion rate (**Table 48**).

Table 47 – Districts with highest number of hectares categorised as highest priority for protective forests based on impact on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gisagara	68,611	3,291	229	226	228	203
Huye	58,611	2,856	191	201	123	40
Nyaruguru	102,022	2,491	277	296	212	51
Nyanza	67,753	2,325	286	224	237	118
Ruhango	63,106	1,586	217	229	145	56

Table 48 – Districts with highest percentage of area categorised as highest priority for protective forests based on impact on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gisagara	68,611	4.80	0.33	0.33	0.33	0.30
Huye	58,611	4.87	0.33	0.34	0.21	0.07
Nyanza	67,753	3.43	0.42	0.33	0.35	0.17
Ruhango	63,106	2.51	0.34	0.36	0.23	0.09
Nyaruguru	102,022	2.44	0.27	0.29	0.21	0.05

7.6. INVEST CONCLUSIONS

This chapter showed how estimating the potential contribution of implementing FLR actions on ecosystem services can be used to prioritise areas and districts to advance Rwanda’s restoration commitments. Considering the four types of restorations, the analysis shows an important variability among the districts that have the highest prioritised areas.

However, three districts were found that have the highest number of prioritised hectares in two different restoration types. Gakenke has about 7,000 ha of land with highest impact on reduction of the estimated annual soil losses split between the potential impact of implementing agroforestry systems with annual crops and managed woodlots. Rusizi is in the same situation with an area around 6,000 ha. Gicumbi is a district with about 4,000 ha of land with highest reduction on soil erosion that is split between agroforestry with perennial crops and managed woodlots.

These results can be used for further prioritisation by excluding areas where FLR actions have already been implemented. A more detailed land-use map will also strengthen further analysis of the potential impact on soil erosion and sediment export of implementing FLR actions on diverse types of land. In addition, to carry out a broader and multi-objective spatial prioritisation, more ecosystem services should be included, as well as other possible social, economic, and environmental objectives.

Finally, the impact potential maps shown in this study only include the biophysical impact but are not connected to potential beneficiaries. In the case of soil erosion, the impact potential maps could be linked with soil fertility or prioritising areas with the lowest agricultural productivity.

8. GENERAL CONCLUSIONS

The high population density, steep slopes and abundant rainfall make the task of erosion control uncommonly difficult in Rwanda, amplifying the country's vulnerability to climate change. Considering the continued direct dependence of much of the population on land resources, and in view of the ambitious development path the country is embarked upon, the restoration and conservation of scarce land resources is essential to the long-term viability of agriculture and other important land uses.

Investing in FLR can yield multiple benefits such as increased resilience to climate change, reduced soil erosion, halted land degradation and increased land productivity. However, delivering on the multiple benefits promised by FLR requires scaling appropriate technical packages in the appropriate agro-ecological zones.

This report illustrated the different FLR technical packages that have been implemented in Gatsibo (semi-arid agro-ecology) and Gicumbi (humid agro-ecology). It also showed the estimated future costs and benefits of this implementation and compared those with what would have happened if the previous land uses had continued. Furthermore, this report provided a first step in how prioritisation can be carried out to further support Rwanda's restoration efforts.

The results show that agroforestry, woodlots, and protective forests are profitable and provide positive net benefits for the proposed rotation periods at a discount rate of 13%.

The analysis showed that the implementation costs of FLR activities are relatively minor compared to the benefits from restoration. However, this study was not assessing the restoration intervention that provided the highest returns; rather, it was assessing the contribution and the profitability of each of the interventions depending on previous agriculture practice or land use. For instance, agroforestry systems provide highest returns from direct benefits (improved crop production) while protective forests and woodlots provide higher benefits for carbon sequestration and erosion control. The restoration activities, especially for woodlots and protective forests, could be more important for public investment on very steep slopes and on riverbanks, whereas agroforestry will bring high returns for private investors and smallholder farmers on land suitable for agriculture.

The geospatial analysis showed that there are about 1,600,000 ha of land with potential for developing the implementation of the restoration activities considered in this study. The potential area is 79%, 16%, 2% and 3% for agroforestry systems with annual crops, managed woodlots, agroforestry systems with perennials and protective forests, respectively. For agroforestry with annual crops, districts with the greatest opportunities in size are by order Bugesera, Gatsibo, Gisagara, Kamonyi and Nyanza.

On the other hand, the top five districts with highest potential for agroforestry with perennial crops are in the Eastern Province, starting with Kirehe, followed by Kayonza, Ngoma, Rwamagana and Gatsibo. This is mainly because of the banana groves and agro-pastoral systems that dominate in the Eastern Province. For expanding the implementation of managed woodlots, the districts with the largest potential areas have land ranging between 19,000 and 22,000 hectares, namely Nyamagabe, Nyaruguru, Karongi and Gicumbi. For increasing protective tree plantations, the highest potential areas suitable for these restoration types vary between 3,000 and 4,000 ha, with the largest area in Gisagara, followed by Huye, Nyaruguru, Nyagatare and Nyanza.

To assess the potential impact of FLR actions, soil erosion was measured by estimating the difference between scenarios with and without the implementation of the restoration actions using the InVEST model. The model results show an average soil erosion rate of 65 t/ha/year with values ranging from 0 to 380 t/ha/year across the country.

The model estimated that more than 54% of the land in Rwanda has erosion rates above 36 t/ha/year. The FLR interventions studied presented high potential to reduce this erosional soil loss across the country.

Generally, it is recommended to prioritise restoration in Gakenke (with 7,000 ha in need of restoration) using the highest impact on reduction of the estimated annual soil losses, split between agroforestry systems with annual crops and managed woodlots. Other districts such as Ngororero, Rusizi, Rulindo, Karongi, Nyabihu and Musanze also present high potential for restoration with high reduction on soil erosion split between agroforestry with annual crops and managed woodlots.

It is worth noting that FLR does not only provide key environmental benefits through the improvement in the provision of ecosystem services and enhancing biodiversity protection. FLR is also a tool for green growth, the path that the government of Rwanda has chosen.

The further implementation of FLR actions will generate jobs in the short term, but also has long-term positive impacts by reversing land degradation and enabling the country to achieve its land degradation neutrality targets while pursuing Rwanda's vision for 2050. Expanding FLR packages should thus be considered an important strategy for both short- and long-term social, financial, and environmental benefits for the country.

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ANNEXES

ANNEX 1 EXAMPLE FINANCIAL MODEL

Financial model for agroforestry system with maize and beans in Gatsibo.

Variables	Quantity	Unit
Discount Rate	13%	
Area	0.5	hectare
Number of trees per 0.5 ha	100	trees
Maize proction	4500	kg/ha
Beans production	3000	kg/ha
Maize price	270	Rwf/kg
Beans Price	300	Rwf/kg
Tree volume at Maturity age	0.917431193	m3/tree
Annual Volume from pruning at year 4 and 5	0.073394495	m3/tree
Annual Volume from pruning After year 5	0.275229358	m3/tree
Price of timber volume	10900	Rwf/m3

Other inputs		
Rotation Period	10	years
Hired labor	11	work days
House labor	99.5	work days
Maize	24	kg/ha
Beans	50	kg/ha
DAP	100	kg/ha
Urea	50	kg/ha
Cost of pruning at year 4 and 5	300	Rwf/tree
Annual Cost of pruning after year 5	1000	Rwf/tree
Organic manure	10	tons/ha

year			1	2	3	4	5	6	7	8	9	10
	Quantity	Unit										
FLR Implementation costs												
Extension costs												
Sensitization + field visit	6000	Rwf/ha	3000									
Cost Sign post	820	Rwf/post	410	0	0	0	0	0	0	0	0	0
Total			3410									
Labour costs												
Labour for Seedbed preparation	83	Rwf/nursey plot	42	0	0	0	0	0	0	0	0	0
Labour for Nursery construction	2587	Rwf/nursey plot	1294	0	0	0	0	0	0	0	0	0
Labour for Sawing and mulching	44	Rwf/nursey plot	22	0	0	0	0	0	0	0	0	0
Labour for Pot filling	4.6666667	Rwf/pot	467	0	0	0	0	0	0	0	0	0
Labour for Pricking out	5	Rwf/pot	500	0	0	0	0	0	0	0	0	0
Labour for Watering and weeding	800	Rwf/nursey plot	400	0	0	0	0	0	0	0	0	0
Labour for grading Grading	467	Rwf/nursey plot	234	0	0	0	0	0	0	0	0	0
Labour for transport and planting per ha	407911667		4079	0	0	0	0	0	0	0	0	0
Labour for Prunning	100	trees	0	0	0	0	30000	30000	100000	100000	100000	100000
s/total			7036.28334	0	0	0	30000	30000	100000	100000	100000	100000
Input costs	Quantity	Unit										
Land lease for nursery	156	Rwf/nursey plot	78	0	0	0	0	0	0	0	0	0
acquisition of mulch	22	Rwf/nursey plot	11	0	0	0	0	0	0	0	0	0
plastic pots acquisition	6.0666667	Rwf/pot	607	0	0	0	0	0	0	0	0	0
Recording book	6	Rwf/nursey plot	3	0	0	0	0	0	0	0	0	0
Manure	234	Rwf/nursey plot	117	0	0	0	0	0	0	0	0	0
Weelbarrow	148	Rwf/nursey plot	75	0	0	0	0	0	0	0	0	0
Watering can	121	Rwf/nursey plot	61	0	0	0	0	0	0	0	0	0
Seeds	244	Rwf/nursey plot	122	0	0	0	0	0	0	0	0	0
S/Total			1072.666667	0	0	0	0	0	0	0	0	0
FLR management costs												
Labour costs												
Pest and disease control (dithane)	5.6	Rwf/plate bande	3	0	0	0	0	0	0	0	0	0
s/total			3	0	0	0	0	0	0	0	0	0
Trees' production cost			11521.75001	0	0	0	30000	30000	100000	100000	100000	100000
Production costs of Maize												
Maize input and labour costs	Quantity	Unit										
Hired labor	1000	Rwf/day	11000	11000	11000	11000	11000	11000	11000	11000	11000	11000
House labour	500	Rwf/day	49750	49750	49750	49750	49750	49750	49750	49750	49750	49750
Seeds	520	Rwf/kg	6240	6240	6240	6240	6240	6240	6240	6240	6240	6240
weeding cost (3 times per season)	60	labor	660	660	660	660	660	660	660	660	660	660
DAP (fertilizer)	480	Rwf/kg	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000
UREA (fertilizer)	430	Rwf/kg	10750	10750	10750	10750	10750	10750	10750	10750	10750	10750
Organic fertilizer	15000	Rwf/ton	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000
Small agriculture equipment	1900	Rwf/ha	950	950	950	950	950	950	950	950	950	950
Harvesting and transport cost	50000	Rwf/ha	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000
Maize cost			203350	203350	203350	203350	203350	203350	203350	203350	203350	203350
Production costs of beans												
beans inputs and labour costs												
Hired labor	1000	Rwf/day	11000	11000	11000	11000	11000	11000	11000	11000	11000	11000
House labour	500	Rwf/day	49750	49750	49750	49750	49750	49750	49750	49750	49750	49750
Seeds	300	Rwf/kg	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Small agriculture equipment	1900	Rwf/ha	950	950	950	950	950	950	950	950	950	950
Harvesting cost	30000	Rwf/ha	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
Beans cost			84200	84200	84200	84200	84200	84200	84200	84200	84200	84200
TOTAL COSTS			299072	287550	287550	287550	317550	317550	387550	387550	387550	387550
Benefits												
Tree Volume at maturity age	0.917431193	m3/tree	0	0	0	0	0	0	0	0	0	91.7431927
Timber income	10900	Rwf/m3	0	0	0	0	0	0	0	0	0	1000000
Tree volume from Pruning	100	trees	0	0	0	7.33944954 1	7.33944954 1	27.5229357 8	27.5229357 8	27.5229357 8	27.5229357 8	27.5229357 8
Fuelwood income			0	0	0	80000	80000	300000	300000	300000	300000	300000
Maiz production	4500	Kg	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250
Maize price	270	Rwf/kg	270	270	270	270	270	270	270	270	270	270
Maize income			607500	607500	607500	607500	607500	607500	607500	607500	607500	607500
Bean production	3000	kg	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Bean price	300	Rwf/kg	300	300	300	300	300	300	300	300	300	300
Beans income			450000	450000	450000	450000	450000	450000	450000	450000	450000	450000
TOTAL BENEFITS			1057500	1057500	1057500	1137500	1137500	1357500	1357500	1357500	1357500	2357500

ANNEX 2 INVEST REFERENCES BIOPHYSICAL TABLE

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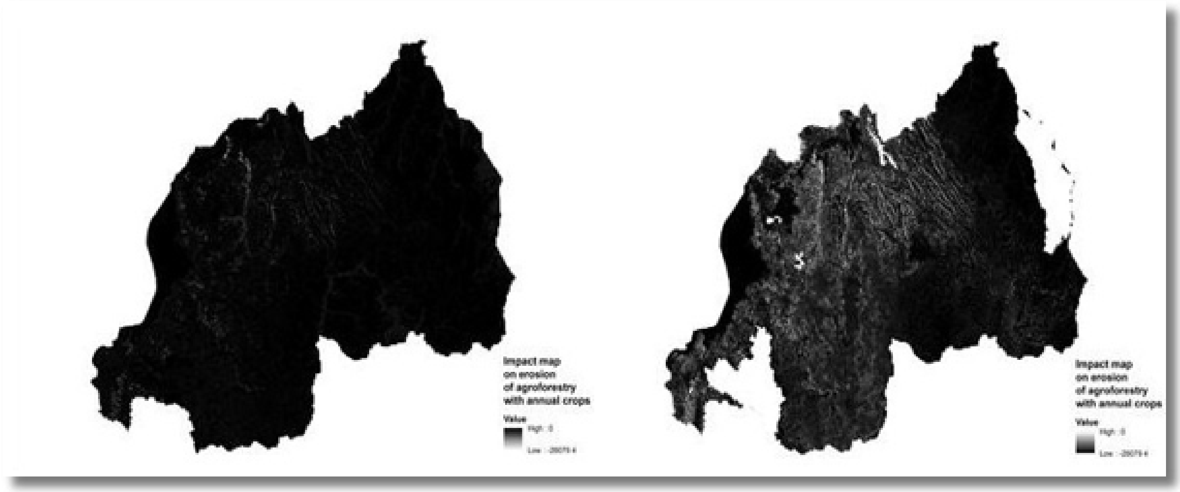
ANNEX 3 DETAILED RESULTS CHAPTER 6

Annex 3.1 Potential area (ha) and percentage of each restoration type by district

District	District area (ha)	Potential area									
		Agroforestry system with annual crops		Agroforestry system with perennial crops		Managed woodlots		Protective trees		Total potential area	
		Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	% of the district
Bugesera	130,410	59,850	46	42	0	1,143	1	2,493	2	63,529	49
Burera	65,001	40,937	63	19	0	5,238	8	1,223	2	47,417	73
Gakenke	70,929	50,751	72	4	0	16,058	23	956	1	67,770	96
Gasabo	43,262	24,963	58	265	1	6,123	14	1,133	3	32,483	75
Gatsibo	159,617	55,893	35	2,225	1	9,973	6	2,271	1	70,362	44
Gicumbi	83,483	53,461	64	1,998	2	19,319	23	1,410	2	76,188	91
Gisagara	68,611	55,729	81	1	0	3,766	5	4,472	7	63,968	93
Huye	58,611	41,819	71	4	0	6,811	12	3,550	6	52,184	89
Kamonyi	66,508	54,905	83	16	0	4,557	7	1,957	3	61,435	92
Karongi	99,712	49,448	50	814	1	19,503	20	1,194	1	70,959	71
Kayonza	194,694	36,237	19	5,313	3	5,727	3	1,928	1	49,205	25
Kicukiro	16,835	7,785	46	159	1	443	3	171	1	8,557	51
Kirehe	119,852	46,502	39	8,738	7	3,228	3	1,536	1	60,004	50
Muhanga	65,172	44,293	68	5	0	15,595	24	1,501	2	61,394	94
Musanze	53,133	34,523	65	6	0	2,529	5	447	1	37,505	71
Ngoma	87,568	47,180	54	3,507	4	4,742	5	1,918	2	57,347	65
Ngororero	68,177	50,062	73	449	1	8,790	13	644	1	59,945	88
Nyabihu	54,183	35,048	65	793	1	3,405	6	492	1	39,739	73
Nyagatare	193,208	46,422	24	423	0	4,397	2	3,405	2	54,646	28
Nyamagabe	110,031	49,307	45	861	1	22,515	20	2,024	2	74,707	68
Nyamasheke	118,108	37,756	32	1,621	1	17,171	15	1,380	1	57,929	49
Nyanza	67,753	53,840	79	1	0	5,631	8	3,353	5	62,825	93
Nyarugenge	13,351	6,876	52	7	0	2,125	16	328	2	9,335	70
Nyaruguru	102,022	43,601	43	1,294	1	19,668	19	3,489	3	68,051	67
Rubavu	38,916	20,421	52	212	1	6,053	16	217	1	26,902	69
Ruhango	63,106	53,591	85	4	0	4,551	7	2,209	4	60,355	96
Rulindo	57,166	39,399	69	659	1	10,679	19	1,465	3	52,203	91
Rusizi	96,858	32,813	34	520	1	14,807	15	1,639	2	49,779	51
Rutsiro	116,996	41,731	36	325	0	8,689	7	753	1	51,498	44
Rwamagana	68,613	41,131	60	2,337	3	4,662	7	1,305	2	49,435	72

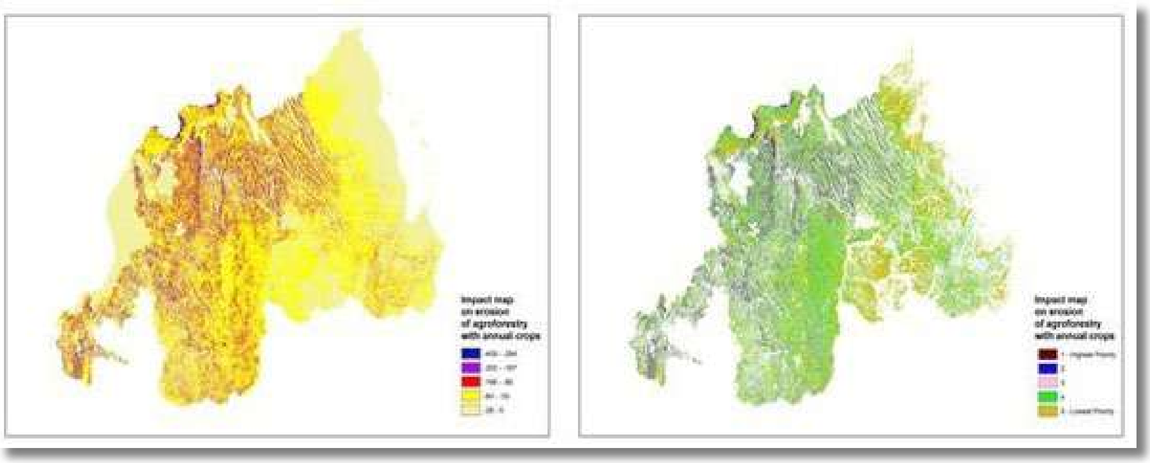
Annex 3.2. Methodology to create the impact potential maps

To create the impact map, Esri ArcMap10.6 software was used. The five intermediate universal soil equation (USLE) outputs of the InVEST tool were used as input files. One output represents the USLE output without FLR actions, and the other four represent the USLE output for each of the restoration actions. These inputs are in a raster format and the minus tool (spatial analyst tool) was applied to create the impact map for each restoration type. This tool provides the difference between two raster images that are geographically overlapping. In this case, the tool subtracts the value of the USLE output without FLR interventions from the value of the USLE output with FLR interventions. An example of the result from this tool is shown in the images below.



The next step was the extraction of the protected areas from this output. For this step, the **extract by mask tool** was used, and the result is shown in the next maps.

The next objective is to identify the different impact levels per restoration activity. To accomplish this, five classes were created using **natural breaks classification**, and then this map was reclassified using the **reclassify** tool. The results of these tools are presented in the next maps and represent five different levels of prioritisation areas from lowest to highest.



After the definition of the level of prioritisation was determined, the area occupied by each prioritisation class in each different type of restoration was calculated. The tool **zonal geometry as table** was used to find the total area in hectares per prioritisation category. This methodology was implemented in each restoration type, using the soil erosion and sediment export as input, at the country level and district level.

Annex 3.3 Additional SDR model result maps

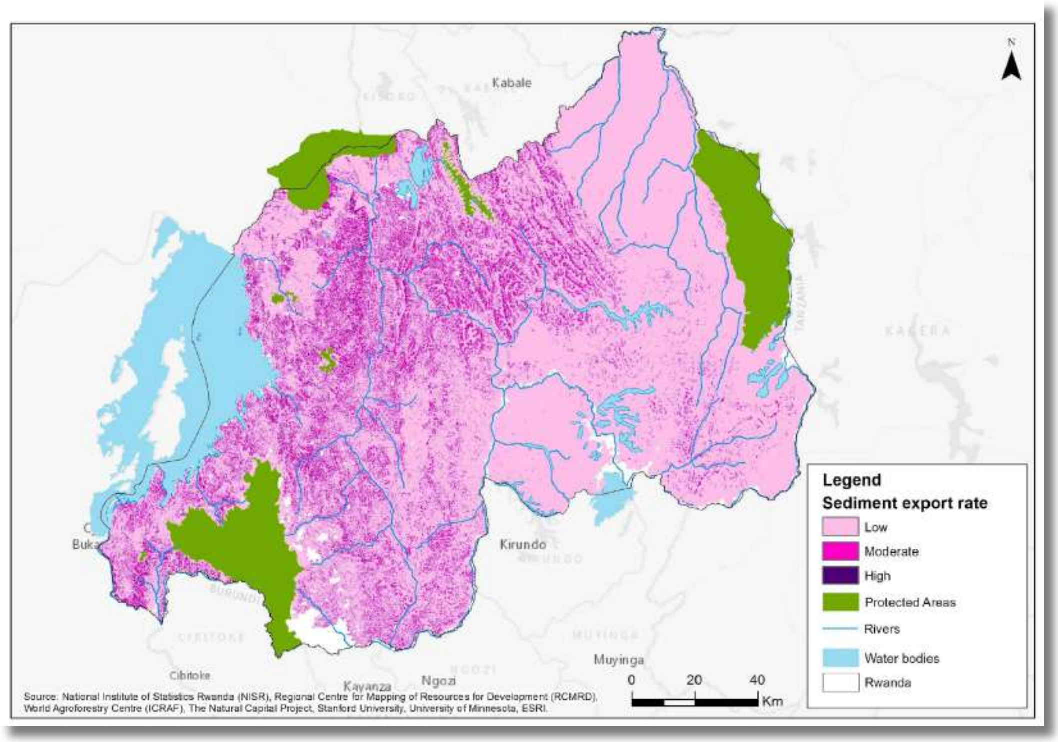


Figure A1 – Total sediment export rate (per hectare and per year) in Rwanda

Annex 3.4 Reduction classes per FLR action

	Reduction classes per FLR action				
	Highest reduction	High reduction	Moderate reduction	Low reduction	Lowest reduction
Agroforestry with annual crops	(-380 - -294)	(-293 - -167)	(-166 - -85)	(-84 - -29)	(-28 - 0)
Agroforestry with perennial crops	(-9 - -8)	(-7 - -5)	(-4 - -3)	(-2 - -1)	(-0.9 - 0)
Managed woodlots	(-60 - -48)	(-47 - -31)	(-30 - -17)	(-16 - -5)	(-4 - 0)
Protective trees	(-24 - -21)	(-20 - -14)	(-13 - -8)	(-7 - -3)	(-2 - 0)

Annex 3.5 Detailed impact potential maps for erosion rate and sediment export rate

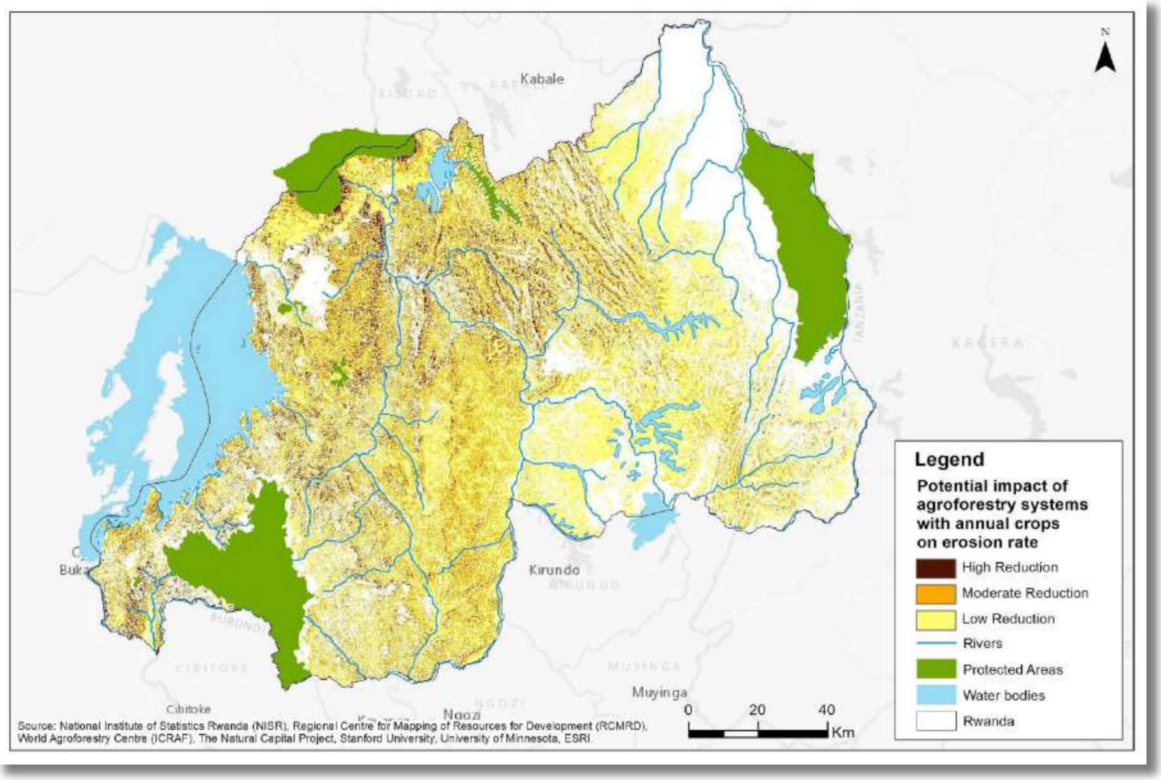


Figure A2 – Impact potential map on erosion rate for agroforestry system with annual crops

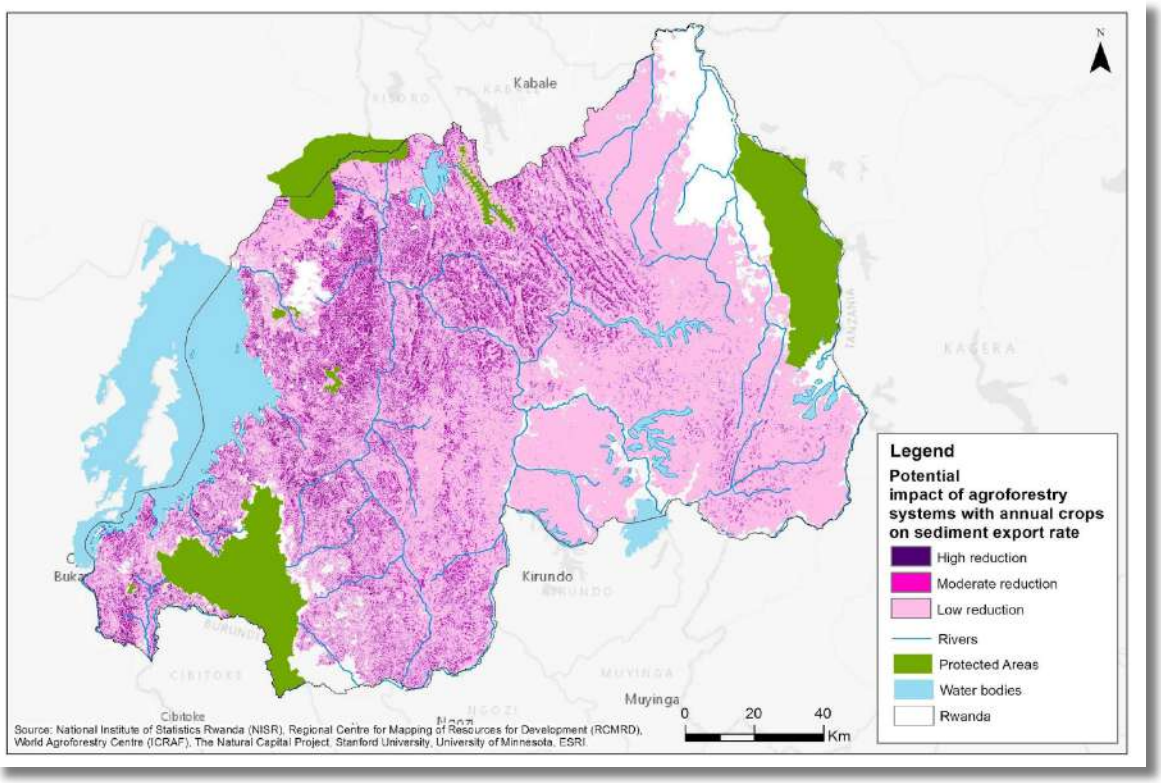


Figure A3 – Impact potential map on sediment export rate for agroforestry with annual crops

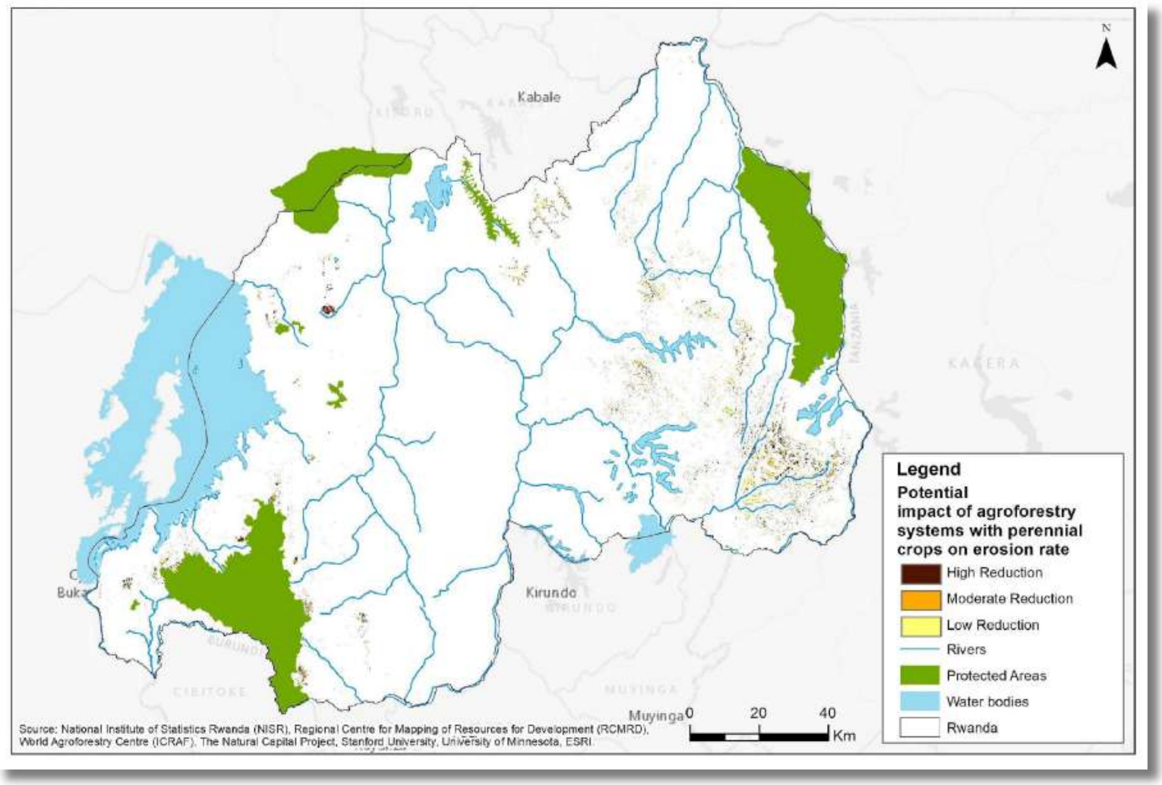


Figure 3.5-3 – Impact potential map on erosion rate for agroforestry system with perennial crops

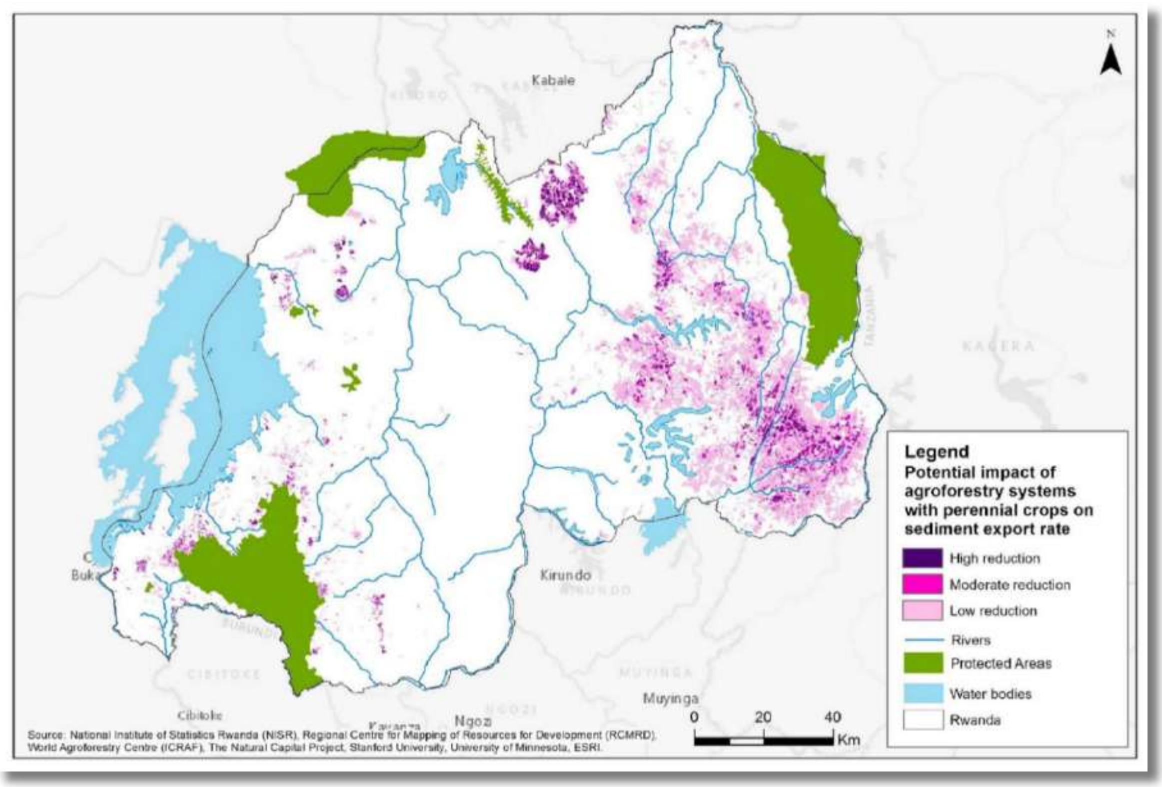


Figure 3.5-4 – Impact potential map on sediment export rate for agroforestry system with perennial crops

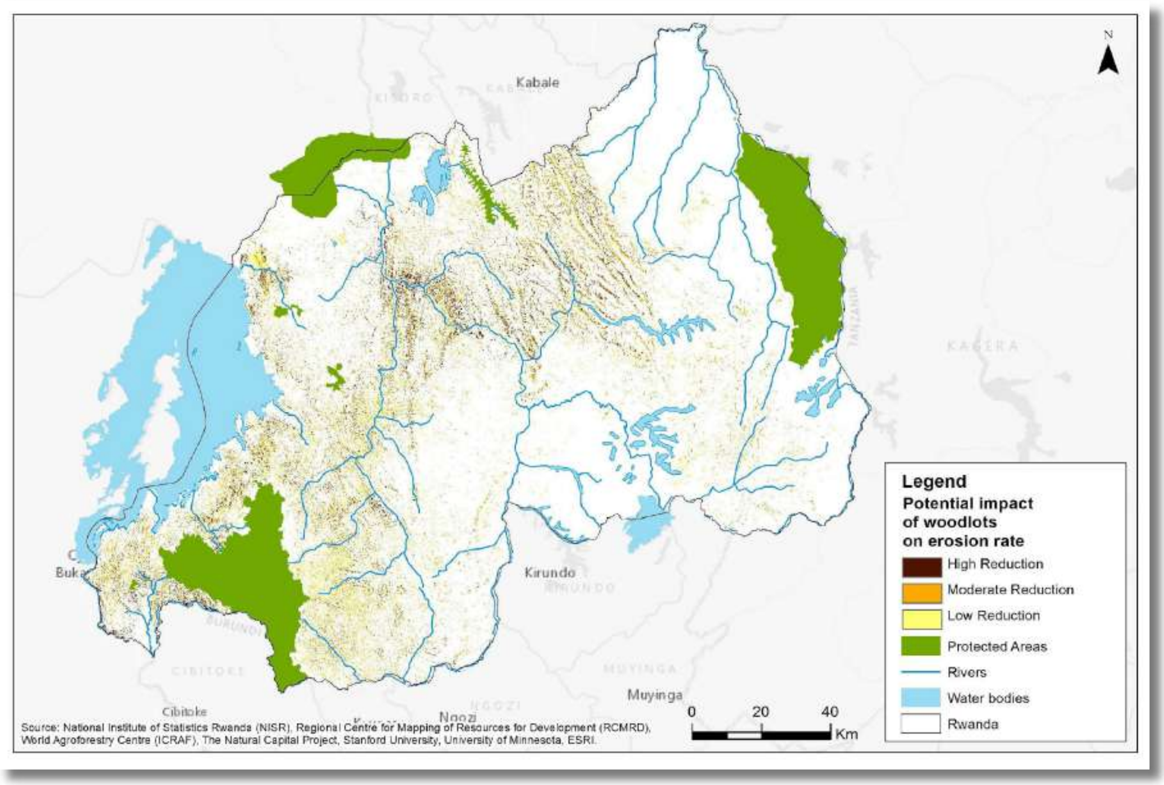


Figure 3.5-5 – Impact potential map for erosion rate of managed woodlots

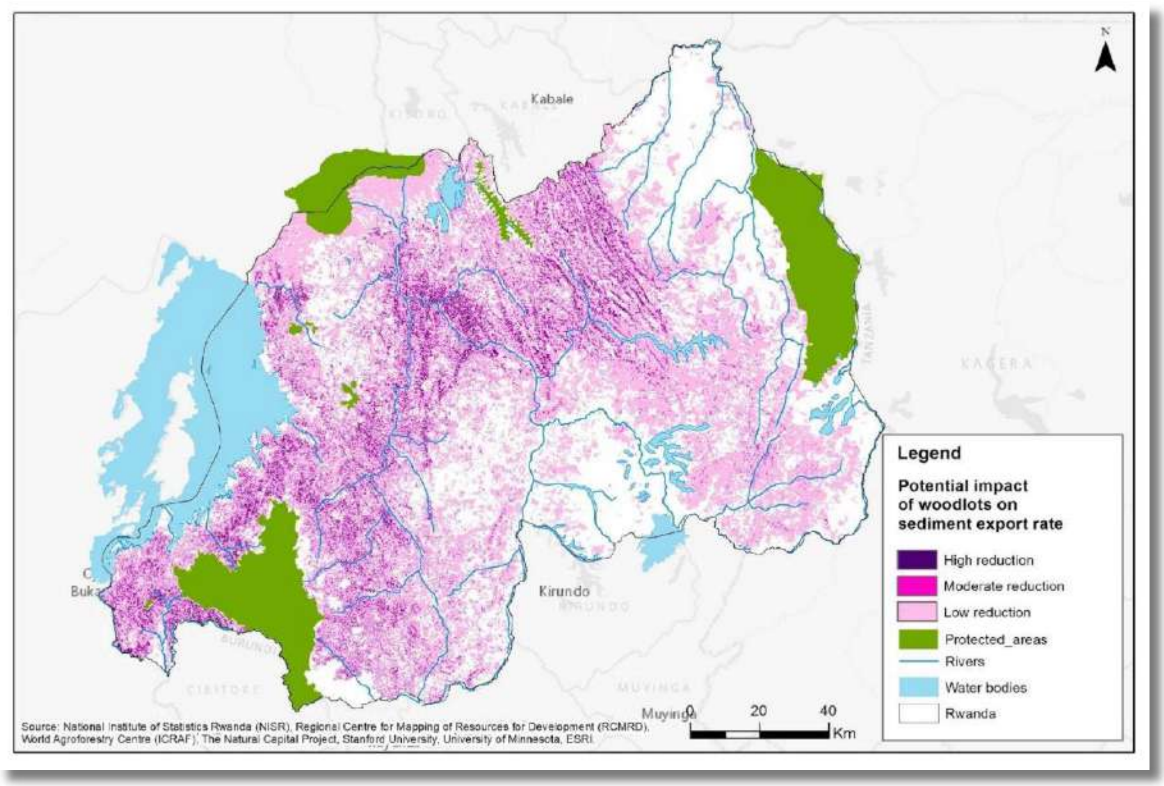


Figure 3.5-6 – Impact potential map on sediment export rate for managed woodlots.

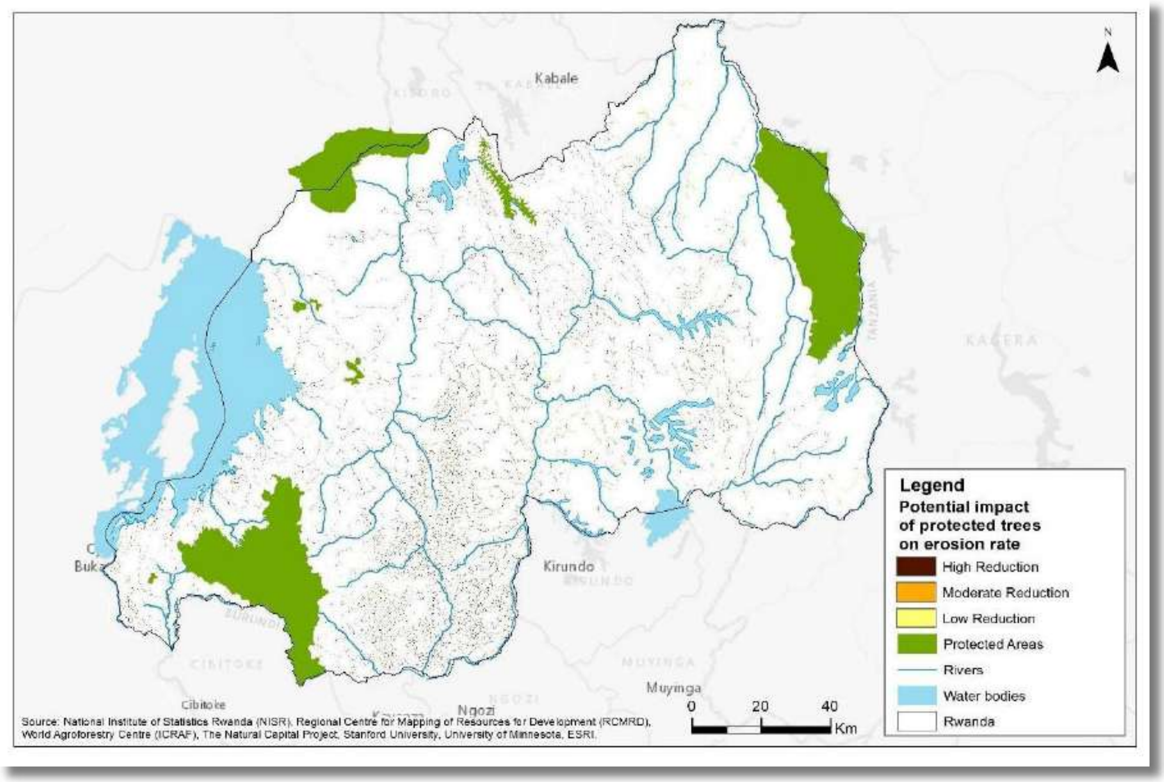


Figure 3.5-7 – Impact potential map on erosion rate for protective trees

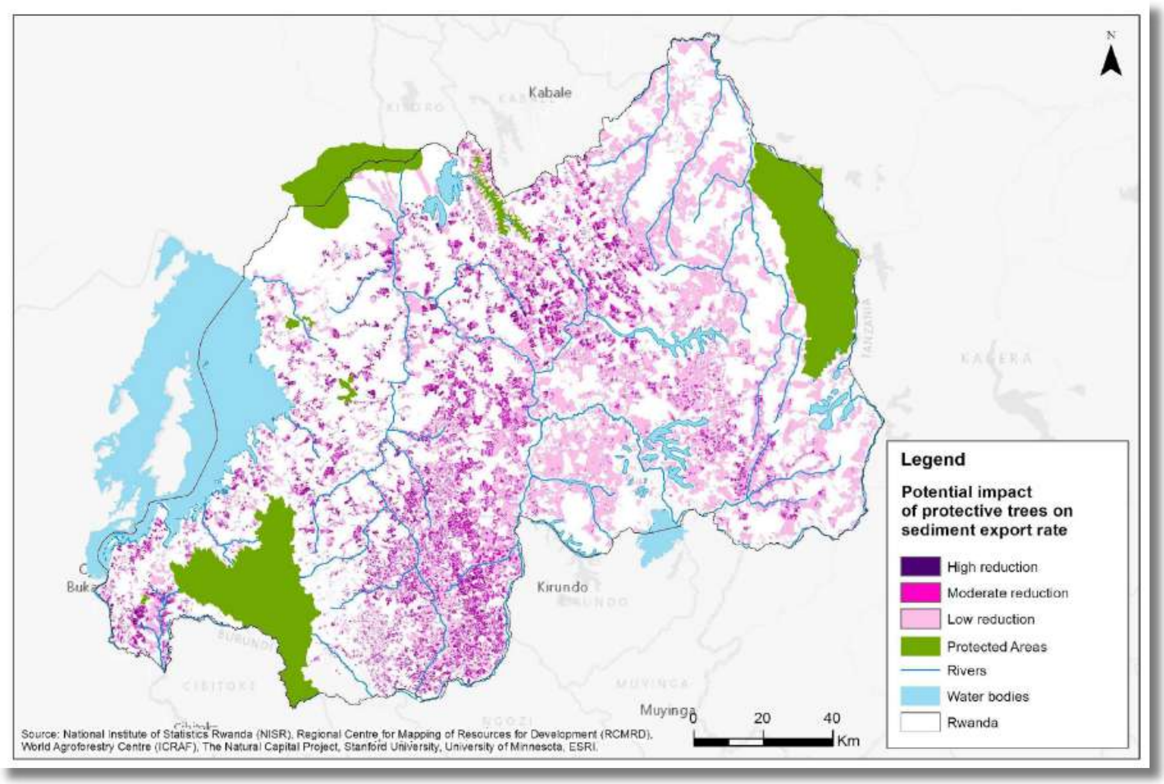


Figure 3.5-8 – Impact potential map on sediment export rate for protective trees

Annex 3.6 Complete classification of districts according to area and percentage with highest potential impact

Table A1 – Districts and number of hectares according to prioritisation category based on impact of agroforestry with annual crops on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gakenke	70,929	3,202	6,758	12,817	16,833	10,825
Ngororero	68,177	2,966	6,476	13,785	16,799	9,698
Rusizi	96,858	2,824	4,535	7,381	8,738	8,452
Rulindo	57,166	2,723	5,768	9,949	11,987	8,727
Karongi	99,712	2,650	5,507	11,381	16,812	12,596
Nyabihu	54,183	2,526	4,978	8,582	10,476	8,247
Nyamasheke	118,108	2,487	5,089	9,144	11,882	8,656
Gicumbi	83,483	2,210	5,656	12,567	18,128	14,497
Muhanga	65,172	2,209	4,355	9,874	16,312	11,193
Rutsiro	116,996	2,153	4,262	8,941	14,224	11,067
Musanze	53,133	2,107	3,083	5,421	10,065	13,158
Nyamagabe	110,031	1,939	4,655	10,890	17,167	14,148
Burera	65,001	1,340	2,928	7,557	13,773	13,022
Rubavu	38,916	1,066	1,612	2,833	5,948	8,703
Kamonyi	66,508	783	2,609	8,977	23,218	19,133
Gasabo	43,262	685	1,753	4,323	8,977	9,089
Nyaruguru	102,022	569	2,448	8,625	16,372	14,711
Nyagatare	193,208	493	947	2,108	8,767	33,551
Huye	58,611	402	1,736	7,880	17,684	13,825
Gisagara	68,611	384	2,430	10,390	21,097	20,113
Nyanza	67,753	373	1,983	8,638	23,859	18,729
Gatsibo	159,617	368	1,515	4,987	17,205	31,661
Ruhango	63,106	353	1,806	7,437	23,365	20,209
Kirehe	119,852	230	1,160	4,760	15,546	24,546
Nyarugenge	13,351	197	536	1,247	2,336	2,465
Rwamagana	68,613	120	712	3,452	14,946	21,670
Ngoma	87,568	86	731	3,897	14,831	27,436
Kayonza	194,694	72	503	2,434	11,029	22,013
Kicukiro	16,835	19	118	634	3,082	3,937
Bugesera	130,410	7	57	662	11,821	46,962
	Total	**37,542**	**86,707**	**211,574**	**423,279**	**483,039**

Table A2 – Districts and percentage of area according to prioritisation category for agroforestry with annual crops

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Rulindo	57,166	4.76	10.09	17.40	20.97	15.27
Nyabihu	54,183	4.66	9.19	15.84	19.33	15.22
Gakenke	70,929	4.51	9.53	18.07	23.73	15.26
Ngororero	68,177	4.35	9.50	20.22	24.64	14.22
Musanze	53,133	3.97	5.80	10.20	18.94	24.76
Muhanga	65,172	3.39	6.68	15.15	25.03	17.17
Rusizi	96,858	2.92	4.68	7.62	9.02	8.73
Rubavu	38,916	2.74	4.14	7.28	15.28	22.36
Gicumbi	83,483	2.65	6.78	15.05	21.71	17.37
Nyamasheke	118,108	2.11	4.31	7.74	10.06	7.33
Burera	65,001	2.06	4.50	11.63	21.19	20.03
Rutsiro	116,996	1.84	3.64	7.64	12.16	9.46
Nyamagabe	110,031	1.76	4.23	9.90	15.60	12.86
Gasabo	43,262	1.58	4.05	9.99	20.75	21.01
Nyarugenge	13,351	1.48	4.01	9.34	17.50	18.46
Kamonyi	66,508	1.18	3.92	13.50	34.91	28.77
Huye	58,611	0.69	2.96	13.44	30.17	23.59
Gisagara	68,611	0.56	3.54	15.14	30.75	29.31
Ruhango	63,106	0.56	2.86	11.78	37.03	32.02
Nyaruguru	102,022	0.56	2.40	8.45	16.05	14.42
Nyanza	67,753	0.55	2.93	12.75	35.21	27.64
Karongi	99,712	0.27	5.52	11.41	16.86	12.63
Nyagatare	193,208	0.26	0.49	1.09	4.54	17.37
Gatsibo	159,617	0.23	0.95	3.12	10.78	19.84
Kirehe	119,852	0.19	0.97	3.97	12.97	20.48
Rwamagana	68,613	0.17	1.04	5.03	21.78	31.58
Kicukiro	16,835	0.11	0.70	3.77	18.31	23.39
Ngoma	87,568	0.10	0.83	4.45	16.94	31.33
Kayonza	194,694	0.04	0.26	1.25	5.66	11.31
Bugesera	130,410	0.01	0.04	0.51	9.06	36.01

Table A3 – Districts and number of hectares according to prioritisation category based on impact of agroforestry with perennial crops on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Kirehe	119,852	4,773	934	1,179	1,206	610
Kayonza	194,694	2,644	530	684	842	523
Ngoma	87,568	1,941	341	472	470	264
Rwamagana	68,613	1,337	220	300	337	125
Gicumbi	83,483	1,126	146	152	217	292
Gatsibo	159,617	1,072	324	329	337	127
Nyamasheke	118,108	950	110	159	214	112
Nyaruguru	102,022	727	151	150	162	27
Nyabihu	54,183	548	55	56	58	42
Nyamagabe	110,031	542	114	101	88	16
Karongi	99,712	496	93	107	98	14
Rusizi	96,858	378	34	35	24	9
Ngororero	68,177	345	48	35	19	4
Rulindo	57,166	254	58	56	102	165
Rutsiro	116,996	211	33	30	29	11
Gasabo	43,262	191	18	19	20	11
Nyagatare	193,208	158	76	95	64	7
Rubavu	38,916	123	12	14	26	40
Kicukiro	16,835	112	10	13	20	10
Bugesera	130,410	12	1	2	1	20
Kamonyi	66,508	8	2	1	1	0
Nyarugenge	13,351	7	0	1	0	0
Muhanga	65,172	5	1	1	0	0
Musanze	53,133	5	0	0	0	0
Ruhango	63,106	5	0	0	1	0
Burera	65,001	4	0	2	3	1
Gakenke	70,929	4	0	0	0	0
Gisagara	68,611	2	0	0	0	0
Huye	58,611	2	2	1	0	1
Nyanza	67,753	1	0	0	0	0
	Total	**17,968**	**3,298**	**3,982**	**4,328**	**2,417**

Table A4 – Districts and percentage of area according to prioritisation category for agroforestry with perennial crops

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Kirehe	119,852	3.98	0.78	0.98	1.01	0.51
Ngoma	87,568	2.22	0.39	0.54	0.54	0.30
Rwamagana	68,613	1.95	0.32	0.44	0.49	0.18
Kayonza	194,694	1.36	0.27	0.35	0.43	0.27
Gicumbi	83,483	1.35	0.17	0.18	0.26	0.35
Nyabihu	54,183	1.01	0.10	0.10	0.11	0.08
Nyamasheke	118,108	0.80	0.09	0.13	0.18	0.09
Nyaruguru	102,022	0.71	0.15	0.15	0.16	0.03
Gatsibo	159,617	0.67	0.20	0.21	0.21	0.08
Kicukiro	16,835	0.67	0.06	0.08	0.12	0.06
Ngororero	68,177	0.51	0.07	0.05	0.03	0.01
Karongi	99,712	0.50	0.09	0.11	0.10	0.01
Nyamagabe	110,031	0.49	0.10	0.09	0.08	0.01
Rulindo	57,166	0.44	0.10	0.10	0.18	0.29
Gasabo	43,262	0.44	0.04	0.04	0.05	0.03
Rusizi	96,858	0.39	0.04	0.04	0.02	0.01
Rubavu	38,916	0.32	0.03	0.04	0.07	0.10
Rutsiro	116,996	0.18	0.03	0.03	0.02	0.01
Nyagatare	193,208	0.08	0.04	0.05	0.03	0.00
Nyarugenge	13,351	0.05	0.00	0.01	0.00	0.00
Kamonyi	66,508	0.01	0.00	0.00	0.00	0.00
Musanze	53,133	0.01	0.00	0.00	0.00	0.00
Bugesera	130,410	0.01	0.00	0.00	0.00	0.02
Ruhango	63,106	0.01	0.00	0.00	0.00	0.00
Muhanga	65,172	0.01	0.00	0.00	0.00	0.00
Burera	65,001	0.01	0.00	0.00	0.00	0.00
Gakenke	70,929	0.01	0.00	0.00	0.00	0.00
Huye	58,611	0.00	0.00	0.00	0.00	0.00
Gisagara	68,611	0.00	0.00	0.00	0.00	0.00
Nyanza	67,753	0.00	0.00	0.00	0.00	0.00

Table A5 – Districts and number of hectares according to prioritisation category based on impact of planting managed woodlots on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gakenke	70,929	4,087	3,040	3,574	3,895	1,325
Rusizi	96,858	3,502	2,286	2,991	3,398	1,512
Gicumbi	83,483	3,299	3,736	5,470	4,791	1,881
Muhanga	65,172	3,003	2,401	3,600	4,632	1,783
Nyamasheke	118,108	2,786	2,486	3,600	5,086	2,457
Karongi	99,712	2,670	2,511	4,467	6,245	3,355
Rulindo	57,166	2,402	2,172	2,580	2,415	1,068
Nyamagabe	110,031	1,969	2,519	4,610	7,628	4,803
Ngororero	68,177	1,443	1,482	2,128	2,595	1,053
Rutsiro	116,996	1,362	1,196	1,837	2,460	1,398
Rubavu	38,916	1,084	677	894	1,519	1,754
Nyaruguru	102,022	1,080	1,790	3,990	7,215	4,369
Gasabo	43,262	1,026	1,053	1,548	1,607	867
Gatsibo	159,617	851	1,432	2,419	3,257	1,836
Kamonyi	66,508	780	629	1,009	1,424	680
Nyabihu	54,183	731	458	575	682	545
Nyagatare	193,208	644	664	968	1,021	959
Nyanza	67,753	552	704	1,272	2,000	1,103
Huye	58,611	494	694	1,679	2,666	1,225
Musanze	53,133	489	263	375	553	542
Burera	65,001	447	535	1,056	1,506	1,206
Nyarugenge	13,351	445	331	494	568	325
Ruhango	63,106	309	460	985	1,746	1,044
Gisagara	68,611	240	454	993	1,325	667
Rwamagana	68,613	210	454	1,021	1,852	1,042
Kirehe	119,852	128	233	641	1,310	894
Kayonza	194,694	127	306	838	1,875	1,727
Ngoma	87,568	112	344	879	1,959	1,428
Kicukiro	16,835	7	15	60	196	192
Bugesera	130,410	3	16	88	503	510
	Total	**36,282**	**35,341**	**56,642**	**77,928**	**43,549**

Table A6 – Districts and percentage of area according to prioritisation category for managed woodlots

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gakenke	70,929	5.76	4.29	5.04	5.49	1.87
Muhanga	65,172	4.61	3.68	5.52	7.11	2.74
Rulindo	57,166	4.20	3.80	4.51	4.22	1.87
Gicumbi	83,483	3.95	4.48	6.55	5.74	2.25
Rusizi	96,858	3.62	2.36	3.09	3.51	1.56
Nyarugenge	13,351	3.33	2.48	3.70	4.25	2.43
Rubavu	38,916	2.79	1.74	2.30	3.90	4.51
Karongi	99,712	2.68	2.52	4.48	6.26	3.36
Gasabo	43,262	2.37	2.43	3.58	3.71	2.00
Nyamasheke	118,108	2.36	2.10	3.05	4.31	2.08
Ngororero	68,177	2.12	2.17	3.12	3.81	1.54
Nyamagabe	110,031	1.79	2.29	4.19	6.93	4.37
Nyabihu	54,183	1.35	0.85	1.06	1.26	1.01
Kamonyi	66,508	1.17	0.95	1.52	2.14	1.02
Rutsiro	116,996	1.16	1.02	1.57	2.10	1.19
Nyaruguru	102,022	1.06	1.75	3.91	7.07	4.28
Musanze	53,133	0.92	0.49	0.71	1.04	1.02
Huye	58,611	0.84	1.18	2.86	4.55	2.09
Nyanza	67,753	0.81	1.04	1.88	2.95	1.63
Burera	65,001	0.69	0.82	1.62	2.32	1.86
Gatsibo	159,617	0.53	0.90	1.52	2.04	1.15
Ruhango	63,106	0.49	0.73	1.56	2.77	1.65
Gisagara	68,611	0.35	0.66	1.45	1.93	0.97
Nyagatare	193,208	0.33	0.34	0.50	0.53	0.50
Rwamagana	68,613	0.31	0.66	1.49	2.70	1.52
Ngoma	87,568	0.13	0.39	1.00	2.24	1.63
Kirehe	119,852	0.11	0.19	0.53	1.09	0.75
Kayonza	194,694	0.07	0.16	0.43	0.96	0.89
Kicukiro	16,835	0.04	0.09	0.36	1.16	1.14
Bugesera	130,410	0.00	0.01	0.07	0.39	0.39

Table A7 – Districts and number of hectares according to prioritisation category based on impact of protective forests on soil erosion

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gisagara	68,611	3,291	229	226	228	203
Huye	58,611	2,856	191	201	123	40
Nyaruguru	102,022	2,491	277	296	212	51
Nyanza	67,753	2,325	286	224	237	118
Ruhango	63,106	1,586	217	229	145	56
Nyamagabe	110,031	1,518	128	117	85	25
Kamonyi	66,508	1,414	154	138	123	105
Muhanga	65,172	1,200	93	93	74	18
Ngoma	87,568	1,175	172	179	205	145
Rulindo	57,166	1,081	118	94	106	38
Nyamasheke	118,108	999	89	85	78	39
Gatsibo	159,617	977	266	342	321	148
Gicumbi	83,483	968	85	88	102	83
Karongi	99,712	933	65	55	38	8
Rusizi	96,858	910	83	106	143	180
Rwamagana	68,613	874	118	121	109	47
Bugesera	130,410	868	314	360	465	364
Gasabo	43,262	780	91	88	90	41
Gakenke	70,929	735	53	74	51	16
Kayonza	194,694	695	148	193	297	300
Kirehe	119,852	636	136	190	273	192
Burera	65,001	587	69	74	114	34
Rutsiro	116,996	561	53	48	58	14
Ngororero	68,177	515	37	34	32	9
Nyagatare	193,208	497	278	601	824	757
Nyabihu	54,183	362	24	20	22	19
Musanze	53,133	337	23	32	31	10
Rubavu	38,916	122	12	20	20	13
Nyarugenge	13,351	121	22	21	47	111
Kicukiro	16,835	100	12	21	25	23
	Total	**31,510**	**3,842**	**4,372**	**4,677**	**3,205**

Table A8 – Districts and percentage of area according to prioritisation category for protective forests

District	Area (ha)	Highest reduction (ha)	High reduction (ha)	Moderate reduction (ha)	Low reduction (ha)	Lowest reduction (ha)
Gisagara	68,611	4.80	0.33	0.33	0.33	0.30
Huye	58,611	4.87	0.33	0.34	0.21	0.07
Nyanza	67,753	3.43	0.42	0.33	0.35	0.17
Ruhango	63,106	2.51	0.34	0.36	0.23	0.09
Nyaruguru	102,022	2.44	0.27	0.29	0.21	0.05
Kamonyi	66,508	2.13	0.23	0.21	0.18	0.16
Rulindo	57,166	1.89	0.21	0.16	0.19	0.07
Muhanga	65,172	1.84	0.14	0.14	0.11	0.03
Gasabo	43,262	1.80	0.21	0.20	0.21	0.09
Nyamagabe	110,031	1.38	0.12	0.11	0.08	0.02
Ngoma	87,568	1.34	0.20	0.20	0.23	0.17
Rwamagana	68,613	1.27	0.17	0.18	0.16	0.07
Gicumbi	83,483	1.16	0.10	0.11	0.12	0.10
Gakenke	70,929	1.04	0.07	0.10	0.07	0.02
Rusizi	96,858	0.94	0.09	0.11	0.15	0.19
Karongi	99,712	0.94	0.07	0.06	0.04	0.01
Nyarugenge	13,351	0.91	0.16	0.16	0.35	0.83
Burera	65,001	0.90	0.11	0.11	0.18	0.05
Nyamasheke	118,108	0.85	0.08	0.07	0.07	0.03
Ngororero	68,177	0.76	0.05	0.05	0.05	0.01
Nyabihu	54,183	0.67	0.04	0.04	0.04	0.04
Bugesera	130,410	0.67	0.24	0.28	0.36	0.28
Musanze	53,133	0.63	0.04	0.06	0.06	0.02
Gatsibo	159,617	0.61	0.17	0.21	0.20	0.09
Kicukiro	16,835	0.59	0.07	0.12	0.15	0.14
Kirehe	119,852	0.53	0.11	0.16	0.23	0.16
Rutsiro	116,996	0.48	0.05	0.04	0.05	0.01
Kayonza	194,694	0.36	0.08	0.10	0.15	0.15
Rubavu	38,916	0.31	0.03	0.05	0.05	0.03
Nyagatare	193,208	0.26	0.14	0.31	0.43	0.39

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