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Erosion Control Success Stories and Challenges in the Context of Sustainable Landscape Management, Rwanda Experience

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Abstract

The Government of Rwanda sets up a conducive policy environment to invest in several development initiatives. Agriculture sector as the main contributor in the economic development received supports to sustainably manage Rwandan hilly landscape, dominantly ranging from 5 to 55% slope gradient. Intensive erosion control interventions confronted with different approaches have been introduced in the country such as participatory landscape management, (participatory) integrated watershed management and site-located intervention without any specified approach. This chapter intends to describe and evaluate the impacts of these previous approaches used in Rwanda in order to retrieve the success stories and encountered challenges as lessons learnt in the future interventions for optimizing land productivity in a sustainable manner. Participatory landscape approach in Gishwati area was a success story in protecting degraded lands and generating ecosystem benefits. It leads to more sustainable natural resources management from participatory planning up to implementation which addressed the frequent landslides, erosion and flooding while sustainably exploit the land to the profit of local farmers in the livelihoods. About 6,600 ha of lands have been successfully protected with full-packaged bench terraces, rangeland blocks and forest regeneration. This participatory approach also helped to relocate people from high risk zones to other safe places and build capacities of farmers through farm-livestock cooperatives. On the other side, Nyanza and Karongi sites under LWH project also emphasized strong evidences how land husbandry technologies (terraces) efficiently reduced erosion risks and improved farmers' livelihoods. Lands were made productive with implementation of bench terraces on 3212 and 2673 hectares respectively for the two selected sites. However, challenges were observed from technical and socio-economic contexts which might have caused farmers to abandon or under-exploit the terraced lands. Finally, the chapter suggests to scale up the participatory landscape management approach which supports the involvement of farmers' communities in the process.

Keywords: erosion, terraces, successes, challenges, participatory, landscape, Rwanda

1. Introduction

Rwanda, the country of thousand hills, has a small coverage area of 26,338 km² with the highest (rural) population of 12 million inhabitants (416 habitants per km²),

among African countries. More than 80% of population depends on agriculture sector which is dominated by subsistence farming at average farm size of 0.5 hectare [1].

Over the last two decades, the Government has experienced tremendous and steady rates of economic growth nationwide averaging 5.7% in 2019 [2]. While this sector contributes approximately to about 27% of the national GDP and 68% of the labor force [1], there is an intense pressure on degradation of natural resources especially land and water, by occupying marginal and non-protected lands. Thus, agriculture is still affected by low productivity due to several factors. Among others, Rwandan biophysical environment is dominantly characterized by steep slopes accentuated from Eastern to Western facings, and this mountainous topography exposes soil to water erosion risks, especially in the Highlands of Northern and Western parts of Rwanda. Particularly, erosion risk is chiefly associated with slope ranges from 5 to 55% on arable land (about 48% of the total area) [3–5].

The combination of soil erosion, climate change condition, poor soil fertility and inappropriate steepland managements have aggravated such low productivity levels. In addition, intensive farming activities resulted into pollution, lowland siltation, soil nutrient depletion and soil acidity [6–8]. The acidic soils cover about 50% of national land area [9, 10]. Recently, climate change conditions have also to harmonize style and droughts reduced the performance of agriculture production system, resulting from rainfall differences as affected by El Niño - Southern Oscillation (ENSO) events (El Niño and La Niña) [11–13]. This renders small-scale, subsistence, rain-fed farming vulnerable and leads to more advanced land degradation problems.

In the framework of finding appropriate solutions to combat land degradation problems, the country sets up a conducive environment with strategic policy tools since the past 20 years such as Vision 2020, Strategic Plan for Agriculture Transformation (PSTA I, II, III, IV). Recently, National Strategy for Agriculture Transformation (NST1) (2017–2024) and its Fourth Strategic Plan for Agriculture and Transformation (PSTA4, 2018–2024) identified increasing productivity and resilience through sustainable land management approach as one of the priority areas in the economic development. Different actions from policy and development aspects had been invested in soil erosion control systems using a wide range of erosion control measures chiefly terraces, towards sustainable environment protection and agricultural transformation pathways. Intensive erosion control interventions confronted with different approaches bringing both on-site and off-site impacts [14, 15]. They adopted either different ways such as participatory landscape management or (Participatory) integrated watershed management. Thirdly, none of them was adopted to establish soil erosion control techniques.

Therefore, this chapter intends to describe and evaluate the impacts of different approaches used in erosion control systems in Rwanda in order to retrieve the success lessons, but also pinpoint challenges of each approach used. The chapter is practically assessing land husbandry interventions undertaken in two government projects namely Gishwati Water and Land Management (GWLM), and Land, Water-harvesting and Hillside-irrigation (LWH) for gaining understandings of the success or issues to be considered in the future interventions in the country as well as in other areas with similar landscape conditions. From lesson learnt, the chapter intended to recommend the best and comprehensive technical strategies aligning to land husbandry in rural farming systems for improving sustainable landscape management and optimize land's productivity.

2. Approach

This chapter compiles two case studies in Rwanda describing and analyzing various approaches used on soil erosion control systems in the recent past years (after 2000). The findings have to inform the success experiences, problems encountered and generated potential policy and technical recommendations to be adopted in future.

The first section concerns the north-western part of Rwanda namely Gishwati area using participatory landscape approach. The second involves the use of two watersheds (Nyanza-23 and Karongi 12–13) developed under support of World bank project namely Land, Water-harvesting and Hillside-irrigation (LWH) which adopted integrated watershed management approach. The last section discussed lessons learnt to inform policy decision makers at national, regional, international scopes of what is the appropriate way to sustainably optimize the land productivity based on Rwandan experience. The study areas are located from different agro-ecological zones: Gishwati site in the Birunga, Nyanza in central plateau, and Karongi in Kivu lake Borders (**Figure 1**).

Figure 1.
Map of Rwanda showing its agro-ecological zones and study sites (Nyanza 23, Gishwati, and Karongi 12–13).
(Source: Author).

3. Sustainable landscape management approach: Gishwati case

3.1 Description of the study area

Gishwati targeted area covers 6,600 ha across Jenda, Karago, Rambura and Bigogwe sectors of Nyabihu district, and Kanama, Nyakiliba and Kanzenze sectors of Rubavu district. This area constitutes 26.5% of the total Gishwati ecosystem in its northern part. The area is geographically located at latitude of 1.689418°S and

longitude of 29.532433° E. The altitude varies from 2,191 to 2,959 m. Gishwati area had greatly suffered with problems of soil erosion, landslide, gully, flooding, human loss and destruction of development infrastructures after 1994 due to occupation of fragile forest reserve by mass return of refugees. Gishwati was before a natural forest ecosystem which has been converted to agriculture, livestock and settlement lands. Land was intensively exploited mainly for agriculture purposes such as crop-ping of Irish potatoes, climbing beans, peas, wheat, tea, etc., but also with livestock activities on scattered pasture grasses and poorly managed woodlots (**Figure 2**).

Figure 2. Map of land cover changes of Gishwati ecosystem from 1986 to 2006 (left to right), Source: GWLM project.

As many places in the country, Gishwati is characterized by a complex lithology and landscape diversity due to elevation differences from valley bottom to mountain summits. Soils in Rwanda vary across very short distances due to the complexity of relief and parent materials [16, 17]. This observation varies from hill to hill and hilltop to the lower slope and valley bottom [17]. Any intervention for its success should consider this biophysical complexity.

The drastic change in land use affected local communities to live regularly with risks of landslide and floodings. These risks are subjected to high rainfall rainfall ranging from 1800 to 2500 mm per year and to fragility of soils (*Ruseseka* in Kinyarwanda local language) from forest soils and volcanic materials lying on a bed-rock at very steep slopes. All these factors together with inappropriate agriculture practices and lack of land and water management measures induced very severe erosion. **Figure 3** demonstrates how eroded soil materials flooded the lowland (left) and leaving plantation tree outcropped (right).

3.2 Approach

Since 2010, Gishwati Water and Land Management Project (GWLM) has been initiated to effectively counteract the landslides, floods and erosion risks but also

Figure 3.
Induced natural hazards: Landslide, erosion, flooding, silting, and root outcropped: Bigogwe, April 2007 (left) and April 2010 (right).

strengthening the potential for agriculture development in Gishwati area in the context of improving livelihood communities. The GWLM project of the Ministry of Agriculture and Animal Resources (MINAGRI) understood the vitality to sustainable restoring the landscape potentials of Gishwati and hence it developed an approach which consists of two resolutions:

- Harmonizing the healthy co-existence of the agrarian communities with the fragile ecosystem of Gishwati;
- Maximizing sustainable economic contribution of Gishwati to the communities' improved way of life.

In this context, the MINAGRI concerted efforts of technical/scientific expertise from potential actors including the local government, the beneficiary farmers, different Government institutions such as MINAGRI, Ministry of Environment, Lands and Water (currently MOE-Ministry of Environment), and other relevant agencies/organizations to support the project goal. This aligns with participatory landscape approach by which key stakeholders contributing to economic development should intervene to establish a comprehensive approach for harmonizing the healthy co-existence of the agrarian communities with the fragile ecosystem of Gishwati.

The core issue of the Gishwati was to find a best way by which land degradation issues would be successfully avoided by linking different soil and water management interventions to the different land potential units of the project area while supporting sustainable existence between human needs and natural resource-based opportunities. A participatory and integrated landscape approach is considered to improved management of natural resources to support sustainable agricultural productivity but also taking into account the effects of climate change. Adoption of landscape approach puts attention to modernizing land and water management technologies as well as promoting extension services that effectively guaranty stability of sloping lands within Wet Rainfall Regimes of Gishwati.

The government realized that the intervention is of momentous challenge to assure stable and resilient environment using scientific-based technologies. Another aspect considered how the fertile Gishwati soil and the year-round rainfall contributes to the improved livelihood of the communities. This calls upon using ingeniously designed physical and biological technologies that guaranty the sustainability and productivity of the land through effective water and soil management practices. To materialize the economic potential of land husbandry technologies, farmers are encouraged to consolidate their lands for construction of suitable and

long-stretching land husbandry structures which guaranteed the increased and continued production of crop value chains of the project area in Nyabihu and Rubavu districts. The landscape restoration of this area has been supported by the policies, among others, the land consolidation, the crop intensification, transformation of subsistence to market-based agriculture, etc., as set by the MINAGRI.

3.2.1 Criteria for selecting appropriate land uses and managements

Factors were itemized in order to define every land unit according to its potentials. Practically, it concerned placement of different soil and water management interventions on the appropriate land potential units of the project area. The following criteria were considered:

- Consulting and exploit existing datasets for Rwanda, specifically in the concerned region;
- Understanding the nature of the slope gradient;
- Exploiting the soil depth and characteristics of the project area.

3.2.1.1 Exploiting available datasets

The agro-climatic data of the Gishwati area have been gathered for analysis of rainfall variability and aggressivity. This area shows agroclimatic zones of wet high-land, wet frost and wet alpine frost conditions. The information of wet moisture regimes with very limited evapotranspiration in high altitudes could be considered in the equation for generating appropriate interventions. Soil database was also explored to understand the soil properties including soil depth, and soil types.

3.2.1.2 Consideration of slope gradient nature

To understand the impact of topography, the map of slope gradient of Gishwati watershed using ArcGIS spatial analysis tools has been generated from the Digital Elevation Model (DEM – 30 m resolution), accessed from the United States Geological Survey (USGS) database (<http://earthexplorer.usgs.gov/>). Digital representation topography (DTM) generated from DEM helped to calculate five slope classes (0–6, 6–16, 16–40, 40–60 and > 60%) (**Figure 4**).

Outputs of the slope map generated provided distribution of slope classes as follow: 50% of the Gishwati area (3290 ha) are located within 16–40%, 23% (1491 ha) within 40–60%, 13% (895 ha) within 6–16%, 10% (659 ha) within 0–6%, and finally 4% (279 ha) is above 60%. However, the forms of slope are so complex so that the slope criterion was not easy for defining recommendation zones [17]. Thus, scientists managed to agree on the approach for protecting this complex biophysical environment. RUSLE model helped to develop erosion risk assessment whereby slope factor contributed more (**Figure 4**).

3.2.1.3 Exploiting soil depth

Soil depth was assessed to see the storage medium for the year-round rainfall that could cause landslides as well as to understand the rooting depth required for the crops to be grown in the area. Field survey of soil depth identified three levels (0–50, 50–100 and 100–200+ cm) for each soil types within different slope categories of the study area using augering method. The pedological prospections were conducted

Figure 4.
Maps of slope gradient, soil depth, erosion risk and dominant soil types in Gishwati area. Source: GWLM project.

on 52 depth tests on the dominant slope class of 16–40%, 29 tests on 40–60% slope class, 34 tests on 6–16% slope class, 27 depth tests on 0–6% slope class, and 14 depth tests on >60% slope category (**Figure 4**). Based on the soil database of Rwanda, field pedological prospection resulted in 156 soil depth tests for dominant soil types such as *Andosols*, *phaeozems*, *Acrisols*, *Cambisols*, *Lixisols* and *Leptosols* [18].

Results showed that most soils are very deep and well developed. More than 80% of conducted auger tests ranged between 100–200+ cm depth. Decisions were taken accordingly to guide recommended options for restoring landscape. The soil depth discloses how soil material with water infiltration storage can exerts pressure over the sloping land. In addition, it also guides to know the relatively most appropriate crops to be grown over each type of soil.

Very shallow soil depth zones such as the bare rook-covered lands are recommended for area closure. The next shallow depth lands (depth of 0–50 cm) are recommended for the shallow rooting grasses (range land). The utilization of soils with depth between 50–100 cm and 100–200+ was variable regarding the combination with other bio-physical factors. If the same land category was in the moist to dry rainfall regime, one could easily recommend the 100–200+ depth land for trees (deep rooting) and the other for the relatively shallow rooting shrubs. On the other hand, the deep rooting on very steep slopes would encourage excessing waterload on the mass of the deep soil materials, hence landslide occurs. In this case, planting shrubs/trees is recommended.

3.2.1.4 Soil characteristics

Soils of Gishwati are dominantly underlaid on a bed rock. Shallow soils (0–50 cm depth) are mainl *Leptosols* and *Andosols*, derived from recent volcanic

ejecta along the Bigogwe plain. These soils are very fragile and less structured on steep slopes, hence prone to landslides as typical forest soils. They are called *Ruseseka* in Kinyarwanda by local farmers. *Andosols*, *Leptosols*, and *Phaeozems* are the dominant soil types in Gishwati.

Regarding fertility potential, Rwanda digital soil dataset revealed that the fertility of the soil is excellent for crop production in such year-round rainfall regime [19, 20]. In this context, soil analysis was done with top-soil samples collected between 0–30 cm soil depth layer for assessing soil nutrient and acidity status. It showed that Gishwati area has a great potential for agriculture in Rwanda once erosion is controlled. Nutrients were above the critical level except for phosphorus. Soil acidity problem in the area was quite low with soil pH range between 5.5 and 6.6 unlike to other Rwanda soils in the North-Western parts. The soils have high organic carbon content (3.2–5.1%) and significantly high contents of crop nutrients.

The study also recognized the main soil types including *Andosols*, *Phaeozems*, *Acrisols* and *Lixisols* on hillsides; *Leptosols* developed on recent volcanic materials along Musanze-Rubavu national road and *Cambisols* derived from colluvial and alluvial sediments in the narrow valleys. Andisols are developed in mild weathering conditions from volcanic eject while *Phaeozems* are developed in moist conditions under grassland or forest with a mollic epipedon. *Acrisols* are developed in wet tropical or subtropical forests, with acid silicates clays, iron and aluminum oxides. *Lixisols* were developed under moist or mildly acid conditions with acid clays accumulation (called “inombe” in Kinyarwanda); and *Leptosols* referred to as younger or recent soils derived from metamorphic parent materials. Specifically, *Andosols*, *Phaeozems*, *Leptosols* and *Cambisols* are very fertile and suitable for a wide range of crops, namely, Irish potatoes, maize, beans, peas, wheat, variety vegetables, etc.

3.2.1.5 Community-based factor

One of the key partners in the success of the project was the great involvement of the local community in the entire process. Participatory landscape approach considered the active participation of rural communities in order to invigorate people-centered solutions in the community livelihoods. Tantoh et al. [21] stated that promotion of rural resources can only be successful if rural communities are integrated and engaged in the land husbandry interventions. It helped increasing ownership of beneficiaries, even after. Leaders of farmers received training for participatory community land use plan and map that was translated from English to Kinyarwanda local language.

The restoration of Gishwati area used this participatory approach through Labour Intensive Public Works namely as HIMO (*Haute Intensité de Main d'œuvre* or *High Intensive Labor*). The latter consists of using people in respective to their social classes towards enforcement of local beneficiaries for job creation purpose and availing income-generating activities. Local leaders, opinion leaders, farmer promoters and other farmers' organizations located in the area as well as national institutions were actively involved in the whole process of planning, relocation of population from land degradation risk zones up to the implementation of sustainable landscape-related solutions (Figure 5).

3.3 Result as success stories in sustainable landscape management

The above discussed factors for determining optimal and appropriate landscape management approaches were combined. To this effect, the guidance relied on soil depth, soil types and slope gradient as well as climatic information. Besides, proper

Figure 5.
 Community involvement in planning and implementation of land and water management. Source: GWLM project.

community mobilization, and sensitization in the whole process of landscape restoration were critically important to the sustainable establish land husbandry interventions.

3.3.1 Participatory planning and implementation of land husbandry interventions

3.3.1.1 Involvement of stakeholders in promoting land husbandry technologies

1. Capacity and knowledge about sustainable landscape management have been expanded through trainings. Trainings were intensively conducted to increase knowledge and understanding of beneficiaries about sustainable and new improved land management techniques. It comprised also how farmers should sustain implemented land husbandry interventions.
2. Farmers were sensitized to be involved in the whole process of landscape restoration of Gishwati area. Activities of sensitization and mobilization have been conducted since project start up in 2010. The project beneficiaries played a big role in mass mobilization campaigns, meetings at all levels (villages, cells, sectors, districts and central government levels). Beneficiaries explored the problems of erosion, flooding, and landslides as well as their causes. They also provided possible suggestions about landscape restoration.
3. After trainings, about 13,056 beneficiaries were involved in and earned income from land husbandry works through locally created companies within HIMO approach.
4. A new pyrethrum crop has been established in the Gishwati area. Farmers benefited as well as the promotion of pyrethrum production through support of seedling provisions, trainings, field visits and other technical assistance (**Figure 6**).
5. For the sustainability of achieved project interventions, cooperatives were formed mainly aligning to pyrethrum, and Irish potato crop commodities in order to optimize production on developed land husbandry infrastructures. Cooperatives have been registered and certificates were issued by Rwanda Co-operative Agency (RCA). In addition, the project created 42 self-help groups (around 600) in Gishwati area for the development and management of land husbandry technologies and other ecosystem services.

Figure 6. Field visits (left) and plantation (right) on pyrethrum grown in Gishwati area. Source: GWLM project.

3.3.1.2 Participation of beneficiaries in land redistribution in Gishwati area

Land redistribution was one of the challenging issues in Gishwati area to avoid any dispute of land among land users. After restoring landscape, all developed lands intended for crop and grazing activities were redistributed back to local people. In this process, a technical team was formed including local leaders at district, sector, cell and village levels. Integrating beneficiaries (farmers) in the decision process of land use planning helped to ensure the sustainable utilization of implemented land husbandry technologies.

This activity was successfully implemented for 5633 households whereby lands were equitably allocated to 4353 and 1280 farmers for crop and grazing activities respectively. For the rangeland, each household was given one hectare. However, to ensure sustainable utilization and management of this land, households were formed into groups of ten, making a total area of ten hectares which were cut into one paddock.

3.3.2 Landscape restoration interventions in Gishwati area

In addition to identified land use plan categories, this section comprised implementation of land husbandry technologies in crop land, development of rangeland, plantation of forests, construction of road and water drainage infrastructures and other ecosystem products.

3.3.2.1 Identification of land sensitivity levels or resilient categories

The first and basic outcome of the project was the identification of different sensitivity levels in Gishwati area. Results pointed out the effective use of graded land management technologies based on the assessment of above discussed factors (slope, soil type, soil depth, and rainfall). Biological measures such as live-fences have been used to compartmentalize into blocks (**Figure 7**).

Twenty (20) land sensitivity level/resilient categories were identified referring to land use units and considered for the specific land and water management technologies. As shown in the **Table 1**, land units 1 and 2 at 603.8 ha (9.5% of the total area) were used for minor agriculture intervention using graded soil bunds combined with grass strips. These land units are characterized by slope class of

Figure 7.
Land management blocks grouping identified land units and boundaries of the different levels of administration. Source: GWLM project.

Soil depth	Land units (ha) by slope classes, soil depths and soil types					Total
	0–6%	6–16%	16–40%	40–60%	>60%	
Rock	0.36 (16)	1.53 (17)	12.42 (18)	21.06 (19)	3.51 (20)	38.88
0 - 50 cm	45.36 (7)	16.74 (8)	10.8 (11)	9.72 (12)	0.54 (15)	83.16
50 - 100 cm	256.77 (2)	144.45 (4)	278.46 (6)	143.37 (10)	34.83 (14)	857.88
100 - 200 cm	347.04 (1)	727.83 (3)	985.75 (5)	1316.43 (9)	240.48 (13)	5617.53
Grand Total	649.53	890.55	3287.43	1490.58	279.36	6597.45

Table 1.
Land units of different management and land uses. Source: GWLM project.

0–6% and soil depth of 0.5 to greater 1 m deep and are more productive for annual cropping with relatively less expensive land management measures. Land units 3 and 4 on slope range of 6–16% and soil depth of 0.5 to 1 m deep or more were treated with graded bench terraces integrated with agroforestry species. The embankments were protected by Kikuyu grasses. These 4 land units embraced crop farming but also some settlement places.

Land unit 5 was allocated to rangeland development using pasture grass (Kikuyu grass, *Phalaris aquatica*, etc), and forage legumes to feed the livestock. This unit was located on slope class of 16–40% and slope depth greater than 100 m but are underlain by rock surface to cause landslide problem when tree planting or continued cultivation is practiced.

Land units of 6–20 were allocated for natural forest regenerations as they are strongly constrained either by absence of soil depth or excessive slope gradient (greater than 60%) and fragile soil. Land Unit 6 was constrained by the combined effect of the rolling topography (16–40%) and the shallow soil depth (50–100 cm). Land units 13–15 were in slope range exceeding 60% with more than 1 deep soil to cause landslide if no natural forest regeneration is applied. Land units 9 and 10

located at slope classe of 40–60% and majorly soil depth greater than 1 m would be prone to landslide. The assignment of land units 7 and 8 were linked to shallow depth (0–50%) while the land units 16–20 were allocated to this land use because of exposed rock. Natural forest regeneration and restoration covered about 2970 ha in these land units. The implemented landscape restoration interventions were accompanied by drainage system of water ways, cut-off drains, agroforestry systems and live fences (rangeland).

Finally, three blocks were formed to group land units with similar land use. Land units 1–4 suited for crop farming while land unit 5 was assigned to rangeland development. Land units from 6–20 matched for natural forest regeneration. With use of GIS tools, concrete pillars were installed demarcating different land management blocks (Cropland, Pastureland and Forestland). However, land use category that occurs in less than 8 ha was not considered to stand as a block by its own but it was annexed to adjacent land unit for ease of management and practicality of implementation point of view.

According to this harmonized block formation, the lands recommended to be put under natural forest regeneration covered about 45% whereas lands for range development and cultivation covered 23.3 and 31.6% respectively. This land use planning helped to not only guide the implementation of appropriate husbandry technologies but also for better allocation and management of resources. As discussed above, farmers participated in the identification at the extent they got informed about the specificity of interventions in their farms and cross-boundary conditions in the context of land consolidation (**Figure 8**).

3.3.2.2 Cropland blocks

Croplands were either subjected to graded terraces connected to cut-off-drains and water ways or minor agriculture intervention with graded soil bunds for about 2087 ha. Among others, coverage area of 1654 ha has been terraced and protected against erosion and floods as it is illustrated in the **Figure 9**. Interventions also included biological measures such as grasses, trees and herbaceous legumes.

Pyrethrum growing activities have successfully been established in Gishwati area under rotation system with Irish potatoes. It contributed to the increase of the national area for pyrethrum cash crop. To this effect, 102 hectares have been planted with pyrethrum in Gishwati which served as seedlings to the areas outside

Figure 8.
Land demarcation and installation of the benchmarks for land consolidation purpose. Source: GWLM project.

Gishwati. At side, nurseries were established at 30 ha for supplying good quality of pyrethrum seedlings.

3.3.2.3 Pasture/rangeland blocks

Degraded lands have been converted to prescribed pasture/rangeland blocks for an area of 1540 ha by planting kikuyu grass (**Figure 10**). This has been supplemented with silvo-pastoral activities.

3.3.2.4 Forestland blocks

Land allocated for natural forest regeneration within forestland blocks received both exotic and indigenous tree species at 2970 ha. Tree planting has been sustained with constant monitoring to protect against grazing and prematured harvesting (**Figure 11**).

3.3.2.5 Complementary engineering works for Gishwati watershed protection

Additional engineering works were constructed to deal with the flooding and poor drainage problems. They comprised the construction of Kinamba Bridge

Figure 9.
Landscape management using bench terraces. Source: GWLM project.

Figure 10.
Degraded land with and without rangeland development. Source: GWLM project.

Figure 11.
Degraded lands restored with tree planting activities for forest regeneration. Source: GWLM project.

Figure 12.
Construction of bridge and river drainage canal. Source: GWLM project.

along with strengthening roadside channels, retaining walls, filling and compaction of main road with gravel soil (**Figure 12**). In addition, drainage rehabilitation of Mizingo River was reinforced with stone masonry to protect flooding in the lowland.

4. Land husbandry interventions within an integrated watershed management approach

4.1 Description of the study areas

Land husbandry interventions that are suitable for hilly landscape were extensively introduced in the country since 2010 to control erosion and run-off. This strategic action has been initiated by the Land Husbandry Water Harvesting and Hillside irrigation (LWH)¹ project under the MINAGRI to

¹ Project funded by the Government of Rwanda and multi-donor organizations such as USAID, the World Bank, the GAFSP, and the Canadian International Development Agency.

boost the land productivity. The purpose was to introduce a wide range of innovations for improving agricultural practices, sustaining land management conditions and combating food insecurity by increasing rural community's livelihoods income.

As precedently discussed, the LWH project lies its focus on modernizing agricultural farming activities in hilly landscapes subjected to erosion, fertility depletion, and acidity problem. The Nyanza and Karongi sites have been selected for solving such problems in rural farming system. Nyanza 23 site is located at latitude of 2.365618°S and longitude of 29.692154°E while Karongi 12–13 sites are located at latitude of 2.0530°S and longitude of 29.468052°E, and latitude of 2.043841°S and longitude of 29.492853°E, respectively.

4.1.1 Nyanza 23 characterization

Nyanza 23 site is located in the Nyanza District of Southern Province. The site covers a good portion of Rwabicuma, Nyagisozi and Cyabakamyi and small part of Busasamana sectors of Nyanza District and Rwaniro sector of Huye District. It covers 5,659 ha as illustrated in the **Figure 13**. It comprises an irrigation dam which is supplied by Gisuma and Gasenyi tributaries of Kagondo stream and irrigates the downward part.

Climatic data from the Rwanda Meteorological Agency (RMA) in Nyanza 23 show the mean annual rainfall of 1,177 mm per year with the driest and wettest months of July and April, 7 and 190 mm respectively. Rainy seasons last from March to June and October to December, alternating with dry seasons. Although Nyanza district generally exhibits moist rainfall conditions but on-site rainfall data showed deficit of water reducing the expected optimal crop yield. Mean temperature is excellent for plant growth but the evapotranspiration values indicated the need for additional water supply (irrigation).

Figure 13.
Location of Nyanza 23 site illustrating implemented land husbandry infrastructures and administrative sectors.
Source: Author.

In terms of topography, Nyanza 23 catchment illustrates five distinct slope categories using the methodology of the Digital Elevation Model (DEM–30 m resolution), accessed from the United States Geological Survey (USGS) database (<http://earthexplorer.usgs.gov/>). Slope gradient ranges from 0–6%, 6–16%, 16–40%, 40–60%, and > 60% that respectively covered the percentage area of 10.7, 30.0, 52.7, 6.0 and 0.61 of the catchment. The range between 16–40% dominates the study area and about 2/3 of this area has shallow soils. About soil characteristics, the catchment is dominated by *Leptosols*, *Lixisols*, *Alisols*, *Gleysols*, *Cambisols*, and *Ferralsols* [19, 20]. The catchment is generally dominated by coarse textured soils up to more than 60% of the total area whereas the remaining part is also moderately fine textured soil.

4.1.2 Karongi characterization

Karongi 12 and 13 sites are located in Rubengera, Rugabano and Mukura sectors of Karongi district. They respectively cover 651.3 and 226.2 hectares (**Figure 14**). The two sites fall in the moist mid-highland agro-climatic zone, which of great potential for agriculture. The altitude varies from 1940 to 2160 m in the catchment while slope gradient ranges from 4 to 71% across the catchment [19, 22]. The dominance of hilly topographic features in the area coupled with soil susceptibility accelerates erosion, thus land-husbandry in this watershed was crucially essential.

According to Rwanda Meteo Agency (RMA), the annual rainfall of the area is around 1300 mm, also expressing two wet seasons from September to December and March to June, respectively. Mean annual temperature is more or less than 18 °C. Although the area does not express the rainfall drought with 10% higher than annual potential evapo-transpiration, shortage of rainy seasons and problems of dry spells drastically affect crop growth. Thus, it requires additional supply of water through irrigation.

The soils are deep with soil depth greater than 50 cm covering more than 90%. Soil types are *Humic Acrisols* and *Cambisols* on the hillside while in the valley

Figure 14. Location of Karongi 12–13 sites illustrating implemented land husbandry infrastructures and administrative sectors. Source: Author.

bottom, *Umbric Gleysols* are present. Soils are dominantly medium textured classes (clay loam and sandy clay loam) with potential to hold more water and have relatively good agricultural potential [19, 20].

4.2 Approach

The development of the two catchments followed a participatory integrated watershed management involving farmer's community's contribution and landscape-based interventions. Socio-economic aspect considered the responsiveness of beneficiaries, local authority, gender aspect and expecting site-specific economic rate of return. On the other side, technical aspect lies on severity erosion towards environmental impact of the catchment protection, and potentiality for hillside irrigation on developed land husbandry works (terraces).

Therefore, the catchment was divided into the command area locates in the downward part of the constructed dam and the catchment area which is the hillside surrounding the dam at upstream part (**Figure 15**). Hillside of both sites are protected against erosion risks with appropriate erosion control measures, especially bench terraces. Terraces in the hillside surrounding the downstream part (command area) are irrigated by water from the dam for increased more number of cultivation times compared to rainfed conditions. Terraced lands under irrigation will allow them to cultivate for three (3) agricultural seasons per year. Extensive community sensitization and participatory approaches ensured that farmers fully participated in their own transformation.

4.2.1 Implementation approach

The approach introduced comprehensive sustainable land husbandry technologies for soil erosion control and increasing soil fertility to boost the land productivity as well as develop water retention dams for hillside irrigation. It is considered as an active process of selecting and implementing systems of land use and management in such ways that there will be an increase in or at least no loss of land quality, soil health and land productivity. The implemented land husbandry interventions respected the participatory watershed-based approach using both erosion control

Figure 15.
Framework of landscape restoration under the LWH project. Source: LWH project.

measures and effective use of soil amendments (lime and compost). The sequencing of implementing activities were as follow: mobilization of staff and local authorities, mobilization of labor (mainly beneficiaries), training of labor on land husbandry technologies, and implementing land husbandry works.

Land husbandry technologies included grass strips, trash lines, earth/stone bunds, bench terraces, protected cut-off drains, water ways, gully plugs, embankment shaping, narrow-cut terraces, pitting, and conservation ridges/ditches as illustrated in the **Figure 16**. These are supplemented by the use of composting, mulching, liming and green manuring applications [14]. These land husbandry technologies have started on the upper side of the hill where the slope is under 6% where the first cut-off drain is located. Below this cut-off drain, other comprehensive land husbandry technologies are applied depending on land use, slope category and agro climatic zones.

Distribution of agro-climatic zones across the country influenced the types and forms of measures (**Table 2**). The wet agroclimatic zones have high rainfall amount of 1400 mm per, that increases its intensity as altitude increases and significantly causes flood, siltation and landslide. Therefore, the choice of land husbandry technologies follows the capacity to obstruct erosive force by an an integrated physical and biological measures, discourage water movement from attaining maximum velocity, improve conditions for surface drainage where infiltration causes landslide, and finally drain water from drained fields to safe storage such as valley dams, cascade ponds, rivers and large drainage canals. Graded bench terraces connected to cut-off-drains and waterways are developed towards reservoirs or river.

The moist agroclimatic zones with annual rainfall amount between 900 and 1400 mm per year require tailored land husbandry measures as leveled bench terraces and contour bunds interspaced by cut-off drains that convey excess of water to water-ways during rainy seasons and finally into a reservoir or water body. The agroclimatic dry zones (<900 mm per year) are characterized by low rainfall that needs land husbandry measures for retaining moisture. The leveled structures (terraces) with tie-ridges are recommended to help supplementary water supply.

Figure 16.
Demonstration of land husbandry implementation. Source: LWH project.

Slope categories (%)	Types of bench terraces	Soil depth in (cm)	Vertical interval (m)	Spacing (m)
16–40	Leveled Bench Terraces	75	1.5	9.4–3.7
20	Idem	75	1.5	7.5
39	Idem	75	1.5	3.8
40–60	Narrow cut- Bench Terraces	100	2	
45	Idem	100	2	4.44
59	Idem	100	2	3.4
Greater than 60	No Bench Terraces are implemented	—	—	—

Source: adapted from Bekele-Tesemma [14].

Table 2.
Specification of some technical guidance for construction of bench terraces.

4.2.2 Technical specifications of terrace establishment

Establishment of well-established terraces is meant to follow technical specifications linked to slope gradient, soil depth, and soil types [14]. They provide technical guidance about how terraces are technically constructed, maintained, and cultivated. The technical recommendations of bench terraces are based on an assumption of a soil depth of between 75 cm and 1 m and Vertical Interval (VI) of between 1.5–2 m and also the calculation counted the Vertical Interval (VI) for the space needed between two succeeding bench terraces. Computation may vary depending on whether bench terraces are being constructed using machines or hand-made (Mesfin [23]).

$$VI = \frac{S * WB}{100 - (S * U)}$$

Where VI: Vertical interval in m; S: Slope in percent (%); WB: Width of bench (flat strip) in m; U: Slope of riser (using value 1 for machine-built terraces, 0.75 for hand-made earth risers and 0.5 for rock risers).

In the **Table 2** shows the comprehensive guidelines for soil erosion control measures based on slope, soil type, depth and agro-climate [14].

4.3 Results of successful land husbandry interventions

4.3.1 Technical achievements

Successful results covered more than 19,500 ha with comprehensive land husbandry technologies across the country out of which over 3,400 ha were located on marginal lands. The lands were made productive after land husbandry works. For this particular study cases, bench terraces were established at 2673 (gross area of 4284 ha) and 3212 ha (gross area of 4800 ha) of lands for Karongi 12–13 and Nyanza 23, respectively (**Figures 13** and **14**). Technologies effectively reduced erosion for about 98% of the total soil losses. Other land uses such as forest, settlements, water reservoirs and papyrus were also rehabilitated on about 901 ha.

Besides the use of land husbandry technologies, the sites were restored in terms of soil fertility replenishment through the use of lime (5 t ha⁻¹), compost/manure

(10 t ha⁻¹) and mineral fertilizer (DAP and Urea) inputs accompanied with irrigation in the command area for optimally increasing productivity. Farmers are growing food crops like beans, maize, cassava, sweet potato, sorghum, banana, vegetables (chili, tomato, eggplant, onion, sweet pepper) and various fruit species (watermelon, tree tomato, avocado, macadamia, etc). However, the productivity did not reach the expected optimal yield.

4.3.2 Social build-up of farmers exploiting developed lands

Participatory consideration was also a key in the successful of sustainable landscape interventions implemented in the degraded lands. At first, farmers have generated more income from labor works of establishing comprehensive land husbandry measures. Through this process, farmers in which 47% were female, earned income which helped to finance their livelihoods through financing facilities. In addition, Communities were grouped into self-help groups (10 persons) building into zones which lead to cooperative formation. Cooperatives were created and strengthened through various trainings to sustainable manage and valorize the established land husbandry works.

As farmers grow several crops, it was worth to built post-harvest handling facilities to reduce postharvest losses while strengthening crop value chains and marketing systems such as storages facilities, drying shelters, collection centers (for banana), horticulture collection centers including charcoal coolers, temporary drying facilities constructed during harvesting seasons, and other necessary equipments. Briefly, activities have not only included the technical aspects but also community sensitization to ensure that people fully participate in their own transformation. This wide range of capacity building initiatives were also supported agriculture and extension services (Districts ...).

5. Lesson learnt and discussion

5.1 Success stories for participatory landscape management in Gishwati area

Gishwati area was restored in a participatory landscape approach within planning and implementation processes at 6,600 ha. It comprises activities of land husbandry on agriculture land, reforestation, and rangeland rehabilitation. The approach also considered the relocation of people from high risk zones to other places and building capacities of farmers through farm-livestock cooperatives. Thus, this approach has successfully facilitated to establish a comprehensive landscape management to effectively address the frequent landslides and flooding and sustainably exploit the land to the profit of local farmers in the livelihoods and the country's economy in general.

The evidences demonstrated how land husbandry interventions within participatory landscape approach especially terraces are very efficient not only in technical aspects of controlling soil erosion and boosting productivity but also improving people's livelihoods. According to Rutebuka et al. [13, 24] in Rwanda, bench and progressive terraces effectively control erosion up to 90% of soil and nutrient losses, once they are well established, managed and regularly maintained by landowners (farmers). The study in Ethiopia highlands substantiated the impact of terracing which reduced loss of soil from 97 to 38 t ha⁻¹ yr⁻¹ during 1984 and 1988 in Minchet catchment [25].

The Government for the sake of promoting agriculture and natural resource management has effectively addressed the challenges linked to bio-physical (land

size, erosion, climate, and acidity), structural, and institutional contexts. The success stories resulted from planned land use, served in solving land related issues. High value indigenous tree species have been re-introduced in the area for the purposes of rehabilitating the ecosystem of Gishwati and developed lands have been effectively redistributed to beneficiaries. To sustain the established land husbandry works required a process of building capacity of people for increasing ownership and commitment of land beneficiaries. It comes into practice through HIMO approach through community sensitization, exploring social relations, monitoring of implemented works, and protecting grazing lands in restricted high risk zones. HIMO approach also created employment to more beneficiaries.

5.2 Success and challenges for establishing and managing terraced lands under LWH development

LWH project development also demonstrated how land husbandry technologies especially bench terraces are technically efficient in soil erosion control wherever they were well established, managed and maintained. Comparing before and after establishment of land husbandry technologies, the rate of soil erosion has been reduced from 50–100 t ha⁻¹ yr⁻¹ in 2011 to less than 50 t ha⁻¹ yr⁻¹ in 2014 as reported in the LWH project report in one of the project site of Rwamagana district (**Figure 17**). This is also confirmed by Rutebuka [8] in the study site of Rwamagana district developed by LWH project that bench terraces reduced soil loss from 23.5 to 1.7 t ha⁻¹ yr⁻¹ in the catchment landscape with slope gradient varying between 0–60%. In Ethiopia highland, terracing techniques controlled soil erosion by 39.1% in the period of four years (1984–1988) [25].

The erosion control is not an end itself, but cropland has to provide expected ecosystem benefits, of which the increase in crop productivity is a paramount. Development of land by terraces increased production of crops compared to what was before. Implementation of integrated land husbandry technogies changed the livelihood conditions of the poorest areas through modernizing agricultural

Figure 17.
Change in soil loss before and after development of land husbandry technologies at Rwamagana 34 site under LWH project. Source: LWH project.

techniques and increasing income levels. Hundreds of thousands of poor rural farmers in the project intervention areas have been supported to break out of poverty and obtain food security. HIMO approach within an integrated participatory watershed management contributed to the creation of jobs and reinforcement of farmer's capacity in during implementation of land husbandry technologies. HIMO provides benefits of promoting employment, organizing farmers into community groups, using local resources such as supplying of organic materials, increasing knowledge and skills of local farmers and offering people access to income and financial schemes (Banks, saving schemes). However, farmers were unable to reach the optimal production potential, as a result many rural farmers barely produced enough to feed their families.

Concerning the study cases of Nyanza 23 and Karongi-12 & 13, it was expected to continue increasing agricultural productivity from this comprehensive land husbandry technologies. Unfortunately, some developed terraces in the case studies have been affected by low productivity of crops, resulting from both under-exploitation and abandonment problems of terraced lands [26]. Productivity problems could originate from the way terraces have been constructed on very acidic and inherently unfertile soils with inadequate supply of organic manure, fertilizers, lime and other land related problems [24, 27, 28].

5.3 Lesson learnt from Rwanda experiences in land husbandry

The same issue was also observed on terrace construction through collective actions such as VUP (Vision 2020 Umurenge Program) or other service providers from the District initiatives. In this case, low productivity is not only related to low productivity but also the establishment approach. Concerns are when the service providers might be driven by the completion rate of the contract signed by compromising technical guidelines like saving the top and nutrient soils during terrace construction, slope and soil types as well as not adopting a participatory integrated watershed management approach.

Another aspect hindering the success of terrace development relies on social-economic context. Farmers might be reluctant in adopting land husbandry technologies like terraces if they are not getting expected optimal yield in the first years because it requires at least four years for restoring soil fertility. The low understanding may result in low efficiency of terrace exploitation [29]. These factors relate on economical and institutional aspects along the implementation of bench terraces that are likely to constrain future use and maintenance of these structures [30]. Higher costs of investment and maintenance compared to the farmer's capacity hindered farmers to exploit these terraces.

Recent study identified problems affecting the poor performance of developed lands due to both technical and socio-economic aspects [31]. The findings proposed possible and best options to ensure that the lands are being optimally utilized for improving crop productivity. It includes improvement of soil fertility with supply of lime and organic amendments, agronomic practices and intensifying agroforestry systems for under-exploited or abandoned terraced lands. At least 2.5 t ha^{-1} of lime should be applied for soil acidity with pH less than 5.5 while 10 t ha^{-1} of organic manure of good quality has to be applied at every cropping season. Apart being well established, socio-economic challenges have to be well addressed by organizing or strengthening cooperatives of farmers and provide financial and technical supports that could help to alleviate identified financial barriers.

All these factors may result in unstable terraces that could accelerate the accumulated runoff volumes, from the destruction of risers and more eroded materials [24]. At some extent, these abandoned terraces can cause landsliding, mass

movements and gullies [32–34]. Thus, it is required to enforce the updated technical guidelines and standards for well-established terraces within an integrated and participatory landscape approach.

6. Conclusion

This chapter described different erosion control approaches that have been adopted in Rwanda, focusing on two selected case studies such as Gishwati area and LWH project sites (Karongi and Nyanza). It pinpoints the success stories in land husbandry interventions that can be scaled up to other regions with similar landscape properties. Challenges observed can also serve as lessons learnt in future interventions within or outside of Rwanda.

Participatory landscape approach promoted in Gishwati area was a success story in protecting degraded lands and generating ecosystem benefits. The more integrated natural resources management, and participatory planning helped for addressing the frequent landslides and flooding while sustainably exploit the land to the profit of local farmers in the livelihoods and the country's economy in general. This approach comprises development of agriculture land, reforestation, and rangeland rehabilitation, relocation of people from high risk zones and building capacities of farmers through farm-livestock farmers's organization.

On the other hand, the LWH projects provided strong evidences how land husbandry technologies (terraces) efficiently reduced erosion risks and improved farmers' livelihoods through crop productivity increase. However, it also highlighted the challenges observed in the adoption of integrated watershed management which did not tackle some technical and socio-economic aspects. Technical problems could result from inappropriate establishment of terraces without incorporating recommended technical guidelines related to soil types, depth and slope. These resulted into terrace destruction leading to mass movements, gullies and siltation in the valleys. Socio-economic challenges importantly cause farmers for abandoning or under-exploiting terraced lands. Terraces on very acidic and inherently unfertile soils require an intensive supply of organic and lime amendments together with use improved agronomic practices and agroforestry systems.

Finally, this chapter recommends the land husbandry policy strategies to successfully adopt the participatory landscape management for optimizing land's productivity in a sustainable manner. This involves the participation of farmers' communities from planning up to the implementation processes as well as valorization of terraced lands. HIMO approach is also suggested in the development of rural communities. Farmers should be grouped in rural communities (cooperatives) to increase their financial and technical skills.

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