



# The State of Soil Erosion Control in Rwanda

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## Acknowledgements

The State of Soil Erosion Control in Rwanda is the result of collaborative efforts between the Government of Rwanda through Rwanda Water Resources Board (RWB) and the International Union for Conservation of Nature (IUCN) as part of the Embedding Integrated Water Resources Management in Rwanda project, funded by the Embassy of Kingdom of the Netherlands in Rwanda. RWB and IUCN warmly thank all partners, institutions, individuals and other stakeholders for their invaluable expert inputs and contributions.

## 1. Background to National Erosion Control Mapping

Soil erosion is the most serious environmental problem in many catchments areas in Rwanda. The main factors affecting the amount of soil eroded include land use and vegetation cover, topography, soil and climate. In order to identify area of *potential* soil erosion risks and to develop adequate erosion prevention measures for Rwanda, a National erosion risk map was generated and validated in July 2018 based on a methodology known as “Catchment Restoration Opportunity Mapping (CROM)” - a spatial model developed by the government through the then Water for growth Rwanda (W4GR) under the former Rwanda Water and Forestry Authority (RWFA). The CROM model identified six erosion risk classes, namely: (1) No risk, (2) Low risk, (3) Moderate risk, (4) high risk zones, (5) very high risk and (6) the extremely high risk zones of erosion.

The erosion risk map shows only the potential soil erosion risk, but fails to show areas already protected against erosion or erosive features proofing the risk. This information gap makes it hard for the government to track the progress made to fight against erosion. Moreover, the plan for the future interventions becomes difficult because the erosion risk map shows only the potential risks while districts need to know where exactly the problem lies and is the appropriate measures to combat soil loss taking into account different land uses. Hence, to make the soil erosion risk map more informative and useful – for multi-scale planning and the decision making process for sustainable management of land and water resources - it was deemed essential to take the erosion risk map into a ground truthing process using most recent World View images available at National Institute of Statistics of Rwanda (NSIR). Using World View images with a resolution of 30 cm to 50 cm and applying visual image interpretation techniques and onscreen digitization erosion risk areas already affected by erosive features (gullies, landslides, rill erosion etc.) and erosion control measures in place were identified and mapped and where such measures are lacking appropriate measures were recommended. This study first covered the 20 districts in Rwanda specifically in the Western, Northern and Southern Province and then was extended to cover Eastern province and Kigali city districts.

In order to serve its purpose in sustainable land and water resources management, the erosion control mapping produces 5 thematic maps: 1) erosion risk distribution, 2) erosive features currently in place, 3) Land use and vegetation cover in high erosion risk areas, 4) existing erosion control techniques and 5) recommended erosion control practices in the view of unprotected land located at erosion risk. The data provided in this report will serve as benchmark for better monitoring of erosion control progress in Rwanda. the erosion control data showing the state of erosion control in Rwanda are also useful inputs in the implementation of catchment management plans and in the village action plans both in support of Integrated water resource management and forest landscape restoration agenda of Rwanda.

## 2. Erosion risk and existence of erosive features in risk areas

The results of the erosion control mapping shows that of the 30 districts of Rwanda, land under high erosion risk is about 1,080,168 hectares (45% of the total provinces land which is estimated to 2, 385, 830 hectares) of which 71 941 hectares (7% of the total risk areas) are at extremely high risk, 190, 433 hectares are at very high risk (18% of the total land at erosion risk), 300,805 hectares are at high risk (28% of the total risk identified), and 516,999 hectares (48% of the total land at risk) are at moderate risk. Ngororero District has the highest risk with a total of 58,003 hectares i.e. 85% of its land at high erosion risk. Muhanga district is ranked the second-highest in erosion risk with 53, 352 hectares under risk (82% of the district land) while Rutsiro district comes third with 48,143 hectares prone to erosion estimated at 73% of the district land. Other districts such as Karongi, Gakenke, Huye, Nyaruguru, Rulindo and Nyamagabe districts needs considerable attention as the risk accounts for more than 60% of the district land.

The observed erosive features in risk areas have shown that about 70,433 hectares (17% of the country land at risk) are affected by Gullies (39% of the affected land), severe gullies on 13,584 hectares (8% of the land affected land), landslides on 2,823 hectares (2% of the affected land) and rill erosion (93,831 hectares, i.e. 52%



of the affected land). Within the catchment, the upper Nyabarongo is the worst affected with 45,961 hectares affected of which 28,123 hectares are affected by rill erosion, 14,337 hectares are affected by gullies, 2,353 hectares are affected by severe gullies, while 1,148 hectares are affected by landslides. Kivu catchment area follows with 34,050 hectares affected of which 15,085 hectares are affected by rill erosion, 16,033 hectares are affected by gullies, 2,426 hectares are affected by severe gullies and 506 hectares affected by landslides.

### **3. Land Use and Vegetation Cover (LUVC) in area at erosion risk**

It is shown that land in the high-risk areas is mostly used for agriculture with seasonal crops accounting for 61% of the high-risk areas identified. Seasonal agriculture exposes soil to splash erosion and further detachment as land is not permanently covered. In fact, the crop management and cover factor (C) is very high for seasonal crops with conventional (regular) tillage. Forests with high canopy density occupy only 188,904 hectares (17% of the risky areas) while seasonal crops occupy 656,304 hectares (61%) and built-up areas occupy 89,595 (8% of the land at risk). Others like banana, coffee, mining and quarry sites, and tea cover less than 2% each. This means that land will continue to be eroded if serious measures are not taken in agricultural lands. Mining areas in high-risk zones account for 0.3%. Built-up area, although relatively small (8%), accelerates water velocity, runoff, and flow accumulation which creates severe gullies downstream. In such areas, storm-water management facilities, as well as the rainwater harvesting infrastructure, should be established to collect storm water from houses in agglomerated zones, while best practices in mining are also reinforced to stop dumping soil sediments from mining in rivers and streams as they fill the river beds or streambeds which in turn expose the river bank to erosion and flooding.

### **4. Efforts made in controlling erosion in Rwanda**

In Rwanda, it was observed that the erosion control techniques i.e. proportion of land at erosion risk which are today protected against erosion for each district is very low. In fact, of 1,080,168 hectares of land at risk in all provinces, only 282,352 hectares are protected against erosion (26% of the country land at risk) of which 28,870 hectares are protected by contour bank terraces (commonly known as progressive terraces covering (10% of the land protected) while forests protect about 190,011 hectares at risk (67 % of land protected). There are other practices like bench terraces (42,379 ha: 15%), hedgerows and shrubs (318 hectares), etc. About 797,816 hectares are not protected yet which is about 74 % of the total country land at risk.

### **5. Recommended erosion control practices**

The recommended erosion control practices are required in unprotected areas or where the existing erosion control techniques are judged inadequate with regard to the type of risks found and existing land use. The contour bank terraces are recommended in high-risk agricultural lands while ditches in the forested area. Bench terraces are recommended in areas at high to extremely high risk where there has been started the bench terracing but which did not complete the entire area which is suitable for that recommendation. Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses can cause severe gullies and destruction of bench terraces created. No-till agriculture (zero tillage) is recommended for perennial crops on the extremely high-risk area while Storm-water management facilities (SWMF) or water harvesting facilities is recommended in built-up areas. No-recommendation is provided where existing erosion control measures are adequate. Bamboos are recommended to close gullies or to protect rivers. Forests (Afforestation or reforestation) are recommended in extremely high-risk areas.

In the view of this concept, contour banks terraces are required on 510,096 hectares, which is about 47% of the total country land at risk, while afforestation and reforestation are required on 39,901 hectares (4% of the country land at risk), Agroforestry and Hedgerows are required on 101,232 hectares (9% of the total country land at risk). Bamboo planting is required on about 14,915 hectares of land affected by gullies and on riverside. No-tillage agriculture is required on 43,552 hectares for perennial crops established on land at very high risk.

Storm-water management facilities or water harvesting facilities are required in urbanized and settlement areas on about 89,679 hectares (8 % of the total land at risk).

## 6. Macroeconomic cost of soil erosion

More than 745 thousand hectares of agricultural land in Rwanda are potentially eroded every year. Using a reference year of 2021A, above 3 million tonnes crop produces are estimated to be lost seasonally (6 million tonnes annually), of which 22 thousand tonnes of maize and 15 thousand tonnes of beans are estimated to be lost every season due to severe erosion. The total economic loss in agricultural productivity due to severe erosion in Rwanda is around 37.9 billion Rwandan francs (RWf) every season. In term of GDP, In the first quarter of 2021, GDP at current market prices was estimated to be 2,579 billion RWf, agriculture sector contributed 27% which is about 690 billion RWf. The crop productivity loss therefore translates into a loss of about 37.9 billion RWf (5.5%) of the agricultural sector contribution to Rwanda's GDP in the first quarter 2021.

In terms of the value of the topsoil loss, considering the national average is about 25t/ha/year, and the total area at risk of about 1,080,168 ha, or 45%% of the country total, the discharge is estimated to an average of 27 million ton of top soil lost annually. Considering the market value of topsoil in Rwanda, a proxy for soil productive capability, which is between US\$34/tonne (RwF30,000) and US\$57/tonne (RwF50,000); the annual loss is therefore estimated to be RWf 810 billion on average, which is about one and half fold of what landscape restoration of the entire country would cost (RWf 513billion).

Another effect of soil erosion is on soil fertility depletion and incurred cost of fertilisers. Soil erosion removes the upper fertile part of soils that contains nutrients. considering that a ratio of soil carbon/nitrogen (C/N) ranges between 8 and 10 (an average ratio of 9) in arable land, one hectare (1ha) of agricultural field contains on average 2t C/ha/yr, and an amount of organic nitrogen is in the order of 0.2t N/ha/year. Considering 641,280 hectares affected by soil erosion and an average soil loss of 25t/ha/yr, it is estimated about 16Mt/yr of soil displaced carrying about 1,282,560t C and 128,256t N loss per year. In order to compensate soil nutrient loss and improve land productivity, urea and di-ammonium phosphate (DAP) is applied. In the substitution of Nitrogen loss with urea, with an average price of RWf 564,000/t; it would cost a total RWf 72 billion per year to Rwandan farmers. A consistent amount of phosphorous (P) is also displaced with sediments from the topsoil. The loss of phosphorus from land to downstream rivers is in the form of dissolved phosphorus and particulate phosphorus. P losses by leaching are usually less than 1 kg/ha/yr. However, losses up to 3 kg/ha/yr have been measured in drain flow. Considering a potential of 1,923 tonnes of phosphorous displaced from 641,280 hectares of agricultural land by soil erosion and the price of P fertiliser is about RWf 633,000/t as di-ammonium phosphate, its substitution would cost about RWf 1,2 billion per year to Rwandan farmers, excluding subsidy cost by the Government of Rwanda.

## 7. Cost and benefits of erosion control actions

The total cost of erosion control actions is estimated to 514 billion Rwandan francs of which 323 billion are for protection of agricultural land against soil erosion (about 60% of the total risk areas) using Bench terraces, contour bank terraces known as progressive terraces and agroforestry and hey plantation on contour banks. This would require about 8 years from 2022 to 2030 to complete the activity by investing about 42 billion RWf every year to protect agricultural land against excessive erosion using community approach. In doing so, we would cut the productivity losses and therefore raise additional agriculture contribution to about 5.5% GDP which are lost every season as a consequence of inaction demonstrated in section 6. However, because soil erosion itself is a symptom of poor land management, erosion control measures alone will remain insufficient to improve the management of land and water resources given the current agricultural land uses and related management. There should be a switch of emphasis to focus on the promotion of a high quality integrated soil management system rather than stand-alone erosion control measures in agricultural land. High quality soil

management could be achieved through an integrated conservation agriculture approach that provides profitable agricultural yields, while minimising environmental damage. Rainwater harvesting in settlements and storm-water infrastructure in urban areas also has the potential to address accelerated erosion and other problems resulting from rainfall run-off across the country.

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# 1. Introduction

## 1.1. Brief description of Rwanda and its vulnerability to soil erosion

Rwanda with an area of 26,338 km<sup>2</sup>, is located in Central Africa between latitudes 1°04' and 2°54' south and longitudes 28°53' and 30°53' east. Geomorphologically, the country occupies the eastern edge of the West African Rift. This one is brand, has this latitude, by Lake Kivu (1,474 m). The edge of the lake is dominating by a large escarpment which constitutes the flank west of the Congo-Nile ridge. This N-S direction ridge rises from 1000 to 1500 m above the level Lake. In the north and south, its altitude is towards 2,700 m with a saddle near Karongi around 2,000 m. Beyond this ridge, which separates the waters of Congo from those of the Nile, the general relief slopes towards the east, forming part of the Lake Victoria basin. The Akagera, that forms the border with Tanzania, lies slightly below 1000 m. The country is bordered to the northeast by the volcanic chain of Birunga whose highest point is located at the top of the Karisimbi volcano (4,507 m). Its location at altitude, due to tectonic upheavals (MOEYERSONS, 1991), goes hand in hand with a steepening of the rivers, especially in the west. Thereby, the region of the Congo-Nil ridge, the area of the central plateau (South Province and Kigali City (Nyarugenge district) and the Northern plateau (Gicumbi, Rulindo and Gakenke Districts). It essentially forms a country with steep slopes, sometimes reaching 45°. The summits of the hills and especially the bottoms of the valleys, which are often wide and marshy, form the only sub-horizontal elements of the country.

In the east of the country, the topography is much less rugged and the density of the hydrographic network decreases. Apart from a few ridges of quartzitic rocks, the differences in level between the summits and the bottoms of valleys there are a few tens of meters.

Apart from Tertiary volcanic rocks (basalts and trachytes) and recent (peralkaline basalts) of western and the north of the country, Rwanda is essentially made up of Precambrian terrain. The distribution of large lithologic units is reflected in the topography by differential erosion: quartzites, quartzitic rocks and rare sandstones dominate the landscape. The rocks "hard" form "mountains" with steep, straight slopes and covered with lithosols. They sometimes rise several hundred meters above the other interfluvies on rocks schistous, lined with a kaolisol that is sometimes quite clayey.

If the benches stand in bundles, they form a "Para-Appalachian" relief (JOST, 1989, MOEYERSONS, 1991) of ridges, separated by deep valleys on schist banks. Thus, the North and Eastern "plateaus". The interfluvies on shales are distinguished from "mountains" not only by their relatively low height, but also by their transverse profile in the form of a flattened dome with a steep flank. Finally, there are the granites. In the east of the country, they form cells whose general level often remains 100 m below the surrounding country. The Bugesera and the Umutara lowland are examples.

On the Congo-Nil ridge, granitic intrusions dominate often other rocks. Thanks to its altitude, Rwanda, close to the equator, enjoys a temperate climate. The climatic characteristics are determined by a topography which rises from east to west and by a supply of humid air masses of the Indian Ocean, forced to follow an ascending path. This causes a progressive cooling and more abundant precipitation towards the west. Thanks to its lower altitude and the "fohn" effect, the edge of the lake Kivu, hidden behind the ridge, enjoys warmer temperatures high and reduced rainfall. The system of rainfall has two rainy seasons. The most important extends from mid-February to the end of May. On average, 40% of precipitation falls in March-May. The short rainy season goes from mid-September to mid-December. The great dry season between the two is sometimes interrupted by the "rains of the cows" around August 15th. During the small dry season, the rains stop rarely entirely and one can consider the period of mid-September to mid-June as a hydrological year of Rwanda.



## 1.2. Problem statement

While soil erosion in Rwanda is a longstanding problem, it has become nowadays more severe. Erosion studies indicated extreme gravity of the soil erosion problem facing Rwanda, with 47 percent and 34 percent of the country experiencing soil erosion rates of between 50 and 100 tonnes per hectare per annum, respectively<sup>1</sup>. Soil erosion in many parts of Rwanda is severe with mean national rates of 250 Mg/ ha/yr<sup>2,3</sup> (i.e. 25t/ha/yr). aggregated at district level, Muhanga is the highest affected with 46t/ha/year, followed by Ngororero (45t/ha/year), and Gakenke with 33t/ha/year of soil loss. These districts are followed by Nyarugenge (32t/ha/year); Rutsiro (32t/ha/year) and Nyamagabe (29t/ha/year). The least eroded districts are Rusizi in Western province, Rwamagana, Gatsibo, and Nyagatare districts in Eastern Province with 3-8t/ha/year soil loss. A maximum discharge of 45,4million ton annually<sup>4</sup>.

Soil erosion processes involve more complex interactions between land use, climate and soil properties than previously assumed in historic interventions. Studies of the dynamics of soil erosion using sequential aerial photographs and Remote sensing techniques in combination with analyses of land use, settlement patterns, and climatic variables have indicated that alternating stages of increased and decreased land degradation can occur. Deforestation and vegetation clearance for inappropriate land use have resulted in significant localised soil erosion in Rwanda. But the extent of this effect was not mapped yet. In severely deforested areas, heavy rains compounded with the area's steep topography have washed great amounts of productive topsoil and caused serious flooding in many places in Rwanda. The lack of contour banks to retain water in agricultural land coupled with permanent bare soil, facilitated splash and accelerated runoff which in turn depletes soil fertility and its lowers productivity. Unsustainable settlements without storm-water management facilities and waterways in built-up have contributed to heavy runoff and flooding downstream in many places including Kigali city. It is important to recognise that unsustainable human activities and insufficient knowledge in land use and management are a significant factor amplifying people's vulnerabilities to disasters. Climate change as an emerging threat can exacerbate already existing environmental degradation and thus contribute to increased disaster vulnerability.

Soil erosion results in a significant decline in soil fertility, which is the primary cause of low agricultural productivity in Rwanda. Heavily degraded soils are incapable of supporting large plant biomass because of low or depleted soil nutrients and soil organic matter. Moreover, soil erosion has important downstream impacts. High sediment loads reduce the size of river channels and water-holding capacities of lakes, choke water harvesting and storage systems, and exacerbate flooding. In addition, erosion is a major cause of progressive eutrophication in many of the country's lakes, promoting the proliferation of algal blooms and water hyacinth, which reduce the amount of dissolved oxygen in the water, hence fish death often observed in Rwandan lakes.

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<sup>1</sup> United Nations Environment Programme (2011). Rwanda: From Post-Conflict to Environmentally Sustainable Development, ISBN: 978-92-807-3040-1, UNEP Nairobi, Kenya. 379p.

<sup>2</sup> Karamage, F., Zhang, C., Ndayisaba, F., Shao, H., Kayiranga, A., Fang, X., Nahayo, L., Nyesheja, E.M., Tian, G., 2016. Extent of cropland and related soil erosion risk in Rwanda. *Sustain.* 8, 1–19.  
<https://doi.org/10.3390/su8070609>

<sup>3</sup> Leigh Ann Winowiecki, Athanase Mukuralinda, Aida Bargués-Tobella, Providence Mujawamaria, Elisée Bahati Ntawuhiganayo, Alex Mugayi, Susan Chomba, Tor-Gunnar Vågen (2020). Assessing biogeochemical and human-induced drivers of soil organic carbon to inform restoration activities in Rwanda. *Soil Discussions*  
<https://doi.org/10.5194/soil-2020-67>

<sup>4</sup> Water for Growth. 2018. PES Scoping Study, Upper Nyabarongo catchment. Report number TR88, Water for Growth.

The objective of this study was to assess the state of erosion control in Rwanda, determine using high resolution satellite images of Rwanda, the areas at erosion risk, characterise these areas in terms of land uses and related management, possibly detect erosive features on the high resolution satellite images, propose recommendations to protect the area at risk while restoring the areas already affected by soil erosion. Existing soil erosion data generated using modelling approach to predict the risk of erosion given the terrain, land cover, soil and rainfall gives only indication of erosion risks, therefore this study translates the modelling theories into practical information necessary for the planning of erosion control in Rwanda.

Erosion risk map of Rwanda was produced in June 2018 using the Catchment Restoration Opportunity Mapping (CROM) – a GIS-based Decision Support tool. CROM model was developed based on the Universal Soil Loss Equation (USLE model) originally introduced by Wischmeier and Smith in 1978. The USLE model counts five input parameters derivable from Rainfall (R), Soils (K), Topography/ Relief (LS), Land cover and crop management (C), and conservation practices (P), each having a multiplier effect as follow:

$$A=R \times K \times LS \times C \times P$$

Where A is the average annual loss (T/Ha); R is the rainfall-runoff erosivity factor; K is the soil erodibility factor; LS is the slop length (L) and steepness (S) factor; C is the cover and management factor; P is the land management and conservation practices factor.

Combining these factors in the GIS model builder, CROM model identified six erosion risk classes: (1) No erosion risk, (2) Low erosion risk, (3) Moderate erosion risk, (4) high erosion risk, (5) very high erosion risk and (6) the extremely high erosion risk.

However, the 2018 CROM output did not capture where erosion controls measures have been put in place. This is because land use and land cover data were not generated from medium resolution satellite images, thus vegetation cover factor was not accurately used during CROM modelling process. Remotely sensed high-resolution data and high-quality World View images have increasingly become available for Rwanda through a memorandum of understanding between the Government of Rwanda and Digital Globe through the National Institute of Statistics of Rwanda (NSIR) and later extended to Rwanda Water board (RWB). Although visual image interpretation requires large manpower and is time demanding, (especially when dealing with small-scale land use systems) several studies have shown that it produces accurate data in mapping landscape interventions towards sustainable land management.

This report therefore, provides the state of soil erosion in Rwanda in terms of land under erosion risk, erosive features currently in high-risk areas, land use and vegetation cover in risk areas, presence or absence of erosion control measures, type and appropriateness, and recommended intervention where erosion control practices are currently missing.

### 1.3. Objective of the erosion analytics

The main objective was to develop a decision support report on soil erosion controls measures for Rwanda with insightful analytics, conclusions and recommendations at the district and provincial level. Using existing CROM data, and in reference with forest cover, national land-use master plan, Village land use and action plans and other relevant national data, establish, analyse and demonstrate the correlation between them before breaking down the analysis into soil erosion control analytics that informs an appropriate roadmap on soil erosion control for Rwanda (analytics segregated at the district level). Furthermore, using information and data on investment going on for erosion control in different parts of the

country, analyse the costs and benefits generated by the long-term investments in the erosion control for Rwanda and provide recommendations related to cost efficient erosion plans and budget.

## 2. Methodology

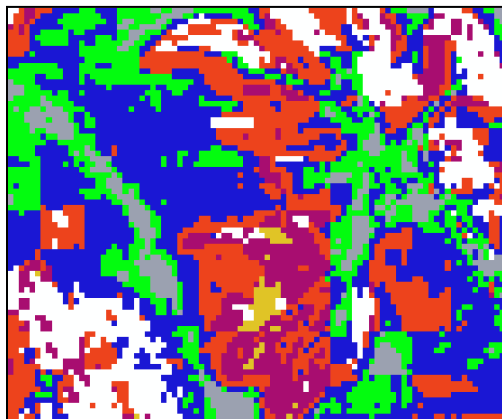
### 2.1 Erosion control mapping

This section describes steps, data and methodology used to map current state of erosion, control measures currently in place as well as recommendations where required in order to mitigate erosion risk and consequences.

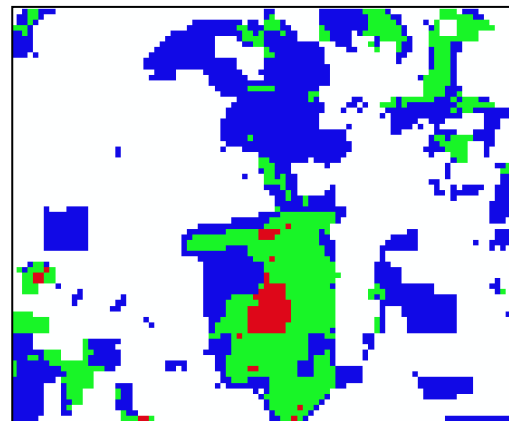
#### 2.1.1. Identification of areas of erosion risk from CROM dataset

The original CROM database has six classes: No risk, Low risk, Moderate risk, high risk zones, very high risk and the extremely high risk zones of erosion. The attention was paid to the four categories: moderate risk, high risk zones, very high risk zones and extremely high risk zones in the twenty Districts of Northern Province, Southern Province and Western Province.

After extracting the concerned erosion classes (from moderate to extremely high risk classes) from erosion risk CROM raster layer, the output was smoothed to remove single pixel with different class as the surrounding classes. In fact, the original dataset has been automatically generated using cartographic modelling techniques, and therefore there were a lot of zones characterized by a salt-and-pepper effect. Below is an example of original (a) and cleaned data (b).



**(a) Original CROM output data**



**(b) Cleaned CROM output using boundary clean tool of ArcGIS spatial analyst**

In order to produce a detailed map of erosion control practices easy to be implemented by different levels of planning (national, districts and sector levels), the erosion risk raster map (30 cm X 30cm) were cleaned up and filtered using 3x3 majority filter and boundary clean of Geoprocessing tool available in ArcGIS/ArcMap (ESRI software). During the smoothing processes, the original risk categories as modelled by CROM were kept. The smoothing processes just allowed the merge of the neighbouring cells (at least three neighbour pixels) in order to produce a map, after conversion to vector map that is easy to manipulate and produce statistics needed for implementation at different scales.

## 2.1.2. Creation of soil erosion geodatabase

This is a fundamental starting point step which consists of creating template geodatabase that will hold all polygons digitized and their respective attributes. In this empty geodatabase, fields' attributes along with their respective domains were created. Using domains helps ensure data integrity by limiting the choice of values for a particular field, i.e. that attributes are captured without any typos errors of hand-writing. The attributes fields created to contain the information described in the section. Using the vector map of erosion risk, a geodatabase were created to contain the (1) four risk categories identified by CROM-DSS model, (2) the erosions features currently in place observable on the World View satellite (WV) images, (3) existing land use/land cover 2019 generated using WV images, (4) erosion control practices currently in place and observable WV satellite images and (4) recommended erosion control interventions for each risk categories following the four inputs criteria briefly described in Table 1. The geodatabase has three important roles: 1) to standardize the erosion and land management practices mainly recommended for Rwanda in the database, 2) to minimize errors which could be produced in the database by ten of GIS technicians while entering information manually. 3) permitting erosion factor analysis and cross tabulation.

**Table 1. Major thematic fields created in the erosion control geodatabase**

Erosion risk class (identified by CROM and confirmed)	Erosive features in place (observed on the image)	Land Cover class (in moderate to extremely high risk areas)	Erosion control practices currently in risk areas	Recommended erosion control practices (choose one appropriate for each erosion category)
1. Moderate 2. High risk 3. Very high risk 4. Extremely high risk	1. Gullies 2. Landslide 3. Rill erosion 4. Severe gullies 5. None	1. Banana 2. Build-up area 3. Coffee 4. Degraded forest 5. Dense forest 6. Mining and Quarries 7. Pasture or prairie grass 8. Seasonal crops 9. Tea 10. Water body 11. None/bare soil	1. Bamboo plantation 2. Bench terraces 3. Contour bank terraces 4. Forest 5. Grassed waterways 6. Hedgerows trees or shrubs 7. Wooded Savannah /shrubland 8. None	1. Afforestation & Reforestation 2. Agroforestry & shrubs & hedgerows 3. Bamboo plantation & river bank protection & closing gullies 4. Bench terraces with grassed waterways 5. Forest ditches (Contour banks) 6. Savannah / shrub restoration 7. Sylvo-pastoralism 8. Contour bank terraces 9. Zero tillage (tea, coffee, banana) 10. Perennial crops 11. Rainwater harvesting facilities & storm water management facilities 12. None



The recommended erosion control practices are required in unprotected areas or where the existing erosion control techniques are inadequate with regard to the type of risks found and existing land use. The contour bank terraces are recommended in high risk agricultural lands and contour banks in the forested area without ditches. Bench terraces are recommended in areas at high to extremely high risk where there has been started the bench terracing but which did not complete the entire area which is suitable for that recommendation. Grassed waterways are recommended for existing terraces which was made without waterways or where waterways exist without grasses which could cause severe gullies and destruction of bench terraces already created. No-till agriculture (with perennial crops) is recommended in extremely high risk area while Storm water management facilities (SWMF) or rainwater harvesting facilities are recommended in built-up areas. No-recommendation is provided on areas with existing erosion control measures which are adequate in reference to the total land protected. Contour banks are recommended for existing forests without ditches. Bamboos are recommended to close gullies or for riverside buffers. Forests are recommended in extremely high risk areas where crops and settlements are discouraged. Table 2 shows the matrix of inputs scenarios for the formulation of the recommendations against soil erosion.

**Table 2. Multicriteria scenarios for recommended erosion control measures and management practices in risk erosion areas**

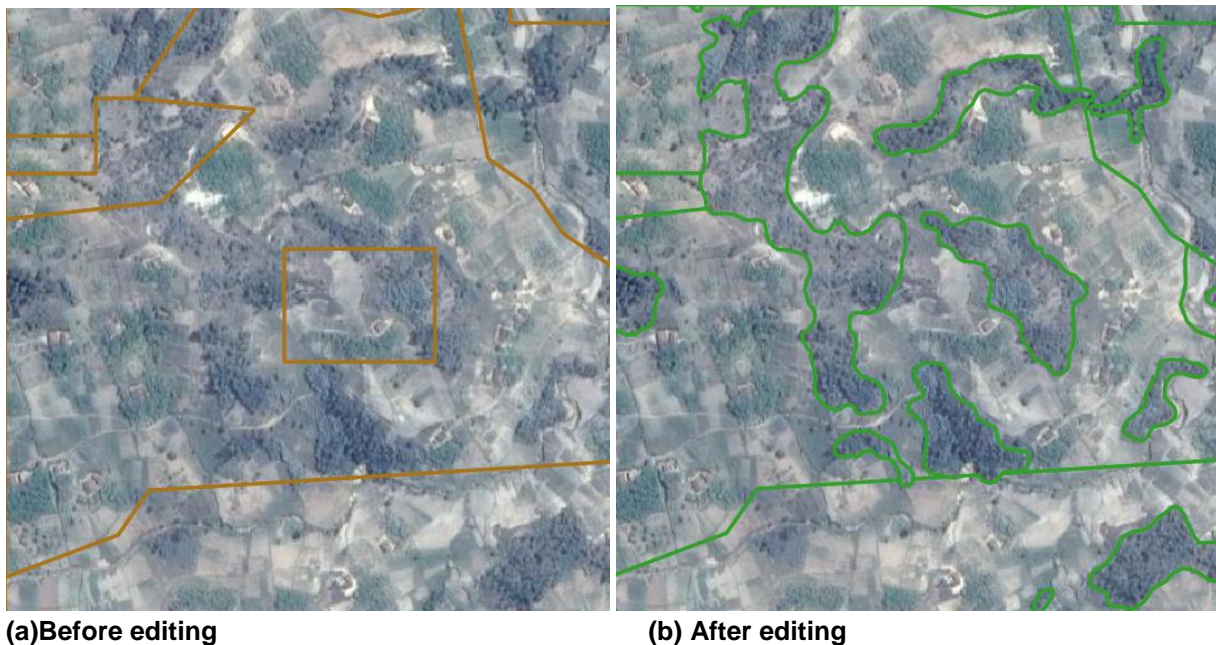
Recommended erosion control measures <u>IS</u>	<u>IFF</u>			
	CROM erosion risk class	Erosive features in place	Land Cover class	Erosion control practices currently in place
1. Afforestation and Reforestation	1,2,3,4	1,2,3,4,5	4, 6,11	4,8
2. Agroforestry & Hedgerows/shrubs	1,2,3,4	2,3,5	8,11	2,3,8
3. Bamboo plantation & river bank protection & closing gullies	1,2,3,4	1,2,4,5	8,11	8
4. Bench terraces with Grassed waterways	2,3	3,5	8,11	8
5. Ditches (along contour lines)	1,2,3,4	3,5	4,5	4
6. Contour bank terraces	1,2,3	3,5	8,11	8
7. Savannah / Shrub restoration	1,2,3,4	1,2,3,4	13	8
8. Silvo pastoralism	1,2,3,4	1,2,3,4	7	8
13. No till (zero tillage)/ Contour banks	3,4	5	1,3,9	8
9. Perennial crops	2,3,4	2,3,5	8	8
10. Rainwater harvesting facilities & Storm water management facilities	1,2,3,4	1,2,3,4,5	2	8
11. None	1,2,3,4	5	1,3,5,9,10	1,2,3,4,5,6,7

**None** is recommended where erosion control practices in place are very commendable and no need of extra protection measures.

### 2.1.3.Editing risk feature areas

This method consists of correcting polygons geometries, completing polygons and adding attributes in the polygons attributes table. Very high resolution World View images (30-50 pixel size) of recent years (2019-2020) were used as base map to check and using on-screen digitising techniques different erosion risk features were delineated, land use and vegetation cover were determined, erosion control techniques in place were assessed and appropriate erosion control practices recommended based on erosion risk category, existing land use, and erosive features in place.

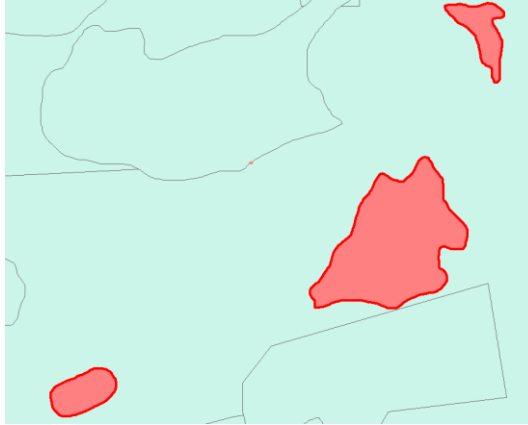
The 10 GIS technicians were organized in two team working in respectively day and night shift. Each computer had a connection to Digital Globe online images. Their tasks were to identify and interpreting the erosion feature types, the erosion control techniques in place, the land cover types and proposing adequate measures for mitigating the identified erosion risk. Technicians were also required to clean or edit polygons geometry if they find that the feature is not well demarcated. This consisted of either reshaping the polygon or completing it by adding a missing part of the identified erosion feature. Below is an illustration of the editing method showing the polygons shapes before (a) and after (b) the editing process.



#### 2.1.4. Data cleaning process and validation

In this step, we applied topology rules to clean and validate the digitized erosion control polygons using the following:

**Topology rules to identify polygons geometry errors:** gaps, overlap and minimum cluster tolerance were the main topology rules applied to clean and validate the polygons. The “**Must not have Gaps**” rule is a way to find to find possible omissions within a polygon or between adjacent polygons. The “**Must not overlap**” rule is applied to detect areas where two or more polygons are overlapping each other. The polygons can share edges or vertices. This rule checks where there is an area that belongs to two or more polygons and marks this area as an error. Below is an example of overlapping polygons.



The “**Must not have gap**” rule requires that there are no voids within a single polygon or between adjacent polygons. All polygons must form a continuous surface. An error will always exist on the perimeter of the surface. Applying this rules helped us to locate and identify polygons which overlap each other or small areas of gaps which must be filled.

**Cleaning topological errors and data validation:** The implementation of topological rules consisted of checking and fixing the detected areas which are not complying with the rules specified above. During validation, the technician decides between merging the overlapping area with only one polygon, creating new polygon, completing the polygons or either ignoring the error (in case of an error marked at the perimeter of isolated polygon). Each time a topological error check is applied to validate the final output.

### 2.1.5. Geoprocessing and cartographic process of soil erosion

After data cleaning, the resulting feature class is then geoprocessed using the following methods to produce disaggregated polygons:

- Disaggregation of the above geoprocessed data according to the administrative level of the country, down to the sector level for further cartographic layouts preparation.
  - Export the features attributes into Excel for further statistical analysis and production of tables and graphs to be included in the report.
- Production of following thematic maps per Province and per District: erosion risk categories, erosion feature types, Land cover types, Erosion control techniques and recommended practices for mitigating erosion risks.

## 2.2 Aggregating soil erosion control status within catchments

The erosion data were aggregated by major catchment of Rwanda to support the implementation of catchment plans.

## 2.3 Macroeconomic costs of soil erosion

Of 1,080,168 hectares of agricultural land, about 746,898 hectares (70%) are affected by soil erosion. Estimating cost of soil fertility loss, and productivity loss for commodity crops are key parameters that

translate severity of soil erosion into the national economy and therefore show the crucial needs for erosion control.

### 2.2.1. Quantifying the cost of erosion on the productivity loss of commodity crops

Crop productivity loss methodology estimates crop yields expressed as tonnes per hectare for commodity crops, predicts areas where severe erosion will occur, and estimates the likely loss in crop productivity. An economic value of crop productivity loss per year was derived by multiplying the loss in production by the average market price of the eleven commodity crops of Rwanda. The eleven crop commodities were reported by the National Institute of Statistics of Rwanda (NISR) and are very common in Rwanda. The crop productivity statistics, taken for the season A 2021 by the (NISR-SAS2021<sup>5</sup>). We used the following two figures: (a) hectares of cultivated area, harvested area (and harvested production) per commodity and yields as tonnes per hectare for each crop. The eleven common crops considered are maize, sorghum, wheat, cassava, sweet potato, irish potato, bananas, beans, vegetables (tomatoes), soybean and groundnuts. Rice is planted in wetland and benefits from erosion deposits (although can also be flooded and destroyed) but the upland crops are most affected by soil erosion and upland soils are depleted from soil nutrients by erosion. Vegetables are also affected a little bit because they are mainly planted in season C (June- July – August and mainly in marshland). The area covered by those eleven crops is about 94% of the country cultivated land (1,026,947 of 1,096,956 hectares for the season 2021A). The area affected by soil erosion is estimated to 746,898 hectares (73% of total cultivated land during the season 2021A).

The market value for each crop is the producer's price (farm gate price). The loss of nutrients and organic carbon due to soil erosion and the subsequent agricultural productivity is also (partially) compensated by the use of chemical fertilisers (Kuhlman et al., 2010). On the basis of relevant literature findings (Annex 1), this study assumes that a crop productivity loss of 8% occurs in agricultural fields that have been intensively cultivated for more than 30 years, where annual erosion rates are high ( $>10 \text{ t ha}^{-1} \text{ year}^{-1}$ ), or  $5 \text{ t ha}^{-1}$  seasonally. The literature review of 18 studies (Annex 1) takes into account the experimental results of crop productivity loss due to erosion, and it is well distributed in the world (United States, Canada, Europe, Spain, Africa, Indonesia, Rwanda etc.). While Rwanda's green landscapes do not generally exhibit the gullies and bare lands associated with severe land degradation resulting to soil erosion, soil fertility has been seriously depleted because of the insufficient use of amendments and fertilisers coupled with the limited ability to compensate productivity losses due to runoff and leaching of nutrients to sub-surface. In this study, any productivity loss in agricultural fields that have low erosion rates ( $< 10 \text{ t ha}^{-1} \text{ year}^{-1}$  or  $2.5 \text{ t ha}^{-1}$  per season) is not considered. In Africa context, a soil loss of  $10 \text{ t ha}^{-1}$  is considered a tolerable rate for agricultural productivity<sup>6</sup>. According to Montgomery (2007), the United States Department of Agriculture also considers soil loss rates of less than  $12 \text{ t ha}^{-1} \text{ year}^{-1}$  (equivalent to 1 mm of erosion per year, assuming an average bulk density of  $1,200 \text{ kg/m}^3$ ) to be tolerable for maintaining crop productivity.

With the abovementioned data, the rate of loss in land productivity for Rwanda is estimated as follows:

$$LPL = \frac{SEA}{TAA} \times 0.08 \quad \text{(equation 1)}$$

<sup>5</sup> National Institute of Statistics of Rwanda (2021). Seasonal Agricultural Survey: Season A 2021 Report

<sup>6</sup> Desta G., Tamene L., Abera W., Amede T, Whitbread A., 2021. Effects of land management practices and land cover types on soil loss and crop productivity in Ethiopia: A review. International Soil and Water Conservation Research. In press.

where LPL is the land productivity loss expressed as %, SEA is the area of severe erosion (ha), and TAA is the total agricultural areas (ha). This assumes that the productivity loss is equally distributed across all crop types within regions and that the variability between them is due to different percentages of severely eroded land and total agricultural area. This hypothesis is made due to a lack of georeferenced crop areas. Once the land productivity loss has been computed using equation 1, crop productivity loss per crop is calculated as:

$$CPL_i = LPL \times CA_i \times CP_i \quad \text{(equation 2)}$$

where CPL is the crop productivity loss per crop, expressed in tonnes, LPL is the land productivity loss estimated using Equation 1, CA is the crop area (ha), and CP is the crop yield (t/ha). The variables i represents the crop. Eleven common crops in Rwanda were considered.

Finally, the crop productivity loss is multiplied by the market price of each crop, to calculate the overall monetary loss. The results are aggregated per crop type.

## 3. Results of soil erosion control mapping

In the results section, we present in details the output of the applied methodology to map and geoprocess the erosion control thematic maps using very recent World View images of 2019. We discuss on the figures related to erosion risks, present erosion feature types, land use and vegetation cover for the land at erosion risk, erosion control practices already in place in risk areas, as well as recommended erosion control measures to mitigate erosion where identified erosion risk without erosion control measures currently in place.

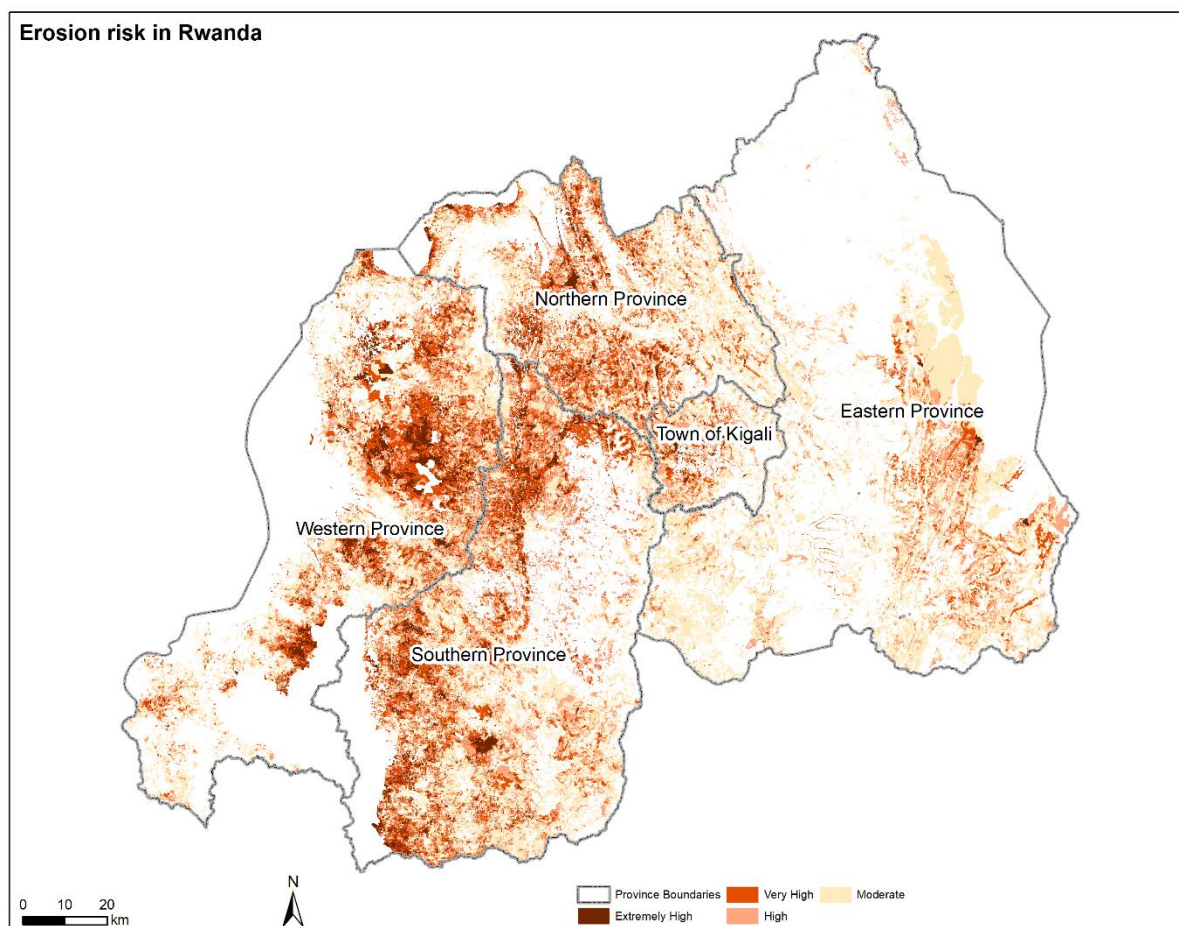
### 3.0 Erosion Control status at national level

Table 3 presents the situation of erosion risk in Rwanda. Land at risk of soil erosion is about 1,080,168 hectares (45% of the total country land). The results show that the Northern Province has the highest risk area with about 187,165 hectares (i.e. 59% of the Province land) followed by the Southern Province with 381,116 hectares (56% of the Province land) and the Western Province with 486,773 hectares i.e. 54% of its land under high risk of erosion. The Eastern Province is the least susceptible to erosion with 29% of the land at risk. The land at extremely high risk, very high risk and high risk is estimated at 7%, 18% and 28% of the total areas at risk respectively, while 48% is considered as areas at moderate risk. Figure 1 shows the spatial distribution of the erosion risk in Rwanda.

**Table 3: Erosion risk per province in Rwanda**

Erosion risk	Provinces /City of Kigali					Grand Total	% per total area at risk
	CITY OF KIGALI	EAST	NORTH	SOUTH	WEST		
Extremely High	1,812	1,593	12,358	26,786	29,392	71,941	7%
Very High	5,663	16,924	37,011	70,262	60,571	190,431	18%
High	12,797	55,016	54,269	106,498	72,223	300,802	28%
Moderate	18,908	187,634	83,527	127,571	99,355	516,995	48%
<b>Grand Total</b>	<b>39,179</b>	<b>261,166</b>	<b>187,165</b>	<b>331,116</b>	<b>261,542</b>	<b>1,080,168</b>	<b>100%</b>
<b>Province Land(Ha)</b>	<b>72,829</b>	<b>910,555</b>	<b>319,318</b>	<b>596,355</b>	<b>486,773</b>	<b>2,385,830</b>	
<b>% Erosion risk per province land</b>	<b>54%</b>	<b>29%</b>	<b>59%</b>	<b>56%</b>	<b>54%</b>	<b>45%</b>	



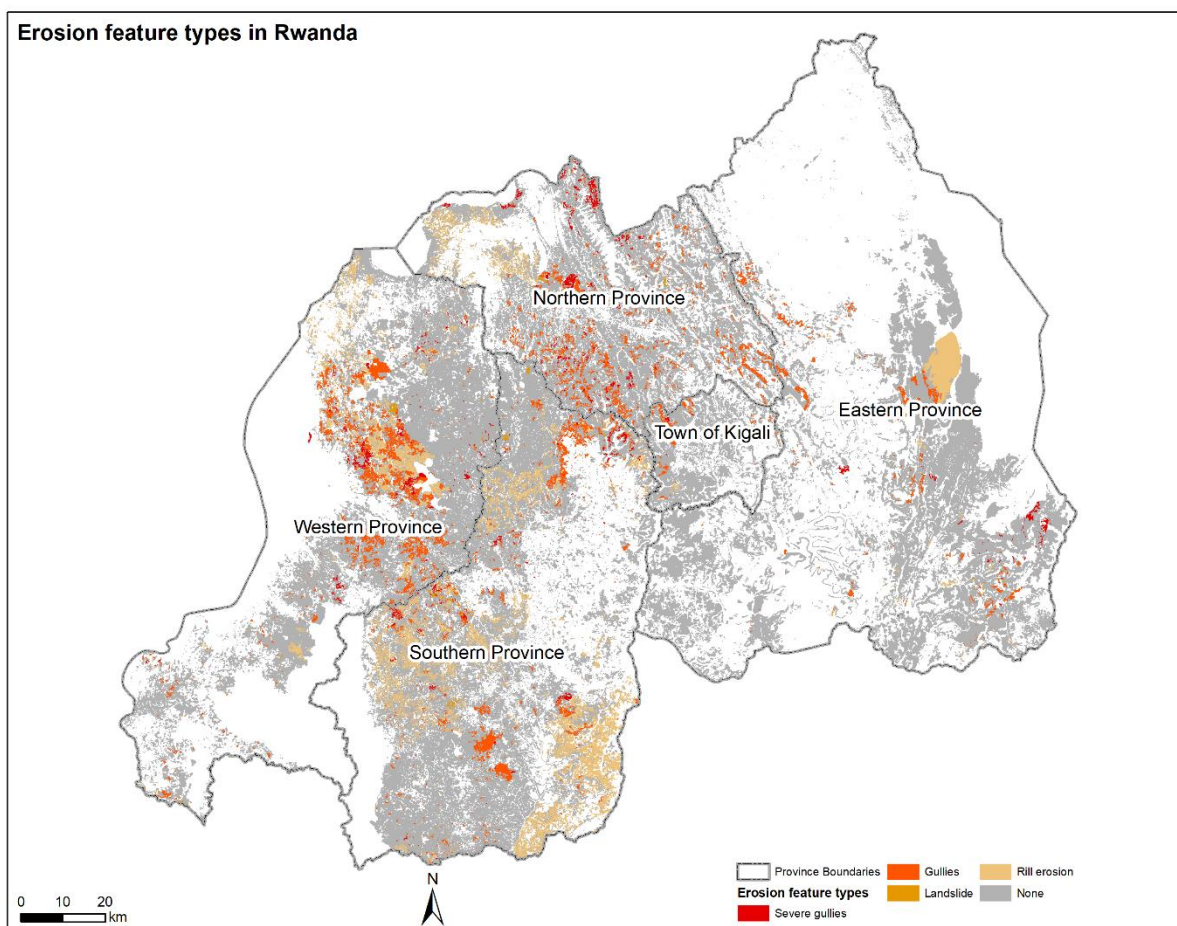


**Figure 1: Erosion risk in Rwanda**

Land at erosion risk already affected by erosive features is amounting to 180,670 hectares (about 17.8% of the total land at risk). Regarding the erosion feature types observed in Rwanda, majority of the total land at erosion risk is affected by rill erosion (52%) followed by gullies (39%). Table 4 and Figure 2 show the distribution of erosion feature types per province in Rwanda.

**Table 4: Land affected by erosive features per province and City of Kigali**

Erosive features	PROVINCES / KIGALI CITY					Grand Total (Ha)	% Feature per total features
	KIGALI CITY	EAST	NORTH	SOUTH	WEST		
Gullies	2,539	7,700	18,081	15,986	26,127	70,433	39%
Landslide	7	117	474	1,397	828	2,823	2%
Rill erosion	270	9,493	8,981	55,416	19,671	93,831	52%
Severe gullies	168	1,517	5,350	2,879	3,669	13,584	8%
<b>Total land affected</b>	<b>2,983</b>	<b>18,827</b>	<b>32,886</b>	<b>75,678</b>	<b>50,296</b>	<b>180,670</b>	<b>17.8%</b>
Not affected	36,196	242,339	154,279	255,438	211,246	899,498	83.2%
Grand Total	39,179	261,166	187,165	331,116	261,542	1,080,168	100%
<b>% features per land at risk</b>	<b>8%</b>	<b>7%</b>	<b>18%</b>	<b>23%</b>	<b>19%</b>	<b>17%</b>	



**Figure 2: Land affected by erosive features in Rwanda**

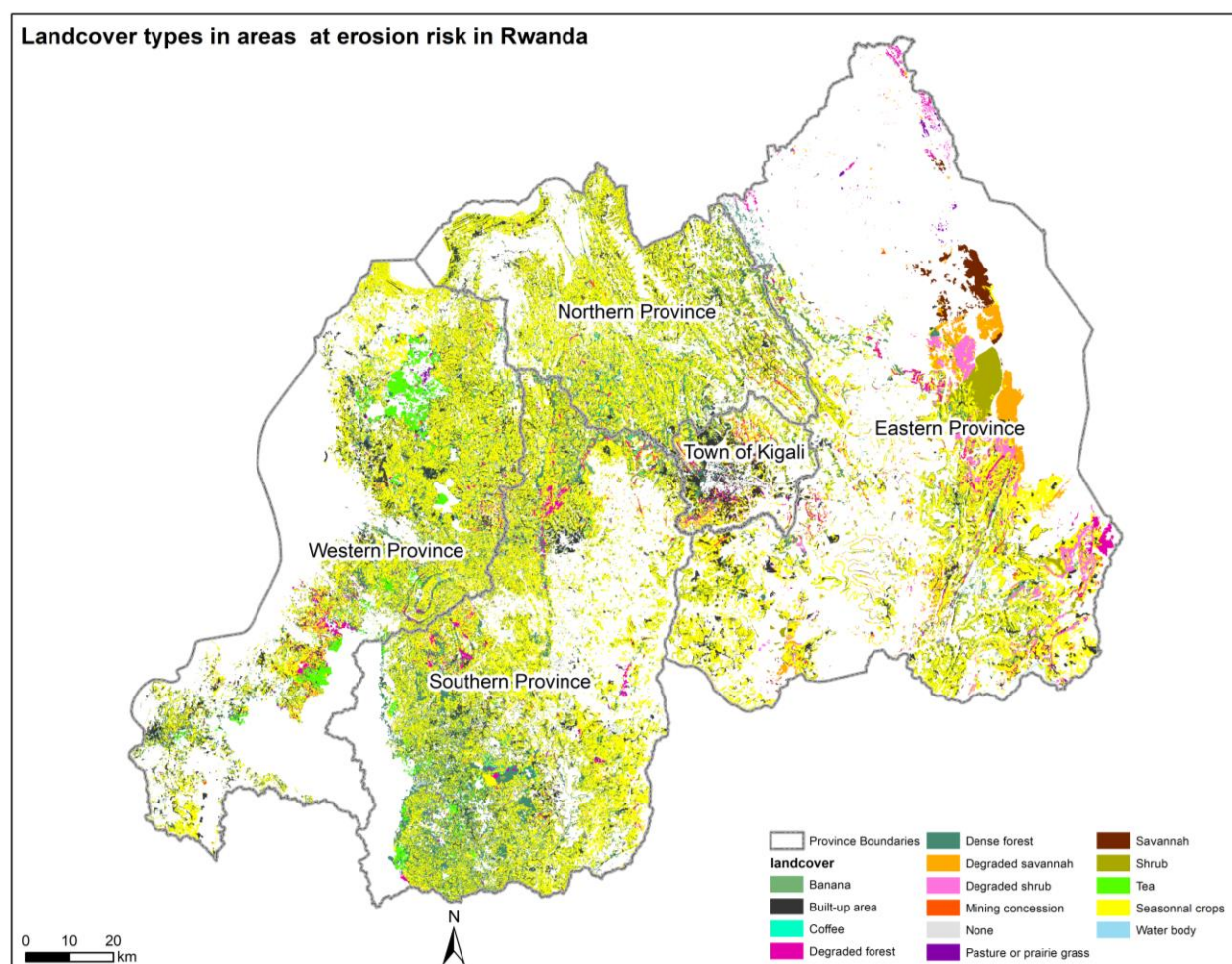
The land cover and land use types observed in the areas at erosion risk are presented in the Table 5 and Figure 3. The seasonal crops are predominant land use affected by soil erosion (61% of total land affected) followed by forests are covering an area of 262,092 hectares (22 % of the total area at risk) followed by the built-up areas on a total area of 8,959 hectares (8% of the total land at risk).

**Table 5: Land cover types in Rwanda**

Land cover types	PROVINCES / KIGALI CITY					Grand Total	%
	KIGALI CITY	EAST	NORTH	SOUTH	WEST		
Banana	931	6,397	2,240	7,582	4,796	<b>21,947</b>	<b>2%</b>
Built-up area	12,525	20,021	15,277	19,028	22,744	<b>89,595</b>	<b>8%</b>
Coffee	12	81	857	1,105	274	<b>2,330</b>	<b>0%</b>
Degraded forest	2,971	12,660	1,834	8,782	6,340	<b>32,587</b>	<b>3%</b>
Degraded savannah		13,954				<b>13,954</b>	<b>1%</b>
Degraded shrub	27	18,591			2	<b>18,620</b>	<b>2%</b>
Dense forest	5,377	20,129	35,242	84,802	43,355	<b>188,904</b>	<b>17%</b>
Mining and Quarries	380	1,327	304	372	340	<b>2,723</b>	<b>0%</b>



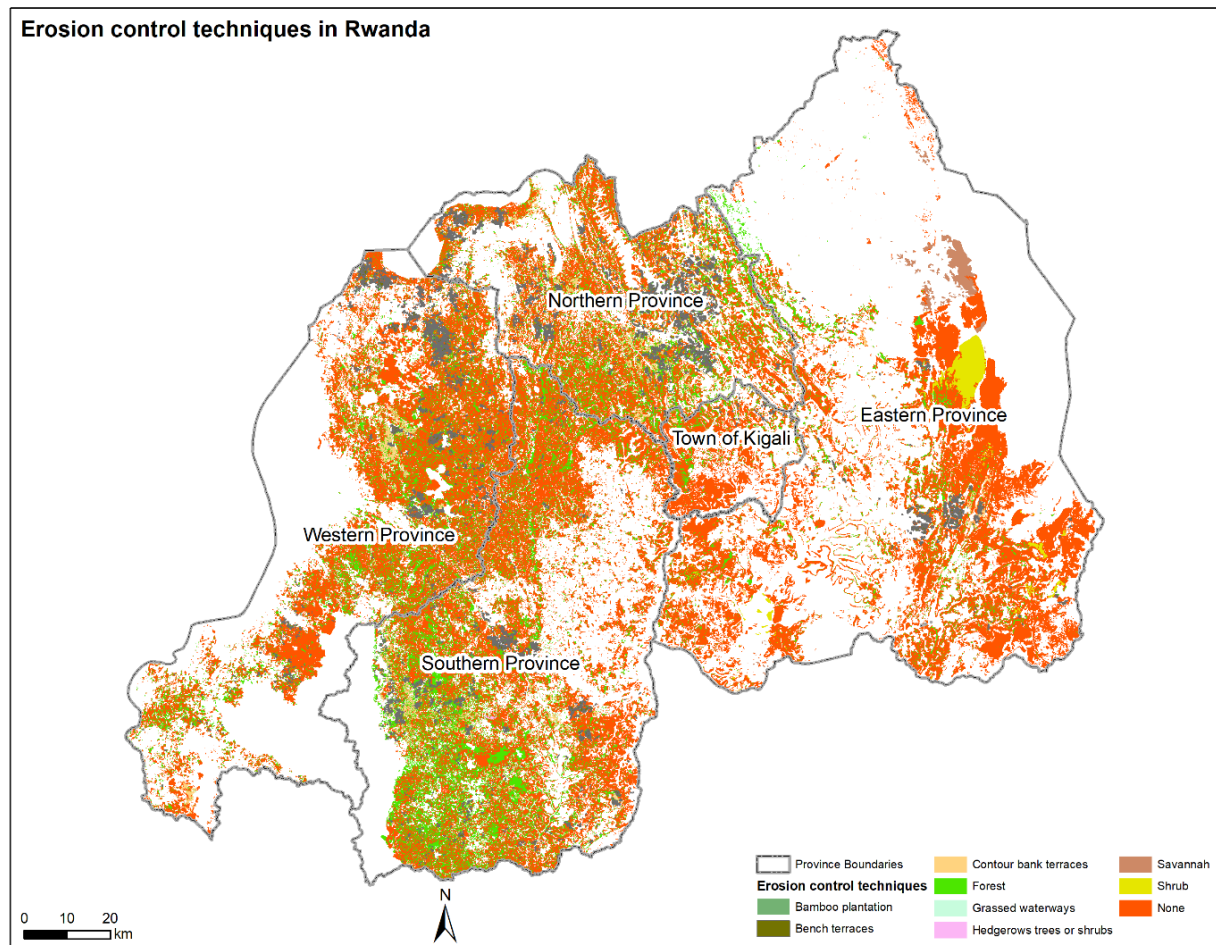
Land cover types	PROVINCES / KIGALI CITY					Grand Total	%
	KIGALI CITY	EAST	NORTH	SOUTH	WEST		
None	173	381	154	687	1,595	2,992	0%
Pasture or prairie grass	10	849	3	6	400	1,268	0%
Savannah		8,027				8,027	1%
Seasonal crops	16,635	145,426	130,237	202,472	161,533	656,304	61%
Shrub	3	12,723		3		12,730	1%
Tea			281	4,335	16,320	20,936	2%
Water body	135	598	734	1,942	3,844	7,253	1%
<b>Grand Total</b>	<b>39,179</b>	<b>261,166</b>	<b>187,165</b>	<b>331,116</b>	<b>261,542</b>	<b>1,080,168</b>	<b>100%</b>



**Figure 3: Land cover on land at erosion risk in Rwanda**

In the areas considered at erosion risk, there are already erosion control measures that have been put in place and that were observed on digital images. These erosion control measures are bamboo plantations, bench terraces, contour bank terraces, forest, grassed waterways, hedgerows trees or shrubs, and savannah. Forests cover an area of 190,011 hectares (67% of the total protected land) followed by bench terraces (15%) and contour bank terraces commonly known as progressive terraces. The Table 6 and Figure 4 show the summary and national distribution of these erosion control in places. As show by Table

6, countrywide, only 26% land at risk are fully protected (282,352ha) leaving 74% not protected (797,816ha). However, Northern province is most protected with 34% protected by forests (35,980ha) contour bank terraces (10,997ha) and bench terraces (15,777ha) followed by South province (31% of the land at risk in the south).



**Figure 4: Erosion control currently in place in Rwanda**

**Table 6: Erosion control currently in place per province**

Erosion control in place	PROVINCES / KIGALI CITY (Ha)					Grand Total	%
	KIGALI CITY	EAST	NORTH	SOUTH	WEST		
Bamboo plantation			7	5		12	0%
Bench terraces	350	3,663	15,777	9,376	13,213	42,379	15%
Contour bank terraces	340	2,325	10,997	9,237	5,971	28,870	10%
Forest	5,341	20,161	35,980	85,058	43,471	190,011	67%
Grassed waterways			14	86	6	106	0%
Hedgerows trees or shrubs	36		32	195	55	318	0%
Savannah		8,025				8,025	3%
Shrub	3	12,625		3		12,631	4%
<b>Total Erosion control (Ha)</b>	<b>6,070</b>	<b>46,798</b>	<b>62,808</b>	<b>103,960</b>	<b>62,716</b>	<b>282,352</b>	<b>26%</b>

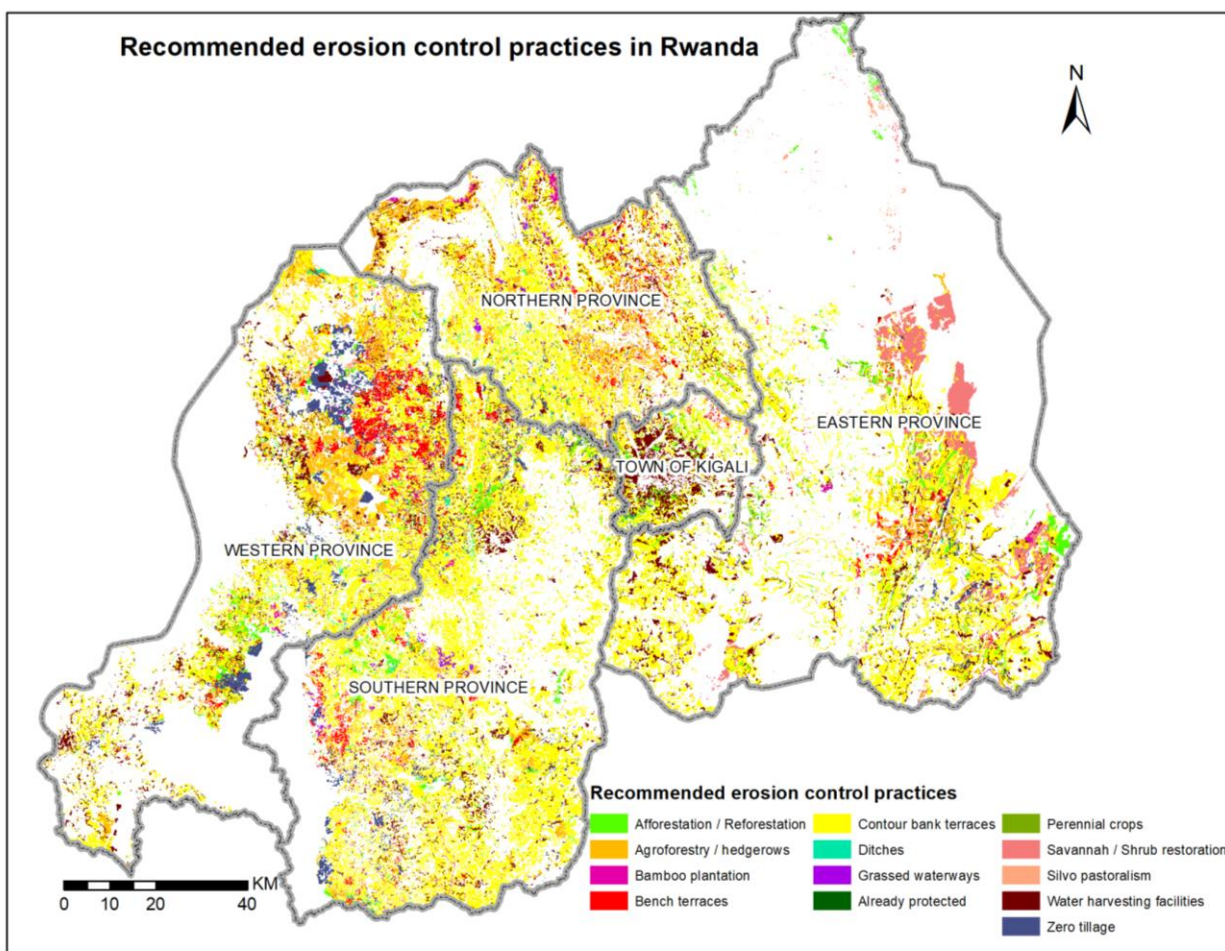
Erosion control in place	PROVINCES / KIGALI CITY (Ha)					Grand Total	%
	KIGALI CITY	EAST	NORTH	SOUTH	WEST		
Not protected against erosion (Ha)	33,110	214,368	124,357	227,157	198,825	797,816	74%
<b>Grand Total</b>	<b>39,179</b>	<b>261,166</b>	<b>187,165</b>	<b>331,116</b>	<b>261,542</b>	<b>1,080,168</b>	<b>100%</b>
<b>% Erosion control per land at risk</b>	<b>15%</b>	<b>18%</b>	<b>34%</b>	<b>31%</b>	<b>24%</b>	<b>26%</b>	

The Table 7 and Figure 5 are respectively the summary and spatial distribution of the recommended practices to mitigate the erosion at the national level. Contour bank terraces are recommended on an area of 510,096 hectares (47% of the area at risk), while agroforestry and hedgerows are recommended on 101,232 hectares (9% of the area at risk), afforestation/reforestation is recommended on an estimated area of 39,901 hectares. Other recommended practices are bamboo plantations to close gullies or protect riversides, ditches, bench terraces, contour bank terraces, grassed waterways, implementing water harvesting facilities and restoring savannah or shrub and practicing silvo-pastoralism.

**Table 7: Recommended erosion control practices in Rwanda**

Recommended practices	PROVINCES / KIGALI CITY					Grand Total	%
	KIGALI CITY	EAST	NORTH	SOUTH	WEST		
Afforestation / Reforestation	3,476	14,651	2,493	10,798	8,483	39,901	4%
Agroforestry / hedgerows	2,129	9,407	33,081	20,014	36,601	101,232	9%
Bamboo plantation	171	2,189	3,886	2,776	5,893	14,915	1%
Bench terraces	555	3,257	4,932	7,703	13,505	29,952	3%
Contour bank terraces	13,748	130,863	87,173	169,917	108,396	510,096	47%
Ditches	78	71	966	1,089	1,286	3,490	0%
Grassed waterways	19	17	1,163	1,595	156	2,951	0%
None	5,388	40,936	35,301	85,636	43,279	210,541	19%
Perennial crops		1	18	25	4	48	0%
Savannah / Shrub restoration	27	32,543	2		2	32,574	3%
Silvo pastoralism	10	830			397	1,237	0%
Water harvesting facilities	12,663	19,981	15,364	18,516	23,155	89,679	8%
Zero tillage	916	6,420	2,786	13,047	20,383	43,552	4%
<b>Grand Total</b>	<b>39,179</b>	<b>261,166</b>	<b>187,165</b>	<b>331,116</b>	<b>261,542</b>	<b>1,080,168</b>	<b>100%</b>





**Figure 5: Recommended erosion control practices in Rwanda**

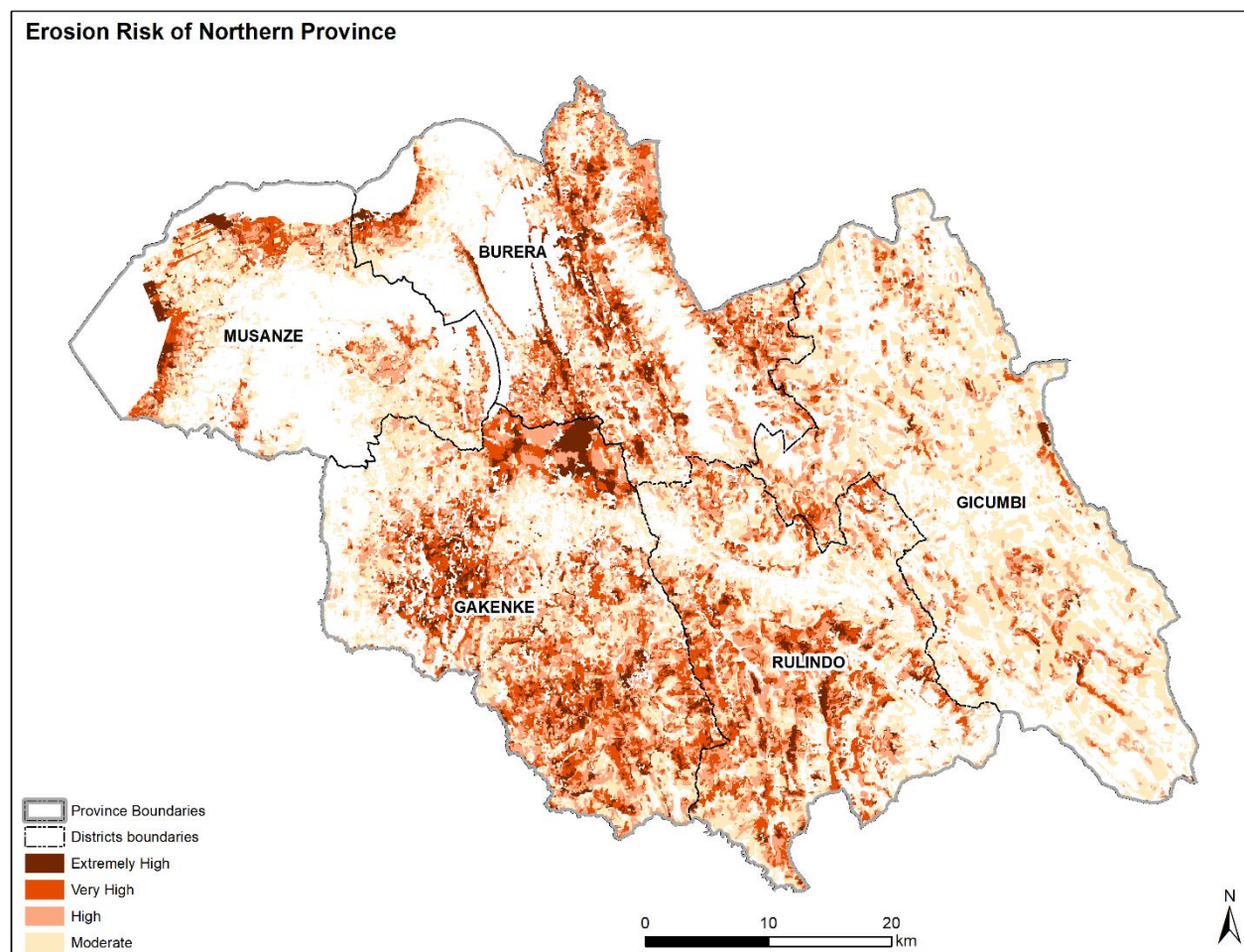
### 3.1 Erosion Control status in Northern Province

Table 8 presents the situation of erosion risk in the Northern Province of Rwanda. Land at risk of soil erosion is about 187,165 hectares (59% of the total province land). The results show that Gakenke is the highest risk area with 49,738 hectares (i.e. 71% of the district land) followed by Rulindo District with 38,344 hectares (68% of the district land) and Gicumbi with 46,980 hectares i.e. 57% of its land under high risk of erosion. Musanze and Burera are the least susceptible to erosion with 37% of the land at risk in Musanze and 56% of land at risk in Burera.

**Table 8: Erosion risk per District in Northern Province**

District	Erosion risk areas (Ha)					District land (ha)	Percent age (%)
	Extremely High	Very High	High	Moderate	Grand Total		
GAKENKE	5,527	13,162	16,241	14,808	49,738	70,325	71%
RULINDO	2,140	8,578	12,346	15,280	38,344	56,699	68%
GICUMBI	603	3,624	9,377	33,376	46,980	82,721	57%

District	Erosion risk areas (Ha)					District land (ha)	Percent age (%)
	Extremely High	Very High	High	Moderate	Grand Total		
BURERA	3,045	8,337	11,809	10,031	33,223	58,856	56%
MUSANZE	1,042	3,311	4,495	10,031	18,880	50,717	37%
<b>Grand Total</b>	<b>12,358</b>	<b>37,011</b>	<b>54,269</b>	<b>83,527</b>	<b>187,165</b>	<b>319,318</b>	<b>59%</b>

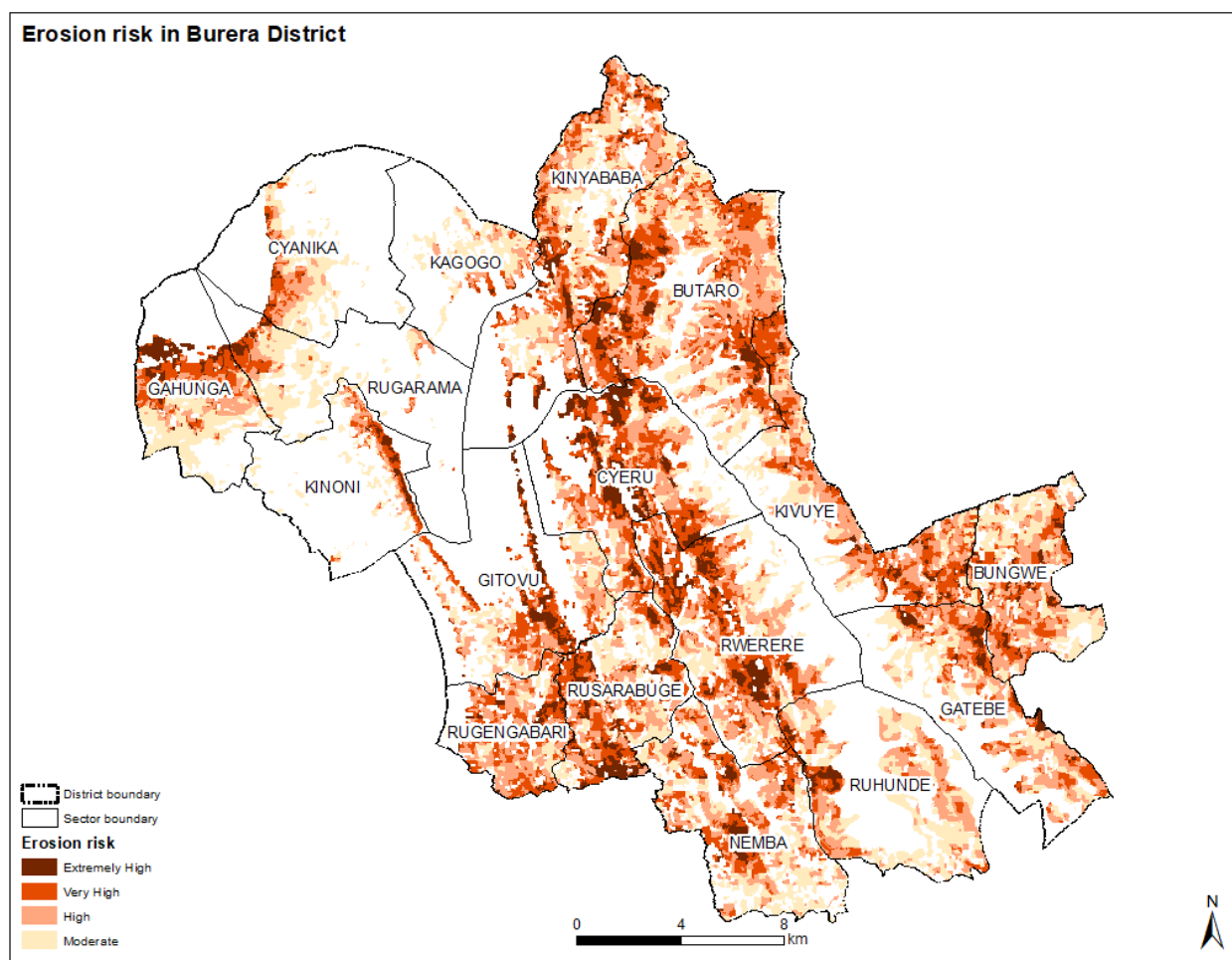


**Figure 6: Erosion risk in Northern Province**

### 3.1.1. Erosion Control status in Burera District

Erosion risk in Burera is summarised in Table 9 and presented in **Error! Reference source not found..** Erosion risk in Burera District is estimated to 56%, about 33,223 hectares are under moderate to extremely high erosion risk of which 2,124 hectares are located in Bungwe sector (83% of sector land), 2,017 hectares are located in Rusarabuge sector (77% of sector land), 4,416 hectares are located in Butaro (75% of the sector), 1,346 hectares are found in Rugengabari sector and 3,093 hectares are located in Kinyababa sector, about 69% of the sector land. The least erosion risk sectors are Kinoni with 528 hectares (17% of

the sector land), Cyanika with 885 hectares (21%) and Kagogo with 629 hectares, only 24% of the total sector land.



**Figure 7: Erosion risk in Burera District**

**Table 9: Erosion risk per sector in Burera District**

Sector Name	Erosion risk				Grand Total	Sector land(ha)	Percentage (%)
	Extremely High	Very High	High	Moderate			
BUNGWE	106	405	873	741	2,124	2,575	83%
RUSARABUG E	359	582	640	436	2,017	2,633	77%
BUTARO	311	1,236	1,797	1,072	4,416	5,876	75%
RUGENGABARI	83	446	665	152	1,346	1,817	74%
KINYABABA	243	696	1,149	1,005	3,093	4,504	69%
NEMBA	184	566	853	832	2,435	3,769	65%
CYERU	529	843	714	341	2,427	3,779	64%

Sector Name	Erosion risk				Grand Total	Sector land(ha)	Percentage (%)
	Extremely High	Very High	High	Moderate			
KIVUYE	118	745	980	527	2,369	3,737	63%
GITOVU	201	407	496	452	1,556	2,672	58%
RWERERE	350	910	927	613	2,800	4,847	58%
GATEBE	151	434	835	678	2,099	3,870	54%
GAHUNGA	182	377	398	580	1,537	2,893	53%
RUHUNDE	88	252	802	938	2,079	4,344	48%
RUGARAMA	47	118	137	578	880	2,642	33%
KAGOGO	3	59	168	398	629	2,229	28%
CYANIKA	25	130	234	496	885	4,147	21%
KINONI	63	131	141	193	528	2,522	21%
<b>Grand Total</b>	<b>3,045</b>	<b>8,337</b>	<b>11,809</b>	<b>10,031</b>	<b>33,223</b>	<b>58,856</b>	<b>56%</b>

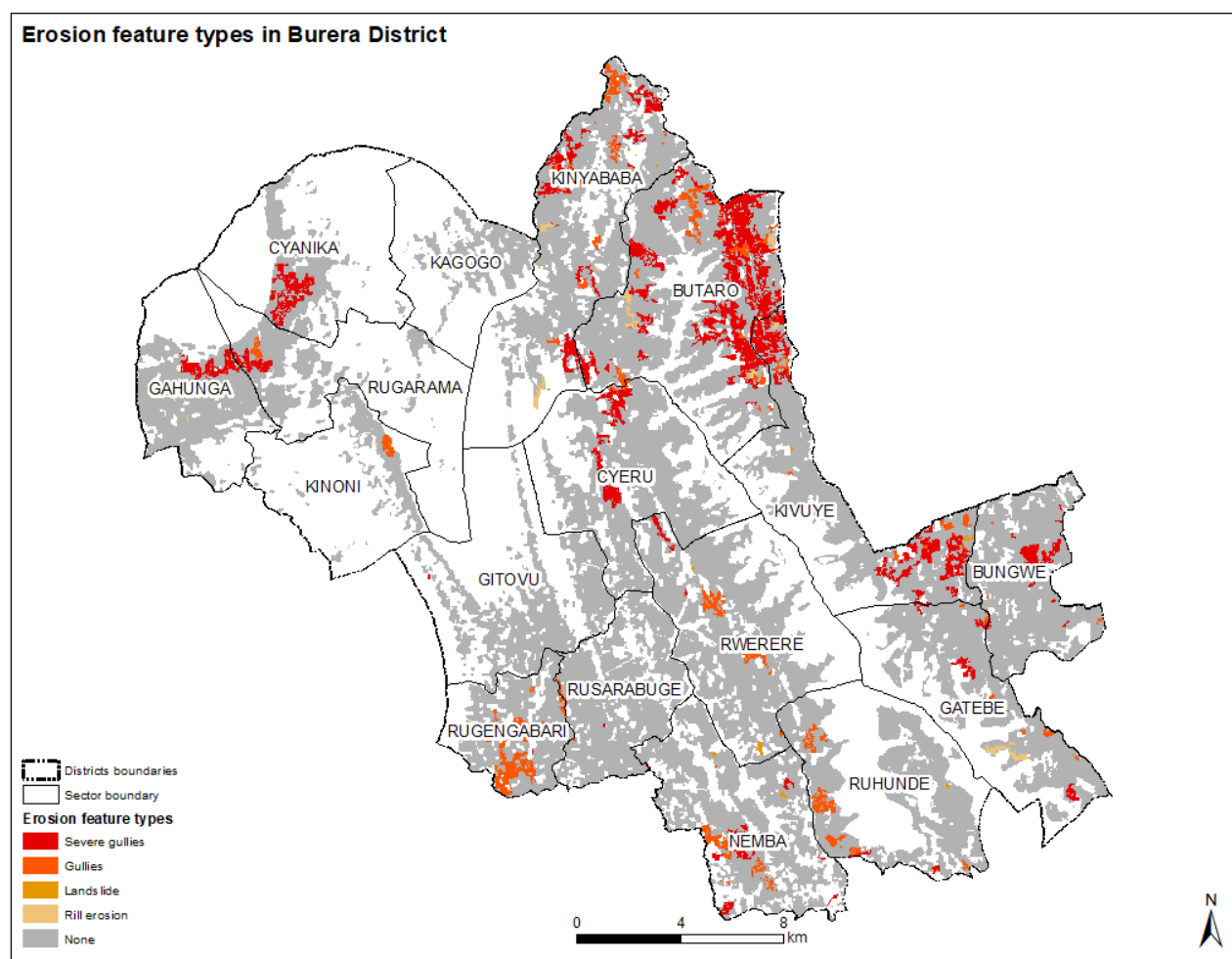
Burera land areas affected by erosive features as detected on World View satellite images of 2019 - 2020 are summarized in Table 10 and the map of erosive features are presented in Figure 8 **Error! Reference source not found.** The results show that Butaro sector is the worst affected by gullies and severe gullies on areas estimated to 1,274 hectares, followed by Kivuye sector on 511 hectares, Cyanika sector on 163 hectares, and Rugendabari on 221 hectares. This study shows that Kagogo is the unique sector that is not affected by erosion risk, whereas Gitovu is the least affected by erosion risk with 3ha (0%) followed by Rusarabuge with 16 ha affected (1%), Bungwe with 95 ha affected, Rwerere with 150 ha affected (5%) and Kinoni 32 ha affected (6%). Moreover, it appears that Rusarabuge, Rwerere, Cyeru, Bungwe sectors which were revealed by CROM model that more than half of the sector lands are at risk, there was less area affected already by erosive features. This should not read that CROM model could not perform well in these sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been prevented, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 5 and 6.

**Table 10: Erosive features and areas affected in Burera District**

Sector Name	Erosive features				Total Feature s (Ha)	None (Ha)	Grand Total	% feature s
	Gullie s	Landslid e	Rill erosion	Severe gullies				
BUTARO	166	2	54	1052	1274	3143	4416	29%
KIVUYE	65	12	5	429	511	1858	2369	22%
CYANIKA				163	163	723	885	18%
RUGENGABARI	221				221	1125	1346	16%
KINYABABA	140	6	40	306	493	2601	3093	16%
RUGARAMA	23			67	90	790	880	10%
NEMBA	92	8		105	205	2230	2435	8%
GAHUNGA			4	121	126	1412	1537	8%
CYERU	17			173	190	2236	2427	8%
RUHUNDE	136	4		21	160	1919	2079	8%



Sector Name	Erosive features				Total Feature s (Ha)	None (Ha)	Grand Total	% feature s
	Gullie s	Landslid e	Rill erosion	Severe gullies				
GATEBE	51		40	68	158	1940	2099	8%
KINONI	32				32	495	528	6%
RWERERE	92	14		44	150	2650	2800	5%
BUNGWE	9			86	95	2029	2124	4%
RUSARABUG E	15	1			16	2001	2017	1%
GITOVU				3	3	1553	1556	0%
KAGOGO					0	629	629	0%
<b>Grand Total</b>	<b>1060</b>	<b>46</b>	<b>143</b>	<b>2639</b>	<b>3888</b>	<b>29335</b>	<b>33223</b>	<b>12%</b>



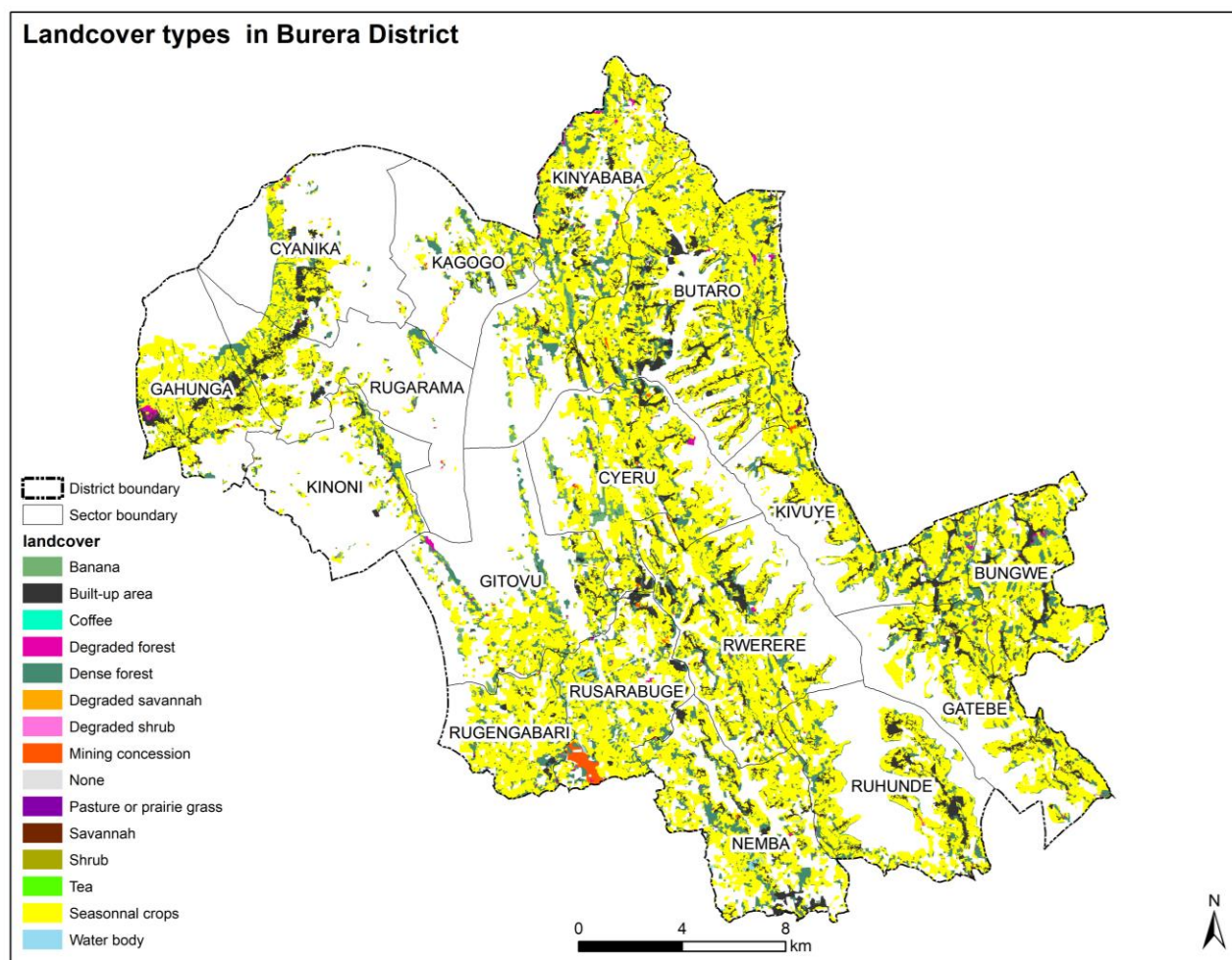
**Figure 8: Erosive features detected using worldview satellite images for Burera District**

In term of land use and vegetation cover in Burera, the results of land cover mapping (Table 11 and Figure 1) show that 25,288 hectares (76% of the total land at risk) are used for crop cultivation, 3,974 hectares (12% of the total land at risk) are covered by healthy forests and 3,315 hectares i.e. 10% are used for built-up and settlement.



**Table 11: Land Use and Vegetation Cover (LUV) of areas at risk in Burera District**

Sector Name	Banana	Built-up area	Degraded forest	Dense forest	Mining concession	None	Pasture or prairie grass	Seasonal crops	Water body	Grand Total
BUNGWE	4	220	3	235				1,655	8	2,124
BUTARO		563	9	405	3	7		3,425	5	4,416
CYANIKA		132		153				601		885
CYERU	101	203	8	221	8	2		1,881	3	2,427
GAHUNGA		208	22	92				1,215	1	1,537
GATEBE		241	1	209				1,648		2,099
GITOVU	106	59	12	273		3		1,103		1,556
KAGOGO	12	25	3	180	1	1		406		629
KINONI	9	49		94	1			374		528
KINYABABA	100	193	14	480		2		2,296	8	3,093
KIVUYE		277	5	293	5	2	3	1,784		2,369
NEMBA	4	285	2	340	1			1,780	22	2,435
RUGARAMA		115		116				649	0	880
RUGENGABARI	6	74		140				1,125	1	1,346
RUHUNDE		256	2	207				1,615		2,079
RUSARABUGE	3	108	3	220	93			1,557	32	2,017
RWERERE		307	4	315				2,174	1	2,800
<b>Grand Total</b>	<b>345</b>	<b>3,315</b>	<b>87</b>	<b>3,974</b>	<b>113</b>	<b>17</b>	<b>3</b>	<b>25,288</b>	<b>81</b>	<b>33,223</b>
%	1%	10%	0%	12%	0%	0%	0%	76%	0%	100%



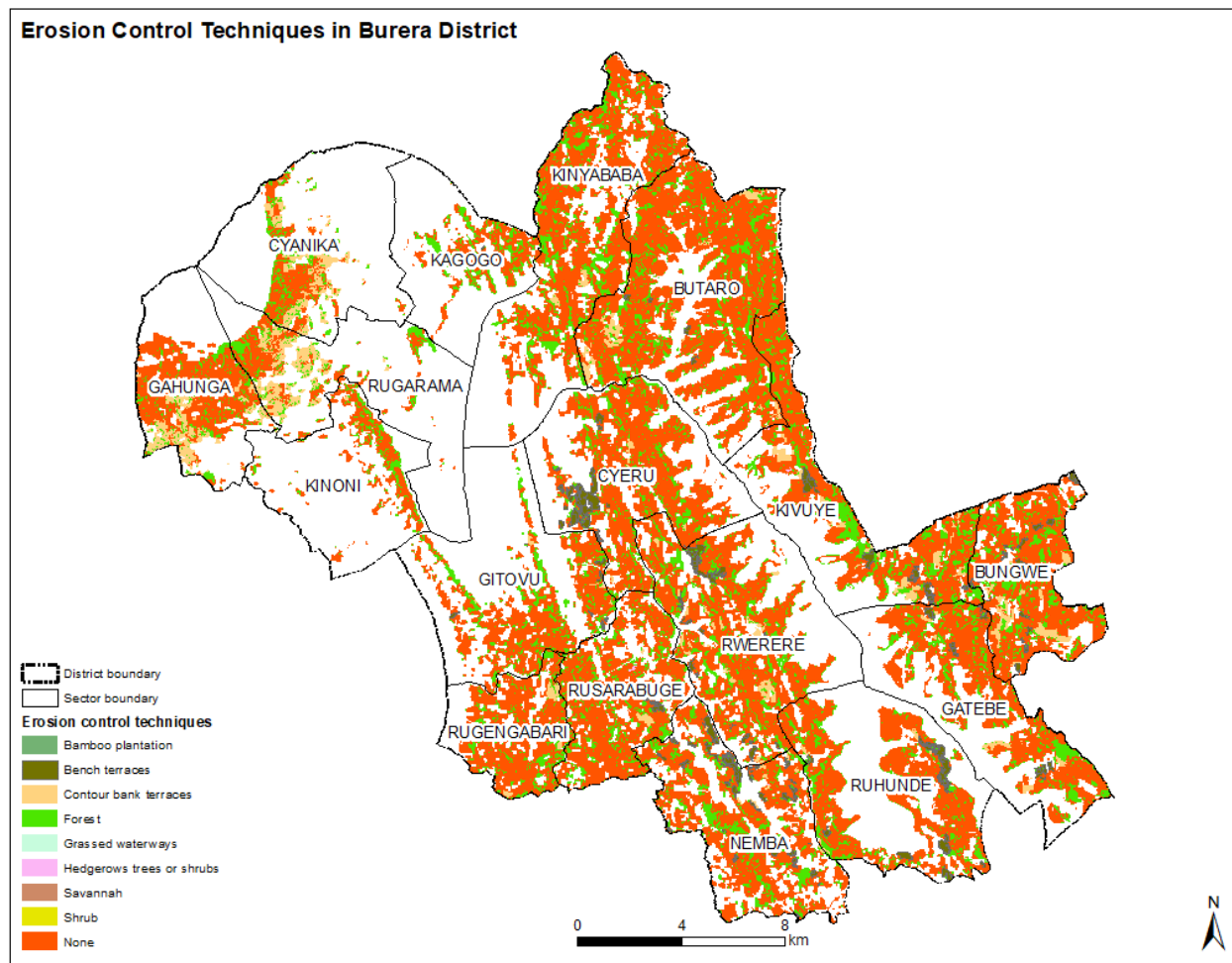
**Figure 9: Land cover types in Burera District**

About existing erosion control practices in Burera district, only 21% of land at risk is protected by forests (4,316 hectares), contour bank terraces (1,766 hectares), and bench terraces (850 hectares). Although still low, the highest protected sectors are Bugarama with 55% of its land at risk protected, followed by Cyanika where 49% of the total land at risk is protected (432 hectares) and Kagogo with 29% of land protected. The least protected sectors are Rusarabuge (13% protected), Rugengabari and Butaro (14%). The visual interpretation of World View images confirms earlier findings by CROM model that Rugengabari, Butaro and Rusarabuge sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected.

**Table 12: Erosion control practices already in place in Burera District**

Sector Name	Erosion control in place			Total protected (Ha)	Unprotected (Ha)	Grand Total (Ha)	% Protected
	Bench terraces	Contour bank terraces	Forest				
RUGARAMA		367	116	484	397	880	55%
CYANIKA		280	153	432	453	885	49%

Sector Name	Erosion control in place			Total protected (Ha)	Unprotected (Ha)	Grand Total (Ha)	% Protected
	Bench terraces	Contour bank terraces	Forest				
KAGOGO	2	2	182	185	444	629	29%
KIVUYE	83	164	408	656	1,713	2,369	28%
GAHUNGA		297	96	393	1,145	1,537	26%
NEMBA	180	31	340	552	1,883	2,435	23%
BUNGWE	71	146	251	468	1,657	2,124	22%
RWERERE	116	117	354	588	2,213	2,800	21%
GITOVU	21	14	283	318	1,238	1,556	20%
KINONI		8	94	102	426	528	19%
GATEBE	53	55	288	396	1,702	2,099	19%
RUHUNDE	132	22	221	375	1,705	2,079	18%
KINYABABA		28	487	516	2,578	3,093	17%
CYERU	157	26	219	402	2,025	2,427	17%
BUTARO	19	150	453	622	3,794	4,416	14%
RUGENGABARI		38	151	189	1,157	1,346	14%
RUSARABUGE	16	28	220	265	1,752	2,017	13%
<b>Grand Total</b>	<b>850</b>	<b>1,775</b>	<b>4,316</b>	<b>6,941</b>	<b>26,282</b>	<b>33,223</b>	<b>21%</b>



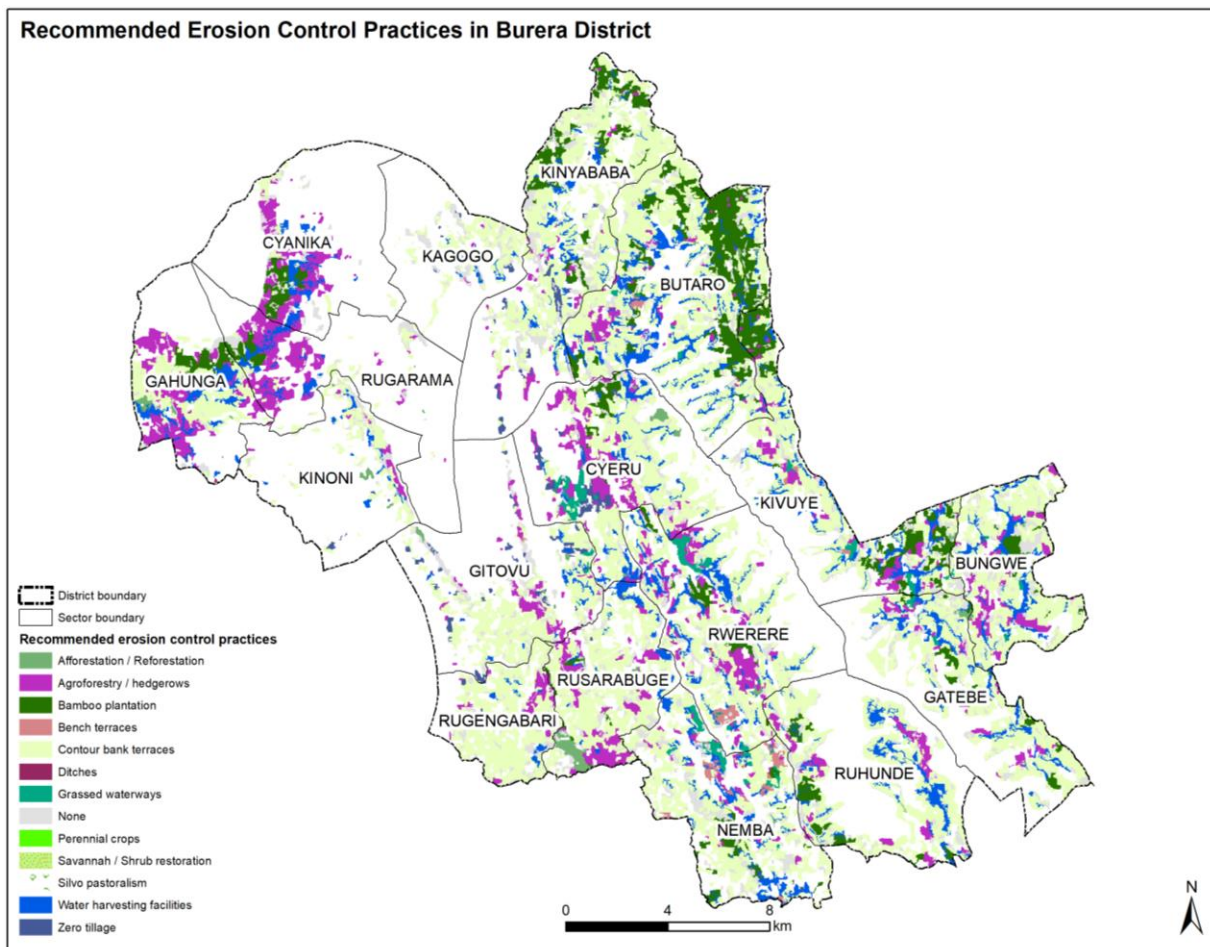
**Figure 10: Erosion control techniques in place in Burera District**

Erosion control practices in Burera district are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 13 shows that contour bank terraces commonly known in Rwanda as progressive terraces are required for land about 17,837 hectares (54% of the total land at risk) used for seasonal crops. Bamboo plantation is required to rehabilitate 2,887 hectares affected by gullies (about 8% of the total land at risk), while storm water management facilities (SWMF) are recommended for built-up areas of about 3,339 hectares (10% of the total risk areas). Agroforestry and hedgerows are need in 3879 hectares of agricultural land. Afforestation and reforestation (267 hectares) and bench terraces (174 hectares) are required on extremely high risk areas.

**Table 13: Recommended erosion control practices in Burera District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedge rows	Bamboo plantation	Bench terraces + grassed waterways	Contour bank terraces	Water harvesting facilities	Zero tillage / perennial crops	Already protected	Grand Total
BUNGWE	8	227	70	25	1,305	220	4	266	2,124
BUTARO	13	173	980	31	2,251	569		399	4,416
CYANIKA	1	355	140		95	132		163	885
CYERU	37	437	100	97	1,229	203	104	220	2,427
GAHUNGA	29	435	123		646	208	2	96	1,537
GATEBE	13	125	118	17	1,346	241		239	2,099
GITOVU	14	153		15	928	59	106	281	1,556
KAGOGO	6	6			400	25	12	180	629
KINONI	17	46			311	51	9	94	528
KINYABABA	18	107	378		1,809	193	98	489	3,093
KIVUYE	7	217	442	65	1,054	282		302	2,369
NEMBA	4	118	141	197	1,329	285	4	357	2,435
RUGARAMA	1	448	77		124	115		116	880
RUGENGABARI		94	1		1,032	74	6	139	1,346
RUHUNDE	2	209	157		1,253	256		204	2,079
RUSARABU	92	342	32		1,218	108	3	220	2,017
RWERERE	16	387	129	133	1,508	317		311	2,800
<b>Grand Total</b>	<b>277</b>	<b>3,879</b>	<b>2,887</b>	<b>580</b>	<b>17,837</b>	<b>3,339</b>	<b>348</b>	<b>4,076</b>	<b>33,223</b>
<b>%</b>	<b>1%</b>	<b>12%</b>	<b>9%</b>	<b>2%</b>	<b>54%</b>	<b>10%</b>	<b>1%</b>	<b>12%</b>	<b>100%</b>

Other interventions: there are grassed waterways that are recommended for 372Ha of existing terraces made without waterways or with them but not grassed which can cause development of severe gullies and destruction of bench terraces already created. No-till agriculture is recommended for 348Ha of perennial crops while Water harvesting facilities are recommended in built-up areas (on 3,339 hectares). Areas already protected: No-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected (Table 12). Contour banks are recommended for existing forests without ditches.



**Figure 11: Recommended erosion control practices in Burera District**

### 3.1.2. Erosion control status in Gakenke District



Soil erosion risk in Gakenke is summarised in

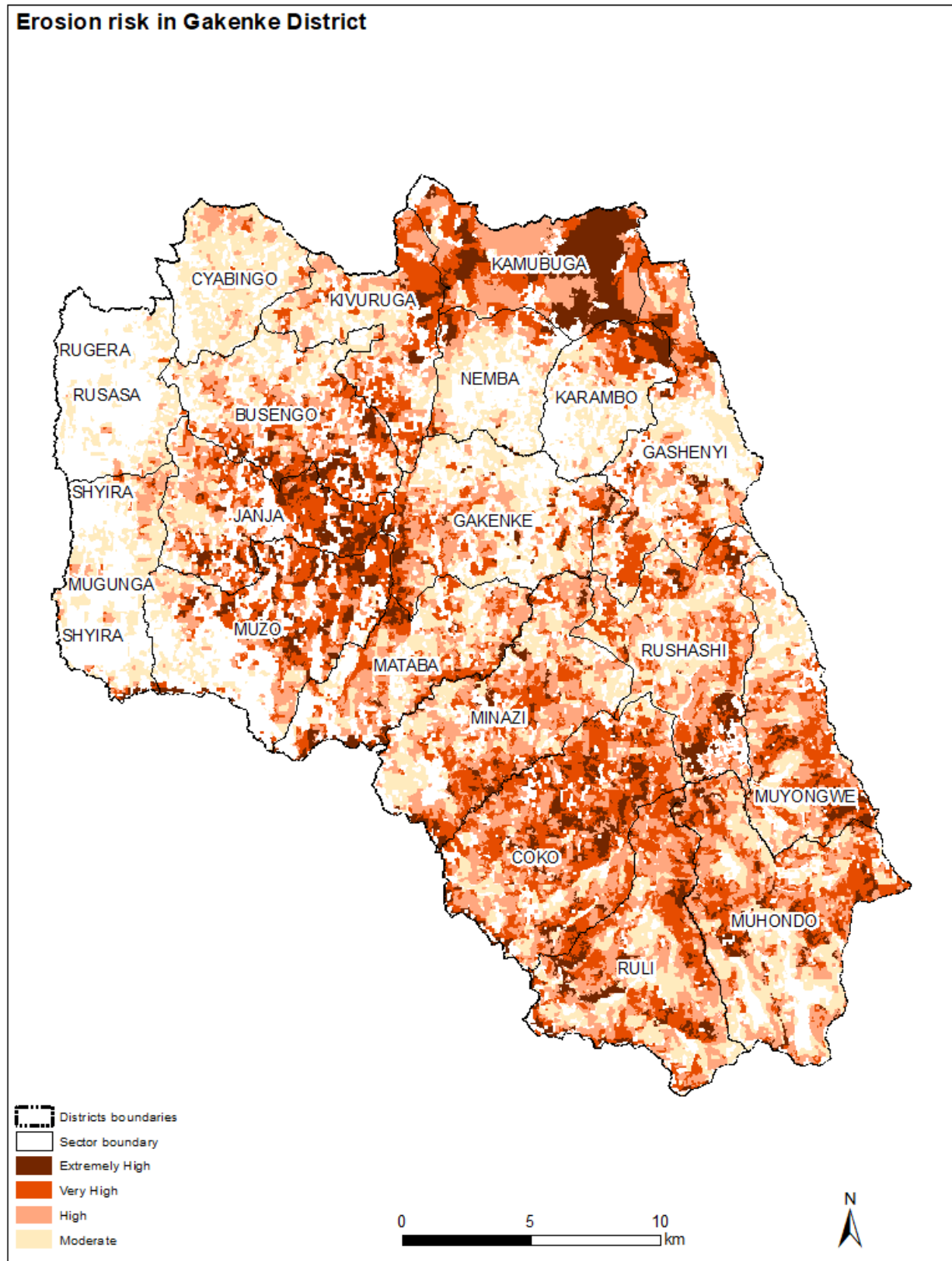


Figure 12: Erosion risk in Gakenke District

Table 14 and presented in Figure 12. Erosion risk in Gakenke District is estimated to 71% of the total district land. About 49,738 hectares are at risk of erosion. In fact of 19 sectors of Gakenke, only 2 sectors out of 19 sectors have less than 40% of the land at risk of erosion while six sectors have more than 80% of the sector land prone to erosion. A total of 4,164 hectares are located in Kamubuga sector (90% of sector land), 4,161 hectares are located in Ruli sector (89% of sector land), 4,867 hectares are located in Coko (88% of the sector land), 4,609 hectares are found in Muhondo sector (84% of the sector land), 3,785 hectares are located in Minazi and 3,208 hectares are located in Rushashi sector, about 80% of the sector land. The least sectors are Rusasa with only 664 hectares (22% of the sector land) susceptible to erosion, Mugunga with 1,165 hectares (40%), Karambo and Nemba respectively with 1,166 hectares, about 53% of the total sector land and 1,225 hectares (54%). Compared to other Districts of the Northern Province, Gakenke is the vulnerable district to soil erosion and need special attention.



## Erosion risk in Gakenke District

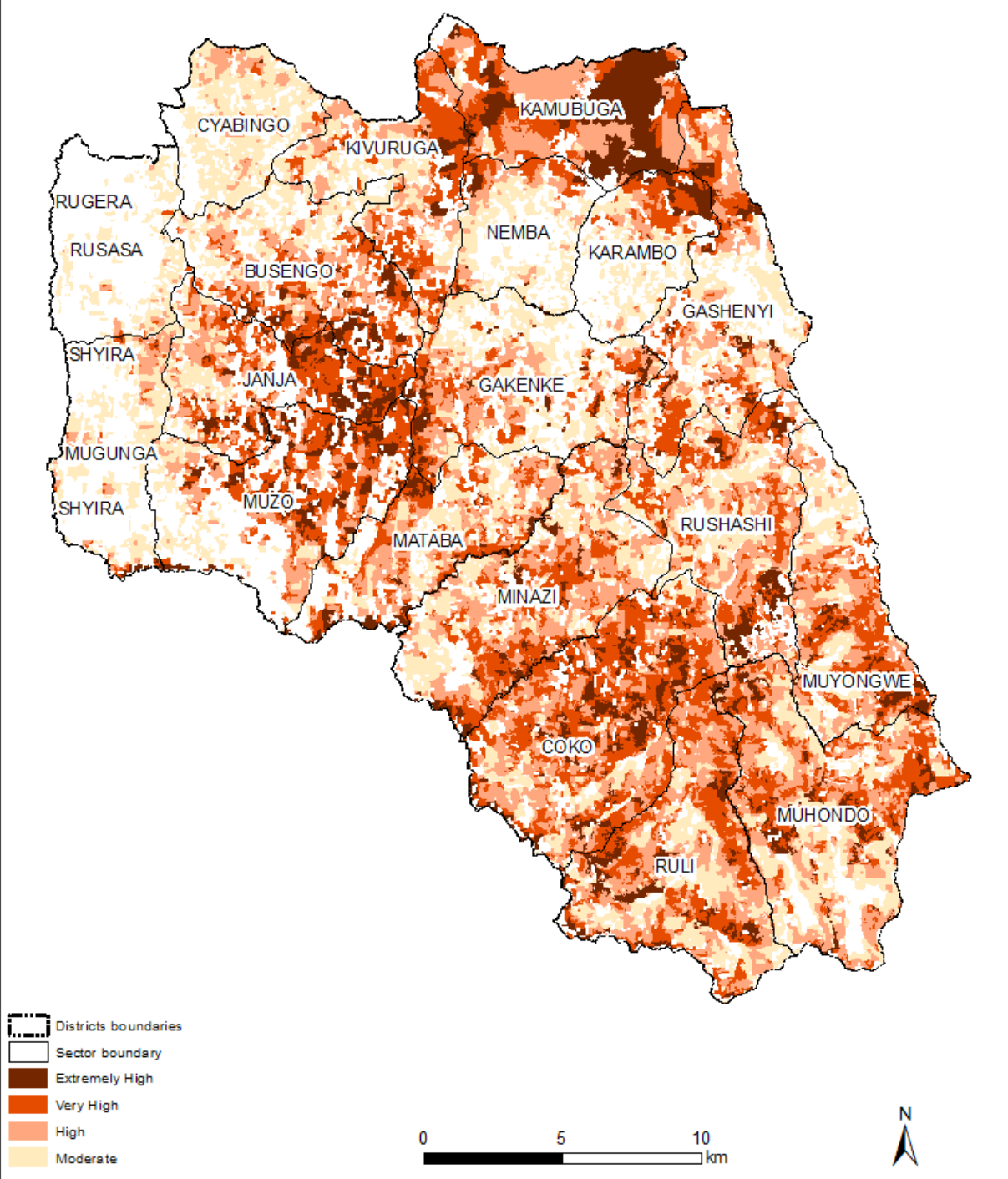


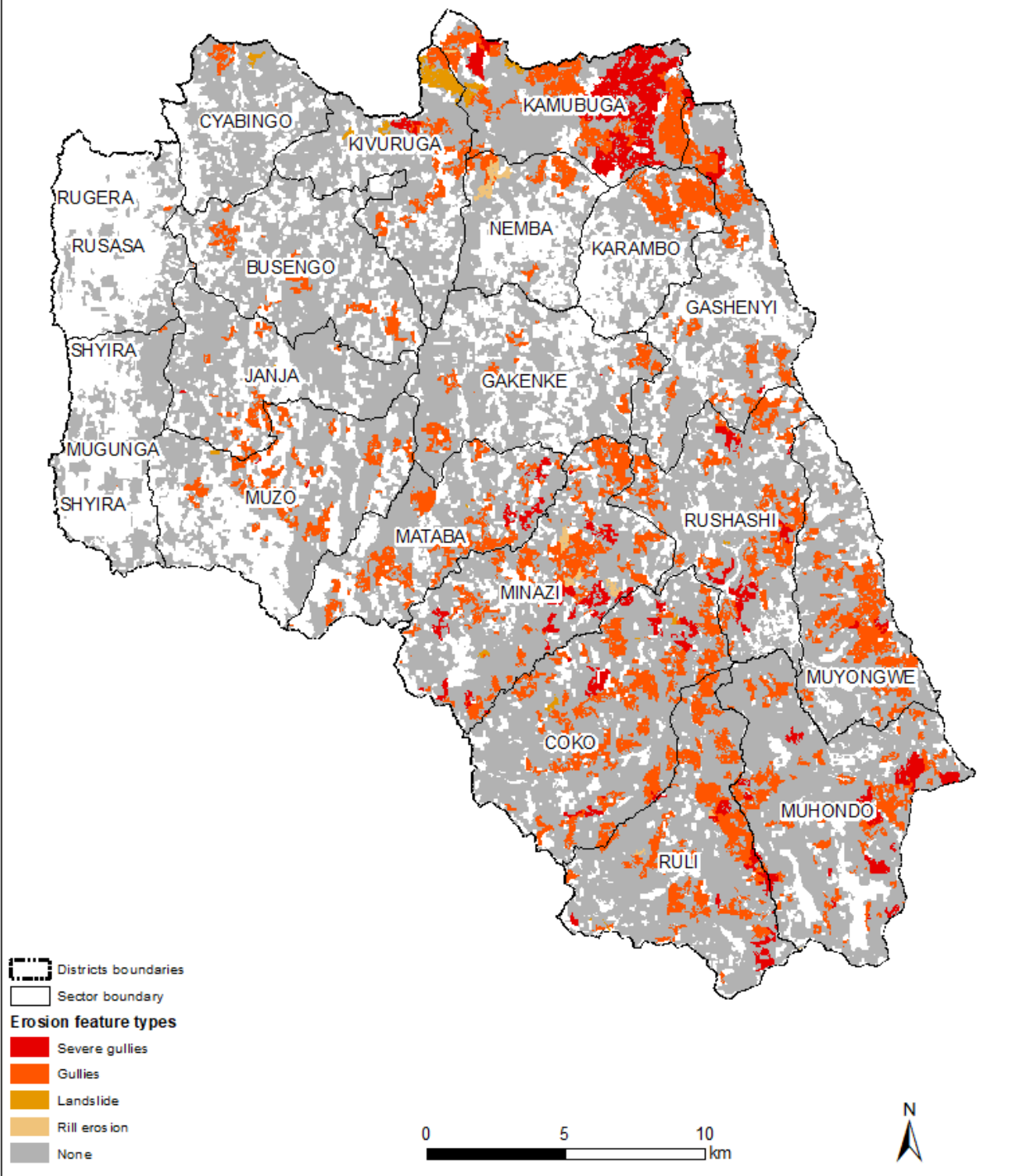
Figure 12: Erosion risk in Gakenke District

**Table 14: Erosion risk per sector in Gakenke District**

Sector Name	Erosion risk					Sector land(ha)	Percentage(%)
	Extremely High	Very High	High	Moderate	Grand Total		
KAMUBUGA	1,172	724	1,100	65	3,061	3,392	90%
RULI	408	1,218	1,588	947	4,161	4,666	89%
COKO	649	1,973	1,680	564	4,867	5,555	88%
MUHONDO	385	1,138	1,618	1,467	4,609	5,494	84%
MINAZI	267	926	1,488	1,104	3,785	4,724	80%
RUSHASHI	297	746	1,223	941	3,208	4,014	80%
MUYONGWE	174	724	986	804	2,687	3,410	79%
KIVURUGA	117	774	715	675	2,280	3,121	73%
MATABA	194	560	871	754	2,380	3,316	72%
JANJA	391	852	552	390	2,184	3,053	72%
BUSENGO	313	691	820	731	2,555	3,821	67%
GAKENKE	210	541	860	1,118	2,729	4,116	66%
GASHENYI	200	662	971	920	2,752	4,177	66%
CYABINGO	4	39	316	1,230	1,590	2,415	66%
MUZO	499	1,015	647	509	2,669	4,662	57%
NEMBA	65	199	269	691	1,225	2,264	54%
KARAMBO	156	308	172	531	1,166	2,187	53%
MUGUNGA	27	52	289	797	1,165	2,913	40%
RUSASA		19	77	568	664	3,026	22%
<b>Grand Total</b>	<b>5,527</b>	<b>13,162</b>	<b>16,241</b>	<b>14,808</b>	<b>49,738</b>	<b>70,325</b>	<b>71%</b>

Land areas at risk which are already affected by erosive features in Gakenke District are summarized in Table 15 and the map of erosive features are presented in Figure 13. The results show that Kamubuga sector is the worst affected by gullies and severe gullies on areas estimated to 1392 hectares, followed by Minazi sector on 2631 hectares, Karambo sector on 331 hectares, and Coko sector on 1267 hectares. The presence of gullies, landslides and severe gullies in Kamubuga, Minazi, Karambo and Coko confirms the findings of CROM model, however Mugunga, Rusasa, Cyabingo, Janja, Gakenke and Busengo sectors which were revealed by CROM model that are above 40% of the sector lands are at risk, there are among the least affected already by erosive features i.e. less or equal to 1% for Mugunga and Rusasa, 4% for Cyabingo, 6% for Janja, 8% for Gakenke and 10% for Muzo sector. This should not read that CROM model could not perform well in these sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been prevented, thus erosive features could not be formed in this case. The least sectors affected by gullies and landslides in Gakenke District are Mugunga with only 4 hectares, Rusasa with 5 hectares and Cyabingo with 67 hectares.

### Erosion feature types in Gakenke District



**Figure 13: Erosive features detected in Gakenke District**

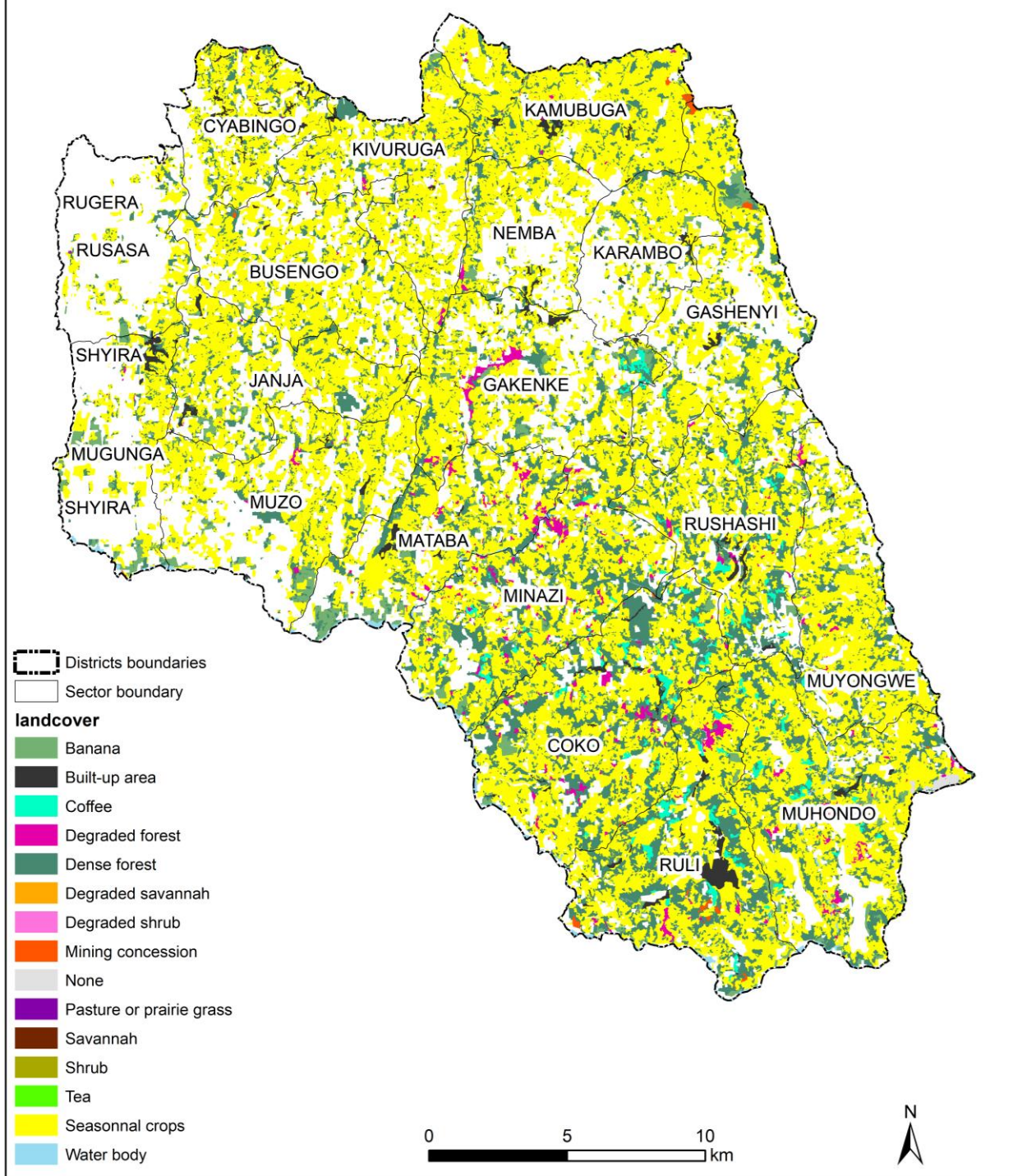
**Table 15: Erosive features and areas affected in Gakenke District**

Sector Name	Erosive features				Total Feature s (Ha)	None (Ha)	Grand Total	% feature s
	Gullies	Landslid e	Rill erosion	Severe gullies				
KAMUBUGA	743	52	4	868	1,669	1,392	3,061	55%
MINAZI	825	7	63	259	1,154	2,631	3,785	30%
KARAMBO	328			3	331	835	1,166	28%
COKO	1,077	21		169	1,267	3,600	4,867	26%
MUYONGWE	670			20	690	1,997	2,687	26%
MATABA	526			81	607	1,773	2,380	26%
RUSHASHI	636	2		157	795	2,413	3,208	25%
RULI	867	4	8	127	1,006	3,155	4,161	24%
KIVURUGA	275	144		35	454	1,826	2,280	20%
GASHENYI	486			57	543	2,209	2,752	20%
NEMBA	172		68		240	984	1,225	20%
MUHONDO	625			269	893	3,715	4,609	19%
MUZO	465	6		4	474	2,195	2,669	18%
BUSENGO	239				239	2,316	2,555	9%
GAKENKE	234				234	2,495	2,729	9%
JANJA	146	2		1	149	2,035	2,184	7%
CYABINGO	52	15			67	1,522	1,590	4%
RUSASA	5				5	659	664	1%
MUGUNGA	4				4	1,161	1,165	0%
<b>Grand Total</b>	<b>8376</b>	<b>253</b>	<b>144</b>	<b>2049</b>	<b>10,822</b>	<b>38,916</b>	<b>49,738</b>	<b>22%</b>

In term of land use and vegetation cover for areas at risk in Gakenke, the results of land cover mapping (Table 16 and Figure 14) show that 36489 hectares (about 73% of the total land at risk) are used for crop cultivation, 9261 hectares (19% of the total land at risk) are covered by healthy forests and 819 hectares i.e. 2% are used for built-up and settlement and 1566 hectares (3% of total land at risk) are covered by banana.



## Landcover types in Gakenke District



**Figure 14: Land cover types in Gakenke District**

**Table 16: Land Use and Vegetation Cover (LUVC) of areas at risk in Gakenke District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Minings/quarries	Seasonal crops	Water body	Grand Total
BUSENGO	18	20			267	2	2,244	4	2,555
COKO	92	58	120	92	1,330	1	3,134	41	4,867
CYABINGO	3	84		1	188		1,313		1,590
GAKENKE	120	49	48	79	475		1,953	6	2,729
GASHENYI	99	23	8		515	20	2,080	7	2,752
JANJA	89	40			272		1,783		2,184
KAMUBUGA		71		7	356	15	2,613		3,061
KARAMBO	21	23			145		976	1	1,166
KIVURUGA	18	23		13	230		1,997		2,280
MATABA	196	40		73	428		1,587	57	2,380
MINAZI	104	6	54	115	951		2,502	53	3,785
MUGUNGA	187	58		2	119	3	776	21	1,165
MUHONDO	131	26	88	84	1,015	58	3,155	51	4,609
MUYONGWE	79	7	10	23	453		2,110	5	2,687
MUZO	155	29		15	302		2,163	6	2,669
NEMBA	27	17		11	154		1,016		1,225
RULI	112	179	143	84	1,099	30	2,469	45	4,161
RUSASA	22	5			120		516		664
RUSHASHI	93	62	85	22	842		2,103	1	3,208
<b>Grand Total</b>	<b>1,566</b>	<b>819</b>	<b>556</b>	<b>621</b>	<b>9,261</b>	<b>129</b>	<b>36,489</b>	<b>298</b>	<b>49,738</b>
<b>%</b>	<b>3%</b>	<b>2%</b>	<b>1%</b>	<b>1%</b>	<b>19%</b>	<b>0%</b>	<b>73%</b>	<b>1%</b>	<b>100%</b>

About existing erosion control practices in Gakenke district, Table 17 indicates that only 27% of land at risk is protected by forests (9,651 hectares), contour bank terraces or progressive terraces with ditches (1,768 hectares), and bench terraces (2,246 hectares). Although still low, the highest protected sectors are Kivuruga with 43% of its land at risk protected, Janja with 43% of its land at risk protected, followed by Kamubuga where 37% of the total land at risk is protected (1,137 hectares) and Rushasi with 32% of land protected. The least protected sectors are Muyongwe with only 18% protected, Mataba (only 19% protected), Karambo (19%) and Mugunga, Nemba and Rusasa (22% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Cyabingo sector remains among the sectors at very high risk of soil erosion since more than 30% of their respective land are not protected. It is the same case for Muyongwe, Mataba and Karambo sectors which also remain at very high risk of soil erosion since more than 70% of their respective land are not protected.

## Erosion Control Techniques in Gakenke District

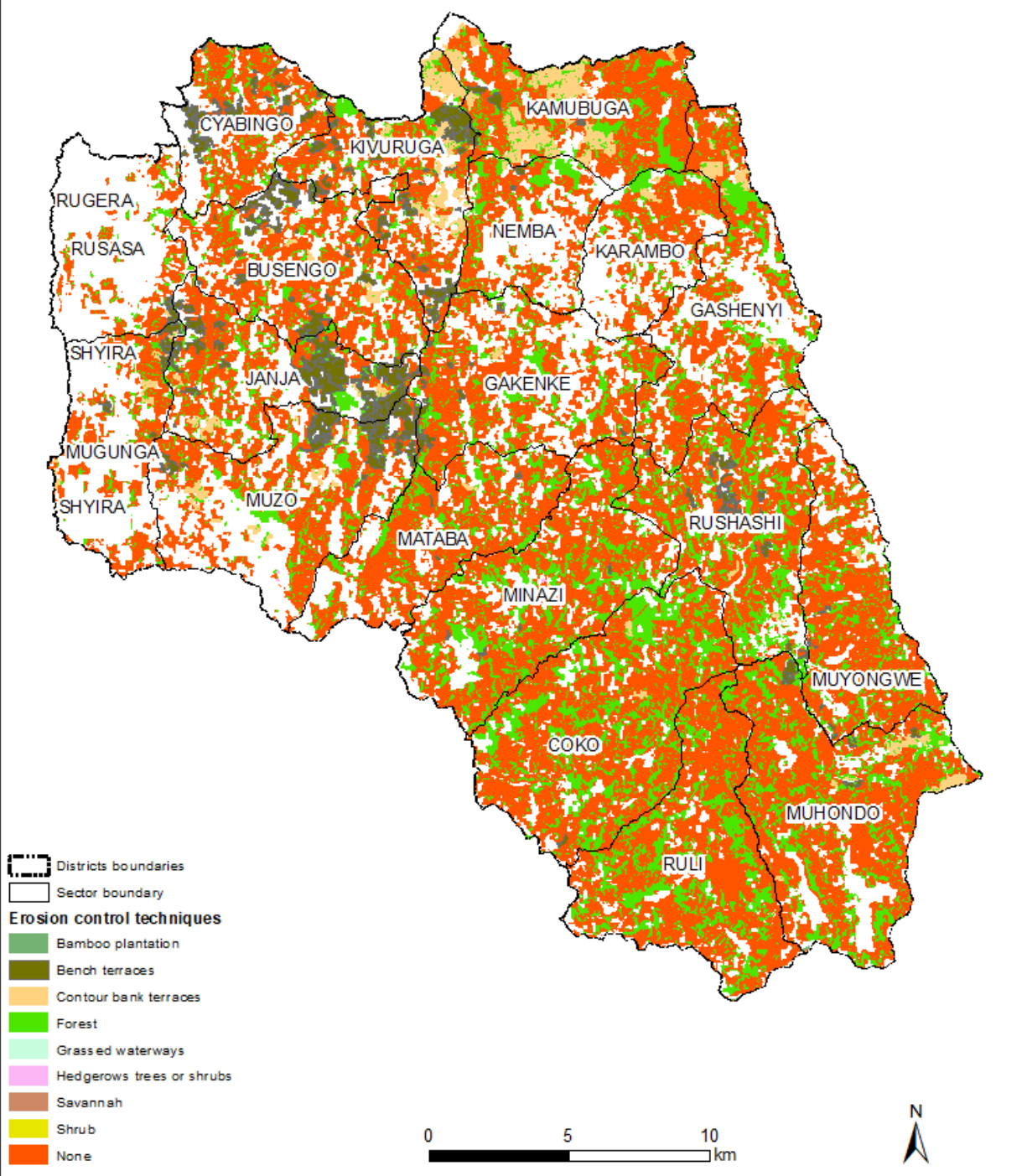


Figure 15: Erosion control techniques in place in Gakenke District

**Table 17: Erosion control practices already in place in Gakenke District**

Sector Name	Erosion control in place			Total protected (Ha)	Unprotected (Ha)	Grand Total (Ha)	% Protected
	Bench terraces	Contour bank terraces	Forest				
KIVURUGA	367	363	248	978	1,302	2,280	43%
JANJA	575	85	276	936	1,248	2,184	43%
KAMUBUGA	58	633	446	1,137	1,924	3,061	37%
RUSHASHI	139	39	842	1,020	2,188	3,208	32%
MUZO	337	113	328	778	1,891	2,669	29%
COKO	9	25	1,363	1,397	3,469	4,867	29%
RULI			1,100	1,099	3,062	4,161	26%
MUHONDO	60	135	1,021	1,216	3,393	4,609	26%
MINAZI	13	4	951	967	2,818	3,785	26%
CYABINGO	202	9	188	399	1,191	1,590	25%
GASHENYI		95	576	671	2,081	2,752	24%
BUSENGO	261	78	277	616	1,940	2,555	24%
GAKENKE	88	17	510	615	2,115	2,729	23%
RUSASA	24	4	120	148	515	664	22%
NEMBA	14	16	243	273	951	1,225	22%
MUGUNGA	73	72	114	259	906	1,165	22%
KARAMBO		37	184	221	945	1,166	19%
MATABA	11	11	419	441	1,939	2,380	19%
MUYONGWE	14	14	453	481	2,206	2,687	18%
<b>Grand Total</b>	<b>2,246</b>	<b>1,750</b>	<b>9,657</b>	<b>13,655</b>	<b>36,083</b>	<b>49,738</b>	<b>27%</b>

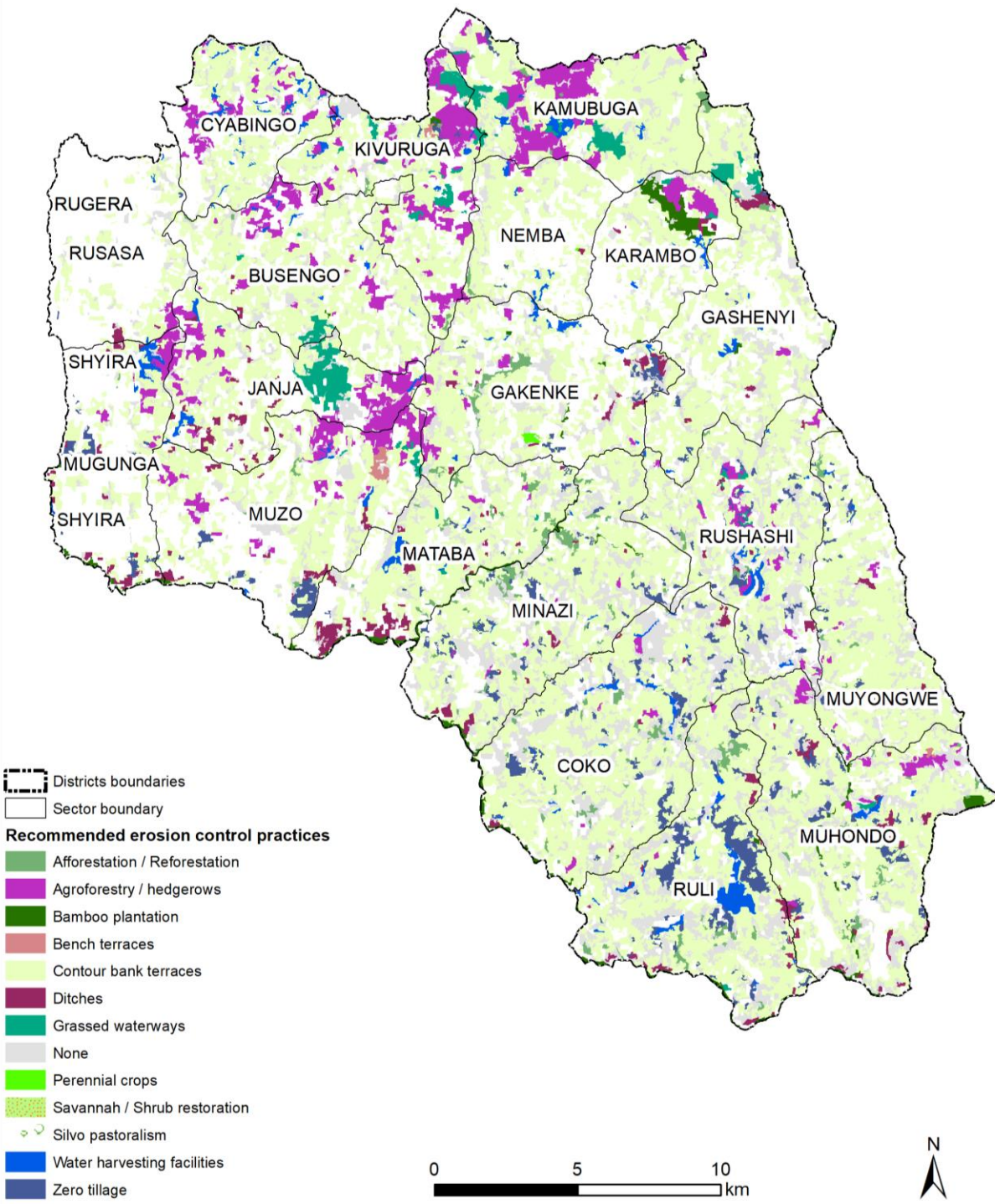
Erosion control practices in Gakenke district are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 18 shows that contour bank terraces commonly known in Rwanda as progressive terraces are required for land on about 32,216 hectares (65% of the total land at risk) used for seasonal crops. Ditches are required on 951 hectares of forest plantation currently without ditches. Hedgerows trees or shrubs are required to protect agricultural land. Grassed waterways are missing on 822 hectares of bench terraces while agroforestry, hedgerows or alley cropping is required on 3,190 hectares on steep slopes. Bamboo plantation is required to rehabilitate 475 hectares affected by gullies and river buffers, while storm water management facilities (SWMF) are recommended for built-up areas of about 842 hectares (2% of the total risk areas). Hedgerows are needed on 3,190 hectares of agricultural land. Afforestation and reforestation are required on extremely high risk areas of about 725 hectares.



Table 18: Recommended erosion control practices in Gakenke District

Sector Name	Afforestation / Refore	Agroforestry / hedgerows	Bambo o plantation	Contour bank terraces	Ditches	Grassed waterways	Already Protected	Water harvesting facilities	Zero tillage/Perennial crops	Grand Total
BUSENGO	4	272	2	1,905	12	55	285	21		2,555
COKO	93	38	41	3,095	33		1,286	58	223	4,867
CYABINGO	1	211		1,108			183	84	1	1,590
GAKENKE	79	103	12	1,817	72	2	516	49	79	2,729
GASHENYI	20	11	7	2,012	54	79	521	23	26	2,752
JANJA		396		1,159	91	225	272	40		2,184
KAMUBUGA	27	565		1,872		167	345	71	13	3,061
KARAMBO		113	142	708	19	16	145	23		1,166
KIVURUGA	15	573	7	1,254	2	150	215	36	28	2,280
MATABA	71	15	57	1,562	175	9	419	40	30	2,380
MINAZI	141	14	53	2,459	48		903	6	161	3,785
MUGUNGA	5	130	24	653	85		114	58	97	1,165
MUHONDO	82	126	76	3,000	120	18	981	26	178	4,609
MUYONGWE	23	32	5	2,078	41	-	447	7	54	2,687
MUZO	15	365	6	1,670	68	76	334	29	107	2,669
NEMBA	11	30		996	3		154	25	5	1,225
RULI	114	7	42	2,458	80	5	890	179	386	4,161
RUSASA		28		487	18		121	5	4	664
RUSHASHI	22	160	1	1,922	28	20	844	62	148	3,208
<b>Grand Total</b>	<b>725</b>	<b>3,190</b>	<b>475</b>	<b>32,216</b>	<b>951</b>	<b>822</b>	<b>8,976</b>	<b>842</b>	<b>1,542</b>	<b>49,738</b>
%	<b>1.5%</b>	<b>6.4%</b>	<b>1%</b>	<b>64.8%</b>	<b>1.9%</b>	<b>1.7%</b>	<b>18%</b>	<b>1.7%</b>	<b>3.1%</b>	<b>100%</b>

## Recommended Erosion Control Practices in Gakenke District



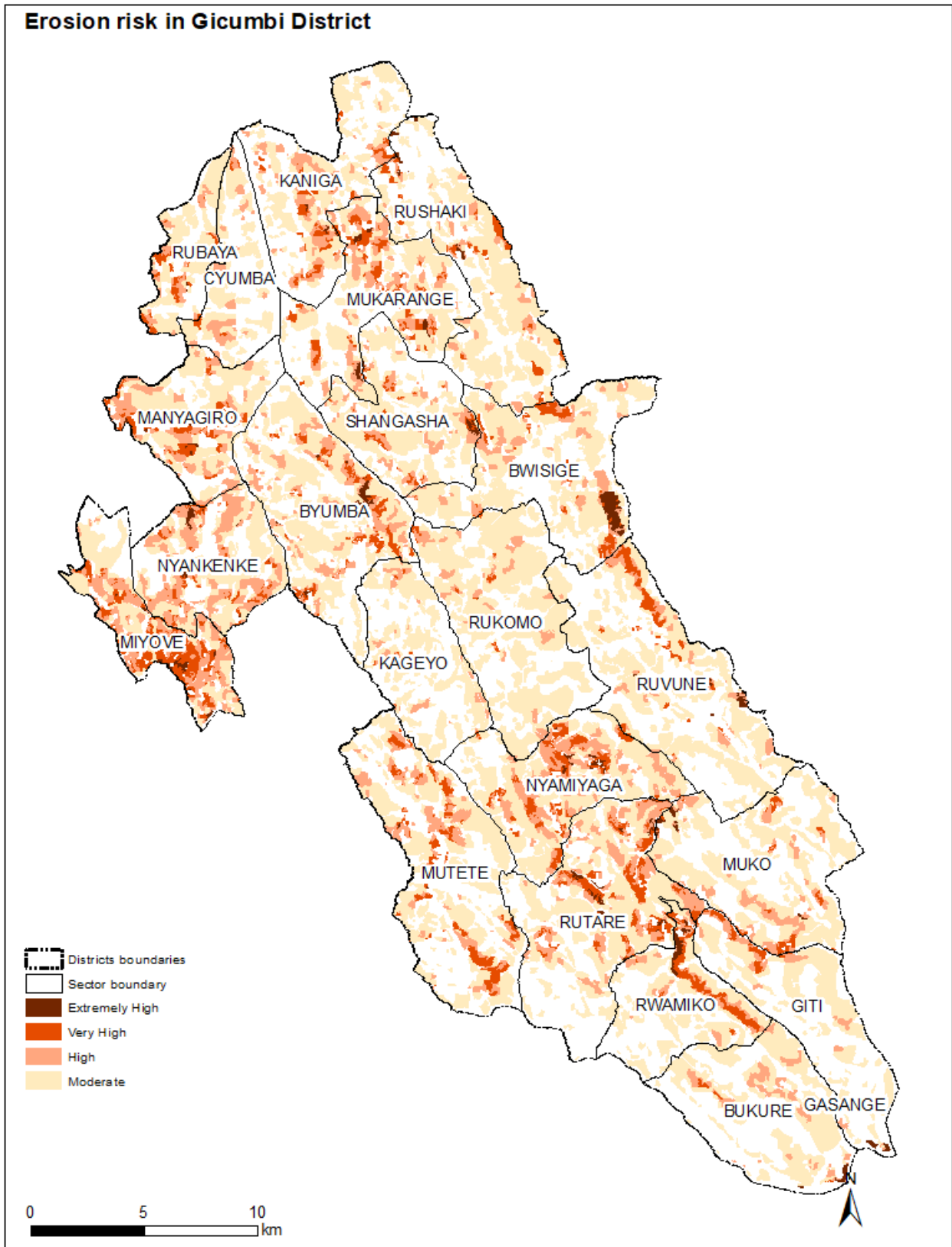
**Figure 16: Recommended erosion control practices in Gakenke District**

### 3.1.3. Erosion control status in Gicumbi District

Erosion risk in Gicumbi is summarised in Table 19 and presented in Figure 17. Erosion risk in Gicumbi District is estimated to **46980** hectares; about 57% of the total district land are highly susceptible to erosion of which 2074 hectares are located in Miyove sector (75% of sector land), 2892 hectares are located in Nyamiyaga sector (75% of sector land), 2054 hectares are located in Manyagiro sector (69% of sector land), 2176 hectares are located in Nyankenke (69% of the sector land), and 1067 hectares are found in Rubaya sector about 66% of the sector land. The least sectors are Giti with 1470 hectares (41%), Kageyo with 1351 hectares (43% of the sector land) susceptible to erosion, Cyumba with 998 hectares (44%), and Bukure with 1806 hectares, about 46% of the total sector land.

**Table 19: Erosion risk per sector in Gicumbi District**

Sector Name	Erosion risk					Sector land(ha)	Percentage(%)
	Extremely High	Very High	High	Moderate	Grand Total (Ha)		
MIYOVE	33	457	733	851	2,074	2,783	75%
NYAMIYAGA	32	302	801	1,757	2,892	3,880	75%
MANYAGIRO	16	213	612	1,212	2,054	2,995	69%
NYANKENKE	27	110	913	1,127	2,176	3,174	69%
RUBAYA	2	101	190	773	1,067	1,622	66%
RUKOMO		34	245	2,843	3,123	5,108	61%
BYUMBA	52	214	612	2,030	2,908	4,896	59%
BWISIGE	111	164	435	2,072	2,782	4,730	59%
RUTARE	53	352	757	2,003	3,165	5,386	59%
SHANGASHA	26	82	348	1,468	1,924	3,285	59%
MUKARANGE	40	275	677	1,366	2358	4,045	58%
RUSHAKI	30	168	267	2,152	2,617	4,675	56%
MUTETE	8	331	606	2,207	3,152	5,654	56%
RWAMIKO	50	223	204	1,074	1,551	2,849	54%
MUKO	32	93	389	1,991	2,505	4,826	52%
RUUVUNE	35	176	283	2,560	3,054	5,930	51%
KANIGA	16	200	501	1,237	1,954	3,926	50%
BUKURE	20	18	272	1,496	1,806	3,966	46%
CYUMBA		23	207	767	998	2,255	44%
KAGEYO		15	147	1,189	1,351	3,134	43%
GITI	21	71	177	1,200	1,470	3,603	41%
<b>Grand Total</b>	<b>603</b>	<b>3.624</b>	<b>9.377</b>	<b>33,376</b>	<b>46,980</b>	<b>82,721</b>	<b>57%</b>



**Figure 17: Erosion risk in Gicumbi District**

Land areas affected by erosive features in Gicumbi District are summarized in Table 18 and the map of erosive features are presented in Figure 18. The results show that Rwamiko sector is the worst affected by gullies on areas estimated to 606 hectares (39% of sector land at risk), followed by Bukure sector on 433 hectares (24% of sector land at risk), and Rutare sector on 712 hectares (22% of sector land at risk). The presence of gullies in Rutare, Manyagiro, and Miyove sectors confirms the findings of CROM model; however the reduced presence of gullies in Miyove (187ha) which was originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 18 and 19. The least sectors affected by gullies are Rushaki with only 63 hectares, Shangasha with only 78 hectares and Nyamiyaga with 115 hectares (4%).

**Table 20: Erosive features and areas affected in Gicumbi District**

Sector Name	Erosive features				Total Features	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
RWAMIKO	606				606	944	1551	39%
BUKURE	420		13		433	1373	1806	24%
RUTARE	688	5	14	5	712	2454	3165	22%
MUKO	521				521	1985	2505	21%
GITI	303		1		304	1166	1470	21%
MANYAGIRO	343			2	345	1709	2054	17%
NYANKENKE	238	116			355	1822	2176	16%
CYUMBA	123		24		148	850	998	15%
MUKARANGE	265	21	12		298	2061	2358	13%
RUBAYA	94		4		98	968	1067	9%
MIYOVE	162	6		20	187	1887	2074	9%
KAGEYO	89	6			96	1255	1351	7%
BYUMBA	200				200	2708	2908	7%
RUUVUNE	209				209	2845	3054	7%
BWISIGE	160				160	2622	2782	6%
RUKOMO	175				175	2948	3123	6%
KANIGA	91	8			98	1856	1954	5%
MUTETE	144	5			150	3002	3152	5%
SHANGASHA	77	1			78	1846	1924	4%
NYAMIYAGA	115				115	2776	2892	4%
RUSHAKI	63				63	2554	2617	2%
<b>Grand Total</b>	<b>5087</b>	<b>168</b>	<b>68</b>	<b>27</b>	<b>5350</b>	<b>41630</b>	<b>46980</b>	<b>11%</b>



### Erosion feature types in Gicumbi District

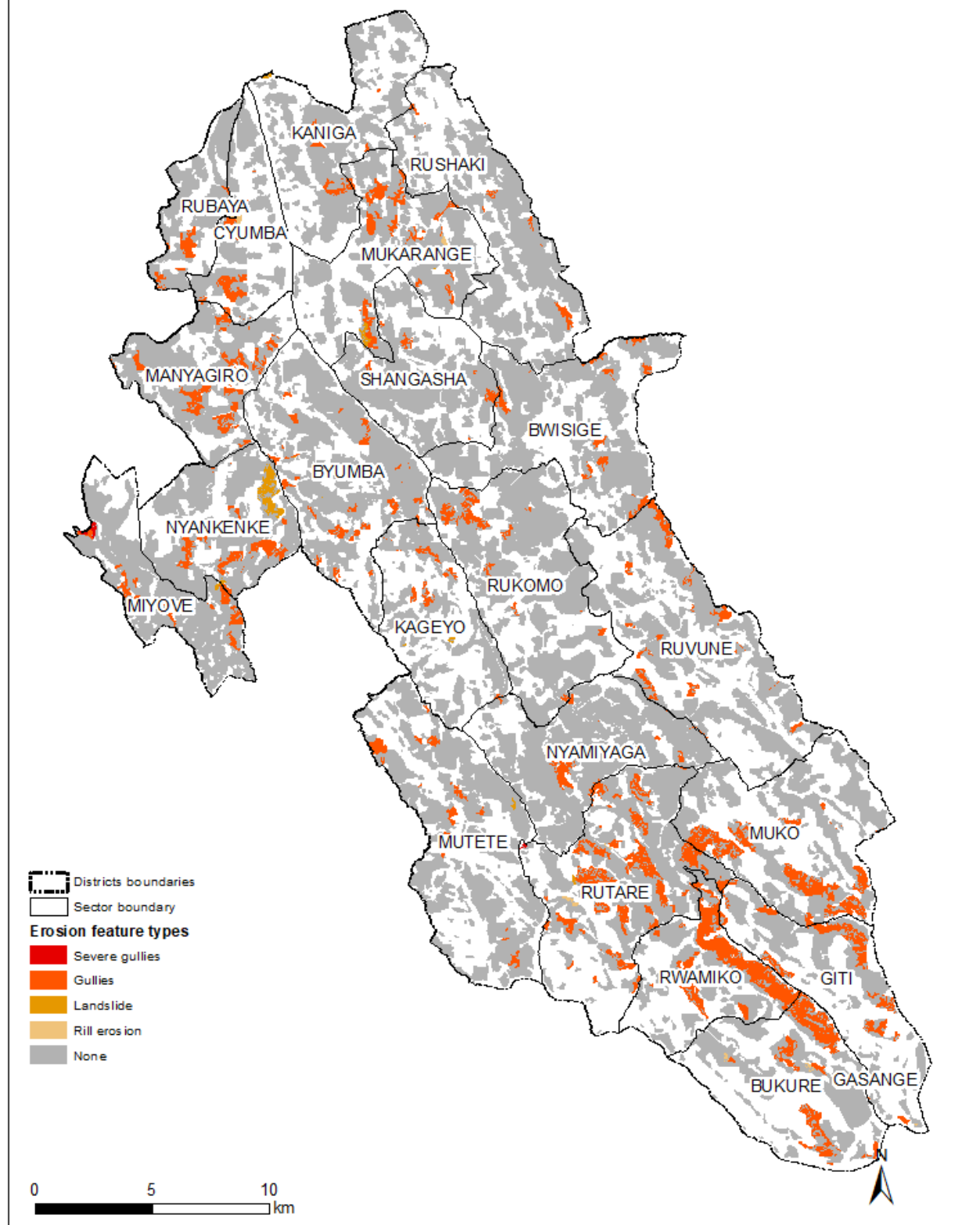


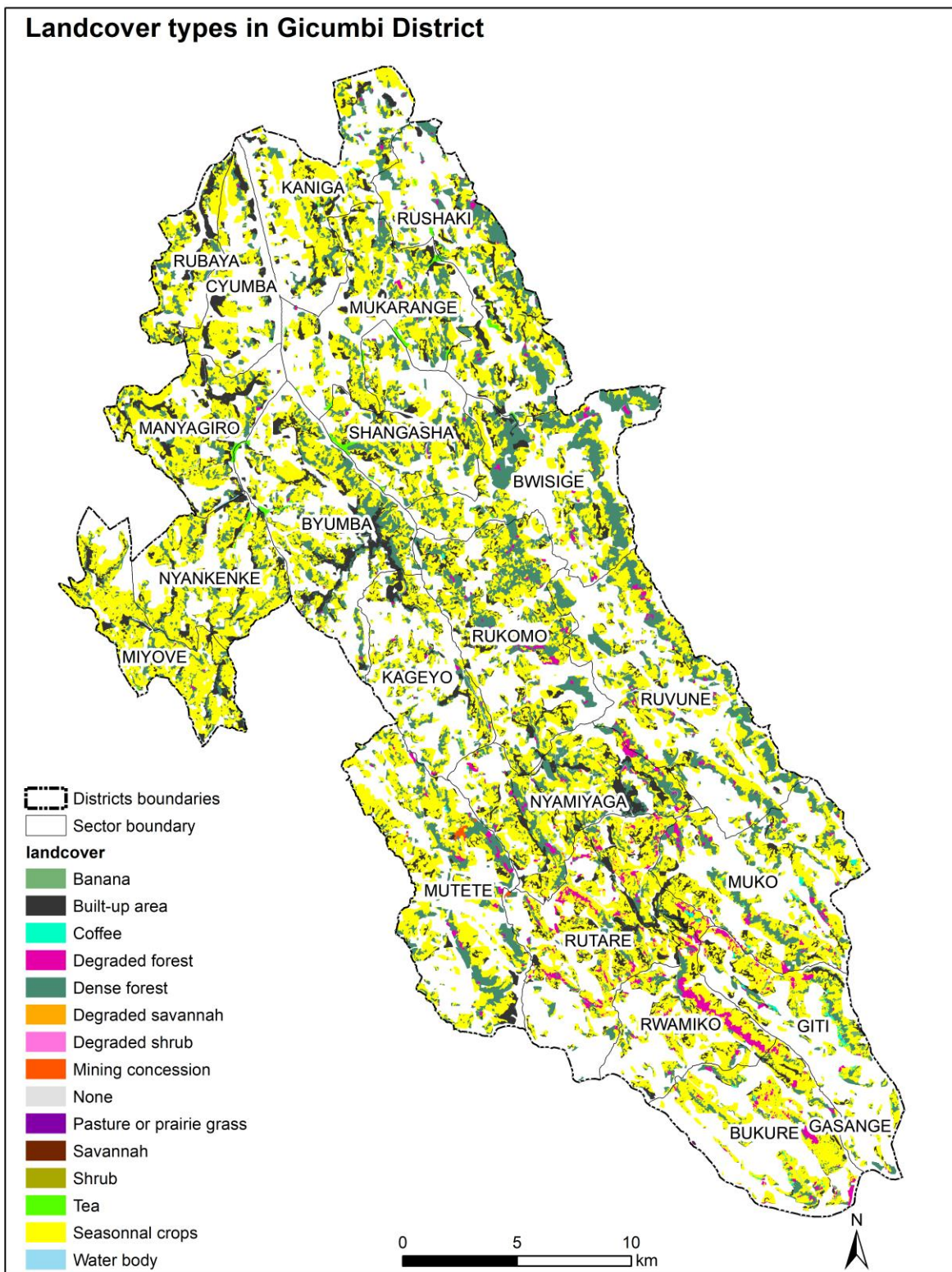
Figure 18: Erosive features detected in Gicumbi District

In term of land use and land cover for areas at risk in Gicumbi, the results of land cover mapping (Table 19 and Figure 19) show that 28,973 hectares (about 62% of the total land at risk) are used for crop cultivation, 10,780 hectares (23% of the total land at risk) are covered by dense forests and 5,606 hectares i.e. 12% are used for built-up and settlement.

**Table 21: Land Use and Vegetation Cover (LUV) for land area at risk in Gicumbi District**

Sector Name	Bana na	Built- up area	Co ffe e	Degra ded forest	Dense forest	Mining and Quarri es	No ne	Seaso nal crops	Tea	Water body	Grand Total
BUKURE	9	98	8	111	227			1347		5	1806
BWISIGE	1	182		36	1176		10	1361	5	10	2782
BYUMBA		593		4	692		2	1583	31	3	2908
CYUMBA	2	199		1	120			666	2	8	998
GITI	41	143	30	51	236			969			1470
KAGEYO		206		13	294			837			1351
KANIGA		319	2	5	376			1249	3		1954
MANYAGIRO		385		4	313		1	1324	9	17	2054
MIYOVE		206		2	227			1618	1	20	2074
MUKARANGE		280		10	592			1420	54	1	2358
MUKO	16	190	19	83	641		2	1546		8	2505
MUTETE	5	203	2	68	793	20		2045		14	3152
NYAMIYAGA	6	504	1	83	661	1		1624		13	2892
NYANKENKE		272			309			1579	9	7	2176
RUBAYA		236			198			628		5	1067
RUKOMO		360	3	59	931			1769		1	3123
RUSHAKI		303		19	953		1	1304	36		2617
RUTARE	6	477	7	225	343	5		2094		8	3165
RUVUNE		144	1	68	1033		4	1795		8	3054
RWAMIKO		139		215	146			1047		5	1551
SHANGASHA		187		5	517			1168	46		1924
<b>Grand Total</b>	<b>87</b>	<b>5626</b>	<b>74</b>	<b>1063</b>	<b>10780</b>	<b>26</b>	<b>20</b>	<b>28973</b>	<b>197</b>	<b>134</b>	<b>46980</b>
<b>%</b>	<b>0%</b>	<b>12%</b>	<b>0%</b>	<b>2%</b>	<b>23%</b>	<b>0%</b>	<b>0%</b>	<b>62%</b>	<b>0%</b>	<b>0%</b>	<b>100%</b>





**Figure 19: Land Cover types in Gicumbi District**

About existing erosion control practices in Gicumbi district, only 38% of land at risk is protected by forests (**10,796** hectares), contour bank terraces or progressive terraces with ditches (**2177** hectares), and bench terraces (**4817** hectares). Although still low, the highest protected sectors are Nyankenke with 73% (1581 hectares) of its land at risk protected, followed by Miyove where 68% (1409 hectares) of the total land at risk is protected and Shangasha with 65% of land protected (1256 hectares). The least protected sectors are Rwamiko with only 10% protected, Bukure (only 13% protected) and Rutare (13%). The visual interpretation of World View images confirms earlier findings by CROM model that Rwamiko, Bukure, Rutare and Cyumba sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected

**Table 22: Erosion control practices already in place in Gicumbi District**

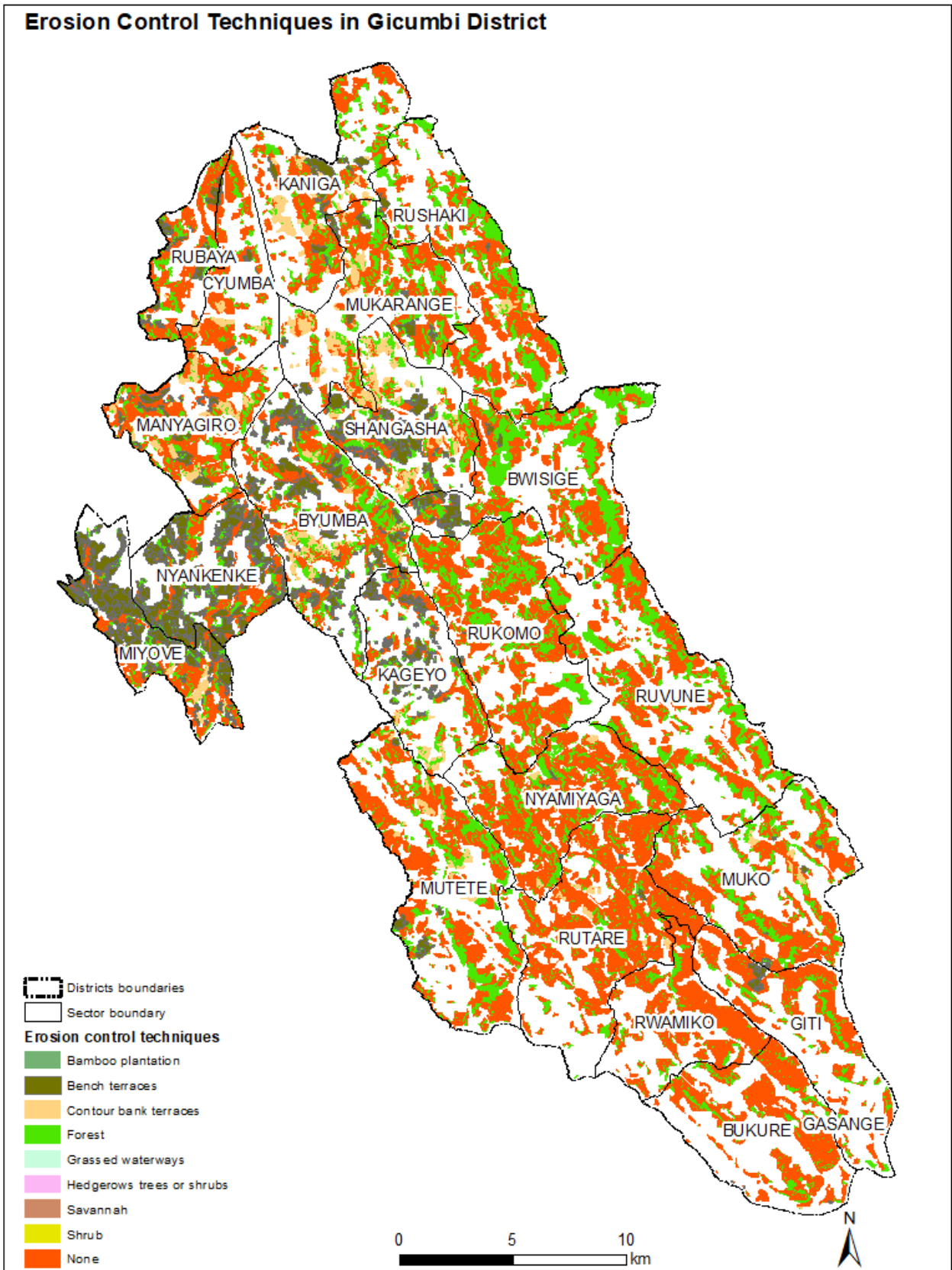
Sector Name	Erosion control in place			Total protected (Ha)	Unprotected (Ha)	Grand Total (Ha)	% Protected
	Bench terraces	Contour bank terraces	Forest				
NYANKENKE	1,273		309	1,581	595	2,176	73%
MIYOVE	1,089	93	227	1,409	665	2,074	68%
SHANGASHA	400	339	517	1,256	668	1,924	65%
BYUMBA	670	251	692	1,614	1,294	2,908	56%
KAGEYO	314	88	294	696	655	1,351	52%
BWISIGE	170		1,185	1,355	1,427	2,782	49%
MUKARANGE	140	335	592	1,067	1,291	2,358	45%
KANIGA	184	278	380	842	1,112	1,954	43%
RUSHAKI	27	61	953	1,041	1,575	2,617	40%
MANYAGIRO	196	281	313	790	1,264	2,054	38%
RUBAYA	159	12	198	369	697	1,067	35%
RUVUNE		2	1,033	1,036	2,018	3,054	34%
MUTETE	72	154	801	1,027	2,125	3,152	33%
RUKOMO	6	9	931	946	2,177	3,123	30%
MUKO	25	52	641	718	1,788	2,505	29%
NYAMIYAGA	12	52	661	725	2,167	2,892	25%
CYUMBA	31	77	120	227	770	998	23%
GITI	51	8	236	295	1,175	1,470	20%
RUTARE	12	74	340	425	2,740	3,165	13%
BUKURE	1	4	227	232	1,574	1,806	13%
RWAMIKO		6	146	152	1,399	1,551	10%
<b>Grand Total</b>	<b>4,831</b>	<b>2,177</b>	<b>10,796</b>	<b>17,804</b>	<b>29,177</b>	<b>46,980</b>	<b>38%</b>

Erosion control practices in Gicumbi District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 21 shows that about 18,700 hectares (which is 40% of the total land at risk) are suitable for contour bank terraces or progressive terraces, 5661 hectares are storm water management facilities or water harvesting infrastructures (SWMF) and 1190 hectares are Afforestation & Reforestation. Others are Bench terraces (2905 hectares).

**Table 23: Recommended erosion control practices in Gicumbi District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	None	Water harvesting facilities	Zero tillage	Grand Total
BUKURE	111	3	5	1	1344		227	98	18	1806
BWISIGE	39	177	12	130	1045		1185	187	6	2782
BYUMBA	9	921	6	426	227		692	594	31	2908
CYUMBA	3	110	8	121	433		120	199	4	998
GITI	55	66		33	866		236	143	71	1470
KAGEYO	13	403		265	170		294	206		1351
KANIGA	10	465		77	703		380	314	5	1954
MANYAGIRO	5	496	18	247	582		313	384	9	2054
MIYOVE	5	1207	20	312	96		227	206	1	2074
MUKARANGE	30	527	1	163	707		596	280	54	2358
MUKO	83	65	10	37	1432		653	190	35	2505
MUTETE	99	245	14	271	1484		795	237	7	3152
NYAMIYAGA	90	65	13	34	1518		661	504	7	2892
NYANKENKE		1268	7	268	43		309	272	9	2176
RUBAYA	4	172	5	320	131		198	238		1067
RUKOMO	68	15	1		1745		931	360	3	3123
RUSHAKI	34	106	1	27	1155		953	303	36	2617
RUTARE	231	104	8	7	1983		343	476	13	3165
RUVUNE	77	35	15	56	1693		1033	144	1	3054
RWAMIKO	215	15	5	17	1014	5	140	139		1551
SHANGASHA	10	745		91	328		517	187	46	1924
Grand Total	1190	7209	149	2905	18700	5	10803	5661	358	46980
%	3%	15%	0%	6%	40%	0%	23%	12%	1%	100%

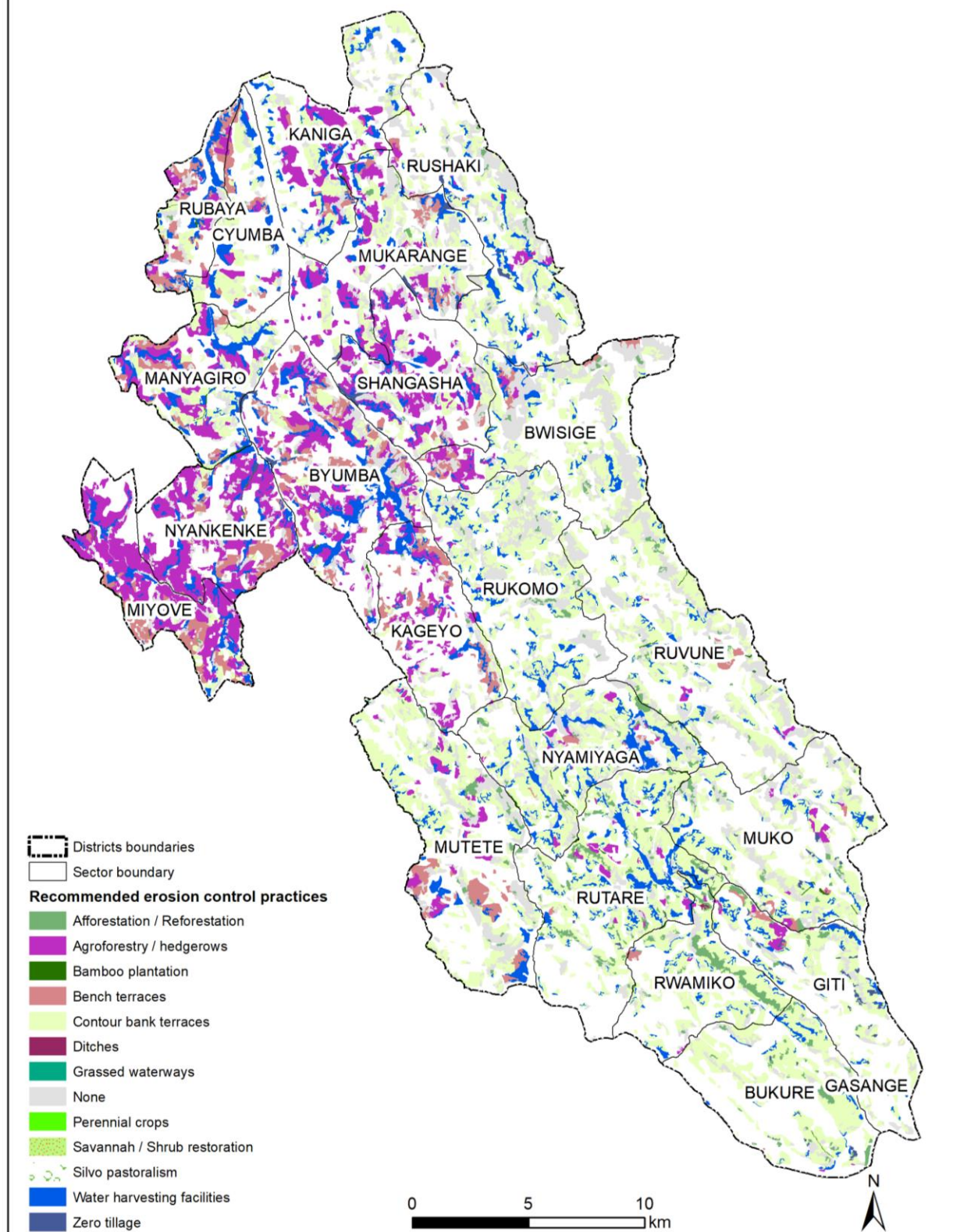
**Note:** No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (**SWMF**) or **water harvesting infrastructure** is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 20: Erosion control techniques in place in Gicumbi District**



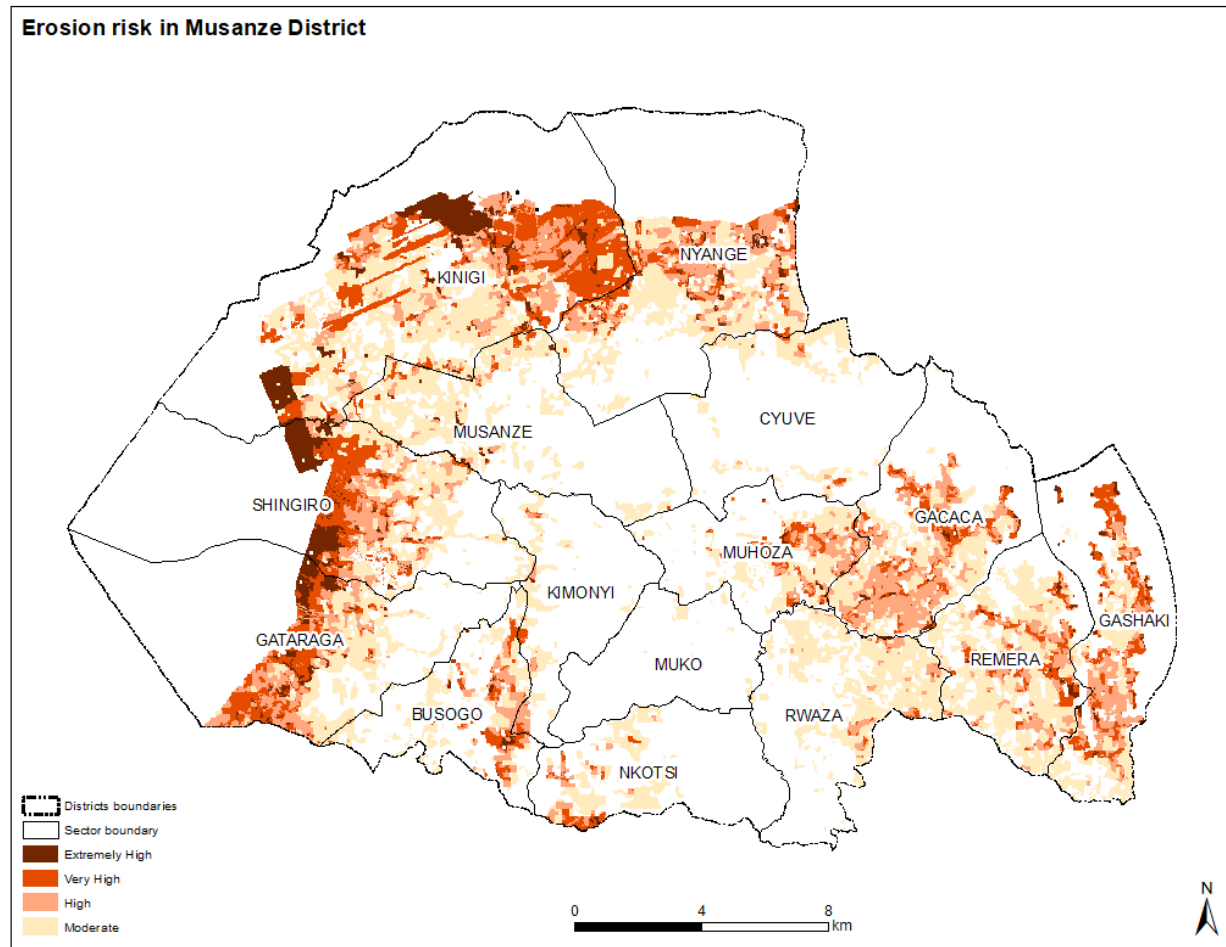
## Recommended Erosion Control Practices in Gicumbi District



**Figure 21: Recommended erosion control practices in Gicumbi District**

### 3.1.4. Erosion control status in Musanze District

Erosion risk in Musanze is summarised in Table 22 and presented in figure 22. Erosion risk area is estimated to 18880 hectares; about 37% of the total district land is highly susceptible to erosion of which 1215 hectares are located in Gashaki sector (94% of sector land), 1610 hectares are located in Remera sector (70% of sector land), and 598 hectares are located in Gacaca sector (52% of the sector land). The least sectors are Muko with only 48 hectares (2%) susceptible to erosion, Cyuve with 424 hectares (14%), and Kimonyi with 231 hectares, about 14% of the total sector land. Compared to other Districts of the Northern Province, Musanze District is the least affected by erosion risk.



**Figure 22: Erosion risk in Musanze District**

**Table 24: Erosion risk per sector in Musanze District**

Sector Name	Erosion risk					Sector land(ha)	Percentage(%)
	Extremely High	Very High	High	Moderate	Grand Total		
GASHAKI	35	280	417	483	1,215	1,299	94%
REMERERA	15	161	326	1,108	1,610	2,298	70%
GACACA	30	245	694	598	1,567	2,987	52%
KINIGI	460	1,182	787	1,576	4,005	8,105	49%

Sector Name	Erosion risk					Sector land(ha)	Percentage(%)
	Extremely High	Very High	High	Moderate	Grand Total		
RWAZA	2	12	92	963	1,068	2,776	38%
NYANGE	61	252	661	1,092	2,065	5,432	38%
BUSOGO	19	112	188	432	751	2,006	37%
MUHOZA	14	91	218	450	773	2,134	36%
SHINGIRO	252	456	419	716	1,844	5,341	35%
GATARAGA	131	363	465	633	1,593	5,053	32%
MUSANZE	18	58	60	924	1,060	3,377	31%
NKOTSI	3	63	80	353	499	2,432	21%
KIMONYI	2	24	64	231	321	2,159	15%
CYUVE		13	23	424	459	3,377	14%
MUKO				48	48	1,940	2%
<b>Grand Total</b>	<b>1,042</b>	<b>3,311</b>	<b>4,495</b>	<b>10,031</b>	<b>18,880</b>	<b>50,717</b>	<b>37%</b>

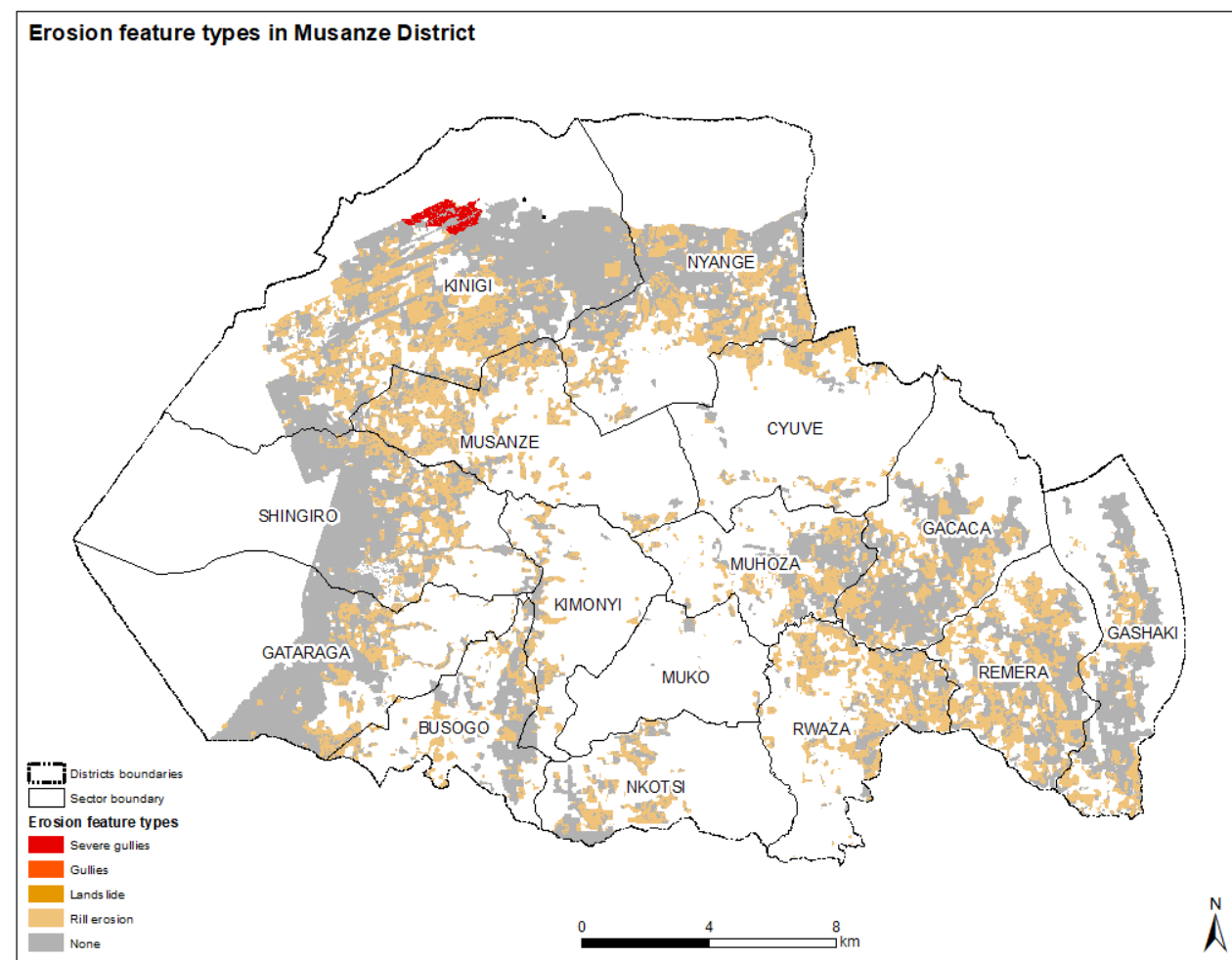
Land areas at risk which are already affected by erosive features in Musanze District are summarized in Table 23 and the map of erosive features are presented in Figure 23. The entire District of Musanze is reported as having rill erosion as the predominant erosion feature type, apart from Kinigi Sector which has severe gullies in addition to rill erosion. The results show that Kinigi sector is also the worst affected by rill erosion on areas estimated to 1,469 hectares followed by Musanze sector with 846 hectares affected, Rwaza sector on 842 hectares, Cyuve sector on 342 hectares, and Remera sector on 967 hectares. The presence of rill erosion in Rwaza, Cyuve, Musanze and Remera confirms the findings of CROM model. The least sectors affected by rill erosion in Musanze District are Gataraga with 396 hectares, Shingiro with 588 hectares and Gashaki with 436 hectares. More details are presented in Table 25.

**Table 25: Erosive features in Musanze District**

Sector Name	Erosive features		Total Features	None	Grand Total	% features
	Rill erosion	Severe gullies				
MUSANZE	846		846	214	1060	80%
RWAZA	842		842	227	1068	79%
CYUVE	352		352	108	459	77%
REMERA	967		967	643	1,610	60%
KIMONYI	183		183	137	321	57%
NKOTSI	268		268	231	499	54%
MUHOZA	387		387	386	773	50%
MUKO	23		23	25	48	49%
NYANGE	957		957	1,108	2,065	46%
BUSOGO	341		341	410	751	45%
KINIGI	1,469	129	1,598	2,408	4,005	40%
GACACA	566		566	1,001	1,567	36%
GASHAKI	436		436	779	1,215	36%
SHINGIRO	588		588	1,255	1,844	32%



Sector Name	Erosive features		Total Features	None	Grand Total	% features
	Rill erosion	Severe gullies				
GATARAGA	396		396	1,197	1,593	25%
<b>Grand Total</b>	<b>8,622</b>	<b>129</b>	<b>8,751</b>	<b>10,129</b>	<b>18,880</b>	<b>46%</b>

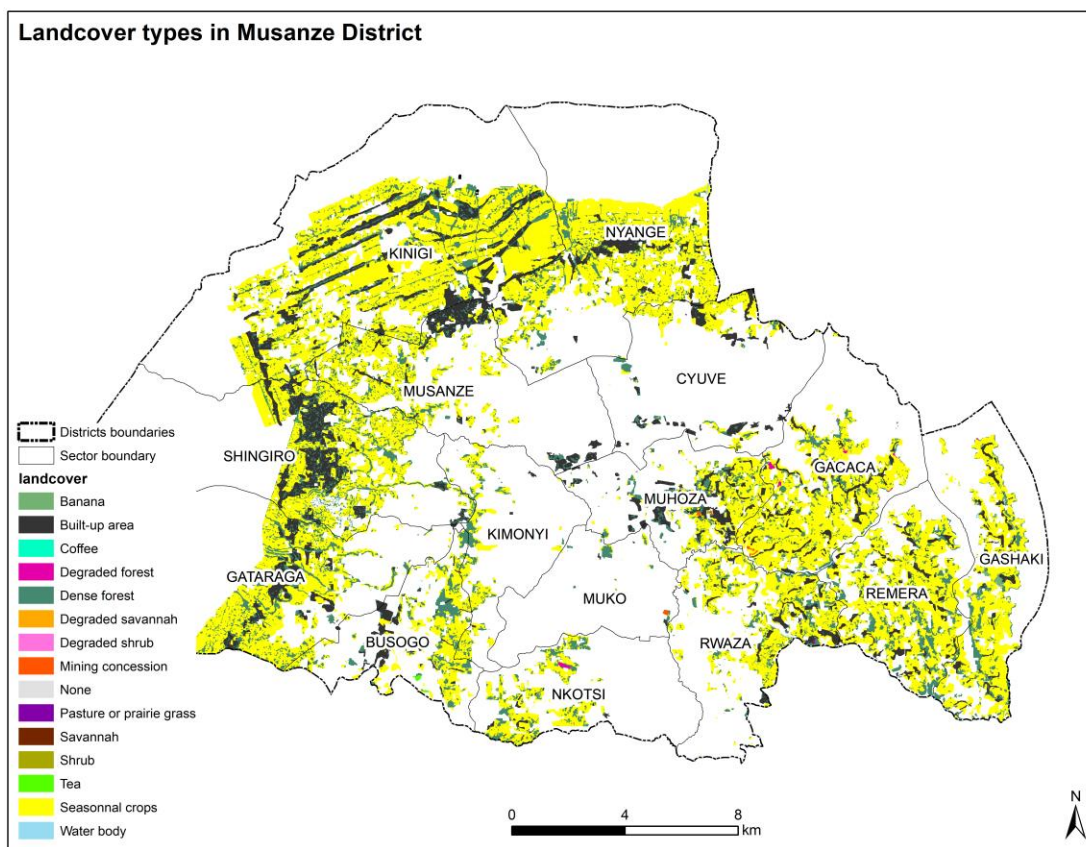


**Figure 23: Erosive features detected in Musanze District**

In term of land use and land cover of areas at risk in Musanze, the results of land cover mapping (Table 24 and Figure 24) show that 13,778 hectares (73% of the total land at risk) are used for seasonal cropping, 2084 hectares (11 % of the total land at risk) are covered by healthy forests and 2,950 hectares i.e. 16% are covered by Built-up area.

**Table 26: Land Use and Vegetation Cover (LUVC) for land area at risk in Musanze District**

Sector Name	Banana	Built-up area	Degraded forest	Dense forest	Mining and Quarries	Seasonal crops	Tea	Water body	Grand Total
BUSOGO		107		170		469	6		751
CYUVE		150		39		270			459
GACACA	5	166	8	114	3	1,268		3	1,567
GASHAKI	15	107		134		957		2	1,215
GATARAGA		221		235		1,136			1,593
KIMONYI		5		64		252			321
KINIGI		632		337		3,036			4,005
MUHOZA		228		101	4	435		4	773
MUKO		7		24	4	13			48
MUSANZE		267		59		734			1,060
NKOTSI	1	16	6	115		361			499
NYANGE		250		184		1,629		2	2,065
REMERA	1	156		212		1,242		0	1,610
RWAZA		118		118		831		2	1,068
SHINGIRO		521		178	1	1,144			1,844
<b>Grand Total</b>	<b>22</b>	<b>2,950</b>	<b>13</b>	<b>2,084</b>	<b>13</b>	<b>13,778</b>	<b>6</b>	<b>14</b>	<b>18,880</b>
<b>%</b>	<b>0%</b>	<b>16%</b>	<b>0%</b>	<b>11%</b>	<b>0%</b>	<b>73%</b>	<b>0%</b>	<b>0%</b>	<b>100%</b>



**Figure 24: Land cover and Land Use in Musanze District**

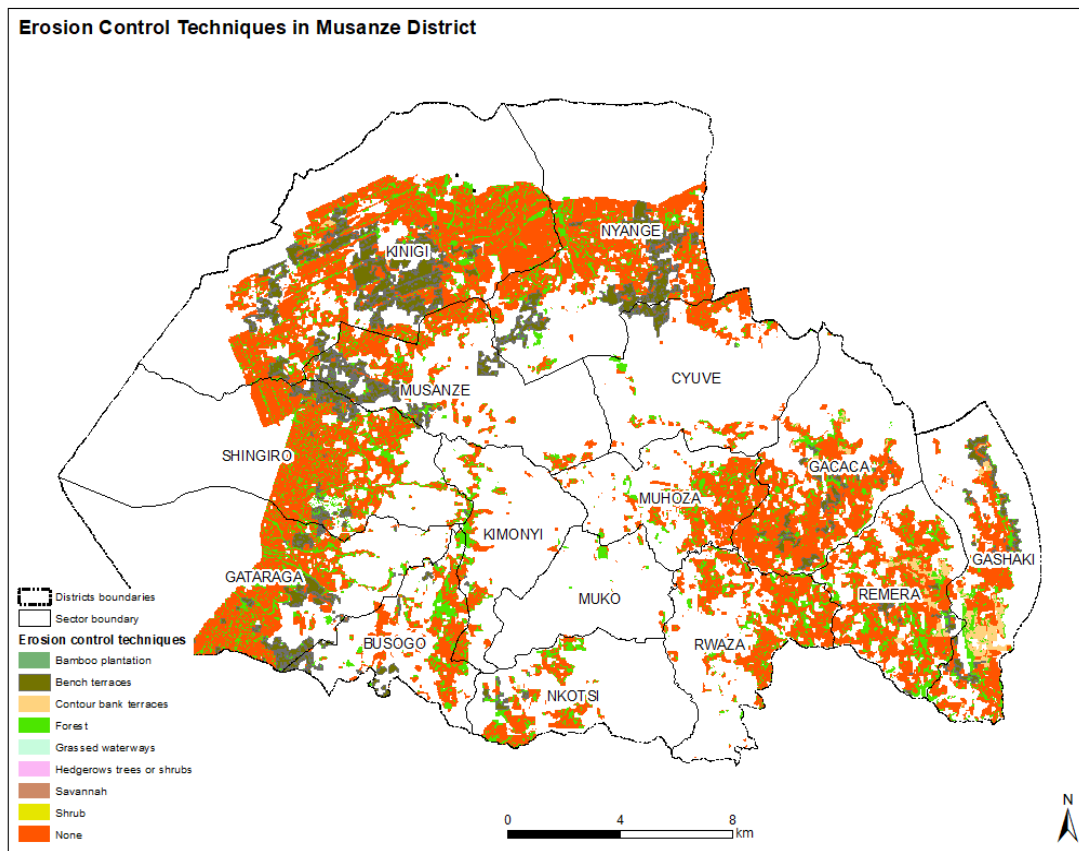
About existing erosion control practices in Musanze district, only 26% of land at risk is protected by forests (2084 hectares), contour bank terraces or progressive terraces with ditches (341 hectares), and bench terraces (2560 hectares). Although still low, the highest protected sectors are Muko with 49% of its land at risk protected (24 hectares), followed by Gashaki where 38% of the total land at risk is protected (464 hectares) and Musanze with 35% of land protected. The least protected sectors are Rwaza with only 11% protected, Muhoza (13% protected), Gacaca (19%) and Shingiro (20% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Muko, Gashaki and Musanze sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected

**Table 27: Erosion control practices already in place in Musanze District**

Sector Name	Erosion control in place			Total protected land (ha)	Unprotected land (ha)	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
MUKO			24	24	24	48	49%
GASHAKI	153	177	134	464	751	1,215	38%
BUSOGO	91		170	261	491	751	35%

Sector Name	Erosion control in place			Total protected land (ha)	Unprotected land (ha)	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
MUSANZE	295		59	354	706	1,060	33%
GATARAGA	261		235	497	1,096	1,593	31%
KINIGI	858	20	337	1215	2,790	4,005	30%
NYANGE	432		184	617	1,449	2,065	30%
NKOTSI	28	2	115	145	354	499	29%
CYUVE	73		39	112	347	459	24%
REMERA	51	110	212	373	1,237	1,610	23%
KIMONYI	2		64	66	255	321	20%
SHINGIRO	167		179	345	1,499	1,844	19%
GACACA	148	30	114	292	1,275	1,567	19%
MUHOZA			103	103	670	773	13%
RWAZA		1	118	119	950	1,068	11%
<b>Grand Total</b>	<b>2560</b>	<b>341</b>	<b>2086</b>	<b>4987</b>	<b>13,893</b>	<b>18,880</b>	<b>26%</b>

Erosion control practices in Musanze District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 26 shows that about 7248 hectares (which is 38% of the total land at risk) are suitable for hedgerows/Agroforestry, while 5996 hectares are suitable for contour bank terraces on agricultural land with seasonal crops, and Storm water management facilities (SWMF) are recommended on 2956 hectares of built-up areas.

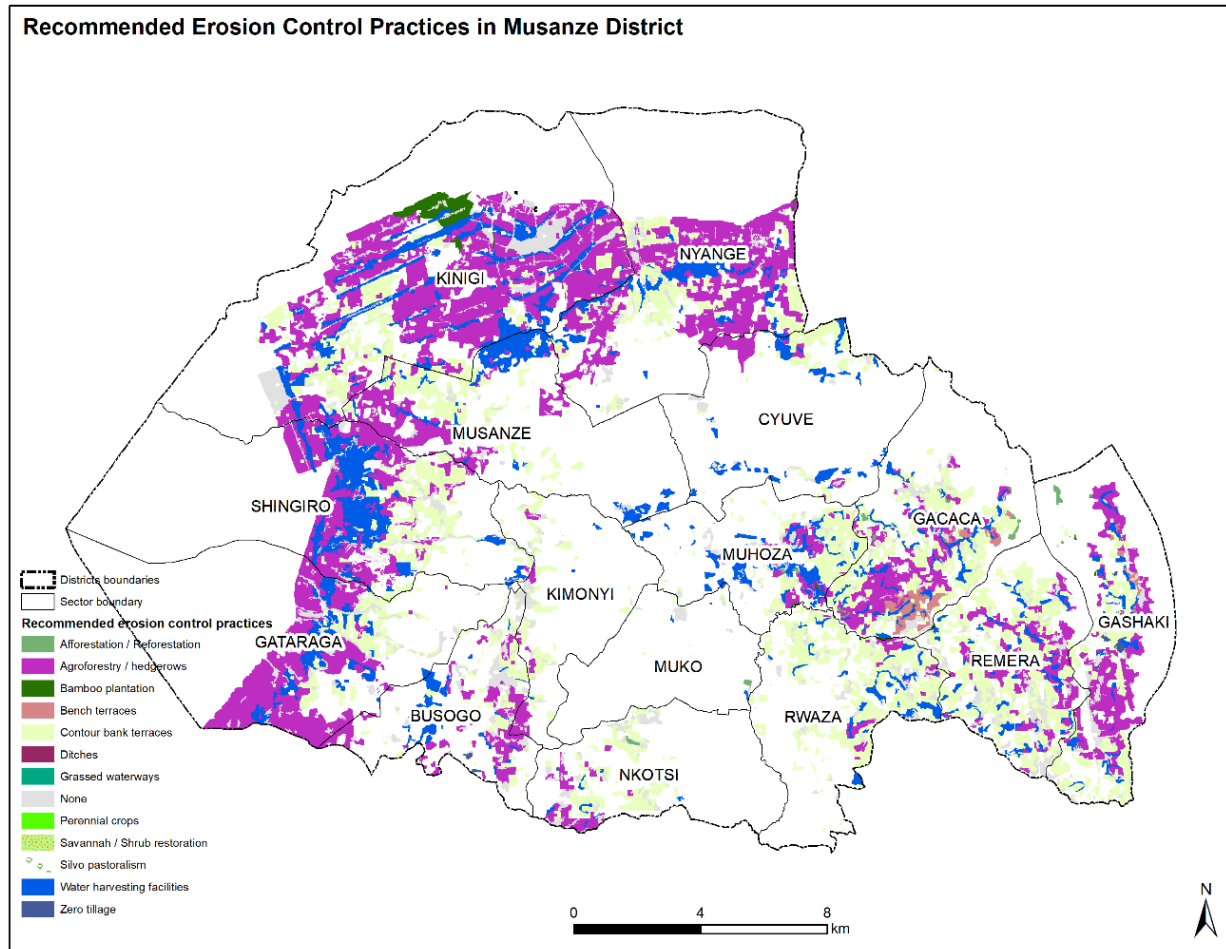


**Figure 25: Erosion control techniques in place in Musanze District**

**Table 28: Recommended erosion control practices in Musanze District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terrace	Zero tillage/ perennial crops	Water harvesting facilities	Already protected	Grand Total
BUSOGO		271			198	6	107	170	751
CYUVE		94			176		150	39	459
GACACA	22	418	3	136	683	5	166	134	1567
GASHAKI	11	490	2	30	420	15	107	139	1215
GATARAGA		880			255		222	235	1593
KIMONYI		73			179		5	64	321
KINIGI		2182	138		555		632	498	4005
MUHOZA	4	124	3		310		228	104	773
MUKO	4				13		7	24	48
MUSANZE		371			363		267	59	1060
NKOTSI	6	100			253	1	17	121	499
NYANGE		1143	2		487		252	181	2065
REMERA		349	0		891	1	156	214	1610
RWAZA		68	2		763		118	118	1068
SHINGIRO		685			450		522	187	1844
<b>Grand Total</b>	<b>48</b>	<b>7248</b>	<b>151</b>	<b>166</b>	<b>5996</b>	<b>28</b>	<b>2956</b>	<b>2287</b>	<b>18880</b>
<b>%</b>	<b>0.3%</b>	<b>38.4%</b>	<b>0.8%</b>	<b>0.9%</b>	<b>31.8%</b>	<b>0.1%</b>	<b>15.7%</b>	<b>12.1%</b>	<b>100.0%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 26: Recommended erosion control practices in Musanze District**



### 3.1.5. Erosion control status in Rulindo District

Erosion risk in Rulindo is summarised in Table 27 and presented in figure 27. Erosion risk area is estimated to 38,344 hectares; i.e. 68% of the total district land is highly susceptible to erosion of which 2,847 hectares are located in Rusiga Sector (89%), 3589 hectares are located in Mbogo sector (87%) and 2,891 hectares are located in Cyinzuzi sector (86% of sector land). The least sectors (although still land at risk remains high) Ntarabana with 1441 hectares susceptible to erosion (41%), Masoro with only 1296 hectares susceptible to erosion (44% of sector land), and Base sector with 1409 hectares, about 49% of the total sector land.

**Table 29: Erosion risk per sector in Rulindo District**

Sector Name	Erosion risk					Sector land(ha )	Percent age(%)
	Extremely High	Very High	High	Moderate	Grand Total		
RUSIGA	91	894	1141	722	2847	3194	89%
MBOGO	271	736	1676	902	3585	4104	87%
CYINZUZI	457	900	955	580	2891	3344	86%
BUSHOKI	267	1031	913	745	2956	3545	83%
SHYORONGI	149	839	983	1712	3682	4609	80%
CYUNGO	15	305	612	522	1454	1966	74%
TUMBA	93	459	896	1030	2478	3380	73%
BUREGA	175	572	625	955	2328	3231	72%
NGOMA	228	605	585	817	2235	3163	71%
RUKOZO	10	211	438	749	1408	1999	70%
KISARO	32	417	724	1241	2415	3797	64%
MURAMBI	35	557	534	657	1782	2946	61%
KINIHIRA	61	308	327	709	1405	2692	52%
BUYOGA	88	306	724	1613	2732	5391	51%
BASE	11	121	420	857	1409	2871	49%
MASORO	68	80	354	794	1296	2966	44%
NTARABANA	89	237	440	675	1441	3500	41%
<b>Grand Total</b>	<b>2140</b>	<b>8578</b>	<b>12346</b>	<b>15280</b>	<b>38344</b>	<b>56699</b>	<b>68%</b>

Land areas affected by erosive features in Rulindo District are summarized in Table 28 and the map of erosive features are presented in Figure 28. The results show that Shyorongi sector is the worst affected by gullies on an area estimated to 800 hectares (22% of sector land at risk) followed by Rukozo sector on 235 hectares (17% of sector land at risk), and Rusiga sector on 466 hectares (16% of sector land at risk). The presence of gullies in Shyorongi, Rukozo, Rusiga, Cyinzuzi and Tumba sectors confirms the findings of CROM model; however the reduced presence of gullies in Kisaro (131 ha) Ntarabana (61 ha) and Burega (208 ha) which was originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in these sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case.

**Table 30: Erosive features and land area affected in Rulindo District**

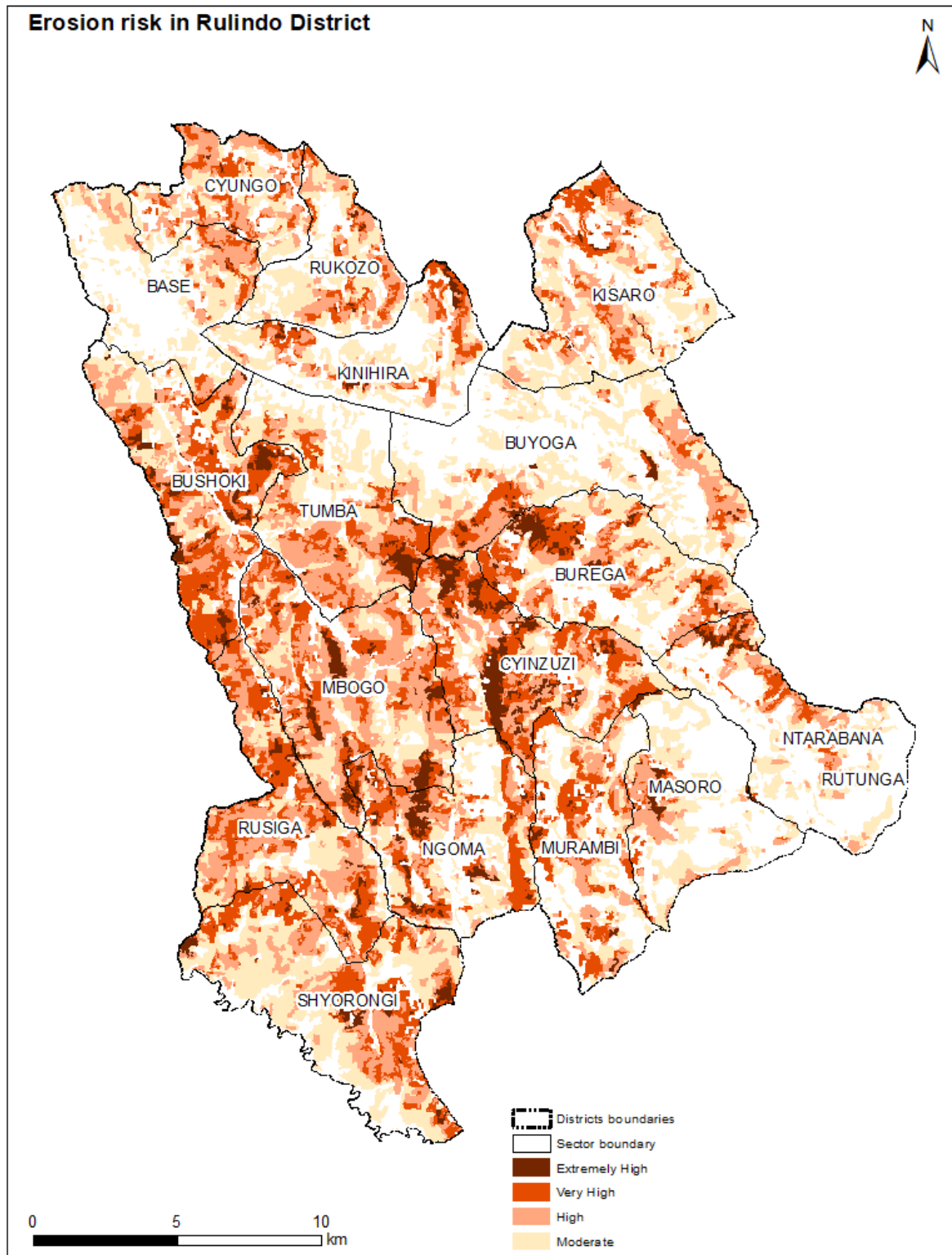
Sector Name	Erosive features				Total Features	None	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
SHYORONGI	780	2	4	14	800	2883	3682	22%
RUKOZO	233	1			235	1174	1408	17%
RUSIGA	431			35	466	2381	2847	16%
TUMBA	390				390	2088	2478	16%
CYINZUZI	384			45	430	2461	2891	15%
BASE	109			95	204	1205	1409	14%
MBOGO	146			221	366	3218	3585	10%
BUREGA	208				208	2120	2328	9%
CYUNGO	79			45	124	1331	1454	9%
MURAMBI	124			1	125	1658	1782	7%
KINIHIRA	79			16	95	1310	1405	7%
BUYOGA	149			19	168	2564	2732	6%
KISARO	131				131	2283	2415	5%
NGOMA	99				99	2136	2235	4%
BUSHOKI	129				129	2827	2956	4%
NTARABANA	59	3			61	1380	1441	4%
MASORO	28	1		16	45	1251	1296	3%
<b>Grand Total</b>	<b>3558</b>	<b>6</b>	<b>4</b>	<b>507</b>	<b>4075</b>	<b>34269</b>	<b>38344</b>	<b>11%</b>

In term of land use and land cover of areas at risk in Rulindo, the results of land cover mapping (Table 29 and Figure 29) show that **25,710** hectares (67% of the total land at risk) are used for seasonal cropping, 9145 hectares (24% of the total land at risk) are covered by healthy forests and 2566 hectares i.e. 7% are covered by Built-up and settlement, 221 hectares (1% of the total land at risk) are covered by Banana and coffee is planted on an area on 228 hectares.

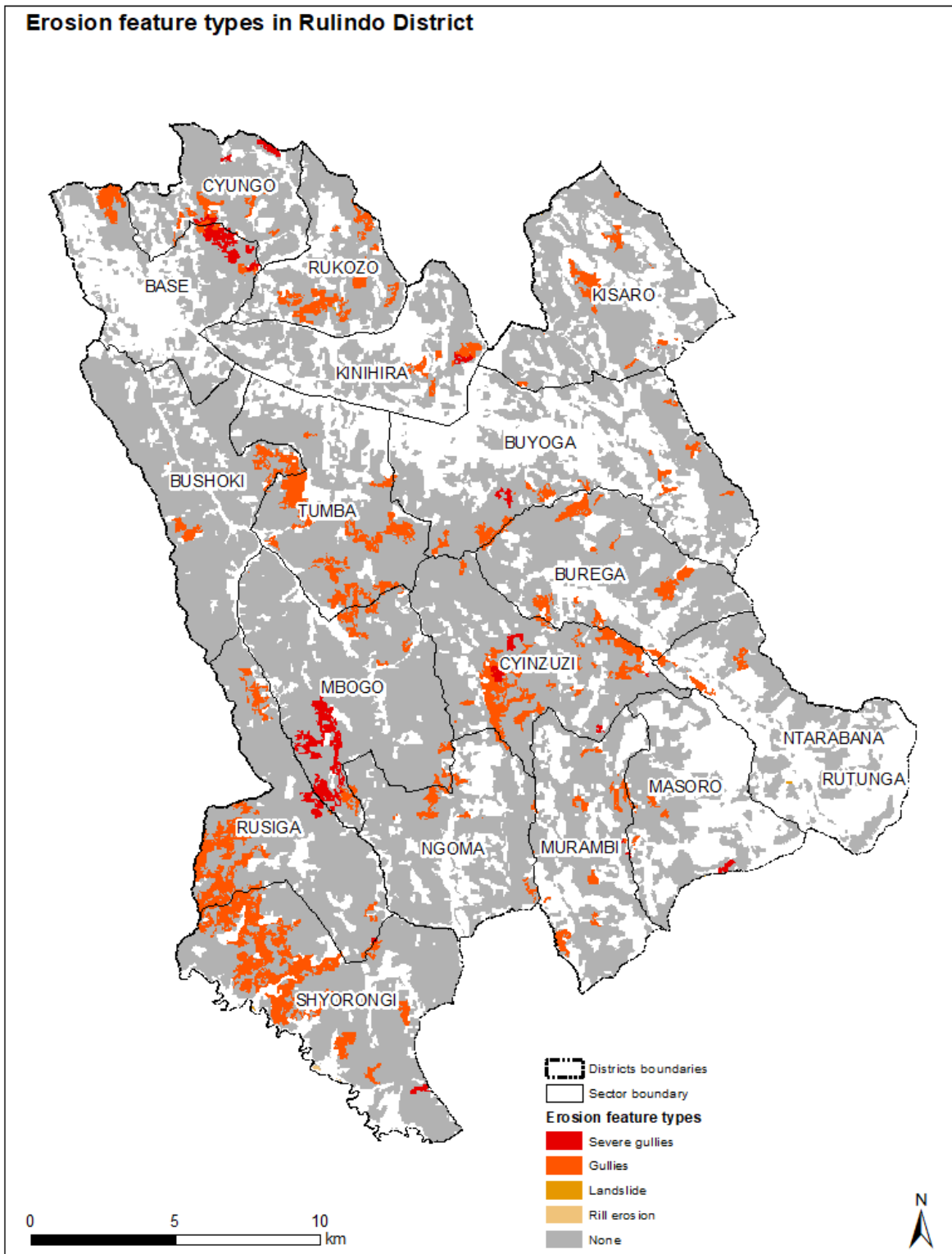
**Table 31: Land Use and Vegetation Cover (LUV) for land area at risk in Rulindo District**

Sector Name	Bana na	Built-up area	Cof fee	Degraded forest	Dense forest	Mining conces sion	No ne	Season nal crops	Tea	Water body	Grand Total
BASE		126		1	252	2		1016	10	2	1409
BUREGA		87	24	1	521	5		1680		10	2328
BUSHOKI	1	169	37	2	500	3	2	2238	2	2	2956
BUYOGA	5	129	37		764	12		1748	9	28	2732
CYINZUZI	25	97	25	4	824	20		1871		25	2891
CYUNGO		91			268	4		1091	0	1	1454
KINIHIRA		152			231		1	1001	20		1405
KISARO	2	122	4	3	453	1		1810	3	17	2415
MASORO	23	285		11	478	20		433		45	1296

Sector Name	Bana na	Built- up area	Cof fee	Degraded forest	Dense forest	Mining conces sion	No ne	Season nal crops	Tea	Water body	Grand Total
MBOGO	19	75	16		803			2663		9	3585
MURAMBI	61	244	16	3	566			888		3	1782
NGOMA	22	52	5	2	645		4	1490		15	2235
NTARABANA	7	117		14	501	12		775		14	1441
RUKOZO		84			267			1021	34	2	1408
RUSIGA	3	55	8	2	743	1		2030		4	2847
SHYORONGI	51	612		7	853		2	2131		26	3682
TUMBA		71	55		477		49	1823		3	2478
<b>Grand Total</b>	<b>221</b>	<b>2566</b>	<b>228</b>	<b>50</b>	<b>9145</b>	<b>81</b>	<b>58</b>	<b>25710</b>	<b>78</b>	<b>207</b>	<b>38344</b>
<b>%</b>	<b>1%</b>	<b>7%</b>	<b>1%</b>	<b>0%</b>	<b>24%</b>	<b>0%</b>	<b>0%</b>	<b>67%</b>	<b>0%</b>	<b>1%</b>	<b>100%</b>

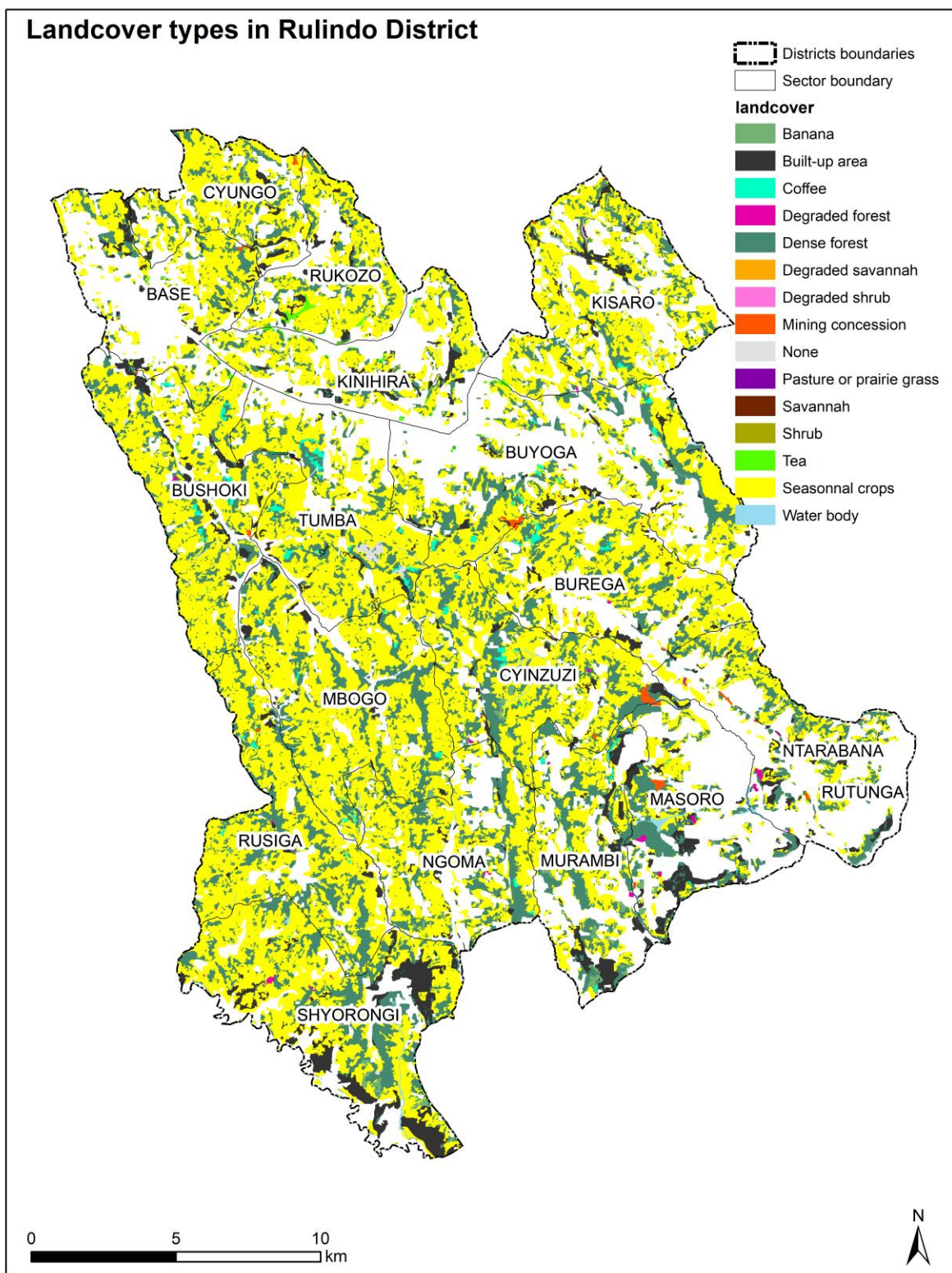


**Figure 27: Erosion risk in Rulindo District**



**Figure 28: Erosive features detected in Rulindo District**





**Figure 29: Land Use and Vegetation Cover for land at erosion risk in Rulindo District**

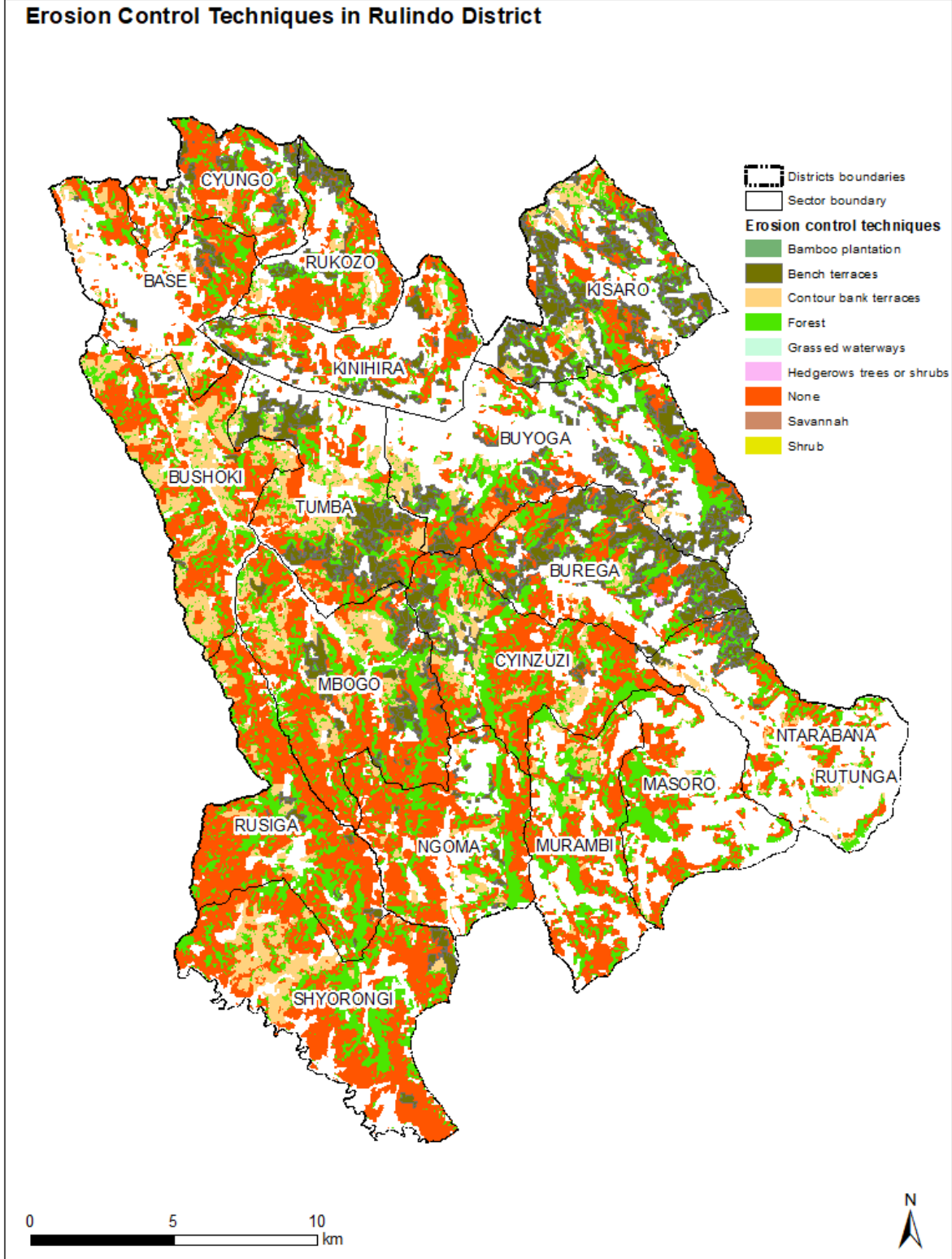


About existing erosion control practices in Rulindo district, Table 30 indicates that 51% of land at risk is protected by forests (9132 hectares), contour bank terraces or progressive terraces with ditches (4,976 hectares), and bench terraces (5,304 hectares). The highest protected sectors are Kisaro with 74% of its land at risk protected, followed by Tumba where 71% of the total land at risk is protected and Burega with 67% of land protected. The least protected sectors are Base with only 34% protected, Rusiga (35% protected) and Ngoma Sector (37% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Shyorongi, Rusiga, Mbogo, Ngoma, Bushoki and Kinzuzi sectors remain at very high risk of soil erosion since more than 60% of the sector land at risk are not protected.

**Table 32: Erosion control practices already in place in Rulindo District**

Sector Name	Erosion control in place			Total protected	Unprotected areas (Ha)	Grand Total (Ha)	% Protected
	Bench terraces	Contour bank terraces	Forest				
KISARO	1,089	243	453	1,785	630	2,415	74%
TUMBA	715	561	477	1,753	725	2,478	71%
BUREGA	939	107	514	1,560	768	2,328	67%
BUYOGA	757	284	764	1,805	927	2,732	66%
NTARABANA	201	155	503	859	582	1,441	60%
MBOGO	411	625	803	1,838	1,747	3,585	51%
BUSHOKI	28	971	500	1,499	1,457	2,956	51%
CYINZUZI	233	402	822	1,458	1,433	2,891	50%
RUKOZO	224	141	267	632	776	1,408	45%
MASORO		64	478	542	754	1,296	42%
CYUNGO	195	141	268	604	851	1,454	42%
SHYORONGI	93	547	853	1,493	2,190	3,682	41%
MURAMBI	9	147	566	722	1,060	1,782	41%
KINIHIRA	227	105	231	563	842	1,405	40%
NGOMA	52	139	641	831	1,404	2,235	37%
RUSIGA	58	193	743	994	1,853	2,847	35%
BASE	74	159	252	485	924	1,409	34%
<b>Grand Total</b>	<b>5,304</b>	<b>4,984</b>	<b>9,134</b>	<b>19,421</b>	<b>18,923</b>	<b>38,344</b>	<b>51%</b>

Erosion control practices in Rulindo District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 31 shows that about 12,424 hectares (which is 32% of the total land at risk) are suitable for Contour bank terraces, 11,555 hectares are agroforestry/hedgerows and 1622 hectares are Bench terraces. Others are afforestation and reforestation (264 hectares) and water harvesting facilities (2566 ha).

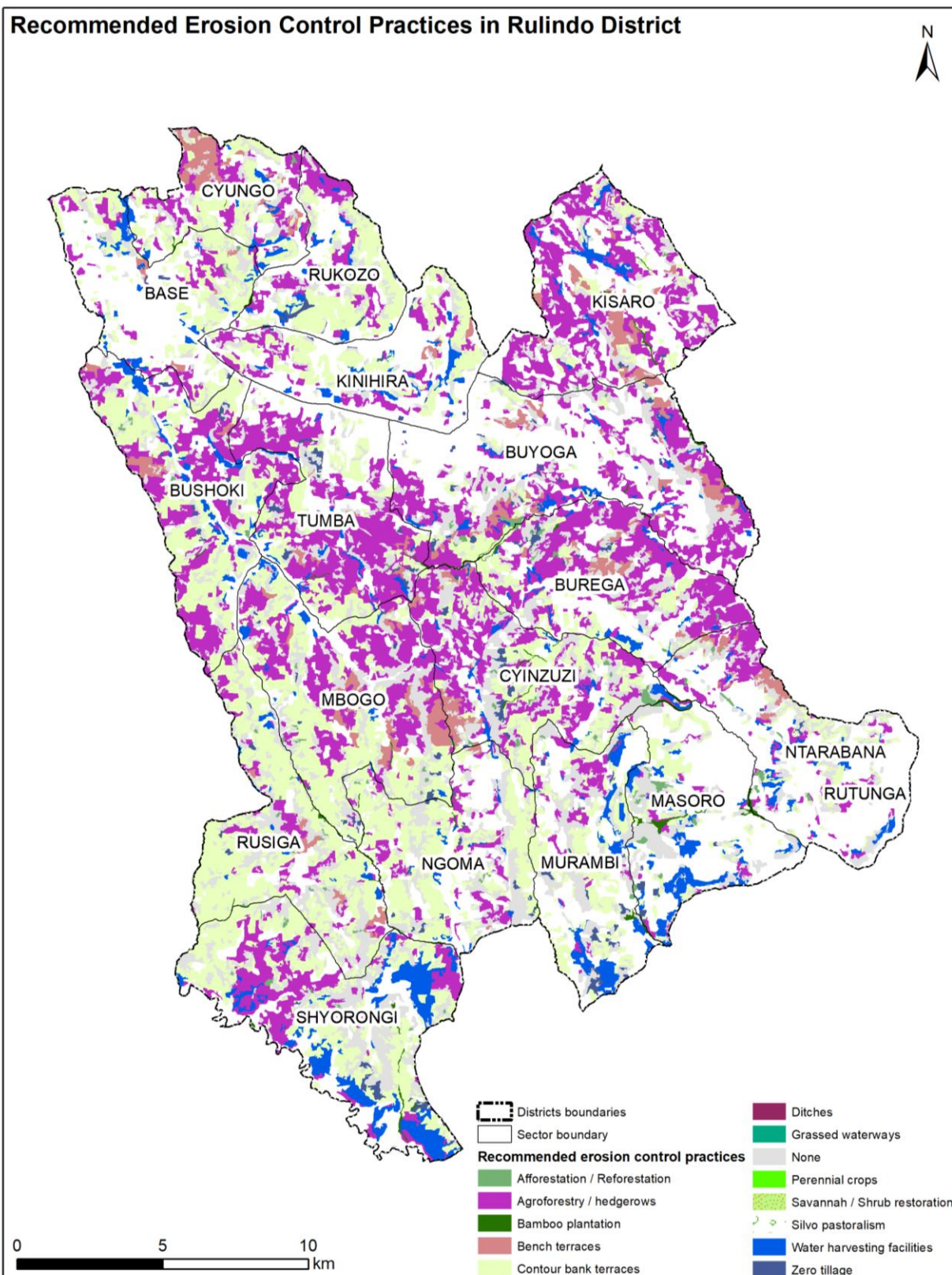


**Figure 30: Erosion control techniques in place in Rulindo District**

**Table 33: Recommended erosion control practices in Rulindo District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	None	Water harvesting facilities	Zero tillage	Grand Total
BASE	8	244	4	33	733	252	126	10	1409
BUREGA	20	1182	10	109	374	521	87	25	2328
BUSHOKI	11	1024	2	80	1130	500	169	40	2956
BUYOGA	25	1237	28	259	240	764	129	51	2732
CYINZUZI	46	981	25	124	744	824	97	49	2891
CYUNGO	4	356	4	231	500	269	91	0	1454
KINIHIRA		346		30	626	231	152	20	1405
KISARO	6	1366	17	214	227	453	122	9	2415
MASORO	41	101	45		322	478	285	23	1296
MBOGO	13	1105	9	289	1254	804	75	36	3585
MURAMBI	10	201	11		673	566	244	78	1782
NGOMA	7	297	17	14	1170	651	52	28	2235
NTARABANA	30	377	12	106	285	506	117	7	1441
RUKOZO		373	2		647	268	84	34	1408
RUSIGA	23	291	6	77	1640	743	55	12	2847
SHYORONGI	20	769	26		1352	853	612	51	3682
TUMBA	2	1305	6	56	506	477	71	55	2478
<b>Grand Total</b>	<b>264</b>	<b>11555</b>	<b>224</b>	<b>1622</b>	<b>12424</b>	<b>9160</b>	<b>2566</b>	<b>528</b>	<b>38344</b>
<b>%</b>	<b>1%</b>	<b>30%</b>	<b>1%</b>	<b>4%</b>	<b>32%</b>	<b>24%</b>	<b>7%</b>	<b>1%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 31: Recommended erosion control practices in Rulindo District**

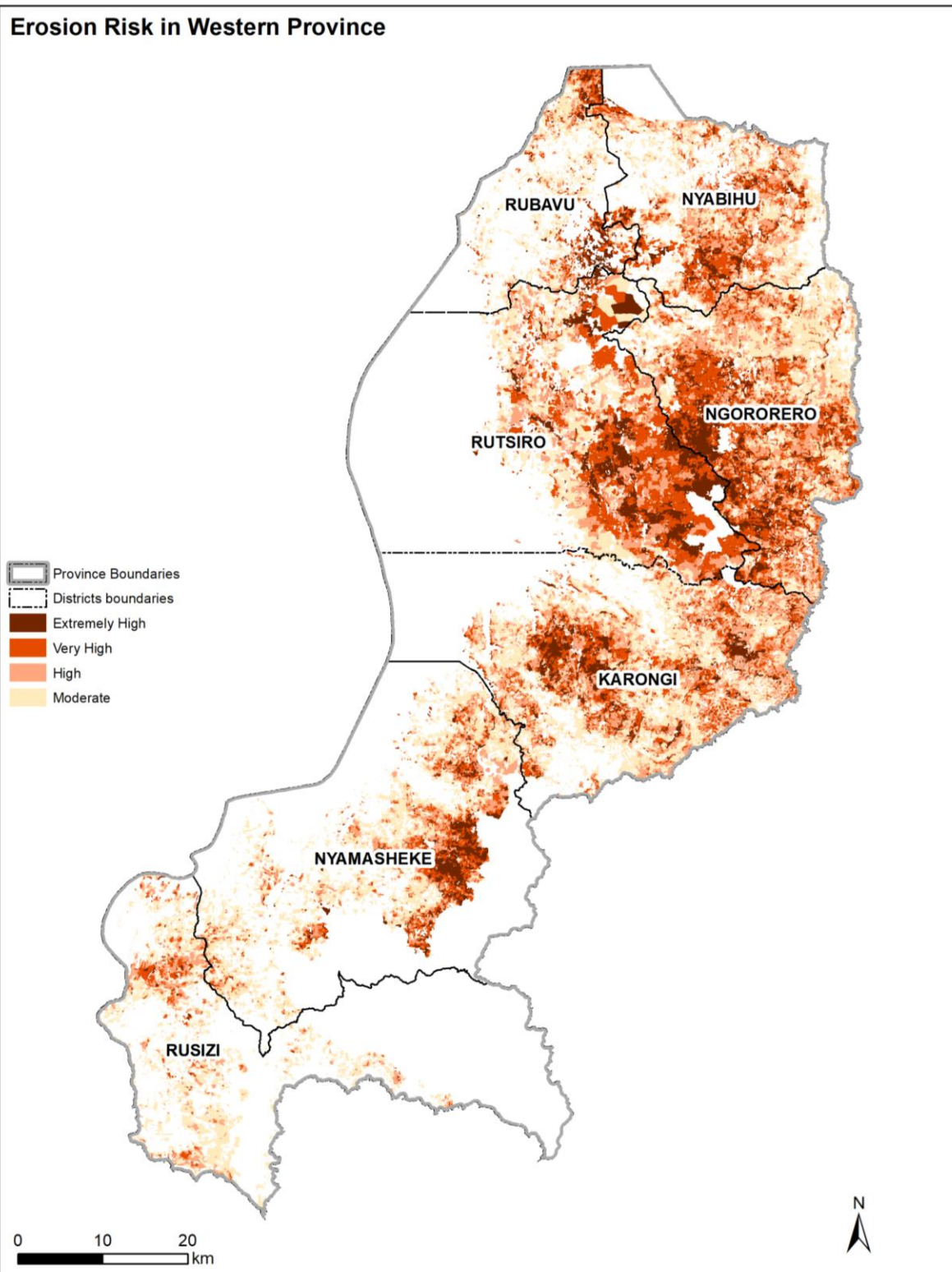
### 3.2. Erosion Control Status in Western Province

Erosion risk in Western Province is summarized in table 32 and presented in figure 32. The total land at high risk of erosion in Western Province is about 261,542 hectares (54% of the total province land). The highest amount of land at erosion risk are found in Ngororero with 58,003 hectares (i.e. 85% of the total district land) followed by Rutsiro District with 48,143 hectares (73% of the district land) and Karongi with 57,187 hectares which is about 72% of the total district land. The least district susceptible to erosion is Rusizi, where only 20% of its district land is at risk, about 18,212 hectares. The contribution of forests in protecting fragile land in Western Province is evident, particularly the Nyungwe National park in Rusizi and Nyamasheke districts as well as forest plantations in steep slopes in highlands of Western Province.

**Table 34: Erosion risk per district in Western Province**

District Name	Erosion risk					District land (Ha)	Percent age (%)
	Extremel y High	Very High	High	Moderat e	Grand Total		
NGORORERO	8,112	16,146	17,417	16328	58,003	67,899	85%
RUTSIRO	8,203	16,422	11,737	11,782	48,143	65,995	73%
KARONGI	5,313	11,169	18,330	22,374	57,187	79,298	72%
NYABIHU	2,203	6,859	9,472	11,172	29,706	52,958	56%
NYAMASHEKE	3,686	5,876	8,583	19,271	37,417	94,802	39%
RUBAVU	1,680	2,395	2,454	6,346	12,874	34,090	38%
RUSIZI	196	1,704	4,230	12,082	18,212	91,731	20%
<b>Grand Total</b>	<b>29,392</b>	<b>60,571</b>	<b>72,223</b>	<b>99,355</b>	<b>261,542</b>	<b>486,773</b>	<b>54%</b>



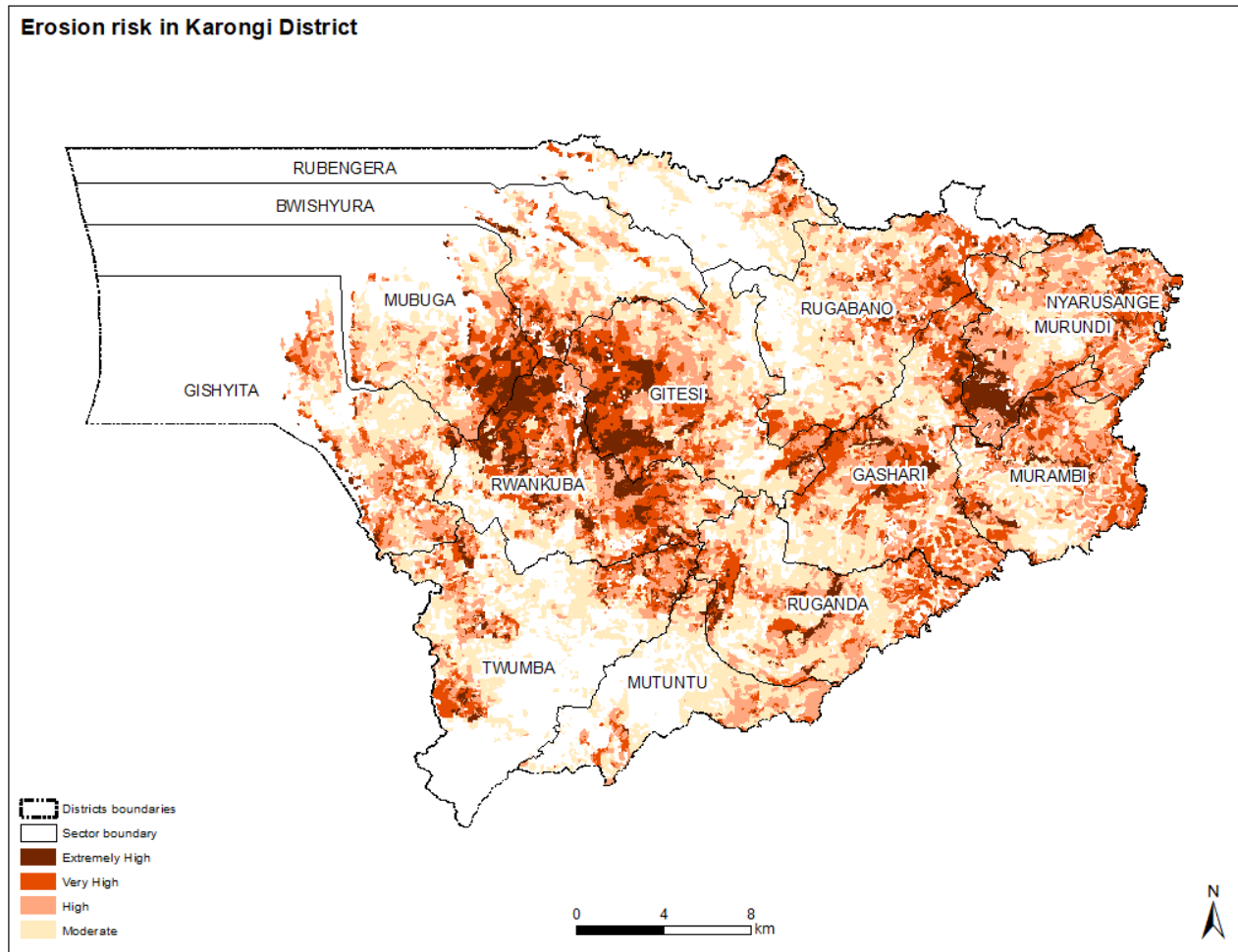


**Figure 32: Erosion risk in Western Province**



### 3.2.1. Erosion control status in Karongi District

Soil erosion risk in Karongi is summarised in Table 33 and presented in figure 33. Land area at risk is estimated to 57,332 hectares; about 58% of the total district land. Murundi sector is the highest susceptible to erosion with 5,674 hectares (89% of the sector land), followed by Gashari sector with 6086 hectares (88% of sector land), Gitesi sector with 6477 hectares (86% of the sector land), Ruganda sector with 5210 hectares, 84% of the sector land and Murambi with 4385 hectares, which is 84% of the sector land. The least affected sectors are Rubengera with 1402 hectares susceptible to erosion (about 35% of sector land), and Twumba sector with 4600 hectares about 47% of the total sector land.



**Figure 33: Erosion risk in Karongi District**

**Table 35: Erosion risk per sector in Karongi District**

Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MURUNDI	723	959	2,550	1,442	5,674	6,342	89%

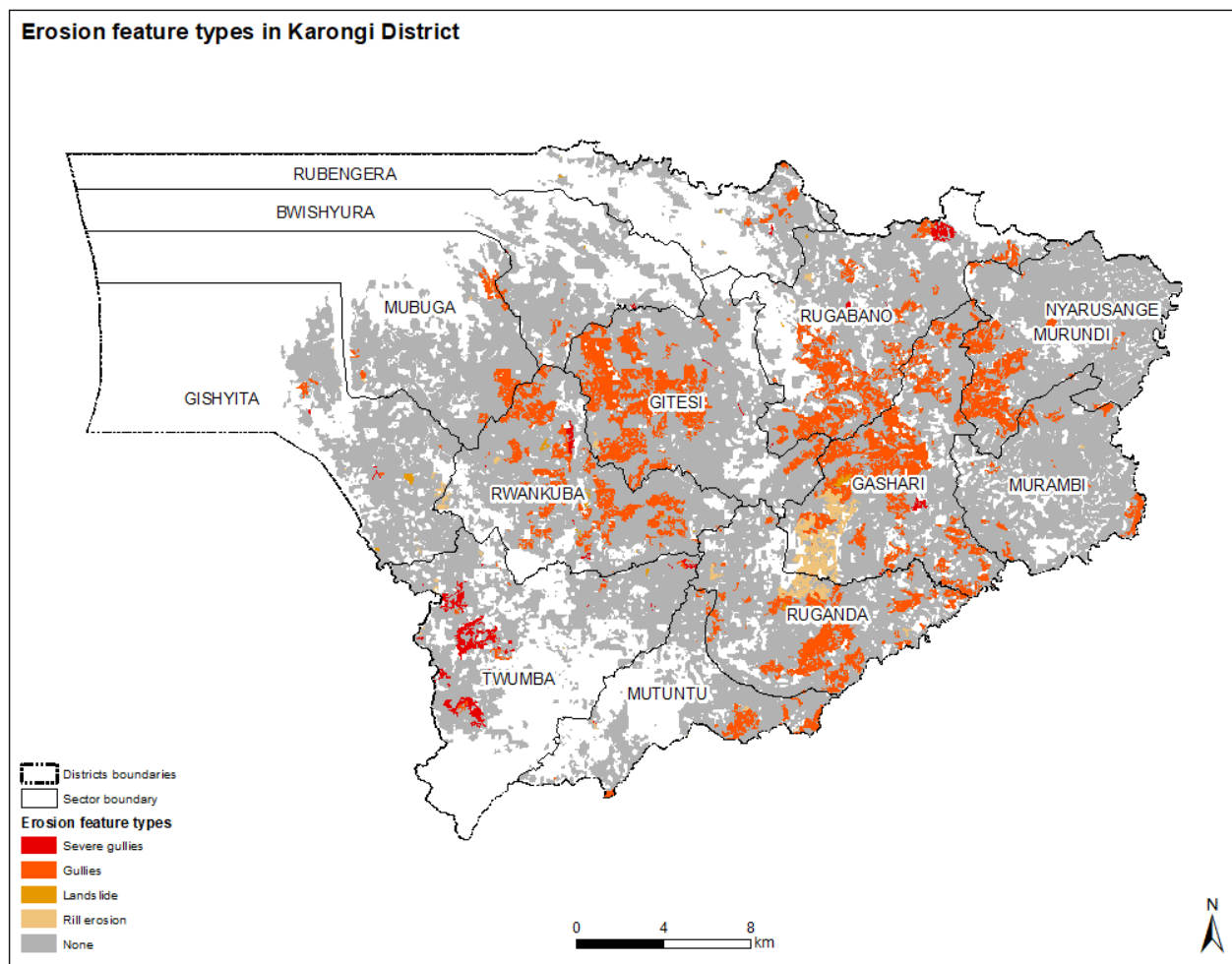
Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
GASHARI	457	1,551	1,987	2,091	6,086	6,931	88%
GITESI	885	1,693	1,905	1,994	6,477	7,568	86%
RUGANDA	377	878	1,545	2,409	5,210	6,183	84%
MURAMBI	321	908	1,737	1,418	4,385	5,246	84%
RWANKUBA	1,324	1,554	1,706	1,168	5,752	6,960	83%
MUBUGA	438	684	869	1,410	3,401	4,536	75%
GISHYITA	104	558	1,264	1,572	3,498	4,704	74%
RUGABANO	135	999	1,757	2,748	5,639	8,054	70%
BWISHYURA	195	324	696	1,314	2,529	4,217	60%
MUTUNTU	55	176	757	1,546	2,535	4,709	54%
TWUMBA	250	747	1,281	2,322	4,600	9,801	47%
RUBENGERA	48	138	276	940	1,402	4,044	35%
<b>Grand Total</b>	<b>5,313</b>	<b>11,169</b>	<b>18,330</b>	<b>22,374</b>	<b>57,187</b>	<b>79,298</b>	<b>72%</b>

Land areas affected by erosive features in Karongi District are summarized in Table 34 and the map of erosive features are presented in Figure 34. The results show that Gashari sector is the worst affected by gullies on areas estimated to 2265 hectares (37% of sector land at risk), followed by Gitesi sector on 1757 hectares (27% of sector land at risk), and Rugabano sector on 1376 hectares (24% of sector land at risk). The presence of gullies in Gitesi, Gashari, Rugabano, and Ruganda sectors confirms the findings of CROM model; however the reduced presence of gullies in Gishyita (75ha) which was originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis on current land use and erosion control practices already in place (Table 34 & 35) will demonstrate that. The least sectors affected by gullies are Gishyita with only 75 hectares, Bwishyura with only 60 hectares and Murambi with 239 hectares affected by gullies.

**Table 36: Erosive features and land area affected in Karongi District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
GASHARI	1757	23	463	22	2265	3821	6086	37%
GITESI	1739		13	6	1757	4719	6477	27%
RUGABANO	1259	3	13	101	1376	4263	5639	24%
RUGANDA	1004	4	183		1191	4019	5210	23%
RWANKUBA	1126	32	36	37	1231	4521	5752	21%
MURUNDI	747				747	4927	5674	13%
TWUMBA	68	5	22	399	495	4106	4600	11%
MUTUNTU	251		11		262	2273	2535	10%
RUBENGERA	98	2	2	4	107	1295	1402	8%
MUBUGA	217		6		223	3178	3401	7%
MURAMBI	236		3		239	4146	4385	5%
BWISHYURA	54	1		5	60	2469	2529	2%

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
GISHYITA	29	18	21	6	75	3423	3498	2%
<b>Grand Total</b>	<b>8585</b>	<b>89</b>	<b>774</b>	<b>580</b>	<b>10027</b>	<b>47160</b>	<b>57187</b>	<b>18%</b>

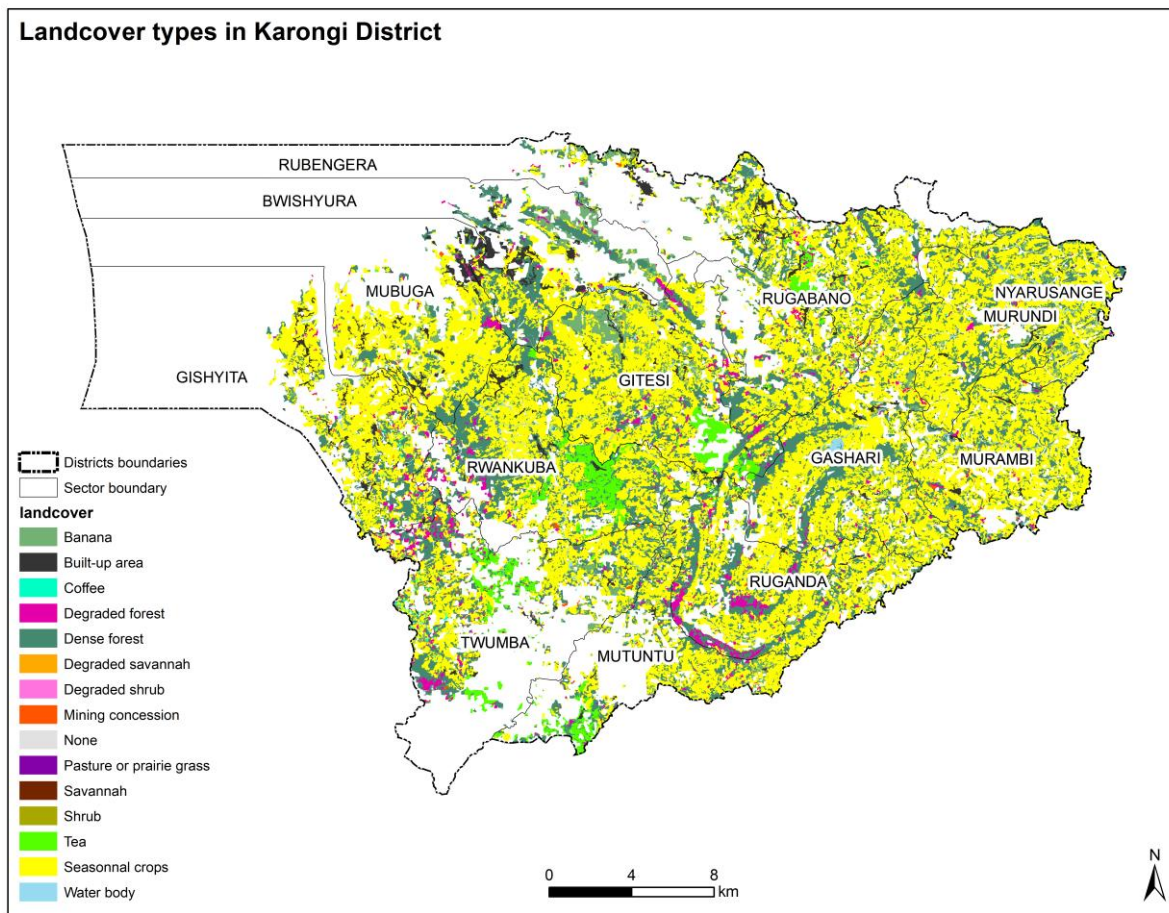


**Figure 34: Erosive features detected in Karongi District**

In term of land use and land cover of areas at risk in Karongi, the results of land cover mapping (Table 35 and Figure 35) show that 34430 hectares (64% of the total land at risk) are used for seasonal cropping, 13340 hectares (23% of the total land at risk) are covered by healthy forests and 1840 hectares (3% of the total area at risk) are covered by tea, 1636 hectares (3% of the total area at risk) are covered by Built-up area and 2100 hectares are covered by Banana crop (4% of the total area at risk).

**Table 37: Land Use and Land Cover (LUVCL) of areas at risk in Karongi District**

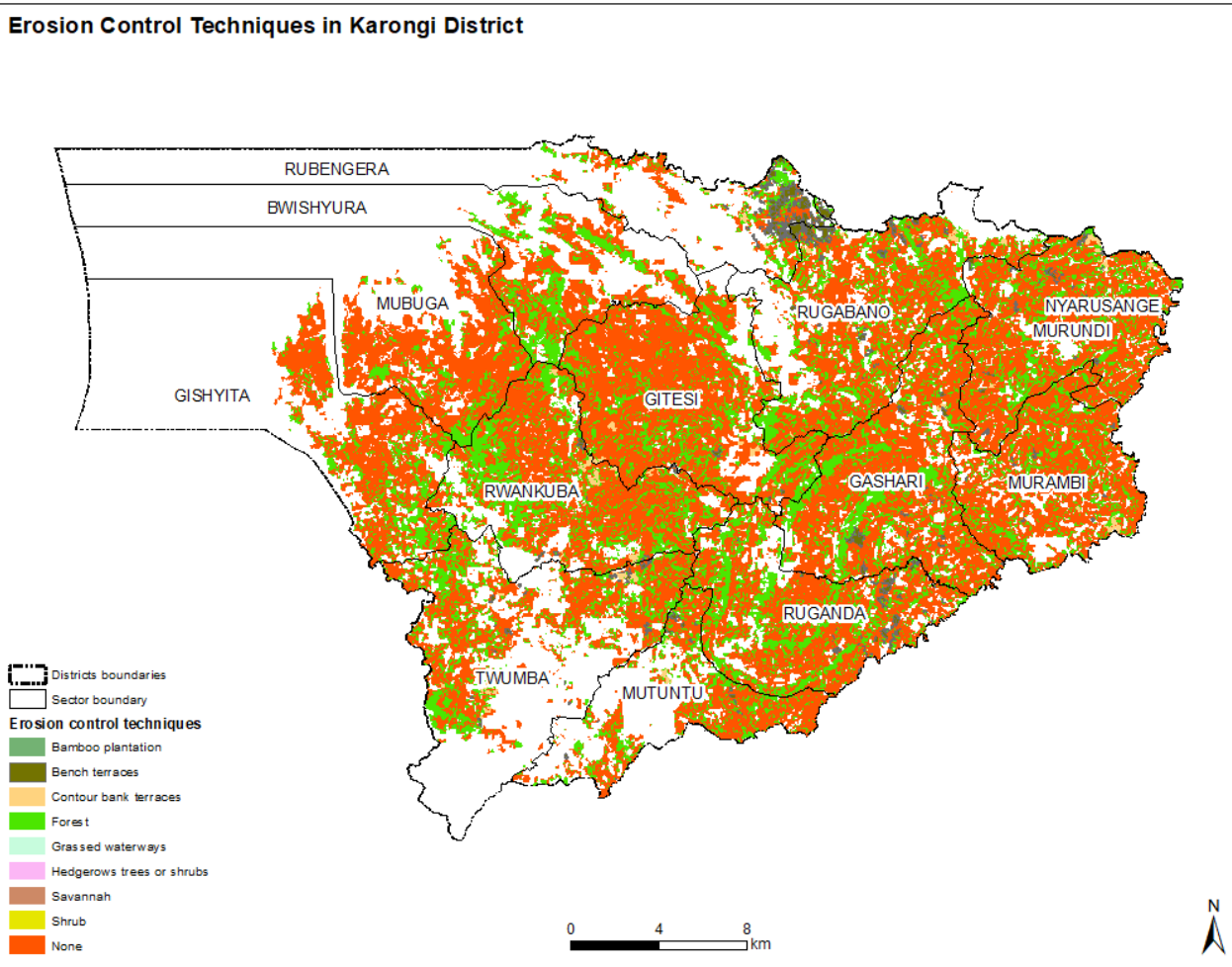
Sector Name	Banana	Built-up area	Coffee	Degraded forest	Degraded shrub	Dense forest	Mining and Quarries	None	Seasonal crops	Tea	Water body	Grand Total
BWISHYURA	369	309		68		876	2	2	889	2	14	2529
GASHARI	192	62		53		1403	2		4231	17	125	6086
GISHYITA	46	194	6	78	2	738	4	10	2399		21	3498
GITESI	501	113		148		1123			4222	324	46	6477
MUBUGA	153	280	1	60		496	4	6	2380		22	3401
MURAMBI	50	52		33		785	5		3413		46	4385
MURUNDI	227	61		29		1107		2	4184		66	5674
MUTUNTU	75	28		42		618			1516	239	17	2535
RUBENGERA	146	154		12		388	5	2	678		17	1402
RUGABANO	94	135		82		1458	3		3635	215	17	5639
RUGANDA	78	53		277		1512	5		3223	15	47	5210
RWANKUBA	10	125	1	95		1649	7	6	3174	605	79	5752
TWUMBA	160	71	13	189		1187	22	1	2487	422	48	4600
<b>Grand Total</b>	<b>2100</b>	<b>1636</b>	<b>21</b>	<b>1165</b>	<b>2</b>	<b>13340</b>	<b>61</b>	<b>29</b>	<b>36430</b>	<b>1840</b>	<b>563</b>	<b>57187</b>
<b>%</b>	<b>4%</b>	<b>3%</b>	<b>0%</b>	<b>2%</b>	<b>0%</b>	<b>23%</b>	<b>0%</b>	<b>0%</b>	<b>64%</b>	<b>3%</b>	<b>1%</b>	<b>100%</b>



**Figure 35: Land cover types in Karongi District**

About existing erosion control practices in Karongi district, Table 38 indicates that 26% of land at risk is protected by forests (13,340 hectares), contour bank terraces or progressive terraces with ditches (514 hectares), bench terraces (880 hectares) and contour bank terraces (514 hectares). The highest protected sectors are Rubengera with 50% of its land at risk protected, followed by Bwishyura where 37% of the total land at risk is protected and Ruganda with 32% of land protected. The least protected sectors are Mubuga with only 15% protected, Gitesi (only 18% protected), Murambi (19%) and Gishyita (21% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Mubuga, Gitesi, Murundi and Murambi sectors remain at very high risk of soil erosion since more than 70% of the sector land at risk are not protected.





**Figure 36: Erosion control techniques in place in Karongi District**

**Table 38: Erosion control practices already in place in Karongi District**

Sector Name	Erosion control in place			Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest				
RUBENGERA	278	32	388	698	705	1,402	50%
BWISHYURA	1		876	877	1,652	2,529	35%
RUGANDA	128	3	1,512	1,644	3,566	5,210	32%
RWANKUBA	25	114	1,649	1,788	3,963	5,752	31%
RUGABANO	187	74	1,458	1,718	3,921	5,639	30%
TWUMBA	46	87	1,188	1,322	3,279	4,600	29%
MUTUNTU	36	29	618	683	1,852	2,535	27%
GASHARI	78	17	1,403	1,499	4,587	6,086	25%
MURUNDI	76	75	1,107	1,258	4,416	5,674	22%



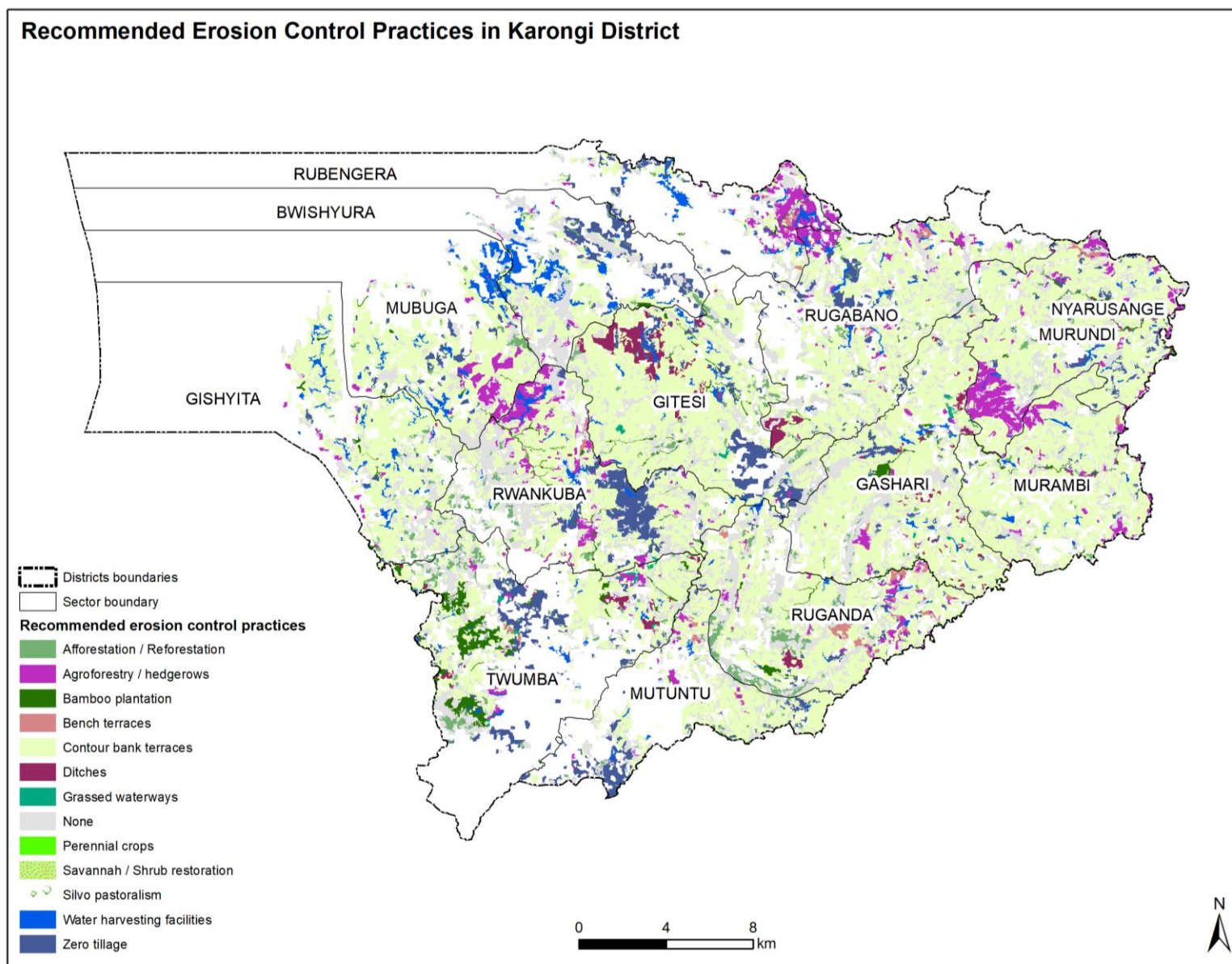
Sector Name	Erosion control in place			Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest				
GISHYITA		2	738	740	2,758	3,498	21%
MURAMBI	13	33	785	831	3,554	4,385	19%
GITESI	15	47	1,123	1,185	5,292	6,477	18%
MUBUGA		1	494	495	2,905	3,401	15%
<b>Grand Total</b>	<b>884</b>	<b>514</b>	<b>13,340</b>	<b>14,738</b>	<b>42,449</b>	<b>57,187</b>	<b>26%</b>

Erosion control practices in Karongi District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 37 shows that about 32648 hectares (which is 53% of the total land at risk) are suitable for Contour bank terraces, 2,705 hectares are cropland that needs agroforestry/hedgerows and 1361 hectares are reforestation/afforestation. Others are riverbanks amounting to 1033 hectares eroded which require bamboo trees for rehabilitation, ditches (684 hectares), bench terraces (330 hectares) and water harvesting infrastructures (1637 hectares).

**Table 39: Recommended erosion control practices in Karongi District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	Grassed waterways	Already protected	Water harvesting facilities	Zero tillage	Grand Total
BWISHYURA	74	42	15		842			876	309	370	2529
GASHARI	67	79	125	5	4110	111	26	1336	62	165	6086
GISHYITA	103	59	32		2313			745	194	52	3498
GITESI	149	19	55		4171	347	20	1123	113	479	6477
MUBUGA	71	257	22		2120		1	496	280	154	3401
MURAMBI	38	207	46	9	3193	4		785	52	50	4385
MURUNDI	41	646	66	28	3490	1		1115	61	227	5674
MUTUNTU	51	67	17	20	1420			618	28	314	2535
RUBENGERA	22	317	21	36	317			388	154	146	1402
RUGABANO	113	269	21	32	3299	86		1376	135	309	5639
RUGANDA	289	180	72	161	2811	40		1512	53	93	5210
RWANKUBA	121	454	80	23	2666	2	3	1661	125	616	5752
TWUMBA	223	111	460	16	1896	92	37	1187	71	505	4600
<b>Grand Total</b>	<b>1363</b>	<b>2705</b>	<b>1033</b>	<b>330</b>	<b>32648</b>	<b>684</b>	<b>89</b>	<b>13219</b>	<b>1637</b>	<b>3480</b>	<b>57187</b>
<b>%</b>	<b>2%</b>	<b>5%</b>	<b>2%</b>	<b>1%</b>	<b>57%</b>	<b>1%</b>	<b>0%</b>	<b>23%</b>	<b>3%</b>	<b>6%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces (see Table 10) which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 37: Recommended erosion control practices in Karongi District**

### 3.2.2. Erosion control status in Ngororero District

Soil erosion risk in Ngororero is summarised in Table 38 and presented in Figure 38. Land area at risk is estimated to 58003 hectares; about 85% of the total district land. Muhororo sector is the highest susceptible to erosion with 3577 hectares (96% of the sector land), followed by Bwira sector with 3688 hectares (95% of sector land), Ndaro sector with 5115 hectares (93% of the sector land), Hindiro and Kabaya sectors with 92% of the sector land (3223 hectares and 4566 hectares respectively). The least affected sectors (but still high) are Matyazo with 2880 hectares susceptible to erosion (about 71% of sector land), and Muhanda sector with 7861 hectares about 73% of the total sector land. Compared to other Districts of the Western Province, Ngororero is the worst affected by erosion risk.

**Table 40: Erosion risk per sector in Ngororero District**

Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MUHORORO	427	1,096	1,496	558	3,577	3,721	96%
BWIRA	640	1,165	1,351	532	3,688	3,862	95%
NDARO	1,372	2,027	1,306	410	5,115	5,516	93%
HINDIRO	77	155	783	2,209	3,223	3,500	92%
KABAYA	154	817	2,087	1,508	4,566	4,983	92%
SOVU	1,941	1,844	962	194	4,940	5,463	90%
KAGEYO	300	1,179	1,634	1,529	4,642	5,183	90%
GATUMBA	506	1,147	1,183	1,044	3,881	4,388	88%
KAVUMU	1,055	2,346	1,061	523	4,985	5,649	88%
NYANGE	719	1,474	1,561	843	4,598	5,406	85%
NGORORERO	182	550	1,109	2,206	4,047	5,324	76%
MUHANDA	636	2,098	2,345	2,783	7,861	10,836	73%
MATYAZO	102	249	540	1,989	2,880	4,068	71%
<b>Grand Total</b>	<b>8,112</b>	<b>16,146</b>	<b>17,417</b>	<b>16,328</b>	<b>58,003</b>	<b>67,899</b>	<b>85%</b>

Land areas affected by erosive features in Ngororero District as reflected on World View images are summarized in Table 39 and the map of erosive features are presented in Figure 39. The results show that Gatumba sector is the worst affected by gullies on areas estimated to 167 hectares (4% of sector land at risk), followed by Ndaro sector on 186 hectares (4% of sector land at risk), and Muhororo sector on 125 hectares (3% of sector land at risk). The presence of gullies in Muhanda, Gatumba, Ndaro, and Muhororo sectors confirms the findings of CROM model; however the reduced presence of gullies in Kabaya (20ha) and Hindiro (30 ha) which was originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 39 and 40. The least sectors affected by gullies are Sovu with only 16 hectares, Kabaya with only 22 hectares and Nyange with 34 hectares affected by gullies.

**Table 41: Erosive features and land area affected in Ngororero District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
GATUMBA	76	15		75	167	3715	3881	4%
NDARO	25	6		154	186	4929	5115	4%
MUHORORO	26	33		66	125	3452	3577	3%
MATYAZO	77		9		86	2794	2880	3%
NGORORERO	57	22	2		80	3967	4047	2%
KAGEYO	39	7	12	9	67	4575	4642	1%
BWIRA	29	8	3	13	52	3636	3688	1%
KAVUMU	67			3	69	4915	4985	1%
HINDIRO	25	2	3		30	3193	3223	1%
MUHANDA	35		3	33	71	7790	7861	1%
NYANGE	14			20	34	4564	4598	1%
KABAYA	22				22	4544	4566	0%
SOVU	10	4		2	16	4924	4940	0%
<b>Grand Total</b>	<b>501</b>	<b>98</b>	<b>31</b>	<b>375</b>	<b>1005</b>	<b>56998</b>	<b>58003</b>	<b>2%</b>

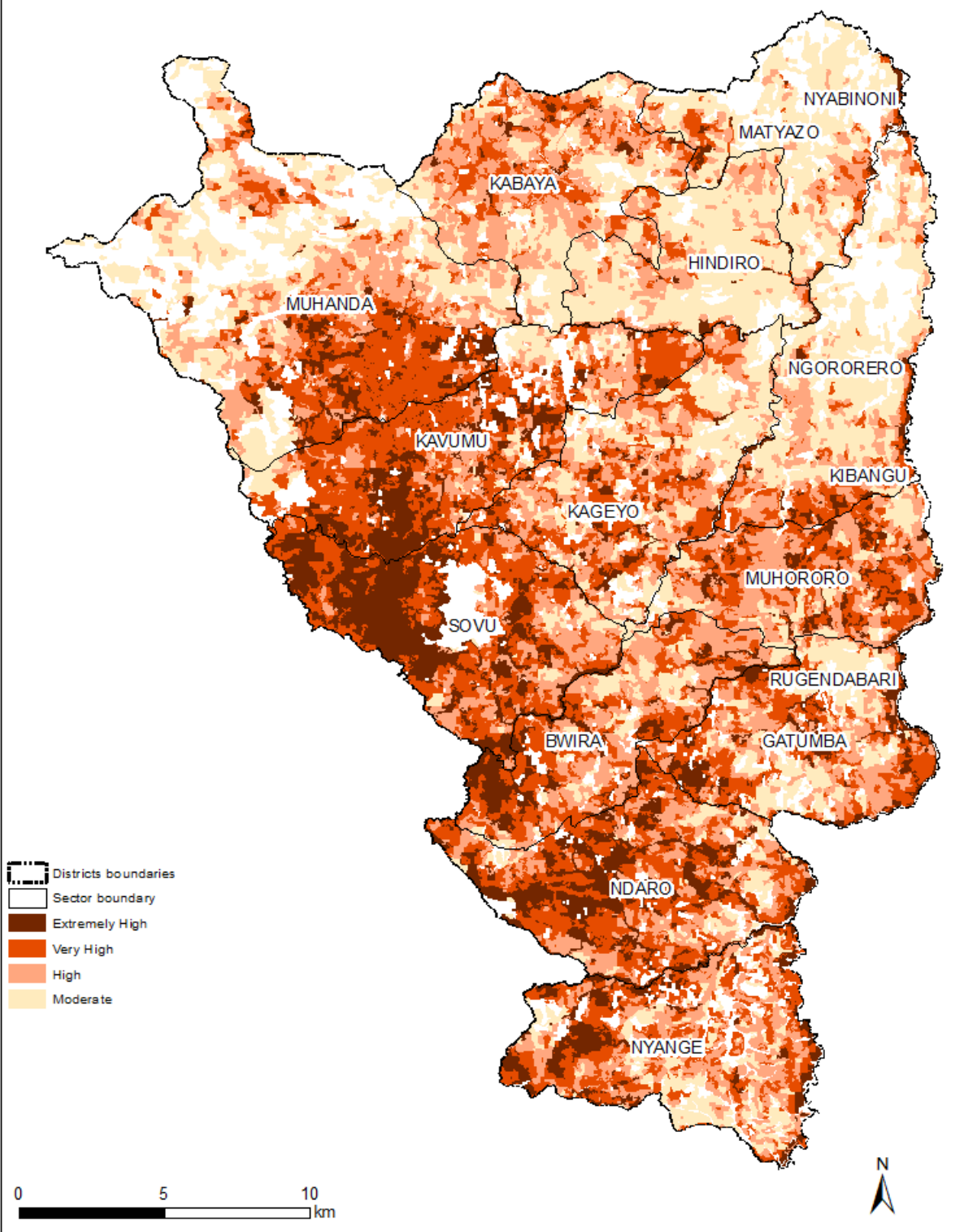
In term of land use and land cover of areas at risk in Ngororero District, the results of land cover mapping (Table 40 and Figure 40) show 36382 hectares (63% of the total land at risk) are used for seasonal cropping, 8422 hectares (15% of the total land at risk) are covered by healthy forests, 3825 hectares (7% of the total land at risk) are covered by built-up area and 1622 hectares are covered by Banana crop. To be noted that tea is covering an area of 3622 hectares, i.e 6% of the land at risk.

**Table 42: Land Use and Vegetation Cover (LUV) of areas at risk in Ngororero District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining and Quarries	Bare soil	Pasture or prairie grass	Seasonal crops	Tea	Water body	Grand Total
BWIRA	28	145	3	92	632	9	16		2517	11	234	3688
GATUMBA	110	395		94	486		129		2474		193	3881
HINDIRO	38	256	5	4	444	12	4		2339	5	116	3223
KABAYA		441		4	744		2		3058	205	112	4566
KAGEYO	23	227	7	24	721		15		3330	112	183	4642
KAVUMU	12	296		32	670	5	11		3561	260	139	4985
MATYAZO	576	100			391				1731		83	2880
MUHANDA		381		69	1159	60	101		2932	2783	377	7861
MUHORORO	150	139		19	427		47		2653		142	3577
NDARO	202	238		290	849	6	134		3111		284	5115
NGORORERO	277	446	7	31	455	2	29	3	2589		209	4047
NYANGE	206	544	6	363	647		34		2637		162	4598
SOVU	3	217		26	797		14		3451	247	186	4940
<b>Grand Total</b>	<b>1622</b>	<b>3825</b>	<b>28</b>	<b>1047</b>	<b>8422</b>	<b>94</b>	<b>536</b>	<b>3</b>	<b>36382</b>	<b>3622</b>	<b>2421</b>	<b>58003</b>
<b>%</b>	<b>3%</b>	<b>7%</b>	<b>0%</b>	<b>2%</b>	<b>15%</b>	<b>0%</b>	<b>1%</b>	<b>0%</b>	<b>63%</b>	<b>6%</b>	<b>4%</b>	<b>100%</b>



### Erosion risk in Ngororero District



**Figure 38: Erosion risk in Ngororero District**

### Erosion feature types in Ngororero District

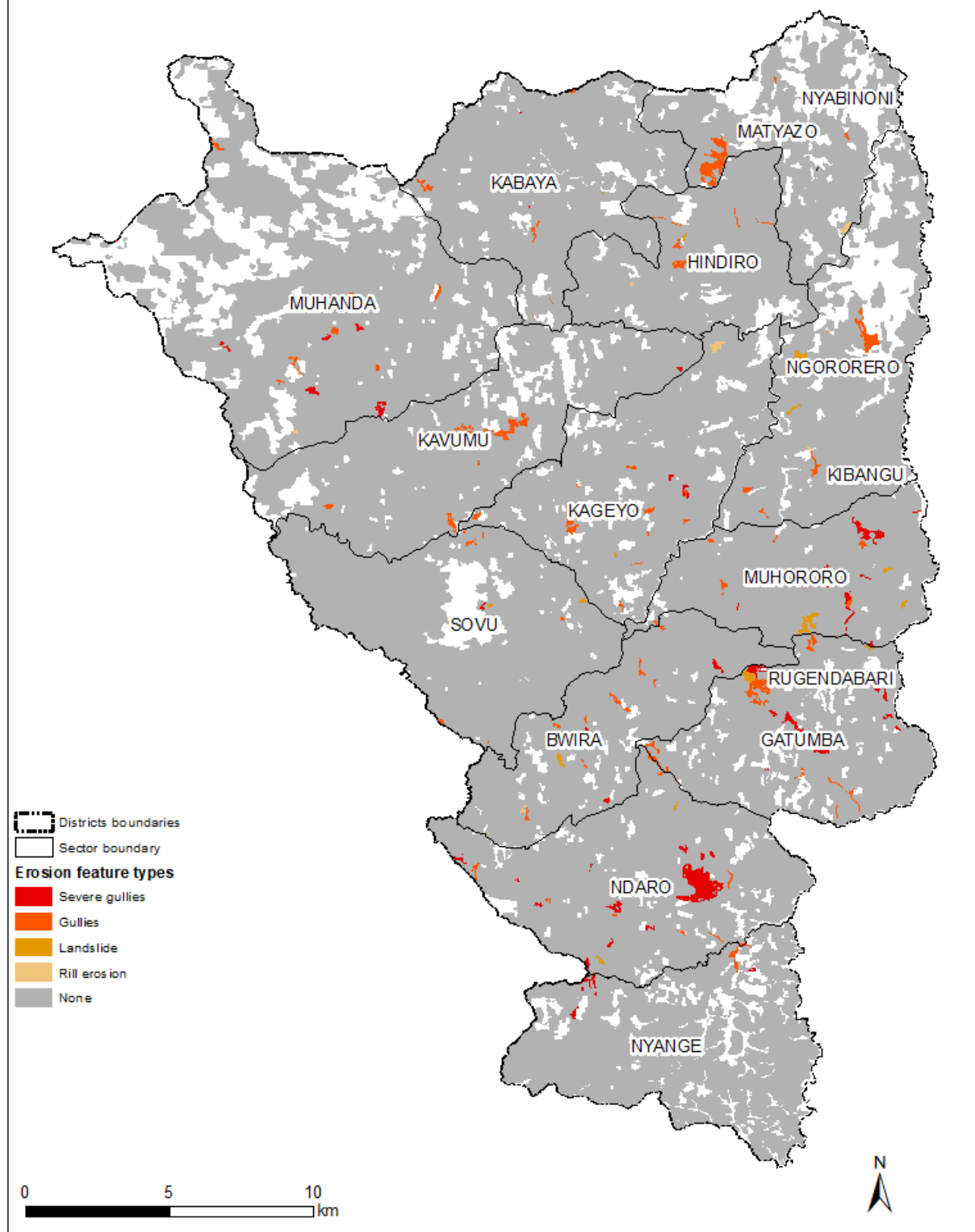
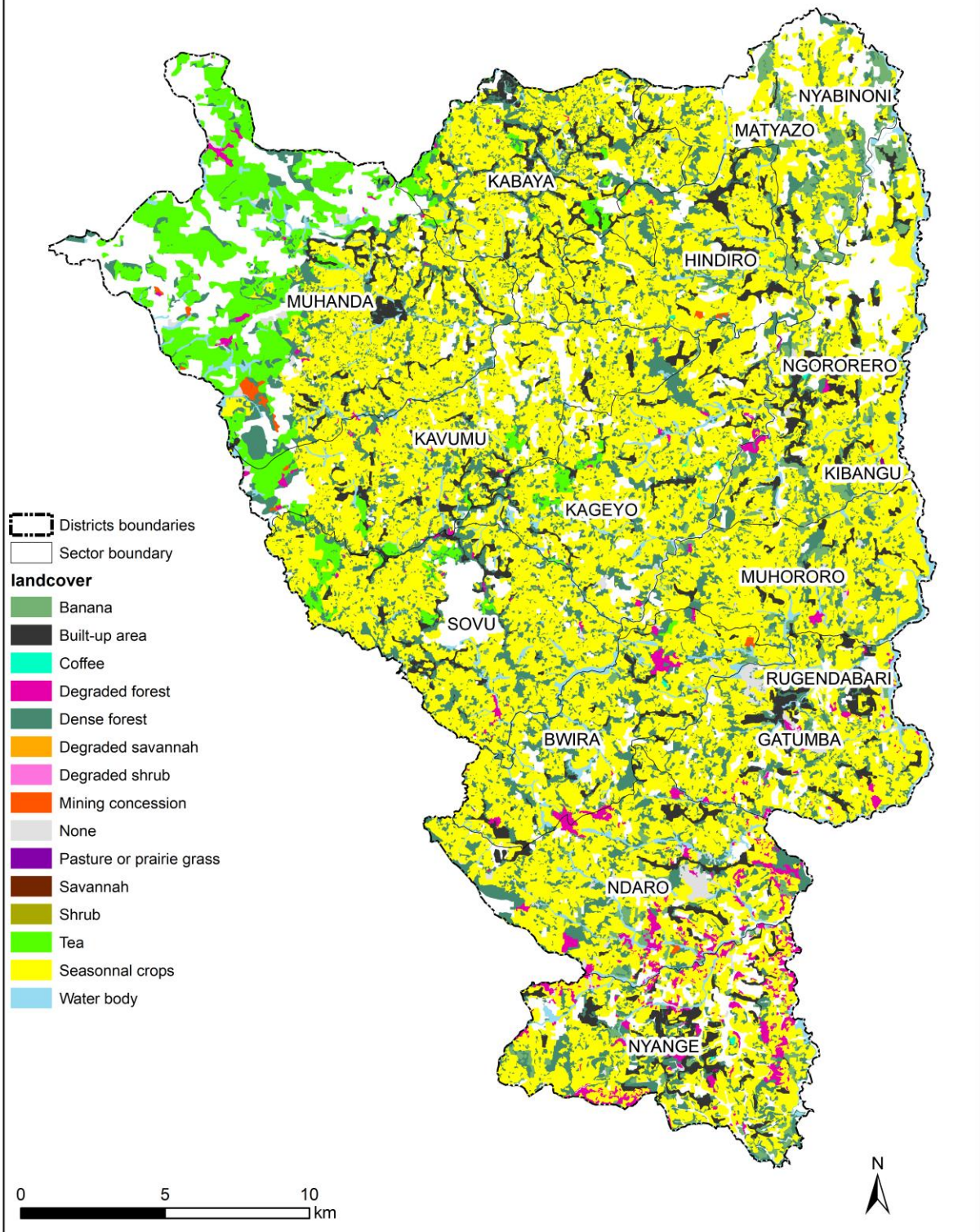


Figure 39: Erosive features detected in Ngororero District

## Landcover types in Ngororero District



**Figure 40: Land cover types in Ngororero District**

About existing erosion control practices in Ngororero district, Table 41 shows that only 20% of land at risk is protected by forests (8440 hectares), contour bank terraces or progressive terraces with ditches (87 hectares), and bench terraces (3226 hectares). The highest protected sectors are Sovu with 32% of its land at risk protected, followed by Kabaya where 28% of the total land at risk is protected and Bwira with 24% of land protected. The least protected sectors are Ngororero with only 13% protected, Matyazo (only 14% protected), Gatumba (15%) and Hindiro (16% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Muhanda, Matyazo, Ngororero and Gatumba sectors remain at very high risk of soil erosion since more than 80% of the sector land at risk are not protected.

**Table 43: Erosion control practices already in place in Ngororero District**

Sector Name	Erosion control in place			Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
SOVU	798		800	1598	3342	4940	32%
KABAYA	539	2	744	1285	3280	4566	28%
BWIRA	240		637	876	2812	3688	24%
NYANGE	324	27	647	998	3600	4598	22%
MUHORORO	319	11	427	757	2820	3577	21%
KAGEYO	230		721	951	3692	4642	20%
NDARO	144	23	852	1020	4095	5115	20%
MUHANDA	231		1159	1390	6471	7861	18%
KAVUMU	164		677	840	4144	4985	17%
HINDIRO	61	17	444	523	2700	3223	16%
GATUMBA	92	6	486	584	3297	3881	15%
MATYAZO	23		391	413	2467	2880	14%
NGORORERO	62		455	516	3531	4047	13%
<b>Grand Total</b>	<b>3226</b>	<b>87</b>	<b>8440</b>	<b>11752</b>	<b>46251</b>	<b>58003</b>	<b>20%</b>



Erosion control practices in Ngororero District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 42 shows that about 19748 hectares (which is 34% of the total land at risk) are suitable for Contour bank terraces, 10,668 hectares are bench terraces (18% of the total land at risk) and 5428 hectares are Agroforestry/hedgerows. Others are gullies or riverbanks amounting to 3181 hectares eroded which require bamboo trees for rehabilitation, Afforestation & Reforestation (1339 hectares), and Storm water management facilities (SWMF) (3879 hectares).

**Table 44: Recommended erosion control practices in Ngororero District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	None	Water harvesting facilities	Zero tillage	Grand Total
BWIRA	116	506	292	552	1402		632	145	42	3688
GATUMBA	95	208	360	113	2113		486	395	110	3881
HINDIRO	30	124	130	589	1602		444	256	48	3223
KABAYA	20	646	127	1688	682	13	745	441	205	4566
KAGEYO	34	343	209	1197	1768		721	229	142	4642
KAVUMU	51	409	165	2239	881		670	296	274	4985
MATYAZO		59	87	234	1434		391	100	576	2880
MUHANDA	158	308	447	1151	1455	13	1159	381	2790	7861
MUHORORO	23	419	280	789	1337	12	427	139	150	3577
NDARO	338	505	445	408	2130		849	238	202	5115
NGORORERO	41	111	244	495	1949	13	455	455	284	4047
NYANGE	378	672	188	307	1649		647	544	213	4598
SOVU	55	1117	207	907	1348		797	260	249	4940
<b>Grand Total</b>	<b>1339</b>	<b>5428</b>	<b>3181</b>	<b>10668</b>	<b>19748</b>	<b>51</b>	<b>8423</b>	<b>3879</b>	<b>5285</b>	<b>58003</b>
<b>%</b>	<b>2%</b>	<b>9%</b>	<b>5%</b>	<b>18%</b>	<b>34%</b>	<b>0%</b>	<b>15%</b>	<b>7%</b>	<b>9%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

## Erosion Control Techniques in Ngororero District

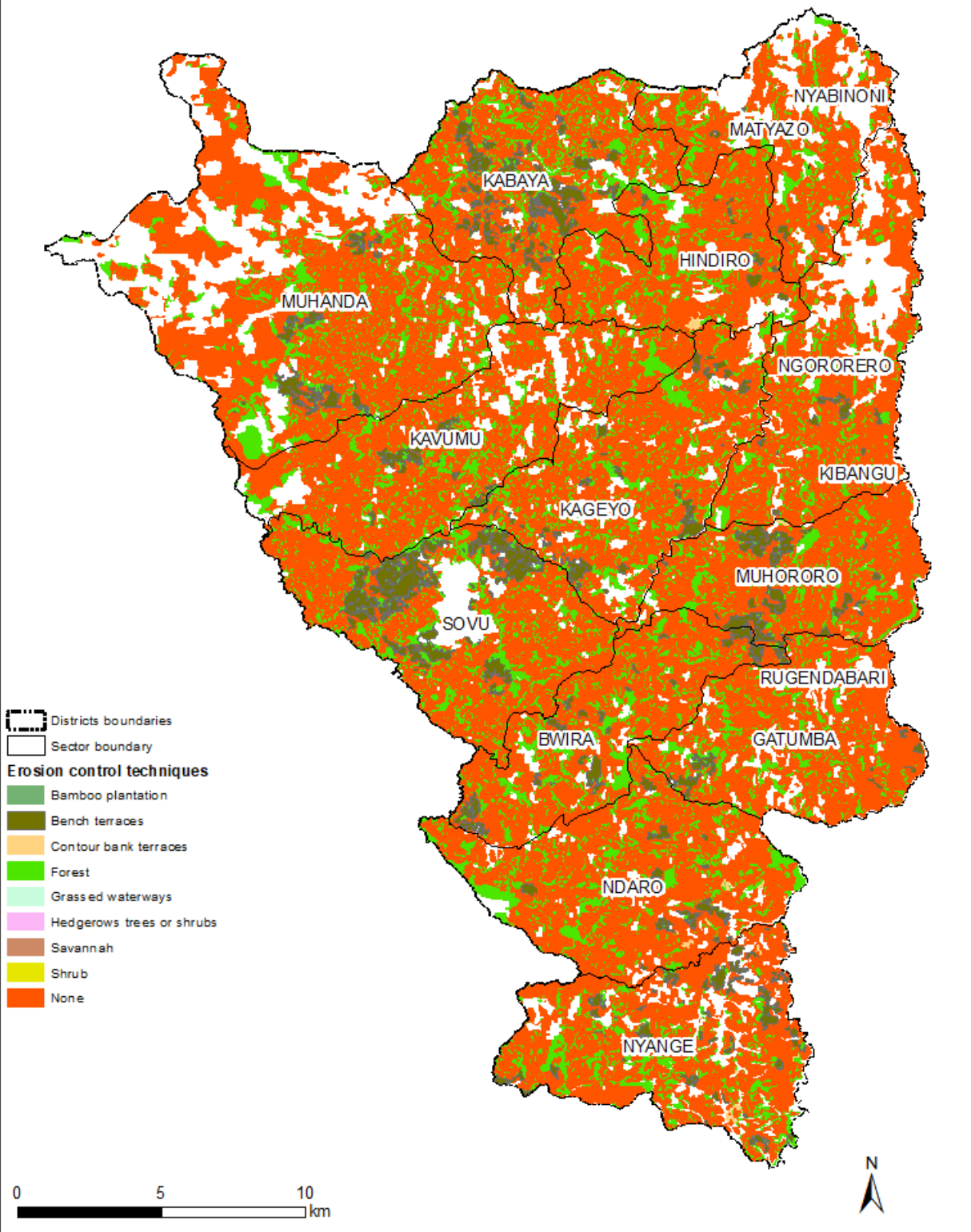
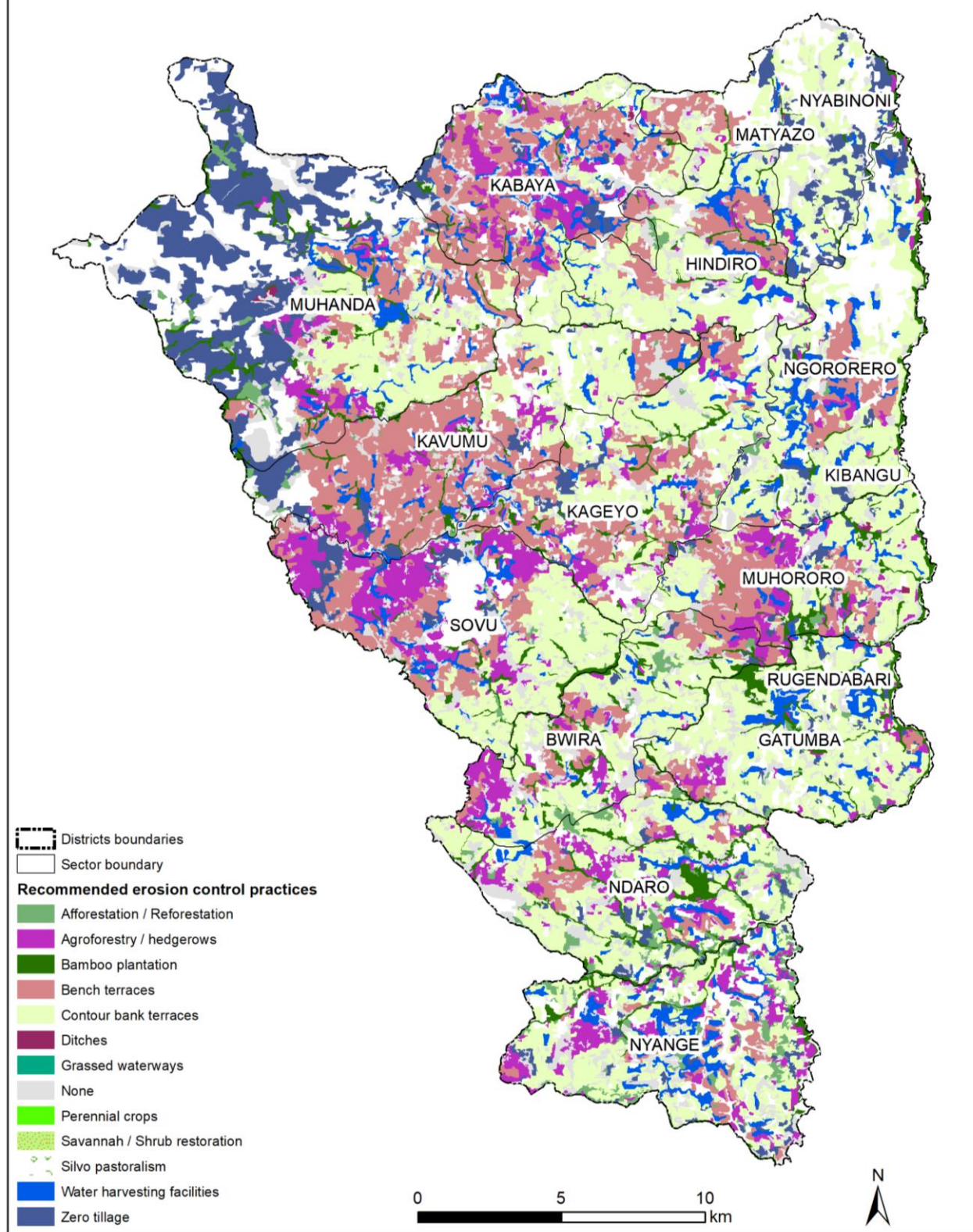


Figure 41: Erosion control techniques in place in Ngororero District



## Recommended Erosion Control Practices in Ngororero District



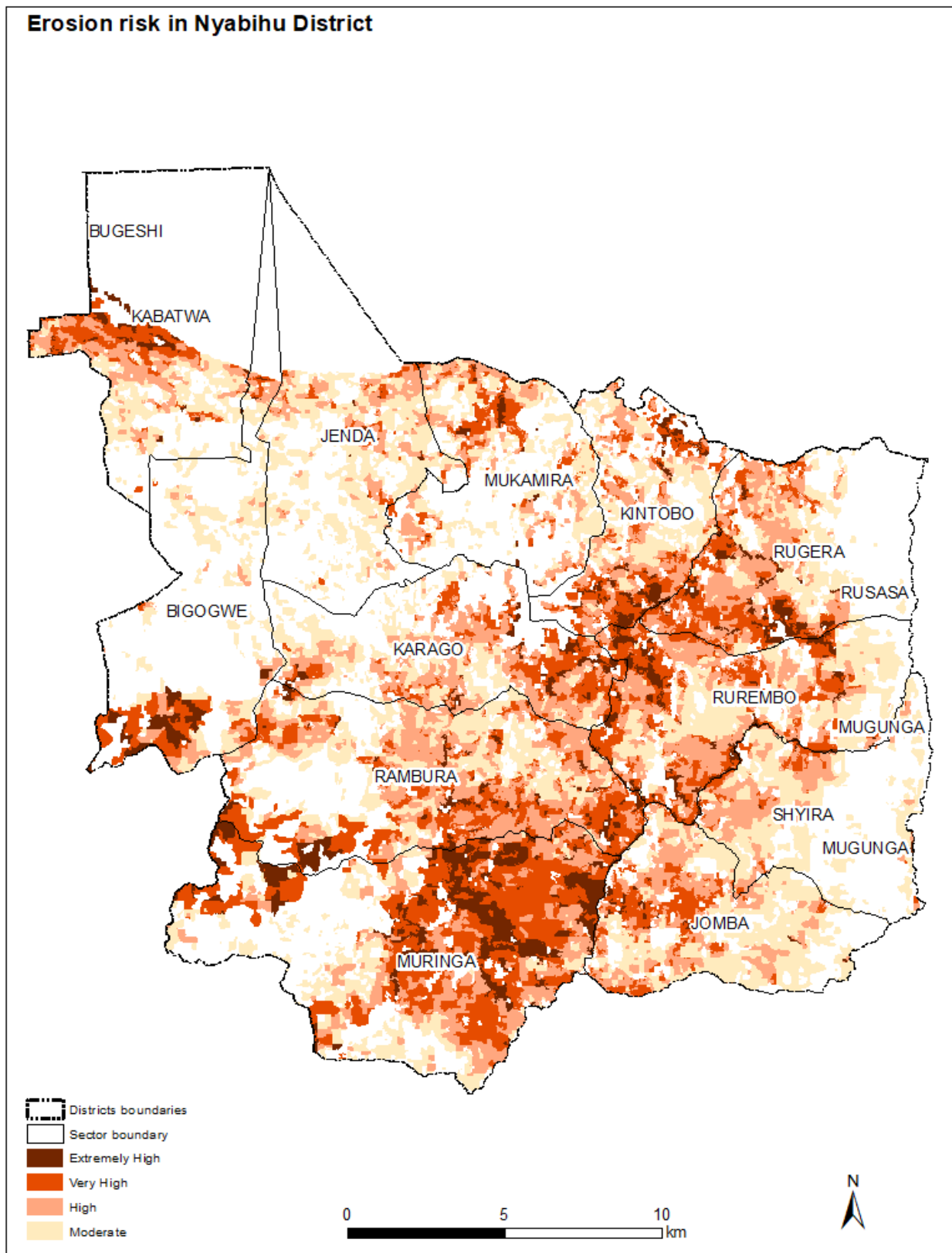
**Figure 42: Recommended erosion control practices in Ngororero District**

### 3.2.3. Erosion control status in Nyabihu District

Soil erosion risk in Nyabihu is summarised in Table 43 and presented in Figure 43. Land area at risk is estimated to 29706 hectares; about 56% of the total district land. Rurembo sector is the highest susceptible to erosion with 3123 hectares (78% of the sector land), followed by Jomba sector with 2600 hectares (74% of sector land), Rambura sector with 4198 hectares (73% of the sector land), Muringa sector with 5307 hectares, 71% of the sector land, Kintobo sector with 1804 hectares (71% of the sector land) and Karago sector with 2343 hectares (64% of the sector land). The least affected sectors are Kabatwa with 1501 hectares susceptible to erosion (about 29% of sector land), and Bigogwe sector with 1464 hectares about 31% of the total sector land.

**Table 45: Erosion risk per sector in Nyabihu District**

Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
RUREMBO	202	756	1034	1131	3123	4006	78%
JOMBA	52	406	804	1339	2600	3506	74%
RAMBURA	236	1064	1573	1325	4198	5726	73%
MURINGA	934	2151	1276	946	5307	7473	71%
KINTOBO	144	399	624	637	1804	2813	64%
KARAGO	114	441	993	795	2343	3679	64%
RUGERA	167	542	958	689	2355	4117	57%
SHYIRA	27	92	539	976	1635	3378	48%
MUKAMIRA	42	280	525	791	1638	3436	48%
JENDA	12	84	415	1224	1736	4814	36%
BIGOGWE	180	303	276	706	1464	4773	31%
KABATWA	93	342	454	612	1501	5235	29%
<b>Grand Total</b>	<b>2203</b>	<b>6859</b>	<b>9472</b>	<b>11172</b>	<b>29706</b>	<b>52958</b>	<b>56%</b>



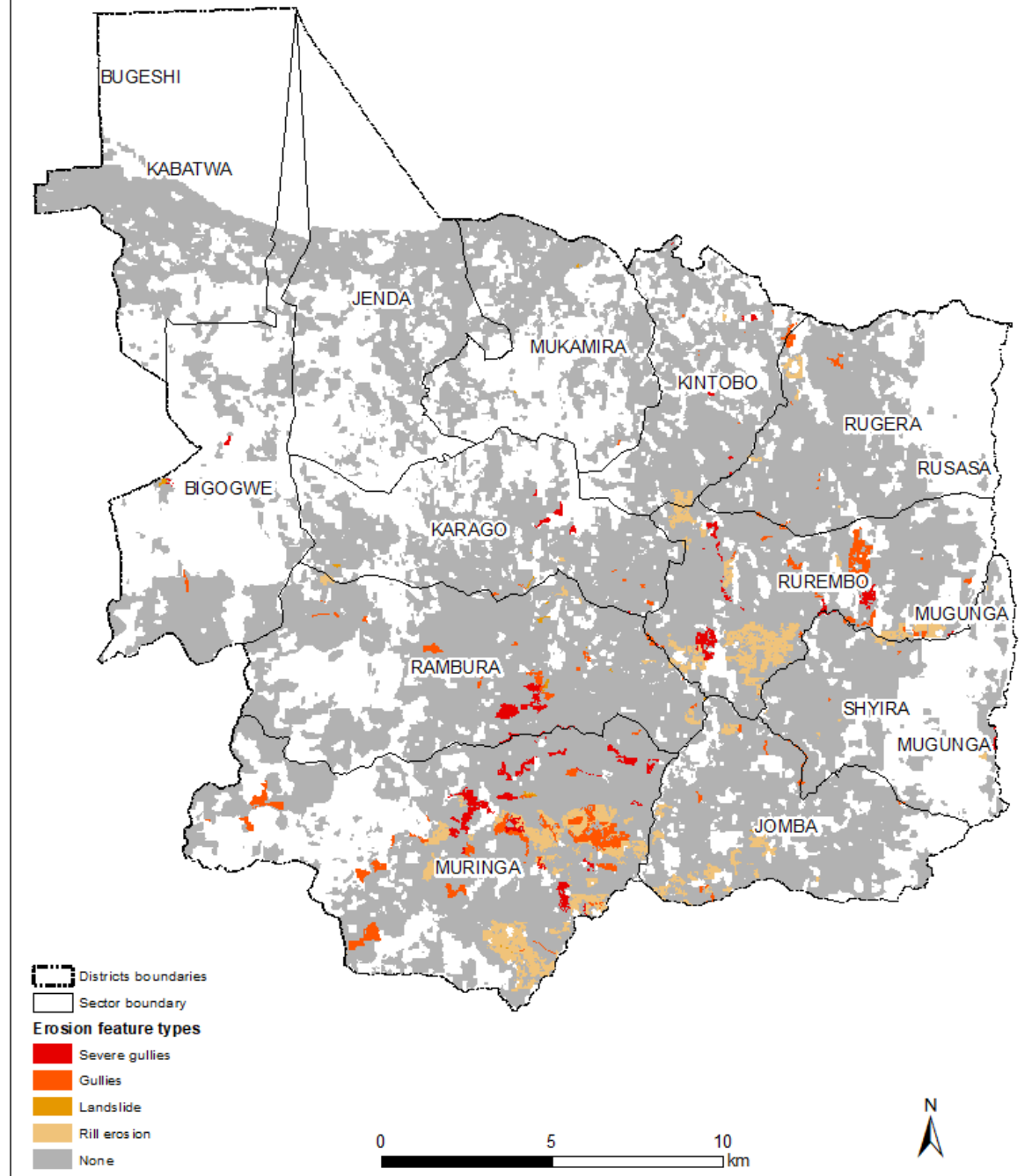
**Figure 43: Erosion risk in Nyabihu District**

Land areas affected by erosive features in Nyabihu District are summarized in Table 44 and the map of erosive features are presented in Figure 44. The results show that Muringa sector is the worst affected by gullies and rill erosion on areas estimated to 964 hectares (18% of sector land at risk), followed by Rurembo sector on 559 hectares (18% of sector land at risk), and Jomba sector on 150 hectares (6% of sector land at risk). The presence of gullies and rill erosion in Muringa, Rurembo, Jomba, Kintobo and Rambura sectors confirms the findings of CROM model; however the reduced presence of gullies in Mukamira (2ha) and Bigogwe (13 ha) and the absence of erosive features in Kabatwa and Jenda which was originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. The least sectors affected by gullies and rill erosion are Kabatwa (0 hectare), Jenda (0 hectare), Mukamira with only 1 hectares and Bigogwe with 13 hectares affected by gullies.

**Table 46: Erosive features and areas affected in Nyabihu District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
MURINGA	273	5	518	169	964	4343	5307	18%
RUREMBO	116		367	76	559	2565	3123	18%
JOMBA	16	2	132		150	2449	2600	6%
RAMBURA	46	6	35	53	140	4058	4198	3%
KINTOBO	6		25	7	38	1766	1804	2%
RUGERA	19		28		47	2308	2355	2%
SHYIRA	6		20	6	32	1603	1635	2%
KARAGO	6	2	3	16	27	2316	2343	1%
BIGOGWE	5	3		6	13	1451	1464	1%
MUKAMIRA	1				1	1637	1638	0%
JENDA					0	1736	1736	0%
KABATWA					0	1501	1501	0%
<b>Grand Total</b>	<b>494</b>	<b>18</b>	<b>1128</b>	<b>333</b>	<b>1973</b>	<b>27733</b>	<b>29706</b>	<b>7%</b>

### Erosion feature types in Nyabihu District



**Figure 44: Erosive features detected in Nyabihu District**

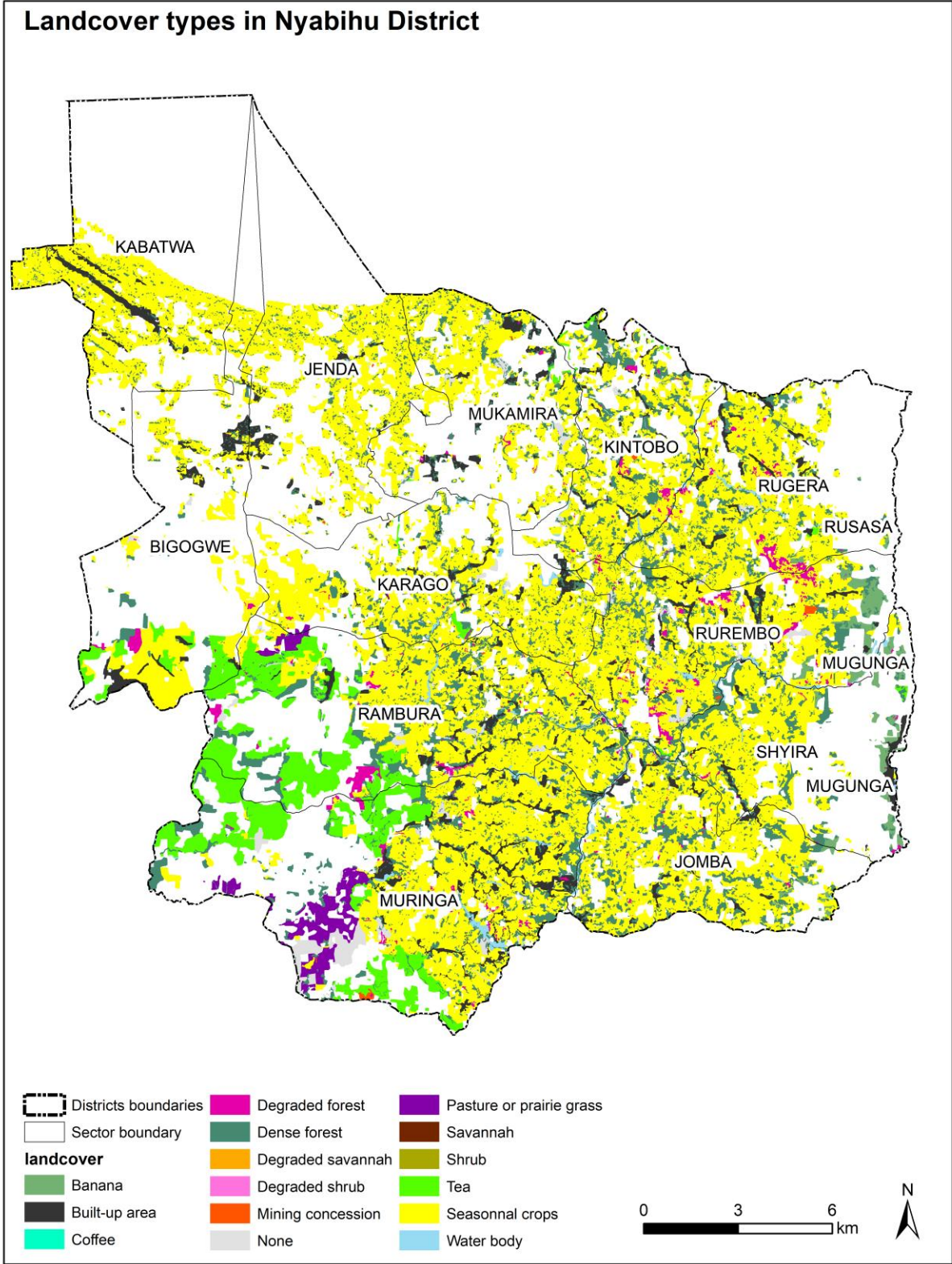


In term of land use and land cover of areas at risk in Nyabihu District, the results of land cover mapping (Table 45 and Figure 45) show 20682 hectares (70% of the total land at risk) are used for seasonal cropping, 3300 hectares (16% of the total land at risk) are covered by healthy forests, 1642 hectares (6% of the total land at risk) are covered by built-up area. To be noted that banana is covering an area of 413 hectares (1% of the total land at risk) and that tea is covering an area of 2094 hectares 7% of the land at risk.

**Table 47: Land Use and Vegetation Cover (LUV) of areas at risk in Nyabihu District**

Sector Name	Banana	Built-up area	Degraded forest	Dense forest	Mining and Quarries	Non e	Pasture or prairie grass	Seasonal crops	Tea	Water body	Grand Total
BIGOGWE		171	30	96		19		939	209		1464
JENDA		80		45	0	3		1608		0	1736
JOMBA	37	96	3	439		1		1990		34	2600
KABATWA		126		18				1357			1501
KARAGO		107	2	205		28	7	1945	30	20	2343
KINTOBO		95	26	344	3	23		1287	17	9	1804
MUKAMIRA		141	6	154		63		1265	8	0	1638
MURINGA		338	38	517	10	258	342	2762	961	81	5307
RAMBURA		150	85	577		80	49	2379	852	26	4198
RUGERA	22	110	63	277		14		1846	6	19	2355
RUREMBO	192	143	90	362	11	73		2219	5	30	3123
SHYIRA	161	85	5	266		3		1086	7	21	1635
<b>Grand Total</b>	<b>413</b>	<b>1642</b>	<b>349</b>	<b>3300</b>	<b>25</b>	<b>564</b>	<b>397</b>	<b>20682</b>	<b>2094</b>	<b>241</b>	<b>29706</b>
<b>%</b>	<b>1%</b>	<b>6%</b>	<b>1%</b>	<b>11%</b>	<b>0%</b>	<b>2%</b>	<b>1%</b>	<b>70%</b>	<b>7%</b>	<b>1%</b>	<b>100%</b>





**Figure 45: Land cover types in Nyabihu District**

About existing erosion control practices in Nyabihu district, Table 46 shows that only 30% of land at risk is protected by forests (3362 hectares), contour bank terraces or progressive terraces with ditches (226 hectares), and bench terraces (5342 hectares). The highest protected sectors are Rambura with 48% of its land at risk protected, followed by Kabatwa where 36% of the total land at risk is protected and Muringa with 35% of land protected. The least protected sectors are Rugera with only 13% protected, Rurembo (only 14% protected), Shyira (22%) and Jomba (23% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Jenda, Rugera, Rurembo and Kabatwa sectors remain at very high risk of soil erosion since more than 70% of the sector land at risk are not protected.

**Table 48: Erosion control practices already in place in Nyabihu District**

Sector Name	Erosion control in place			Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
RAMBURA	1448		577	2025	2173	4198	48%
KABATWA	522		18	540	961	1501	36%
MURINGA	1126	149	578	1853	3454	5307	35%
MUKAMIRA	416		154	570	1069	1638	35%
BIGOGWE	409		96	505	959	1464	34%
KINTOBO	222	21	346	589	1214	1804	33%
KARAGO	543	12	197	752	1592	2343	32%
JOMBA	153	4	439	596	2004	2600	23%
JENDA	337	3	51	390	1346	1736	22%
SHYIRA	59	35	266	360	1275	1635	22%
RUREMBO	73	3	363	439	2685	3123	14%
RUGERA	35		277	312	2043	2355	13%
<b>Grand Total</b>	<b>5344</b>	<b>226</b>	<b>3362</b>	<b>8931</b>	<b>20774</b>	<b>29706</b>	<b>30%</b>

Erosion control practices in Nyabihu District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 47 shows that about 11626 hectares (which is 39% of the total land at risk) are suitable for Contour bank terraces, 7701 hectares are hedgerows and cropland that need agroforestry/alley cropping, Afforestation & Reforestation (1013 hectares). Others are Storm water management facilities (SWMF) (1650 hectares), gullies or riverbanks amounting to 716 hectares eroded which require bamboo trees for rehabilitation, and contour banks (338 hectares).

## Erosion Control Techniques in Nyabihu District

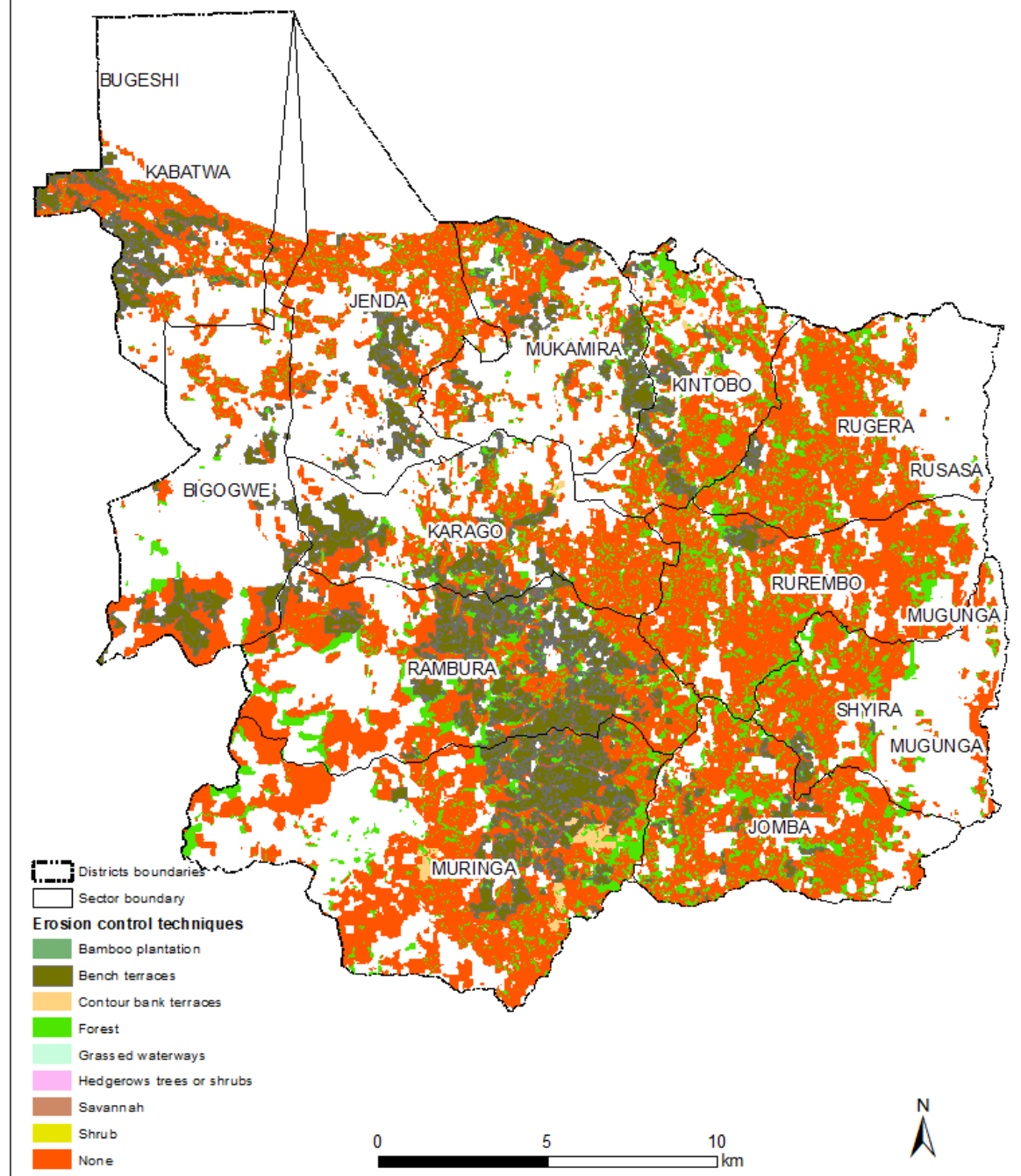


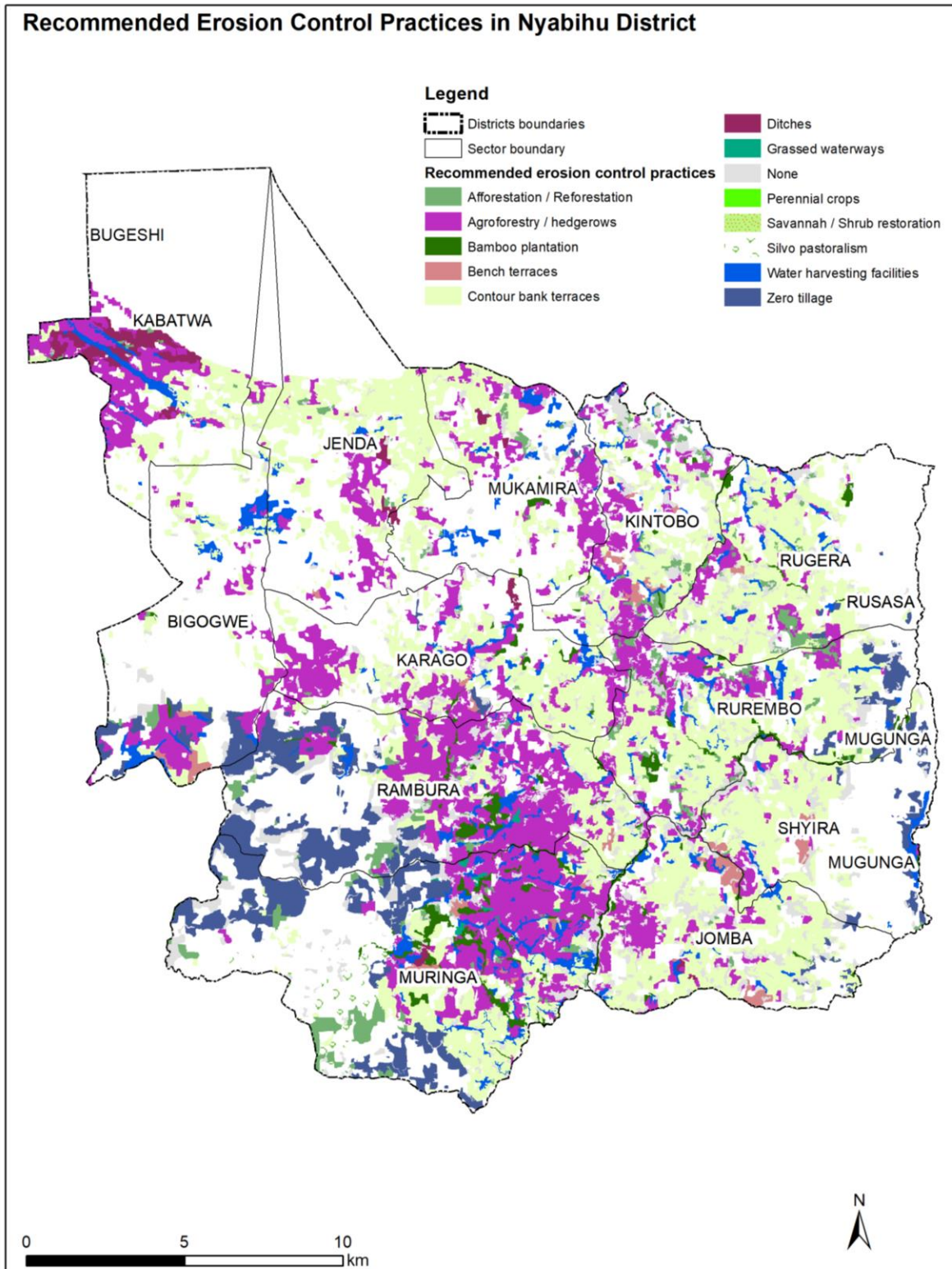
Figure 46: Erosion control techniques in place in Nyabihu District

**Table 49: Recommended erosion practices in Nyabihu District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	Grassed waterways	None	Silvopastoralism	Water harvesting facilities	Zero tillage	Grand Total
BIGOGWE	37	448	7	55	441			97		171	209	1464
JENDA	27	406	0	5	1132	31		55		80		1736
JOMBA	13	426	46	90	1452	9		430		96	37	2600
KABATWA	18	654			427	259		18		126		1501
KARAGO	17	825	40	12	1088	19		197	7	107	30	2343
KINTOBO	125	452	22	63	682	2		346		95	17	1804
MUKAMIRA	41	530	27		707	30		154		141	8	1638
MURINGA	291	1390	292	75	1048	17	33	529	342	340	949	5307
RAMBURA	154	1530	116	15	734		7	585	49	156	852	4198
RUGERA	110	281	44	9	1493			282		110	28	2355
RUREMBO	169	619	90		1544			362		143	197	3123
SHYIRA	10	140	30	57	878			266		85	168	1635
<b>Grand Total</b>	<b>1013</b>	<b>7701</b>	<b>716</b>	<b>380</b>	<b>11626</b>	<b>367</b>	<b>41</b>	<b>3320</b>	<b>397</b>	<b>1650</b>	<b>2495</b>	<b>29706</b>
<b>%</b>	<b>3%</b>	<b>26%</b>	<b>2%</b>	<b>1%</b>	<b>39%</b>	<b>1%</b>	<b>0%</b>	<b>11%</b>	<b>1%</b>	<b>6%</b>	<b>8%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.





**Figure 47: Recommended erosion control practices in Nyabihu District**

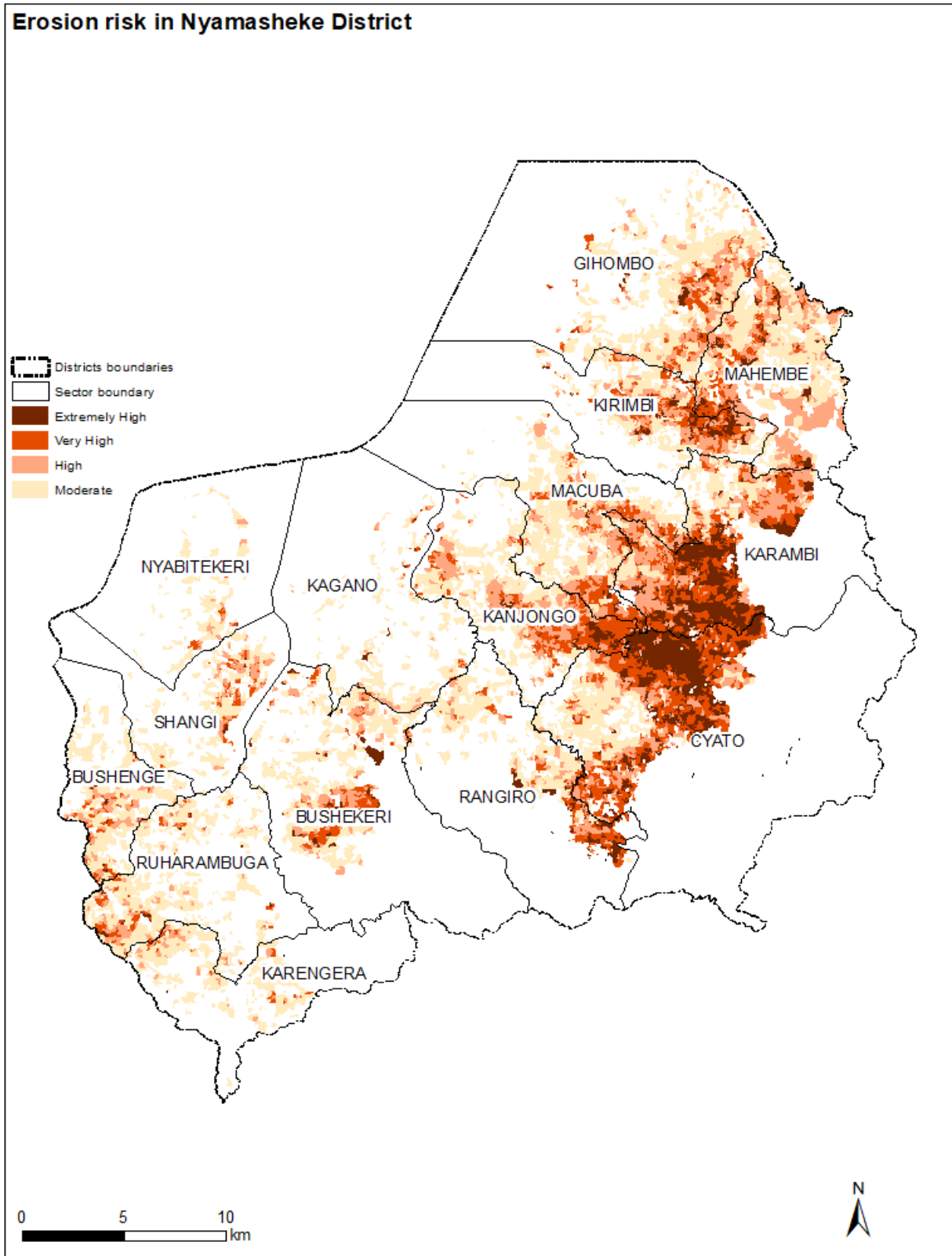
### 3.2.4. Erosion control status in Nyamasheke District

Soil erosion risk in Nyamasheke is summarised in Table 48 and presented in Figure 48. Land area at risk is estimated to 37417 hectares; about 39% of the total district land. Mahembe sector is the highest susceptible to erosion with 3921 hectares (73% of the sector land), followed by Kanjongo sector with 3003 hectares (62% of sector land), Macuba sector with 3207 hectares (61% of the sector land), and Gihombo sector with 3269 hectares, 60% of the sector land. The least affected sectors are Karengera sector with 1256 hectares about 22% of the total sector land, Nyabitekero with only 716 hectares susceptible to erosion (23% of sector land) and Kagano sector with 1042 hectares (23% of the sector land).

**Table 50: Erosion risk per sector in Nyamasheke District**

Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MAHEMBE	201	355	1404	1961	3921	5381	73%
KANJONGO	137	603	862	1402	3003	4881	62%
MACUBA	85	447	802	1873	3207	5239	61%
GIHOMBO	67	328	716	2158	3269	5488	60%
KARAMBI	1185	1107	1286	769	4347	7956	55%
KIRIMBI	206	416	654	905	2182	4034	54%
BUSHENGE	23	98	279	1271	1670	3183	52%
RUHARAMBUGA	37	167	297	1743	2244	6181	36%
SHANGI	11	85	249	799	1144	3444	33%
CYATO	1350	1539	903	1179	4972	17369	29%
BUSHEKERI	176	330	512	1538	2557	10301	25%
RANGIRO	186	292	294	1113	1885	8084	23%
KAGANO	20	20	102	900	1042	4516	23%
NYABITEKERI	2	35	86	594	717	3156	23%
KARENTERA		54	137	1066	1256	5589	22%
<b>Grand Total</b>	<b>3686</b>	<b>5876</b>	<b>8583</b>	<b>19271</b>	<b>37417</b>	<b>94802</b>	<b>39%</b>





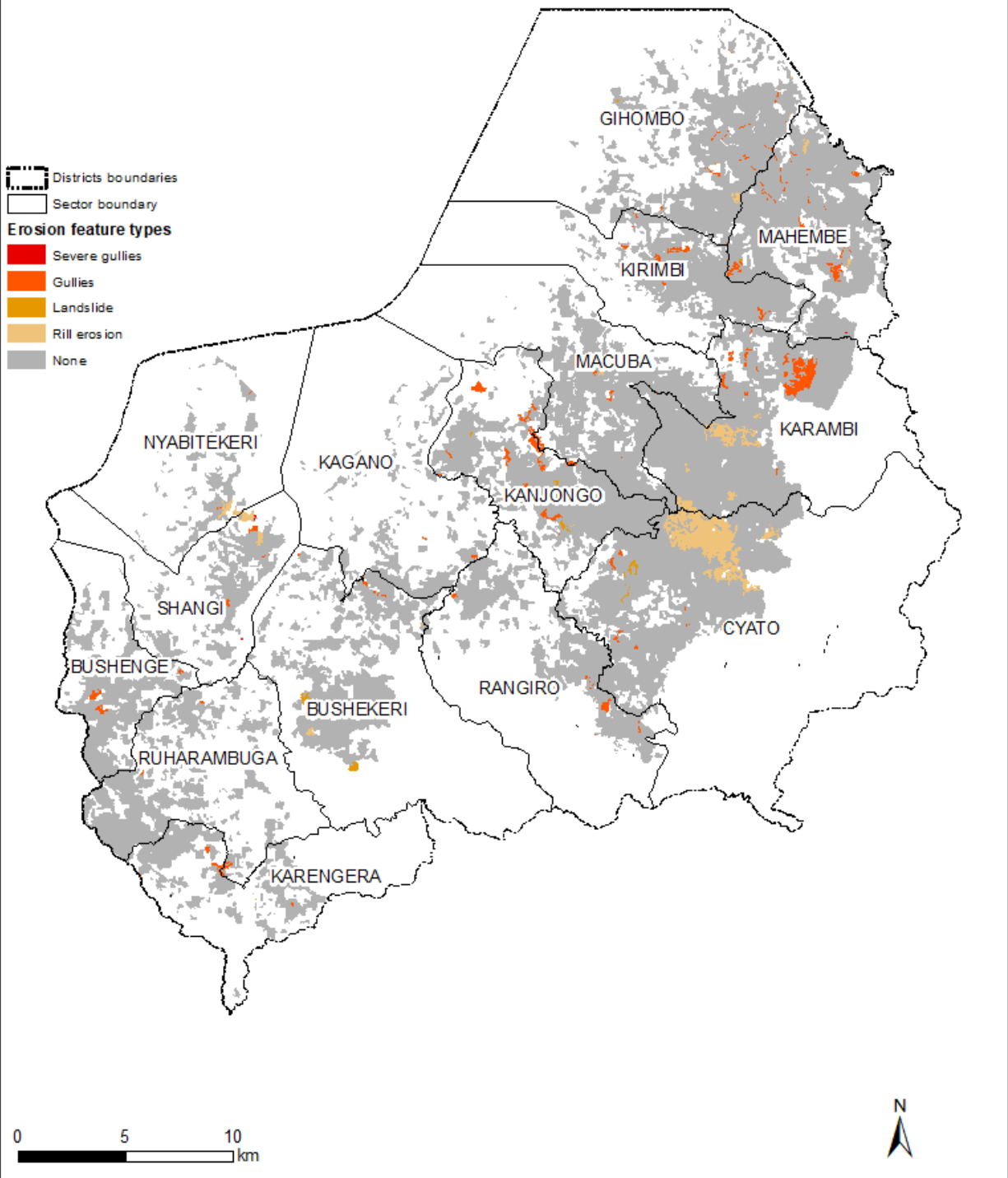
**Figure 48: Erosion risk in Nyamasheke District**

Erosive features are clearly observed on World View images. Land areas affected by erosive features in Nyamasheke District are summarized in Table 49 and the map of erosive features are presented in Figure 49. The results show that Cyato sector is the worst affected by rill erosion on areas estimated to 687 hectares (14% of sector land at risk), followed by Karambi sectors. This confirms the findings of CROM model; however the reduced presence of gullies in Rangiro, Kirimbi, Bushekeri, Gihombo, Macuba, Ruharambuga, Kagano, Bushenge, Karengera, Kanjongo (all these sectors have less than 3 ha affected by gullies) which were originally predicted by CROM model as sectors at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. The least sectors affected by gullies and rill erosion are Kagano, Ruharambuga, Macuba, Gihombo, Karengera, Rangiro, Bushenge, Bushekeri and Kirimbi where, in each sector, the areas affected by gullies is less than 3 hectares.

**Table 51: Erosive features and areas affected in Nyamasheke District**

Sector Name	Erosive features			Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion				
CYATO	25	23	639	687	4284	4972	14%
KARAMBI	191		181	372	3976	4347	9%
KANJONGO	174	12		186	2817	3003	6%
SHANGI	21		43	64	1081	1144	6%
NYABITEKERI	3		32	35	682	717	5%
MAHEMBE	119	3	17	139	3782	3921	4%
KIRIMBI	53			53	2129	2182	2%
BUSHENGE	34			34	1637	1670	2%
BUSHEKERI	9	26	12	47	2510	2557	2%
RANGIRO	31			31	1855	1885	2%
KARENGERA	20	0		20	1236	1256	2%
GIHOMBO	30	1	16	47	3222	3269	1%
MACUBA	35		7	42	3165	3207	1%
RUHARAMBUGA	20			20	2224	2244	1%
KAGANO	7			7	1036	1042	1%
<b>Grand Total</b>	<b>768</b>	<b>66</b>	<b>948</b>	<b>1782</b>	<b>35635</b>	<b>37417</b>	<b>5%</b>

### Erosion feature types in Nyamasheke District



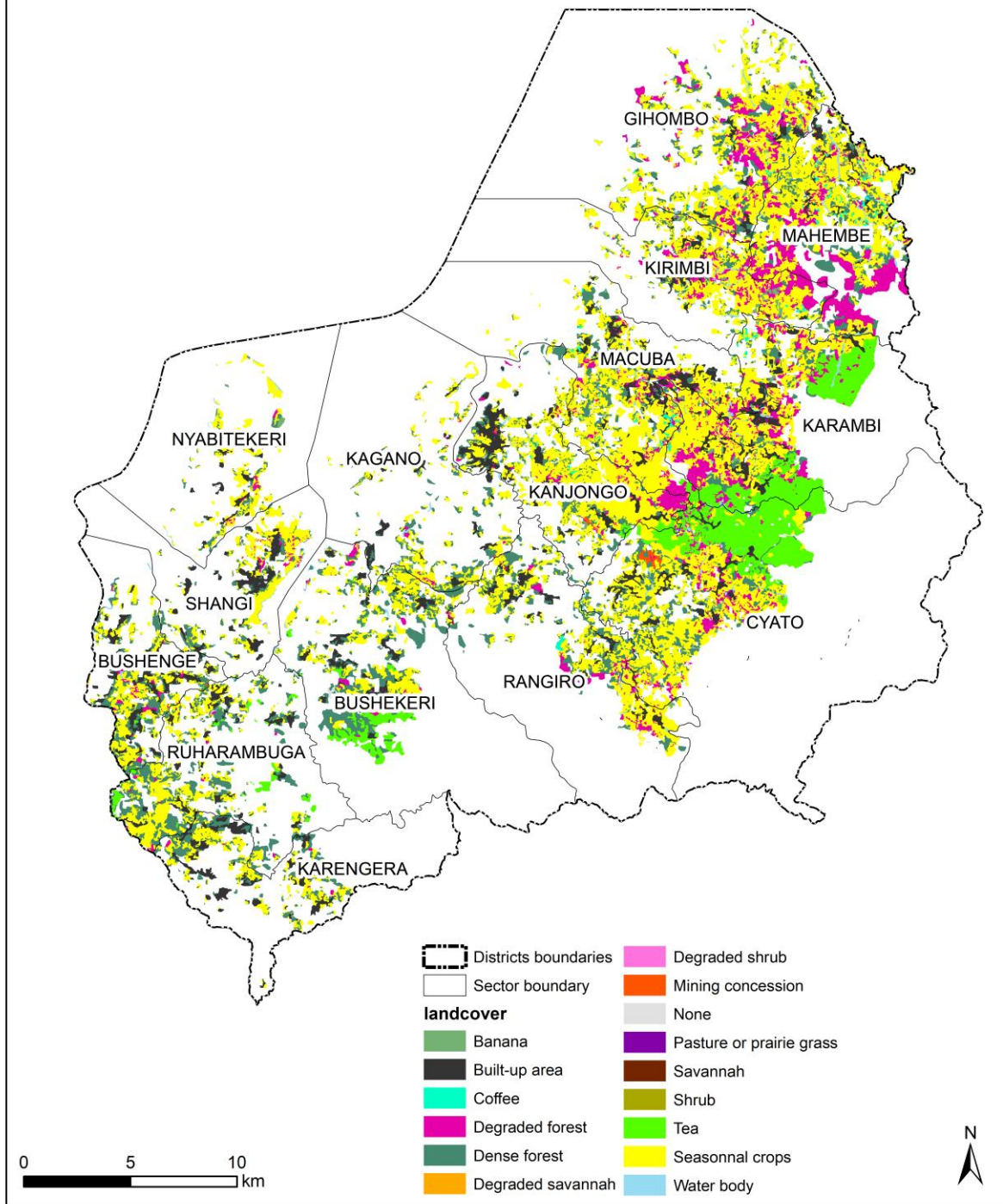
**Figure 49: Erosive features detected in Nyamasheke District**

In term of land use and land cover of areas at risk in Nyamasheke, the results of land cover mapping (Table 50 and Figure 50) show 19134 hectares (51% of the total land at risk) are used for seasonal cropping, 3,337 hectares (9% of the total land at risk) are covered by degraded forests, 6476 hectares (17% of the total land at risk) are covered by healthy forests, 4022 hectare used for built-up (11%) and 380 hectares i.e. 1% are covered by Banana crop. In this district there are coffee and tea plantations which cover respectively 158 hectares (0% of the total land at risk) and 3285 hectares (9% of the total land at risk).

**Table 52: Land Use and Vegetation Cover (LUV) of areas at risk in Nyamasheke District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining and Quarries	None	Seasonal crops	Tea	Water body	Grand Total
BUSHEKERI	4	269		74	913		11	879	381	26	2557
BUSHENGE	4	402		50	458	1	1	730	8	15	1670
CYATO	22	289		254	565	41	3	2221	1510	67	4972
GIHOMBO	67	139	8	481	499		16	2000		60	3269
KAGANO	9	150		18	314		3	528		19	1042
KANJONGO	15	465	7	180	346	10	4	1899	57	22	3003
KARAMBI	50	389	18	578	249		8	1855	1145	55	4347
KARENTERA	6	346		11	381		3	509			1256
KIRIMBI	66	144	11	391	204		2	1333		31	2182
MACUBA	37	394	37	223	362		7	2072	45	30	3207
MAHEMBE	73	185	60	861	538			2093		112	3921
NYABITEKERI	15	97		18	105		3	465		14	717
RANGIRO	8	211	17	133	475		2	1019		19	1885
RUHARAMBUGA	2	251		41	858		16	935	139	2	2244
SHANGI	1	291		24	209		3	598		19	1144
<b>Grand Total</b>	<b>380</b>	<b>4022</b>	<b>158</b>	<b>3337</b>	<b>6476</b>	<b>53</b>	<b>81</b>	<b>19134</b>	<b>3285</b>	<b>490</b>	<b>37417</b>
<b>%</b>	<b>1%</b>	<b>11%</b>	<b>0%</b>	<b>9%</b>	<b>17%</b>	<b>0%</b>	<b>0%</b>	<b>51%</b>	<b>9%</b>	<b>1%</b>	<b>100%</b>

## Landcover Types in Nyamasheke District



**Figure 50: Land cover types in Nyamasheke District**

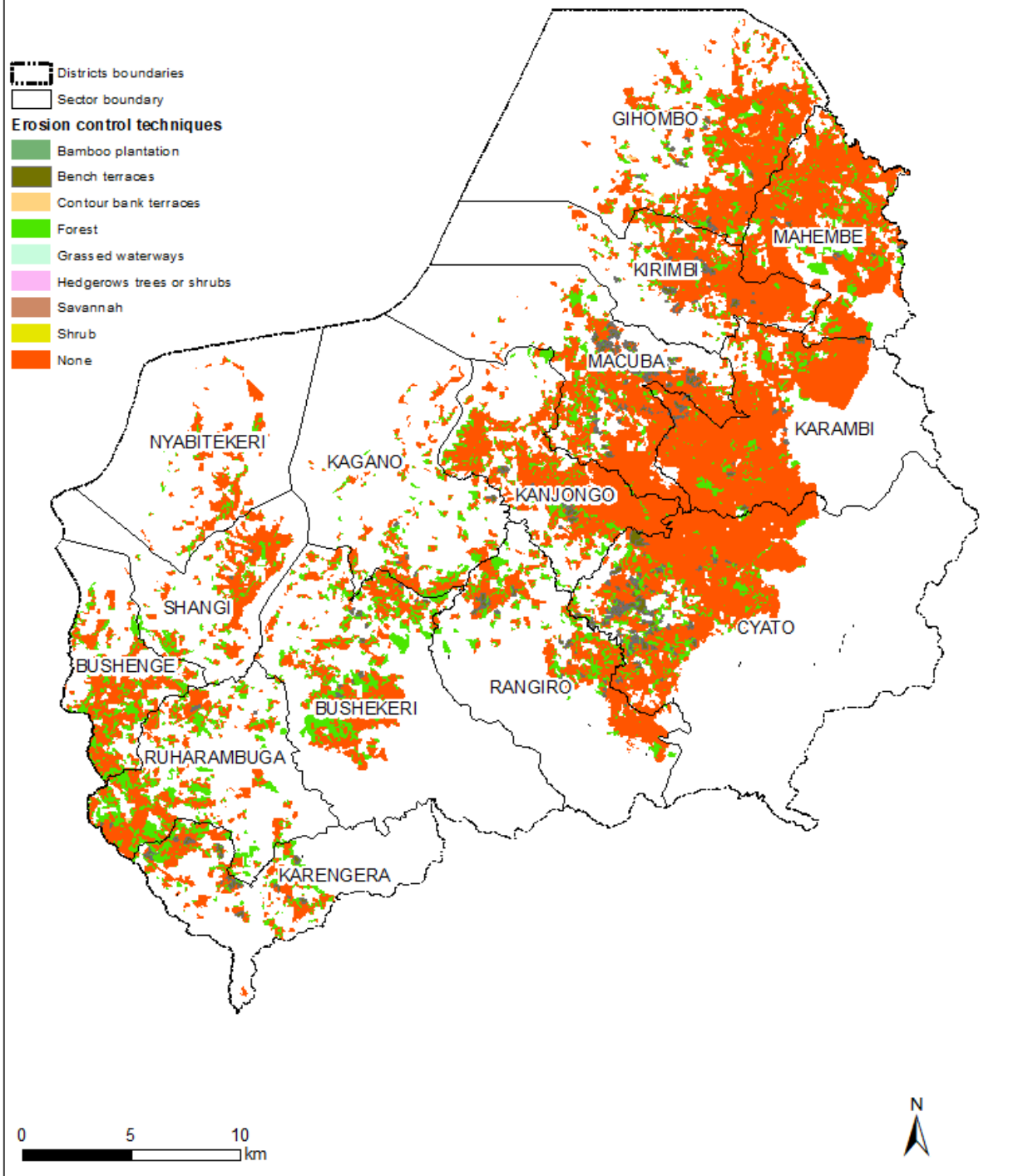
About current erosion control practices in Nyamasheke district, only 20% of land at risk is protected by forests (6476 hectares) and bench terraces (942 hectares). The highest protected sectors are Ruharambuga with 39% of its land at risk protected, followed by Karengera where 37% of the total land at risk is protected and Bushekeri with 37% of land protected. The least protected sectors are Karambi with only 7% protected, Kirimbi (only 12% protected), Mahembe (15%) and Kanjongo (13% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Nyabitekera, Gihombo, Cyato, Karambi, Mahembe and Kirimbi sectors remain at very high risk of soil erosion since more than 80% of the sector land at risk are not protected

**Table 53: Erosion control practices already in place in Nyamasheke District**

Sector Name	Erosion control			Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
RUHARAMBUGA	7	4	858	869	1375	2244	39%
KARENGERA	86		381	467	790	1256	37%
BUSHEKERI	34		913	947	1610	2557	37%
KAGANO	13		314	327	715	1042	31%
RANGIRO	50		475	525	1360	1885	28%
BUSHENGE			458	458	1213	1670	27%
MACUBA	249		362	612	2595	3207	19%
SHANGI	2		209	211	933	1144	18%
GIHOMBO	40	19	499	558	2712	3269	17%
CYATO	273		565	838	4134	4972	17%
NYABITEKERI			105	105	611	717	15%
MAHEMBE	14	17	538	570	3351	3921	15%
KANJONGO	54		346	400	2603	3003	13%
KIRIMBI	61		204	265	1916	2182	12%
KARAMBI	58		249	307	4041	4347	7%
<b>Grand Total</b>	<b>942</b>	<b>40</b>	<b>6476</b>	<b>7458</b>	<b>29959</b>	<b>37417</b>	<b>20%</b>



## Erosion Control Techniques in Nyamasheke District



**Figure 51: Erosion control techniques in place in Nyamasheke District**

Erosion control practices in Nyamasheke District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 52 shows that about 15690 hectares (which is 42% of the total land at risk) are suitable for Contour bank terraces, 3456 hectares are Afforestation/Reforestation and 2353 hectares for agroforestry/alley cropping and hedgerows. Others are Storm water management facilities (SWMF) (4045 hectares), gullies or riverbanks amounting to 631 hectares eroded which require bamboo trees for rehabilitation, and bench terraces (935 hectares).

**Table 54: Recommended erosion control practices in Nyamasheke District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	None	Water harvesting facilities	Zero tillage	Grand Total
BUSHEKERI	76	103	37		774	913	269	385	2557
BUSHENGE	53	12	15		718	458	402	12	1670
CYATO	298	637	69	447	1132	567	289	1532	4972
GIHOMBO	488	79	89	28	1862	503	145	75	3269
KAGANO	22	37	27	22	457	314	154	9	1042
KANJONGO	191	179	33	25	1683	346	468	78	3003
KARAMBI	591	415	58	59	1374	249	389	1213	4347
KARENGERA	12	88	3	71	349	381	346	6	1256
KIRIMBI	401	163	33	48	1112	204	144	77	2182
MACUBA	224	277	41	157	1632	362	394	120	3207
MAHEMBE	868	115	153	2	1928	538	185	132	3921
NYABITEKERI	18	24	17		441	105	97	15	717
RANGIRO	140	153	24	76	780	475	211	25	1885
RUHARAMBUGA	48	32	4		898	858	261	142	2244
SHANGI	26	38	28		550	209	291	1	1144
<b>Grand Total</b>	<b>3456</b>	<b>2353</b>	<b>631</b>	<b>935</b>	<b>15690</b>	<b>6484</b>	<b>4045</b>	<b>3824</b>	<b>37417</b>
<b>%</b>	<b>9%</b>	<b>6%</b>	<b>2%</b>	<b>2%</b>	<b>42%</b>	<b>17%</b>	<b>11%</b>	<b>10%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

## Recommended Erosion Control Practices in Nyamasheke District

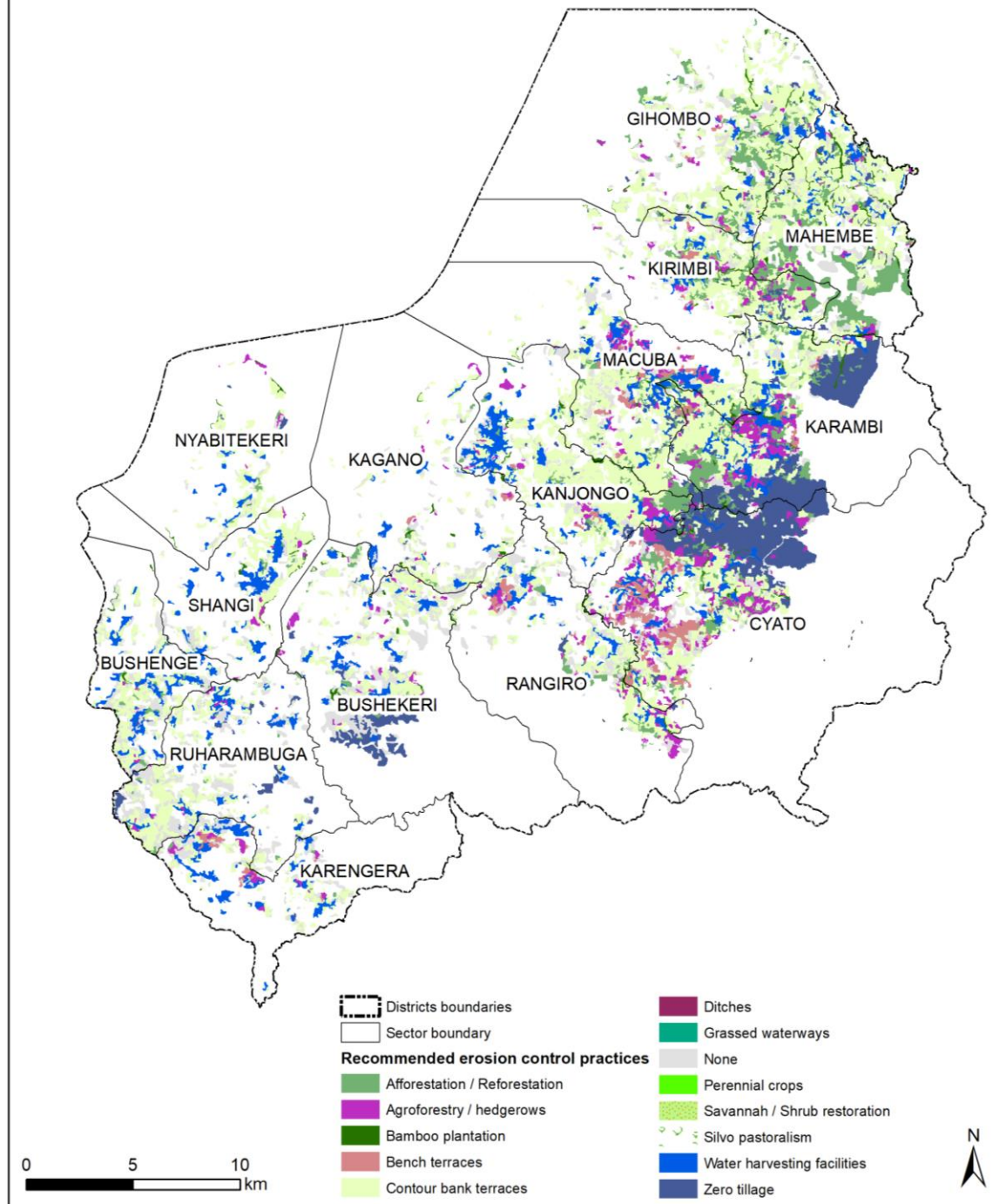


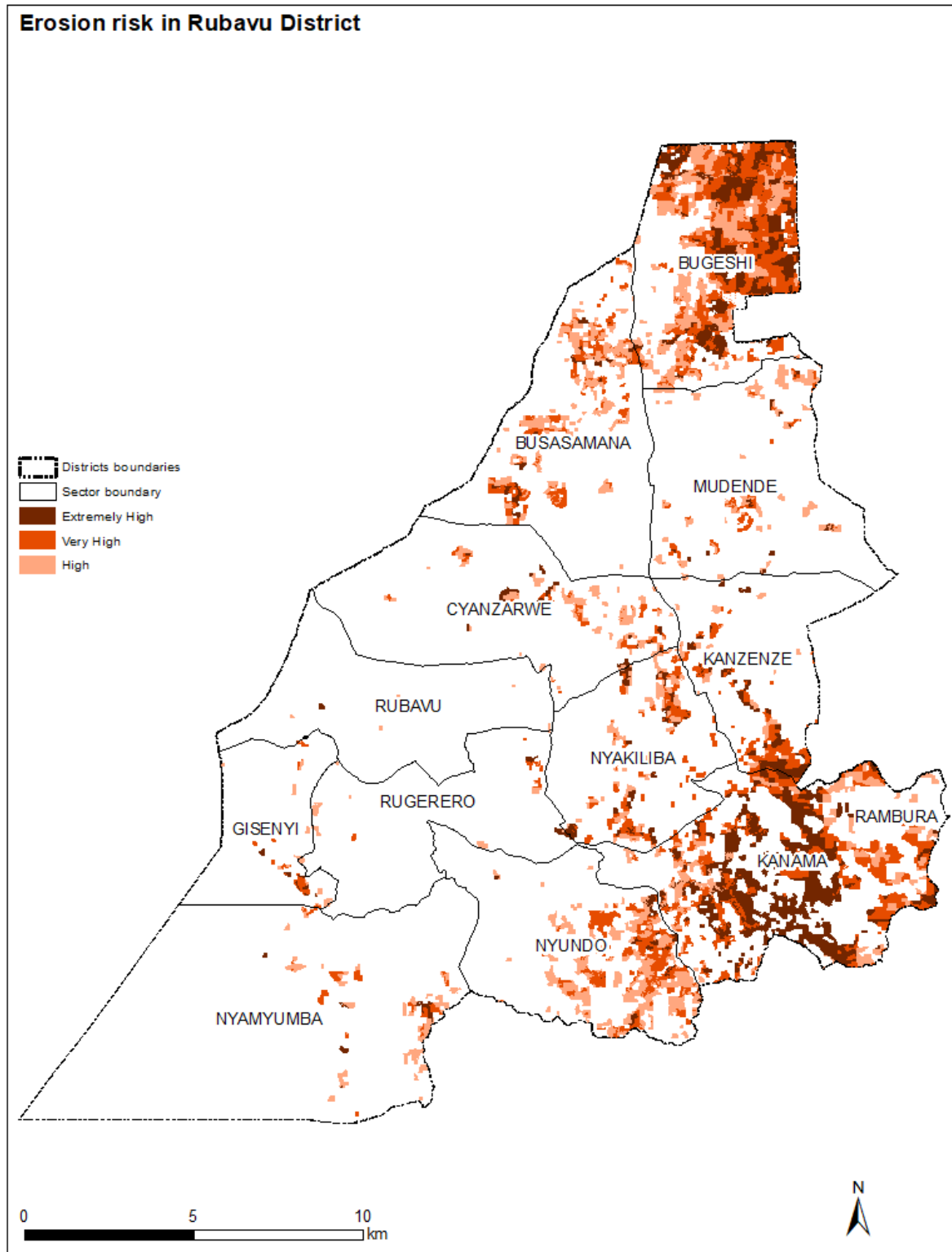
Figure 52: Recommended erosion control practices in Nyamasheke District

### 3.2.5. Erosion control status in Rubavu District

Soil erosion risk in Rubavu is summarised in Table 53 and presented in Figure 53. Land area at risk is estimated to 12874 hectares; about 38% of the total district land. Bugeshi sector is the highest susceptible to erosion with 2646 hectares (86% of the sector land), followed by Kanama sector with 2184 hectares (50% of sector land), and Nyundo sector with 1444 hectares (46% of the sector land). The least affected sectors are many and among them Rubavu is the lowest with only 317 hectares susceptible to erosion 12% of the sector land), Gisenyi sector with 182 hectares (16% of the sector land) and Rugerero sector with 494 hectares about 19% of the total sector land.

**Table 55: Erosion risk per sector in Rubavu District**

Sector Name	Erosion risk					District land (Ha)	Percentage (%)
	Extremel y High	Very High	High	Moderate	Grand Total		
BUGESHI	493	792	625	736	2,646	3,083	86%
KANAMA	851	669	356	308	2,184	4,363	50%
NYUNDO	35	255	445	710	1,444	3,114	46%
BUSASAMAN A	38	184	290	822	1,334	3,447	39%
MUDENDE	18	59	190	994	1,260	3,384	37%
NYAKILIBA	67	139	140	444	790	2,330	34%
KANZENZE	101	154	65	351	671	2,232	30%
NYAMYUMBA	19	47	131	471	669	2,344	29%
CYANZARWE	33	51	156	644	883	3,498	25%
RUGERERO	11	15	26	442	494	2,535	19%
GISENYI	9	30	25	119	182	1,117	16%
RUBAVU	6		5	306	317	2,642	12%
<b>Grand Total</b>	<b>1,680</b>	<b>2,395</b>	<b>2454</b>	<b>6,346</b>	<b>12,874</b>	<b>34,090</b>	<b>38%</b>



**Figure 53: Erosion risk in Rubavu District**

The entire District of Rubavu is reported as not having any severe gullies and landslides, apart from Nyundo Sector where landslides have affected an area of 5 hectares. Rill erosive features are clearly observed on World View images. Land areas affected by this type of erosive features in Rubavu District are summarized

in Table 54 and the map of erosive features are presented in Figure 54. The results show that Rugerero sector is the worst affected by rill erosion on areas estimated to 375 hectares (76% of sector land at risk), followed by Rubavu sector on an area estimated to 191 hectares (60% of the Sector land), and Busasamana sector on an area of 718 hectares (54% of sector land). This confirms the findings of CROM model; however the reduced presence of rill erosion in Kanama, Kanzenze, Bugeshi and Nyakiliba which were originally predicted by CROM model as sectors at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. The least sectors affected by gullies and rill erosion are Kanama, Kanzenze and Bugeshi where their respective affected lands are estimated to 10%, 16% and 24%.

**Table 56: Erosive features in Rubavu District**

Sector Name	Erosive features		Total feature	None	Grand Total	% Features
	Landslide	Rill erosion				
RUGERERO		375	375	118	494	76%
RUBAVU		191	191	126	317	60%
BUSASAMANA		718	718	617	1334	54%
NYAMYUMBA		345	345	324	669	52%
MUDENDE		629	629	631	1260	50%
CYANZARWE		403	403	480	883	46%
NYUNDO	5	604	609	836	1444	42%
GISENYI		74	74	108	182	41%
NYAKILIBA		262	262	528	790	33%
BUGESHI		623	623	2023	2646	24%
KANZENZE		107	107	564	671	16%
KANAMA		223	223	1961	2184	10%
<b>Grand Total</b>	<b>5</b>	<b>4554</b>	<b>4559</b>	<b>8316</b>	<b>12874</b>	<b>35%</b>

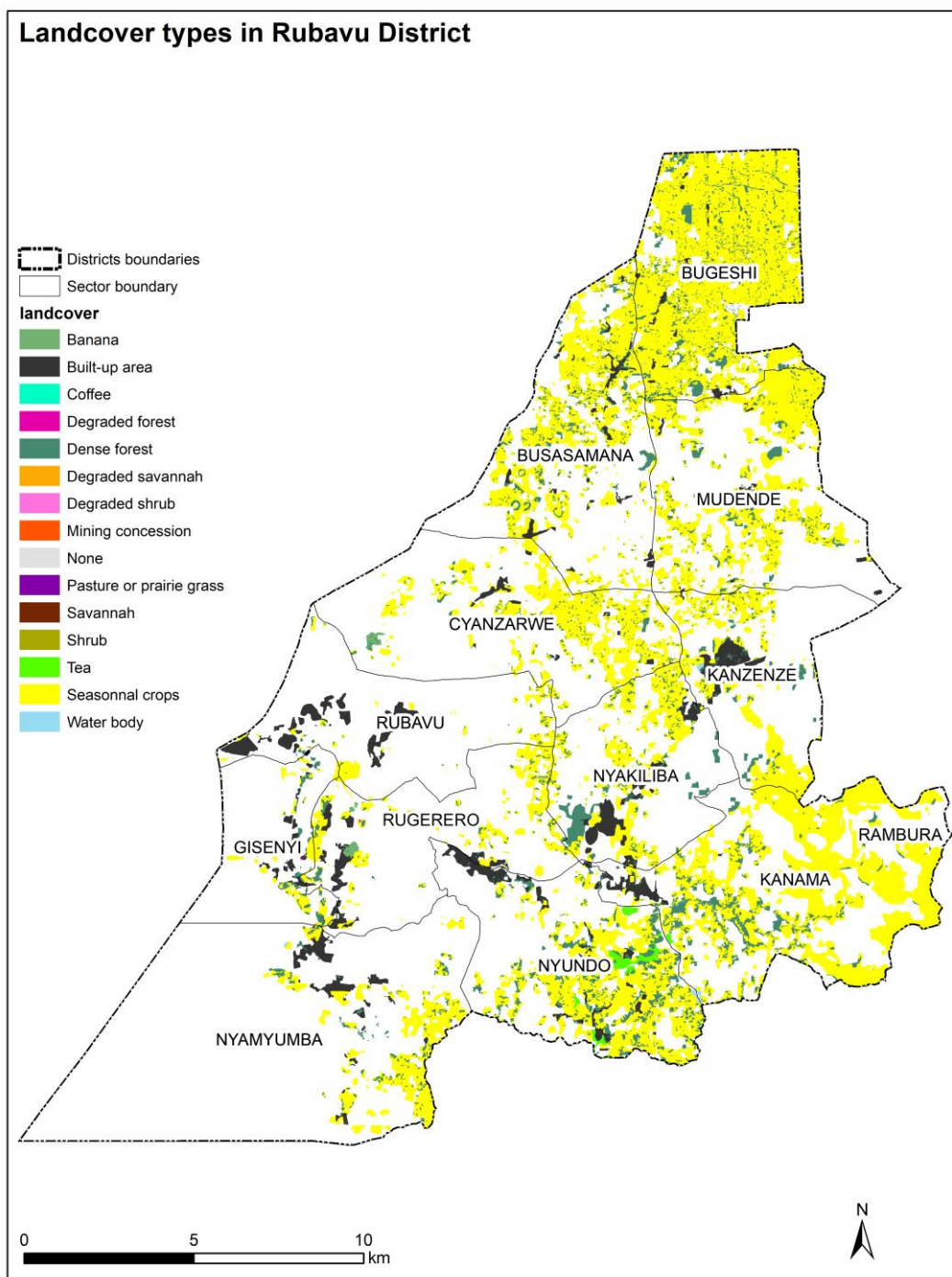
In term of land use and land cover of areas at risk in Rubavu District, the results of land cover mapping (Table 55 and Figure 55) show that 10773 hectares (84% of the total land at risk) are used for seasonal crops and 898 hectares (7% of the total land at risk) are covered by healthy forests and 1086 hectares (8%) are built-up lands.

**Table 57: Land Use and Vegetation Cover (LUVC) of areas at risk in Rubavu District**

Sector Name	Banana	Built-up area	Dense forest	Seasonal crops	Tea	Water body	Grand Total
BUGESHI		33	108	2504			2646
BUSASAMANA		78	73	1183			1334
CYANZARWE	15	36	22	811			883
GISENYI		47	41	94			182
KANAMA		62	189	1926	4	3	2184
KANZENZE		117	56	494		3	671
MUDENDE		20	60	1180			1260
NYAKILIBA		144	107	539			790
NYAMYUMBA		111	35	522		1	669
NYUNDO		142	173	1055	71	3	1444

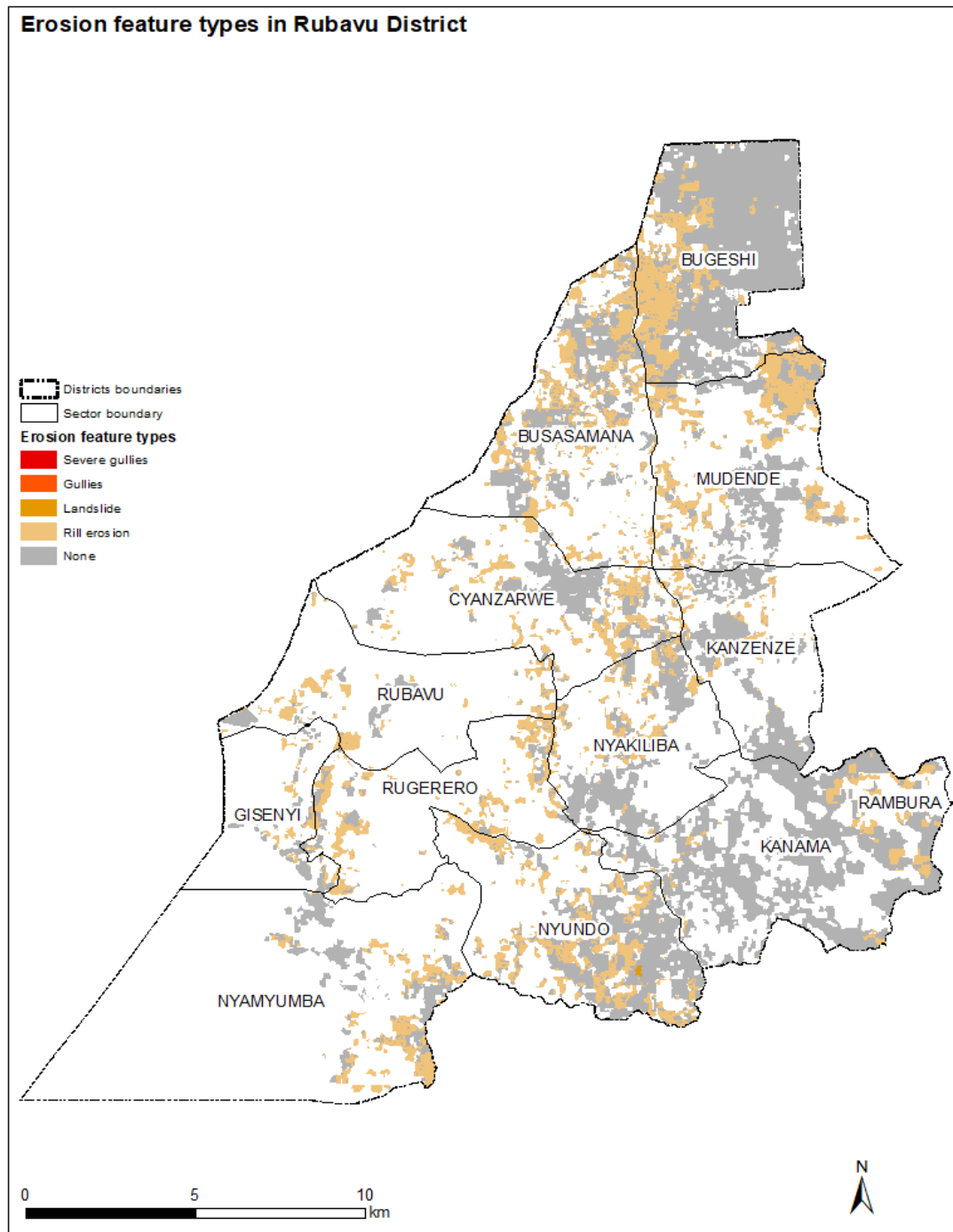


Sector Name	Banana	Built-up area	Dense forest	Seasonal crops	Tea	Water body	Grand Total
RUBAVU	0	187	5	125			317
RUGERERO	17	108	29	340			494
<b>Grand Total</b>	<b>32</b>	<b>1086</b>	<b>898</b>	<b>10773</b>	<b>75</b>	<b>10</b>	<b>12874</b>
<b>%</b>	<b>0%</b>	<b>8%</b>	<b>7%</b>	<b>84%</b>	<b>1%</b>	<b>0%</b>	<b>100%</b>



**Figure 54: Land cover types in Rubavu District**

About existing erosion control practices in Rubavu district, Table 56 shows that only 18% of land at risk is protected by forests (898 hectares) and bench terraces (1379 hectares). The highest protected sectors are Mudende with 36% of its land at risk protected, followed by Bugeshi where 27% of the total land at risk is protected, Gisenyi Sector where 25% is protected and Busasamana with 23% of land protected. The least protected sectors are Rubavu with only 3% protected, Nyamyumba (only 5% protected), Rugerero (8%) and Kanzenze (9% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Nyamyumba, Rubavu, Cyanzarwe sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected



**Figure 55: Erosive features detected in Rubavu District**

**Table 58: Erosion control practices already in Rubavu District**

Sector Name	Erosion control in place		Total protected (ha)	Unprotected (ha)	Grand Total (ha)	% protected
	Bench terraces	Forest				
MUDENDE	394	60	454	806	1260	36%
BUGESHI	600	108	708	1938	2646	27%
GISENYI	6	41	46	136	182	25%
BUSASAMANA	239	73	312	1022	1334	23%
NYAKILIBA		107	107	683	790	14%
NYUNDO	0	173	173	1271	1444	12%
CYANZARWE	76	22	98	785	883	11%
KANAMA	50	189	239	1945	2184	11%
KANZENZE	1	56	57	613	671	9%
RUGERERO	9	29	38	456	494	8%
NYAMYUMBA		35	35	634	669	5%
RUBAVU	4	5	9	308	317	3%
<b>Grand Total</b>	<b>1379</b>	<b>898</b>	<b>2277</b>	<b>10597</b>	<b>12874</b>	<b>18%</b>

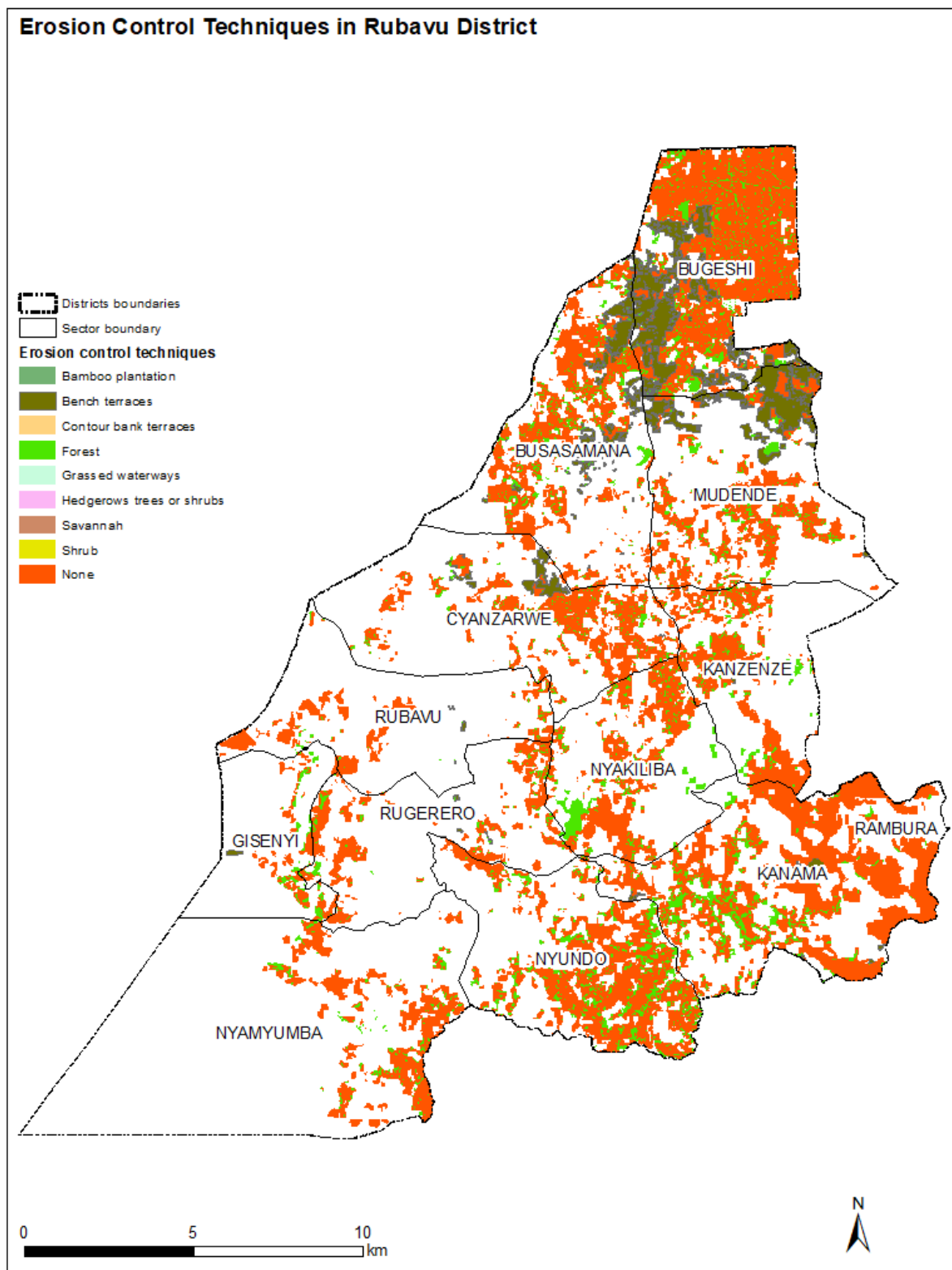
Erosion control practices in Rubavu District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 57 shows that about 7841 hectares (which is 61% of the total land at risk) are suitable for Contour bank terraces and 2898 hectares are cropland that need agroforestry/alley cropping and Hedgerows.

**Table 59: Recommended erosion control practices in Rubavu District**

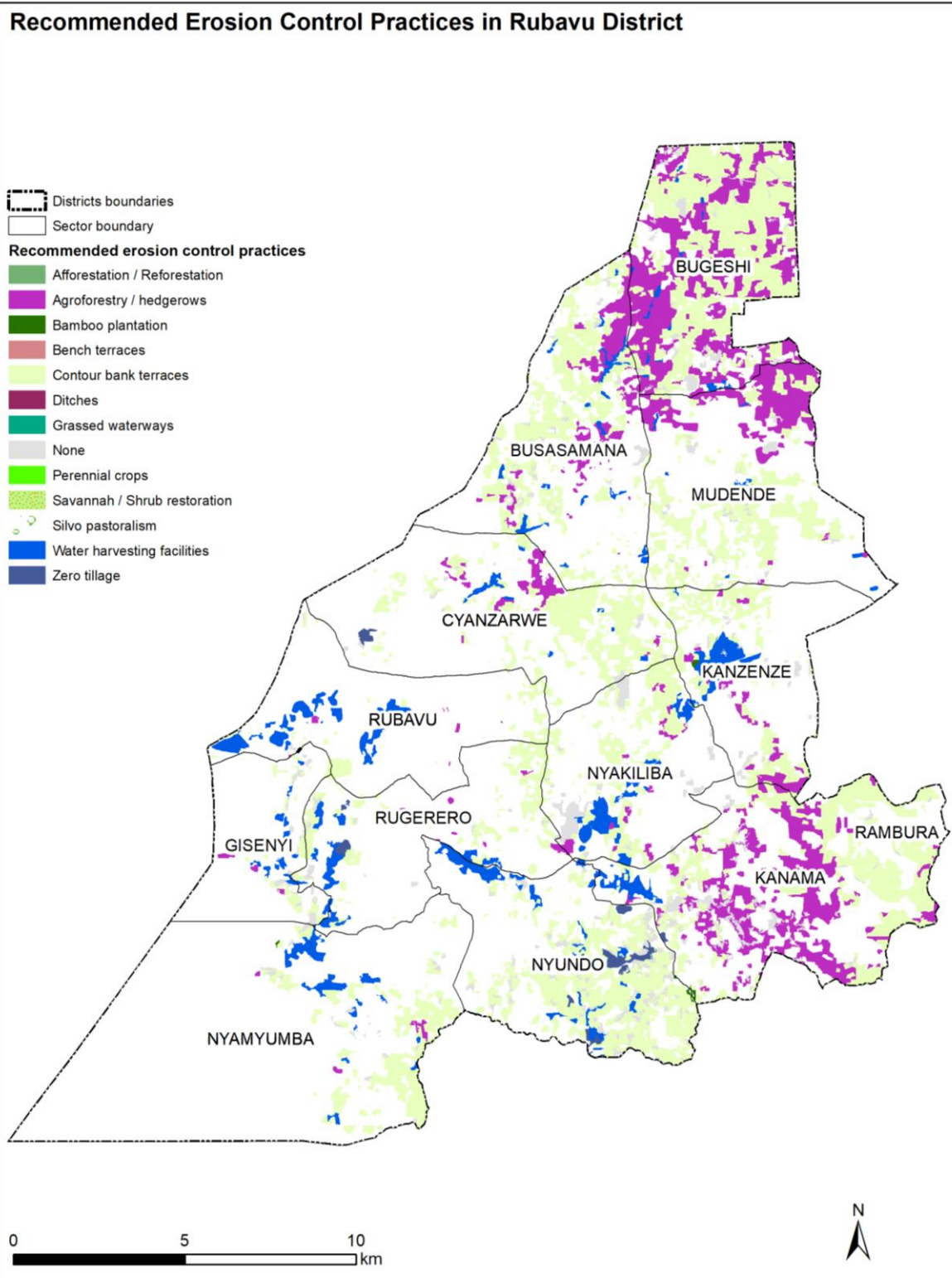
Sector Name	Agroforestry / hedgerows	Bamboo plantation	Contour bank terraces	Already protected	Water harvesting facilities	Zero tillage	Grand Total
BUGESHI	1062		1442	108	33		2646
BUSASAMANA	275		908	73	78		1334
CYANZARWE	105		700	29	36	15	883
GISENYI	11		83	41	47		182
KANAMA	838	3	1088	189	62	4	2184
KANZENZE	99	3	395	56	117		671
MUDENDE	409		771	60	20		1260
NYAKILIBA	52		463	132	144		790
NYAMYUMBA	17	1	501	35	114		669
NYUNDO	0	3	1055	173	142	71	1444
RUBAVU	10		115	5	187	0	317
RUGERERO	19		320	29	108	17	494
<b>Grand Total</b>	<b>2898</b>	<b>10</b>	<b>7841</b>	<b>930</b>	<b>1089</b>	<b>107</b>	<b>12874</b>
<b>%</b>	<b>23%</b>	<b>0%</b>	<b>61%</b>	<b>7%</b>	<b>8%</b>	<b>1%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate

with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 56: Erosion control techniques in place in Rubavu District**



**Figure 57: Recommended erosion control practices in Rubavu District**



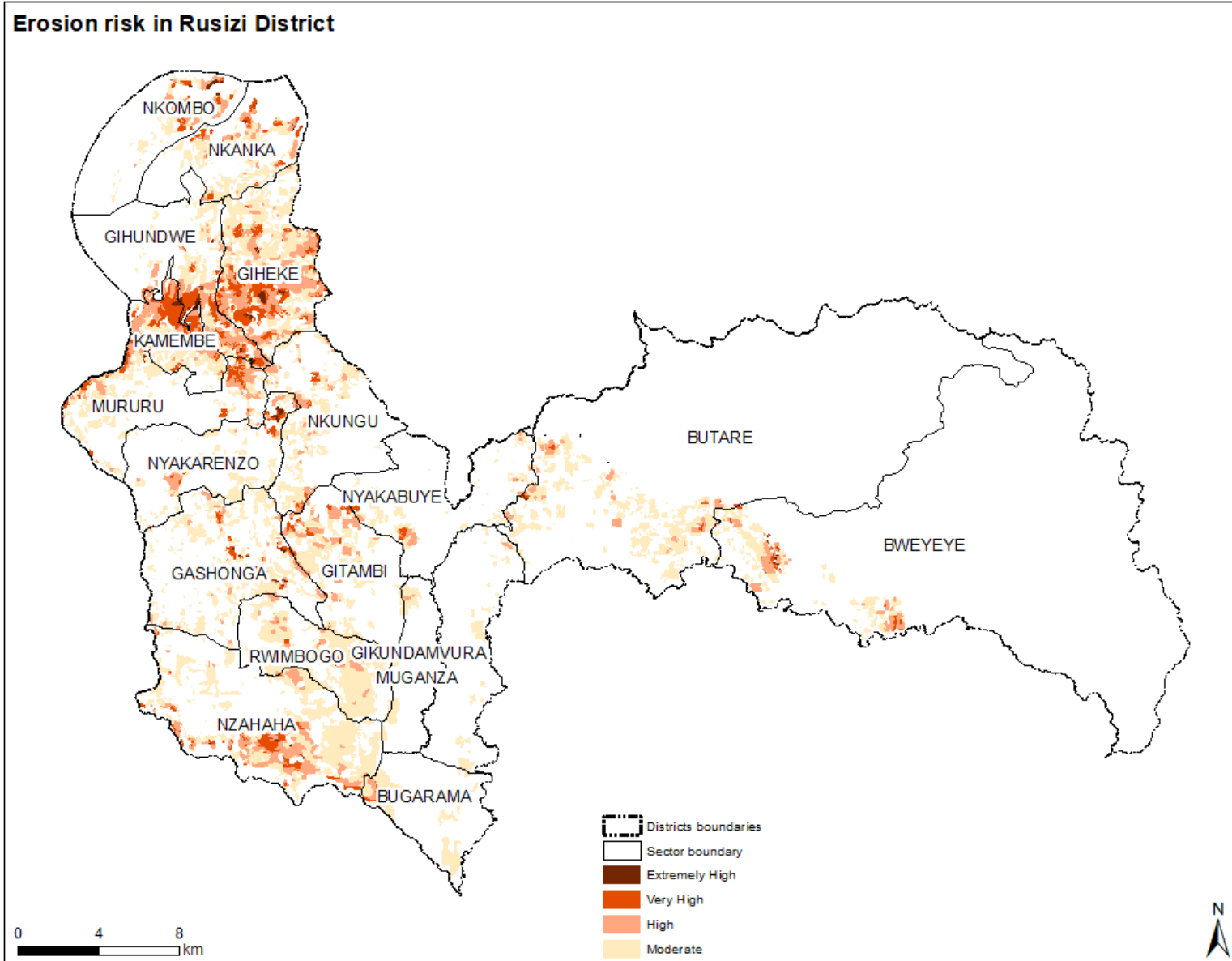
### 3.2.6. Erosion control in Rusizi District

Soil erosion risk in Rusizi is summarised in Table 58 and presented in Figure 58. Land area at risk is estimated to 18212 hectares; about 20% of the total district land. Giheke sector is the highest susceptible to erosion with 2621 hectares (74% of the sector land), followed by Kamembe sector with 1055 hectares (73% of sector land), and Rwimbogo sector with 1436 hectares (54% of the sector land) and Nkombo sector with 482 hectares (53% of the sector land). The least affected sectors are Bweyeye, Gikundamvura and Butare sectors with respectively 760 hectares, 208 hectares and 1365 hectares susceptible to erosion. The influence of Nyungwe and Cyamudongo natural forest including its buffer zone as well as other forests plantations on reducing soil erosion is very high. In fact, the results of forest cover mapping 2019 has shown that Rusizi is the highest forested with 48,255ha of forest cover (i.e. 52.6% of the total district land area) followed by Nyamasheke District with 45,935ha of forests area (48.5%) in western province,

**Table 60: Erosion risk per sector in Rusizi District**

Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
GIHEKE	48	437	958	1179	2621	3535	74%
KAMEMBE	28	255	353	419	1055	1445	73%
RWIMBOGO		13	138	1285	1436	2634	54%
NKOMBO	20	64	178	220	482	903	53%
GIHUNDWE	30	208	370	461	1070	2556	42%
NZAHAAHA	5	181	576	1667	2429	5992	41%
NKANKA	8	87	160	568	822	2035	40%
GITAMBI	3	53	280	689	1025	3104	33%
MURURU	9	154	255	675	1093	3316	33%
GASHONGA	11	58	161	1016	1246	4603	27%
NKUNGU	5	30	157	693	885	3690	24%
NYAKARENZO	18	55	102	465	640	3116	21%
BUGARAMA		21	35	353	409	2539	16%
MUGANZA			8	211	219	1760	12%
NYAKABUYE		27	81	340	448	3859	12%
BUTARE	4	22	175	1164	1365	20328	7%
GIKUNDAMVURA			10	198	208	3698	6%
BWEYEYE	7	37	236	480	760	22618	3%
<b>Grand Total</b>	<b>196</b>	<b>1704</b>	<b>4230</b>	<b>12082</b>	<b>18212</b>	<b>91731</b>	<b>20%</b>



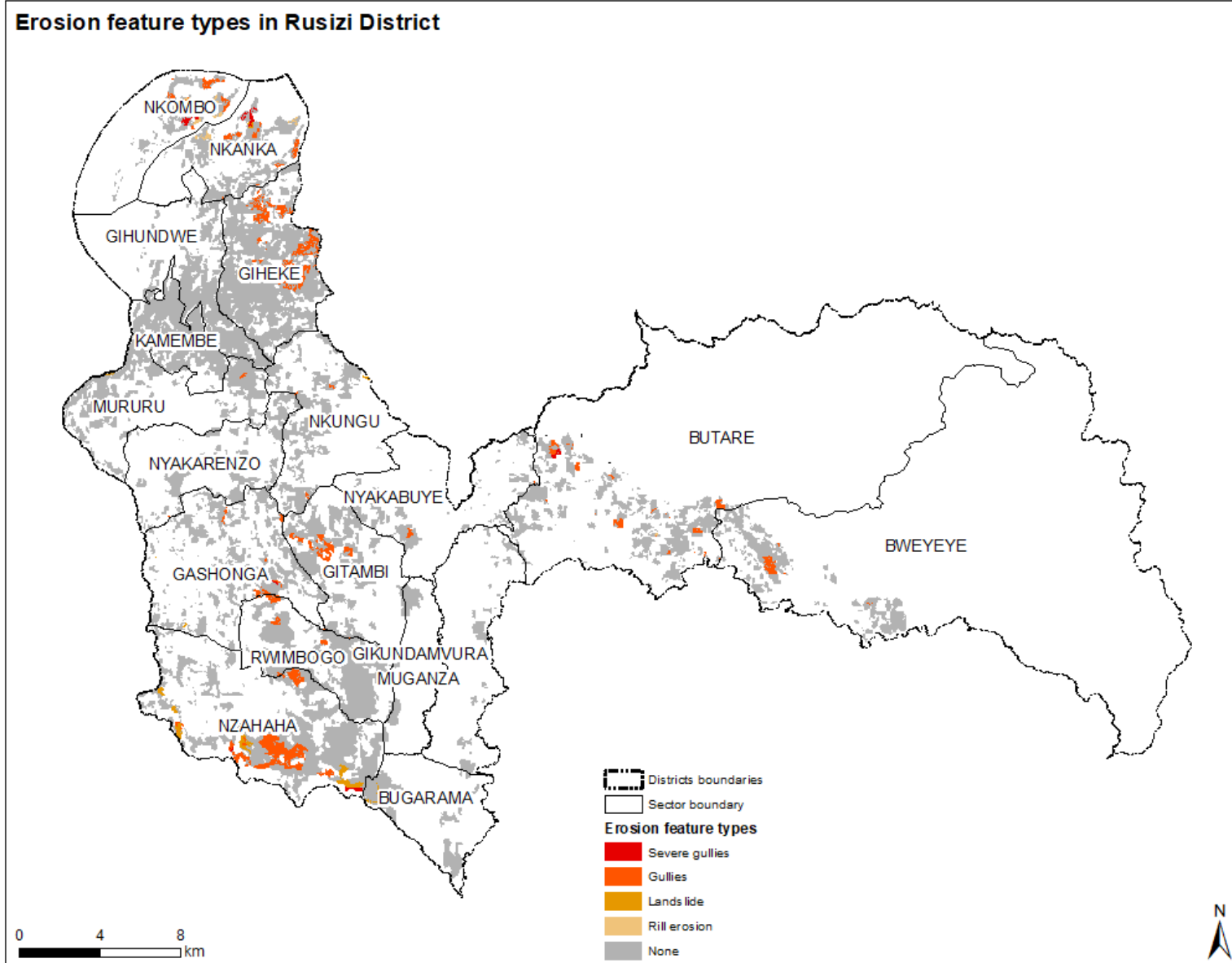


**Figure 58: Erosion risk in Rusizi District**

Land areas affected by erosive features in Rusizi District, as observed on World View images, are summarized in Table 61 and the map of erosive features are presented in Figure 59. The results show that Nkombo sector is the worst affected by gullies on areas estimated to 153 hectares (32% of sector land at risk), followed by Nzahaha sector affected by gullies and rill erosion on 477 hectares and Nkanka sector (110 hectares). The presence of gullies and rill erosion in Nzahaha, Nkombo and Nkanka sectors confirms the findings of CROM model; however the reduced presence of gullies in Gihundwe, Nyakarenzo, Mururu (all these sectors have less than 5 ha affected by gullies) and the absence of erosive features in Muganza, Kamembe and Gikundamvura which were originally predicted by CROM model as sectors at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. The least sectors affected by gullies and rill erosion are Kamembe, Gikundamvura, Gihundwe and Nyakarenzo where, in each sector, the areas affected by gullies is less than 5 hectares.

**Table 61: Erosive features and areas affected in Rusizi District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
NKOMBO	77		48	29	153	329	482	32%
NZAHABA	348	113		15	477	1952	2429	20%
NKANKA	57	5	22	26	110	712	822	13%
GIHEKE	312				312	2309	2621	12%
GITAMBI	92				92	933	1025	9%
BUTARE	82		4	12	98	1267	1365	7%
BWEYEYE	49				49	712	760	6%
BUGARAMA		19			19	390	409	5%
RWIMBOGO	55				55	1380	1436	4%
GASHONGA	38	3		4	45	1201	1246	4%
NYAKABUYE	10				10	438	448	2%
NKUNGU	11	5			16	869	885	2%
MUGANZA	2				2	217	219	1%
MURURU	4	5			9	1084	1093	1%
NYAKARENZO	1				1	639	640	0%
GIHUNDWE					0	1070	1070	0%
GIKUNDAMVURA					0	208	208	0%
KAMEMBE					0	1055	1055	0%
<b>Grand Total</b>	<b>1139</b>	<b>150</b>	<b>73</b>	<b>87</b>	<b>1449</b>	<b>16762</b>	<b>18212</b>	<b>8%</b>

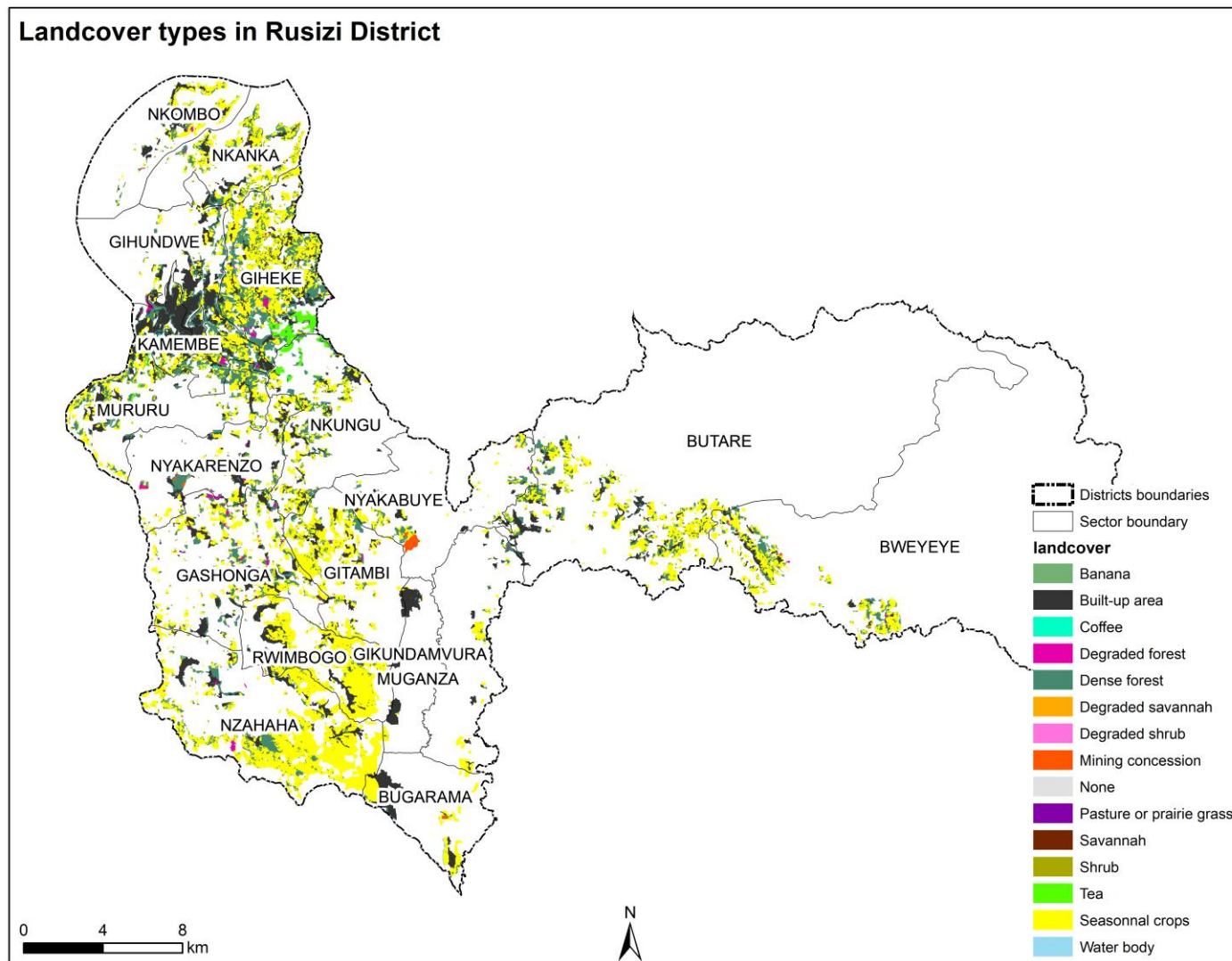


**Figure 59: Erosive features detected in Rusizi District**

In term of land use and land cover of areas at risk in Rusizi District, the results of land cover mapping (Table 60 and Figure 60) show that 10369 hectares (57% of the total land at risk) are used for seasonal crops, 3454 hectares (19% of the total land at risk) are covered by healthy forests and 3861 hectares (16% of the total land at risk) are covered by built-up area.

**Table 62: Land Use and Vegetation Cover (LUV) of areas at risk in Rusizi District**

Sector Name	Banana	Built-up area	Degraded forest	Dense forest	Mining and Quarries	Seasonal crops	Tea	Water body	Grand Total
BUGARAMA		166		10	5	219		9	409
BUTARE	10	302		248		805			1365
BWEYEYE	7	91	5	153	3	499		1	760
GASHONGA	2	266	31	287		658		2	1246
GIHEKE	9	264	26	736		1453	133		2621
GIHUNDWE	3	440	8	297		321			1070
GIKUNDAMVURA	2	57	2	25		122			208
GITAMBI	2	138	6	99		777		3	1025
KAMEMBE	3	534	17	267	1	232			1055
MUGANZA		191		1		27			219
MURURU	1	202	1	380		491	18		1093
NKANKA		129	2	164		527			822
NKOMBO		127	8	50		293		3	482
NKUNGU	4	162		228		420	72		885
NYAKABUYE	2	89	10	99	47	201			448
NYAKARENZO		191	17	157	7	267			640
NZAHAAHA	15	254	14	213		1931		2	2429
RWIMBOGO	2	257	1	39		1131		5	1436
<b>Grand Total</b>	<b>62</b>	<b>3861</b>	<b>148</b>	<b>3454</b>	<b>63</b>	<b>10374</b>	<b>222</b>	<b>27</b>	<b>18212</b>
<b>%</b>	<b>0%</b>	<b>21%</b>	<b>1%</b>	<b>19%</b>	<b>0%</b>	<b>57%</b>	<b>1%</b>	<b>0%</b>	<b>100%</b>



**Figure 60: Land cover types in Rusizi District**

About existing erosion control practices in Rusizi district, Table 61 shows that only 25% of land at risk is protected by forests (3452 hectares) and Contour bank terraces (1027 hectares). The highest protected sectors are Rwimbogo with 45% of its land at risk protected, followed by Mururu where 42% of the total land at risk is protected and Nyakarenzo with 34% of land protected. The least protected sectors are Muganza with only 1% protected, Bugarama (only 3% protected), Gitambi (11%) and Nkombo (11% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Muganza, Bugarama, Gitambi, Nkombo, Gikundamvura and Nzahaha sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected.

**Table 63: Erosion control practices already in place in Rusizi District**

Sector Name	Erosion control in place				Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest	Hedgerows trees or shrubs				
RWIMBOGO		606	39		645	791	1436	45%
MURURU	15	64	380		459	633	1093	42%
NYAKARENZO	10	52	157		219	421	640	34%
GIHEKE		9	735		744	1876	2621	28%
GIHUNDWE		6	297		303	767	1070	28%
NKUNGU		18	228		245	640	885	28%
GASHONGA	10	46	286		343	904	1246	27%
NYAKABUYE		21	99		120	329	448	27%
KAMEMBE		8	267		275	780	1055	26%
BWEYEYE	10	8	153		171	590	760	22%
NKANKA	2	13	164		179	643	822	22%
BUTARE			248	0	248	1117	1365	18%
GIKUNDAMVURA		7	25		33	175	208	16%
NZAHAAHA	0	150	213		363	2066	2429	15%
GITAMBI		17	99		116	909	1025	11%
NKOMBO		3	50		53	429	482	11%
BUGARAMA			10		10	399	409	3%
MUGANZA			1		1	218	219	1%
<b>Grand Total</b>	<b>47</b>	<b>1027</b>	<b>3452</b>	<b>0</b>	<b>4526</b>	<b>13686</b>	<b>18212</b>	<b>25%</b>



### Erosion Control Techniques in Rusizi District

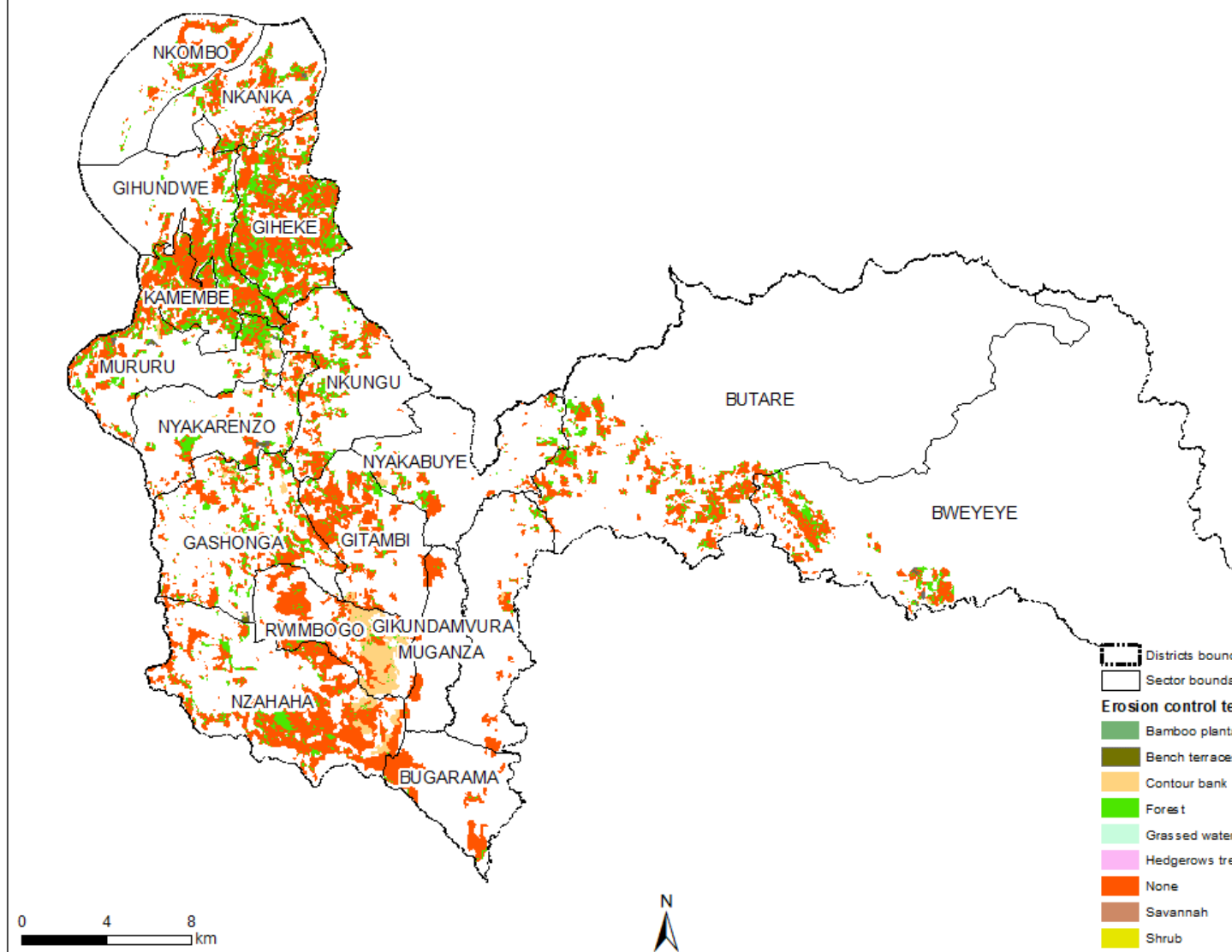
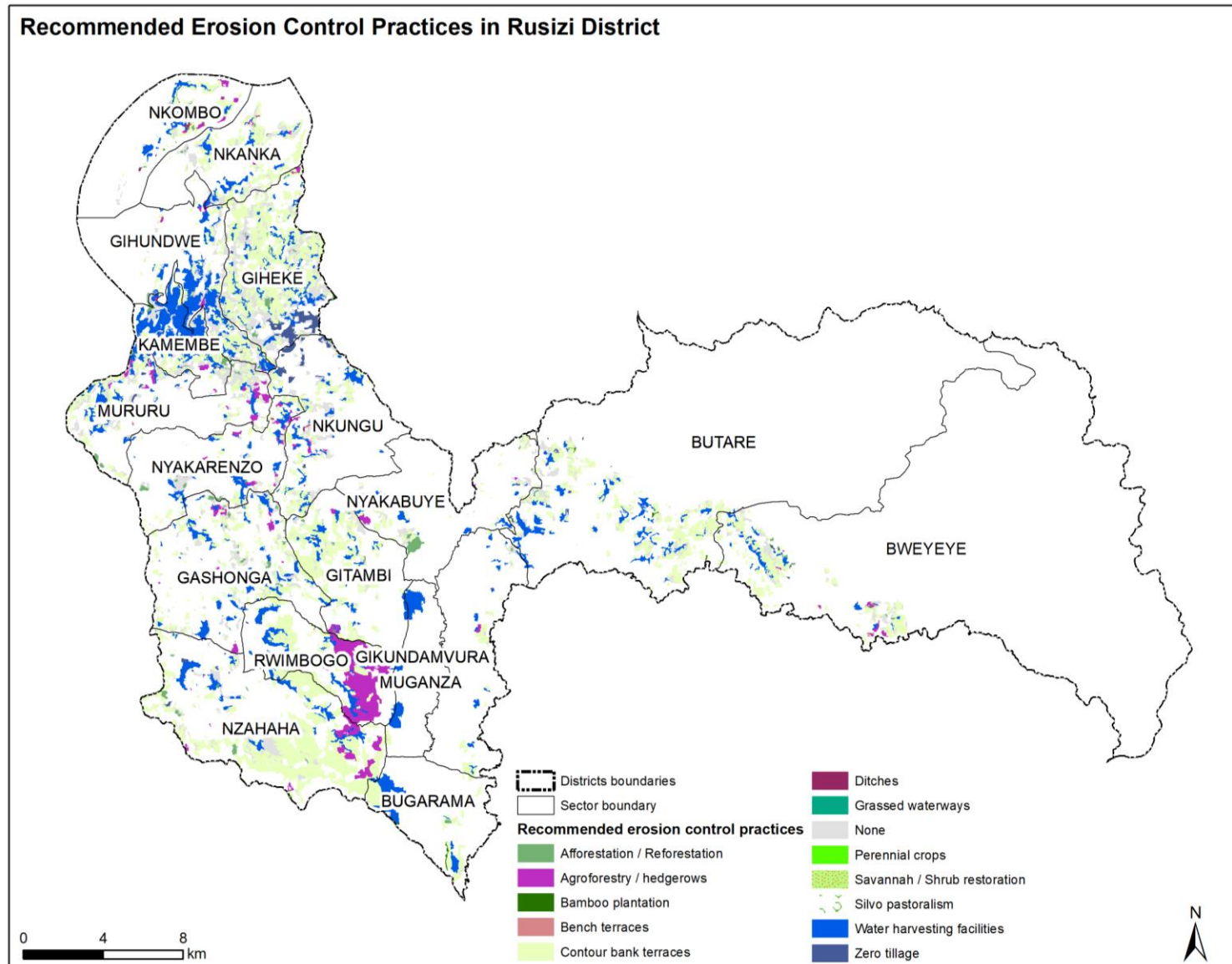


Figure 61: Erosion control techniques in place in Rusizi District

Erosion control practices in Rusizi District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 62 shows that about 9041 hectares (which is 50% of the total land at risk) are suitable for Contour bank terraces, 3869 hectares are SWMF and 285 hectares are Afforestation & Reforestation. Others are cropland that needs agroforestry/hedgerows (1159 hectares).

**Table 64: Recommended erosion control practices in Rusizi District**

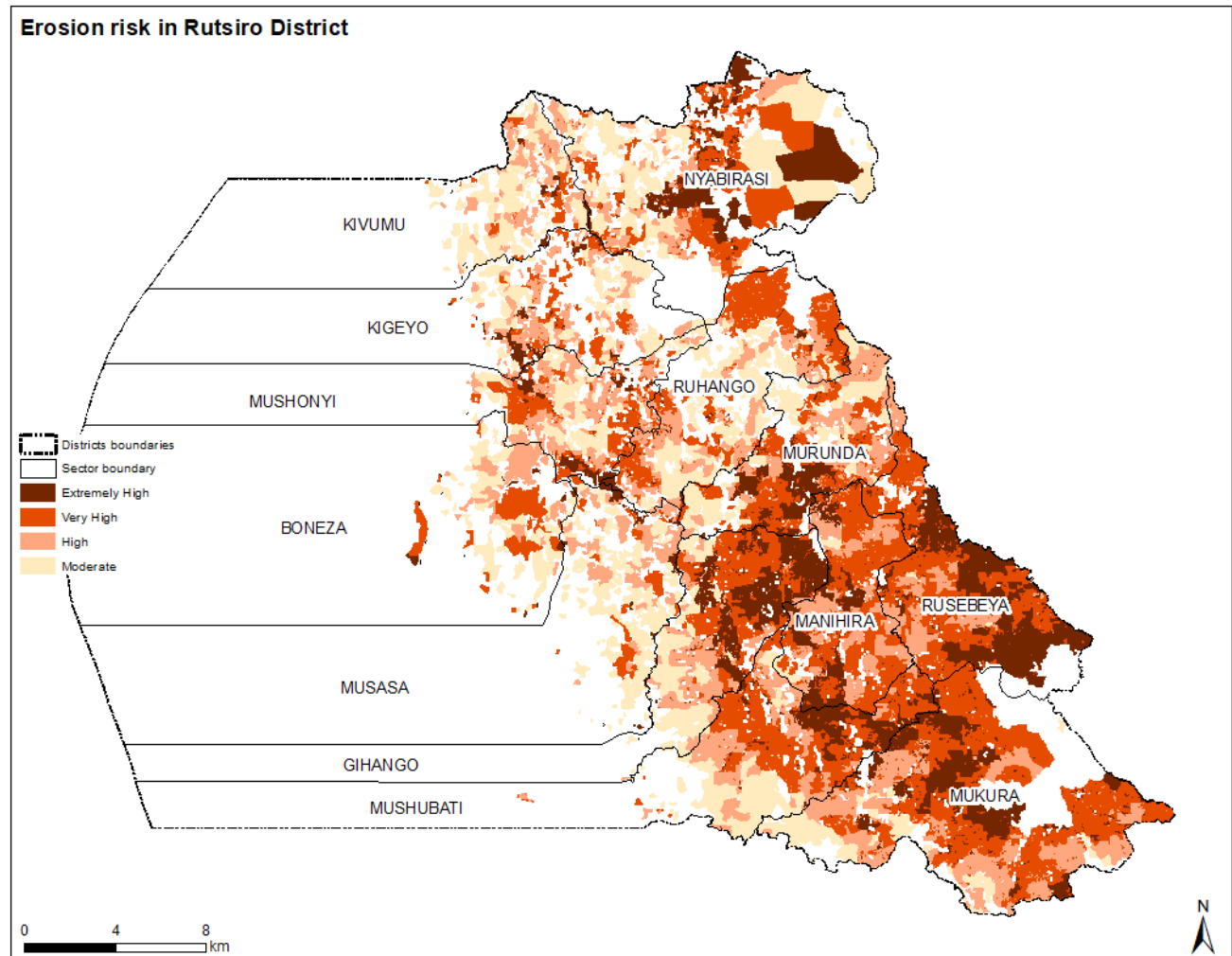
Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	None	Water harvesting facilities	Zero tillage	Grand Total
BUGARAMA	5		9		219		10	166		409
BUTARE			7		790		249	309	10	1365
BWEYEYE	11	23	2	7	466		153	91	7	760
GASHONGA	36	54	2		598		289	266	2	1246
GIHEKE	29	9	1		1440		737	264	139	2621
GIHUNDWE	15	18			294		299	440	3	1070
GIKUNDAMVURA	2	7			115		25	57	2	208
GITAMBI	14	23	4		746		99	138	2	1025
KAMEMBE	23	19			200		272	534	7	1055
MUGANZA			2		22		2	192		219
MURURU	18	87		1	383		382	202	19	1093
NKANKA	6	12			496		179	129		822
NKOMBO	9	45	3		247	7	44	127		482
NKUNGU	2	18			371	9	248	162	76	885
NYAKABUYE	57	21			176		104	89	2	448
NYAKARENZO	25	61			203		159	191		640
NZAHABA	31	157	2		1751		218	254	15	2429
RWIMBOGO	1	604	5		525		41	257	2	1436
<b>Grand Total</b>	<b>285</b>	<b>1159</b>	<b>39</b>	<b>8</b>	<b>9041</b>	<b>16</b>	<b>3509</b>	<b>3869</b>	<b>286</b>	<b>18212</b>
<b>%</b>	<b>2%</b>	<b>6%</b>	<b>0%</b>	<b>0%</b>	<b>50%</b>	<b>0%</b>	<b>19%</b>	<b>21%</b>	<b>2%</b>	<b>100%</b>



**Figure 62: Recommended erosion control practices in Rusizi District**

### 3.2.7. Erosion control status in Rutsiro District

Soil erosion risk in Rutsiro is summarised in Table 63 and presented in Figure 63. Land area at risk is estimated to 48143 hectares; about 42% of the total district land. Manihira sector is the highest susceptible to erosion with 3472 hectares (93% of the sector land), followed by Rusebeya sector with 4692 hectares (87% of sector land), Gihango sector with 3911 hectares (85% of the sector land), Murunda sector with 3576 hectares (83% of the sector land), Mushubati sector with 4236 hectares (82% of the sector land) and Mukura sector with 7503 hectares (76% of the sector land). The least affected sectors are Musasa sector with 2308 hectares (53% of the total sector land), and Kageyo sectors with 2232 hectares at erosion risk (54% of the sector land).



**Figure 63: Erosion risk in Rutsiro District**

**Table 65: Erosion risk per sector in Rutsiro District**

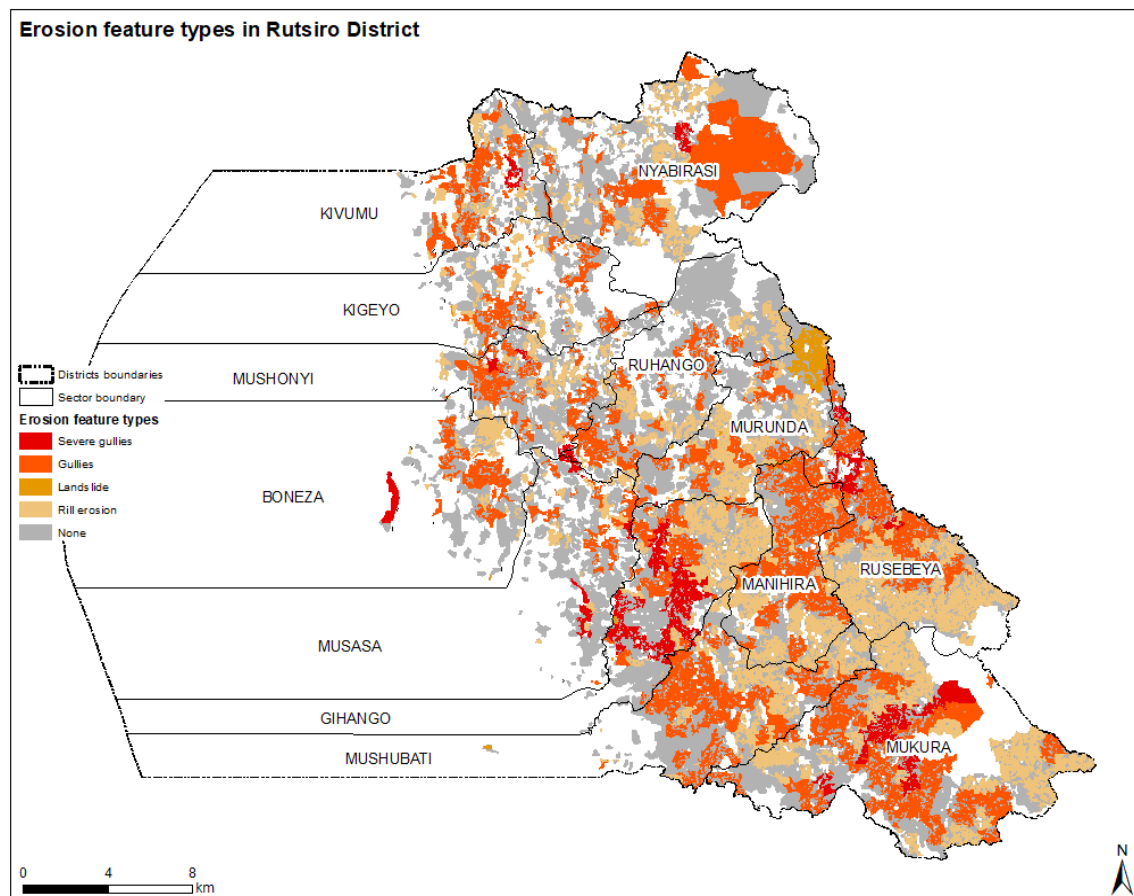
Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremel y High	Very High	High	Moderate	Grand Total		
MANIHIRA	612	1697	1086	77	3472	3719	93%
RUSEBEYA	1832	2137	695	29	4692	5370	87%

Sector Name	Erosion risk					District land(Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MANIHIRA	612	1697	1086	77	3472	3719	93%
GIHANGO	1249	1083	734	845	3911	4583	85%
MURUNDA	526	1179	936	936	3576	4285	83%
MUSHUBATI	549	1739	1037	911	4236	5189	82%
MUKURA	1320	3400	2051	731	7503	9887	76%
MUSHONYI	194	669	902	760	2526	3337	76%
RUHANGO	91	1423	1040	1318	3872	5400	72%
KIVUMU	56	167	578	1100	1901	2883	66%
NYABIRASI	1433	1680	826	2078	6017	9351	64%
BONEZA	51	537	474	834	1897	3460	55%
KIGEYO	175	424	732	902	2232	4145	54%
MUSASA	114	286	647	1262	2308	4388	53%
<b>Grand Total</b>	<b>8203</b>	<b>16422</b>	<b>11737</b>	<b>11782</b>	<b>48143</b>	<b>65995</b>	<b>73%</b>

Land areas affected by erosive features in Rutsiro District are summarized in Table 64 and the map of erosive features are presented in Figure 64. The results show that Rusebeya sector is the worst affected by gullies and rill erosion on areas estimated to 3856 hectares (82% of sector land at risk), followed by Manihira sector with 2645 hectares and Mukura sector (5442 hectares). The presence of gullies and rill erosion in all sectors confirms the findings of CROM model. In fact, the Erosive features observed on World View images affect the entire District at 40% of its land, and 11 out of 13 sectors are affected at more than 50% of the sector land. The least sectors affected by gullies and rill erosion are Musasa and Ruhango that have the areas affected by gullies and rill erosion of respectively 768 hectares and 1487 hectares, i.e. 33% and 38% of their respective land.

**Table 66: Erosive features and areas affected in Rutsiro District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
RUSEBEYA	1416	2	2206	232	3856	836	4692	82%
MANIHIRA	1702	10	919	14	2645	827	3472	76%
MUKURA	2545		2232	665	5442	2061	7503	73%
GIHANGO	635	8	1102	879	2624	1287	3911	67%
MUSHUBATI	1681	7	1113	20	2822	1414	4236	67%
KIVUMU	768	5	320	65	1158	742	1901	61%
MURUNDA	701	358	1020	7	2086	1490	3576	58%
NYABIRASI	2185		1081	80	3346	2671	6017	56%
MUSHONYI	733	1	545	68	1347	1179	2526	53%
KIGEYO	641	6	387	4	1038	1194	2232	47%
BONEZA	509	2	284	86	881	1016	1897	46%
RUHANGO	782	2	680	23	1487	2385	3872	38%
MUSASA	348	1	273	145	768	1540	2308	33%
<b>Grand Total</b>	<b>14646</b>	<b>402</b>	<b>12164</b>	<b>2288</b>	<b>29500</b>	<b>18643</b>	<b>48143</b>	<b>61%</b>



**Figure 64: Erosive features detected in Rutsiro District**

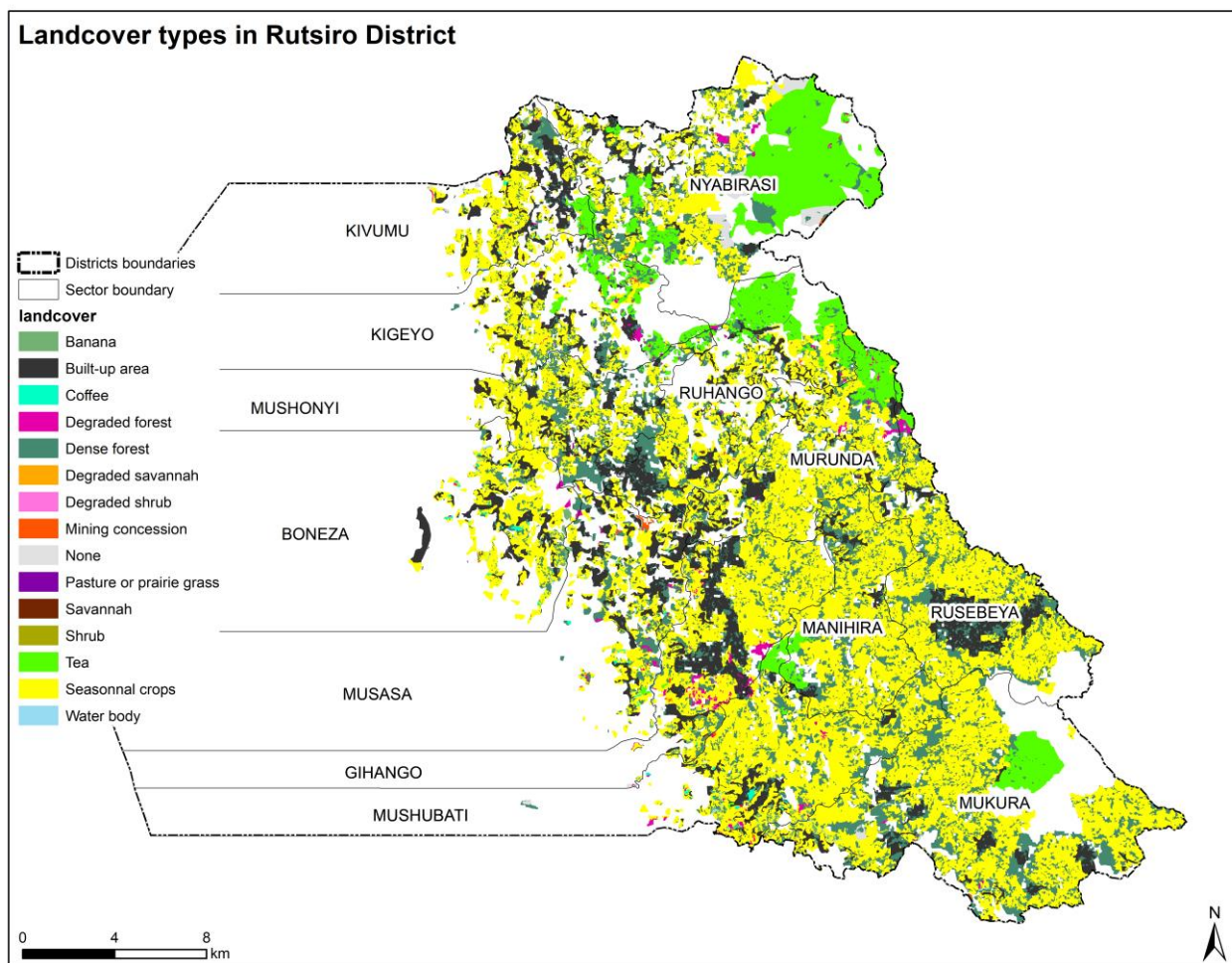
In term of land use and land cover of areas at risk in Rutsiro, the results of land cover mapping (Table 65 and Figure 65) show that 27764 hectares (58% of the total land at risk) are used for seasonal crops, and 7464 hectares (16% of the total of the total land at risk) are covered by healthy forests. In Rutsiro District there are also Mining and Quarriess and tea plantations which cover respectively areas of 45 hectares (less than 1% of the total land at risk) and 5181 hectares (11% of the total land at risk) as well as built-up areas covering 6672 hectares (14%).

**Table 67: Land Use and Vegetation Cover (LUVC) of areas at risk in Rutsiro District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining concession	None	Seasonal crops	Tea	Water body	Grand Total
BONEZA	49	424	22	14	170			1206		12	1897
GIHANGO	15	912		78	435	4	6	2449	7	5	3911
KIGEYO		376		24	344	1	5	1065	413	4	2232
KIVUMU	30	587	4	5	139	1	13	1014	104	4	1901
MANIHIRA		152			630			2543	148		3472
MUKURA	25	486		5	1502	4	18	4960	487	16	7503
MURUNDA		383		29	537	3	3	2221	398	3	3576
MUSASA	26	678	11	26	411	19		1117	8	13	2308
MUSHONYI		449		6	584		4	1418	63	2	2526



Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining concession	None	Seasonal crops	Tea	Water body	Grand Total
MUSHUBATI	40	334	24	40	637	3	7	3024	106	20	4236
NYABIRASI		439		38	719	7	328	1983	2503		6017
RUHANGO		686	2	8	571	2		1708	883	11	3872
RUSEBEYA		765		21	786			3057	62	1	4692
<b>Grand Total</b>	<b>186</b>	<b>6672</b>	<b>63</b>	<b>293</b>	<b>7464</b>	<b>45</b>	<b>384</b>	<b>27764</b>	<b>5181</b>	<b>91</b>	<b>48143</b>
<b>%</b>	<b>0%</b>	<b>14%</b>	<b>0%</b>	<b>1%</b>	<b>16%</b>	<b>0%</b>	<b>1%</b>	<b>58%</b>	<b>11%</b>	<b>0%</b>	<b>100%</b>

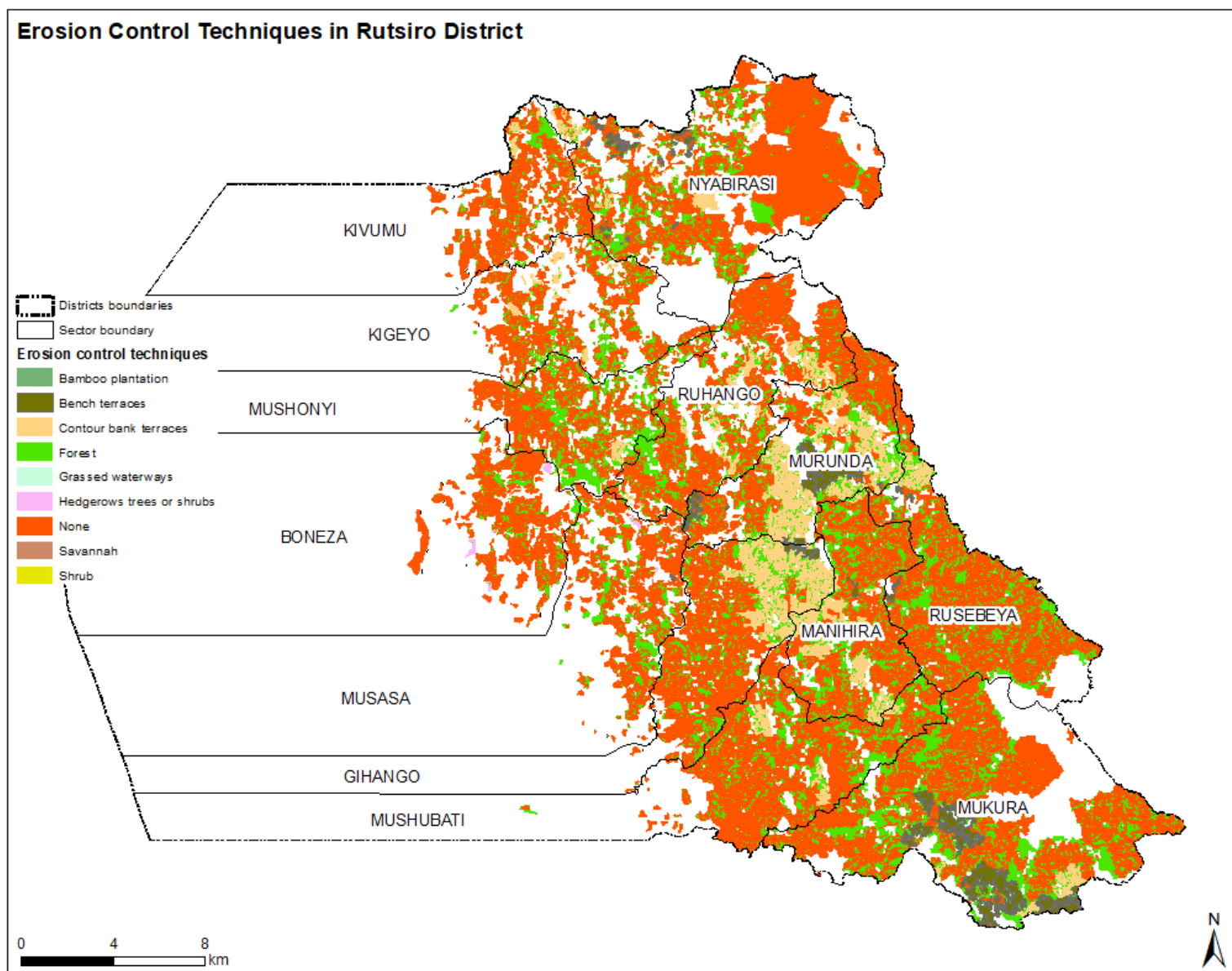


**Figure 65: Land cover types in Rutsiro District**

About existing erosion control practices in Rutsiro district, Table 66 shows that only 27% of land at risk is protected by forests (7503 hectares), Contour bank terraces (4077 hectares) and bench terraces (1,398 hectares). The highest protected sectors are Murunda with 58% of its land at risk protected, followed by Gihango where 37% of the total land at risk is protected and Manihira with 33% of land protected. The least protected sectors are Boneza with only 11% protected, Kivumu (only 10% protected), Musasa (19%) and Nyabirasi (19% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Mukura, Nyabirasi, Rusebeya, Mushubati and Ruhango sectors remain at very high risk of soil erosion since more than 75% of their respective land are not protected

**Table 68: Erosion control practices already in place in Rutsiro District**

Sector Name	Erosion control in place				Total protect ed	Unpro- tected	Grand Total	% Protec ted
	Bench terraces	Contour bank terraces	Forest	Hedgero ws trees or shrubs				
MURUNDA	349	1183	540		2072	1504	3576	58%
GIHANGO	42	963	449		1453	2457	3911	37%
MANIHIRA	18	495	630		1142	2330	3472	33%
MUKURA	796	155	1502		2453	5050	7503	33%
MUSHONYI		60	584		645	1881	2526	26%
RUHANGO	1	410	564	1	977	2895	3872	25%
RUSEBEYA	45	152	807		1004	3688	4692	21%
KIGEYO	1	128	344		472	1760	2232	21%
MUSHUBATI		183	637		820	3416	4236	19%
MUSASA	7	9	412	14	442	1867	2308	19%
NYABIRASI	141	288	719		1148	4869	6017	19%
BONEZA			170	40	210	1687	1897	11%
KIVUMU		50	144		194	1706	1901	10%
<b>Grand Total</b>	<b>1398</b>	<b>4077</b>	<b>7503</b>	<b>55</b>	<b>13033</b>	<b>35110</b>	<b>48143</b>	<b>27%</b>



**Figure 66: Erosion control techniques in place in Rutsiro District**

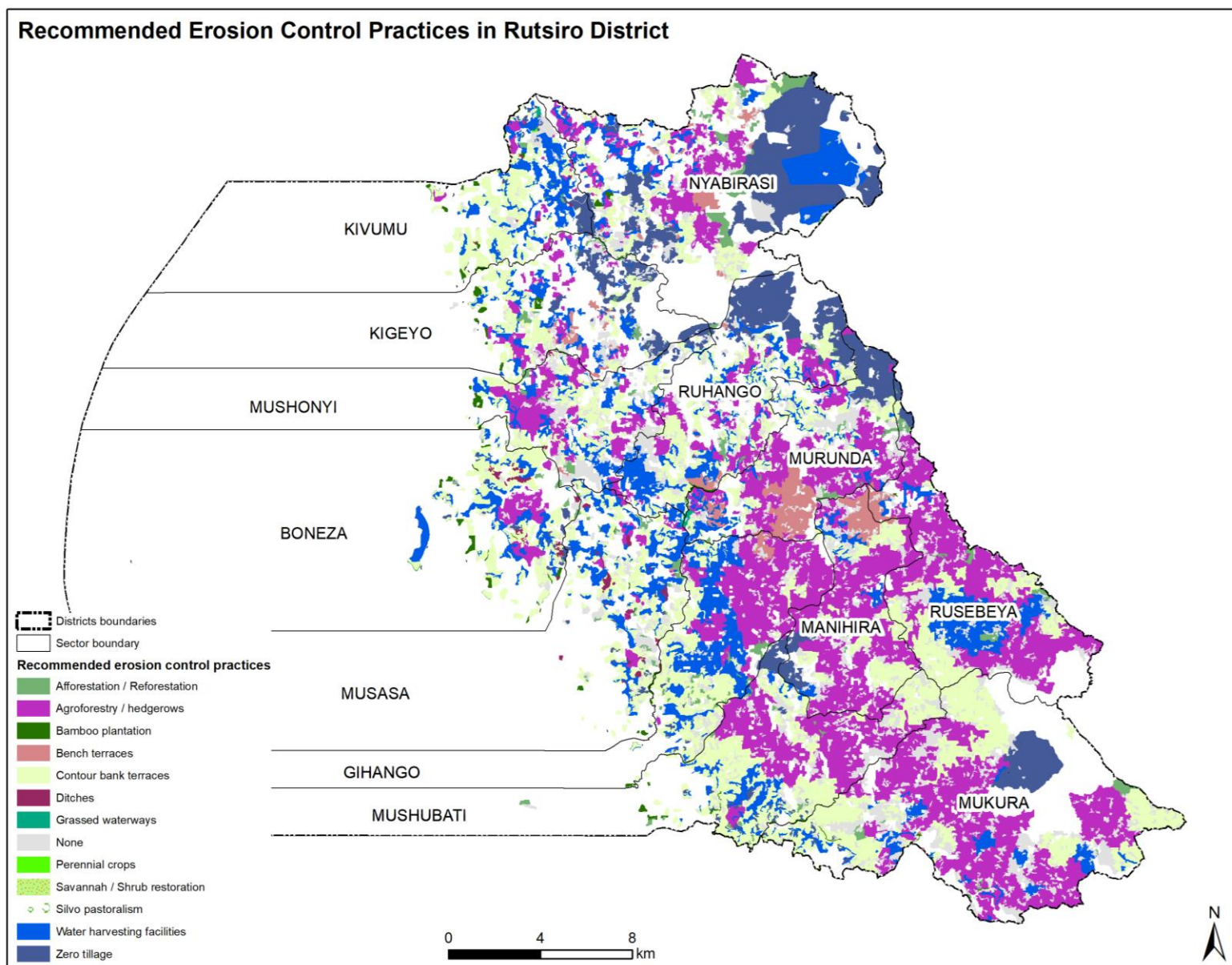
Erosion control practices in Rutsiro District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 67 shows that about 14357 hectares (which is 30% of the total land at risk) are suitable for cropland that need agroforestry/hedgerows cropping, 11802 hectares are Contour bank terraces and 6988 hectares are Storm water management facilities (SWMF). Others are Afforestation & Reforestation (1029 hectares), bench terraces (1184 hectares) and gullies or riverbanks amounting to 282 hectares eroded which require bamboo trees for rehabilitation.

**Table 69: Recommended erosion control practices in Rutsiro District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	Grassed waterways	None	Perennial crops	Water harvesting facilities	Zero tillage	Grand Total
BONEZA	34	258	60	1	879	63		106		424	73	1897
GIHANGO	89	1478	10	56	909			435		912	22	3911
KIGEYO	71	312	50	95	571	0		344		376	413	2232
KIVUMU	22	93	30		891	17	7	132	4	574	130	1901
MANIHIRA	26	1759		194	563			630		152	148	3472
MUKURA	69	3056	16	3	1922			1502		423	512	7503
MURUNDA	68	1311	3	463	441		14	610		269	398	3576
MUSASA	79	131	24	3	933	81	4	329		678	46	2308
MUSHONYI	59	672	24	6	688	8		575		430	63	2526
MUSHUBATI	54	1456	38		1549			662		309	167	4236
NYABIRASI	331	1022	16	222	712			719		1006	1989	6017
RUHANGO	38	663	11	59	962		1	568		685	885	3872
RUSEBEYA	89	2145	1	82	782			785		747	62	4692
<b>Grand Total</b>	<b>1029</b>	<b>14357</b>	<b>282</b>	<b>1184</b>	<b>11802</b>	<b>168</b>	<b>27</b>	<b>7395</b>	<b>4</b>	<b>6988</b>	<b>4906</b>	<b>48143</b>
<b>%</b>	<b>2%</b>	<b>30%</b>	<b>1%</b>	<b>2%</b>	<b>25%</b>	<b>0%</b>	<b>0%</b>	<b>15%</b>	<b>0%</b>	<b>15%</b>	<b>10%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.





**Figure 67: Recommended erosion control practices in Rutsiro District**

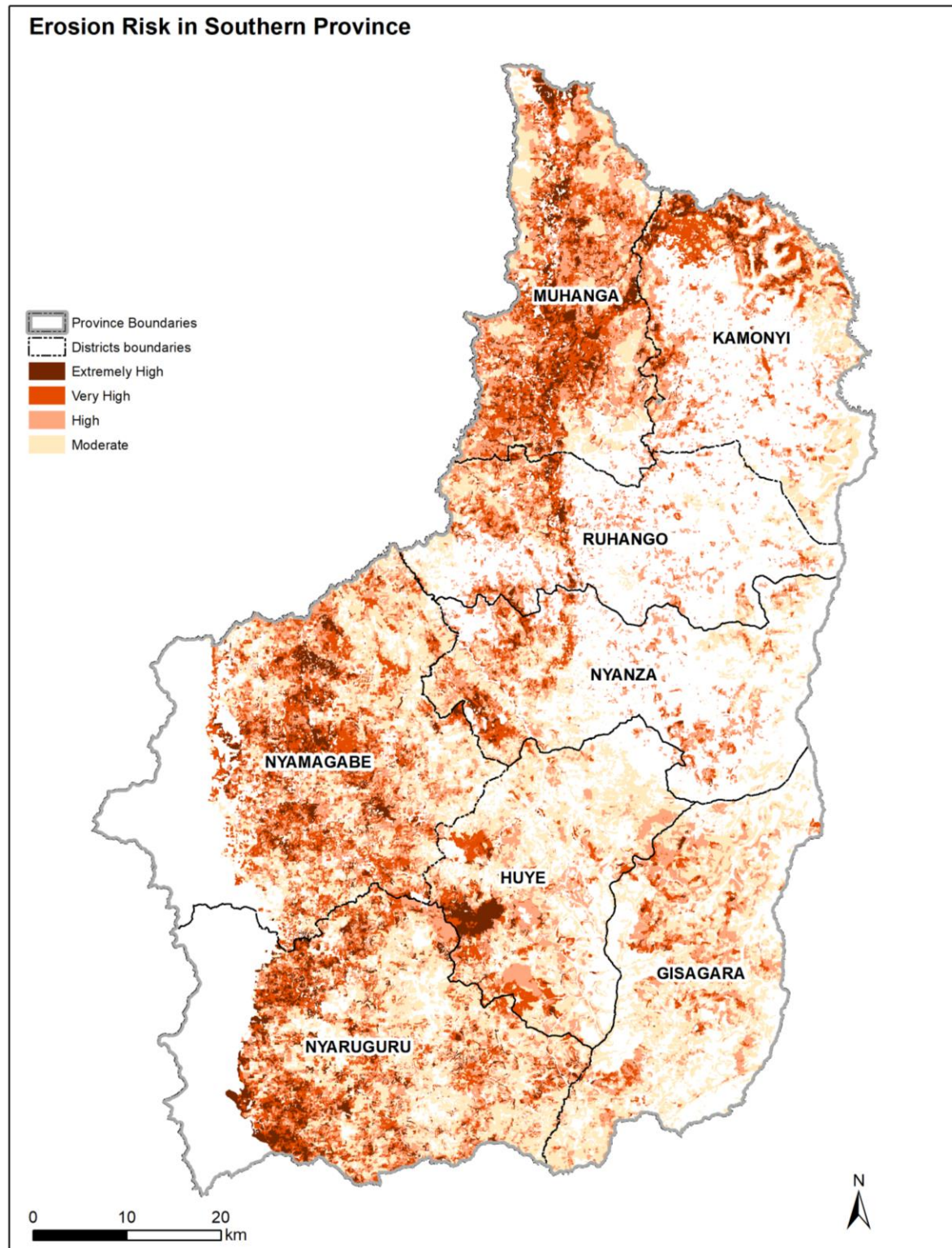
### 3.3. Erosion Control Status in Southern Province

Erosion risk in Southern Province is summarized in table 68 and presented in figure 68. The total land at high risk of erosion in Southern Province is about 311,116 hectares (56% of the total province land). The highest amount of land at erosion risk are found in Muhanga with 53352 hectares (i.e. 82% of the total district land) followed by Nyaruguru District with 64382 hectares (64% of the district land), and Nyamagabe with 66578 hectares (61% of district land). The least district susceptible to erosion is Ruhango, where 33% of its district land is at risk, about 20618 hectares. The contribution of forests in protecting fragile land in Southern Province is evident, particularly the Nyungwe National park in Nyamagabe and Nyaruguru districts as well as forest plantations in steep slopes of Southern mountains and plateau.

**Table 70: Erosion risk in Southern Province**

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MUHANGA	7094	15584	19189	11486	53352	64772	82%
NYARUGURU	7221	14392	16789	25979	64382	101027	64%
NYAMAGABE	5999	17734	19665	23180	66578	109036	61%
HUYE	2154	4825	9599	18725	35304	58153	61%
GISAGARA	325	3012	11476	23723	38536	67920	57%
KAMONYI	2080	6911	10034	8324	27349	65553	42%
NYANZA	780	4152	9771	10296	24999	67215	37%
RUHANGO	1133	3652	9975	5857	20618	62678	33%
<b>Grand Total</b>	<b>26786</b>	<b>70262</b>	<b>106498</b>	<b>127571</b>	<b>331116</b>	<b>596355</b>	<b>56%</b>





**Figure 68: Erosion risk in Southern Province**

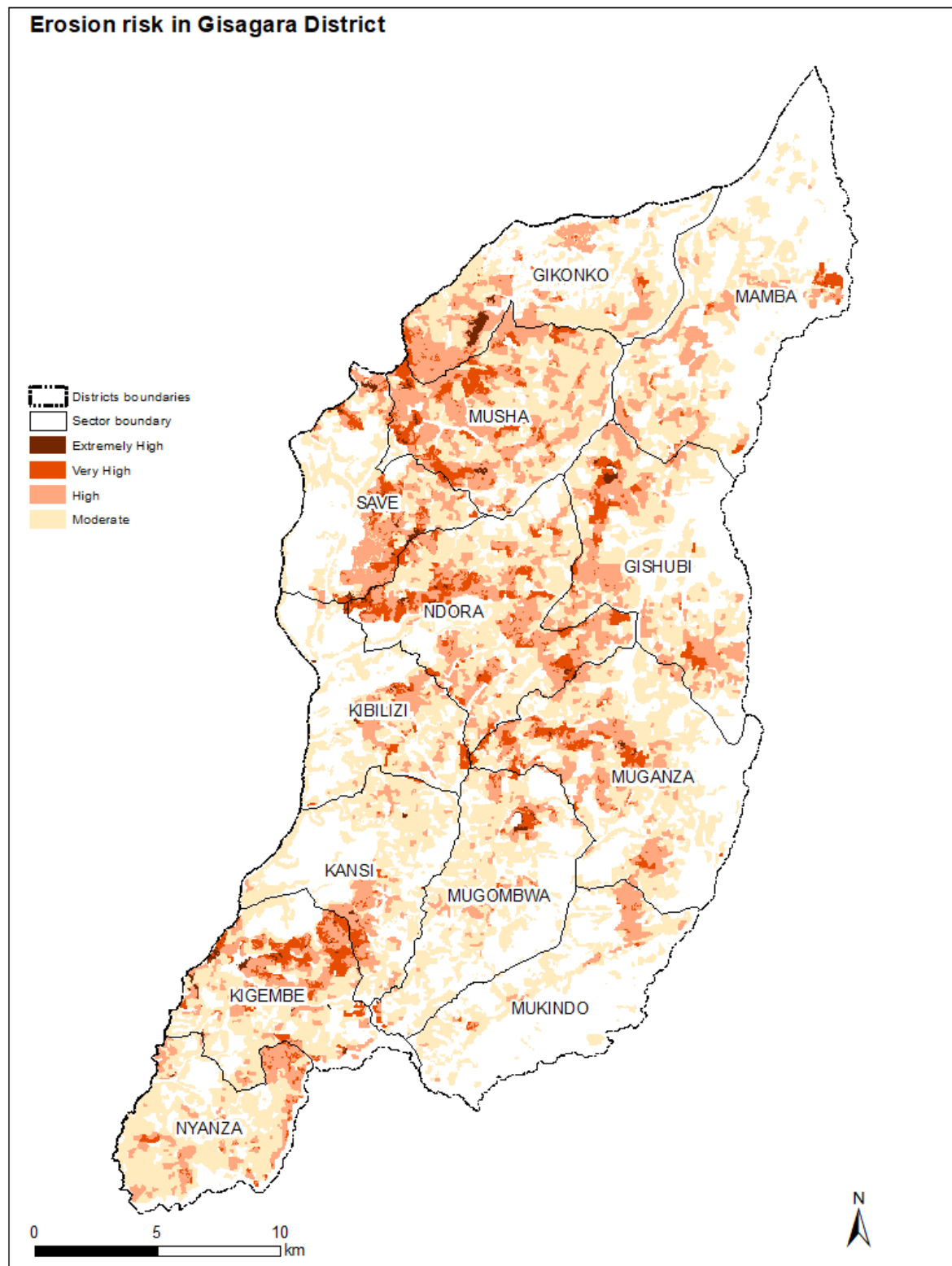
### 3.3.1. Erosion control in Gisagara District

Erosion risk in Gisagara is summarised in Table 69 and presented in figure 69. Erosion risk in Gisagara District is estimated to 38536 hectares; about 57% of the total district land are highly susceptible to erosion of which 4269 hectares are located in Musha sector (86% of sector land), 4679 hectares are located in Ndora sector (77% of sector land), 2734 hectares are located in Nyanza (71% of the sector land), and 3060 hectares are found in Kigembe sector about 68% of the sector land. The least sectors are Mukindo with only 1356 hectares (27% of the sector land) susceptible to erosion, Mamba with 2944 hectares (37%), and Kibirizi with 1894 hectares, about 48% of the total sector land.

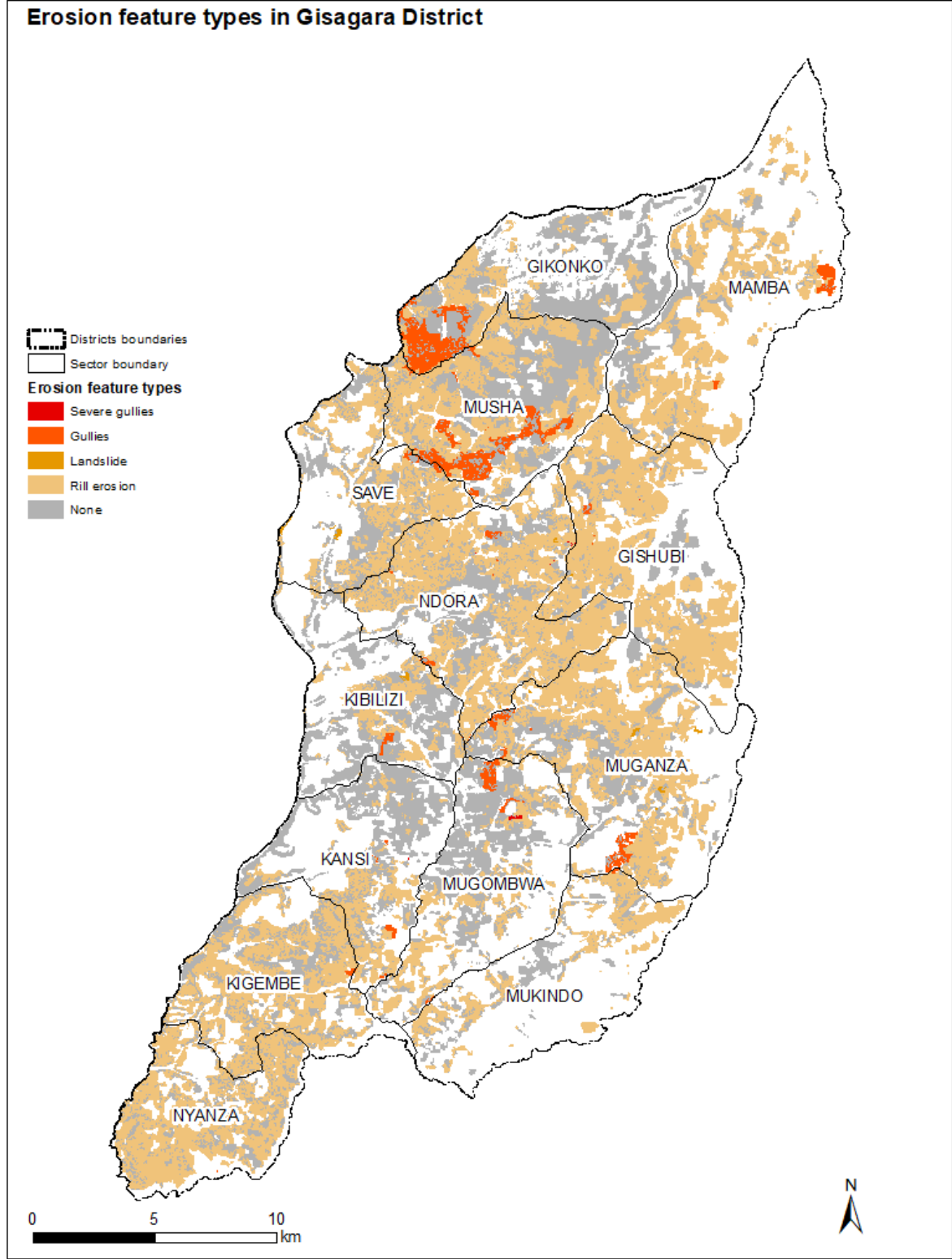
**Table 71: Erosion risk per sector in Gisagara District**

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MUSHA	36	539	1653	2041	4269	4977	86%
NDORA	48	642	1595	2395	4679	6103	77%
NYANZA	2	75	656	2002	2734	3876	71%
KIGEMBE	49	433	865	1713	3060	4482	68%
GISHUBI	25	243	1292	2129	3688	6143	60%
GIKONKO	62	85	1085	1626	2859	4929	58%
MUGANZA	12	299	1142	2594	4047	7039	58%
SAVE	61	291	868	1071	2290	4108	56%
KANSI	7	80	478	1657	2222	4241	52%
MUGOMBWA	14	89	418	1971	2492	4985	50%
KIBILIZI	10	109	377	1398	1894	3983	48%
MAMBA		107	765	2072	2944	8011	37%
MUKINDO		19	283	1054	1356	5044	27%
<b>Grand Total</b>	<b>325</b>	<b>3012</b>	<b>11476</b>	<b>23723</b>	<b>38536</b>	<b>67920</b>	<b>57%</b>

Land areas affected by erosive features in Gisagara District are summarized in Table 70 and the map of erosive features are presented in Figure 70. The results show that Gishubi sector is the worst affected by rill erosion on areas estimated to 3159 hectares (86% of sector land at risk), followed by Nyanza, Mamba and Kigembe sectors affected by gullies and rill erosion on 85%, 78% and 77 respectively of their sector land at risk. The presence of gullies in all sectors, except Mukindo and Nyanza confirms the findings of CROM model; however the absence of gullies in Mukindo and Nyanza which were originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis of Land cover and erosion control practices in place will demonstrate that (Table 71 and 72).



**Figure 69: Erosion risk in Gisagara District**



**Figure 70: Erosive features detected in Gisagara District**

**Table 72: Erosive features and areas affected in Gisagara District**

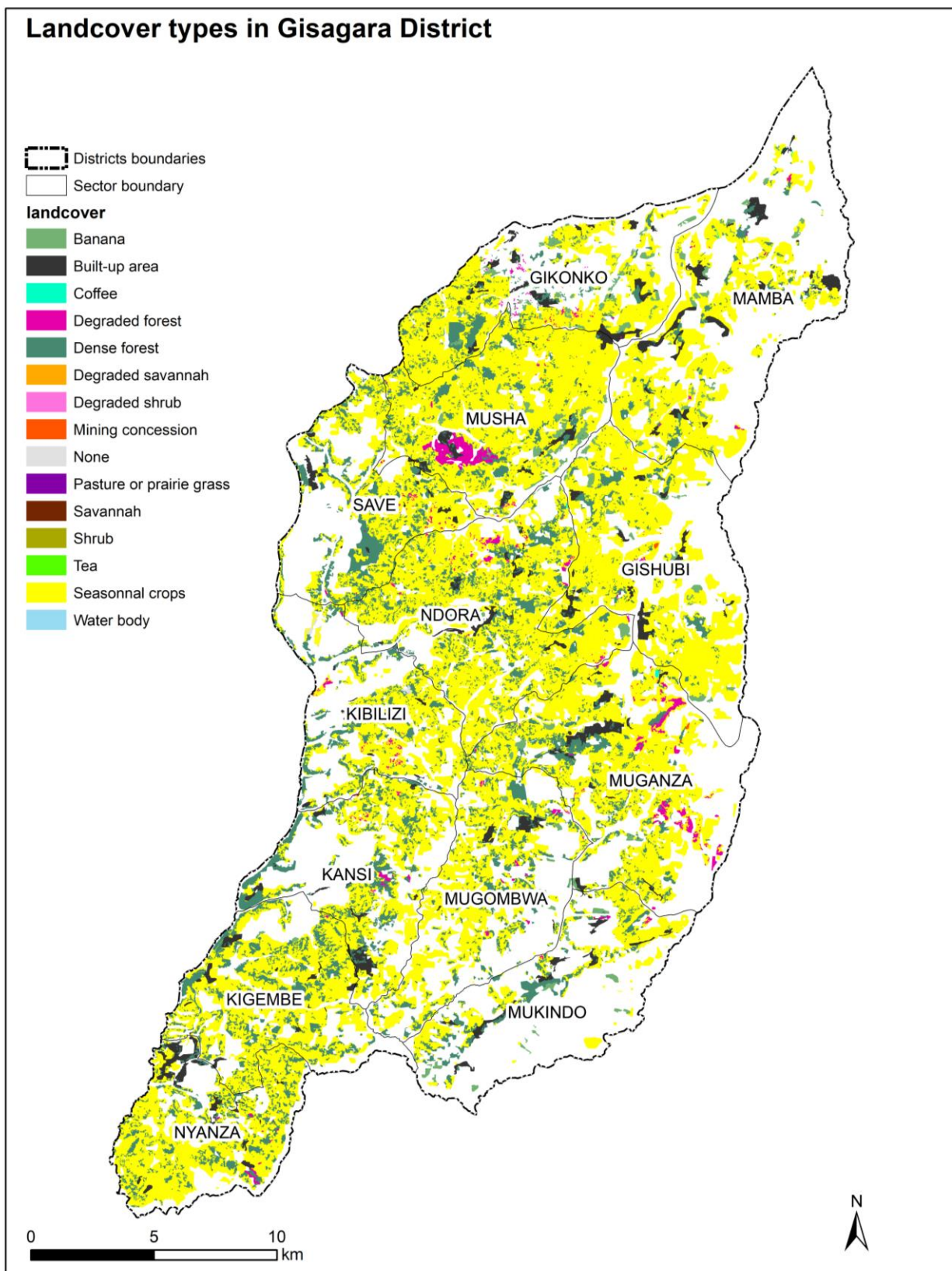
Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Land slide	Rill erosion	Severe gullies				
GISHUBI	10	2	3148		3159	529	3688	86%
NYANZA	1		2328		2329	405	2734	85%
MAMBA	76		2207		2282	662	2944	78%
KIGEMBE	7		2351		2358	702	3060	77%
NDORA	27	3	3396	2	3427	1253	4679	73%
MUGANZA	120	20	2810		2950	1097	4047	73%
SAVE	20	31	1476		1527	763	2290	67%
MUKINDO	6		898		904	452	1356	67%
MUSHA	410		2154		2565	1705	4269	60%
GIKONKO	395		808		1203	1656	2859	42%
MUGOMBWA	79		952	7	1038	1455	2492	42%
KANSI	22		819	1	842	1380	2222	38%
KIBILIZI	20	8	584		612	1282	1894	32%
<b>Grand Total</b>	<b>1192</b>	<b>63</b>	<b>23930</b>	<b>9</b>	<b>25195</b>	<b>13341</b>	<b>38536</b>	<b>65%</b>

In term of land use and land cover of areas at risk in Gisagara, the results of land cover mapping (Table 71 and Figure 71) show that 30077 hectares (78% of the total land at risk) are used for seasonal cropping, 5275 hectares (14% of the total of the total land at risk) are covered by healthy forests and 1767 hectares (5% of the total land at risk) are covered by built-up area. In Gisagara District there are also coffee plantations which cover an area of 8 hectares (less than 1% of the total land at risk) whereas banana plantations cover an area of 921 hectares (2% of the total land at risk).

**Table 73: Land Use and Vegetation Cover (LUV) for land at risk in Gisagara District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining and Quarries	Barren soil	Seasonal crops	Grand Total
GIKONKO	245	193		20	267			2133	2859
GISHUBI	115	165		12	221	3		3171	3688
KANSI		121		19	544			1538	2222
KIBILIZI		34		17	419		18	1405	1894
KIGEMBE	7	84		1	578			2389	3060
MAMBA	112	287	3	10	197			2334	2944
MUGANZA	62	169	4	133	427	4		3248	4047
MUGOMBWA	58	77		19	382			1955	2492
MUKINDO	96	132		10	287			832	1356
MUSHA	155	149		164	370			3431	4269
NDORA	69	102	1	36	619			3851	4679
NYANZA		181		14	375			2164	2734
SAVE		72		6	588			1625	2290
<b>Grand Total</b>	<b>921</b>	<b>1767</b>	<b>8</b>	<b>461</b>	<b>5275</b>	<b>8</b>	<b>18</b>	<b>30077</b>	<b>38536</b>
<b>%</b>	<b>2%</b>	<b>5%</b>	<b>0%</b>	<b>1%</b>	<b>14%</b>	<b>0%</b>	<b>0%</b>	<b>78%</b>	<b>100%</b>





**Figure 71: Land cover types in Gisagara District**



About existing erosion control practices in Gisagara district, Table 72 shows that only 19% of land at risk is protected by forests (5238 hectares), contour bank terraces (615 hectares) and bench terraces (1454 hectares). The highest protected sectors are Kansi with 32% of its land at risk protected, followed by Save where 31% of the total land at risk is protected and Kigembe with 26% of land protected. The least protected sectors are Mamba with only 8% protected, Gishubi (only 8% protected), Gikonko (13%) and Ndora (15% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Gishubi, Mamba, Mugombwa and Kibirizi sectors remain at very high risk of soil erosion since more than 70% of their respective land are not protected

**Table 74: Erosion control practices already in place in Gisagara District**

Sector Name	Erosion control in place				Total protect ed (ha)	Unprotect ed (ha)	Gran d Total	% protect ed
	Bench terrace s	Contour bank terraces	Fore st	Grassed waterwa ys				
KANSI	150	25	544		719	1503	2222	32%
SAVE	26	98	588		712	1578	2290	31%
KIBILIZI	55	6	429		490	1404	1894	26%
MUKINDO	50	9	287		346	1011	1356	25%
KIGEMBE	127	57	578	7	770	2290	3060	25%
MUGANZA	346	158	427		931	3116	4047	23%
MUSHA	392	69	370	7	837	3432	4269	20%
NYANZA	125		375		501	2234	2734	18%
MUGOMBWA	43	9	382		435	2058	2492	17%
NDORA	22	49	623		693	3986	4679	15%
GIKONKO	67	83	217		366	2493	2859	13%
GISHUBI	24	53	221		298	3390	3688	8%
MAMBA	27		197		225	2720	2944	8%
<b>Grand Total</b>	<b>1454</b>	<b>615</b>	<b>5238</b>	<b>14</b>	<b>7321</b>	<b>31214</b>	<b>38536</b>	<b>19%</b>

## Erosion Control Techniques in Gisagara District

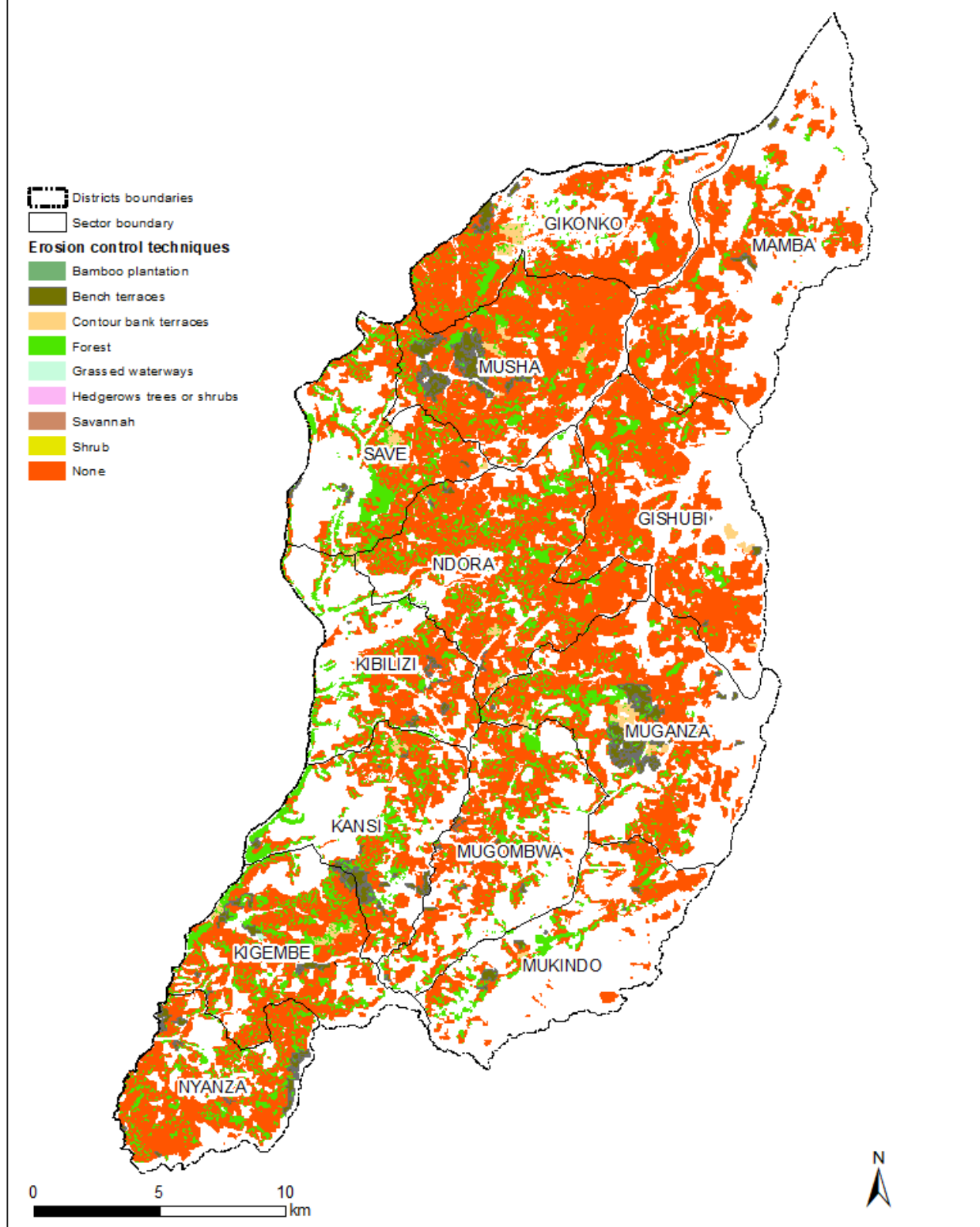


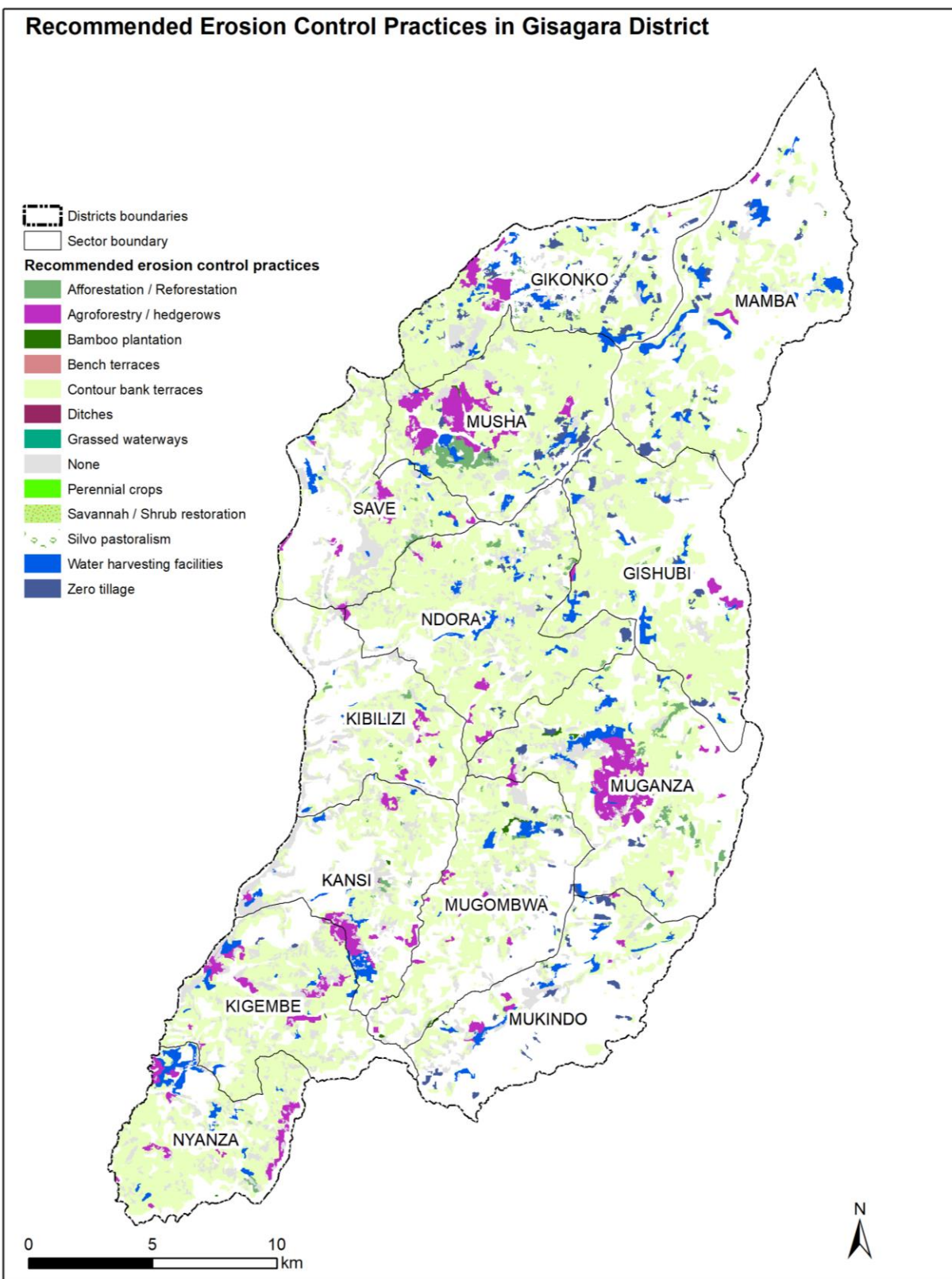
Figure 72: Erosion control techniques in place in Gisagara District

Erosion control practices in Gisagara District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 73 shows that about 27797 hectares (which is 72% of the total land at risk) are suitable for Contour bank terraces, 2109 hectares are Hedge rows and agroforestry, 507 hectares for afforestation/reforestation and 1798 hectares are Storm water management facilities (SWMF).

**Table 75: Recommended erosion control practices in Gisagara District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Already protected	Water harvesting facilities	Zero tillage	Grand Total
GIKONKO	20	149			1,981	270	193	245	2,859
GISHUBI	15	77			3,087	221	172	115	3,688
KANSI	20	171	3		1,358	544	126		2,222
KIBILIZI	25	61			1,345	429	34		1,894
KIGEMBE	1	192			2,197	578	84	7	3,060
MAMBA	10	27	5		2,269	197	302	135	2,944
MUGANZA	141	504	12		2,727	428	169	66	4,047
MUGOMBWA	26	52	20		1,876	382	77	58	2,492
MUKINDO	10	59	2		752	287	132	115	1,356
MUSHA	164	463	4		2,961	372	149	155	4,269
NDORA	40	70	2	1	3,766	623	106	71	4,679
NYANZA	14	159	1		2,004	375	181		2,734
SAVE	20	124		12	1,474	588	72		2,290
<b>Grand Total</b>	<b>507</b>	<b>2,109</b>	<b>47</b>	<b>14</b>	<b>27,797</b>	<b>5,295</b>	<b>1,798</b>	<b>968</b>	<b>38,536</b>
<b>%</b>	<b>1.3%</b>	<b>5.5%</b>	<b>0.1%</b>	<b>0.04%</b>	<b>72.1%</b>	<b>13.7%</b>	<b>4.7%</b>	<b>2.5%</b>	<b>100.0%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



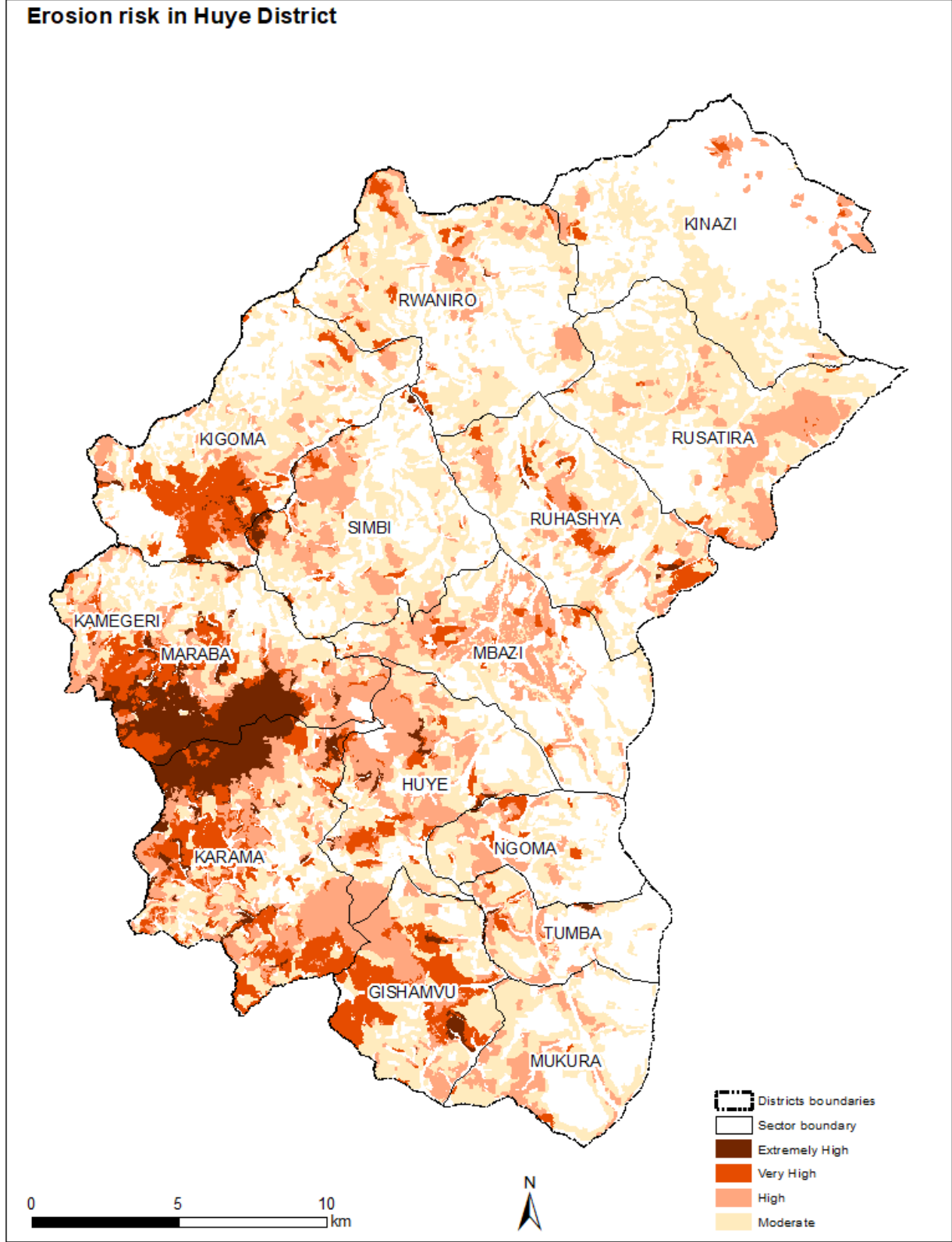
**Figure 73: Recommended erosion control practices in Gisagara District**

### 3.3.2. Erosion control status in Huye District

Erosion risk in Huye is summarised in Table 74 and presented in figure 74. Erosion risk in Huye District is estimated to 35304 hectares; about 61% of the total district land are highly susceptible to erosion of which 4621 hectares are located in Karama sector (86% of sector land), 2540 hectares are located in Gishamvu sector (84% of sector land), 4084 hectares are located in Maraba (79% of the sector land), and 2520 hectares are found in Huye sector about 72% of the sector land. The least sectors are Kinazi with only 1701 hectares (28% of the sector land) susceptible to erosion, Tumba with 791 hectares (44%), and Ngoma with 934 hectares, about 45% of the total sector land. As compared to other districts in Southern Province, Huye is the forth susceptible to erosion, due to intensible protection of agricultural land by bench terraces and forests.

**Table 76: Erosion risk per sector in Huye District**

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
KARAMA	779	1176	1424	1242	4621	5377	86%
GISHAMVU	68	831	562	1079	2540	3028	84%
MARABA	1055	754	999	1275	4084	5161	79%
HUYE	63	233	1146	1079	2520	3523	72%
RUSATIRA	6	43	914	2419	3382	5155	66%
SIMBI	62	114	678	1776	2631	4264	62%
RUHASHYA	23	290	581	1647	2541	4189	61%
KIGOMA	63	873	490	1585	3011	5102	59%
RWANIRO	11	165	613	2271	3061	5445	56%
MBAZI		134	959	996	2090	4153	50%
MUKURA		20	420	959	1399	2804	50%
NGOMA	3	103	294	534	934	2070	45%
TUMBA	21	47	246	477	791	1801	44%
KINAZI	1	42	272	1386	1701	6081	28%
<b>Grand Total</b>	<b>2154</b>	<b>4825</b>	<b>9599</b>	<b>18725</b>	<b>35304</b>	<b>58153</b>	<b>61%</b>



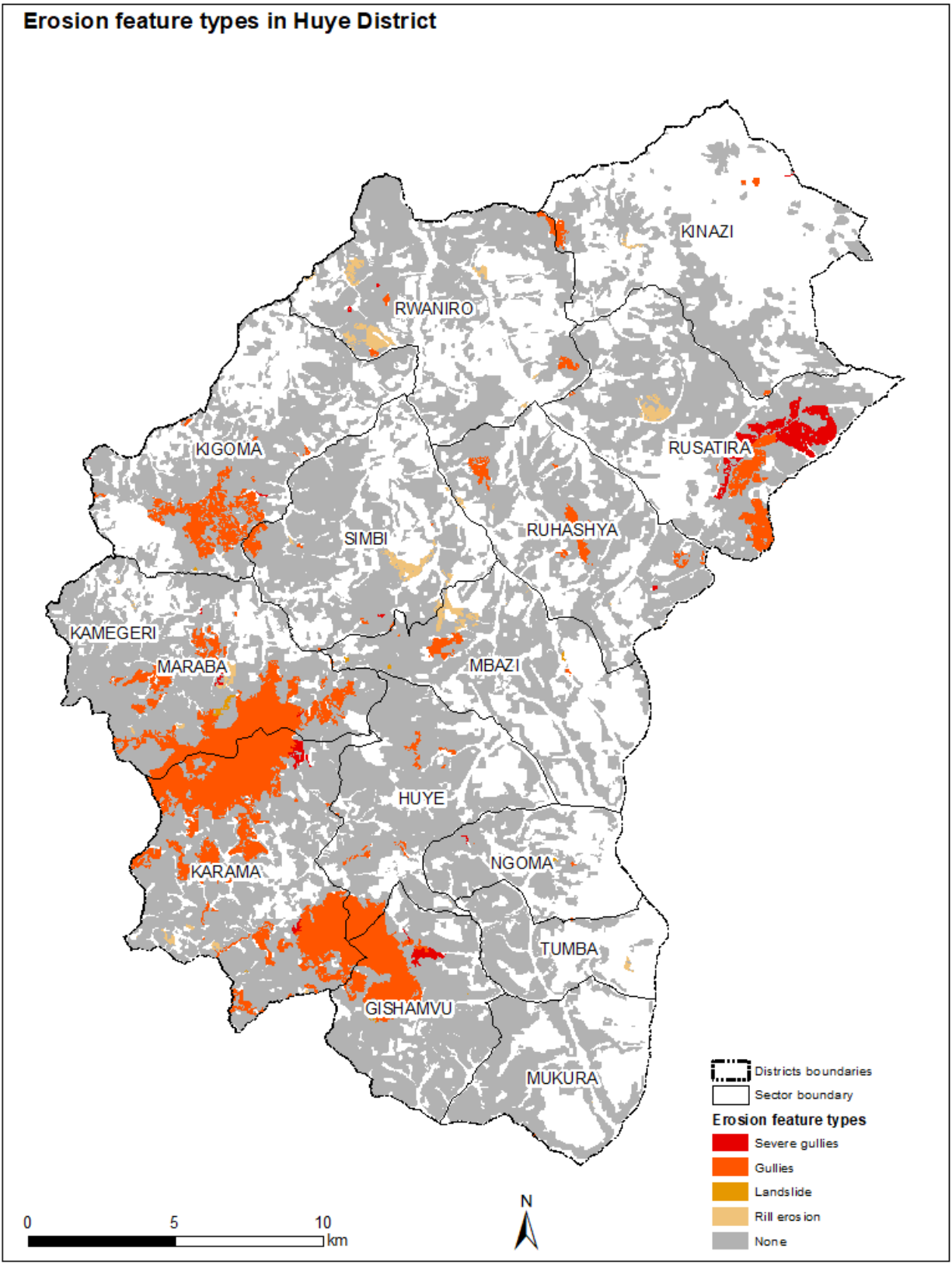
**Figure 74: Erosion risk in Huye District**



Land areas affected by erosive features in Huye District are summarized in Table 75 and the map of erosive features are presented in Figure 75. The results show that Karama sector is the worst affected by gullies and severe gullies on areas estimated to 1685 hectares (36% of sector land at risk), followed by Maraba sector on 945 hectares (23% of sector land at risk), and Gishamvu sector on 533 hectares (21% of sector land at risk). The presence of gullies in Rusatira, Karama, Gishamvu and Maraba sectors confirms the findings of CROM model; however the reduced presence of gullies in Mukura (1 ha), Ngoma and Tumba which were originally predicted by CROM model as sectors at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 76 and 177. The least sectors affected by gullies are Mukura with only 1 hectare, Ngoma with only 6 hectares and Tumba with 8 hectares affected by gullies.

**Table 77: Erosive features and areas affected in Huye District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
KARAMA	1627		21	37	1685	2935	4621	36%
MARABA	880	15	33	16	945	3139	4084	23%
GISHAMVU	491	6		36	533	2006	2540	21%
RUSATIRA	246		57	304	607	2776	3382	18%
KIGOMA	405	1		1	408	2603	3011	14%
HUYE	169				169	2350	2520	7%
MBAZI	58	7	63		129	1961	2090	6%
RWANIRO	48		126	3	178	2882	3061	6%
RUHASHYA	137		8	2	147	2394	2541	6%
SIMBI	48		85	2	135	2496	2631	5%
KINAZI	41		11	2	54	1647	1701	3%
TUMBA	1		7		8	782	791	1%
NGOMA	2	3		2	6	927	934	1%
MUKURA	1				1	1398	1399	0%
<b>Grand Total</b>	<b>4156</b>	<b>33</b>	<b>412</b>	<b>406</b>	<b>5006</b>	<b>30297</b>	<b>35304</b>	<b>14%</b>

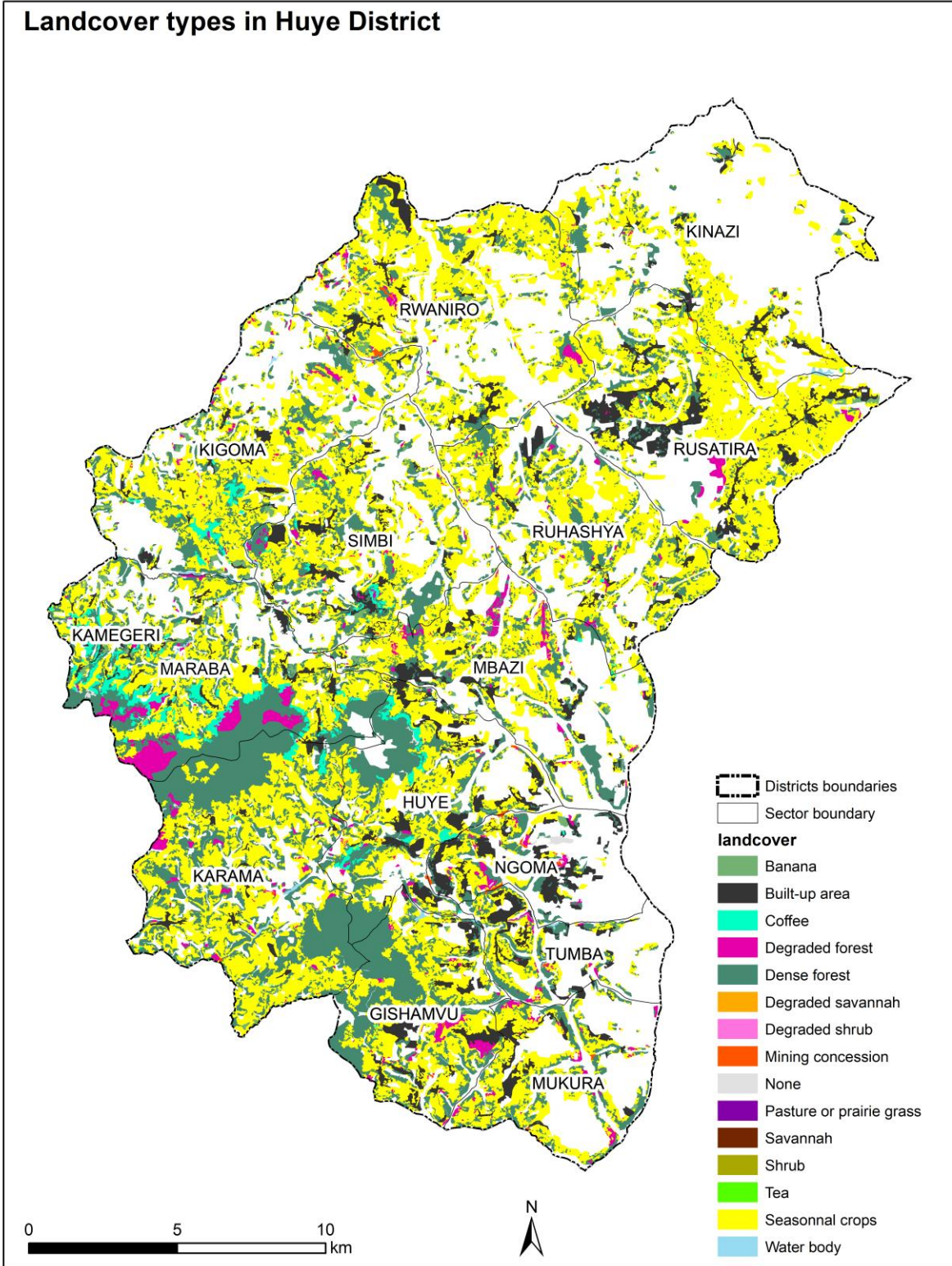


**Figure 75: Erosive features detected in Huye District**

In term of land use and land cover of areas at risk in Huye District, the results of land cover mapping (Table 76 and Figure 76) show that 20242 hectares (57% of the total land at risk) are used for seasonal cropping, 9370 hectares (27% of the total land at risk) are covered by healthy forests, 3345 hectares (9% of the total land at risk) are covered by built-up area.

**Table 78: Land Use and Vegetation Cover (LUVC) for land at risk in Huye District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining and Quarries	None	Seasonal crops	Shrub	Water body	Grand Total
GISHAMVU	9	276	6	88	943	3		1207		9	2540
HUYE	20	355	119	18	881	5	5	1117			2520
KARAMA	13	99	35	81	1979	2	2	2399		12	4621
KIGOMA	153	141	83	38	638			1926		31	3011
KINAZI	5	160	1	1	222			1304		8	1701
MARABA	109	203	385	314	1360		12	1684		17	4084
MBAZI	33	220	3	103	545			1183		3	2090
MUKURA	15	150		53	374	4		802			1399
NGOMA	9	328		48	214	14	22	299		0	934
RUHASHYA	14	156	1	25	546			1799			2541
RUSATIRA	27	579	1	73	343	1		2341	3	14	3382
RWANIRO	47	237		48	439	11		2265		13	3061
SIMBI	45	248	38	42	655			1587		16	2631
TUMBA	9	195		20	231	3	1	328		3	791
<b>Grand Total</b>	<b>508</b>	<b>3345</b>	<b>672</b>	<b>951</b>	<b>9370</b>	<b>43</b>	<b>43</b>	<b>20242</b>	<b>3</b>	<b>127</b>	<b>35304</b>
<b>%</b>	<b>1%</b>	<b>9%</b>	<b>2%</b>	<b>3%</b>	<b>27%</b>	<b>0%</b>	<b>0%</b>	<b>57%</b>	<b>0%</b>	<b>0%</b>	<b>100%</b>



**Figure 76: Land cover types in Huye District**

About existing erosion control practices in Huye district, Table 77 shows that 35% of land at risk is protected by forests (9398 hectares), contour bank terraces (2003 hectares) and bench terraces (794 hectares). The highest protected sectors are Karama with 53% of its land at risk protected, followed by Gishamvu where 44% of the total land at risk is protected and Ruhashya with 42% of land protected. The least protected sectors are Kinazi with only 18% protected, Ngoma (only 25% protected), Rwaniro (24%) and Mukura (28% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Kinazi, Simbi and Ngoma sectors remain at very high risk of soil erosion since more than 65% of their respective land are not protected

**Table 79: Erosion control practices already in place in Huye District**

Sector Name	Erosion control in place				Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest	Hedgerows trees or shrubs				
KARAMA	38	372	1979		2389	2232	4621	52%
GISHAMVU		168	942		1110	1429	2540	44%
RUHASHYA		512	548		1060	1481	2541	42%
HUYE	3	104	881		989	1531	2520	39%
TUMBA		63	229		292	498	791	37%
RUSATIRA	627	235	346		1207	2175	3382	36%
MARABA		37	1359		1397	2687	4084	34%
SIMBI	86	56	651		794	1837	2631	30%
MBAZI		57	549		605	1484	2090	29%
KIGOMA		54	639	157	851	2160	3011	28%
MUKURA		16	375		392	1007	1399	28%
NGOMA		32	200		232	702	934	25%
RWANIRO	15	281	439		735	2326	3061	24%
KINAZI	25	15	263		303	1398	1701	18%
<b>Grand Total</b>	<b>794</b>	<b>2003</b>	<b>9,402</b>	<b>157</b>	<b>12357</b>	<b>22946</b>	<b>35304</b>	<b>35%</b>



## Erosion Control Techniques in Huye District

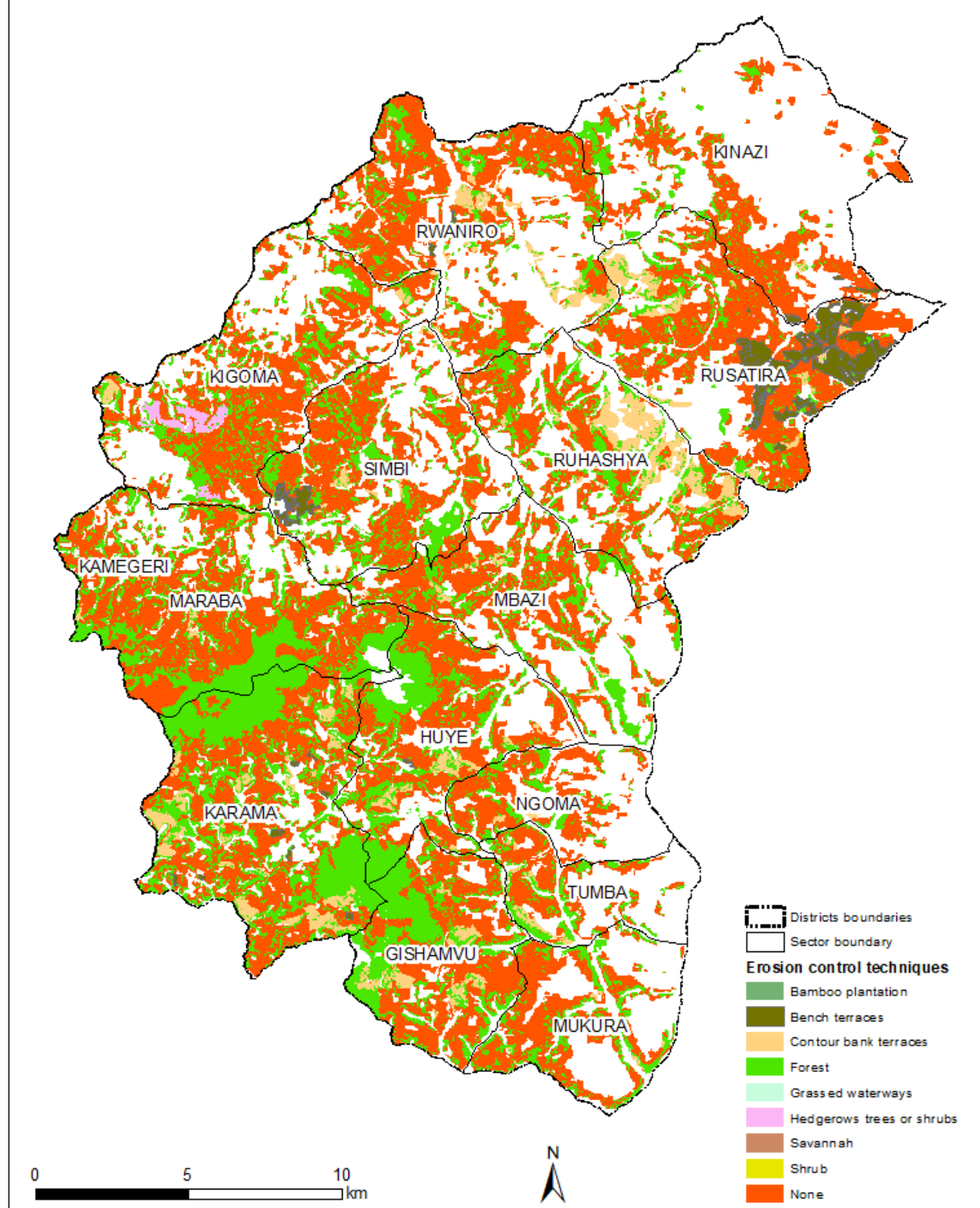


Figure 77: Erosion control techniques in place in Huye District



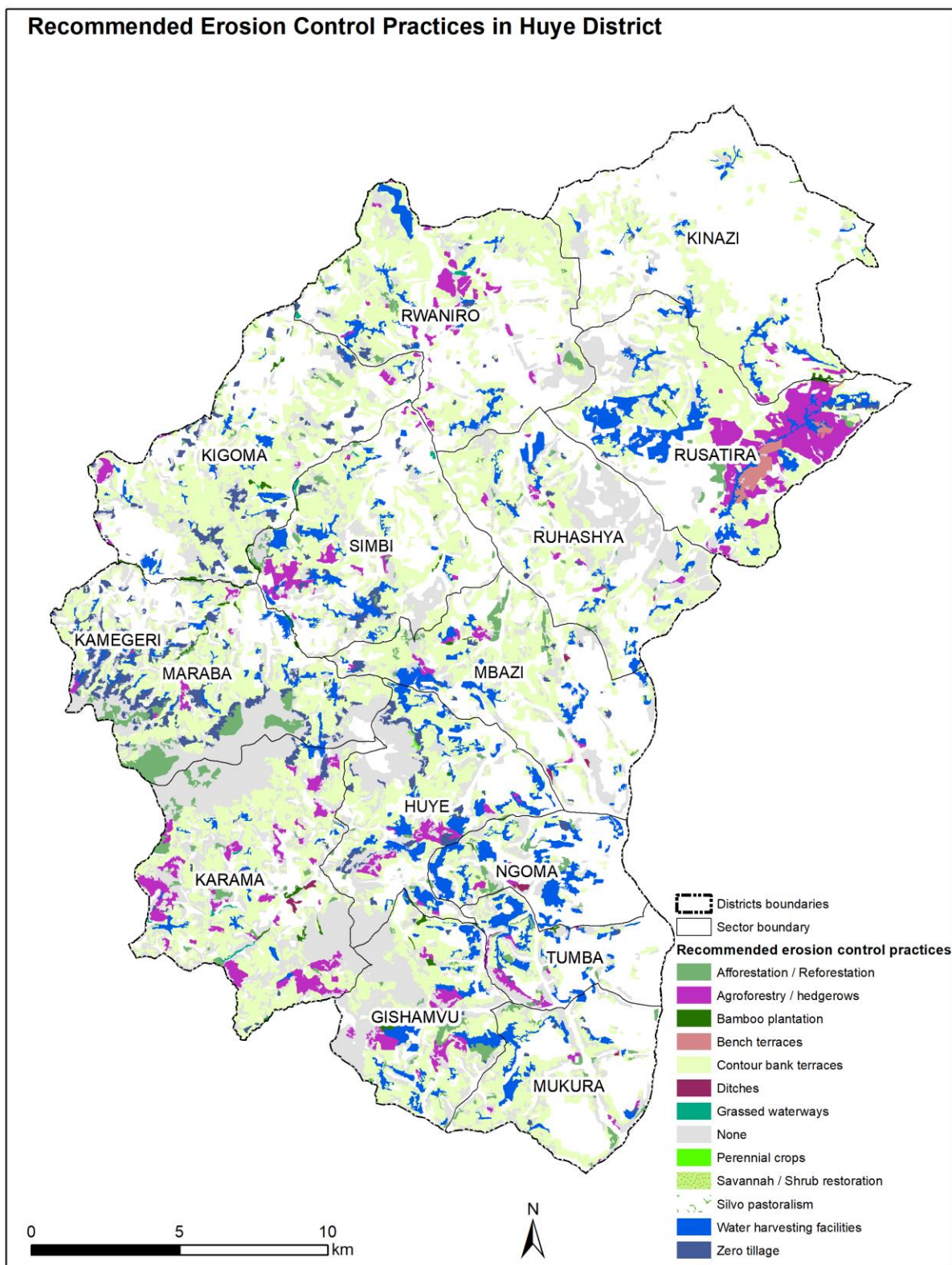
Erosion control practices in Huye District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 78 shows that about 17141 hectares (which is 49% of the total land at risk) are suitable for Contour bank terraces, 2012 hectares are Agroforestry/Hedgerows and 112107 hectares are Afforestation/Reforestation. Other interventions are 3224 hectares of water harvesting infrastructures and 165 hectares of bamboo plantation to close gullies and protect riversides.

**Table 80: Recommended erosion control practices in Huye District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Forest Ditches	Grassed waterways	Already protected	Water harvesting facilities	Zero tillage/ Perennial crops	Grand Total
GISHAMVU	93	147	27		1017			964	276	17	2540
HUYE	23	107	1		1007			883	355	144	2520
KARAMA	137	407	23		1911	17	17	1962	99	47	4621
KIGOMA	44	55	31		1864		4	636	141	236	3011
KINAZI	1	40	10		1261			222	160	6	1701
MARABA	330	41	20		1634		3	1360	203	494	4084
MBAZI	103	54	3		1118	11		534	231	35	2090
MUKURA	61	16			786	2		369	150	15	1399
NGOMA	67	32	2		256	9		198	360	9	934
RUHASHYA	29	44			1271	1		1014	167	15	2541
RUSATIRA	76	688	14	138	1380			480	579	28	3382
RWANIRO	58	184	13		1960		10	551	237	47	3061
SIMBI	53	143	16		1418		15	651	248	87	2631
TUMBA	34	54	3		259			237	195	9	791
<b>Grand Total</b>	<b>1107</b>	<b>2012</b>	<b>165</b>	<b>138</b>	<b>17141</b>	<b>40</b>	<b>50</b>	<b>10061</b>	<b>3400</b>	<b>1183</b>	<b>35304</b>
<b>%</b>	<b>3%</b>	<b>6%</b>	<b>0%</b>	<b>0%</b>	<b>49%</b>	<b>0%</b>	<b>0%</b>	<b>28%</b>	<b>10%</b>	<b>3%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

## Recommended Erosion Control Practices in Huye District



**Figure 78: Recommended erosion control practices in Huye District**

### 3.3.3. Erosion status in Kamonyi District

Erosion risk in Kamonyi is summarised in Table 79 and presented in figure 79. Erosion risk in Kamonyi District is estimated to 27349 hectares; about 42% of the total district land are highly susceptible to erosion of which 3166 hectares are located in Kayenzi sector (88% of sector land), 2273 hectares are located in Ngamba sector (72% of sector land), 3531 hectares are located in Runda (70% of the sector land), and 3312 hectares are found in Rukoma sector about 64% of the sector land. The least sectors are Gacurabwenge with only 626 hectares (12% of the sector land) susceptible to erosion, Nyamiyaga with 1333 hectares (17%), Rugalika with 2018 hectares, about 27% of the total sector land and Karama with 1799 hectares of the total sector land. As compared to other districts in Southern Province, Kamonyi is the sixth susceptible to erosion.

**Table 81: Erosion risk per sector in Kamonyi District**

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
KAYENZI	572	1739	361	493	3166	3588	88%
NGAMBA	377	809	718	368	2273	3157	72%
RUNDA	78	651	1076	1727	3531	5009	70%
RUKOMA	430	1067	1147	667	3312	5154	64%
KAYUMBU	261	362	1107	359	2090	3372	62%
MUSAMBIRA	131	466	1529	221	2347	6317	37%
MUGINA	6	149	553	2573	3281	8871	37%
NYARUBAKA	30	236	1109	198	1573	4486	35%
KARAMA	178	990	536	95	1799	5231	34%
RUGALIKA		72	680	1266	2018	7475	27%
NYAMIYAGA	2	207	832	292	1333	7785	17%
GACURABWENGE	14	161	386	65	626	5108	12%
<b>Grand Total</b>	<b>2080</b>	<b>6911</b>	<b>10034</b>	<b>8324</b>	<b>27349</b>	<b>65553</b>	<b>42%</b>

### Erosion risk in Kamonyi District

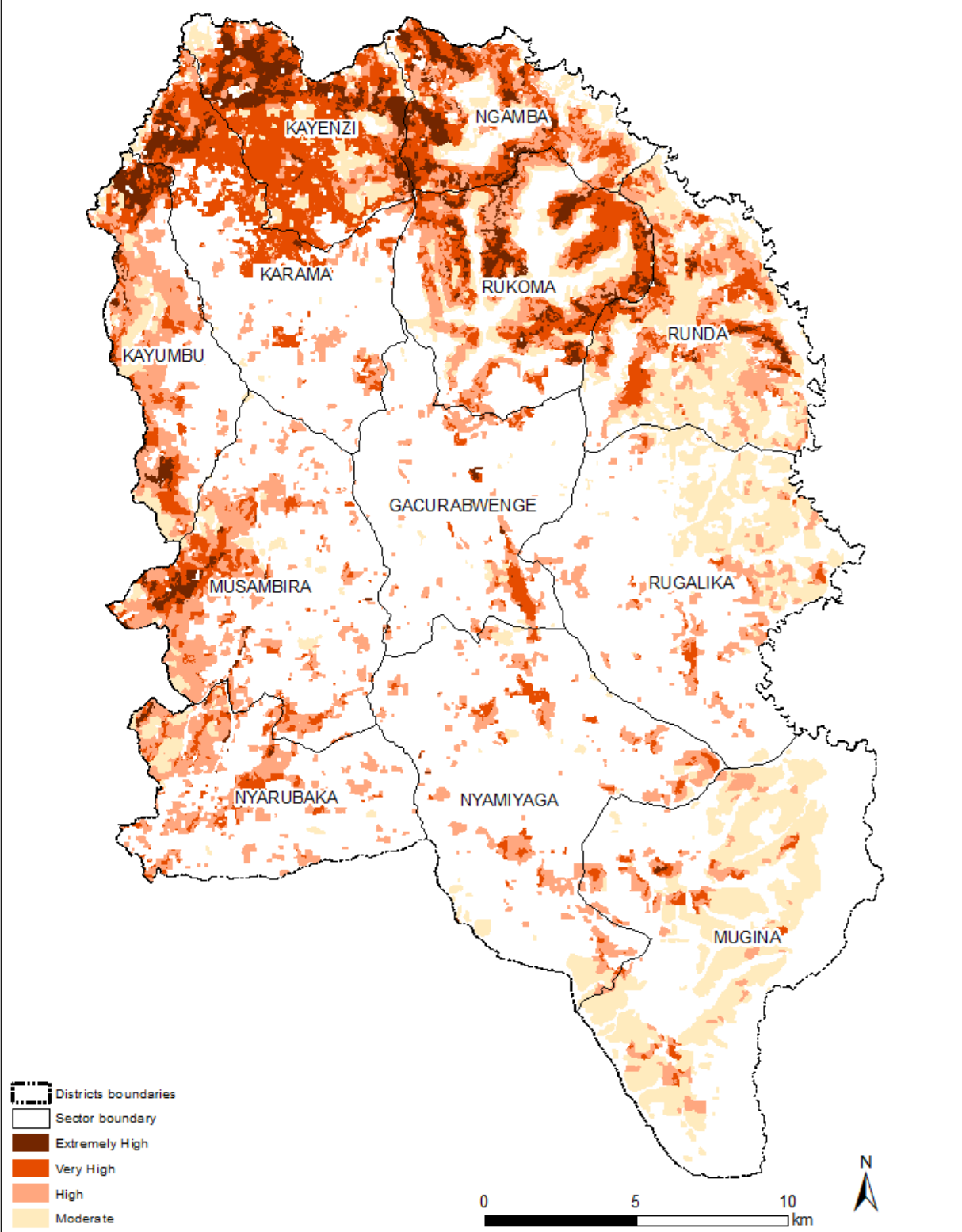


Figure 79: Erosion risk in Kamonyi District

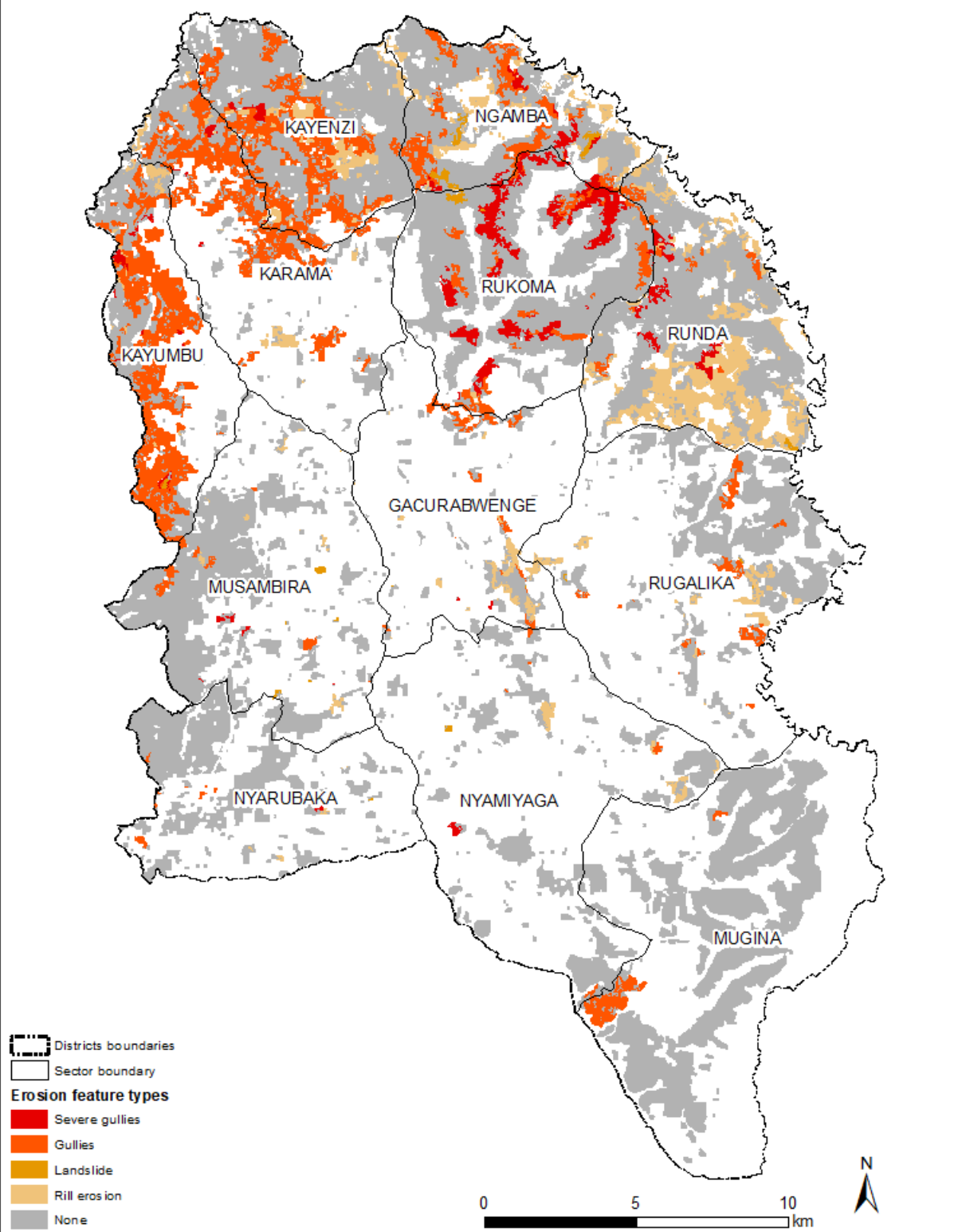
Land areas affected by erosive features in Kamonyi District are summarized in Table 80 and the map of erosive features are presented in Figure 80. The results show that Kayumbu sector is the worst affected by gullies on areas estimated to 1,317 hectares (63% of sector land at risk), followed by Karama sector on 819 hectares (54% of sector land at risk), and Kayenzi sector on 1259 hectares (40% of sector land at risk) and Gacurabwenge on 249 hectares (40% of sector land at risk). The presence of gullies in Kayumbu, Karama, Gacurabwenge and Kayenzi sectors confirms the findings of CROM model; however reduced presence of gullies in Nyarubaka, Musambira and Nyamiyaga and the absence of gullies in Mugina which were originally predicted by CROM model as sectors at high risk should not read that and this shows that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 81 and 82. The least sectors affected by gullies are Nyarubaka (48 ha), Mugina with only 140 hectares, Musambira with only 135 hectares and Nyamiyaga with 105 hectares, affected by Gullies, Landslides and Rill erosion.

**Table 82: Erosive features and areas affected in Kamonyi District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Land slide	Rill erosion	Severe gullies				
KAYUMBU	1217	5	56	40	1317	773	2090	63%
KARAMA	872		95	13	981	819	1799	54%
KAYENZI	977		256	25	1259	1907	3166	40%
GACURABWENGE	110		134	4	249	377	626	40%
RUNDA	100	9	1103	124	1336	2195	3531	38%
NGAMBA	397	67	269	102	834	1439	2273	37%
RUKOMA	261	19	7	542	829	2483	3312	25%
RUGALIKA	147	3	147		297	1721	2018	15%
NYAMIYAGA	20	4	69	11	105	1229	1333	8%
MUSAMBIRA	68	13	35	19	135	2212	2347	6%
MUGINA	140				140	3141	3281	4%
NYARUBAKA	28	1	14	5	48	1525	1573	3%
<b>Grand Total</b>	<b>4336</b>	<b>120</b>	<b>2186</b>	<b>887</b>	<b>7529</b>	<b>19821</b>	<b>27349</b>	<b>28%</b>



### Erosion feature types in Kamonyi District



**Figure 80: Erosive features detected in Kamonyi District**

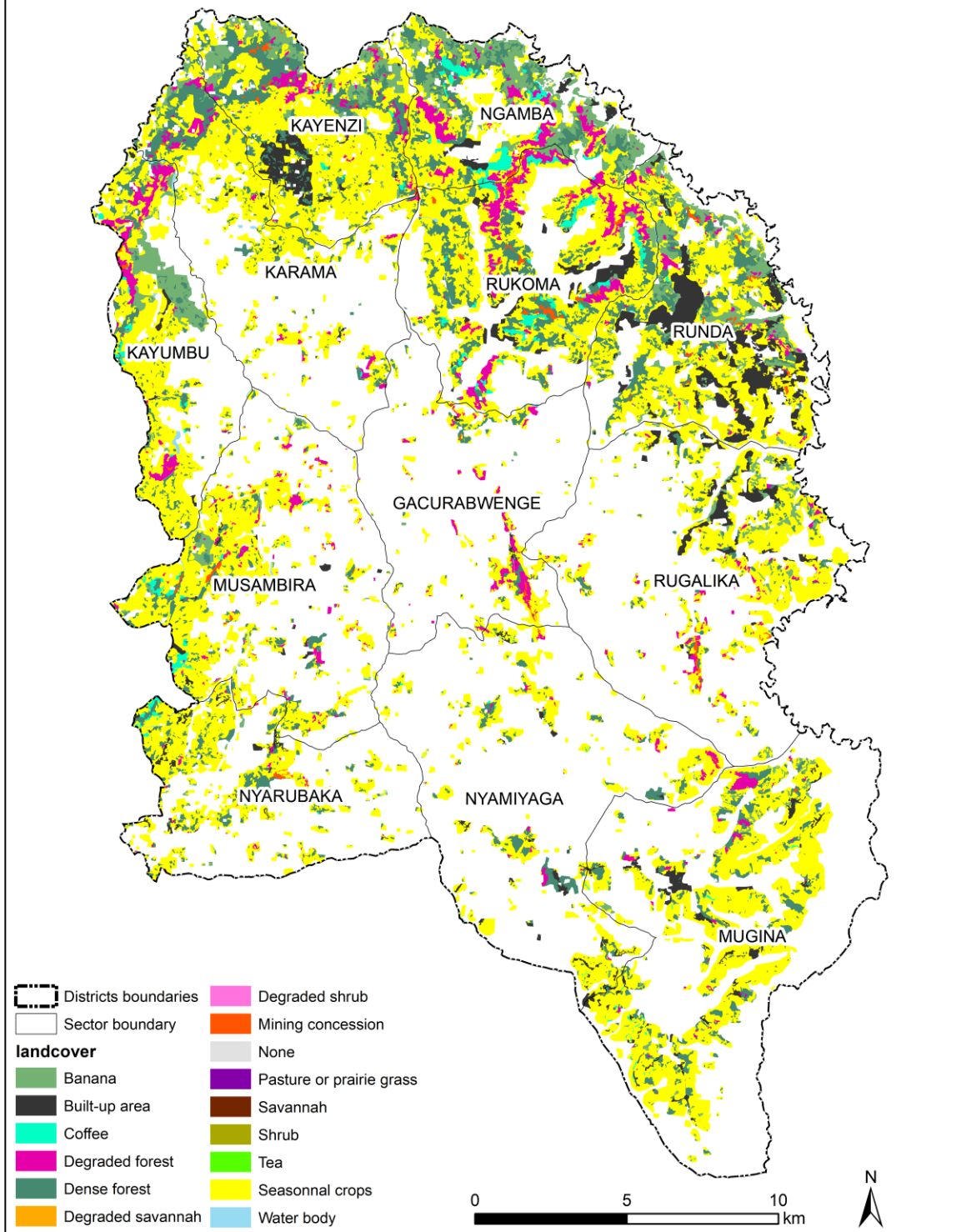


In term of land use and land cover of areas at risk in Kamonyi, the results of land cover mapping (Table 81 and Figure 81) show that 17702 hectares (65% of the total land at risk) are used for seasonal cropping, 3765 hectares (14% of the total land at risk) are covered by healthy forests, 1777 hectares (6% of the total land at risk) are covered by built-up areas and 2066 hectares i.e. 8% are covered by Banana crop. In Kamonyi district there are also mining and quarries sites, and coffee plantations which cover respectively 134 hectares (less than 1% of the total land at risk) and 387 hectares (1% of the total land at risk).

**Table 83: Land Use and Vegetation Cover (LUVC) for land at risk in Kamonyi District**

<b>Sector Name</b>	<b>Banana</b>	<b>Built-up area</b>	<b>Coffee</b>	<b>Degraded forest</b>	<b>Dense forest</b>	<b>Mining and Quarries</b>	<b>Seasonal crops</b>	<b>Water body</b>	<b>Grand Total</b>
GACURABU	3	12		113	69	7	423	0	626
KARAMA	49	9	1	81	324		1329	5	1799
KAYENZI	345	219	10	115	599	10	1861	6	3166
KAYUMBU	305	25	22	192	178	9	1335	24	2090
MUGINA	50	163	5	62	358		2644		3281
MUSAMBIRI	67	39	48	76	230	15	1863	9	2347
NGAMBA	571	71	126	259	412	3	831	1	2273
NYAMIYAGA	2	73		36	181	3	1035	3	1333
NYARUBAKI	12	60	15	13	210	8	1251	4	1573
RUGALIKA	119	203		65	117	12	1502		2018
RUKOMA	59	188	153	379	627	45	1855	6	3312
RUNDA	484	715	6	66	462	21	1774	3	3531
<b>Grand Total</b>	<b>2066</b>	<b>1777</b>	<b>387</b>	<b>1458</b>	<b>3765</b>	<b>134</b>	<b>17702</b>	<b>61</b>	<b>27349</b>
<b>%</b>	<b>8%</b>	<b>6%</b>	<b>1%</b>	<b>5%</b>	<b>14%</b>	<b>0.5%</b>	<b>65%</b>	<b>0.2%</b>	<b>100%</b>

## Landcover types in Kamonyi District

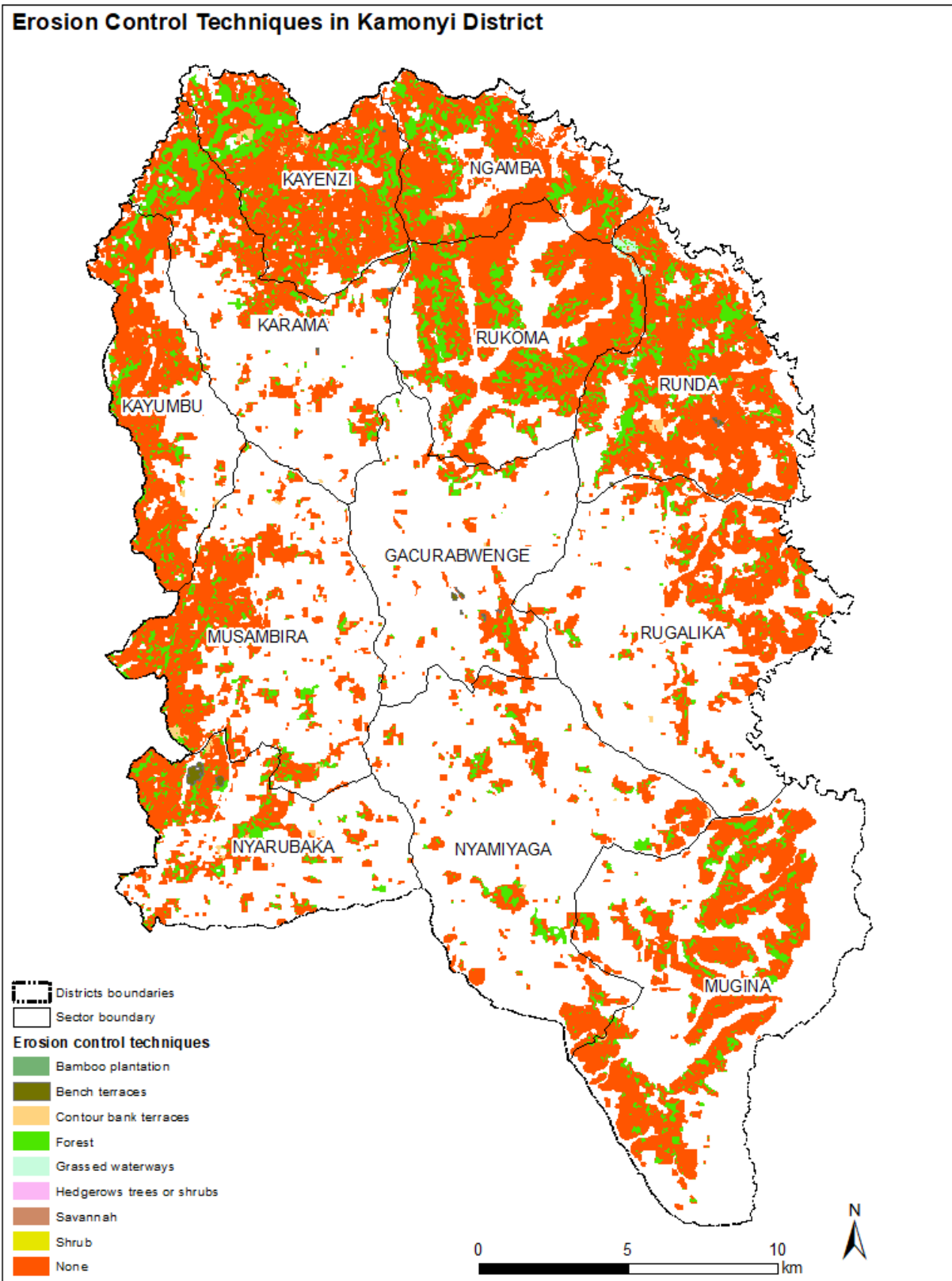


**Figure 81: Land cover types in Kamonyi District**

About existing erosion control practices in Kamonyi district, Table 82 shows that only 15% of land at risk is protected by forests (3811 hectares) and Contour bank terraces (173 hectares), bench terraces (53 hectares) and bamboo (3 hectares). The highest protected sectors are Kayenzi and Rukoma where 20% of their respective total land at risk is protected and Ngamba and Karama with 19% of land protected in each sector. The least protected sectors are Rugalika with only 6% protected, Kayumbu (only 10% protected), Mugina and Musambira (11%) and Gacurabwenge (13% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Rugalika, Musambira, Gacurabwenge and Kayumbu sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected.

**Table 84: Erosion control practices already in place in Kamonyi District**

Sector Name	Erosion control in place				Total protect ed	Unprot ected	Grand Total	% Prote cted
	Bench terraces	Contour bank terraces	Forest	Grasse d waterw ays				
KAYENZI		31	599		630	2536	3166	20%
RUKOMA		5	627	21	653	2660	3312	20%
NGAMBA		25	412		436	1837	2273	19%
KARAMA	3	5	324		333	1466	1799	19%
NYARUBAKA	35	21	221		277	1296	1573	18%
RUNDA	6	25	465	44	541	2991	3531	15%
NYAMIYAGA		10	184		194	1139	1333	15%
GACURABWENGE	8	6	69		83	542	626	13%
MUSAMBIRA		27	236		263	2083	2347	11%
MUGINA		3	359		362	2919	3281	11%
KAYUMBU		11	202		213	1877	2090	10%
RUGALIKA		3	117		120	1898	2018	6%
<b>Grand Total</b>	<b>53</b>	<b>173</b>	<b>3816</b>	<b>65</b>	<b>4105</b>	<b>23245</b>	<b>27349</b>	<b>15%</b>



**Figure 82: Erosion control techniques in place in Kamonyi District**

Erosion control practices in Kamonyi District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 83 shows that about 16094 hectares (which is 59% of the total land at risk) are suitable for Contour bank terraces, 1598 hectares are for afforestation/reforestation and 1185 hectares of cropland that need agroforestry/hedge rows cropping. Other interventions are 323 Ha for bamboo to close gullies and protect riverside and 1783 Ha for water harvesting infrastructures.

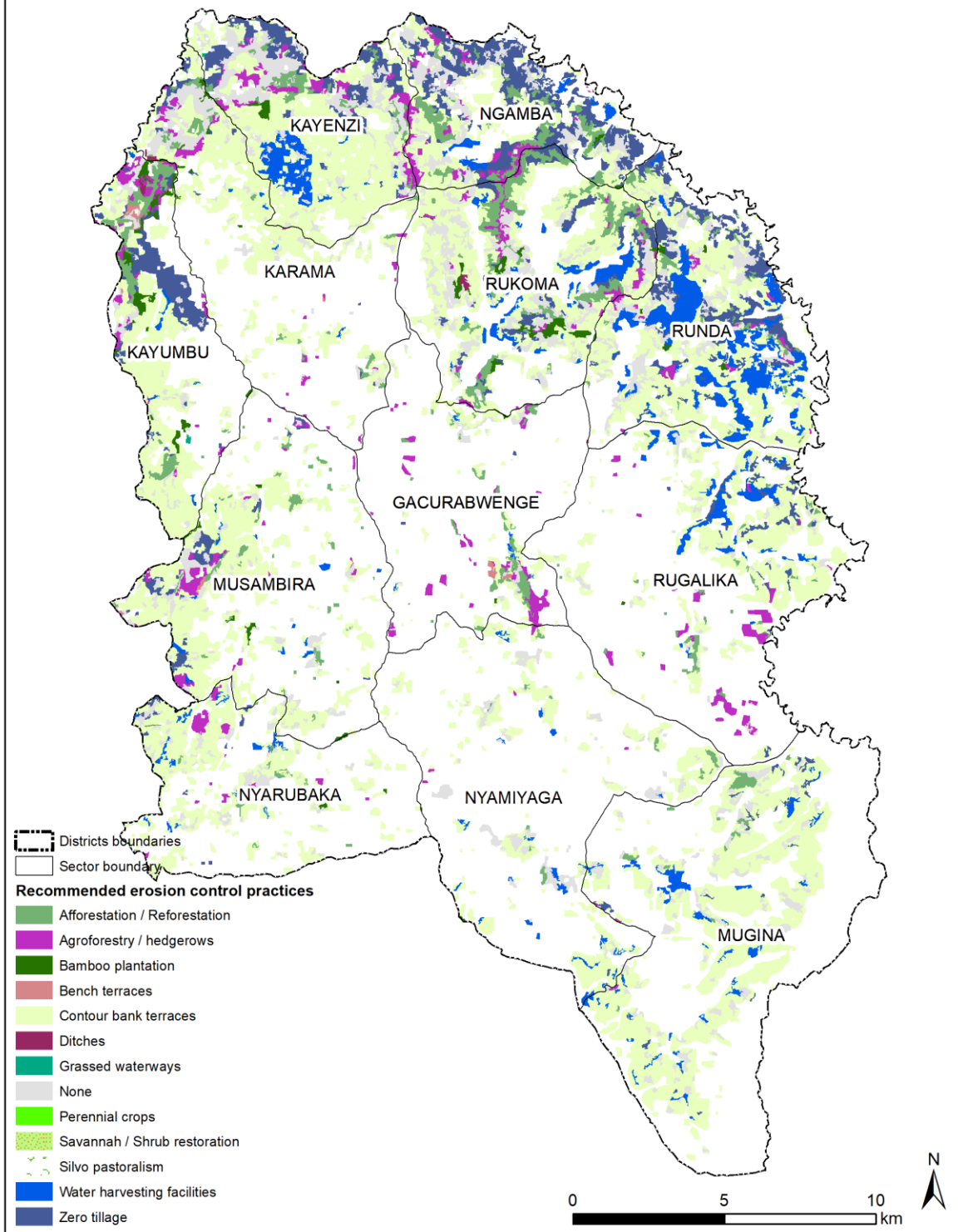
**Table 85: Recommended erosion control practices in Kamonyi District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	Grassed waterways	None	Water harvesting facilities	Zero tillage	Grand Total
GACURABWENGE	119	139	3	14	266			69	12	3	626
KARAMA	81	79	21	1	1239	5		319	9	45	1799
KAYENZI	125	168	28		1670		2	599	219	355	3166
KAYUMBU	201	121	109	20	1135	7	4	172	25	296	2090
MUGINA	62	6			2627			369	163	54	3281
MUSAMBIRA	91	116	20	7	1693			265	39	116	2347
NGAMBA	262	143	8		673			418	71	698	2273
NYAMIYAGA	39	10	3		956			250	73	2	1333
NYARUBAKA	26	65	9		1175			210	60	28	1573
RUGALIKA	77	154	1		1347			117	203	119	2018
RUKOMA	426	124	103		1623	10		627	188	213	3312
RUNDA	87	60	17		1691			470	721	485	3531
<b>Grand Total</b>	<b>1598</b>	<b>1185</b>	<b>323</b>	<b>42</b>	<b>16094</b>	<b>21</b>	<b>5</b>	<b>3883</b>	<b>1783</b>	<b>2415</b>	<b>27349</b>
<b>%</b>	<b>6%</b>	<b>4%</b>	<b>1%</b>	<b>0%</b>	<b>59%</b>	<b>0%</b>	<b>0%</b>	<b>14%</b>	<b>7%</b>	<b>9%</b>	<b>100%</b>

Others interventions: 21Ha Contour bank, 6Ha Grassed waterways

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

## Recommended Erosion Control Practices in Kamonyi District



**Figure 83: Recommended erosion control practices in Kamonyi District**

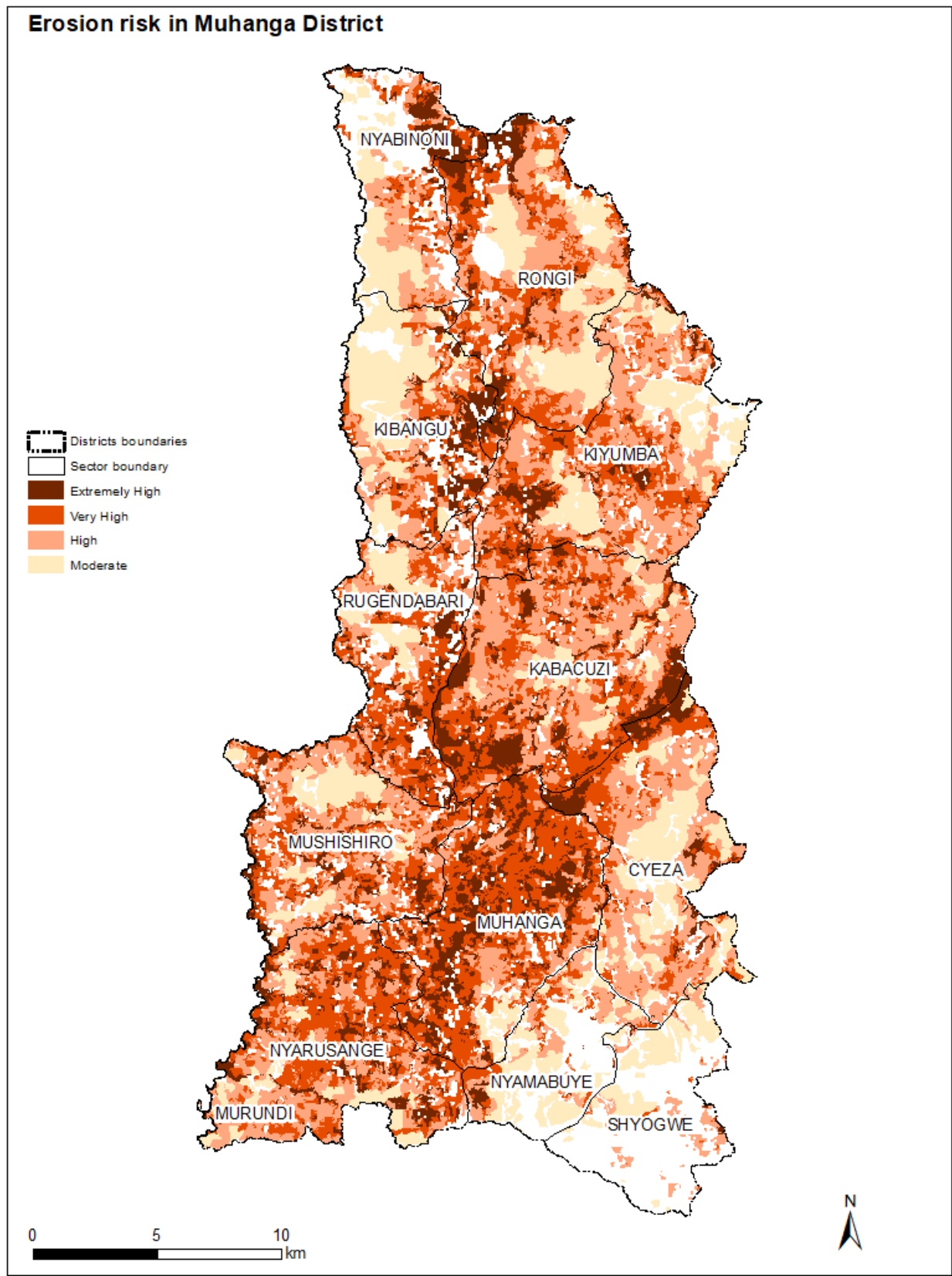


### 3.3.4. Erosion control status Muhanga District

Erosion risk in Muhanga is summarised in Table 86 and presented in figure 84. Erosion risk in Muhanga District is estimated to 53352 hectares; about 82% of the total district land are highly susceptible to erosion of which 7170 hectares are located in Kabacuzi sector (96% of sector land), 5739 hectares are located in Nyarusange sector (92% of sector land), 5612 hectares are located in Muhanga (90% of the sector land), and 6160 hectares are found in Rongi sector about 89% of the sector land. The least sectors are Shyogwe with only 1095 hectares (29% of the sector land) susceptible to erosion and Nyamabuye with 1796 hectares (61%). Other sectors are affected by high erosion risk at more than 60% of their respective total land. As compared to other districts in Southern Province, Muhanga is the first susceptible to erosion.

**Table 86: Erosion risk per sector in Muhanga District**

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Mode-rate	Grand Total		
KABACUZI	1,206	2,132	3,144	687	7,170	7,505	96%
NYARUSANGE	749	2,180	2,210	600	5,739	6,253	92%
MUHANGA	1,450	2,939	1,017	206	5,612	6,252	90%
RONGI	710	1,694	2,124	1,632	6,160	6,931	89%
CYEZA	449	840	2,269	1,513	5,072	5,758	88%
KIYUMBA	524	1,654	2,835	1,360	6,373	7,277	88%
MUSHISHIRO	532	1,372	1,897	816	4,617	5,315	87%
KIBANGU	563	734	984	1,567	3,848	4,680	82%
RUGENDABARI	436	1,319	988	604	3,347	4,215	79%
NYABINONI	400	411	846	867	2,523	3,900	65%
NYAMABUYE	61	283	533	918	1,796	2,938	61%
SHYOGWE	13	25	341	716	1,095	3,748	29%
<b>Grand Total</b>	<b>7,094</b>	<b>15,584</b>	<b>19,189</b>	<b>11,486</b>	<b>53,352</b>	<b>64,772</b>	<b>82%</b>

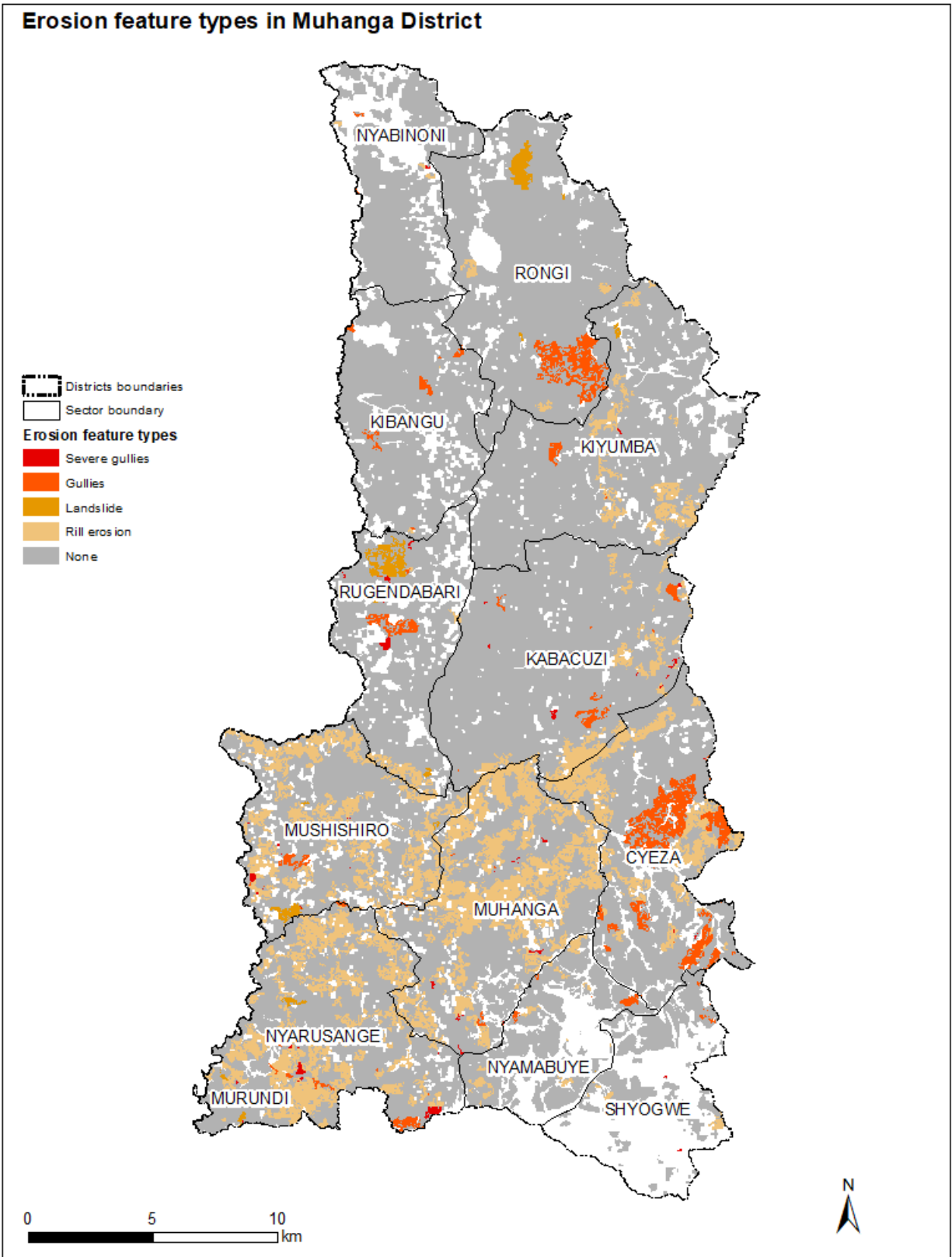


**Figure 84: Erosion risk in Muhanga District**

Land areas affected by erosive features in Muhanga District are summarized in Table 85 and the map of erosive features are presented in Figure 85. The results show that Muhanga sector is the worst mostly affected by rill erosion on areas estimated to 2304 hectares (41% of sector land at risk), followed by Nyarusange sector on 2010 hectares (35% of sector land at risk), and Mushishiro sector on 1563 hectares (34% of sector land at risk). The presence of rill erosion in most of Muhanga sectors confirms the findings of CROM model; however the reduced presence of erosive features (rill and gullies) in Shyogwe (54 ha) and Nyabinoni (24ha) which was originally predicted by CROM model as sectors at high risk should not read that CROM model which did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 86 and 87. The least sectors affected by rill erosion are Nyabinoni with 24 hectares and Kibangu with 63 hectares affected by rill erosion and some gullies.

**Table 87: Erosive features and areas affected in Muhanga District**

Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
MUHANGA	11		2275	18	2304	3309	5612	41%
NYARUSANGE	87	31	1847	45	2010	3729	5739	35%
MUSHISHIRO	41	55	1459	8	1563	3054	4617	34%
CYEZA	719		891	1	1612	3460	5072	32%
RUGENDABARI	86	158	133	27	404	2944	3347	12%
NYAMABUYE	33		121		154	1642	1796	9%
RONGI	330	113	61		504	5656	6160	8%
KIYUMBA	36	11	462	2	511	5861	6373	8%
KABACUZI	81		420	15	517	6653	7170	7%
SHYOGWE	9	5	36	3	54	1041	1095	5%
KIBANGU	60		3		63	3785	3848	2%
NYABINONI	8		14	2	24	2499	2523	1%
<b>Grand Total</b>	<b>1501</b>	<b>373</b>	<b>7723</b>	<b>120</b>	<b>9718</b>	<b>43634</b>	<b>53352</b>	<b>18%</b>



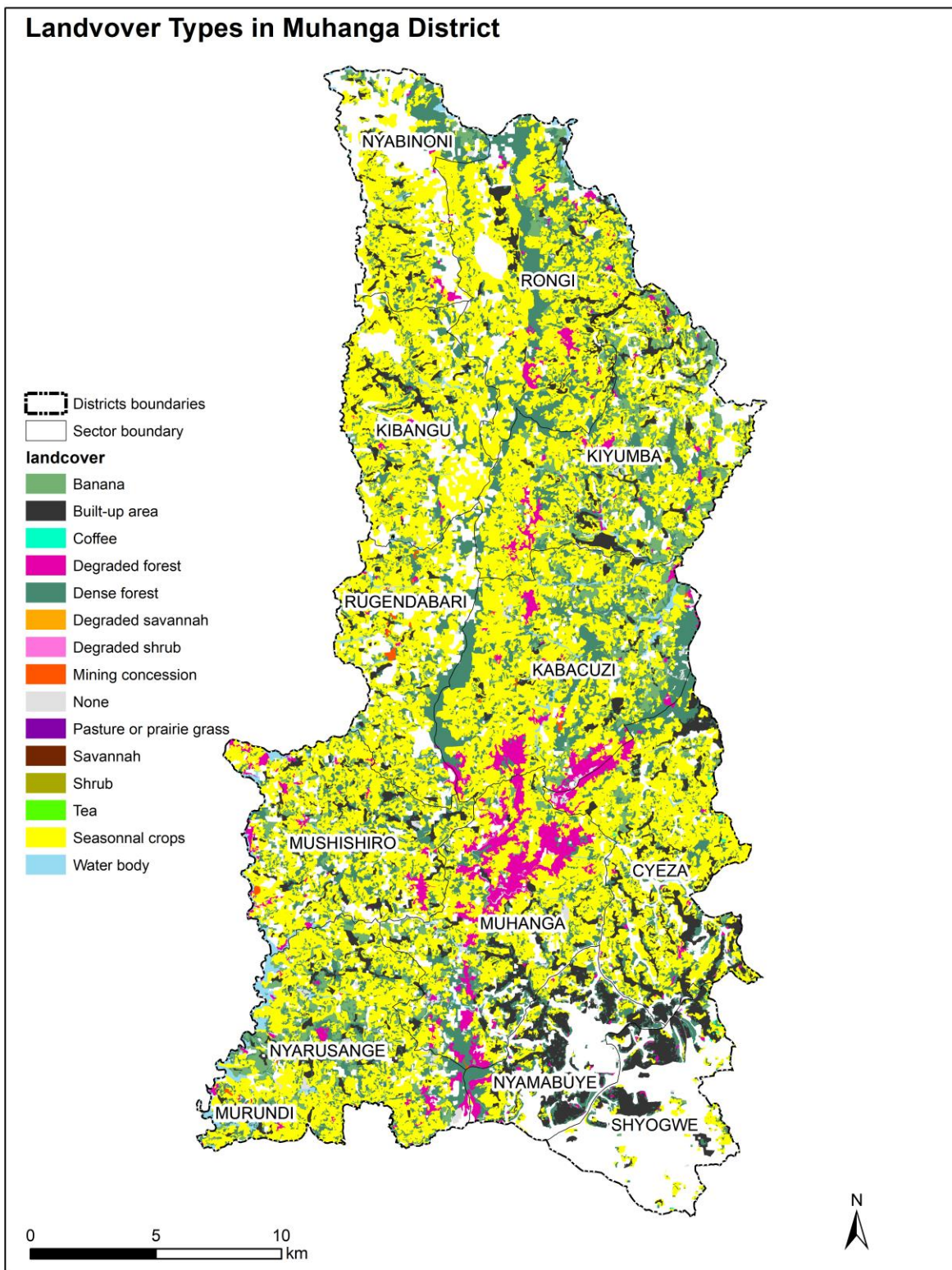
**Figure 85: Erosive features detected in Muhanga District**

In term of land use and land cover of areas at risk in Muhanga, the results of land cover mapping (Table 86 and Figure 86) show that 31654 hectares (59% of the total land at risk) are used for seasonal cropping, 9665 hectares (18% of the total land at risk) are covered by healthy forests, 5029 hectares (9% of the total land at risk) are covered by built-up areas and 3278 hectares i.e. 6% are covered by Banana crop.

**Table 88: Land Use and Vegetation Cover (LUVC) for land at risk in Muhanga District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining and Quarries	None	Seasonal crops	Water body	Grand Total
CYEZA	128	865	7	158	708		24	3162	19	5072
KABACUZI	631	199		445	1645	16	54	4046	135	7170
KIBANGU	111	268		21	548	1	1	2845	52	3848
KIYUMBA	903	434		167	1133		17	3650	69	6373
MUHANGA	204	458		943	855	2	104	3015	30	5612
MUSHISHIRO	189	380		186	711	8	34	2946	162	4617
NYABINONI	130	159		41	495		10	1638	50	2523
NYAMABUYE	13	817		68	369		15	515	0	1796
NYARUSANGE	669	343		124	853	8	96	3358	287	5739
RONGI	195	338		147	1570		7	3828	75	6160
RUGENDABARI	94	165		26	629	29	11	2339	54	3347
SHYOGWE	10	603	2	15	149		4	313	0	1095
<b>Grand Total</b>	<b>3278</b>	<b>5029</b>	<b>9</b>	<b>2341</b>	<b>9665</b>	<b>65</b>	<b>378</b>	<b>31654</b>	<b>933</b>	<b>53352</b>
<b>%</b>	<b>6%</b>	<b>9%</b>	<b>0%</b>	<b>4%</b>	<b>18%</b>	<b>0%</b>	<b>1%</b>	<b>59%</b>	<b>2%</b>	<b>100%</b>





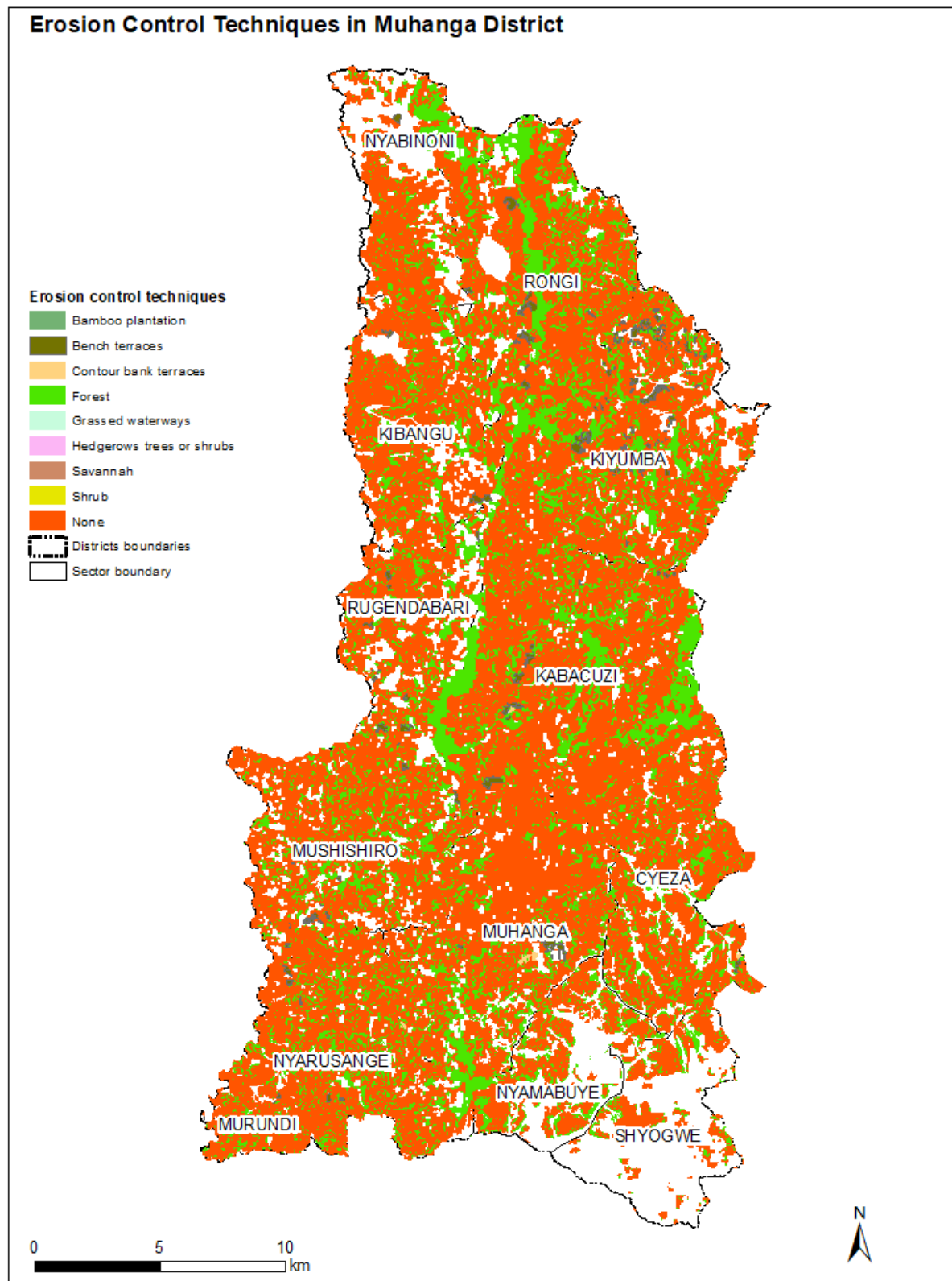
**Figure 86: Land cover types in Muhanga District**



About existing erosion control practices in Muhanga district, Table 87 shows that only 19% of land at risk is protected by forests (9705 hectares) and Contour bank terraces (37 hectares) and bench terraces (528 hectares). The highest protected sectors are Rongi with 27% of its land at risk protected, followed by Kabacuzi where 24% of the total land at risk is protected and Nyamabuye with 21% of land protected. The least protected sectors are Kibangu with only 14% protected, Cyeza (only 14% protected), Kibangu Nyarusange(15%), Nyarusange (15%), Mushishiro (16%) and Muhanga (17% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Kibangu, Cyeza, Nyarusange and Muhanga sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected

**Table 89: Erosion control practices already in place in Muhanga District**

Sector Name	Erosion control in place			Total protected	Unprotected	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
RONGI	90		1575	1666	4495	6,160	27%
KABACUZI	70	6	1665	1741	5428	7,170	24%
NYAMABUYE			379	379	1417	1,796	21%
KIYUMBA	175		1133	1307	5065	6,373	21%
RUGENDABARI	55		631	686	2661	3,347	20%
NYABINONI	8		499	506	2017	2,523	20%
MUHANGA	59	24	854	938	4675	5,612	17%
MUSHISHIRO	22		711	733	3884	4,617	16%
NYARUSANGE	24	1	852	876	4862	5,739	15%
KIBANGU	19	1	546	566	3282	3,848	15%
CYEZA	8	5	708	720	4351	5,072	14%
SHYOGWE			151	151	944	1,095	14%
<b>Grand Total</b>	<b>528</b>	<b>38</b>	<b>9705</b>	<b>10270</b>	<b>43,081</b>	<b>53,352</b>	<b>19%</b>



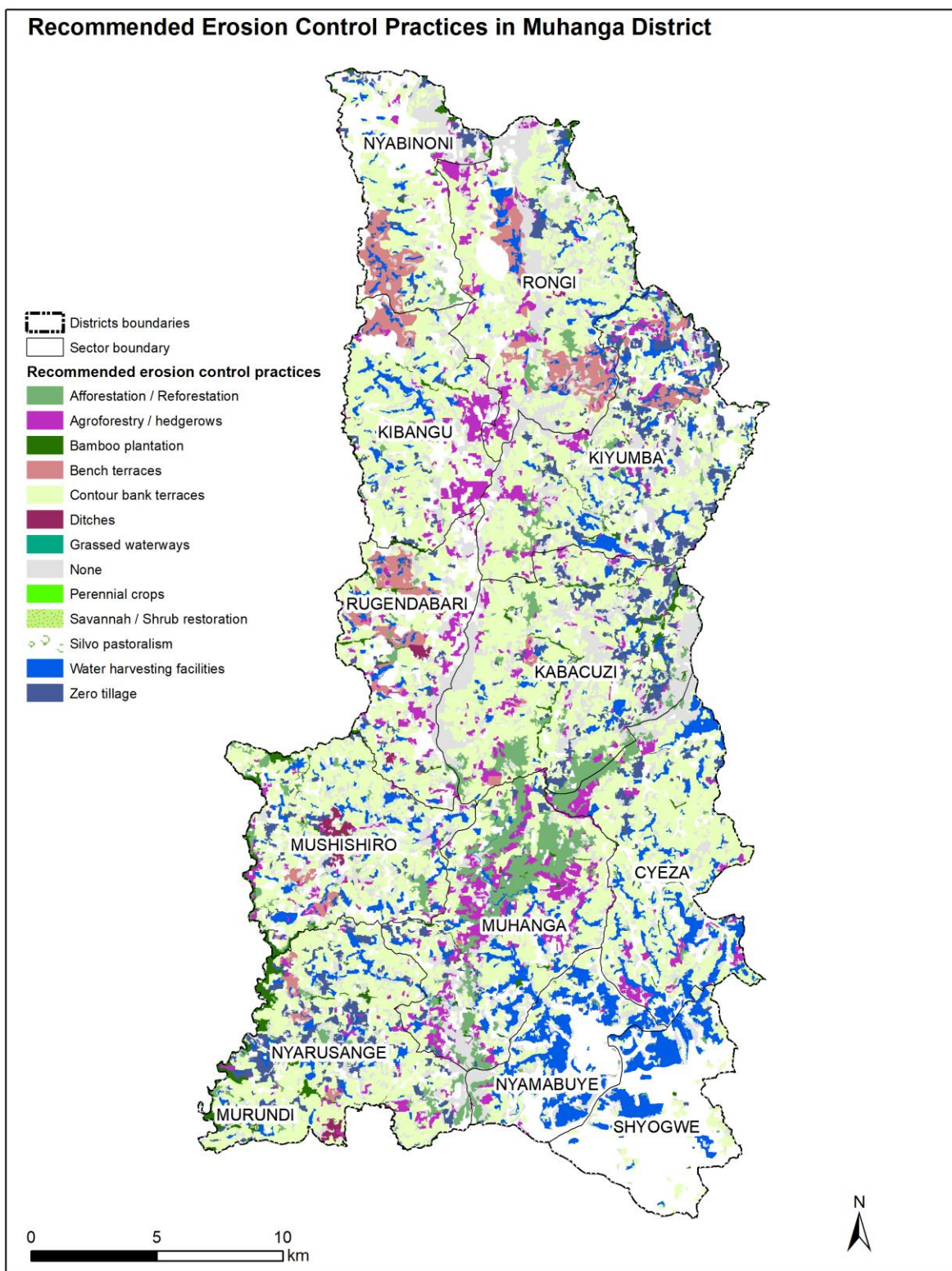
**Figure 87: Erosion control techniques in place in Muhanga District**

Erosion control practices in Muhanga District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 88 shows that about 25822 hectares (which is 48% of the total land at risk) are suitable for Contour bank terraces, 2755 hectares are Afforestation & Reforestation and 3431 hectares of cropland that need agroforestry/hedgerows/alley cropping. Other interventions are 5050 hectares for Storm water management facilities (SWMF), gullies or riverbanks amounting to 1034 hectares eroded which require bamboo trees for rehabilitation, 1989 hectares of bench terraces and 260 hectares of ditches.

**Table 90: Recommended erosion control practices in Muhanga District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	None	Water harvesting facilities	Zero tillage	Grand Total
CYEZA	200	306	17	2	2836		708	844	159	5072
KABACUZI	521	301	148	56	3668	2	1645	199	631	7170
KIBANGU	23	386	51	174	2285		548	265	115	3848
KIYUMBA	179	359	71	196	3090		1141	431	905	6373
MUHANGA	1075	884	56	4	2040	4	862	484	202	5612
MUSHISHIRO	213	181	162	88	2506	140	723	414	189	4617
NYABINONI	50	96	51	367	1176		495	159	130	2523
NYAMABUYE	80	29	0		484		376	814	13	1796
NYARUSANGE	188	165	337	90	3054	44	849	343	669	5739
RONGI	158	424	75	574	2822	14	1570	328	195	6160
RUGENDABARI	55	300	62	438	1548	56	629	165	94	3347
SHYOGWE	14		3		313		151	603	11	1095
<b>Grand Total</b>	<b>2755</b>	<b>3431</b>	<b>1034</b>	<b>1989</b>	<b>25822</b>	<b>260</b>	<b>9696</b>	<b>5050</b>	<b>3316</b>	<b>53352</b>
<b>%</b>	<b>5%</b>	<b>6%</b>	<b>2%</b>	<b>4%</b>	<b>48%</b>	<b>0%</b>	<b>18%</b>	<b>9%</b>	<b>6%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 88: Recommended erosion control practices in Muhanga District**

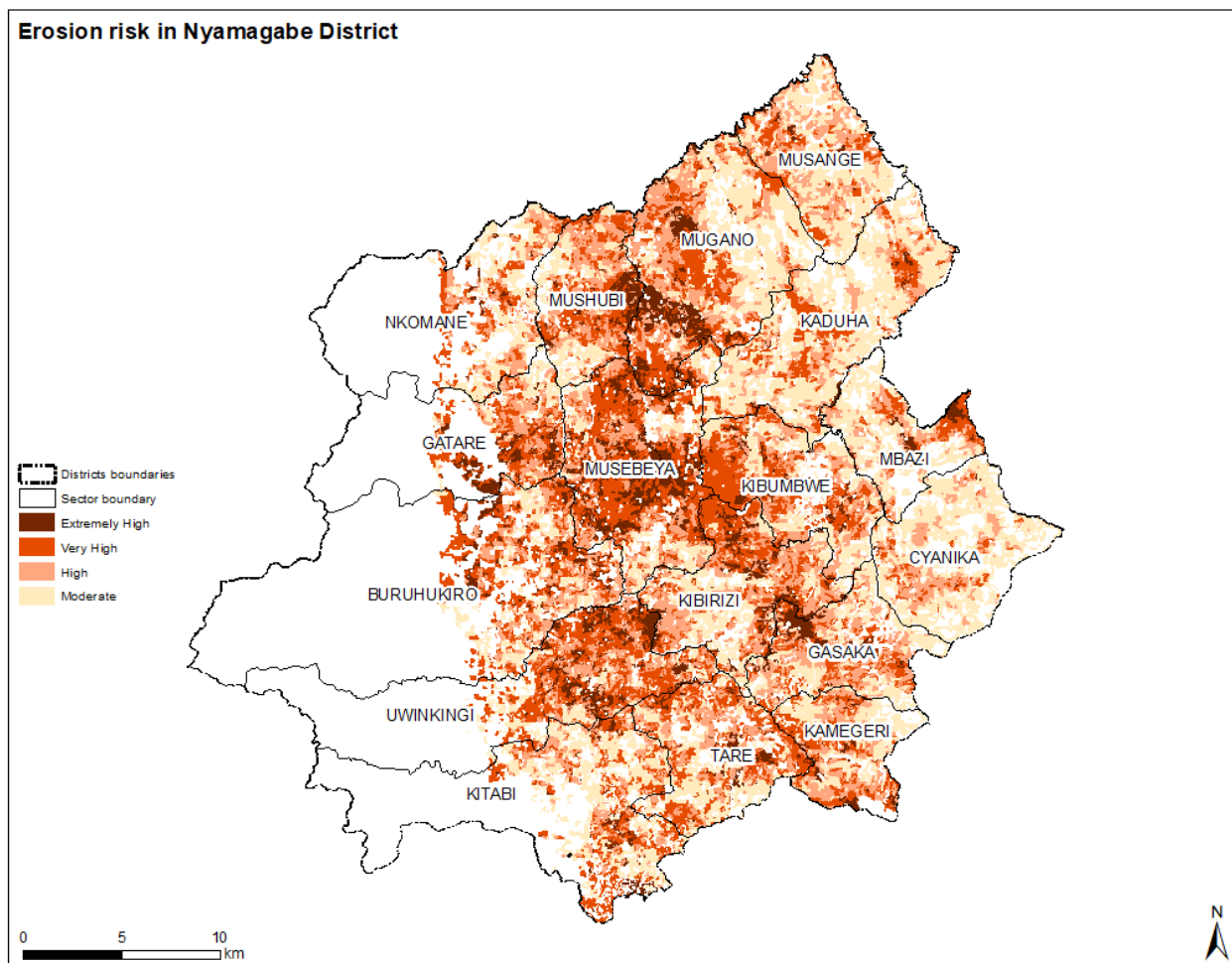
### 3.3.5. Erosion control status Nyamagabe District

Erosion risk in Nyamagabe District is summarised in Table 89 and presented in figure 84. Erosion risk in Nyamagabe District is estimated to 66578 hectares; about 61% of the total district land are highly susceptible to erosion of which 3189 hectares are located in Mushubi sector (88% of sector land), 4465 hectares are located in Kibirizi sector (87% of sector land), 5848 hectares are located in Musebeya (86% of the sector land), and 6843 hectares are found in Mugano sector about 85% of the sector land. The least affected sectors are Buruhukiro with 4133 hectares (26% of the sector land) susceptible to erosion, Nkomane with 2519 hectares (32%), and Gatara with 2280 hectares, about 36% of the total sector land. As compared to other districts in Southern Province, Nyamagabe is the third district susceptible to erosion.

**Table 91: Erosion risk per sector in Nyamagabe District**

District	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MUSHUBI	394	923	1,092	780	3,189	3,630	88%
KIBIRIZI	459	1,189	1,679	1,138	4,465	5,138	87%
MUSEBEYA	1,299	2,222	1,529	798	5,848	6,826	86%
MUGANO	955	1,617	1,987	2,285	6,843	8,020	85%
KIBUMBWE	214	1,393	1,268	1,060	3,935	4,623	85%
MUSANGE	104	535	1,369	1,851	3,859	4,578	84%
KAMEGERI	123	786	915	875	2,699	3,247	83%
GASAKA	308	623	1,286	1,127	3,344	4,046	83%
TARE	187	1,157	1,129	1,178	3,651	4,470	82%
KADUHA	75	961	1,151	3,473	5,660	7,092	80%
MBAZI	169	359	621	1,213	2,362	3,335	71%
CYANIKA	14	209	902	2,571	3,696	5,390	69%
UWINKINGI	648	1,808	1,085	604	4,145	8,974	46%
KITABI	187	1,074	919	1,769	3,950	9,654	41%
GATARE	398	798	686	397	2,280	6,409	36%
NKOMANE	80	592	763	1,084	2,519	7,880	32%
BURUHUKIRO	387	1,488	1,282	976	4,133	15,723	26%
<b>Grand Total</b>	<b>59,99</b>	<b>1,7734</b>	<b>19,665</b>	<b>23,180</b>	<b>66,578</b>	<b>109,036</b>	<b>61%</b>





**Figure 89: Erosion risk in Nyamagabe District**

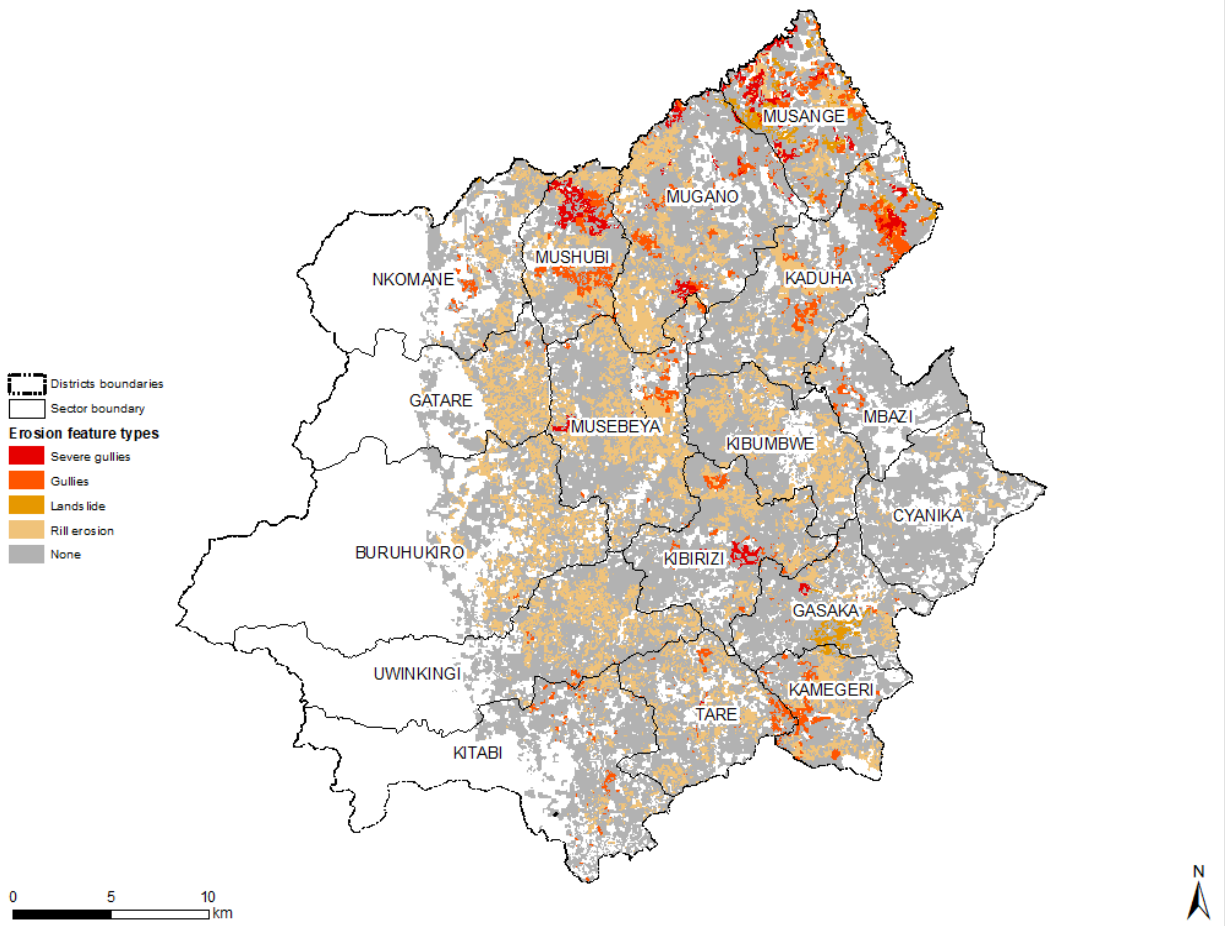
Land areas affected by erosive features in Nyamagabe District are summarized in Table 90 and the map of erosive features are presented in Figure 90. The results show that Mushubi sector is the worst affected by gullies, landslide and rill erosion on areas estimated to 1478 hectares (46% of sector land at risk), followed by Musange sector on 1683 hectares (44% of sector land at risk), and Gatare sector on 945 hectares (41% of sector land at risk). The presence of gullies and rill erosion in most of Nyamagabe Districts such as in Musange, Kaduha, Mushubi, and Kamegeri sectors, among others, confirms the findings of CROM model; however the reduced presence of gullies and rill erosion in Mbazi (139 ha) which was originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 14 and 15. The least sectors affected by gullies and rill erosion are Mbazi with only 139 hectares and Cyanika with only 259 hectares affected by gullies and rill erosion.

**Table 92: Erosive features and areas affected in Nyamagabe District**



Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
MUSHUBI	371		788	319	1478	1711	3189	46%
MUSANGE	439	352	580	313	1683	2176	3859	44%
GATARE	10		935		945	1335	2280	41%
MUSEBEYA	159		2181	42	2383	3465	5848	41%
BURUHUKIRO	4		1664		1669	2464	4133	40%
KAMEGERI	232	27	735		995	1704	2699	37%
KIBUMBWE	5		1436		1441	2494	3935	37%
UWINKINGI	31		1399		1429	2715	4145	34%
MUGANO	360	17	1808	138	2322	4521	6843	34%
NKOMANE	66	5	672	3	745	1774	2519	30%
TARE	134	2	881	6	1022	2629	3651	28%
KADUHA	497	87	752	118	1454	4205	5660	26%
KIBIRIZI	135	2	851	88	1076	3389	4465	24%
GASAKA	27	198	340	22	587	2757	3344	18%
KITABI	114		363		477	3473	3950	12%
CYANIKA			259		259	3438	3696	7%
MBAZI	67		72		139	2223	2362	6%
<b>Grand Total</b>	<b>2651</b>	<b>690</b>	<b>15717</b>	<b>1048</b>	<b>20105</b>	<b>46473</b>	<b>66578</b>	<b>30%</b>

### Erosion feature types in Nyamagabe District

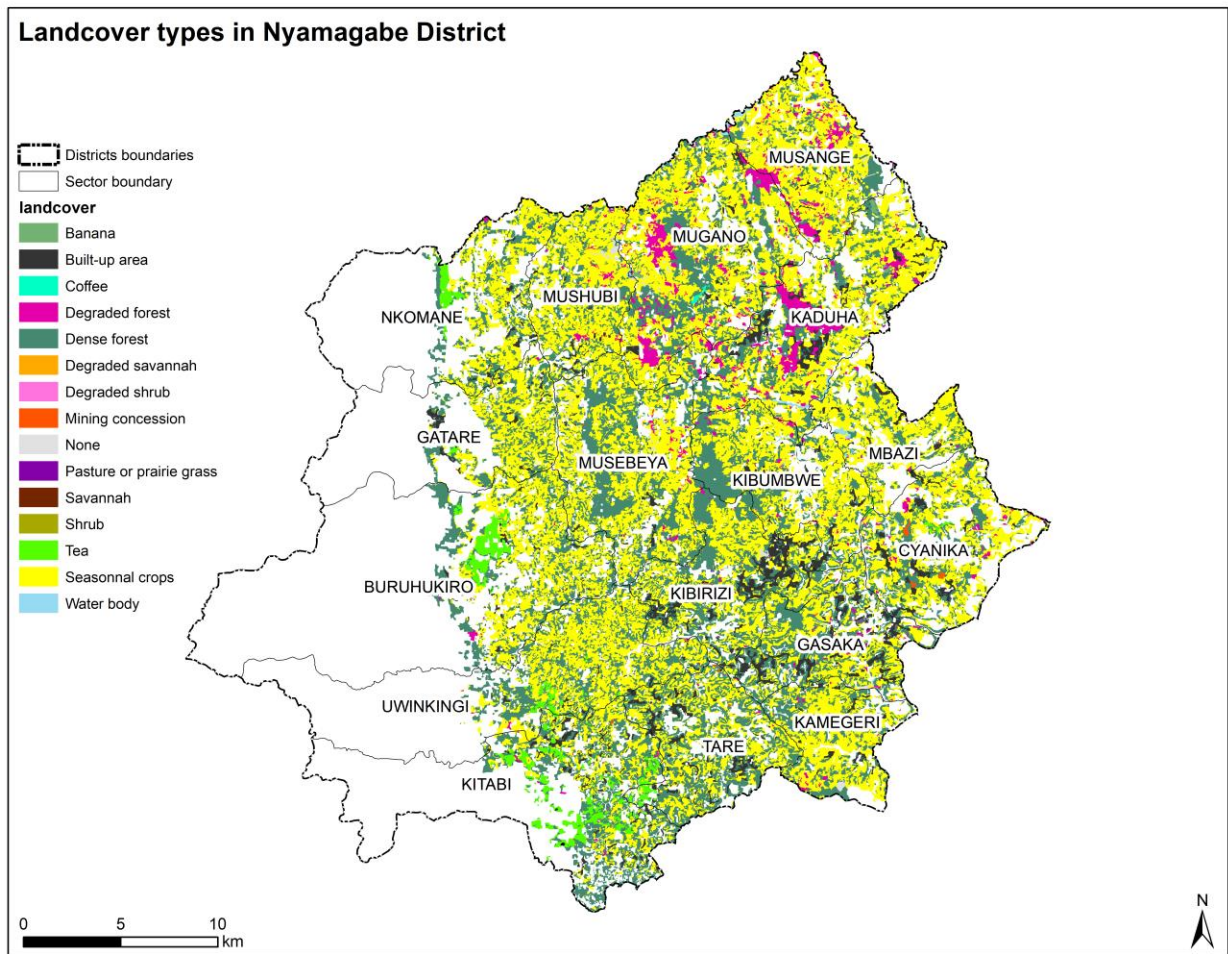


In term of land use and land cover of areas at risk in Nyamagabe, the results of land cover mapping (Table 91 and Figure 91) show that 36422 hectares (55% of the total land at risk) are used for seasonal cropping, 22714 hectares (34% of the total land at risk) are covered by healthy forests and 3352 hectares (5% of the total land at risk) are covered by built-up areas.

**Table 93: Land Use and Vegetation Cover (LUVC) for land at risk in Nyamagabe District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Dense forest	Mining and Quarries	None	Pasture or prairie grass	Seasonal crops	Tea	Water body	Grand Total
BURUHUKIRO		80		17	1491		1		2200	344		4133
CYANIKA		272		86	1118	29			2138	33	21	3696
GASAKA	4	450		44	1505		14		1321		6	3344
GATARE		162		3	828				1274	14		2280
KADUHA	86	416		665	1362		2		3073		55	5660
KAMEGERI		90		28	929		17		1636		1	2699
KIBIRIZI		596		12	1834	4	15		2001		3	4465
KIBUMBWE		185		40	1372		3		2319	4	11	3935
KITABI		259		19	1838	3			1194	638		3950
MBAZI	1	78		16	539				1677	2	49	2362
MUGANO	27	123	21	634	2042	4	22		3937		32	6843
MUSANGE	12	48		342	673	2	10	6	2726		40	3859
MUSEBEYA		73		88	2241		45		3389		11	5848
MUSHUBI	3	67		72	749		48		2240		11	3189
NKOMANE		66		7	870				1416	158	3	2519
TARE		325		5	1775	3			1469	58	16	3651
UWINKINGI		61		9	1549	1	7		2412	106		4145
<b>Grand Total</b>	<b>133</b>	<b>3352</b>	<b>21</b>	<b>2086</b>	<b>22714</b>	<b>46</b>	<b>183</b>	<b>6</b>	<b>36422</b>	<b>1356</b>	<b>258</b>	<b>66578</b>
<b>%</b>	<b>0%</b>	<b>5%</b>	<b>0%</b>	<b>3%</b>	<b>34%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>55%</b>	<b>2%</b>	<b>0%</b>	<b>100%</b>

**Figure 90: Erosive features detected in Nyamagabe District**

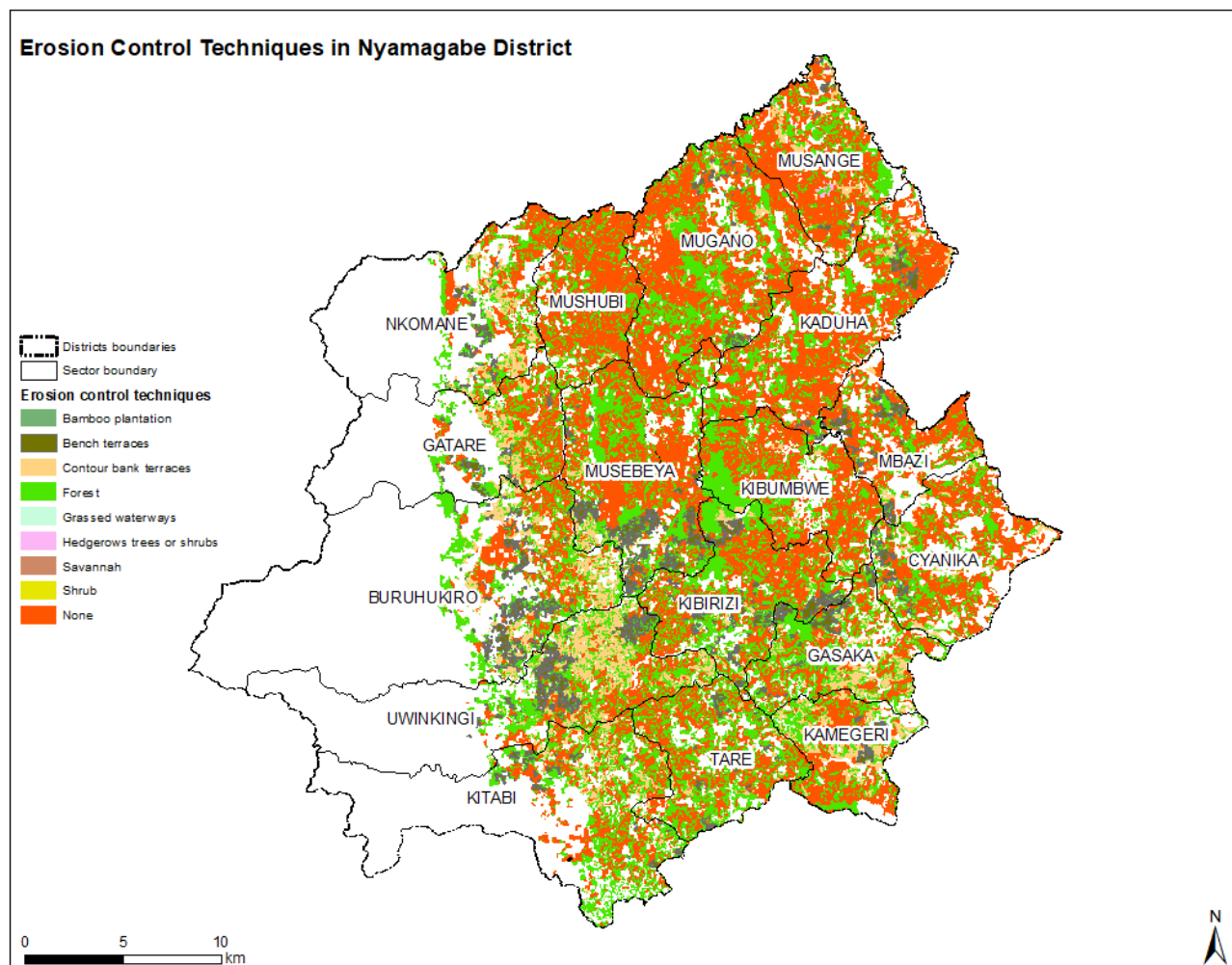


**Figure 91: Land cover types in Nyamagabe District**

About existing erosion control practices in Nyamagabe district, Table 92 indicates that only 48% of land at risk is protected by forests (22841 hectares) and Contour bank terraces (5578 hectares) and bench terraces (3304 hectares). The highest protected sectors are Uwinkingi with 75% of its land at risk protected, followed by Buruhukiro where 67% of the total land at risk is protected and Gasaka with 65% of land protected. The least protected sectors are Mushubi with only 26% protected, Kaduha (only 29% protected), Mugano (34%) and Musange (35% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Mushubi, Kaduha and Mugano sectors remain at very high risk of soil erosion since more than 65% of their respective land are not protected.

**Table 94: Erosion control practices already in place in Nyamagabe District**

Sector Name	Erosion control in place					Total protect ed (ha)	Unpro tected (ha)	Grand Total	% prote cted
	Bench terraces	Contour bank terraces	Forest	Grass ed water ways	Hedgero ws trees or shrubs				
UWINKINGI	484	1096	1549			3129	1016	4145	75%
BURUHUKIRO	463	812	1491			2765	1368	4133	67%
GASAKA	182	455	1521	6		2163	1181	3344	65%
KITABI	132	414	1841			2386	1564	3950	60%
KAMEGERI	130	537	929			1596	1103	2699	59%
NKOMANE	125	467	871			1463	1056	2519	58%
GATARE	114	308	829			1251	1029	2280	55%
TARE	86	158	1746			1990	1661	3651	55%
KIBIRIZI	383	145	1832			2361	2104	4465	53%
MUSEBEYA	595	193	1966			2754	3094	5848	47%
CYANIKA	125	221	1117			1462	2234	3696	40%
KIBUMBWE	0	95	1372			1467	2468	3935	37%
MBAZI	214	103	537			855	1507	2362	36%
MUSANGE	53	261	1011		33	1359	2500	3859	35%
MUGANO	103	124	2067	2		2297	4547	6843	34%
KADUHA	110	152	1377		3	1642	4018	5660	29%
MUSHUBI	6	37	783			826	2363	3189	26%
<b>Grand Total</b>	<b>3304</b>	<b>5578</b>	<b>22841</b>	<b>7</b>	<b>36</b>	<b>31767</b>	<b>34811</b>	<b>66578</b>	<b>48%</b>



**Figure 92: Erosion control techniques in place in Nyamagabe District**

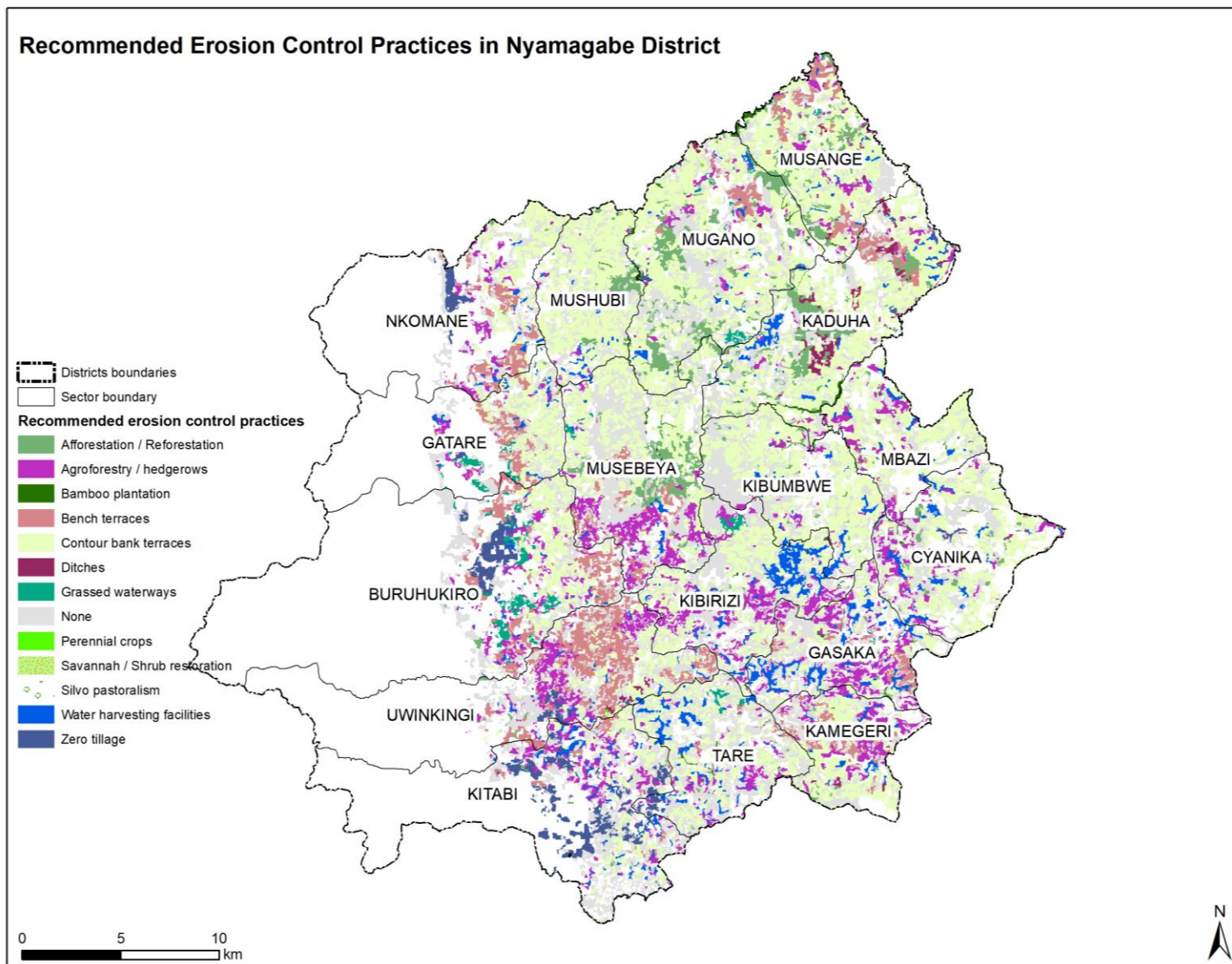
Erosion control practices in Nyamagabe District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 93 shows that about 24916 hectares (which is 37% of the total land at risk) are suitable for Contour bank terraces, 3064 hectares are Afforestation & Reforestation and 4349 hectares of Bench terraces. Other interventions are 5892 hectares for Agroforestry/Hedgerows, and 2585 hectares of Storm water management facilities (SWMF).



**Table 95: Recommended erosion control practices in Nyamagabe District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bambooplantation	Bench terraces	Contour bank terraces	Ditches	Grassed water ways	None	Perennial crops	Water harvesting facilities	Zero tillage	Grand Total
BURUHUROI	19	358		683	892		285	1491		61	344	4133
CYANIKA	118	403	21	7	1632			1285		197	33	3696
GASAKA	49	607	10	220	566		1	1517		373		3344
GATARE	6	147	3	328	777		104	828		73	14	2280
KADUHA	704	144	57	221	2651	287	4	1362		191	38	5660
KAMEGERI	27	448	2	249	940	18		935		80		2699
KIBIRIZI	22	666	11	17	1430		58	1844		418		4465
KIBUMBWE	59	125	16	3	2178			1379		171	4	3935
KITABI	25	476		139	597			1854		223	638	3950
MBAZI	18	282	25	16	1349			590		78	3	2362
MUGANO	802	210	54	187	3325	19	51	2048	2	119	27	6843
MUSANGE	383	218	51	376	2069	36	10	651	3	54	9	3859
MUSEBEYA	588	686	11	328	1908		18	2234		73		5848
MUSHUBI	182	44	14	2	2077			801		67	3	3189
NKOMANE	8	258	3	366	777			883		66	158	2519
TARE	23	245	27	48	1146		41	1786		278	58	3651
UWINKINGI	29	576	2	1161	601	42		1560	4	62	106	4145
<b>Grand Total</b>	<b>3064</b>	<b>5892</b>	<b>307</b>	<b>4349</b>	<b>24916</b>	<b>402</b>	<b>572</b>	<b>23047</b>	<b>9</b>	<b>2585</b>	<b>1434</b>	<b>66578</b>
<b>%</b>	<b>5%</b>	<b>9%</b>	<b>0%</b>	<b>7%</b>	<b>37%</b>	<b>1%</b>	<b>1%</b>	<b>35%</b>	<b>0%</b>	<b>4%</b>	<b>2%</b>	<b>100%</b>

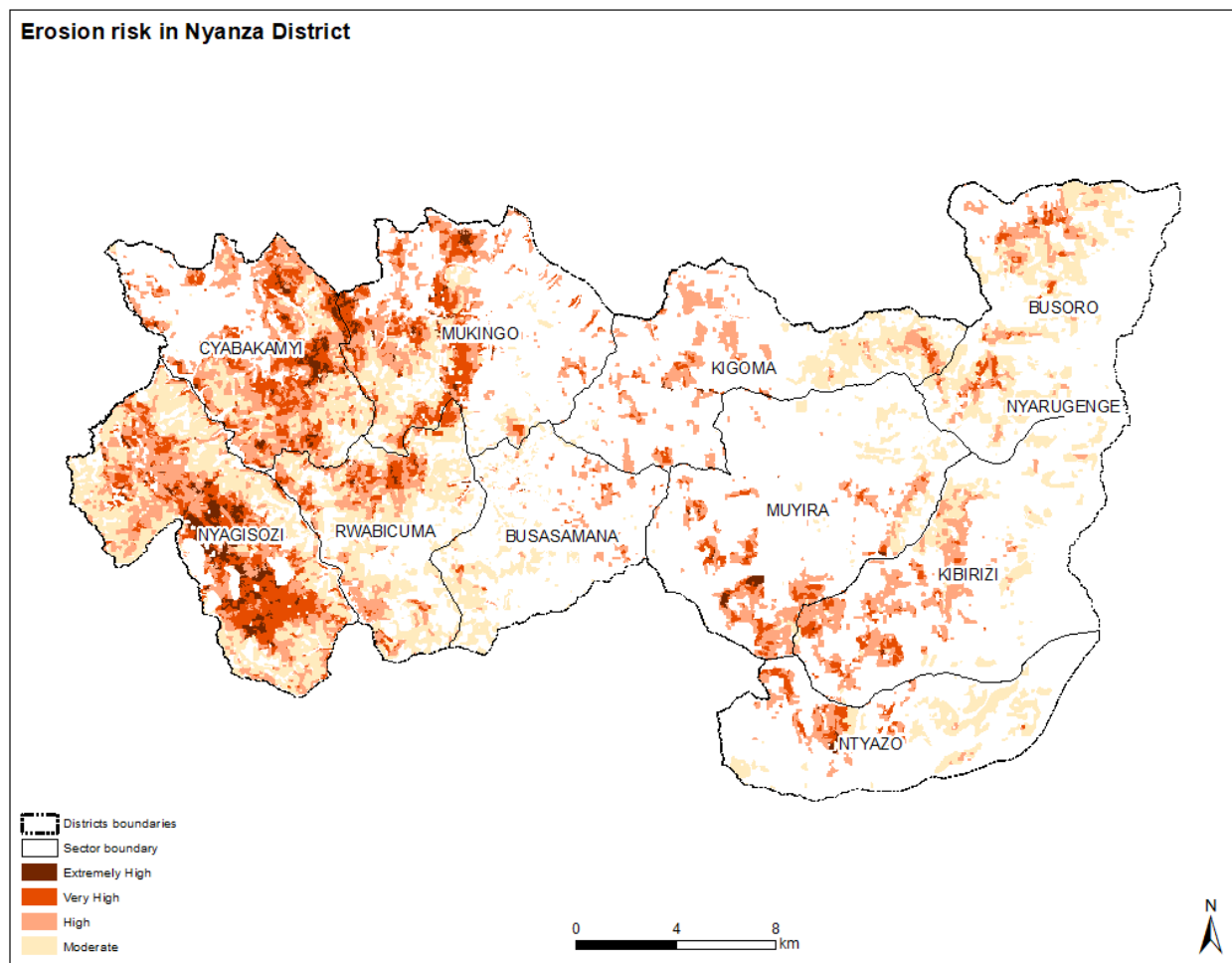
**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 93: Recommended erosion control practices in Nyamagabe District**

### 3.3.6. Erosion control status in Nyanza District

Erosion risk in Nyanza is summarised in Table 94 and presented in figure 94. Erosion risk in Nyanza District is estimated to 24999 hectares; about 37% of the total district land are highly susceptible to erosion of which 5824 hectares are located in Nyagisozi sector (80% of sector land), 3721 hectares are located in Cyabakamyi sector (62% of sector land), 2733 hectares are located in Rwabicuma (57% of the sector land), and 3002 hectares are found in Mukingo sector about 39% of the sector land. The least sectors are Busasamana with only 893 hectares (18% of the sector land) susceptible to erosion, Muyira with 1601 hectares (18%), and Ntyazo with 1214 hectares, about 22% of the total sector land.



**Figure 94: Erosion risk in Nyanza District**

**Table 96: Erosion risk per sector in Nyanza District**

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
NYAGISOZI	416	1253	1826	2328	5824	7253	80%
CYABAKAMYI	175	890	1760	895	3721	6042	62%

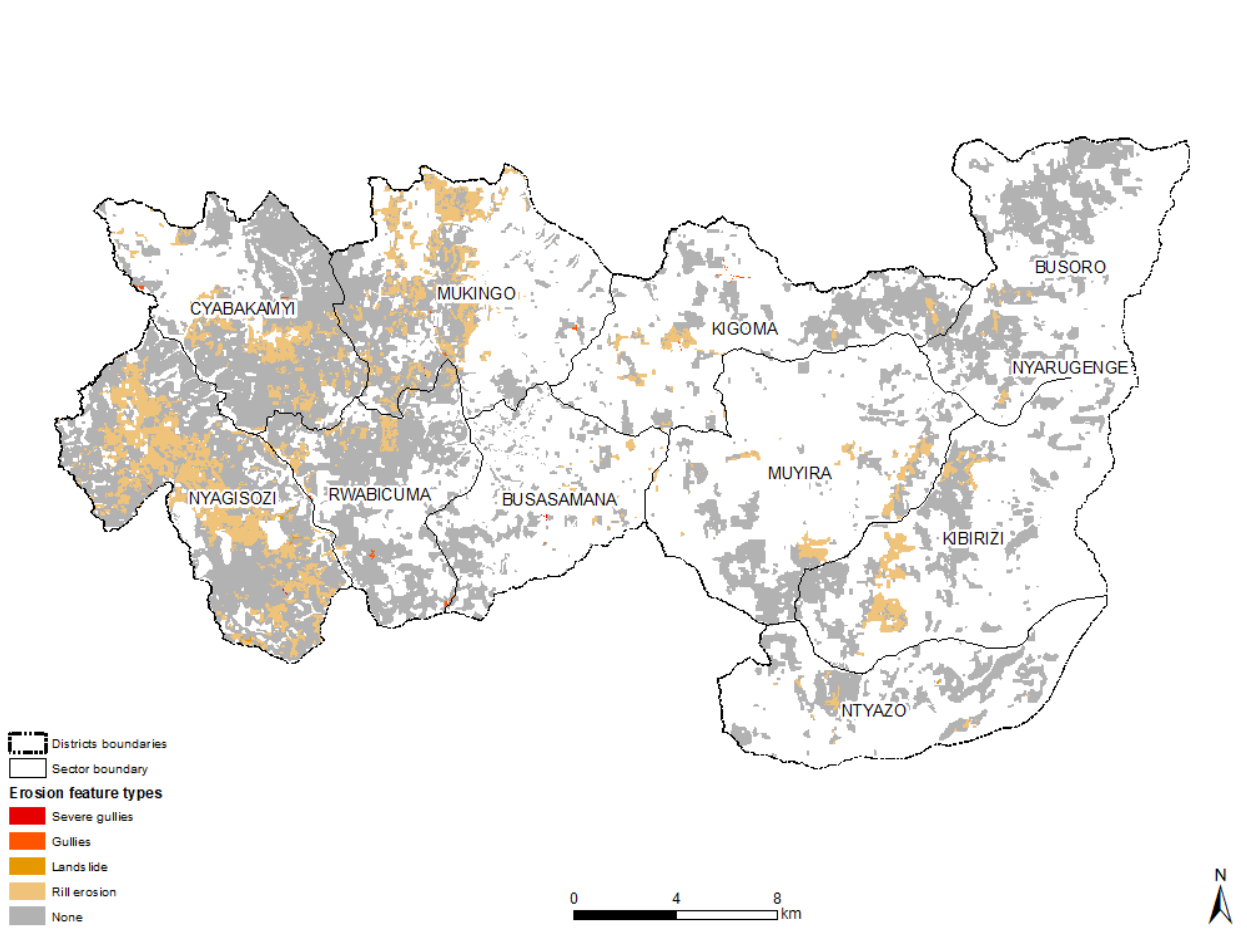
District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
RWABICUMA	23	340	808	1562	2733	4765	57%
MUKINGO	86	780	1314	821	3002	7614	39%
BUSORO	2	143	615	1543	2304	7361	31%
KIGOMA	12	99	859	746	1716	6597	26%
KIBIRIZI	2	196	1109	683	1990	8327	24%
NTYAZO	14	154	374	673	1214	5564	22%
MUYIRA	49	264	878	411	1601	8787	18%
BUSASAMANA	1	32	228	632	893	4903	18%
<b>Grand Total</b>	<b>780</b>	<b>4152</b>	<b>9771</b>	<b>10296</b>	<b>24999</b>	<b>67215</b>	<b>37%</b>

Land areas affected by erosive features in Nyanza District are summarized in Table 95 and the map of erosive features are presented in Figure 95. The results show that Mukingo sector is the worst affected by rill erosion on areas estimated to 1061 hectares (35% of sector land at risk), followed by Nyagisozi sector on 1,976 hectares (34% of sector land at risk), and Kibirizi sector on 355 hectares (18% of sector land at risk). The presence of rill erosion in Nyagisozi, Mukingo, Kibirizi, and Muyira sectors confirms the findings of CROM model; however the reduced presence of rill erosion in Busoro (48 ha), Ntyazo (48 ha) and Busasamana (49 ha) which was originally predicted by CROM model as sector at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 96 and 97. The least sectors affected by rill erosion are Busoro with only 48 hectares, Ntyazo with only 48 hectares, Busasamana with 49 hectares and Rwabicuma with 222 hectares affected by rill erosion.

**Table 97: Erosive features and areas affected in Nyanza District**

Sector Name	Erosive features				Total Feature s (Ha)	None (Ha)	Grand Total	% feature s
	Gullie s	Landslid e	Rill erosion	Severe gullies				
MUKINGO	4		1057	0	1061	1941	3002	35%
NYAGISOZI		12	1963	1	1976	3848	5824	34%
KIBIRIZI			355		355	1635	1990	18%
CYABAKAMY I	6		609		614	3107	3721	17%
MUYIRA			259		259	1343	1601	16%
KIGOMA	8		177		186	1531	1716	11%
RWABICUMA	8		218		226	2507	2733	8%
BUSASAMAN A			48	1	49	844	893	5%
NTYAZO		2	46		48	1166	1214	4%
BUSORO			48		48	2256	2304	2%
<b>Grand Total</b>	<b>26</b>	<b>14</b>	<b>4780</b>	<b>2</b>	<b>4821</b>	<b>20177</b>	<b>24999</b>	<b>19%</b>

**Erosion feature types in Nyanza District**



**Figure 95: Erosive features detected in Nyanza District**

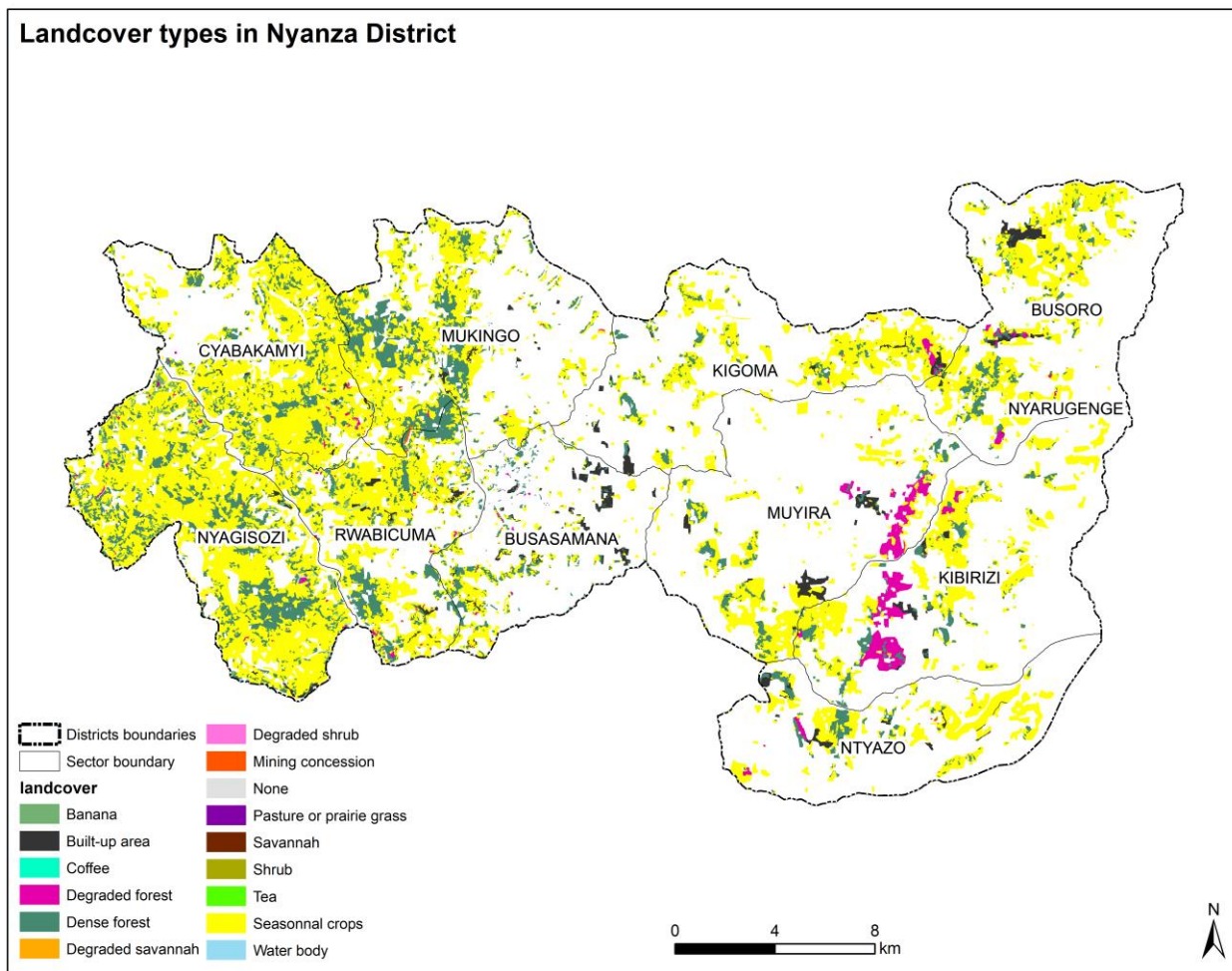
In term of land use and land cover of areas at risk in Nyanza, the results of land cover mapping (Table 96 and Figure 96) show that 18924 hectares (76% of the total land at risk) are used for seasonal cropping and 4381 hectares (18% of the total land at risk) are covered by healthy forests, 758 hectares (3% of the total land at risk) are covered by built-up areas.

**Table 98: Land Use and Vegetation Cover (LUVC) for land at risk in Nyanza District**

Sector Name	Banana	Built-up area	Degraded forest	Dense forest	Mining and Quarries	None	Seasonal crops	Water body	Grand Total
BUSASAMANA	1	162	10	215			505		893
BUSORO	11	117	31	259			1885		2304
CYABAKAMYI	29	15	14	552			3096	15	3721
KIBIRIZI	2	48	298	273			1368		1990



Sector Name	Banana	Built-up area	Degraded forest	Dense forest	Mining and Quarries	None	Seasonal crops	Water body	Grand Total
KIGOMA		83	27	207			1399		1716
MUKINGO	6	36	4	856			2098	2	3002
MUYIRA	3	135	187	222			1054		1601
NTYAZO		72	22	175	2		943		1214
NYAGISOZI	147	30	16	1047		10	4547	26	5824
RWABICUMA	44	60	12	574	5		2030	9	2733
<b>Grand Total</b>	<b>244</b>	<b>758</b>	<b>623</b>	<b>4381</b>	<b>7</b>	<b>10</b>	<b>18924</b>	<b>51</b>	<b>24999</b>
<b>%</b>	<b>1%</b>	<b>3%</b>	<b>2%</b>	<b>18%</b>	<b>0%</b>	<b>0%</b>	<b>76%</b>	<b>0%</b>	<b>100%</b>



**Figure 96: Land cover types in Nyanza District**

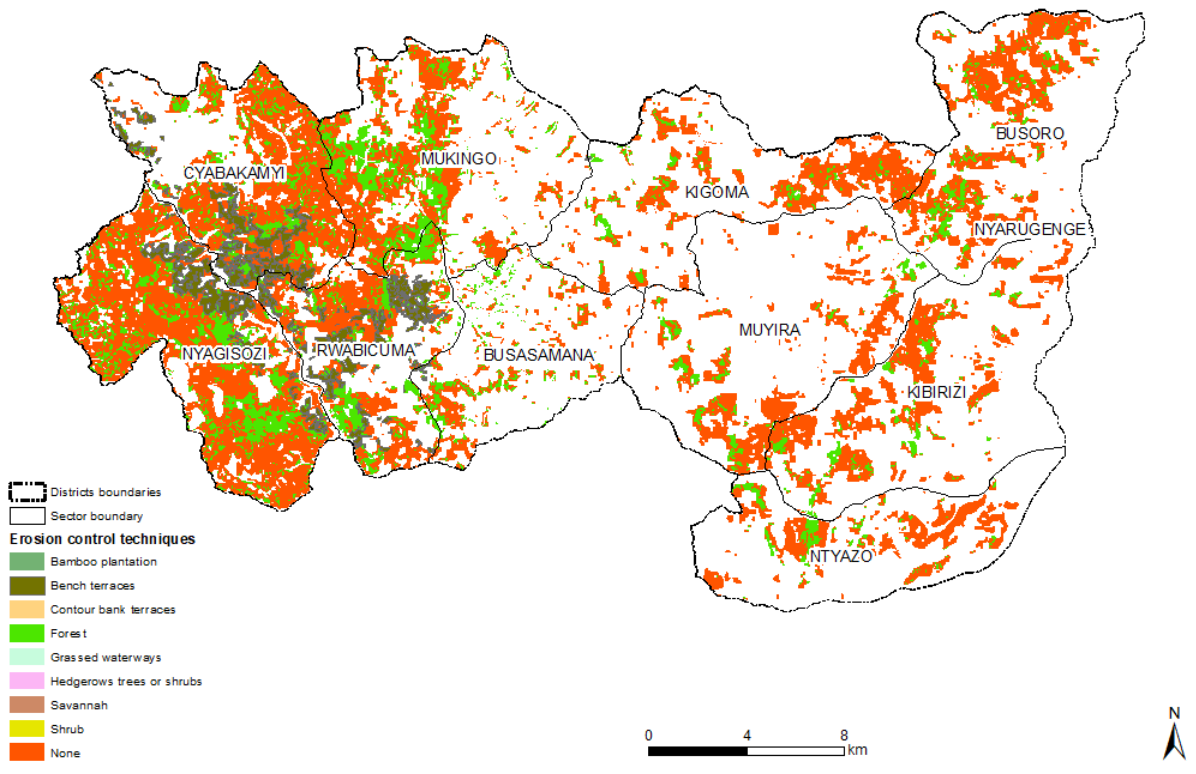


About existing erosion control practices in Nyanza district, Table 97 shows that only 26% of land at risk is protected by forests (4462 hectares) and bench terraces (1928 hectares). Although still low, the highest protected sectors are Rwabicuma with 49% of its land at risk protected, followed by Cyabakamyi where 32% of the total land at risk is protected and Mukingo (only 29% protected). The least protected sectors are Busoro, Kigoma, and Muyira with only 11%, 12% and 14% protected respectively in each sector. The visual interpretation of World View images confirms earlier findings by CROM model that Muyira, Kibirizi, Kigoma and Busoro sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected.

**Table 99: Erosion control practices already in place in Nyanza District**

Sector Name	Erosion control in place			Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest				
RWABICUMA	750	2	582	1334	1399	2733	49%
CYABAKAMYI	627		552	1180	2541	3721	32%
MUKINGO	0		856	856	2146	3002	29%
NYAGISOZI	538	3	1120	1661	4163	5824	29%
BUSASAMANA	13		215	228	666	893	25%
NTYAZO			175	175	1039	1214	14%
MUYIRA			222	222	1379	1601	14%
KIBIRIZI			273	273	1717	1990	14%
KIGOMA			207	207	1509	1716	12%
BUSORO			259	259	2044	2304	11%
<b>Grand Total</b>	<b>1928</b>	<b>5</b>	<b>4462</b>	<b>6395</b>	<b>18603</b>	<b>24999</b>	<b>26%</b>

### Erosion Control Techniques in Nyanza District



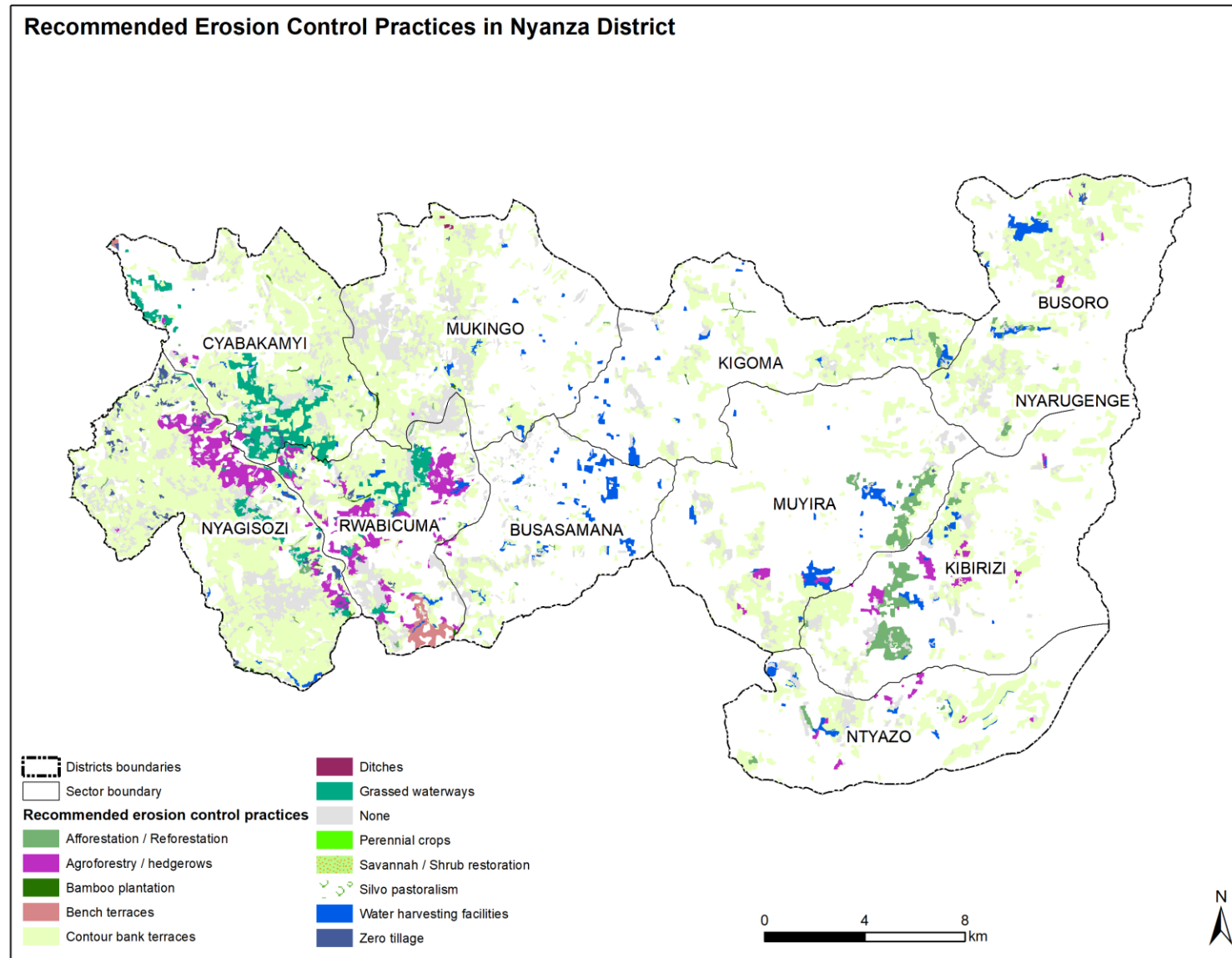
**Figure 97: Erosion control techniques in place in Nyanza District**

Erosion control practices in Nyanza District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 98 shows that about 16395 hectares (which is 66% of the total land at risk) are suitable for Contour bank terraces, 1290 hectares are cropland that needs agroforestry/hedgerows and 967 hectares of Grassed waterways. Other interventions are 640 hectares for Reforestation/Afforestation, riverbanks amounting to 959 hectares eroded which require bamboo trees for rehabilitation as well as water harvesting infrastructures on an area of 848 hectares.

**Table 100: Recommended erosion control practices in Nyanza District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Forest Ditches	Grassed waterways	Already protected	Water harvesting facilities	Zero tillage Perennial crops /	Grand Total
BUSASAMANA	10	13	1		476			215	177	1	893
BUSORO	31	16			1864			259	121	13	2304
CYABAKAMYI	14	35	20	6	2458		592	552	15	29	3721
KIBIRIZI	298	147			1201			273	68	2	1990
KIGOMA	27		8		1364			207	109		1716
MUKINGO	4	1	4		2072	7	0	856	52	6	3002
MUYIRA	187	43			1001			222	145	3	1601
NTYAZO	25	47			896			175	72		1214
NYAGISOZI	26	477	27		3929		138	1047	30	149	5824
RWABICUMA	17	510	12	132	1136		237	584	60	46	2733
<b>Grand Total</b>	<b>640</b>	<b>1290</b>	<b>72</b>	<b>138</b>	<b>16395</b>	<b>7</b>	<b>967</b>	<b>4391</b>	<b>848</b>	<b>250</b>	<b>24999</b>
<b>%</b>	<b>3%</b>	<b>5%</b>	<b>0%</b>	<b>1%</b>	<b>66%</b>	<b>0%</b>	<b>4%</b>	<b>18%</b>	<b>3%</b>	<b>1%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



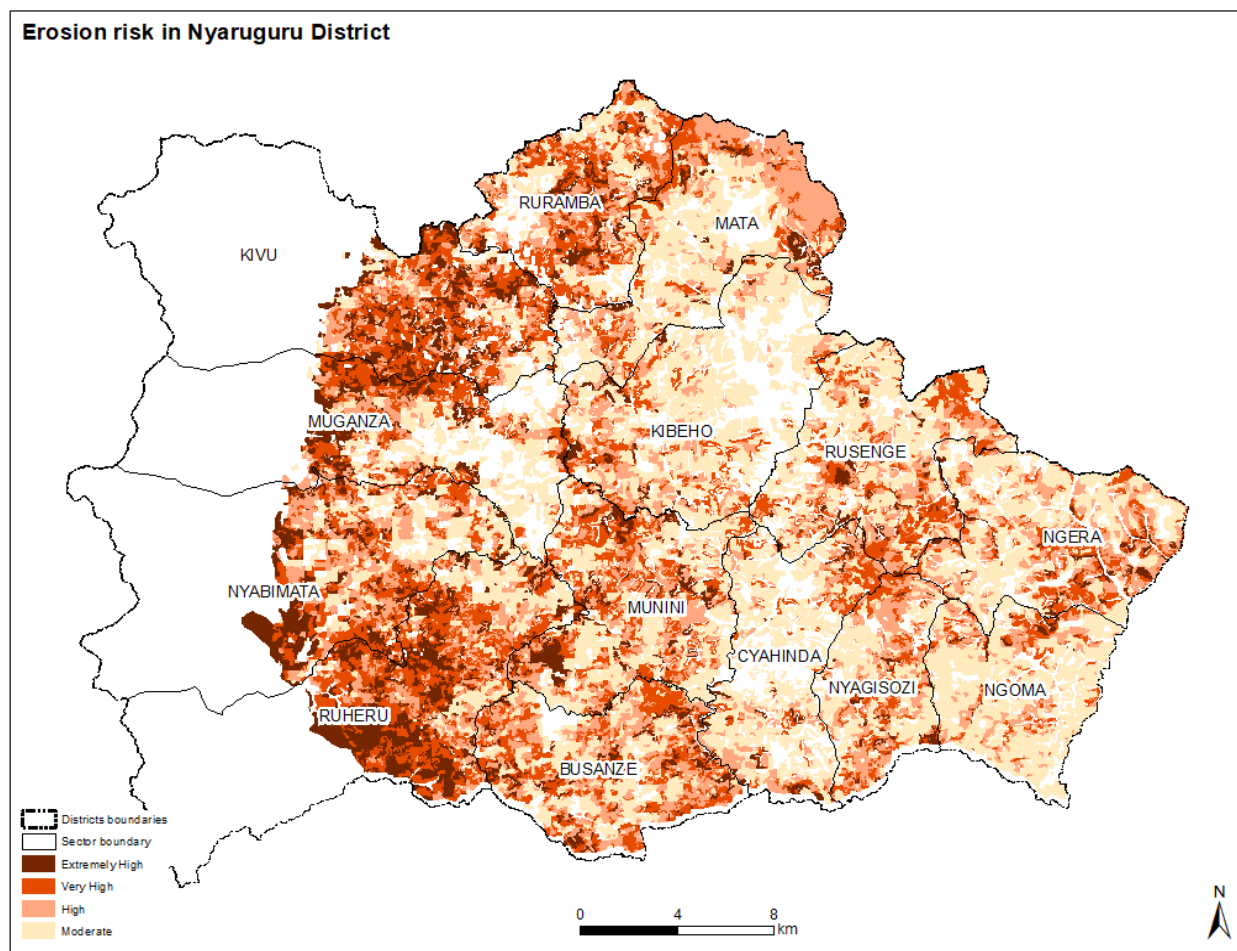
**Figure 98: Recommended erosion control practices in Nyanza District**

### 3.3.7. Erosion control status in Nyaruguru District

Erosion risk in Nyaruguru is summarised in Table 99 and presented in figure 99. Erosion risk in Nyaruguru District is estimated to 64380 hectares; about 64% of the total district land are highly susceptible to erosion of which 5412 hectares are located in Munini sector (88% of sector land), 4889 hectares are located in Busanze sector (87% of sector land), 5045 hectares are located in Rusenge (84% of the sector land), and 2933 hectares are found in Nyagisozi sector about 84% of the sector land. The least sectors are Kivu with only 417 hectares (34% of the sector land) susceptible to erosion, Nyabimata with 4916 hectares (41%), and Muganza with 3937 hectares, about 43% of the total sector land. As compared to other districts in Southern Province, Nyaruguru is the second susceptible to erosion.

**Table 101: Erosion risk per sector in Nyaruguru District**

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MUNINI	580	1241	1432	2159	5412	6130	88%
BUSANZE	425	1371	1605	1488	4889	5651	87%
NYAGISOZI	115	508	1087	1223	2933	3482	84%
RUSENGE	241	1125	1247	2433	5045	5993	84%
RURAMBA	527	1307	1146	1147	4128	4939	84%
MATA	298	709	1777	2276	5060	6202	82%
NGOMA	74	342	761	2652	3829	4695	82%
NGERA	222	750	1471	2383	4827	5928	81%
KIBEHO	199	613	1138	3665	5615	7827	72%
CYAHINDA	163	459	734	2322	3679	5301	69%
RUHERU	1677	2156	1155	954	5942	11392	52%
MUGANZA	691	938	819	1489	3937	9167	43%
NYABIMATA	963	1297	1411	1244	4916	11949	41%
KIVU	1045	1576	1006	543	4170	12372	34%
<b>Grand Total</b>	<b>7221</b>	<b>14392</b>	<b>16789</b>	<b>25979</b>	<b>64382</b>	<b>101027</b>	<b>64%</b>



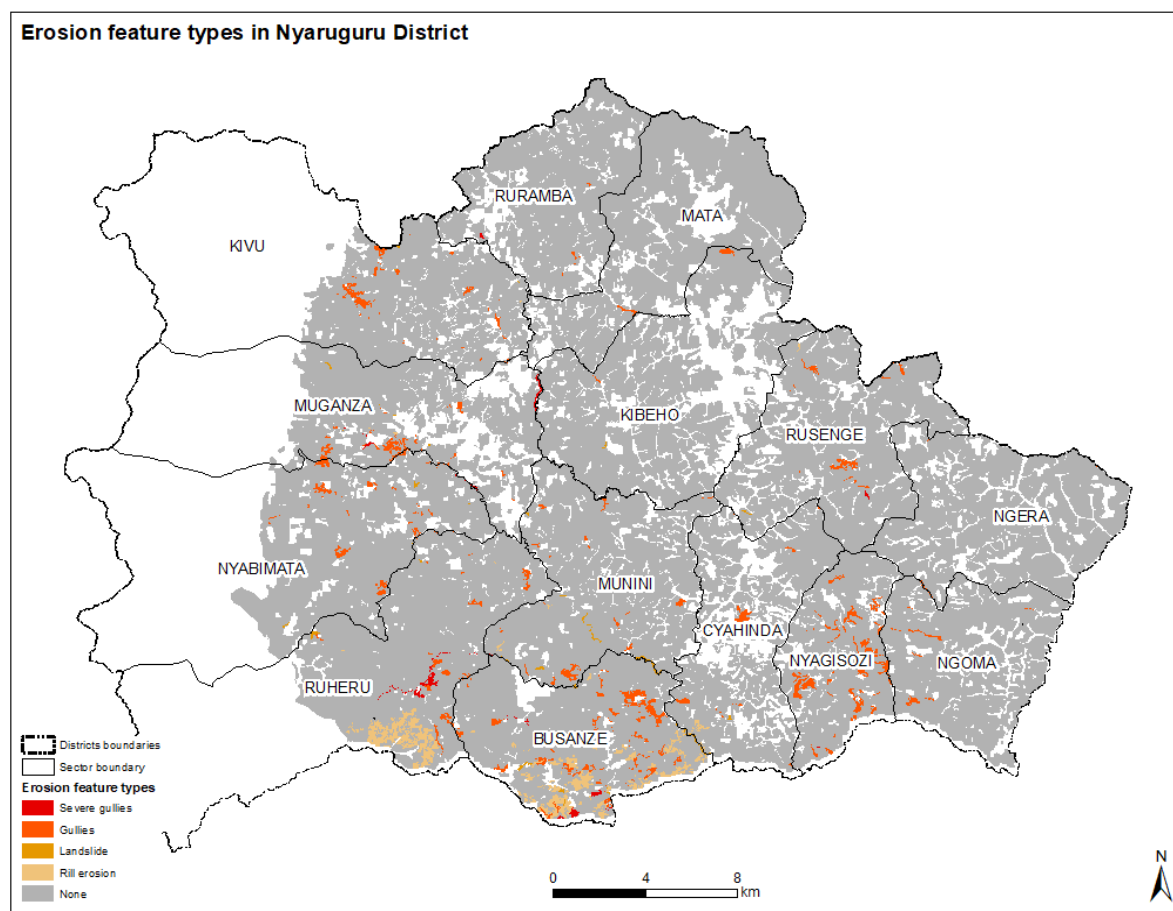
**Figure 99: Erosion risk in Nyaruguru District**

Land areas affected by erosive features in Nyaruguru District are summarized in Table 100 and the map of erosive features are presented in Figure 100. The results show that Busanze sector is the worst affected by rill erosion and gullies on areas estimated to 657 hectares (13% of sector land at risk), followed by Nyagisozi sector on 249 hectares (9% of sector land at risk), and Ruheru sector on 411 hectares (7% of sector land at risk). These affected sectors confirm the findings of CROM model; however the reduced presence of gullies and rill erosion in Ngera, Ruramba, Mata, Nyagisozi, Munini and Kibeho which was originally predicted by CROM model as sectors at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 101 and 102. The least affected sectors are Ngera, Ruramba, Mata, Kibeho, Nyagisozi and Rusenge which are affected by few gullies and rill erosion.

**Table 102: Erosive features and areas affected in Nyaruguru District**



Sector Name	Erosive features				Total Features (Ha)	None (Ha)	Grand Total	% features
	Gullies	Landslide	Rill erosion	Severe gullies				
BUSANZE	243	29	357	28	657	4,232	4,889	13%
NYAGISOZI	249				249	2,683	2,933	9%
RUHERU	77	7	283	44	411	5,531	5,942	7%
MUGANZA	87	3	1	23	114	3,822	3,937	3%
NYABIMATA	119	7		4	129	4,787	4,916	3%
KIVU	98	2			100	4,070	4,170	2%
MUNINI	71	30	6	2	109	5,302	5,412	2%
CYAHINDA	44	3	19		66	3,613	3,679	2%
RUSENGE	67	3	2	4	77	4,969	5,045	2%
NGOMA	40				40	3,789	3,829	1%
KIBEHO	16	2		2	21	5,595	5,615	0%
RURAMBA	8			3	11	4,116	4,128	0%
MATA	9				9	5,052	5,060	0%
NGERA	6				6	4,821	4,827	0%
<b>Grand Total</b>	<b>1135</b>	<b>88</b>	<b>669</b>	<b>109</b>	<b>2,001</b>	<b>62,381</b>	<b>64,382</b>	<b>3%</b>

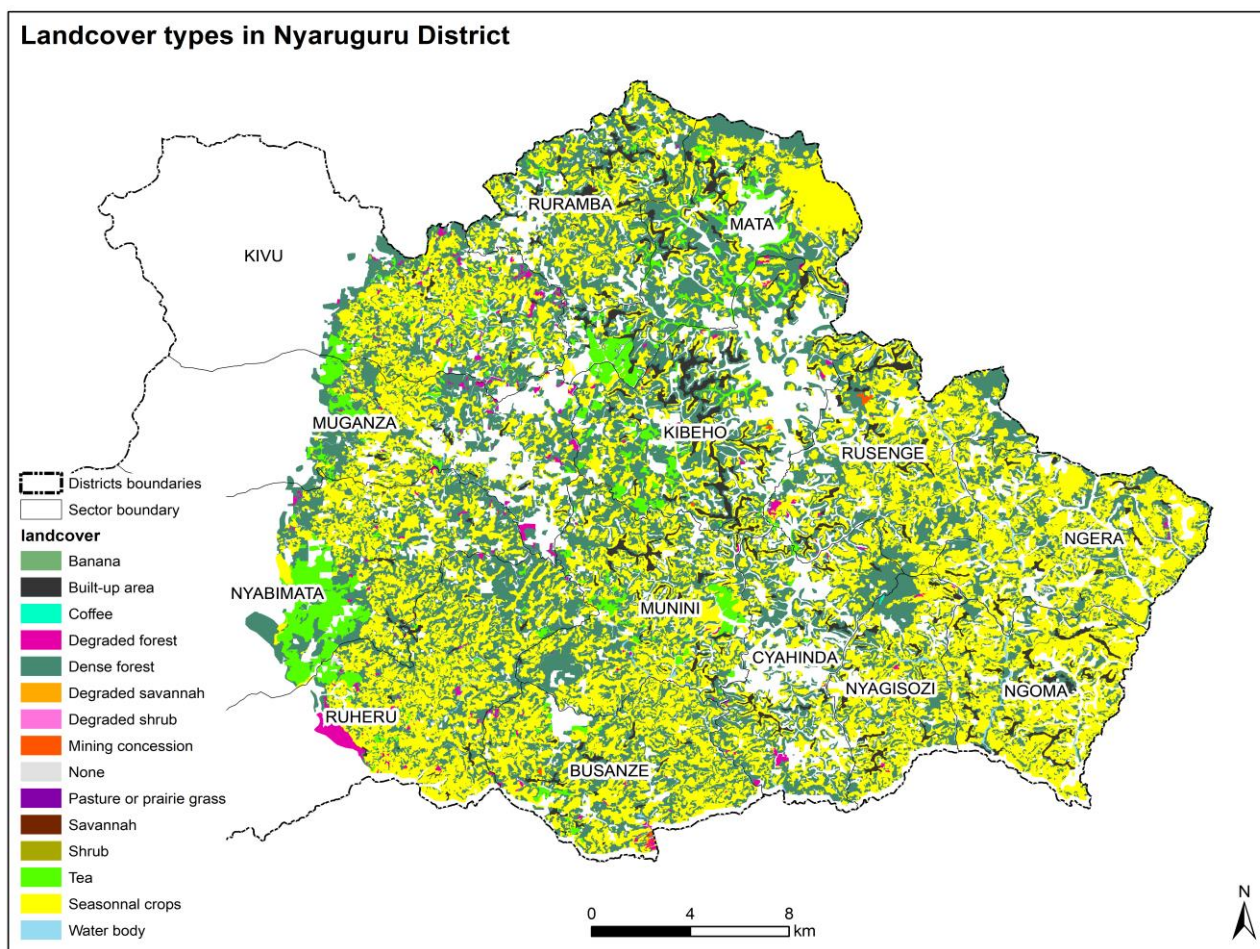


**Figure 100: Erosive features detected in Nyaruguru District**

In term of land use and land cover of areas at risk in Nyaruguru, the results of land cover mapping (Table 101 and Figure 102) show that 30933 hectares (48% of the total land at risk) are used for seasonal cropping, 26700 hectares (41% of the total land at risk) are covered by healthy forests, 2978 hectares (5% of the total land at risk) covered by tea plantations and 2729 hectares (4% of the total land at risk) are covered by built-up areas.

**Table 103: Land Use and Vegetation Cover (LUVC) for land at risk in Nyaruguru District**

Sector Name	Bana na	Buil t-up area	Coff ee	Degrad ed forest	Den se forest	Mining and Quarries	Non e	Season al crops	Tea	Wat er body	Gran d Total
BUSANZ E		110		35	1820	13	2	2780	97	31	4889
CYAHIND A		173		34	1849			1599	14	9	3679
KIBEHO		575		41	2864	8		1679	438	10	5615
KIVU		34		92	1884	1	4	2000	156		4170
MATA		313		8	2310	0		1827	600	2	5060
MUGANZ A	1	50		89	2005		10	1469	268	44	3937
MUNINI		248		11	2325		2	2502	253	71	5412
NGERA		99		8	1444	1	9	3226		39	4827
NGOMA	21	343			752			2657		56	3829
NYABIMA TA		31		33	2063		12	1849	915	12	4916
NYAGISO ZI	2	186	3	12	990			1713		27	2933
RUHERU		58		176	2220		12	3298	149	27	5942
RURAMB A		262		3	2117			1676	70		4128
RUSENG E		247		24	2054	14	2	2657	19	29	5045
<b>Grand Total</b>	<b>24</b>	<b>2729</b>	<b>3</b>	<b>567</b>	<b>26700</b>	<b>37</b>	<b>54</b>	<b>30933</b>	<b>2978</b>	<b>357</b>	<b>64382</b>
<b>%</b>	<b>0%</b>	<b>4%</b>	<b>0%</b>	<b>1%</b>	<b>41%</b>	<b>0%</b>	<b>0%</b>	<b>48%</b>	<b>5%</b>	<b>1%</b>	<b>100%</b>



**Figure 101: Land cover types in Nyaruguru District**

About existing erosion control practices in Nyaruguru district, Table 102 shows that only 44% of land at risk is protected by forests (26671 hectares), contour bank terraces (612 hectares) and bench terraces (1266 hectares). The highest protected sectors are Kibeho with 56% of its land at risk protected, followed by Muganza where 54% of the total land at risk is protected and Cyahinda with 54% of land protected. The least protected sectors are Ngoma with only 24% protected, Ngera (only 31% protected), Nyagisozi (35% protected) and Busanze (40%). The visual interpretation of World View images confirms earlier findings by CROM model that Busanze, and Ngera, sectors remain at very high risk of soil erosion since more than 60% of their respective land are not protected.

**Table 104: Erosion control practices already in place in Nyaruguru District**

Sector Name	Erosion control in place			Total protected	Unprotected	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
KIBEHO	198	74	2864	3137	2479	5615	56%

Sector Name	Erosion control in place			Total protected	Unprotected	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest				
MUGANZA	81	44	2005	2130	1806	3937	54%
CYAHINDA	27	106	1849	1982	1698	3679	54%
RURAMBA	62	25	2117	2205	1923	4128	53%
MUNINI	266	65	2326	2657	2754	5412	49%
MATA	58	25	2310	2392	2669	5060	47%
KIVU	15	15	1884	1913	2257	4170	46%
NYABIMATA	137	42	2063	2242	2674	4916	46%
RUSENGE	58	31	2024	2113	2933	5045	42%
RUHERU	98	118	2220	2436	3506	5942	41%
BUSANZE	69	63	1820	1952	2937	4889	40%
NYAGISOZI	21	2	990	1013	1920	2933	35%
NGERA	30		1444	1474	3353	4827	31%
NGOMA	147	4	752	904	2925	3829	24%
<b>Grand Total</b>	<b>1266</b>	<b>612</b>	<b>26671</b>	<b>28549</b>	<b>35833</b>	<b>64382</b>	<b>44%</b>

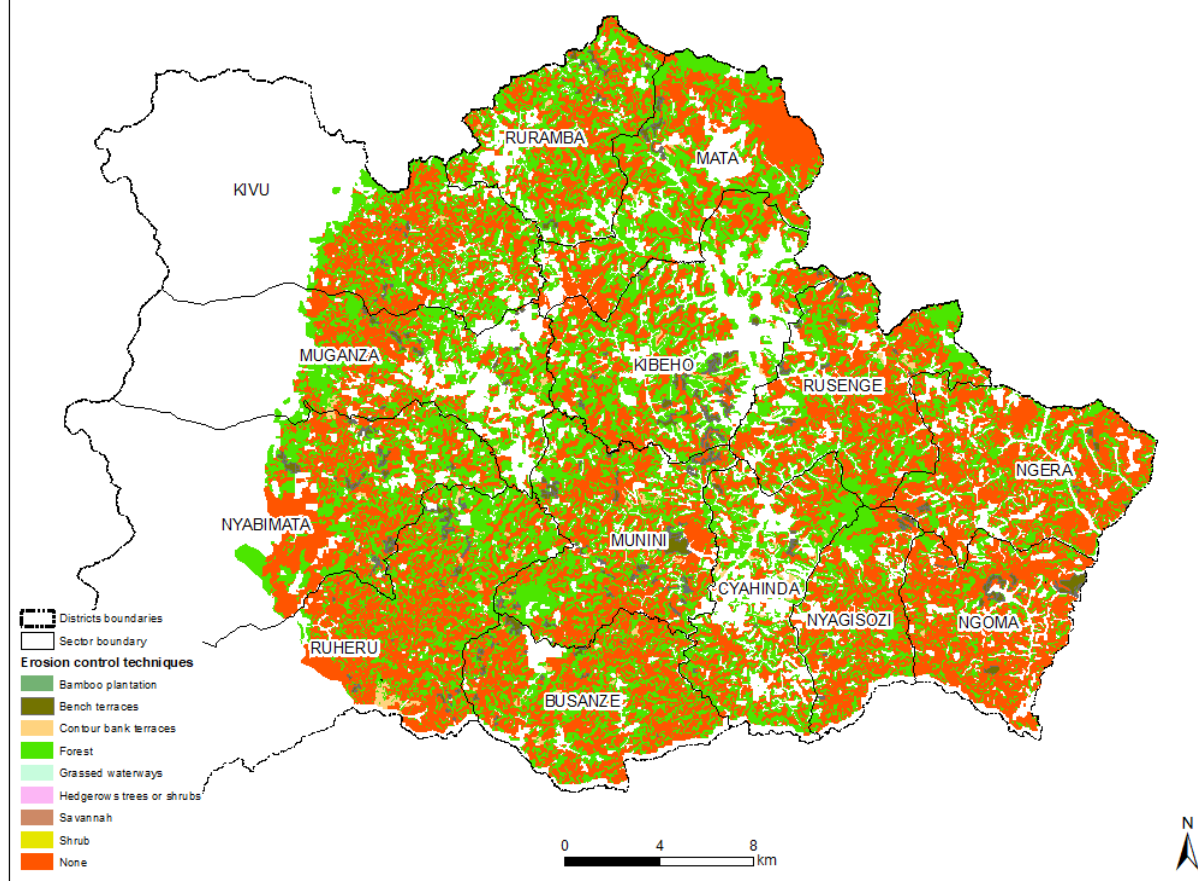
Erosion control practices in Nyaruguru District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 103 shows that about 25917 hectares (which is 40% of the total land at risk) are suitable for Contour bank terraces, 3807 hectares are cropland that need agroforestry/hedgerows and 760 hectares are Afforestation & Reforestation. Other interventions are, 509 hectares of bamboo plantations on gullies or riverbanks, 913 hectares of bench terraces and 2729 hectares of water harvesting infrastructures.

**Table 105: Recommended erosion control practices in Nyaruguru District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	Grassed waterways	None	Perennial crops	Water harvesting facilities	Zero tillage	Grand Total
BUSANZE	61	277	73	156	2296	263		1556		110	97	4889
CYAHINDA	37	193	11		1398			1850	3	173	14	3679
KIBEHO	52	328	12	85	1258			2864	3	575	438	5615
KIVU	102	264	6	36	1688		1	1884		34	156	4170
MATA	13	114	4	37	1669			2310		313	600	5060
MUGANZA	104	231	46	58	1172			2005	1	50	269	3937
MUNINI	38	474	73	112	1887			2326		248	253	5412
NGERA	18	88	60	9	3103			1448		99		4827
NGOMA	3	182	78	65	2354			784		343	21	3829
NYABIMATA	81	330	13	6	1476			2021		31	958	4916
NYAGISOZI	13	123	49	3	1565			990		186	5	2933
RUHERU	185	847	38	291	2150	96		2127		58	149	5942
RURAMBA	7	174		25	1479			2111		262	70	4128
RUSENGE	47	181	46	29	2423			2054		247	19	5045
<b>Grand Total</b>	<b>760</b>	<b>3807</b>	<b>509</b>	<b>913</b>	<b>25917</b>	<b>359</b>	<b>1</b>	<b>26331</b>	<b>7</b>	<b>2729</b>	<b>3047</b>	<b>64382</b>
<b>%</b>	<b>1%</b>	<b>6%</b>	<b>1%</b>	<b>1%</b>	<b>40%</b>	<b>1%</b>	<b>0%</b>	<b>41%</b>	<b>0%</b>	<b>4%</b>	<b>5%</b>	<b>100%</b>

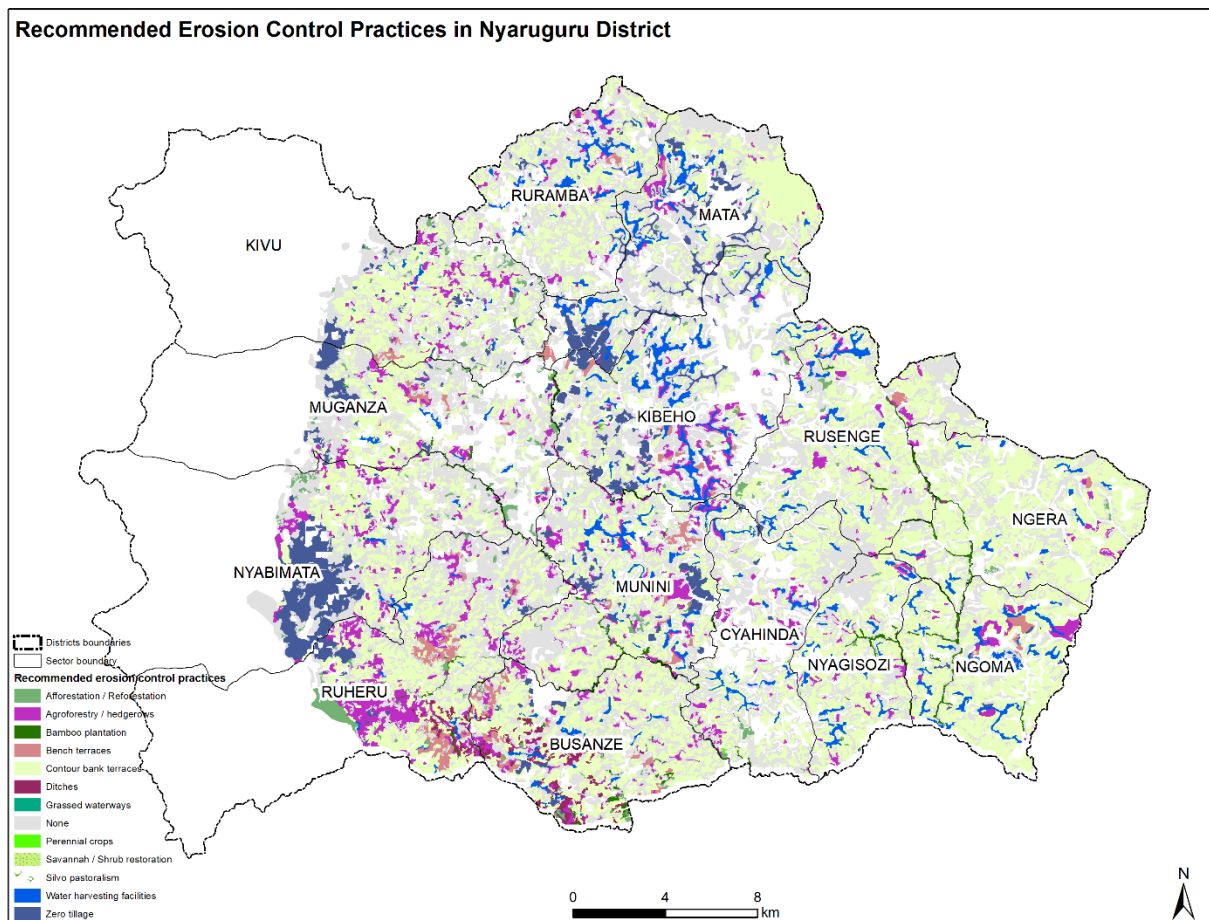
**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

### Erosion Control Techniques in Nyaruguru District



**Figure 102: Erosion control techniques in place in Nyaruguru District**





**Figure 103: Recommended erosion control practices in Nyaruguru District**

3.3.8. Erosion control status in Ruhango District

Erosion risk in Ruhango is summarised in Table 104 and presented in figure 104. Erosion risk in Ruhango District is estimated to 20618 hectares; about 33% of the total district land are highly susceptible to erosion of which 4636 hectares are located in Mwendo sector (83% of sector land), 4162 hectares are located in Kinihira sector (68% of sector land), 2249 hectares are located in Bweramana (41% of the sector land), and 2084 hectares are found in Kabagali sector about 34% of the sector land. The least sectors are Ntongwe with only 1315 hectares (15% of the sector land) susceptible to erosion, Mbuye with 1264 hectares (16%), and Ruhango with 1649 hectares, about 17% of the total sector land. As compared to other districts in Southern Province, Ruhango is the least susceptible to erosion.

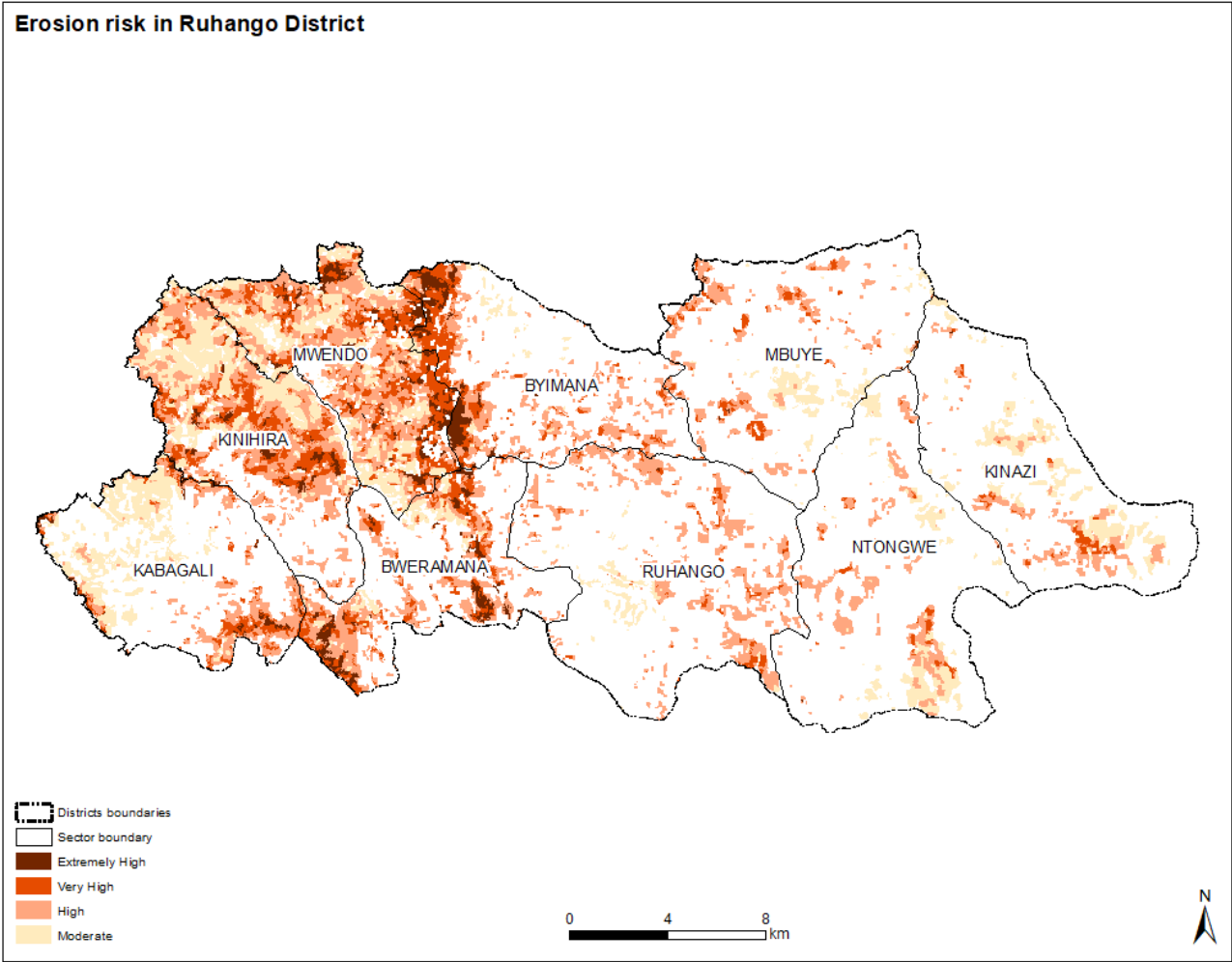


Figure 104: Erosion risk in Ruhango District

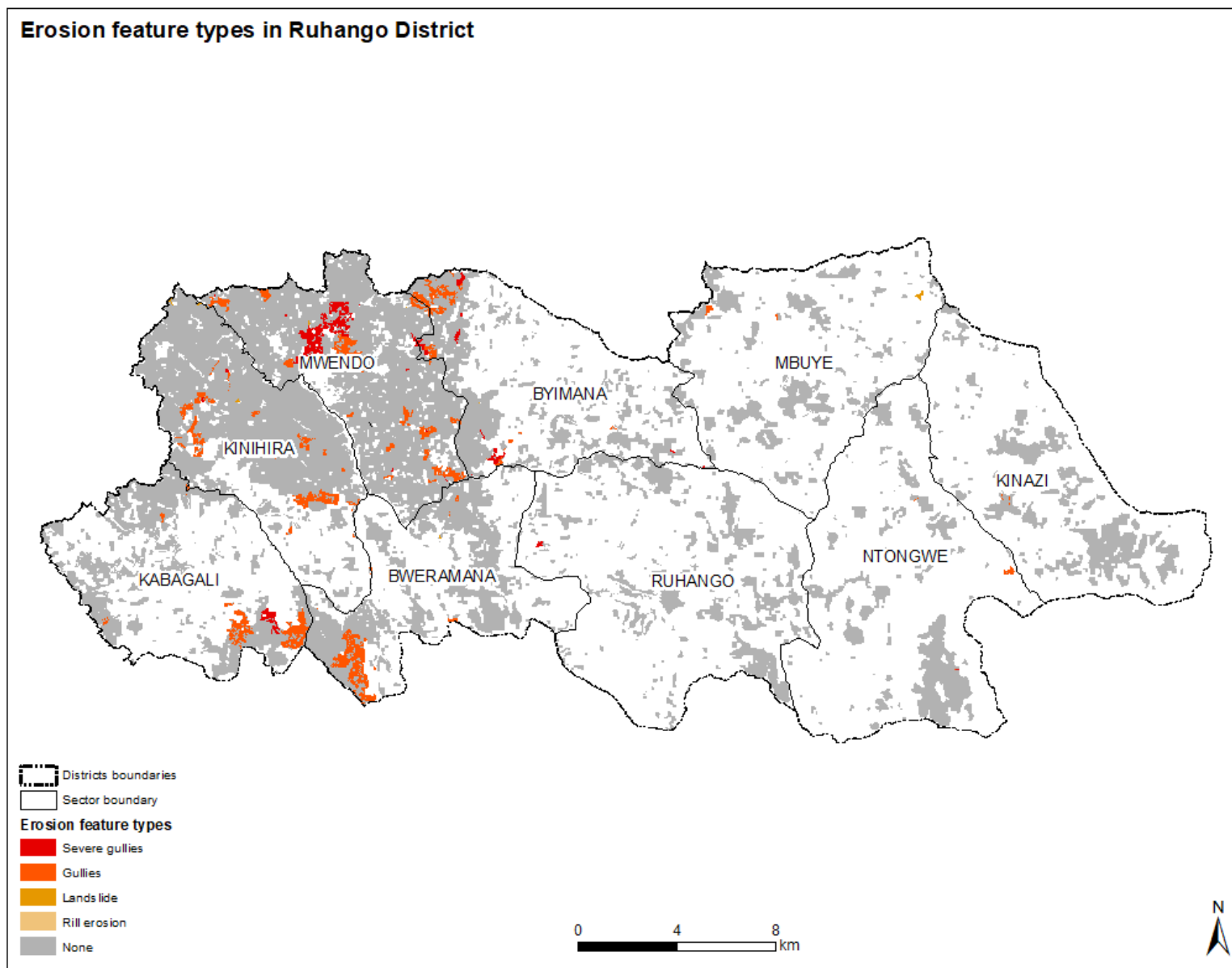
Table 106: Erosion risk per sector in Ruhango District

District	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MWENDO	329	1023	1956	1327	4636	5555	83%
KINIHIRA	156	836	1839	1332	4162	6084	68%
BWERAMAN A	259	508	1243	240	2249	5492	41%
KABAGALI	85	256	744	1000	2084	6059	34%
BYIMANA	281	536	995	136	1948	6182	32%
KINAZI	2	98	497	713	1310	7198	18%
RUHANGO	2	134	1294	219	1649	9426	17%
MBUYE	17	183	726	338	1264	7784	16%
NTONGWE	2	78	682	553	1315	8897	15%
<b>Grand Total</b>	<b>1133</b>	<b>3652</b>	<b>9975</b>	<b>5857</b>	<b>20618</b>	<b>62678</b>	<b>33%</b>

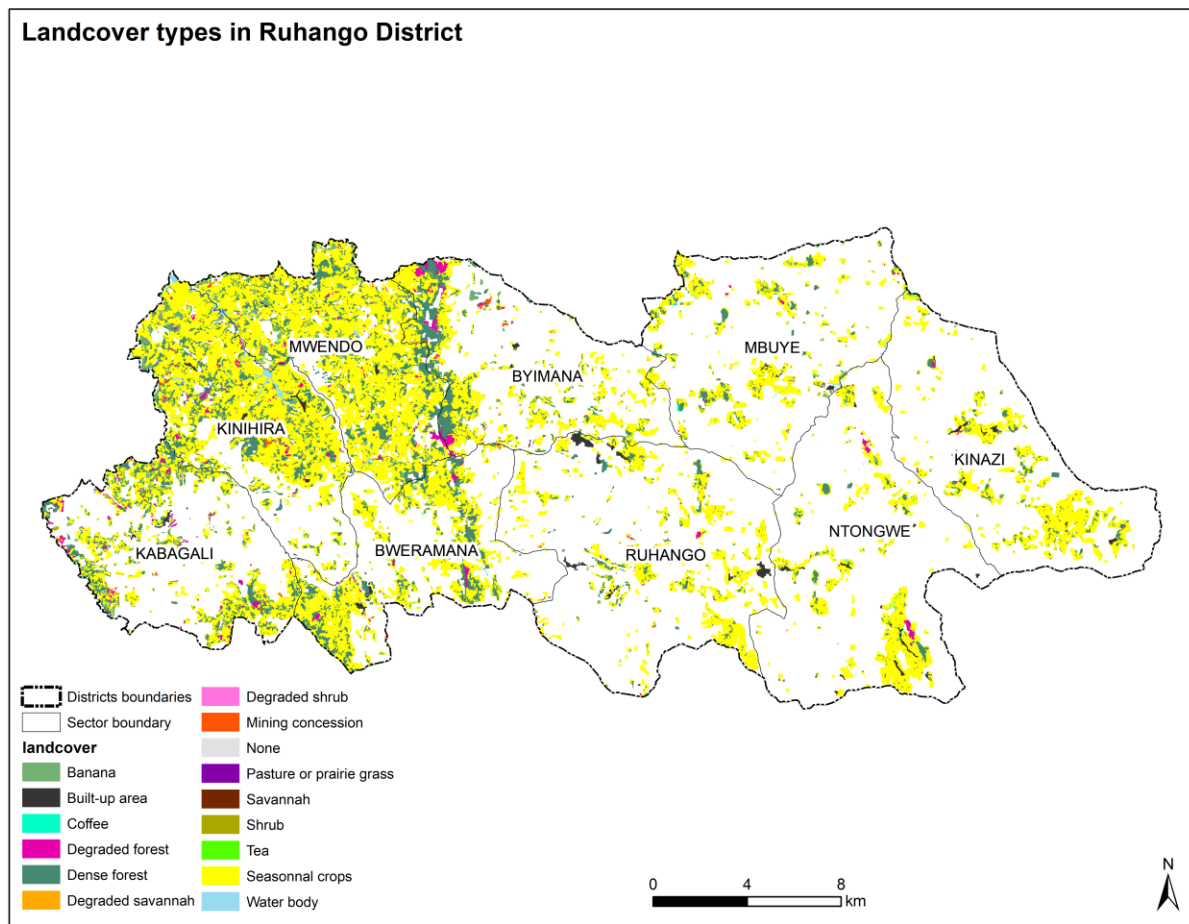
Land areas affected by erosive features in Ruhango District are summarized in Table 105 and the map of erosive features are presented in Figure 105. The results show that Mwendo sector is the worst affected by gullies on areas estimated to 470 hectares (10% of sector land at risk), followed by Kabagali sector on 206 hectares (10% of sector land at risk), and Byimana sector on 169 hectares (9% of sector land at risk) and Bweramana sector on 194 hectares (9% of sector land at risk). The presence of gullies in Bweramana, Mwendo, Kabagali and Mwendo sectors confirms the findings of CROM model; however the absence of gullies in Ruhango and Kinazi and the reduced presence of gullies in Ntongwe (10ha) and Mbuye (17 ha) which were originally predicted by CROM model as sectors at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 100 and 101. The least sectors affected by gullies are Kinazi, Ruhango and Ntongwe affected some severe gullies.

**Table 107: Erosive features and areas affected in Ruhango District**

Sector Name	Erosive features			Total feature	None	Grand Total	% Features
	Gullies	Landslide	Severe gullies				
MWENDO	267	1	201	470	4167	4636	10%
KABAGALI	173	0	33	206	1879	2084	10%
BYIMANA	115		53	169	1780	1948	9%
BWERAMANA	193	2		194	2055	2249	9%
KINIHIRA	222	7	4	234	3929	4162	6%
MBUYE	10	6		17	1247	1264	1%
NTONGWE	10			10	1305	1315	1%
RUHANGO			5	5	1643	1649	0%
KINAZI				0	1310	1310	0%
<b>Grand Total</b>	<b>989</b>	<b>17</b>	<b>297</b>	<b>1303</b>	<b>19314</b>	<b>20618</b>	<b>6%</b>

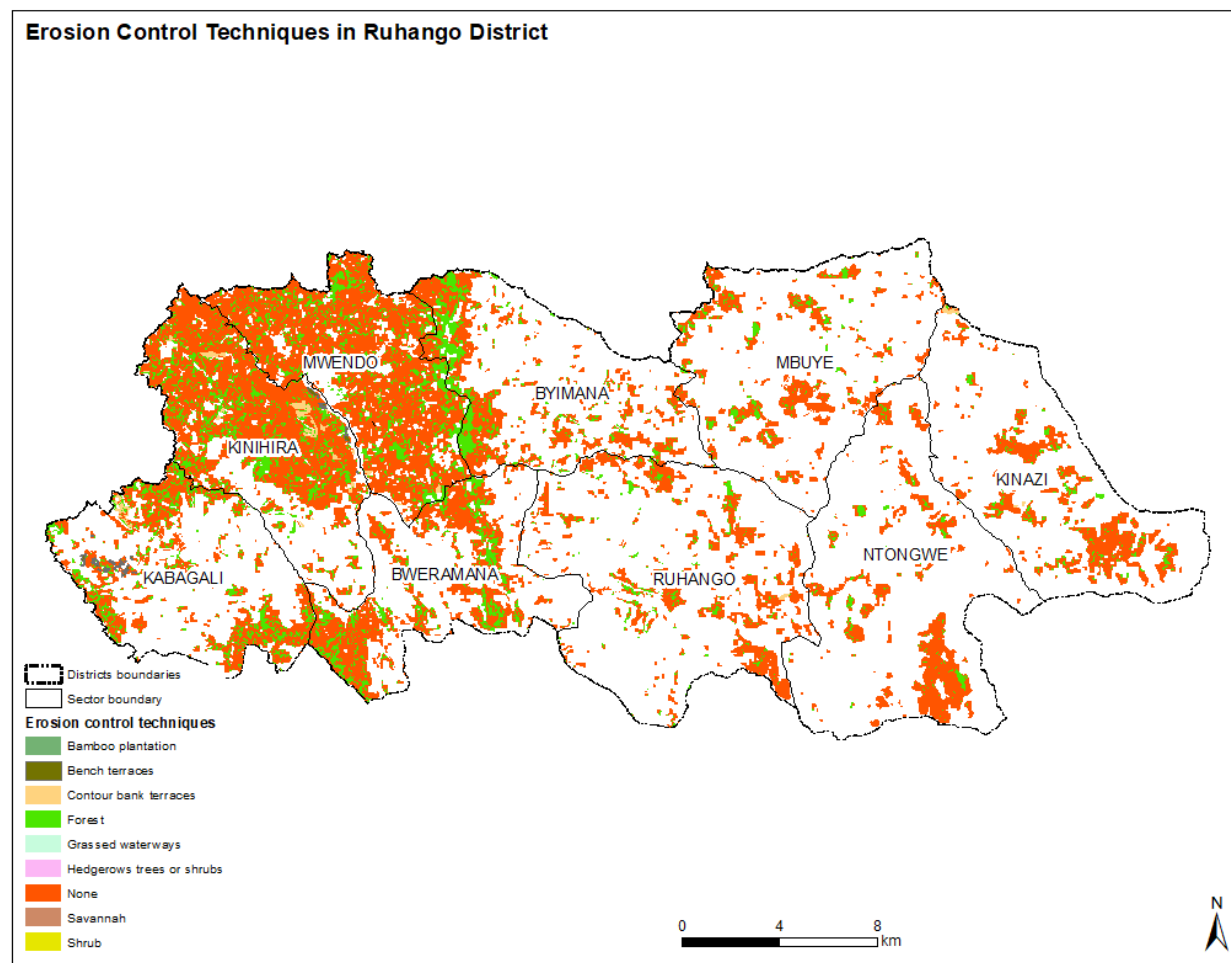


**Figure 105: Erosive features detected in Ruhango District**



**Figure 106: Land cover types in Ruhango District**

About existing erosion control practices in Ruhango district, only 15% of land at risk is protected by forests (3195 hectares) and Contour bank terraces (215 hectares). The highest protected sectors are Kabagali with 25% of its land at risk protected, followed by Byimana where 23% of the total land at risk is protected and Kinihira (only 18% protected). The least protected sectors are Ntongwe with only 6% protected Kinazi (only 8% protected) and Ruhango (9% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Ruhango Ntongwe, and Kinazi sectors remain at very high risk of soil erosion since more than 80% of their respective land are not protected.



**Figure 107: Erosion control techniques in place in Ruhango District**

**Table 108: Erosion control practices already in place in Ruhango District**

Sector Name	Erosion control in place			Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest				
KABAGALI	29	38	448	515	1570	2084	25%
BYIMANA			443	443	1505	1948	23%
BWERAMANA			408	408	1841	2249	18%
KINIHIRA	20	115	602	737	3425	4162	18%
MWENDO		28	575	604	4033	4636	13%
MBUYE			141	141	1123	1264	11%



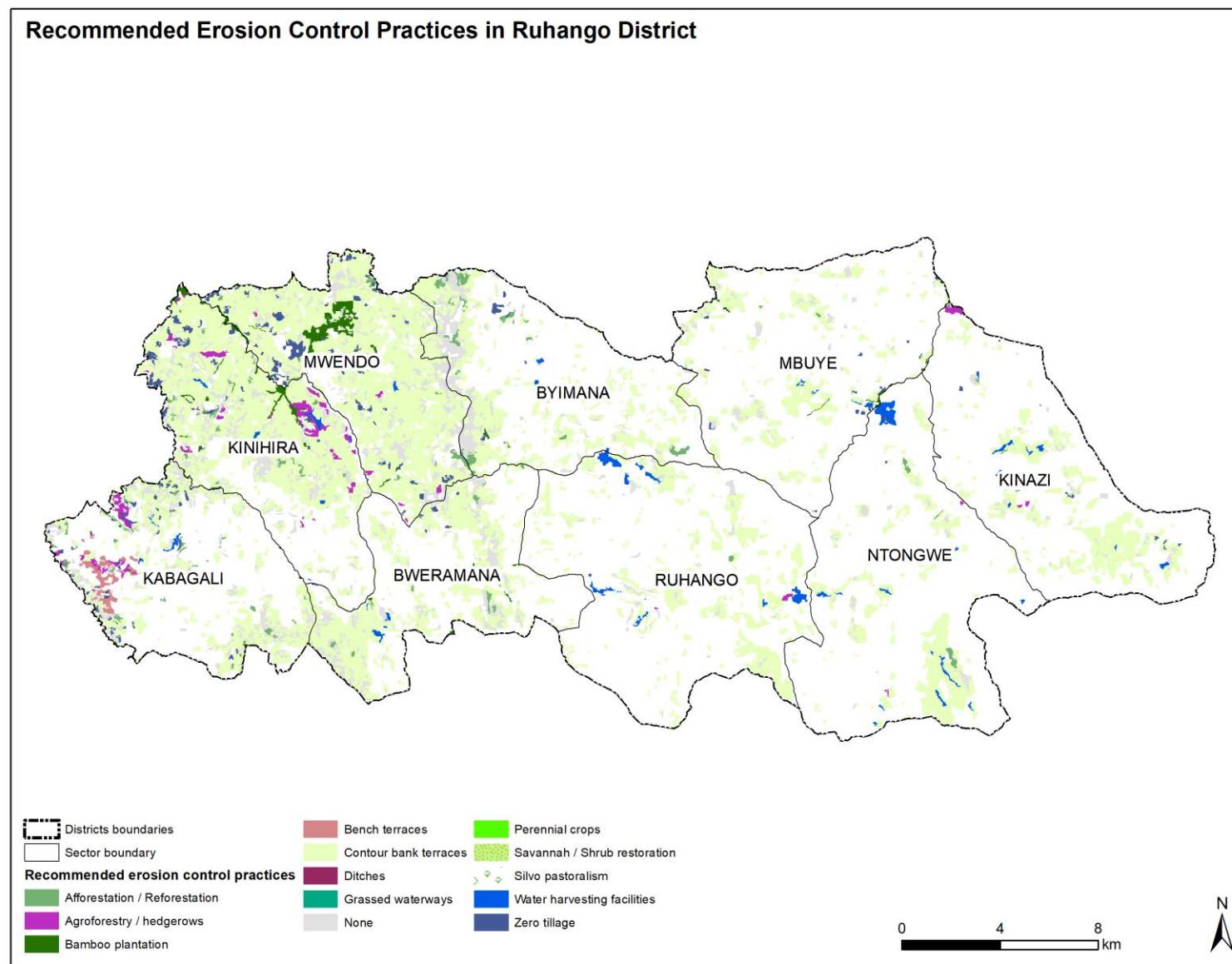
Sector Name	Erosion control in place			Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest				
KINAZI		25	99	124	1186	1310	9%
RUHANGO		8	130	138	1511	1649	8%
NTONGWE			85	85	1230	1315	6%
<b>Grand Total</b>	<b>48</b>	<b>215</b>	<b>2932</b>	<b>3195</b>	<b>17423</b>	<b>20618</b>	<b>15%</b>

Erosion control practices in Ruhango District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 108 shows that about 15834 hectares (which is 77% of the total land at risk) are suitable for Contour bank terraces, 367 hectares are Afforestation & Reforestation and 319 hectares of Bamboo to close gullies and protect riverside. Other interventions are 120 hectares for bench terraces and 322 hectares are for water harvesting facilities.

**Table 109: Recommended erosion practices in Ruhango District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	None	Water harvesting facilities	Zero tillage	Grand Total
BWERAMANA	32		12		1770	408	16	12	2249
BYIMANA	120		5		1349	443	9	23	1948
KABAGALI	76	72	15	120	1255	448	19	78	2084
KINAZI	5	26	0		1135	99	34	12	1310
KINIHIRA	59	150	100		3125	602	29	97	4162
MBUYE	4		17		1064	141	12	26	1264
MWENDO	42	28	169		3632	575	6	183	4636
NTONGWE	25	4	1		1098	85	98	3	1315
RUHANGO	5	8	0		1406	130	99	1	1649
<b>Grand Total</b>	<b>367</b>	<b>288</b>	<b>319</b>	<b>120</b>	<b>15834</b>	<b>2932</b>	<b>322</b>	<b>436</b>	<b>20618</b>
<b>%</b>	<b>2%</b>	<b>1%</b>	<b>2%</b>	<b>1%</b>	<b>77%</b>	<b>14%</b>	<b>2%</b>	<b>2%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



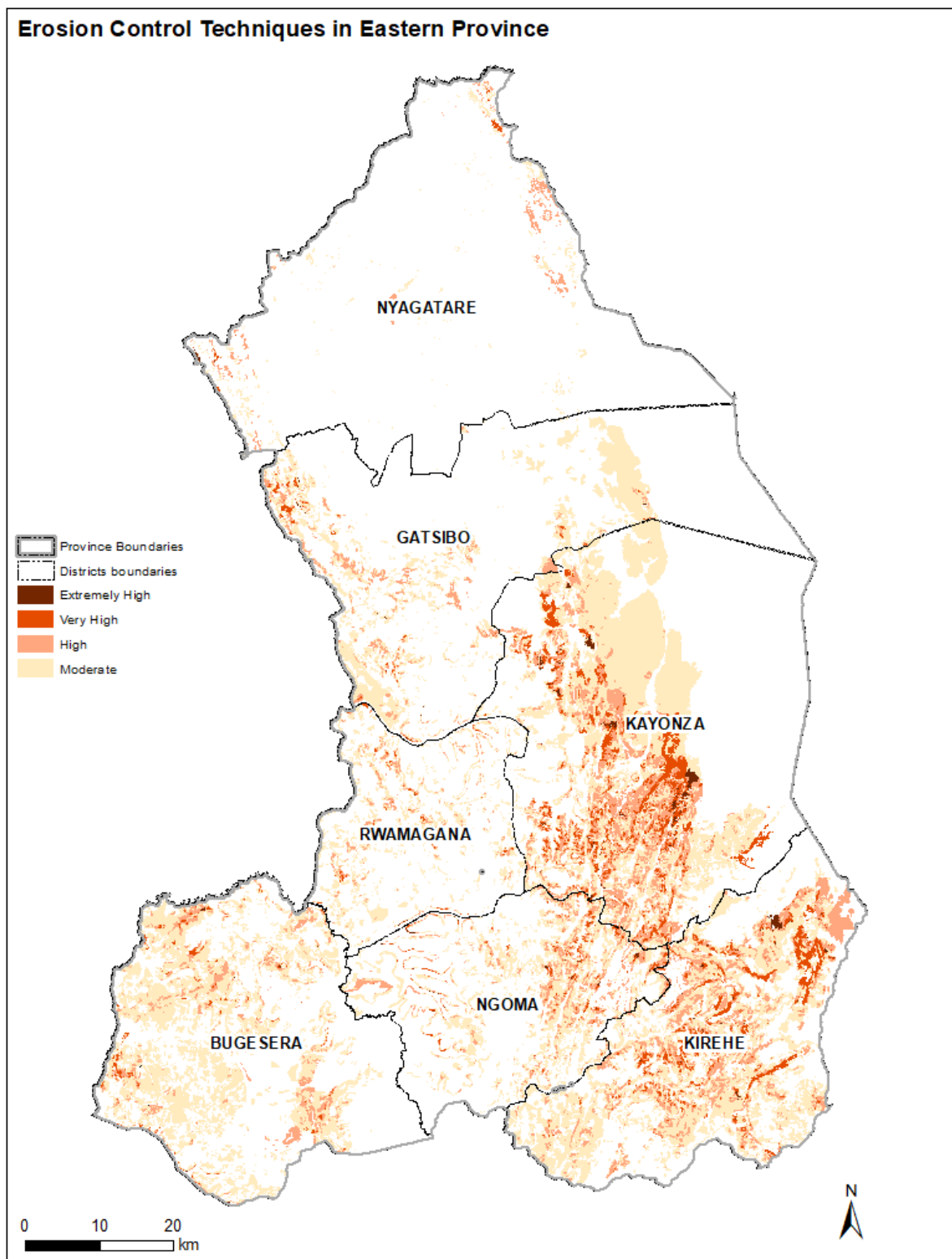
**Figure 108: Recommended erosion control practices in Ruhango District**

### 3.4. Erosion Control Status in Eastern Province

Erosion risk in Eastern Province is summarized in table 109 and presented in figure 109. The total land at high risk of erosion in Eastern Province is about 261166 hectares (29% of the total province land). The highest amount of land at erosion risk are found in Kirehe with 61597 hectares (i.e. 53% of the total district land) followed by Kayonza District with 83008 hectares (46% of the district land), and Bugesera with 46226 hectares (38% of district land). The least district susceptible to erosion is Nyagatare, where 3% of its district land is at risk, about 5664 hectares. The contribution of Akagera National Park in protecting fragile land in Eastern Province is evident, particularly in Kayonza and Gatsibo districts.

**Table 110: Erosion risk in Eastern Province**

District Name	Erosion risk					District land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
KIREHE	336	5319	15845	40098	61597	115813	53%
KAYONZA	918	8540	19000	54550	83008	179128	46%
BUGESERA	38	860	5937	39392	46226	122543	38%
NGOMA	131	1068	6298	18468	25966	81445	32%
RWAMAGANA	22	392	1871	10872	13156	65627	20%
GATSIBO	48	484	3874	21142	25548	154667	17%
NYAGATARE	100	261	2192	3112	5664	191333	3%
<b>Grand Total</b>	<b>1593</b>	<b>16924</b>	<b>55016</b>	<b>187634</b>	<b>261166</b>	<b>910555</b>	<b>29%</b>



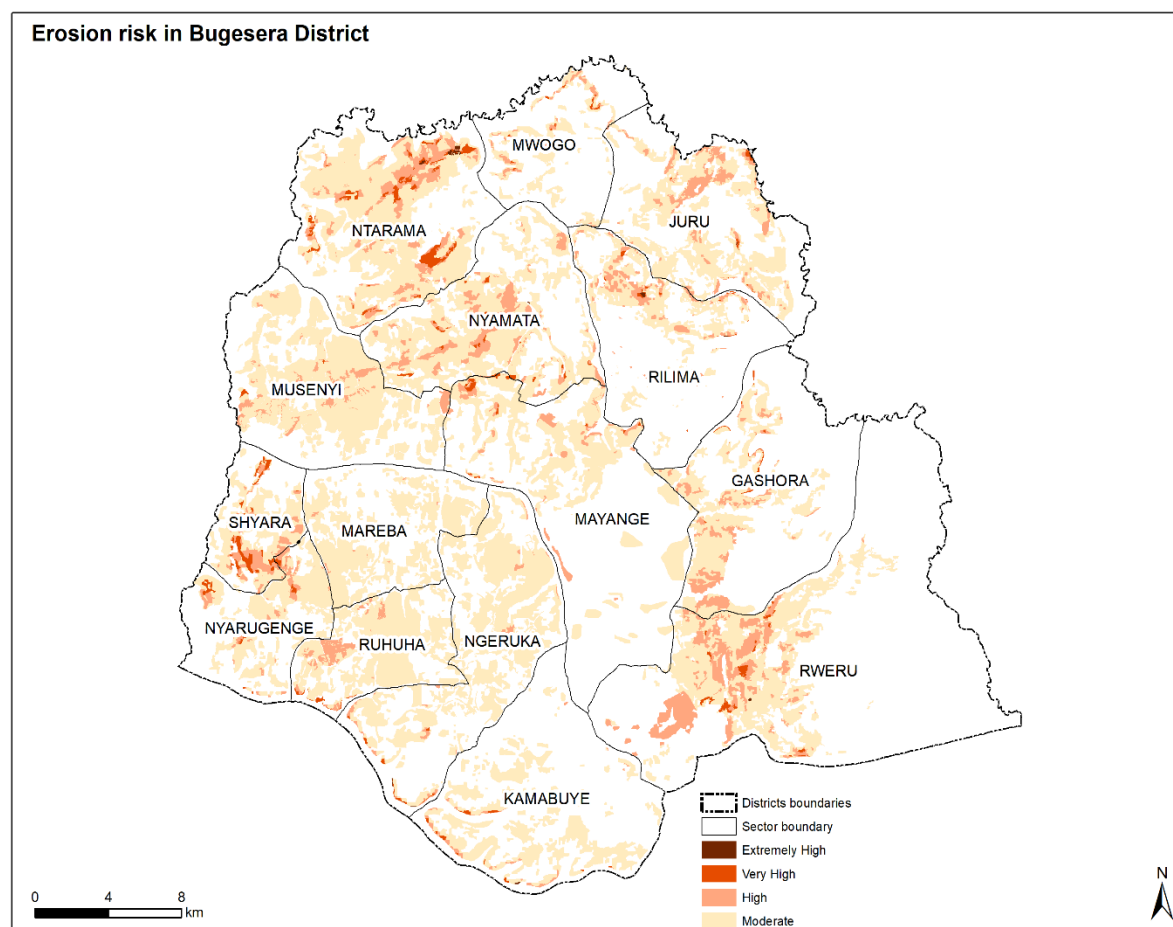
**Figure 109: Erosion risk in Eastern Province**

### 3.4.1. Erosion control in Bugesera District

Erosion risk in Bugesera is summarised in Table 110 and presented in figure 110. Erosion risk in Bugesera District is estimated to 46226 hectares; about 38% of the total district land are highly susceptible to erosion of which 2369 hectares are located in Ruhuha sector (64% of sector land), 5515 hectares are located in Ntarama sector (56% of sector land), 1659 hectares are located in Shyara (54% of the sector land), and 4485 hectares are found in Nyamata sector about 53% of the sector land. The least sectors are Mwogo with only 1000 hectares (19% of the sector land) susceptible to moderate erosion, Rilima with 1787 hectares (23%), and Rweru with 4820 hectares, about 27% of the total sector land. As compare to other district in Eastern Province, Bugesera is the third susceptible to moderate erosion.

**Table 111: Erosion risk per sector in Bugesera District**

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
RUHUHA		23	241	2369	2634	4138	64%
NTARAMA	23	279	859	4354	5515	9883	56%
SHYARA		159	349	1151	1659	3072	54%
NYAMATA	2	60	720	3704	4485	8408	53%
MUSENYI		10	335	4147	4492	8431	53%
NGERUKA	2	22	102	3887	4012	8685	46%
NYARUGENGE		52	227	1735	2014	4466	45%
MAREBA			13	2451	2464	5538	44%
JURU	3	17	500	2604	3124	7995	39%
GASHORA		30	494	2124	2648	9263	29%
RWERU	2	92	1276	3450	4820	17998	27%
KAMABUYE	2	33	80	2248	2363	9205	26%
MAYANGE		43	275	2891	3210	12593	25%
RILIMA	5	23	337	1423	1787	7610	23%
MWOGO		18	128	853	1000	5259	19%
<b>Grand Total</b>	<b>38</b>	<b>860</b>	<b>5937</b>	<b>39392</b>	<b>46226</b>	<b>122543</b>	<b>38%</b>



**Figure 110: Erosion risk in Bugesera District**

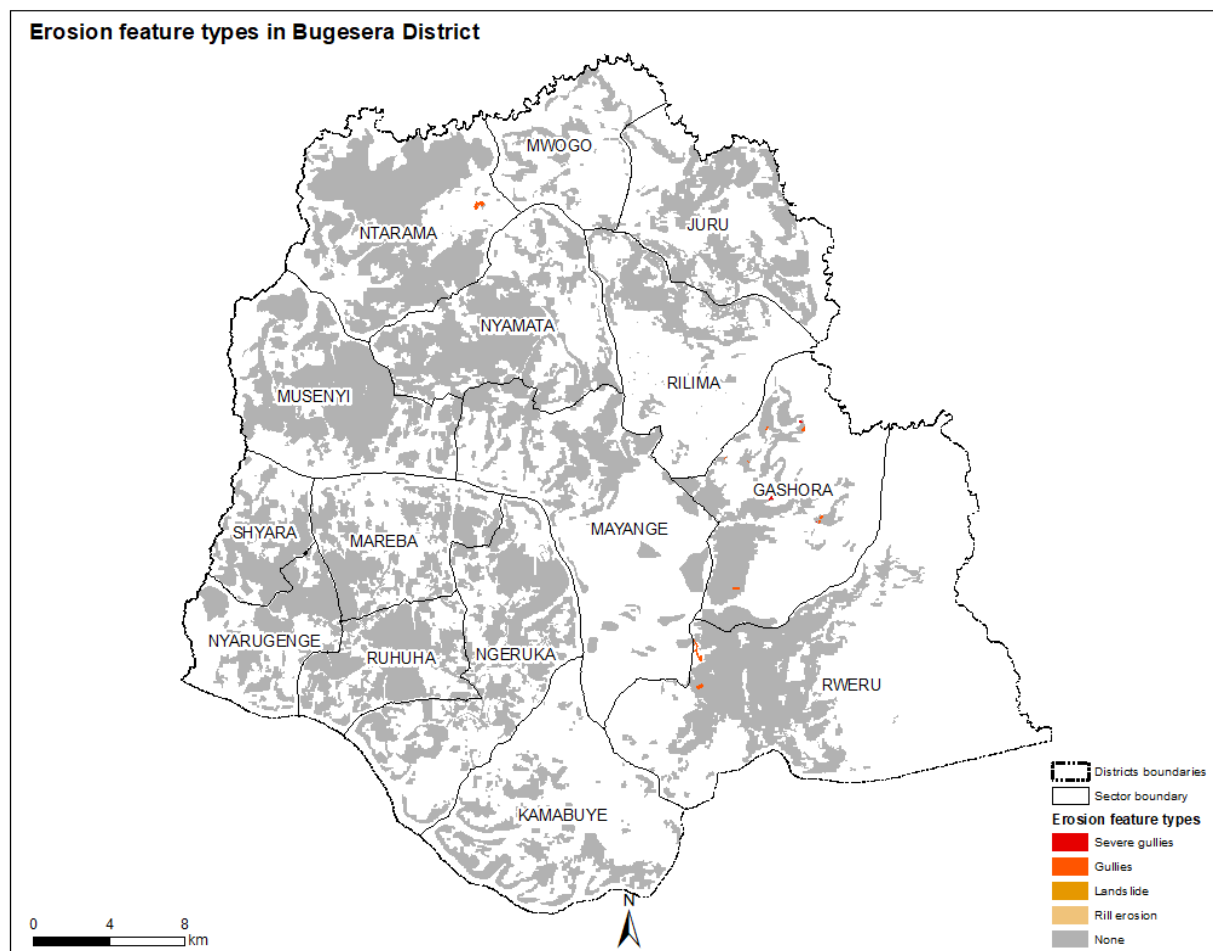
Land areas affected by erosive features in Bugesera District are summarized in Table 111 and the map of erosive features are presented in Figure 111. The results show that Gashora sector is the worst affected by rill erosion on areas estimated to 23 hectares (1% of sector land at risk). All other sectors of Bugesera District have few areas affected by gullies. The quasi absence of gullies in all sectors, except Gashora and Ntarama confirm the findings of CROM model that Bugesera District is less affected by erosion. In fact, the observed 85% of land affected by erosion risk is classified as moderate, while 13% is classified as high erosion risk.

**Table 112: Erosive features and areas affected in Bugesera District**

Sector Name	Erosive features		Total Features	None	Grand Total	% features
	Gullies	Severe gullies				
GASHORA	18	5	23	2624	2648	1%
JURU			0	3124	3124	0%
KAMABUYE			0	2363	2363	0%
MAREBA			0	2464	2464	0%
MAYANGE			0	3210	3210	0%
MUSENYI			0	4492	4492	0%
MWOGO			0	1000	1000	0%



Sector Name	Erosive features		Total Features	None	Grand Total	% features
	Gullies	Severe gullies				
NGERUKA			0	4012	4012	0%
NTARAMA	15		15	5500	5515	0%
NYAMATA			0	4485	4485	0%
NYARUGENGE			0	2014	2014	0%
RILIMA			0	1787	1787	0%
RUHUHA			0	2634	2634	0%
RWERU	22		22	4798	4820	0%
SHYARA			0	1659	1659	0%
<b>Grand Total</b>	<b>54</b>	<b>5</b>	<b>60</b>	<b>46167</b>	<b>46226</b>	<b>0%</b>

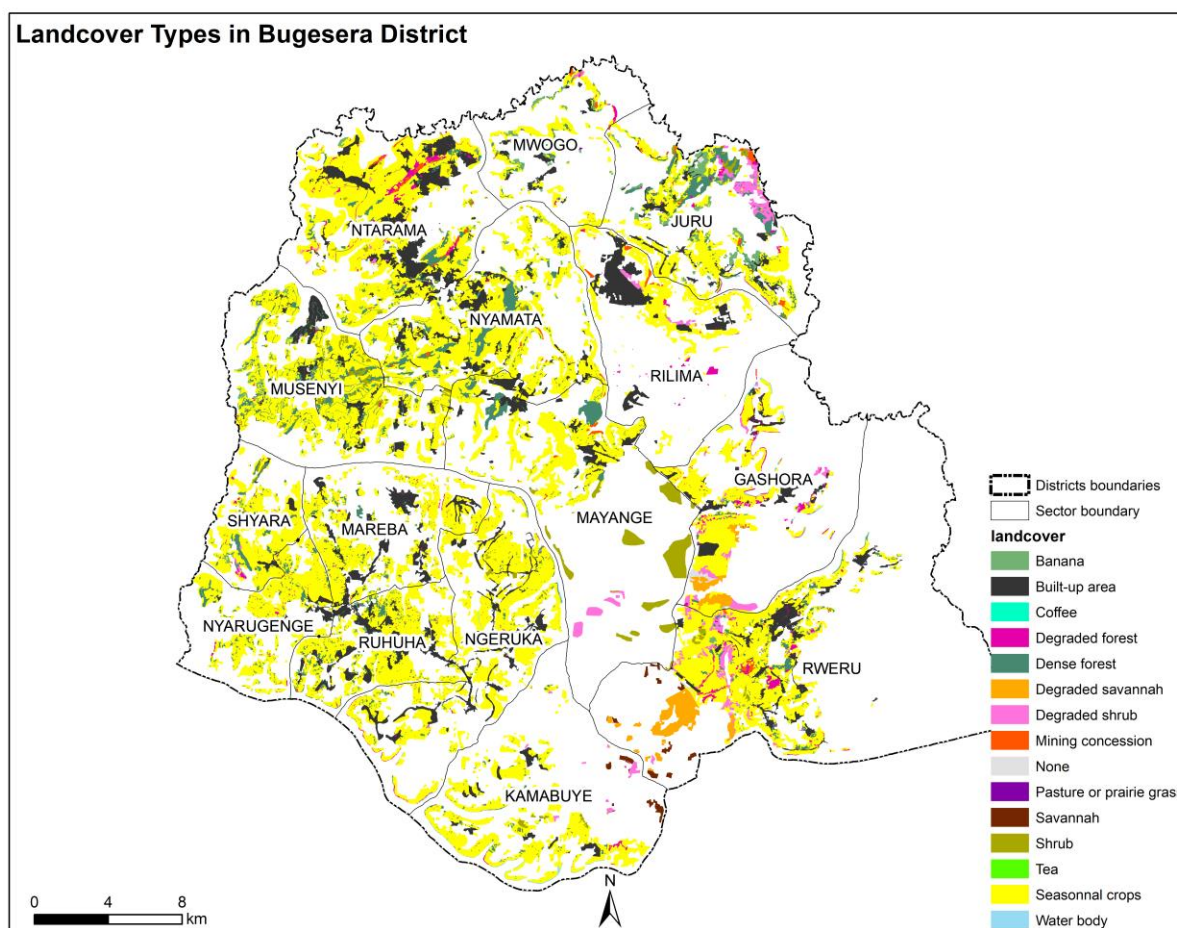


**Figure 111: Erosive features detected in Bugesera District**

In term of land use and land cover of areas at risk in Bugesera District, the results of land cover mapping (Table 112 and Figure 112) show that 31319 hectares (70% of the total land at risk) are used for seasonal cropping, **2657** hectares (6% of the total of the total land at risk) are covered by healthy forests and 6774 hectares (15% of the total land at risk) are covered by built-up area. In Bugesera District there are also degraded shrub which cover an area of 983 hectares (2% of the total land at risk), Mining and Quarriess covering an area of 253 (1% of land at risk), shrub on 1062 hectares (2% of land at risk and banana on 660 hectares (1% of land at risk)..

**Table 113: Land Use and Vegetation Cover (LUVC) for land at risk in Bugesera District**

Sector Name	Banana	Built-up area	Degraded forest	Degraded savannah	Degraded shrub	Dense forest	Mining and Quarries	Non e	Pasture or prairie grass	Savannah	Seasonal crops	Shrub	Water body	Grand Total
GASHORA		342	84	208	174	38	4	60			1694	3	40	2648
JURU	333	328	46		251	424	54	8			1607	65	8	3124
KAMABUYE		169	16		63	44				66	1925	41	40	2363
MAREBA	3	540	11			66					1844			2464
MAYANGE	4	371	0		110	267	25	0		0	1828	604		3210
MUSENYI	78	539	5		2	416	1	4			3251	195		4492
MWOGO	115	154	16		14	57	18		5		617		3	1000
NGERUKA	1	595	18		4	47		1			3300	30	16	4012
NTARAMA	39	1150	120		25	243	66	1			3820	50		5515
NYAMATA	38	554	2			475	18				3382	15		4485
NYARUGENGE	4	131	9			116					1753			2014
RILIMA		703	46		60		32				943	2		1787
RUHUHA	14	550	1			125	2				1941			2634
RWERU	14	583	114	448	246	192	32	8		89	3048	42	4	4820
SHYARA	15	64	20		34	147					1365	14		1659
<b>Grand Total</b>	<b>660</b>	<b>6774</b>	<b>510</b>	<b>656</b>	<b>983</b>	<b>2657</b>	<b>253</b>	<b>82</b>	<b>5</b>	<b>155</b>	<b>32319</b>	<b>1062</b>	<b>111</b>	<b>46226</b>
<b>%</b>	<b>1%</b>	<b>15%</b>	<b>1%</b>	<b>1%</b>	<b>2%</b>	<b>6%</b>	<b>1%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>70%</b>	<b>2%</b>	<b>0%</b>	<b>100%</b>



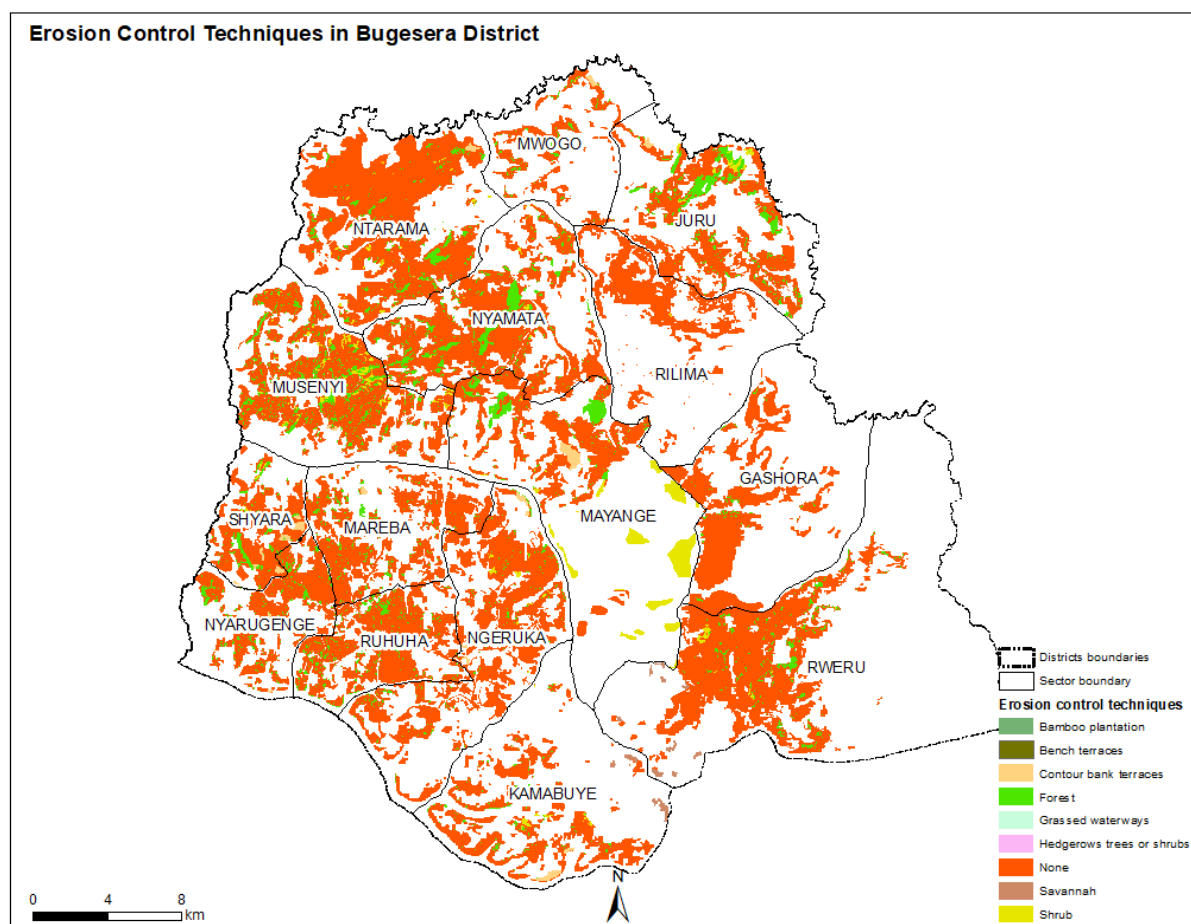
**Figure 112: Land cover types in Bugesera District**

About existing erosion control practices in Bugesera district, Table 113 shows that only 9% of land at risk is protected by forests (2657 hectares), contour bank terraces (418 hectares), shrub (1060 hectares) and savanna (155 hectares). The highest protected sectors are Mayange with 30% of its land at risk protected, followed by Juru where 16% of the total land at risk is protected and Musenyi with 15% of land protected. The least protected sectors are Rilima with less than 1% protected, Gashora (only 2% protected), Ngeruka (3%) and Mareba (3% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Bugesera sectors remain at moderate risk of soil erosion.

**Table 114: Erosion control practices already in place in Bugesera District**

Sector Name	Erosion control in place				Total protected	None	Grand Total	% Protected
	Contour bank terraces	Forests	Savannah	Shrub				
MAYANGE	87	267	0	604	959	2251	3210	30%
JURU	18	424		65	507	2616	3124	16%
SHYARA	90	147		14	251	1408	1659	15%
MUSENYI	12	416		195	623	3869	4492	14%

Sector Name	Erosion control in place				Total protected	None	Grand Total	% Protected
	Contour bank terraces	Forest	Savannah	Shrub				
NYAMATA	2	475		15	492	3993	4485	11%
KAMABUYE	92	44	66	40	242	2122	2363	10%
MWOGO	20	57			77	923	1000	8%
RWERU		192	89	42	323	4496	4820	7%
NYARUGENGE	14	116			130	1884	2014	6%
NTARAMA	21	243		50	314	5201	5515	6%
RUHUHA		125			125	2509	2634	5%
MAREBA	14	66			79	2385	2464	3%
NGERUKA	47	47		30	124	3888	4012	3%
GASHORA		38		3	41	2606	2648	2%
RILIMA				2	2	1785	1787	0%
<b>Grand Total</b>	<b>418</b>	<b>2657</b>	<b>155</b>	<b>1060</b>	<b>4290</b>	<b>41936</b>	<b>46226</b>	<b>9%</b>



**Figure 113: Erosion control techniques in place in Gisagara District**

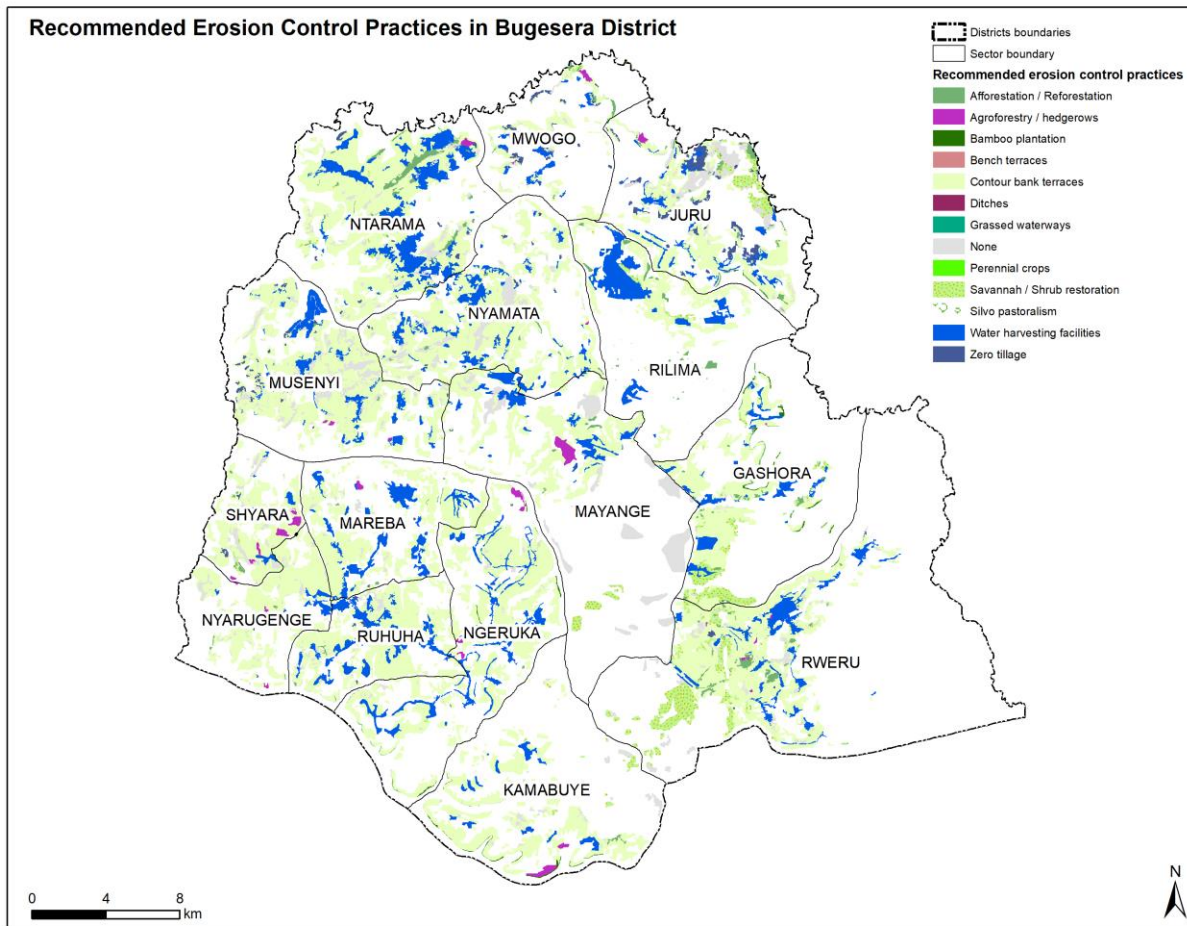
Erosion control practices in Bugesera District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model.

Table 114 shows that about 31850 hectares (which is 69 % of the total land at risk) are suitable for Contour bank terraces, 6840 hectares are water harvesting facilities (Storm water management facilities -SWMF). Other erosion control practices needed are shrub/Savannah restoration (4 ha), reforestation & afforestation on 807 ha and agroforestry/hedgerows on 420 hectares.

**Table 115: Recommended erosion control practices in Bugesera District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Contour bank terraces	None	Savannah / Shrub restoration	Silvo pastoralism	Water harvesting facilities	Zero tillage	Grand Total
GASHORA	105	1	46	1685	41	382		387		2648
JURU	101	18	8	1589	488	251		336	335	3124
KAMABUYE	16	92	40	1833	151	63		169		2363
MAREBA	11	14		1831	66			540	3	2464
MAYANGE	25	87		1740	872	110		371	4	3210
MUSENYI	8	12		3237	611	2		543	78	4492
MWOGO	34	22	3	595	60	14	5	154	111	1000
NGERUKA	18	47	16	3253	77	4		596	1	4012
NTARAMA	203	21		3783	293	25		1151	39	5515
NYAMATA	22	2		3378	490			554	38	4485
NYARUGENGE	9	14		1739	116			131	4	2014
RILIMA	78			943	2	60		703		1787
RUHUHA	9			1935	125			550	14	2634
RWERU	146	15	4	3034	323	694		591	14	4820
SHYARA	20	75		1275	177	34		64	15	1659
<b>Grand Total</b>	<b>807</b>	<b>420</b>	<b>116</b>	<b>31850</b>	<b>3891</b>	<b>1640</b>	<b>5</b>	<b>6840</b>	<b>657</b>	<b>46226</b>
<b>%</b>	<b>2%</b>	<b>1%</b>	<b>0%</b>	<b>69%</b>	<b>8%</b>	<b>4%</b>	<b>0%</b>	<b>15%</b>	<b>1%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

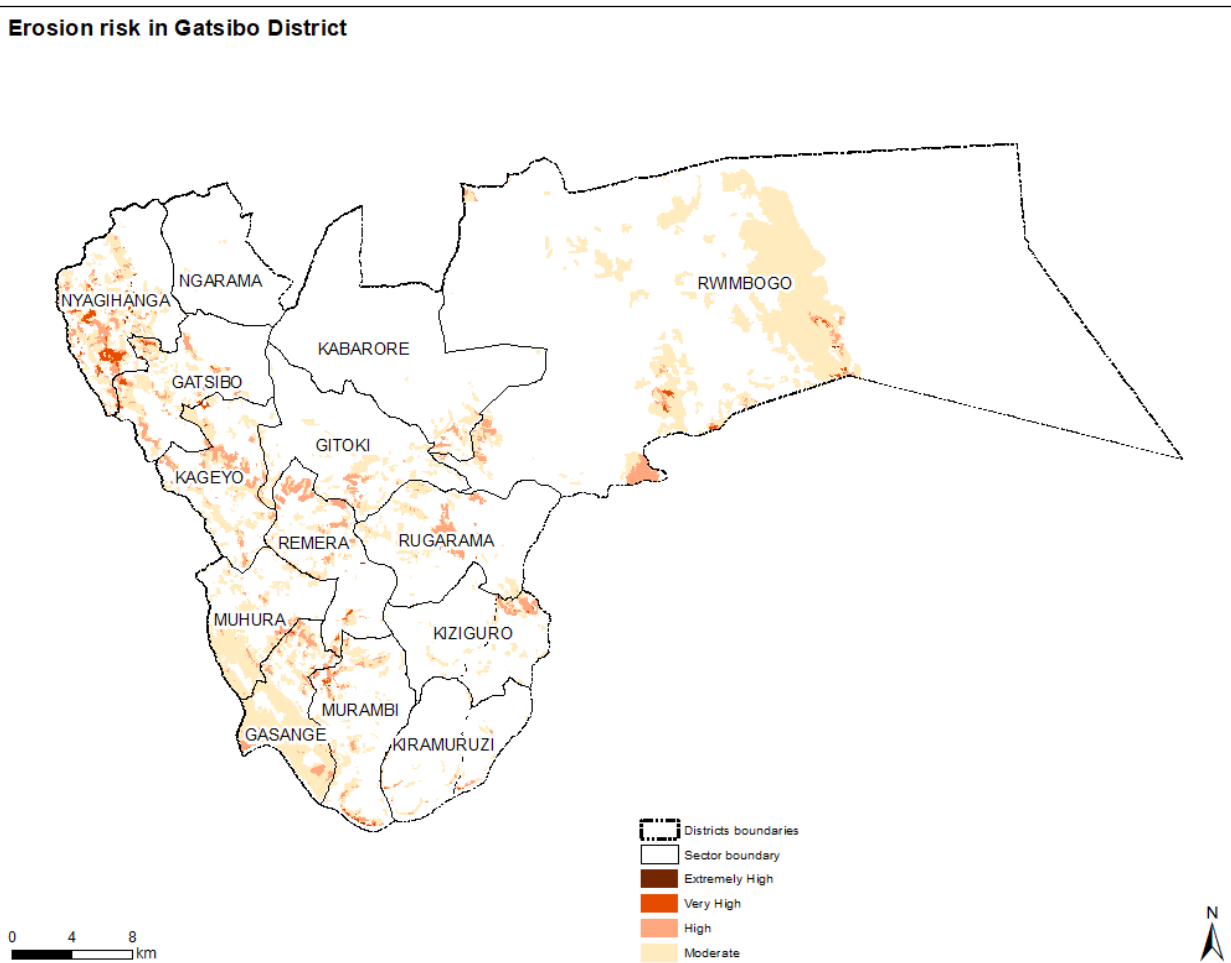


**Figure 114: Recommended erosion control practices in Bugesera District**

### 3.4.2. Erosion control status in Gatsibo District

Erosion risk in Gatsibo is summarised in Table 115 and presented in figure 115. Erosion risk in Gatsibo District is estimated to 25548 hectares; about 17% of the total district land are moderately susceptible to erosion of which 2880 hectares are located in Karama sector (65% of sector land), 2733 hectares are located in Nyagihanga sector (38% of sector land), 1703 hectares are located in Muhura (34% of the sector land), and 1837 hectares are found in Kageyo sector about 33% of the sector land. The least sectors are Ngarama with only 32 hectares (1% of the sector land) susceptible to moderate erosion, Kabarore with 389 hectares (3%), and Kiramuruzi with 291 hectares, about 5% of the total sector land. As compared to other districts in Eastern Province, Gatsibo is the second least susceptible to erosion.





**Figure 115: Erosion risk in Gatsibo District**

**Table 116: Erosion risk per sector in Gatsibo District**

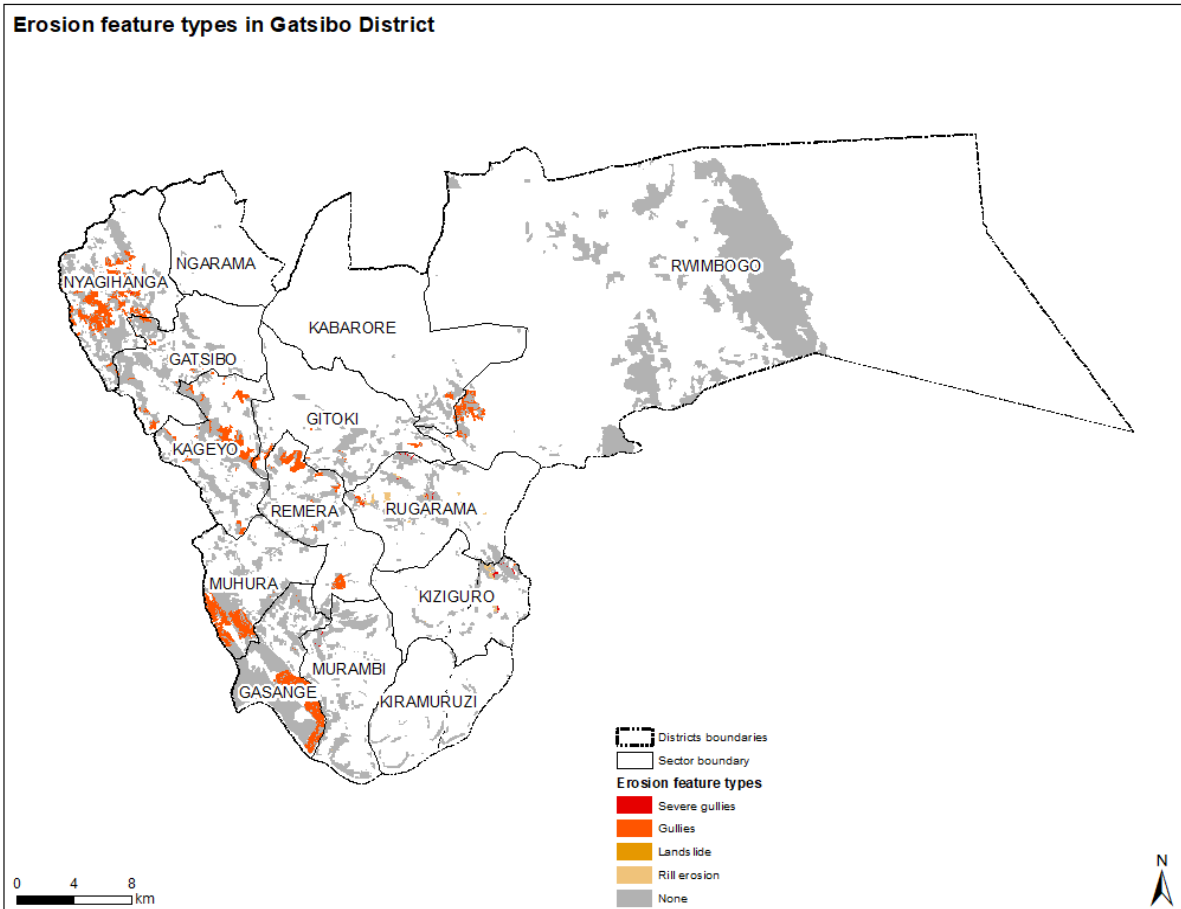
Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
GASANGE		21	394	2465	2880	4230	68%
NYAGIHANGA	12	275	573	1874	2733	7122	38%
MUHURA		1	141	1561	1703	4944	34%
KAGEYO		18	513	1306	1837	5555	33%
GATSIBO	12	43	319	1002	1377	6156	22%
MURAMBI	6	31	211	1002	1250	5752	22%
REMERA	6	19	388	737	1150	5316	22%
RUGARAMA	1	3	316	847	1166	7575	15%
GITOKI		0	126	875	1001	7537	13%
RWIMBOGO	5	64	598	8376	9043	70687	13%
KIZIGURO		7	188	501	696	6150	11%
KIRAMURUZI	6	2	41	242	291	5483	5%

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
KABARORE			65	324	389	12635	3%
NGARAMA				32	32	5524	1%
<b>Grand Total</b>	<b>48</b>	<b>484</b>	<b>3874</b>	<b>21142</b>	<b>25548</b>	<b>154667</b>	<b>17%</b>

Land areas affected by erosive features in Gatsibo District are summarized in Table 116 and the map of erosive features are presented in Figure 116. The results show that Nyagihanga sector is the worst affected by gullies on areas estimated to 754 hectares (28% of sector land at risk), followed by Muhura sector on 452 hectares (27% of sector land at risk), and Remera sector on 279 hectares (24% of sector land at risk). The least sectors affected by gullies are Kiramuruzi and Ngarama where there is no observed gullies, and Murambi, Rwimbogo and Kabarore where gullies are observed on an estimated area of 7 hectares (1%), 188 hectares (2%) and 23 hectares (6%).

**Table 117: Erosive features and areas affected in Gatsibo District**

Sector Name	Erosion feature			Total Features	None	Grand Total	% features
	Gullies	Rill erosion	Severe gullies				
NYAGIHANGA	752		2	754	1980	2733	28%
MUHURA	452			452	1251	1703	27%
REMERA	279			279	871	1150	24%
KAGEYO	394			394	1442	1837	21%
GASANGE	496		0	496	2384	2880	17%
RUGARAMA	24	98	10	132	1034	1166	11%
KIZIGURO	4	53	18	75	621	696	11%
GITOKI	88	0		89	913	1001	9%
GATSIBO	99			99	1278	1377	7%
KABARORE	23			23	366	389	6%
RWIMBOGO	188			188	8854	9043	2%
MURAMBI	3		4	7	1243	1250	1%
KIRAMURUZI				0	291	291	0%
NGARAMA				0	32	32	0%
<b>Grand Total</b>	<b>2804</b>	<b>151</b>	<b>33</b>	<b>2989</b>	<b>22559</b>	<b>25548</b>	<b>12%</b>

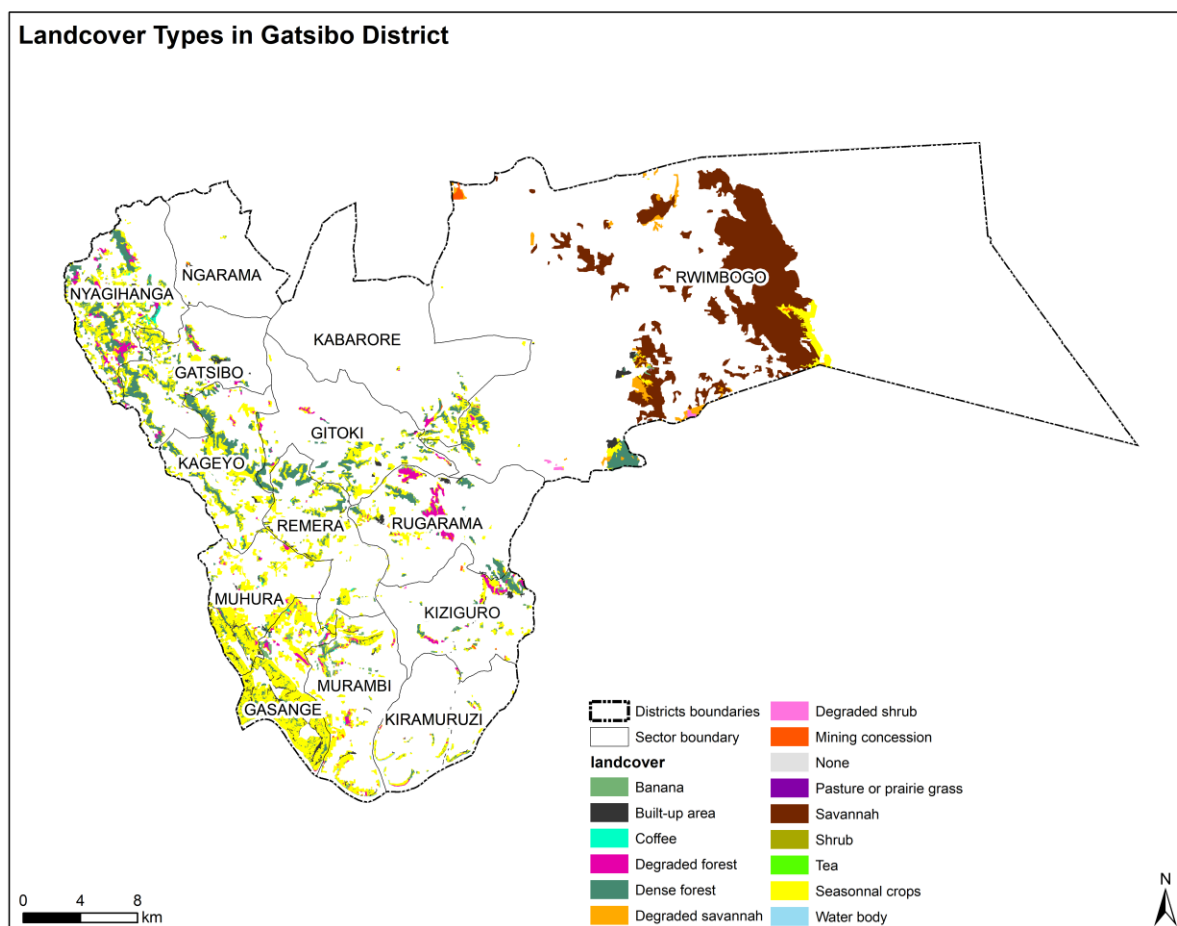


**Figure 116: Erosive features detected in Gatsibo District**

In term of land use and land cover of areas at risk in Gatsibo District, the results of land cover mapping (Table 117 and Figure 117) show that 10923 hectares (**43%** of the total land at risk) are used for seasonal cropping, 4522 hectares (**18%** of the total land at risk) are covered by healthy forests, 649 hectares (**3%** of the total land at risk) are covered by built-up area, 7218 hectares (28% of the land at risk) are covered by savannah. Degraded forests and degraded savannah are covering an estimated area of respectively 1093 hectares (4%) and 448 hectares (2% of the total land at risk).

**Table 118: Land Use and Vegetation Cover (LUVC) for land at risk in Gatsibo District**

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Degraded savannah	Degraded shrub	Dense forest	Mining and Quarries	None	Savannah	Seasonal crops	Shrub	Water body	Grand Total
GASANGE	82	150	6	74		3	178		12		2375			2880
GATSIBO		33		55			588				701			1377
GITOKI	2	23		46			391				539			1001
KABARORE		7		27			139	3			213			389
KAGEYO	24	7	3	28			720	1			1053			1837
KIRAMURUZI		4		20			41				208	4	15	291
KIZIGURO	49	56	1	111		3	195	12			269			696
MUHURA	12	95	5	53			137				1401			1703
MURAMBI	112	44	4	72			94	5			910		9	1250
NGARAMA		15						3			14			32
NYAGIHANGA	78	23	46	256			907				1424			2733
REMERA	8	28	5	5			421				684			1150
RUGARAMA	54	63		333			277	7			429		3	1166
RWIMBOGO	15	101		14	448	48	433	63		7218	701	1		9043
<b>Grand Total</b>	<b>433</b>	<b>649</b>	<b>70</b>	<b>1093</b>	<b>448</b>	<b>54</b>	<b>4522</b>	<b>94</b>	<b>12</b>	<b>7218</b>	<b>10923</b>	<b>5</b>	<b>26</b>	<b>25548</b>
<b>%</b>	<b>2%</b>	<b>3%</b>	<b>0%</b>	<b>4%</b>	<b>2%</b>	<b>0%</b>	<b>18%</b>	<b>0%</b>	<b>0%</b>	<b>28%</b>	<b>43%</b>	<b>0%</b>	<b>0%</b>	<b>100%</b>



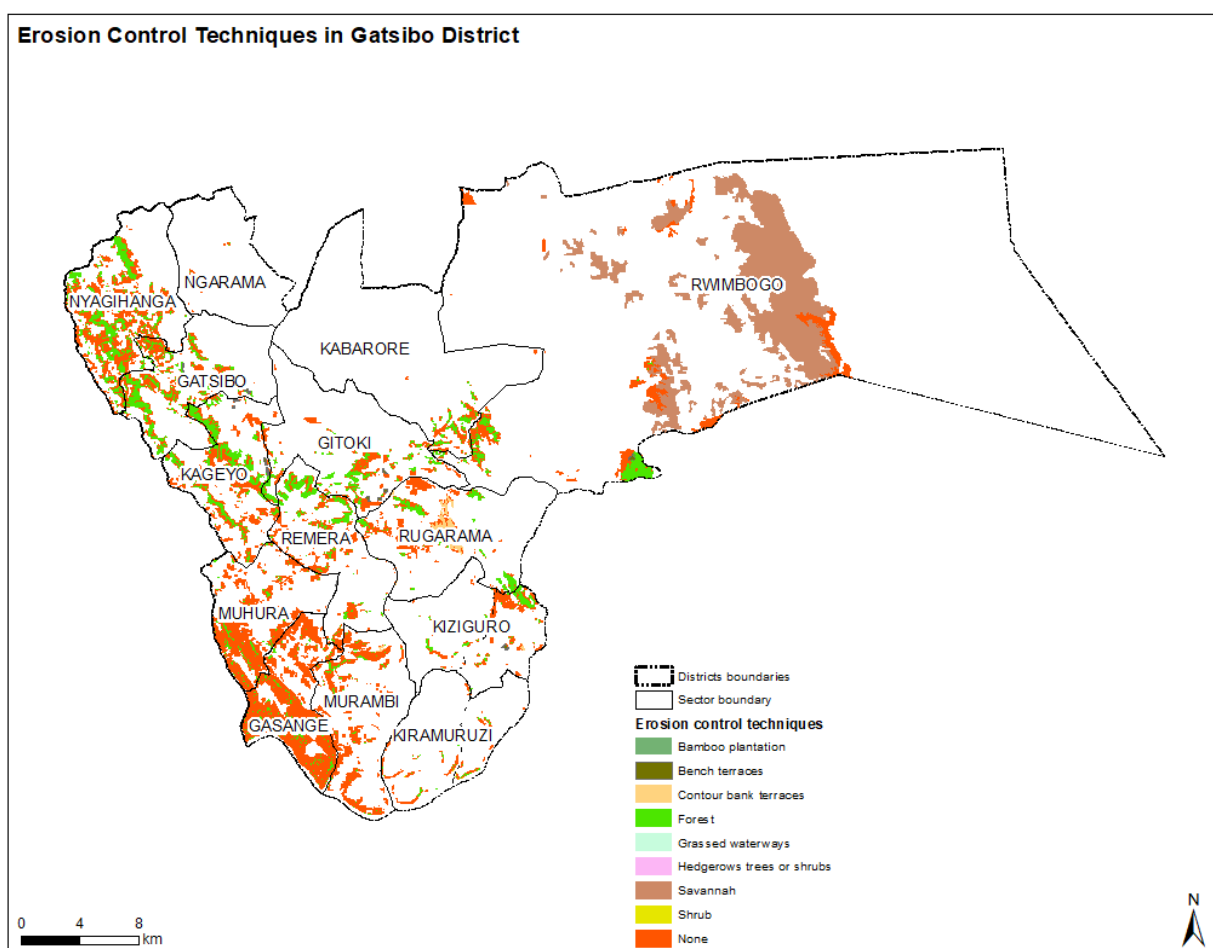
**Figure 117: Land cover types in Gatsibo District**

About existing erosion control practices in Gatsibo district, Table 118 shows that 47% of land at risk is protected by forests (4528 hectares), contour bank terraces (266 hectares) and some bench terraces (81 hectares). The highest protected sectors are Rwimbogo with 85% of its land at risk protected, followed by Gatsibo where 44% of the total land at risk is protected and Rugarama with 45% of land protected. The least protected sectors are Ngarama with less than 1% protected, Gasange (6% protected), Muhura (8%) and Murambi (8% of the total land at risk protected).

**Table 119: Erosion control practices already in place in Gatsibo District**

Sector Name	Erosion control in place					Total protect ed	None	Grand Total	% Protec ted
	Benc h terraces	Conto ur bank terrace s	Fores t	Savanna h	Shru b				
RWIMBOGO	19		433	7216	1	7668	1374	9043	85%
RUGARAMA		243	283			526	640	1166	45%
GATSIBO	13	3	588			603	774	1377	44%
GITOKI	21		391			412	589	1001	41%
KAGEYO	13		720			733	1104	1837	40%

Sector Name	Erosion control in place					Total protect ed	None	Grand Total	% Protec ted
	Benc h terraces	Contour bank terraces	Forest	Savannah	Shrub				
REMERA			421			421	729	1150	37%
KABARORE			139			139	250	389	36%
NYAGIHANGA		2	907			909	1825	2733	33%
KIZIGURO	11	7	195			213	483	696	31%
KIRAMURUZI			41		4	44	247	291	15%
MURAMBI		12	94			106	1144	1250	8%
MUHURA	5		137			142	1561	1703	8%
GASANGE			178			178	2702	2880	6%
NGARAMA						0	32	32	0%
<b>Grand Total</b>	<b>81</b>	<b>266</b>	<b>4528</b>	<b>7216</b>	<b>5</b>	<b>12095</b>	<b>13453</b>	<b>25548</b>	<b>47%</b>



**Figure 118: Erosion control techniques in place in Gatsibo District**

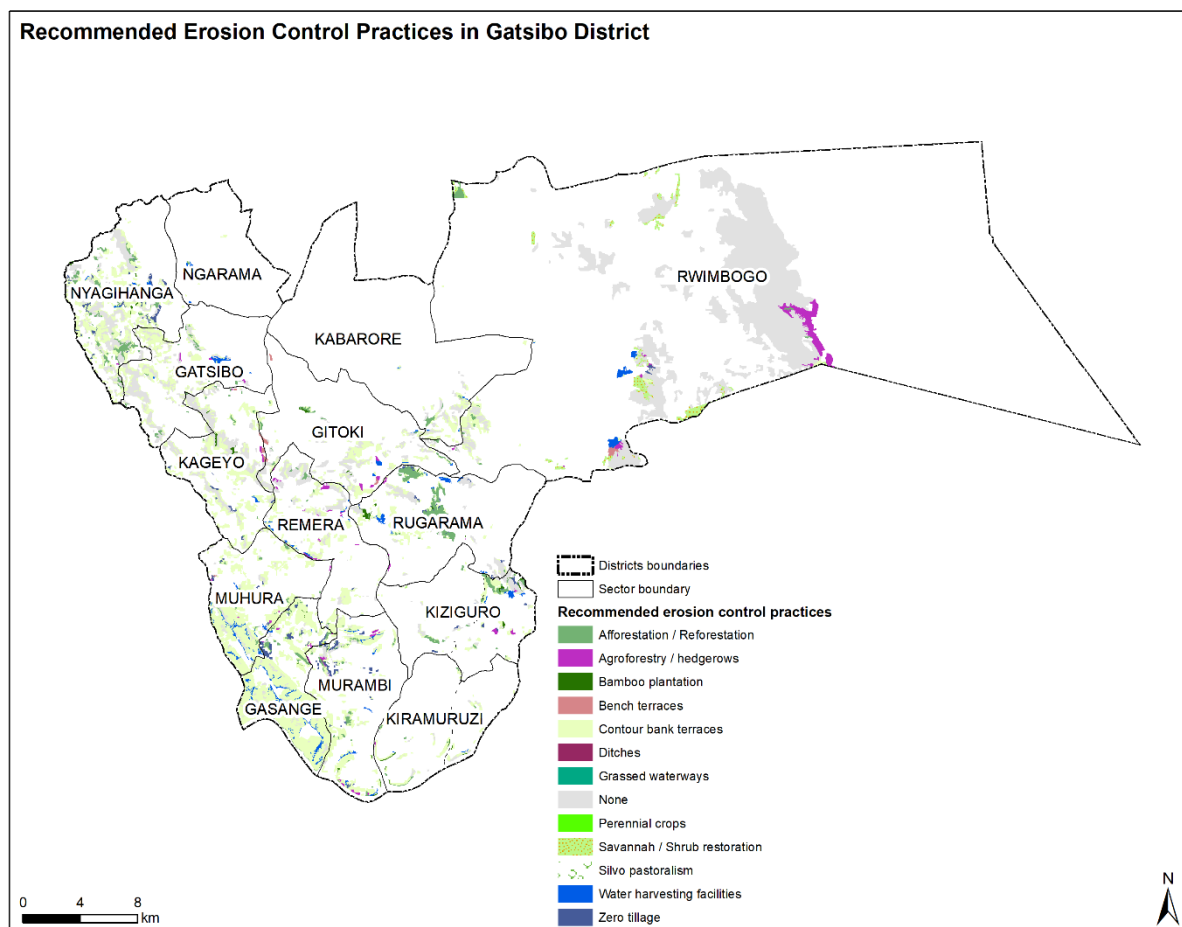


Erosion control practices in Gatsibo District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 119 shows that about 10123 hectares (which is 40% of the total land at risk) are suitable for Contour bank terraces, 569 hectares are Agroforestry/Hedgerows and 1231 hectares are Afforestation & Reforestation. Other interventions are 150 hectares of bamboo to close gullies and protect river banks and 649 hectares of water harvesting facilities. Savannah and shrub will need to be rehabilitated on an area of 504 hectares.

**Table 120: Recommended erosion control practices in Gatsibo District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	None	Savannah / Shrub restoration	Water harvesting facilities	Zero tillage	Grand Total
GASANGE	84	11	2		2364	178	3	150	88	2880
GATSIBO	55	16		4	682	588		33		1377
GITOKI	46	22	10	28	479	391		23	2	1001
KABARORE	30				213	139		7		389
KAGEYO	29	13	33	21	986	720		7	27	1837
KIRAMURUZI	22	2	15		205	44		4		291
KIZIGURO	122	20	22		233	195	3	56	44	696
MUHURA	51	9	1	3	1388	139		95	17	1703
MURAMBI	77	41	13		866	94		44	114	1250
NGARAMA	3				14			15		32
NYAGIHANGA	256	3	22		1399	907		23	124	2733
REMERA	22	51			617	421		28	12	1150
RUGARAMA	340	13	31		391	277		63	50	1166
RWIMBOGO	94	370		30	285	7650	498	101	15	9043
<b>Grand Total</b>	<b>1231</b>	<b>569</b>	<b>150</b>	<b>85</b>	<b>10123</b>	<b>11744</b>	<b>504</b>	<b>649</b>	<b>492</b>	<b>25548</b>
<b>%</b>	<b>5%</b>	<b>2%</b>	<b>1%</b>	<b>0%</b>	<b>40%</b>	<b>46%</b>	<b>2%</b>	<b>3%</b>	<b>2%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

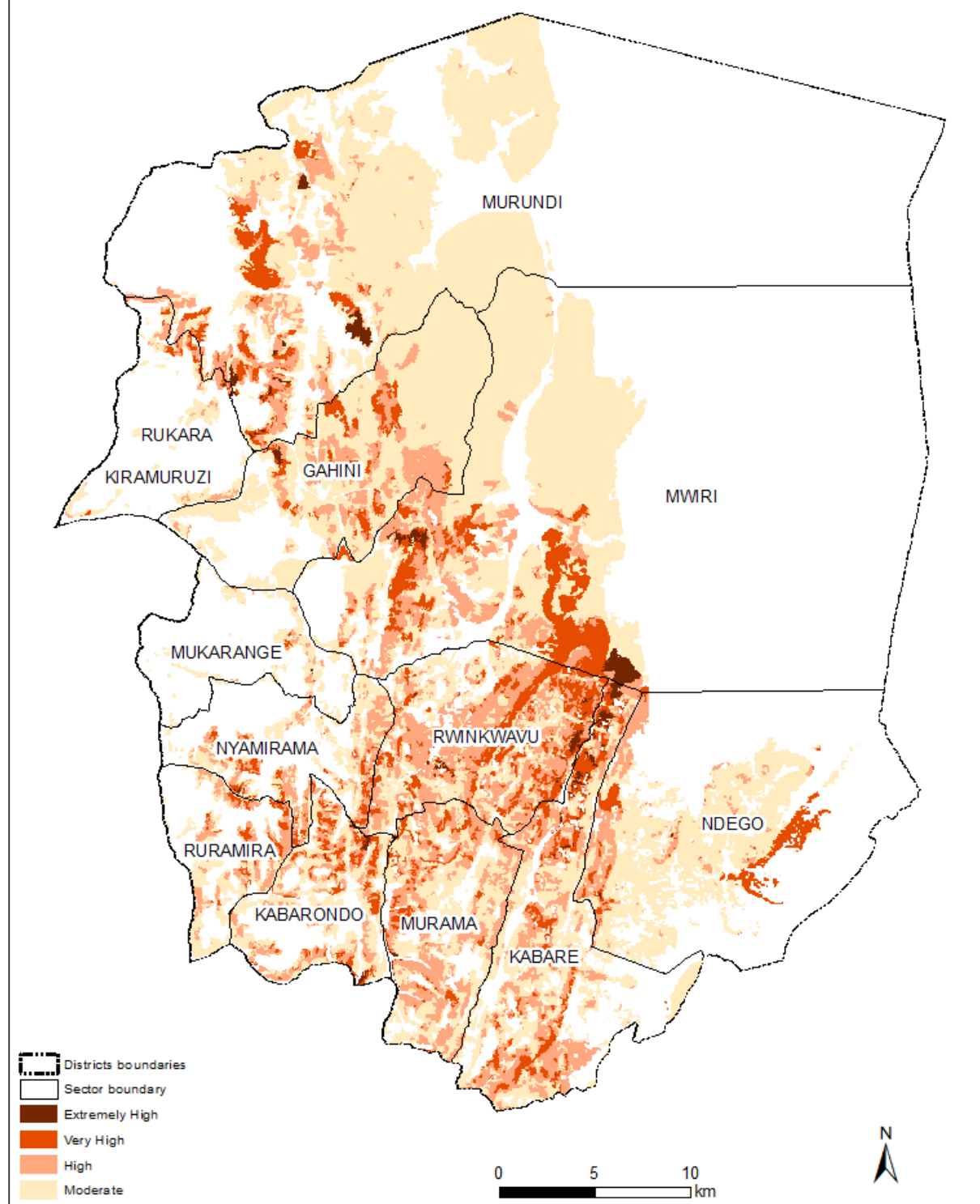


**Figure 119: Recommended erosion control practices in Gatsibo District**

### 3.4.3. Erosion status in Kayonza District

Erosion risk in Kayonza is summarised in Table 120 and presented in figure 120. Erosion risk in Kayonza District is estimated to 83008 hectares; about 46% of the total district land are highly susceptible to moderate and high erosion of which 7689 hectares are located in Rwinkwavu sector (86% of sector land), 9491 hectares are located in Gahini sector (81% of sector land), 5605 hectares are located in Murama (79% of the sector land), and 7803 hectares are found in Kabare sector about 79% of the sector land. The least sectors are Mukarange with only 915 hectares (17% of the sector land) susceptible to erosion, Rukara with 1158 hectares (18%), Murundi with 17884 hectares of the total sector land (36% of the total sector land) and Mwiri with 17240 hectares, about 37% of the total sector land. As compared to other districts in Eastern Province, Kayonza is the second susceptible to erosion.

# Erosion risk in Kayonza District



**Figure 120: Erosion risk in Kayonza District**

**Table 121: Erosion risk per sector in Kayonza District**

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	High	Moderate	Very High	Grand Total		
RWINKWAVU	90	1506	3457	2635	7689	8923	86%
GAHINI	34	566	1748	7142	9491	11712	81%
MURAMA	18	427	2302	2857	5605	7061	79%
KABARE	167	993	2727	3916	7803	11210	70%
KABARONDO	52	456	1021	1946	3476	5503	63%
NYAMIRAMA	11	319	921	1458	2708	5946	46%
RURAMIRA	4	223	656	1014	1897	4190	45%
NDEGO	3	675	1063	5400	7141	16772	43%
MWIRI	288	2147	2674	12131	17240	46052	37%
MURUNDI	245	1116	2000	14523	17884	50230	36%
RUKARA	3	93	325	737	1158	6101	19%
MUKARANGE	2	17	106	791	915	5426	17%
<b>Grand Total</b>	<b>918</b>	<b>8540</b>	<b>19000</b>	<b>54550</b>	<b>83008</b>	<b>179128</b>	<b>46%</b>

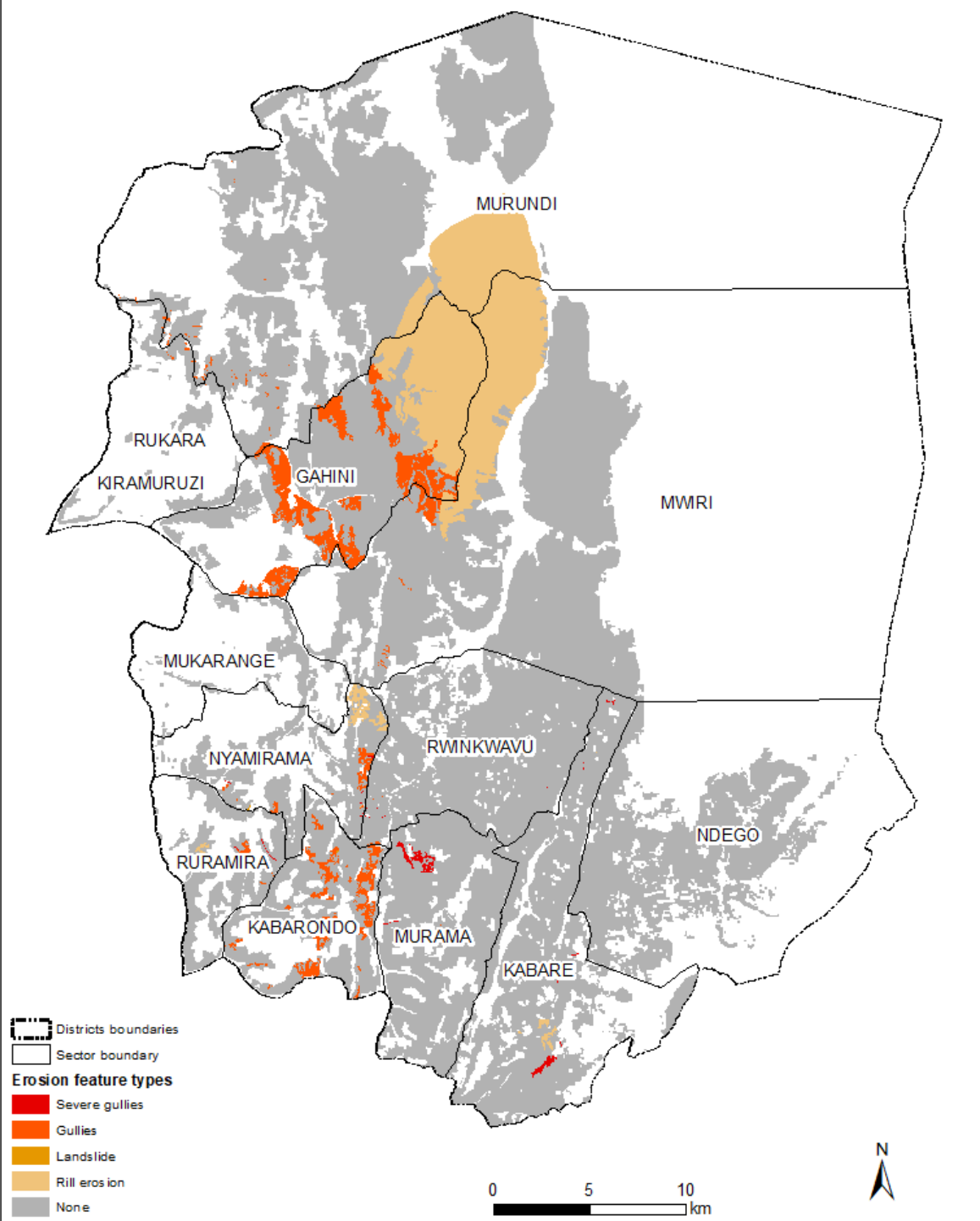
Land areas affected by erosive features in Kayonza District are summarized in Table 121 and the map of erosive features are presented in Figure 121. The results show that Gahini sector is the worst affected by gullies and rill erosion on areas estimated to 4681 hectares (49% of sector land at risk), followed by Mwiri sector on 3234 hectares (19% of sector land at risk), and Kabarondo sector on 593 hectares (17% of sector land at risk) and Murundi on 2442 hectares (14% of sector land at risk). The presence of gullies in Gahini, Mwiri and Kabarondo sectors confirms the findings of CROM model; however reduced presence of gullies in Rwinkwavu, Rukara and Kabare and the absence of gullies in Ndego and Mukarange which were originally predicted by CROM model as sectors at high risk should not read that the CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed erosion features, or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. The least sectors affected by gullies are Ndego, Mukarange and Rwinkwavu where we observe the quasi absence of erosive features, while Rukara, Kabare, Murama and Ruramira are affected with erosive features at less than 5% of the total sector land.

**Table 122: Erosive features and areas affected in Kayonza District**

Sector Name	Erosion feature				Total Features	None	Grand Total	% features
	Gullies	Land slide	Rill erosion	Severe gullies				
GAHINI	1775		2906		4681	4810	9491	49%
MWIRI	166		3068		3234	14006	17240	19%
KABARONDO	592	1			593	2882	3476	17%
MURUNDI	66		2376		2442	15442	17884	14%

Sector Name	Erosion feature				Total Feature s	None	Grand Total	% features
	Gullies	Land slide	Rill erosion	Severe gullies				
NYAMIRAMA	108	3	181	5	297	2412	2708	11%
RURAMIRA	54		17	8	80	1817	1897	4%
MURAMA	2			97	99	5506	5605	2%
KABARE			54	57	111	7692	7803	1%
RUKARA	11				11	1147	1158	1%
RWINKWAVU	10			8	18	7670	7689	0%
MUKARANGE					0	915	915	0%
NDEGO					0	7141	7141	0%
<b>Grand Total</b>	<b>2784</b>	<b>4</b>	<b>8603</b>	<b>175</b>	<b>11566</b>	<b>71442</b>	<b>83008</b>	<b>14%</b>

### Erosion feature types in Kayonza District



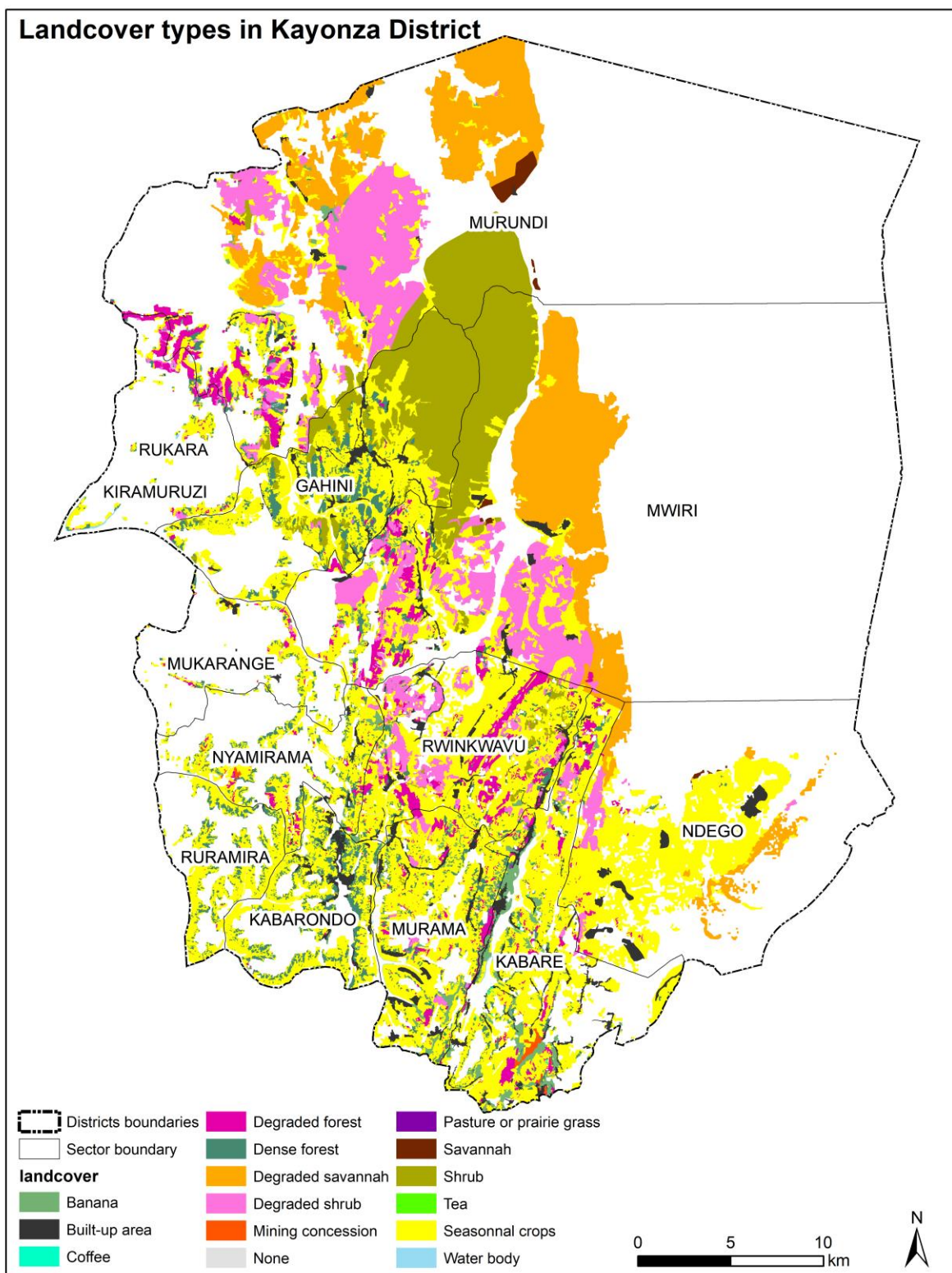
**Figure 121: Erosive features detected in Kayonza District**



In term of land use and land cover of areas at risk in Kayonza District, the results of land cover mapping (Table 122 and Figure 122) show 37725 hectares (45% of the total land at risk) are used for seasonal cropping, 3950 hectares (5% of the total land at risk) are covered by healthy forests, 3338 hectares (4% of the total land at risk) are covered by built-up areas and 1409 hectares i.e. 2% are covered by Banana crop. In Kayonza district there are also mining and quarries sites, and coffee plantations which cover respectively 112 hectares (less than 1% of the total land at risk) and 11 hectares (less than 1% of the total land at risk). Other landcover types are shrub with 9867 hectares (12% of the total land at moderate risk), degraded shrub on 10046 hectares (12%), degraded savannah on 12485 hectares (15%) and degraded forests on 3470 hectares (4% of the total land at risk).

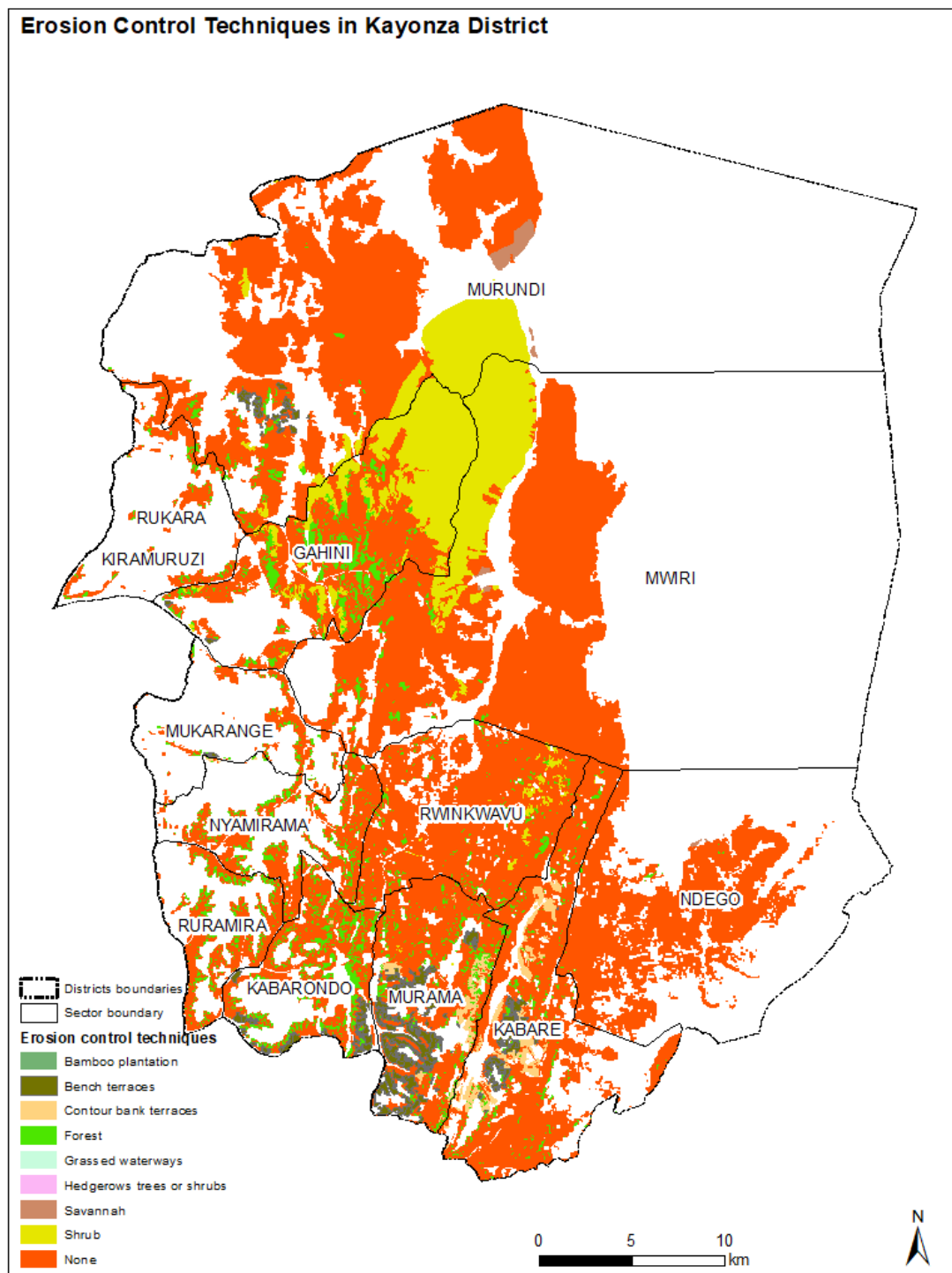
**Table 123: Land Use and Vegetation Cover (LUVC) for land at risk in Kayonza District**

Sector Name	Bana na	Built -up area	Coff ee	Degra ded forest	Degra ded savan nah	Degra ded shrub	Dense forest	Minin g and Quar ries	Non e	Sav ann ah	Seaso nal crops	Shru b	Water body	Grand Total
GAHINI	5	388		29		48	950				4337	3733	1	9491
KABARE	782	656	11	461	69	152	295	84			5276	7	10	7803
KABARONDO	71	330		6			727				2342			3476
MUKARANGE		64		59		10	104				672	7		915
MURAMA	237	418		254		142	419	5			4110	9	11	5605
MURUNDI	142	252		675	5926	4777	242		59	287	2885	2628	13	17884
MWIRI	111	376		580	5548	3418	183		23	37	3709	3254		17240
NDEGO		362		69	930	360	18			18	5383		1	7141
NYAMIRAMA	83	83		137		16	380	20			1987		2	2708
RUKARA	6	4		295		87	98		13		626		27	1158
RURAMIRA	8	5		7			305				1571		1	1897
RWINKWAVU	44	400		898	13	1035	229	3	9		4828	230		7689
<b>Grand Total</b>	<b>1490</b>	<b>3338</b>	<b>11</b>	<b>3470</b>	<b>12485</b>	<b>10046</b>	<b>3950</b>	<b>112</b>	<b>105</b>	<b>342</b>	<b>37725</b>	<b>9867</b>	<b>67</b>	<b>83008</b>
<b>%</b>	<b>2%</b>	<b>4%</b>	<b>0%</b>	<b>4%</b>	<b>15%</b>	<b>12%</b>	<b>5%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>45%</b>	<b>12%</b>	<b>0%</b>	<b>100%</b>



**Figure 122: Land cover types in Kayonza District**

About existing erosion control practices in Kayonza district, Table 123 shows that only 21% of land at risk is protected by forests (3979 hectares), Contour bank terraces (1176 hectares), bench terraces (1971 hectares), shrub (9867 hectares) and savannah (342 hectares). The highest protected sectors are Gahini with 50% of its land at risk protected, followed by Murama where 35% of the total land at risk is protected and Kabarondo with 30% of land protected. The least protected sectors are Rwinkwavu with only 1% protected, Ruramira (only 6%), Rukara (8%) and Nyamirama (13% protected).



**Figure 123: Erosion control techniques in place in Kayonza District**

**Table 124: Erosion control practices already in place in Kayonza District**

Sector Name	Erosion control in place					Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest	Savannah	Shrub				
GAHINI	18		950		3733	4701	4790	9491	50%
KABARE	1101	390	434		9	1934	3671	5605	35%
KABARONDO	283	4	740			1028	2448	3476	30%
MUKARANGE			183	37	3254	3474	13766	17240	20%
MURAMA	189		242	287	2628	3346	14539	17884	19%
MURUNDI	369	766	295		7	1437	6366	7803	18%
MWIRI			305			305	1592	1897	16%
NDEGO		16	380			396	2312	2708	15%
NYAMIRAMA	10		104		7	120	795	915	13%
RUKARA			98			98	1060	1158	8%
RURAMIRA			229		230	459	7230	7689	6%
RWINKWAVU			18	18		36	7105	7141	1%
<b>Grand Total</b>	<b>1971</b>	<b>1176</b>	<b>3979</b>	<b>342</b>	<b>9867</b>	<b>17335</b>	<b>65673</b>	<b>83008</b>	<b>21%</b>

Erosion control practices in Kayonza District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 124 shows that about 31065 hectares (which is 37% of the total land at risk) are suitable for Contour bank terraces, 3690 hectares are Afforestation & Reforestation and 5190 hectares of cropland that need agroforestry/hedgerows cropping. Other interventions are 273 hectares for Bamboo to close gullies and protect river banks, 42Ha ditches and 3338Ha for water harvesting facilities. Savannah and shrub will need to be rehabilitated on an estimated area of 22541 ha.

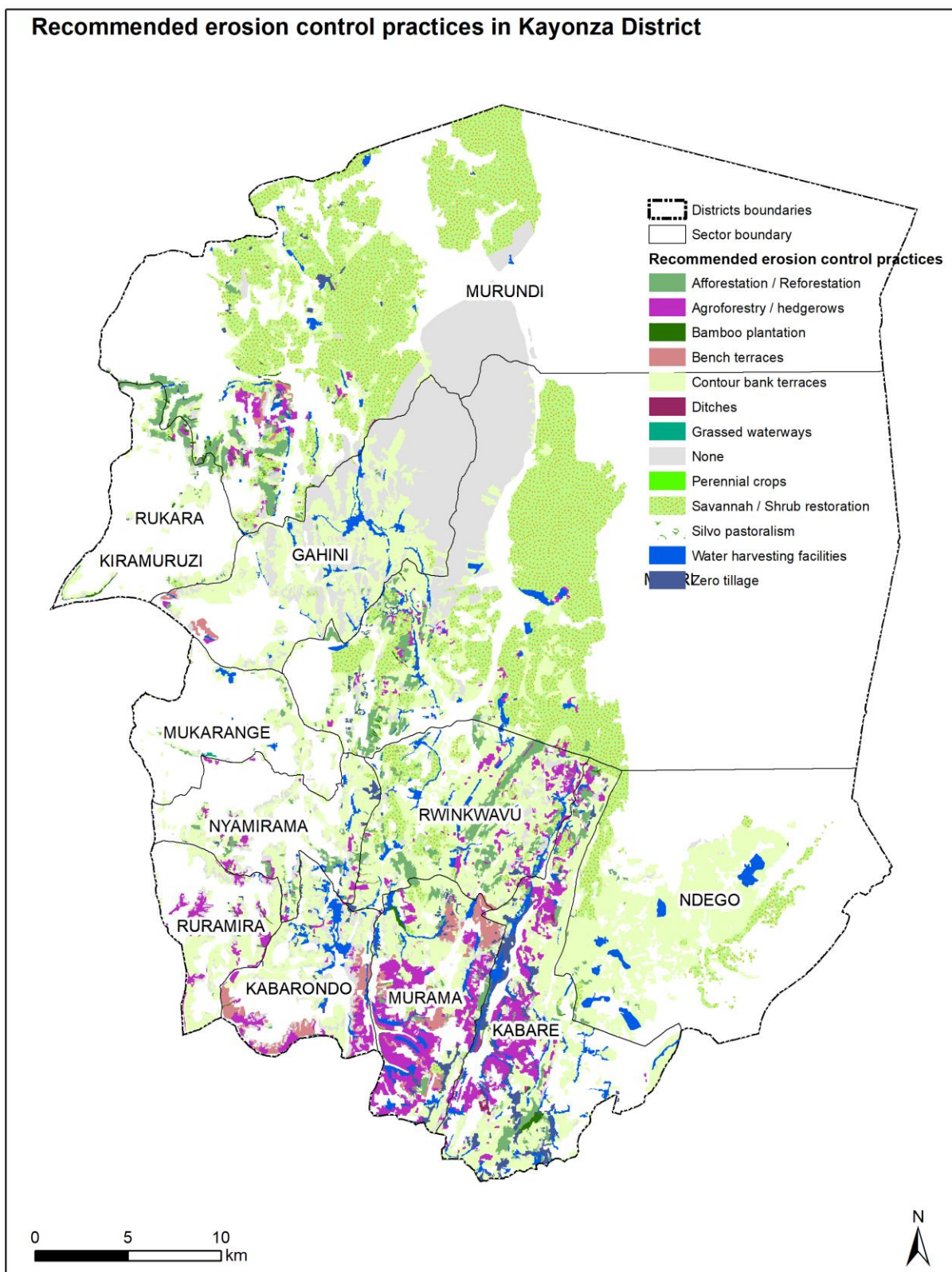
**Table 125: Recommended erosion control practices in Kayonza District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Ditches	Grassed waterways	None	Savannah / Shrub restoration	Water harvesting facilities	Zero tillage	Grand Total
GAHINI	32	18	1	89	4224			4683	51	388	5	9491
KABARE	554	1452	71	17	3716	42		324	221	656	749	7803
KABARONDO	9	423	3	388	1523			729		330	71	3476
MUKARANGE	59				662		10	110	10	64		915
MURAMA	262	1672	40	601	1805			428	142	418	237	5605
MURUNDI	686	323	61	103	2453			3157	10708	252	142	17884
MWIRI	584	204	19		3506			3474	8967	376	111	17240
NDEGO	69		1		5383			36	1290	362		7141
NYAMIRAMA	230	215	6		1696			380	16	83	83	2708
RUKARA	297	20	38		606			98	87	4	6	1158
RURAMIRA	7	321	23		1221			311		5	8	1897
RWINKWAVU	900	542	9	15	4271			459	1048	400	44	7689
<b>Grand Total</b>	<b>3690</b>	<b>5190</b>	<b>273</b>	<b>1213</b>	<b>31065</b>	<b>42</b>	<b>10</b>	<b>14190</b>	<b>22541</b>	<b>3338</b>	<b>1456</b>	<b>83008</b>
<b>%</b>	<b>4%</b>	<b>6%</b>	<b>0%</b>	<b>1%</b>	<b>37%</b>	<b>0%</b>	<b>0%</b>	<b>17%</b>	<b>27%</b>	<b>4%</b>	<b>2%</b>	<b>100%</b>

Others interventions: 35Ha Contour bank, 16Ha Grassed waterways

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



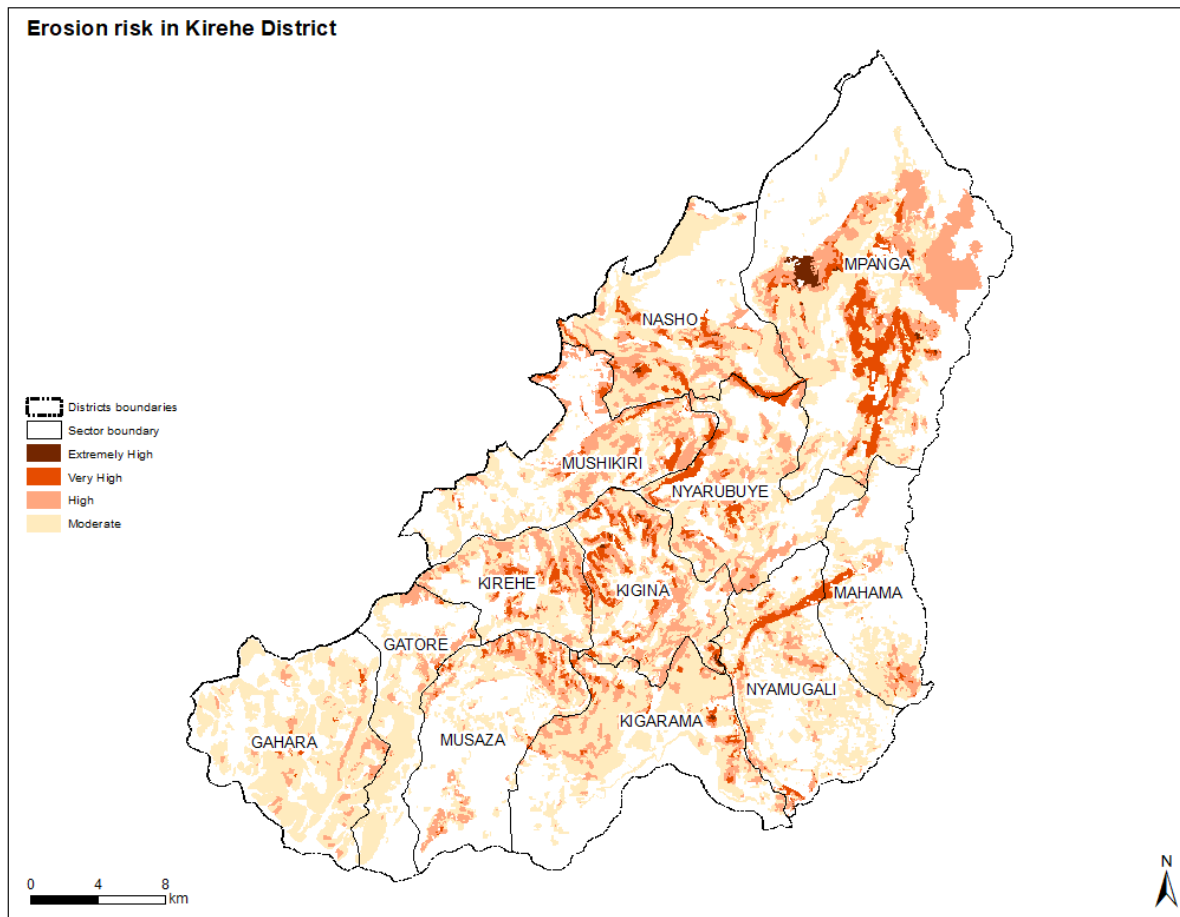


**Figure 124: Recommended erosion control practices in Kayonza District**



### 3.4.4. Erosion control status Kirehe District

Erosion risk in Kirehe is summarised in Table 77 and presented in figure 44. Erosion risk in Kirehe District is estimated to 61615 hectares; about 52% of the total district land are highly susceptible to erosion of which 4987 hectares are located in Kigina sector (72% of sector land), 3266 hectares are located in Kirehe sector (65% of sector land), 5853 hectares are located in Nasho (64% of the sector land), and 5324 hectares are found in Nyarubuye sector about 61% of the sector land. The least sectors are Mahama with only 2322 hectares (34% of the sector land) susceptible to erosion and Musaza with 3322 hectares (37%). As compared to other districts in Eastern Province, Kirehe is the first susceptible to erosion.



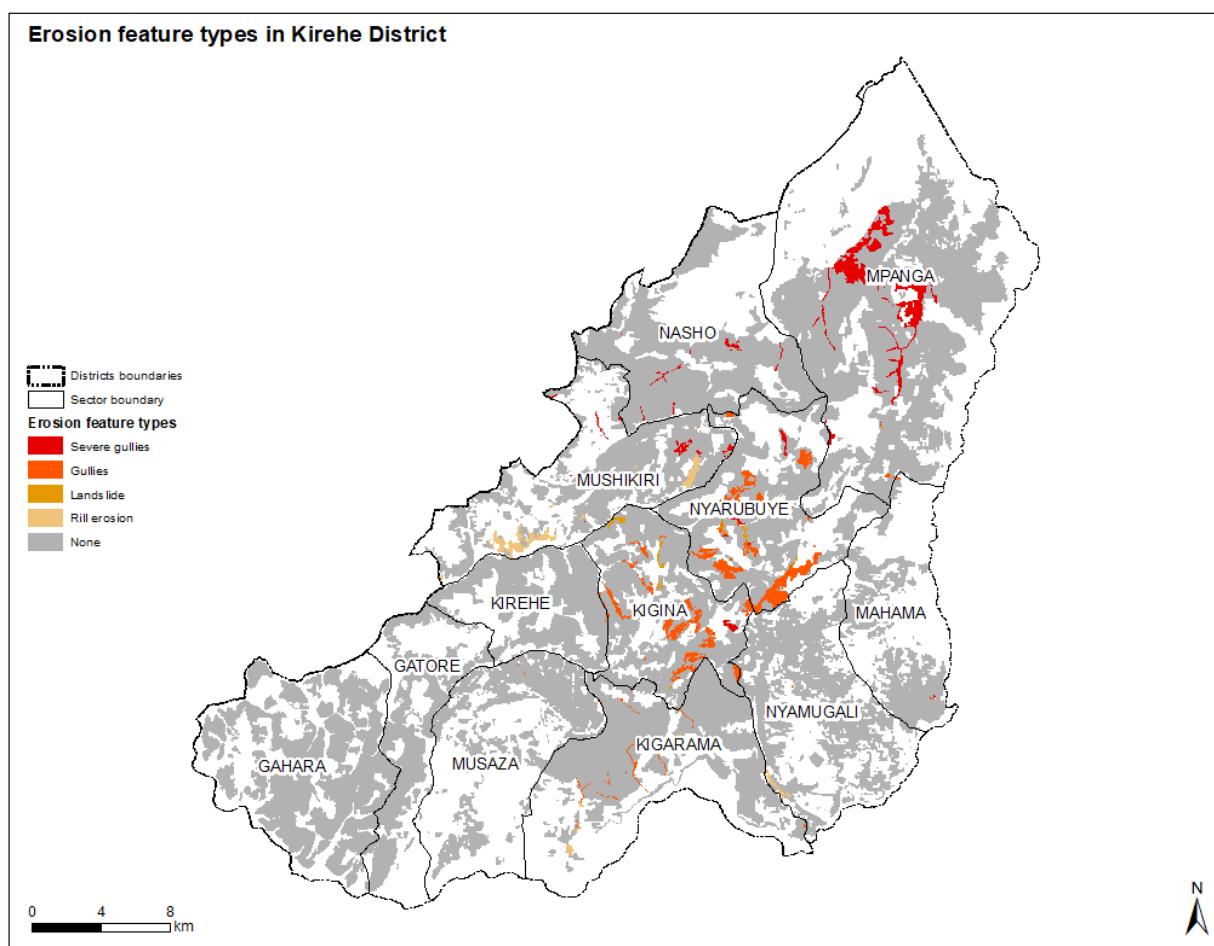
**Figure 125: Erosion risk in Kirehe District**

**Table 126: Erosion risk per sector in Kirehe District**

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
KIGINA	44	708	1669	2566	4987	6893	72%
KIREHE	7	363	1041	1856	3266	5004	65%
NASHO	19	565	1376	3893	5853	9090	64%
NYARUBUYE	6	543	1599	3177	5324	8661	61%
GAHARA		48	714	5577	6338	10897	58%
KIGARAMA	6	206	1191	4423	5827	11339	51%

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MUSHIKIRI	3	370	1789	2714	4876	9494	51%
MPANGA	244	1794	3924	5850	11812	23077	51%
NYAMUGALI	7	392	694	3717	4810	9518	51%
GATORE		26	429	2405	2859	6032	47%
MUSAZA		164	998	2161	3322	9052	37%
MAHAMA		139	422	1762	2322	6757	34%
<b>Grand Total</b>	<b>336</b>	<b>5319</b>	<b>15845</b>	<b>40098</b>	<b>61597</b>	<b>115813</b>	<b>53%</b>

Land areas affected by erosive features in Kirehe District are summarized in Table 126 and the map of erosive features are presented in Figure 126. The results show that Nyarubuye sector is the worst mostly affected by gullies on areas estimated to 820 hectares (15% of sector land at risk), followed by Kigina sector on 600 hectares (12% of sector land at risk), and Mushikiri sector on 392 hectares (8% of sector land at risk). The presence of rill erosion in some of Kirehe sectors confirms the findings of CROM model. The least sectors affected by rill erosion are Gatore and Gahara where any erosion feature was detected, and Kirehe, Musaza, Muhama where little erosive features were detected on an area of less than 5 hectares.

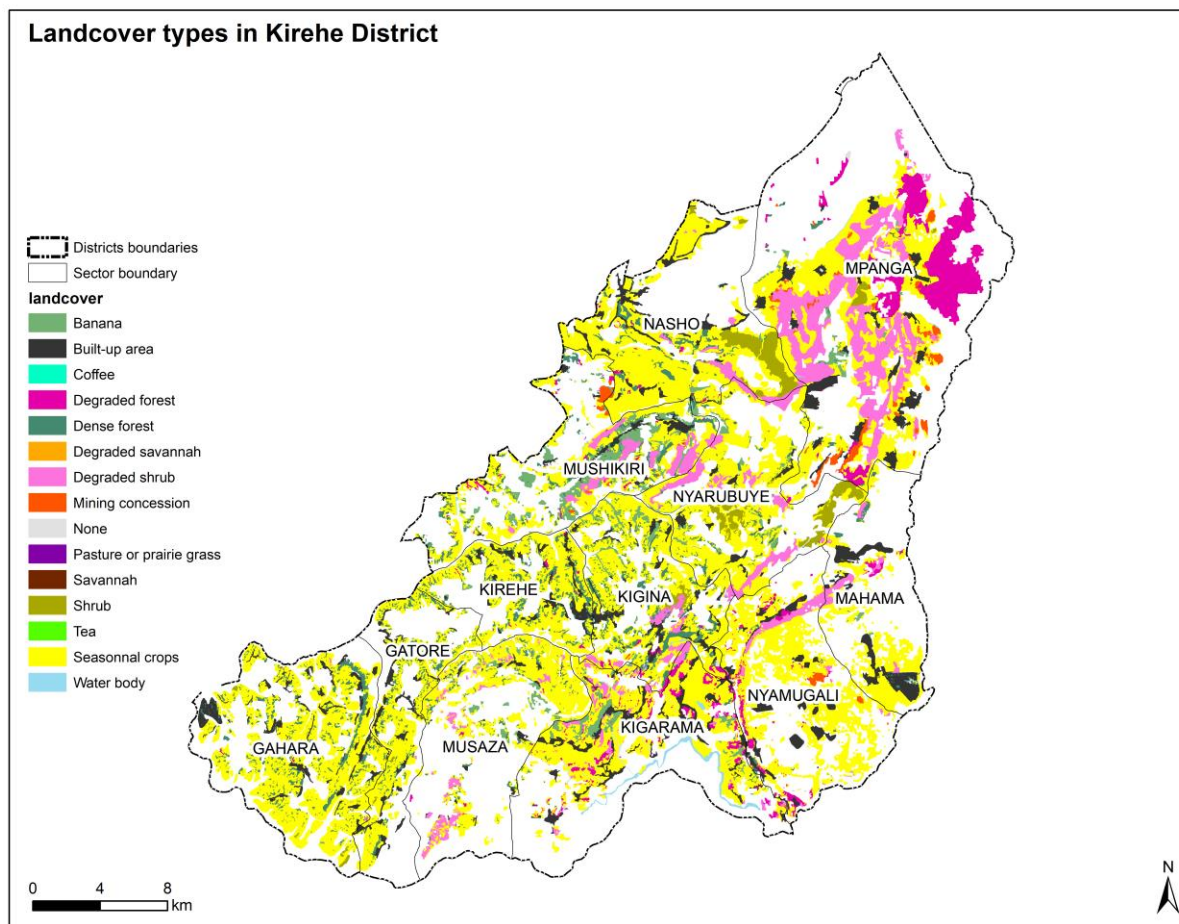


**Figure 126: Erosive features detected in Kirehe District**

**Table 127: Erosive features and areas affected in Kirehe District**

Sector Name	Erosion feature				Total Feature s	None	Grand Total	% feature s
	Gullie s	Landslide	Rill erosio n	Severe gullies				
NYARUBUYE	741	34		45	820	4504	5324	15%
KIGINA	509	65		26	600	4387	4987	12%
MUSHIKIRI	9		297	87	392	4484	4876	8%
MPANGA	9	2		834	844	10968	11812	7%
KIGARAMA	90		37	1	128	5698	5827	2%
NASHO				69	69	5784	5853	1%
NYAMUGALI	10		47		56	4754	4810	1%
MAHAMA	5			2	6	2316	2322	0%
KIREHE	2				2	3264	3266	0%
MUSAZA	2				2	3321	3322	0%
GAHARA					0	6338	6338	0%
GATORE					0	2859	2859	0%
<b>Grand Total</b>	<b>1376</b>	<b>101</b>	<b>380</b>	<b>1063</b>	<b>2921</b>	<b>58677</b>	<b>61597</b>	<b>5%</b>

In term of land use and land cover of areas at risk in Kirehe, the results of land cover mapping (Table 127 and Figure 127) show that 38349 hectares (62% of the total land at risk) are used for seasonal cropping, 3278 hectares (5% of the total land at risk) are covered by healthy forests, 5766 hectares (9% of the total land at risk) are covered by built-up areas, 2169 hectares i.e. 4% are covered by Banana crop, degraded forests and degraded shrub are covering an area of 3152 hectares (5%) and 6346 hectares (10% of total land at risk) respectively. In Kirehe district, Mining and Quarries cover an area of 646 hectares (1% of total land at risk).

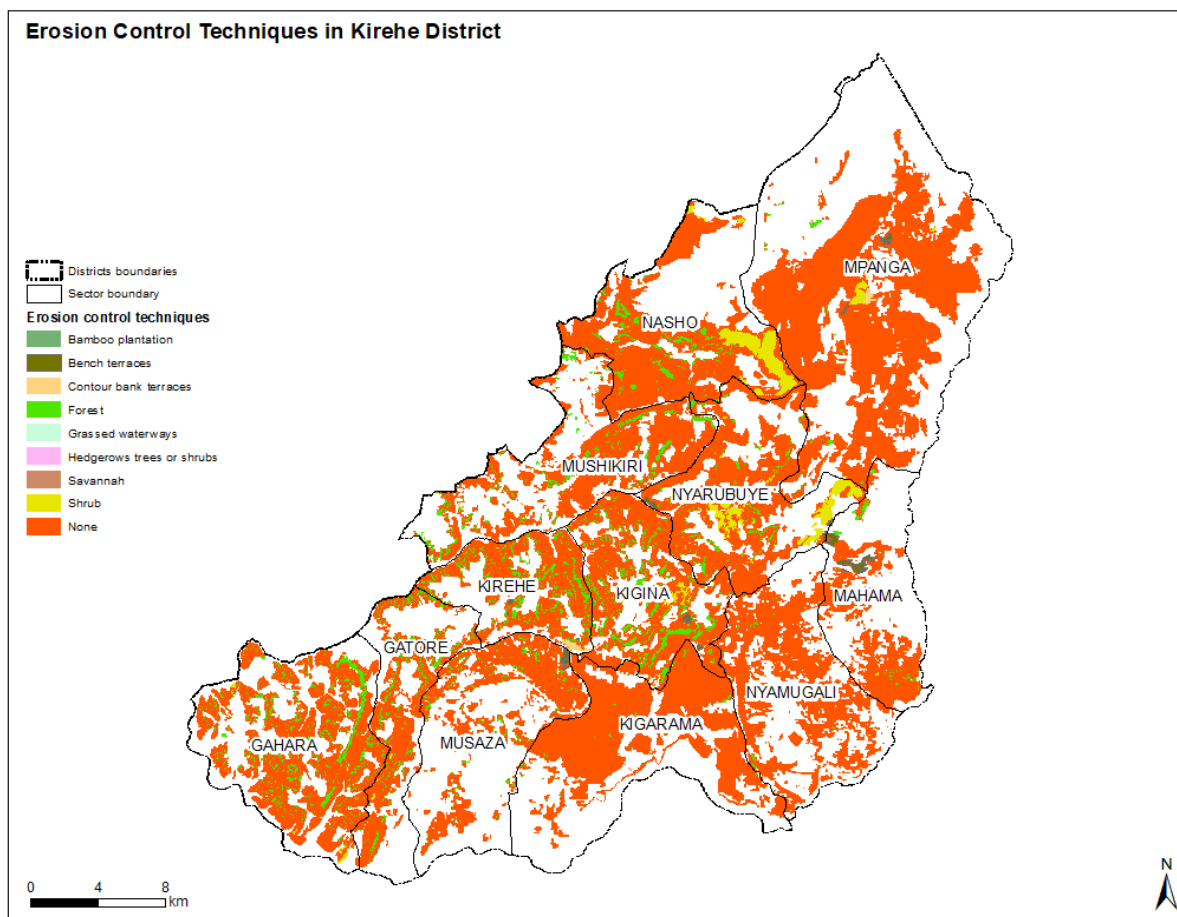


**Figure 127: Land cover types in Kirehe District**

**Table 128: Land Use and Vegetation Cover (LUVC) for land at risk in Kirehe District**

Sector Name	Banana	Built-up area	Degraded forest	Degraded shrub	Dense forest	Mining and Quarries	None	Seasonal crops	Shrub	Water body	Grand Total
GAHARA	4	653	6	9	591	1		5036	38		6338
GATORE	8	385	1	2	301			2150	12		2859
KIGARAMA	362	725	392	318	30	2	100	3670	2	224	5827
KIGINA	230	458	80	283	608	5	22	3171	120	11	4987
KIREHE	30	374	25		467			2356	6	8	3266
MAHAMA	20	589	45	180	64		3	1418	4		2322
MPANGA	176	890	2204	3367	60	462	24	4521	95	13	11812
MUSAZA	199	117	18	346	155		2	2484	1		3322
MUSHIKIRI	917	292	88	607	458	105		2400	1	9	4876
NASHO	36	542	38	219	316	9		4095	591	7	5853
NYAMUGALI	3	533	252	282	28	62	5	3645			4810
NYARUBUYE	184	208	3	733	200		10	3402	584		5324
<b>Grand Total</b>	<b>2169</b>	<b>5766</b>	<b>3152</b>	<b>6346</b>	<b>3278</b>	<b>646</b>	<b>166</b>	<b>38349</b>	<b>1454</b>	<b>271</b>	<b>61597</b>
<b>%</b>	<b>4%</b>	<b>9%</b>	<b>5%</b>	<b>10%</b>	<b>5%</b>	<b>1%</b>	<b>0%</b>	<b>62%</b>	<b>2%</b>	<b>0%</b>	<b>100%</b>

About existing erosion control practices in Kirehe district, Table 128 shows that only 8% of land at risk is protected by forests (3273 hectares) and Contour bank terraces (114 hectares) and bench terraces (273 hectares). The highest protected sectors are Kirehe with 17% of its land at risk protected, followed by Nasho where 15% of the total land at risk is protected and Nyarubuye with 15% of land protected. The least protected sectors are Kigarama with only 1% protected, Nyamugali with only 1% protected, and Mpanga (2%). It is noted that all sectors of Kirehe districts have erosion control in place extending an area of less than 20% of the total land affected by moderate to high erosion risk.



**Figure 128: Erosion control techniques in place in Kirehe District**

**Table 129: Erosion control practices already in place in Kirehe District**

Sector Name	Erosion control in place				Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest	Shrub				
KIREHE	20	49	466	6	541	2725	3266	17%
NASHO			314	591	905	4948	5853	15%
NYARUBUYE	34		200	584	818	4506	5324	15%
KIGINA	25		608	120	753	4234	4987	15%
GATORE			301	12	313	2547	2859	11%
GAHARA			591	38	629	5709	6338	10%



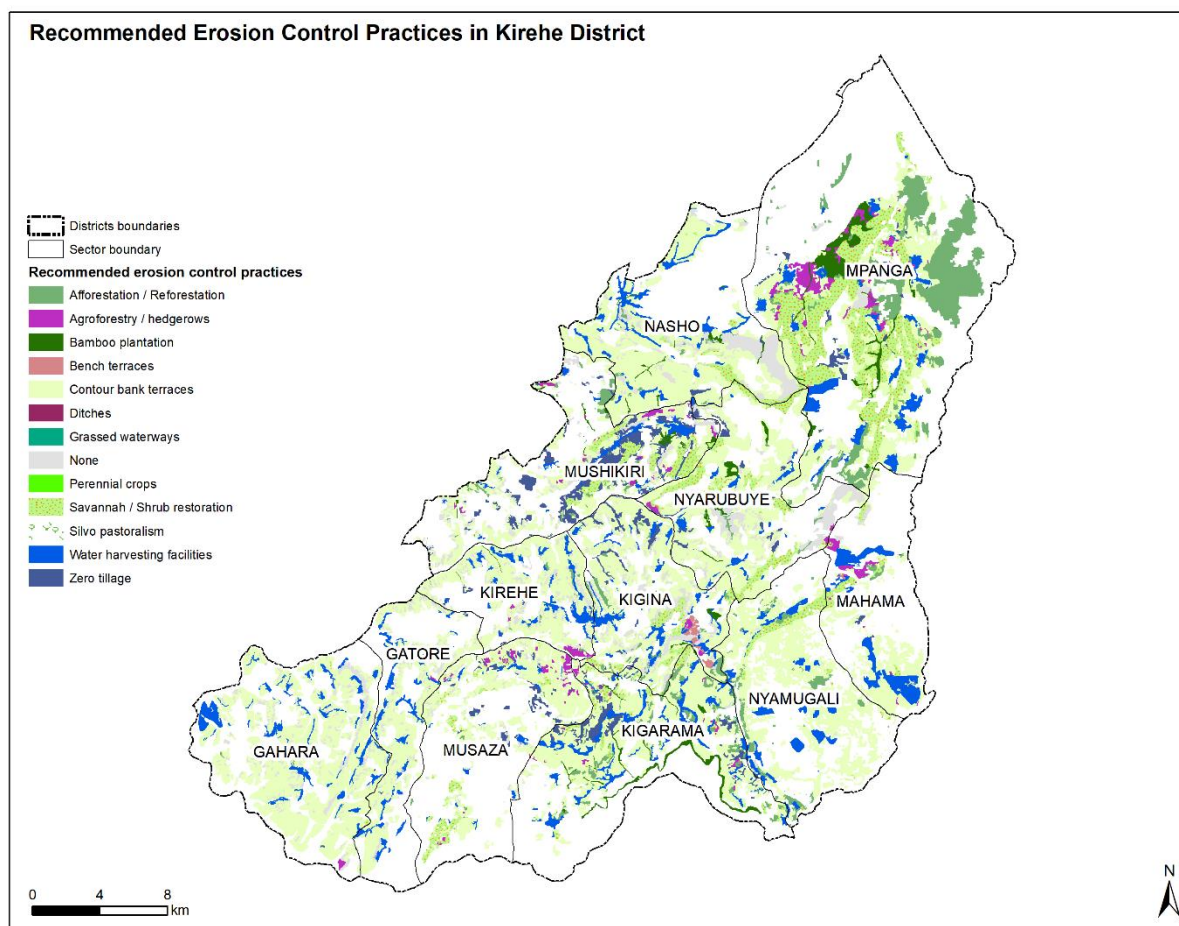
Sector Name	Erosion control in place				Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest	Shrub				
MUSHIKIRI		5	458	1	464	4412	4876	10%
MAHAMA	113		64	4	181	2141	2322	8%
MUSAZA	34		155	1	190	3132	3322	6%
MPANGA	47	60	60	95	261	11551	11812	2%
NYAMUGALI			27		27	4783	4810	1%
KIGARAMA	0		30	2	32	5794	5827	1%
<b>Grand Total</b>	<b>273</b>	<b>114</b>	<b>3273</b>	<b>1454</b>	<b>5114</b>	<b>56483</b>	<b>61597</b>	<b>8%</b>

Erosion control practices in Kirehe District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 129 shows that about 36107 hectares (which is 59% of the total land at risk) are suitable for Contour bank terraces, 4049 hectares are Afforestation & Reforestation and 1151 hectares of cropland that need agroforestry/hedgerows cropping. Other interventions are 5775 hectares for Storm water management facilities (SWMF), gullies and riverbanks amounting to 1252 hectares eroded which require bamboo trees for rehabilitation, 109 hectares of bench terraces.

**Table 130: Recommended erosion control practices in Kirehe District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	None	Savannah / Shrub restoration	Water harvesting facilities	Zero tillage	Grand Total
GAHARA	7	16			5020	629	9	653	4	6338
GATORE	1	5			2145	313	2	385	8	2859
KIGARAMA	410	64	310		3603	32	318	728	362	5827
KIGINA	193	26	38	98	2933	728	283	458	230	4987
KIREHE	49	69	8		2263	473		374	30	3266
MAHAMA	45	125	5	8	1281	68	180	590	20	2322
MPANGA	2687	517	606		3489	155	3292	890	176	11812
MUSAZA	18	136	2		2348	156	346	117	199	3322
MUSHIKIRI	193	156	97		2177	471	580	292	911	4876
NASHO	70	1	76		3998	911	219	542	36	5853
NYAMUGALI	325				3636	28	282	537	3	4810
NYARUBUYE	51	34	111	3	3214	784	733	210	184	5324
<b>Grand Total</b>	<b>4049</b>	<b>1151</b>	<b>1252</b>	<b>109</b>	<b>36107</b>	<b>4748</b>	<b>6244</b>	<b>5775</b>	<b>2163</b>	<b>61597</b>
<b>%</b>	<b>7%</b>	<b>2%</b>	<b>2%</b>	<b>0%</b>	<b>59%</b>	<b>8%</b>	<b>10%</b>	<b>9%</b>	<b>4%</b>	<b>100%</b>

**Note:** No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 129: Recommended erosion control practices in Kirehe District**

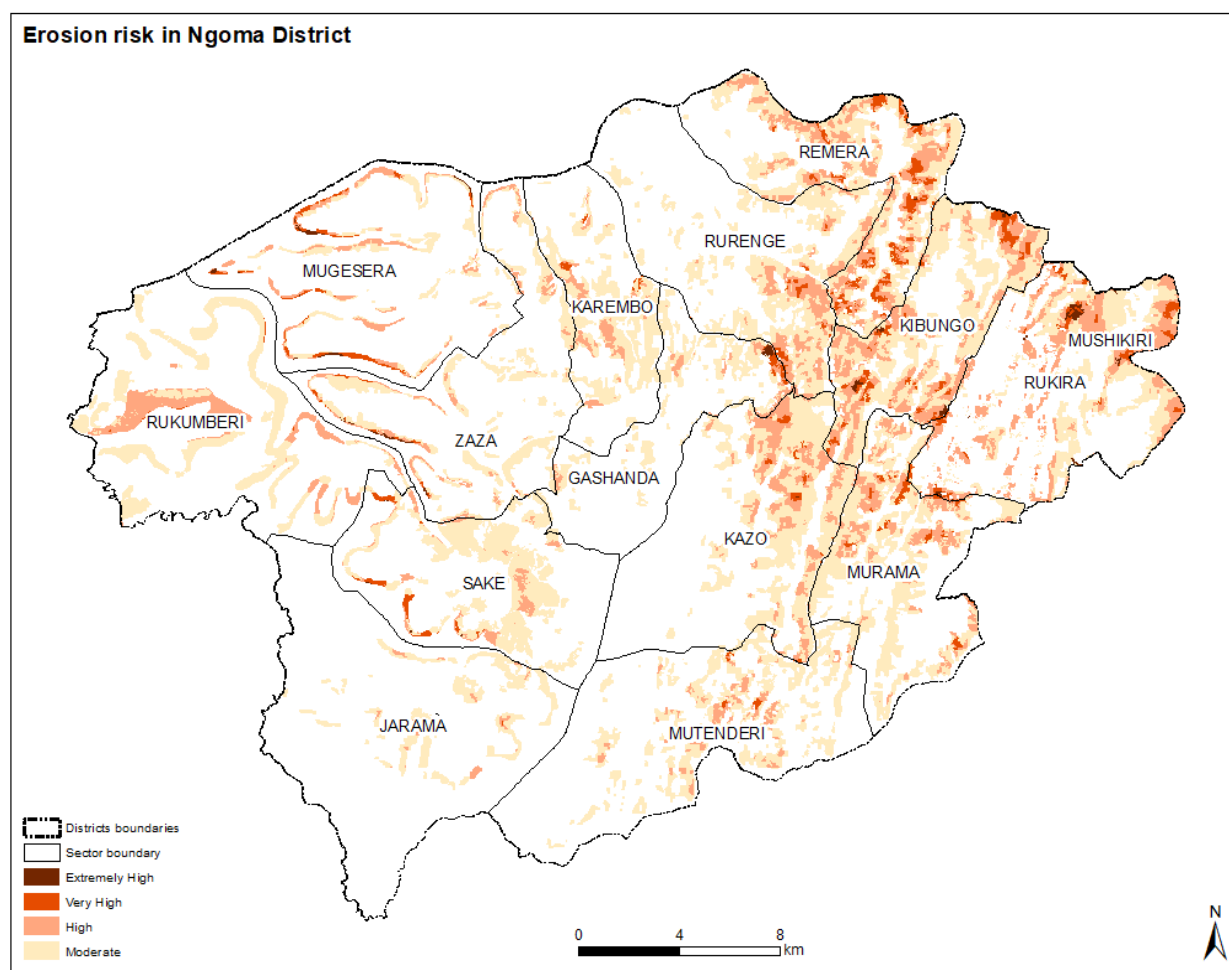
### 3.4.5. Erosion control status Ngoma District

Erosion risk in Ngoma District is summarised in Table 130 and presented in figure 130. Erosion risk in Ngoma District is estimated to 25966 hectares; about 32% of the total district land are highly susceptible to erosion of which 2971 hectares are located in Kibungo sector (70% of sector land), 2832 hectares are located in Remera sector (57% of sector land), 2359 hectares are located in Murama (47% of the sector land), and 2713 hectares are found in Rukira sector about 40% of the sector land. The least sectors are Jarama with 782 hectares (9% of the sector land) susceptible to erosion, Mugesera with 952 hectares (17%), and Gashanda with 858 hectares, about 22% of the total sector land. As compared to other districts in Eastern1 Province, Ngoma district is the fourth district susceptible to erosion.

**Table 131: Erosion risk per sector in Ngoma District**

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
KIBUNGO	25	182	873	1891	2971	4256	70%
REMERA		253	923	1655	2832	4989	57%
MURAMA		83	528	1748	2359	5040	47%

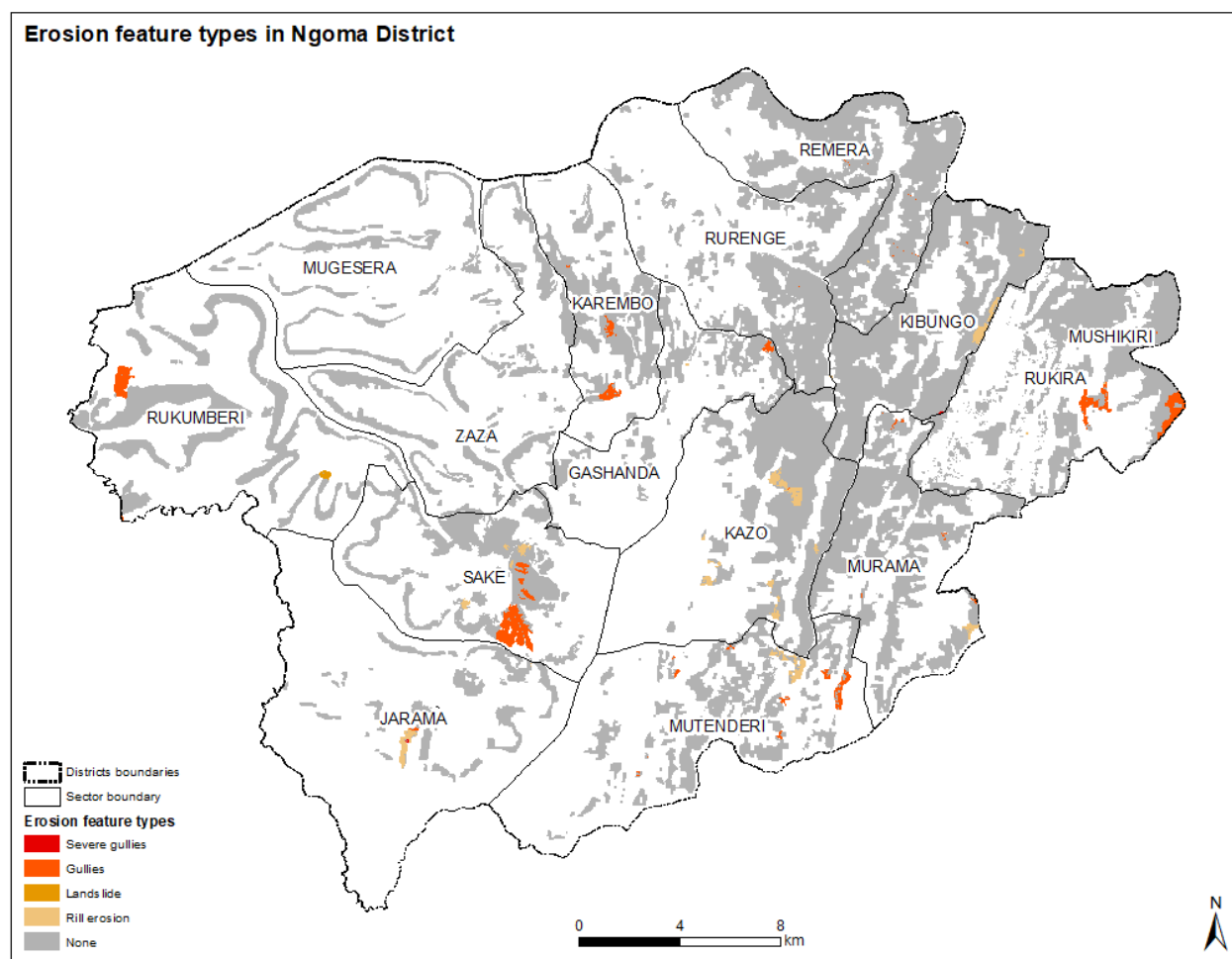
Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
RUKIRA	39	170	1061	1443	2713	6866	40%
KAZO		42	625	1840	2508	6963	36%
KAREMBO		26	197	1028	1251	3641	34%
SAKE		78	168	1424	1670	5035	33%
RURENGE	2	44	453	1563	2062	6513	32%
RUKUMBERI		12	576	1395	1982	6798	29%
MUTENDERI		22	224	1511	1757	7606	23%
ZAZA	18	20	203	1028	1269	5530	23%
GASHANDA	16	25	103	713	858	3840	22%
MUGESERA	31	111	291	519	952	5664	17%
JARAMA		1	72	709	782	8706	9%
<b>Grand Total</b>	<b>131</b>	<b>1068</b>	<b>6298</b>	<b>18468</b>	<b>25966</b>	<b>81445</b>	<b>32%</b>



**Figure 130: Erosion risk in Ngoma District**

Land areas affected by erosive features in Ngoma District are summarized in Table 131 and the map of erosive features are presented in Figure 131. The results show that Sake sector is the worst affected by gullies, landslide and rill erosion on areas estimated to 211 hectares (13% of sector land at risk), followed

by Jarama sector on 62 hectares (8% of sector land at risk), and Mutenderi sector on 125 hectares (7% of sector land at risk). The following sectors don't have any erosion feature on their respective land: Zaza and Mugesera, while Rurenge and Remera have little land affected by gullies and rill erosion with less 1 hectare and 5 hectares of total land at risk respectively.



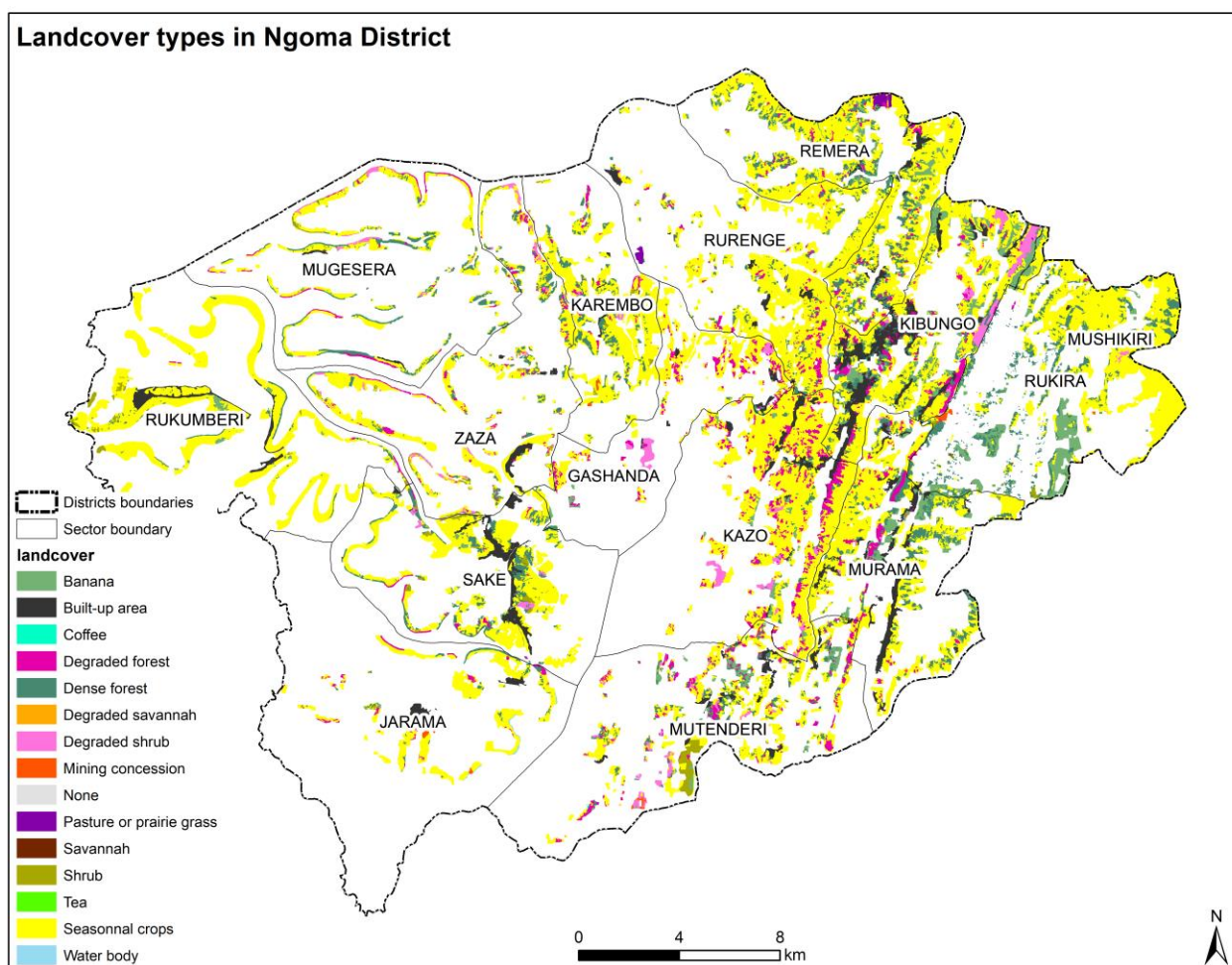
**Figure 131: Erosive features detected in Ngoma District**

**Table 132: Erosive features and areas affected in Ngoma District**

Sector Name	Erosion feature				Total Feature s	None	Grand Total	% features
	Gullie s	Landslid e	Rill erosion	Severe gullies				
SAKE	177		34		211	1459	1670	13%
JARAMA	13		47	2	62	720	782	8%
MUTENDERI	75		50		125	1632	1757	7%
RUKIRA	145		2		148	2565	2713	5%
KAZO			109		109	2398	2508	4%
KAREMBO	52				52	1200	1251	4%
RUKUMBERI	68	12			81	1902	1982	4%
GASHANDA	15		1		17	841	858	2%

Sector Name	Erosion feature				Total Feature s	None	Grand Total	% features
	Gullie s	Landslid e	Rill erosion	Severe gullies				
KIBUNGO			49	2	51	2920	2971	2%
MURAMA	10		16		26	2333	2359	1%
REMERA	2				2	2830	2832	0%
RURENGE			0		0	2062	2062	0%
MUGESERA					0	952	952	0%
ZAZA					0	1269	1269	0%
<b>Grand Total</b>	<b>558</b>	<b>12</b>	<b>311</b>	<b>3</b>	<b>884</b>	<b>25082</b>	<b>25966</b>	<b>3%</b>

In term of land use and land cover of areas at risk in Ngoma district, the results of land cover mapping (Table 132 and Figure 132) show that 18227 hectares (70% of the total land at risk) are used for seasonal cropping, 2512 hectares (10% of the total land at risk) are covered by healthy forests and 1718 hectares (7% of the total land at risk) are covered by built-up areas.



**Figure 132: Land cover types in Ngoma District**



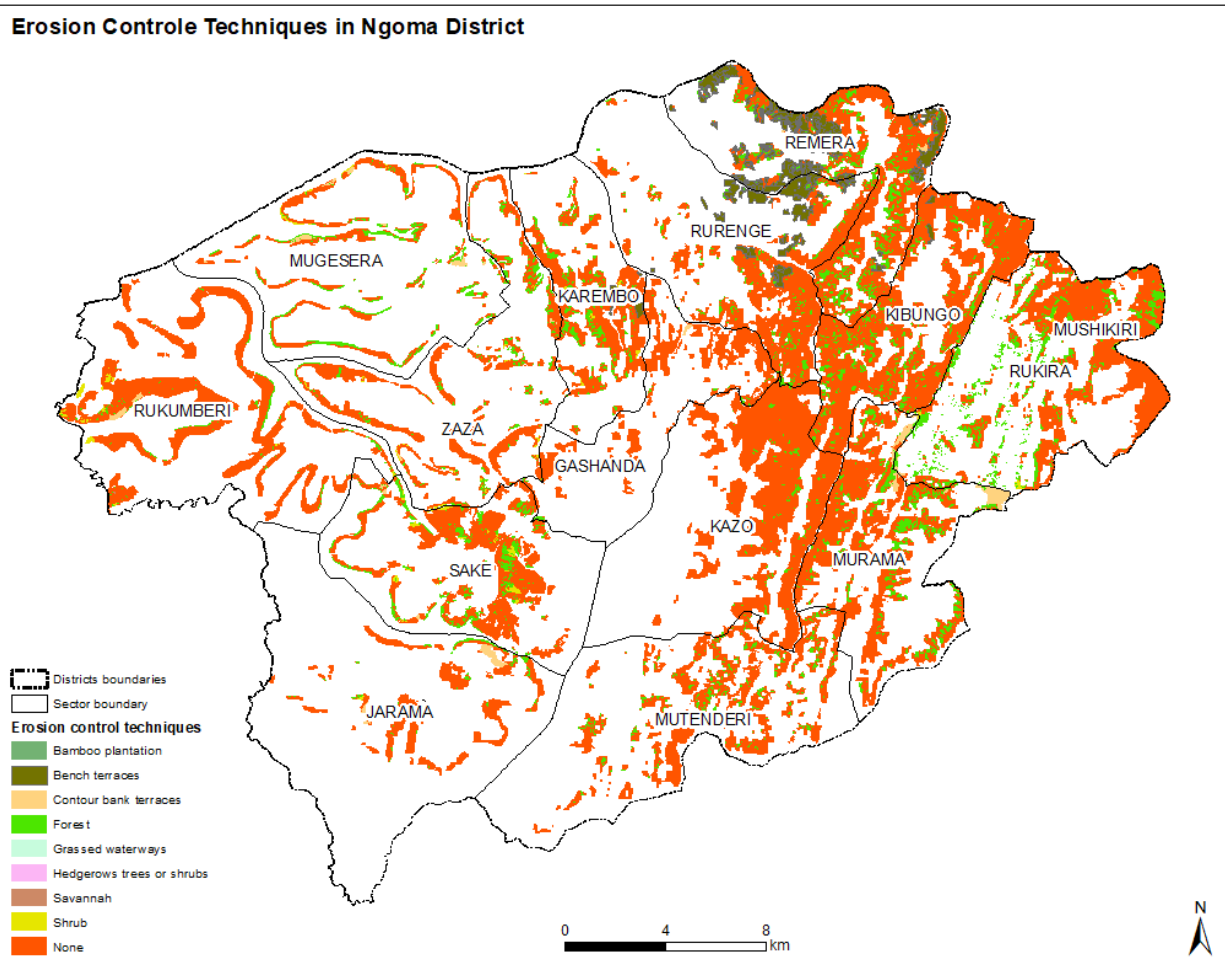
**Table 133: Land Use and Vegetation Cover (LUV) for land at risk in Ngoma District**

Sector Name	Banana	Built-up area	Degraded forest	Degraded shrub	Dense forest	Mining and Quarries	None	Pasture or prairie grass	Seasonal crops	Shrub	Water body	Grand Total
GASHANDA	18	41	119	79	15				586			858
JARAMA	3	56	44	2	43	30			589	2	12	782
KAREMBO		20	42	10	155	7			996	21		1251
KAZO	67	128	300	80	35				1898			2508
KIBUNGO	325	503	141	170	210		5		1617			2971
MUGESERA		17	70	39	215		1		590	19		952
MURAMA	172	270	106	3	328	1			1466	4	7	2359
MUTENDERI	131	129	182	76	139	8	2		1007	83		1757
REMER	111	80	59		359		2	33	2189			2832
RUKIRA	368	8	9	10	532	17			1750	17	3	2713
RUKUMBERI	38	135	9	10	48		6		1691	45		1982
RURENGE	6	64	81		90			17	1804			2062
SAKE	19	203	29	31	208				1129	52		1670
ZAZA		64	56	56	135				915	41	1	1269
<b>Grand Total</b>	<b>1258</b>	<b>1718</b>	<b>1247</b>	<b>566</b>	<b>2512</b>	<b>63</b>	<b>16</b>	<b>50</b>	<b>18227</b>	<b>284</b>	<b>24</b>	<b>25966</b>
<b>%</b>	<b>5%</b>	<b>7%</b>	<b>5%</b>	<b>2%</b>	<b>10%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>70%</b>	<b>1%</b>	<b>0%</b>	<b>100%</b>

About existing erosion control practices in Ngoma district, Table 133 indicates that only 18% of land at risk is protected by forests (2514 hectares) and Contour bank terraces (282 hectares) and bench terraces (1173 hectares). The highest protected sectors are Remera with 40% of its land at risk protected, followed by Mugesera where 29% of the total land at risk is protected and Rurenge with 21% of land protected. The least protected sectors are Kazo with only 1% protected, Gashanda (only 3% protected) and Rukumberi (6%).

**Table 134: Erosion control practices already in place in Ngoma District**

Sector Name	Erosion control in place				Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest	Shrub				
REMERA	761	10	348		1120	1712	2832	40%
MUGESERA		46	215	18	279	673	952	29%
RURENGE	344		98		442	1620	2062	21%
RUKIRA		8	532	17	557	2156	2713	21%
MURAMA		123	342		465	1894	2359	20%
KAREMBO	47		155	21	223	1028	1251	18%
SAKE		9	208	52	269	1402	1670	16%
ZAZA		9	132	32	173	1096	1269	14%
JARAMA		44	43	2	89	693	782	11%
KIBUNGO	20	0	210		231	2741	2971	8%
MUTENDERI			134		134	1623	1757	8%
RUKUMBERI		24	48	45	117	1865	1982	6%
GASHANDA		9	15		24	834	858	3%
KAZO			35		35	2473	2508	1%
<b>Grand Total</b>	<b>1173</b>	<b>282</b>	<b>2514</b>	<b>187</b>	<b>4156</b>	<b>21810</b>	<b>25966</b>	<b>16%</b>



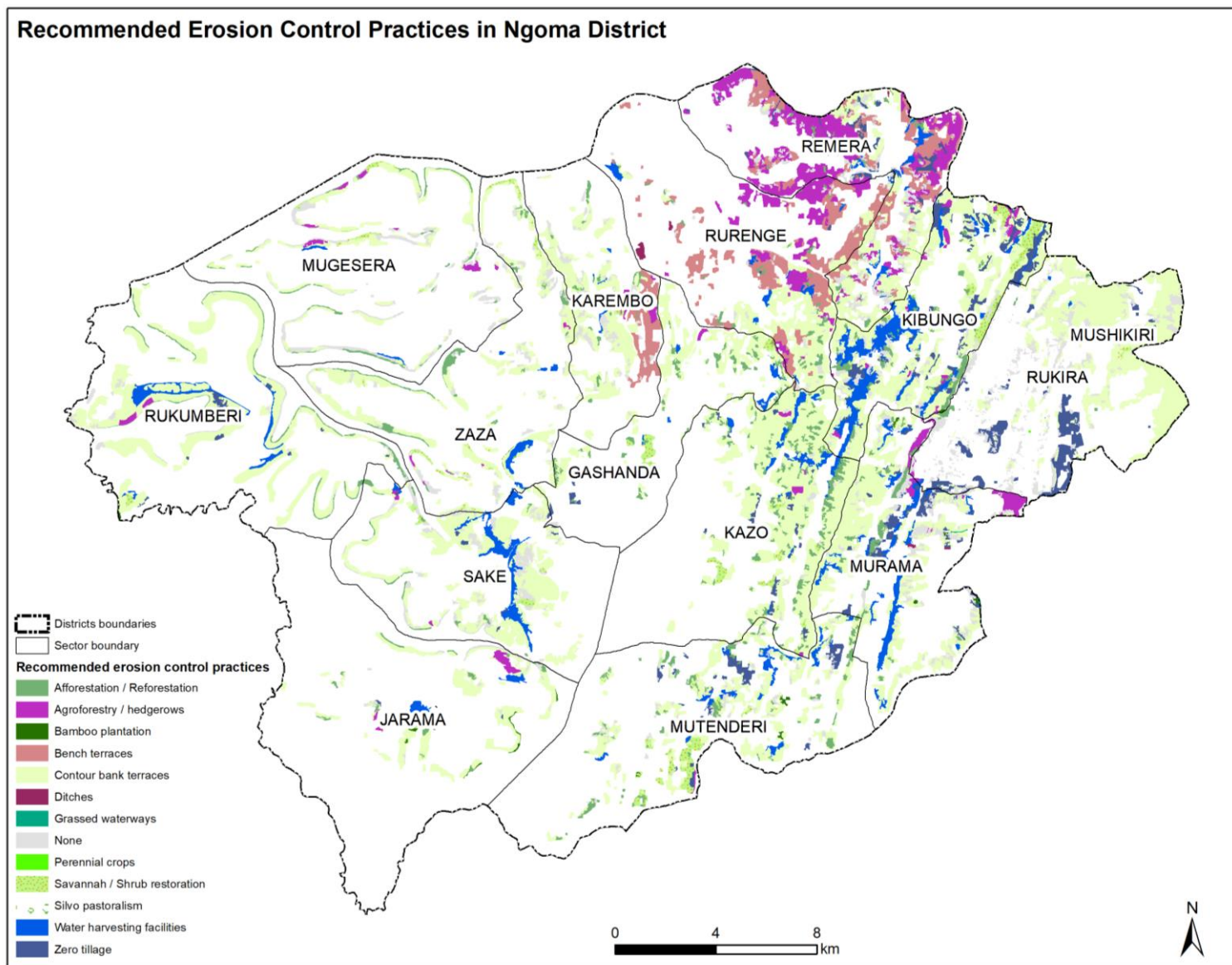
**Figure 133: Erosion control techniques in place in Ngoma District**

Erosion control practices in Ngoma District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 134 shows that about 14572 hectares (which is 56% of the total land at risk) are suitable for Contour bank terraces, 1520 hectares are Afforestation & Reforestation and 1592 hectares of Bench terraces. Other interventions are 1724 hectares for Storm water management facilities (SWMF), 1728 hectares of agroforestry/hedgerows in cropland and 655 hectares for restoration of savannah and shrub.

**Table 135: Recommended erosion control practices in Ngoma District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedge rows	Bamboo plantation	Bench terraces	Contour bank terraces	Forest Ditches	Already protected	Savannah / Shrub restoration	Silvopastoralism	Water harvesting facilities	Zero tillage	Grand Total
GASHANDA	119	13		6	567		15	79		41	18	858
JARAMA	74	44	27		530		45	2		56	3	782
KAREMBO	50	47		236	713		176	10		20		1251
KAZO	301	24		2	1871		35	80		128	67	2508
KIBUNGO	145	82	2		1535		210	170		503	325	2971
MUGESERA	86	51			467		290	40		17		952
MURAMA	109	125	11	7	1333	6	326	2		270	170	2359
MUTENDERI	195	4	12		993		137	156		129	131	1757
REMERA	59	894	2	608	688	1	359		31	80	111	2832
RUKIRA	26	8	3		1742		549	10		8	368	2713
RUKUMBERI	125	24	4		1535		111	10		135	38	1982
RURENGE	76	393		740	667	22	90			69	6	2062
SAKE	45	9			1104		260	31		203	19	1670
ZAZA	112	11	1		828		187	65		64		1269
<b>Grand Total</b>	<b>1520</b>	<b>1728</b>	<b>62</b>	<b>1599</b>	<b>14572</b>	<b>29</b>	<b>2790</b>	<b>655</b>	<b>31</b>	<b>1724</b>	<b>1256</b>	<b>25966</b>
<b>%</b>	<b>6%</b>	<b>7%</b>	<b>0%</b>	<b>6%</b>	<b>56%</b>	<b>0%</b>	<b>11%</b>	<b>3%</b>	<b>0%</b>	<b>7%</b>	<b>5%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.



**Figure 134: Recommended erosion control practices in Ngoma District**

### 3.4.6. Erosion control status in Nyagatare District

Erosion risk in Nyagatare is summarised in Table 135 and presented in figure 135. Erosion risk in Nyagatare District is estimated to 5664 hectares; about 3% of the total district land are highly susceptible to erosion of which 1280 hectares are located in Kiyombe sector (19% of sector land), 815 hectares are located in Matimba sector (10% of sector land), 459 hectares are located in Mukama (7% of the sector land), and 1913 hectares are found in Rwimiyaga sector about 6% of the sector land. The least sectors are Mimuli, Katabagemu, Rwempasha, Mimuli and Rukomo where the land affected by moderate erosion is less than 1% of the total sector land of each sector.

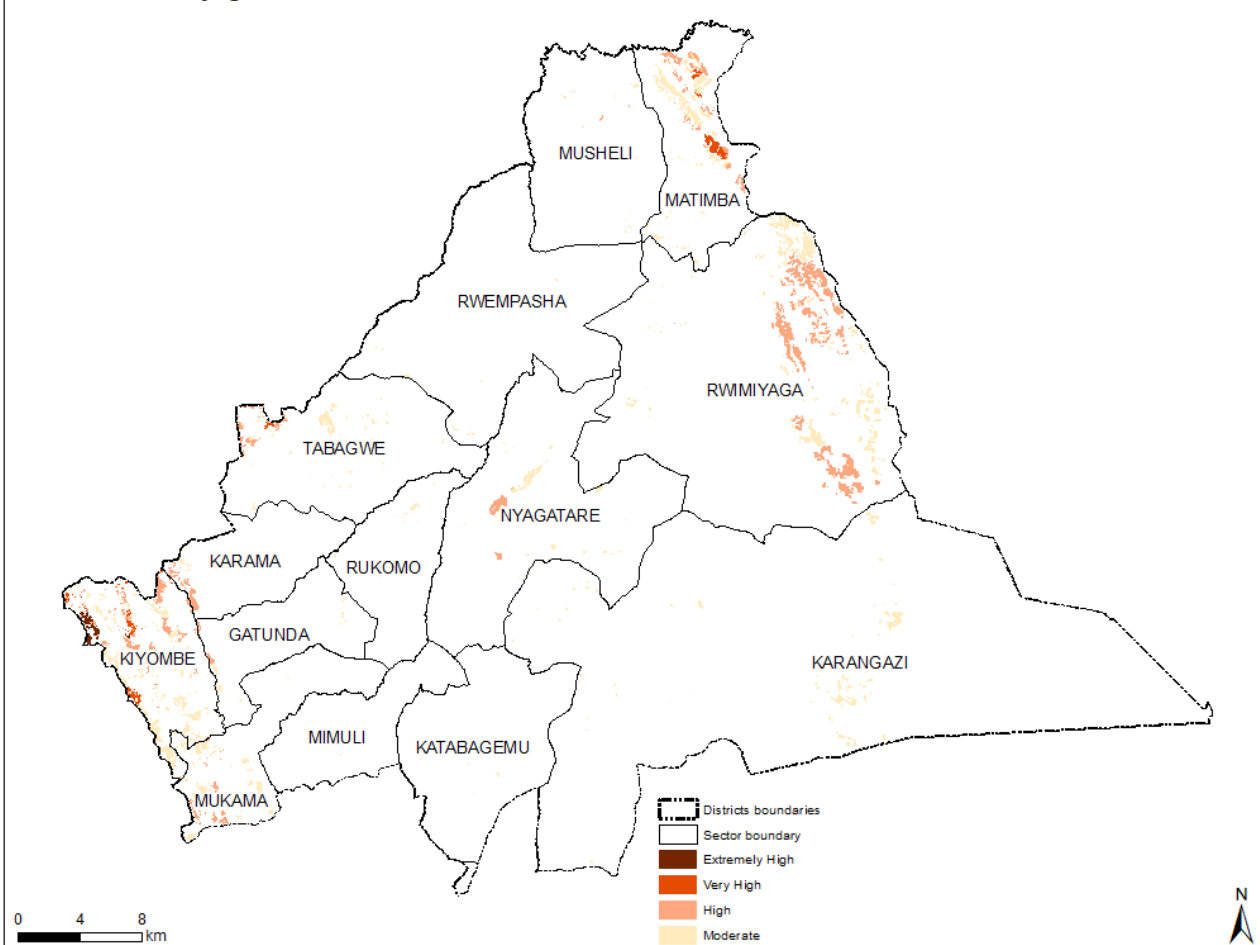
**Table 136: Erosion risk per sector in Nyagatare District**

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
KIYOMBE	100	127	345	708	1280	6909	19%
MATIMBA		117	235	463	815	7912	10%
MUKAMA			163	297	459	6316	7%
RWIMIYAGA			1126	786	1913	29947	6%
TABAGWE		16	85	185	286	10588	3%
KARAMA			102	28	131	5381	2%
GATUNDA			29	58	87	5310	2%
NYAGATARE			100	155	255	15713	2%
KARANGAZI			0	334	335	54896	1%
RUKOMO				28	28	5854	0%
MUSHELI			6	32	38	9875	0%
RWEMPASHA				27	27	16816	0%
KATABAGEMU				7	7	10090	0%
MIMULI				3	3	5726	0%
<b>Grand Total</b>	<b>100</b>	<b>261</b>	<b>2192</b>	<b>3112</b>	<b>5664</b>	<b>191333</b>	<b>3%</b>

No erosion feature type was observed on satellite images for Nyagatare district.



**Erosion risk in Nyagatare District**

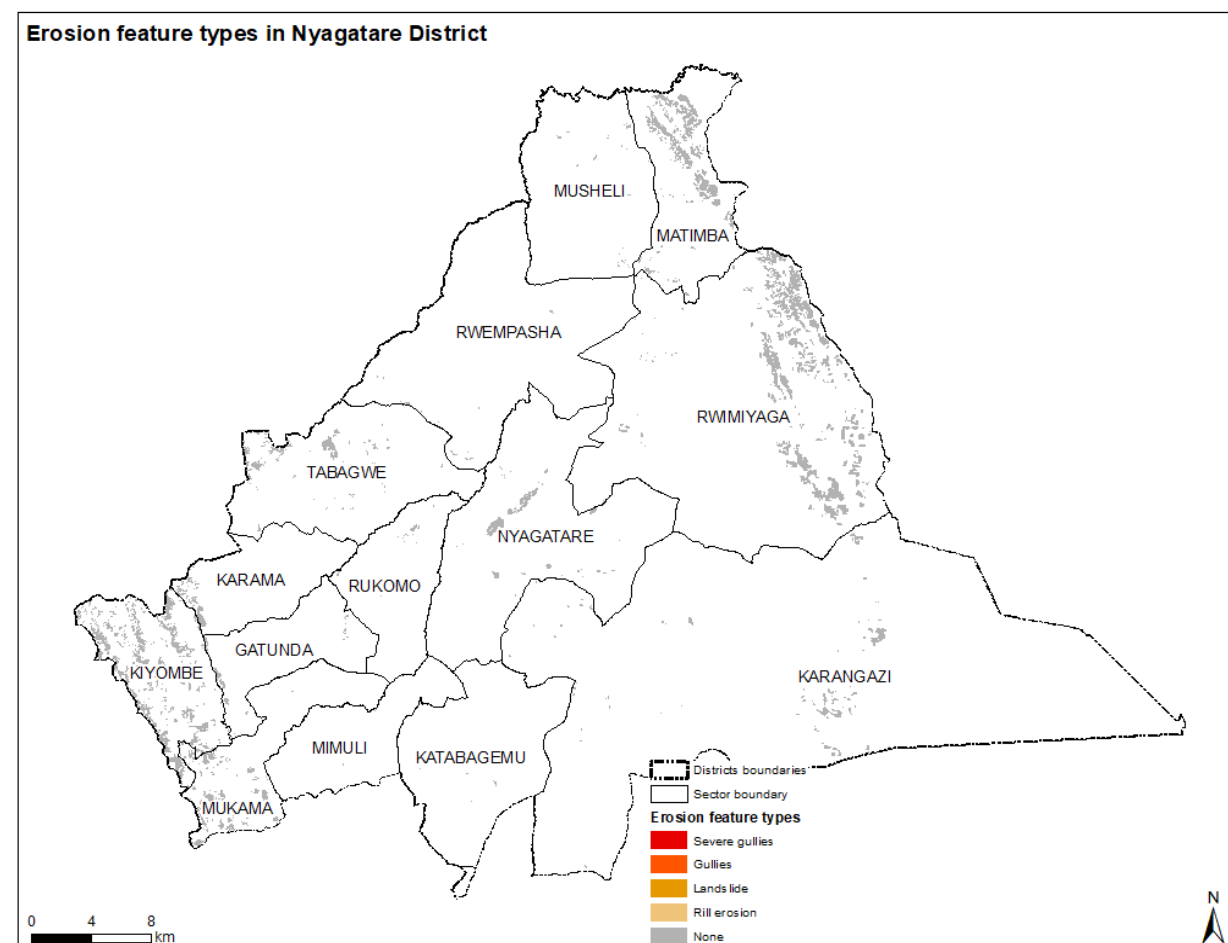


**Figure 135: Erosion risk in Nyagatare District**

**Table 137: Erosive features and areas affected in Nyagatare District**

Sector Name	Total Features	None	Grand Total	% features
GATUNDA	0	87	87	0%
KARAMA	0	131	131	0%
KARANGAZI	0	335	335	0%
KATABAGEMU	0	7	7	0%
KUYOMBE	0	1280	1280	0%
MATIMBA	0	815	815	0%
MIMULI	0	3	3	0%
MUKAMA	0	459	459	0%
MUSHALI	0	38	38	0%
NYAGATARE	0	255	255	0%
RUKOMO	0	28	28	0%
RWEMPASHA	0	27	27	0%
RWIMIYAGA	0	1913	1913	0%

Sector Name	Total Features	None	Grand Total	% features
TABAGWE	0	286	286	0%
Grand Total	0	5664	5664	0%



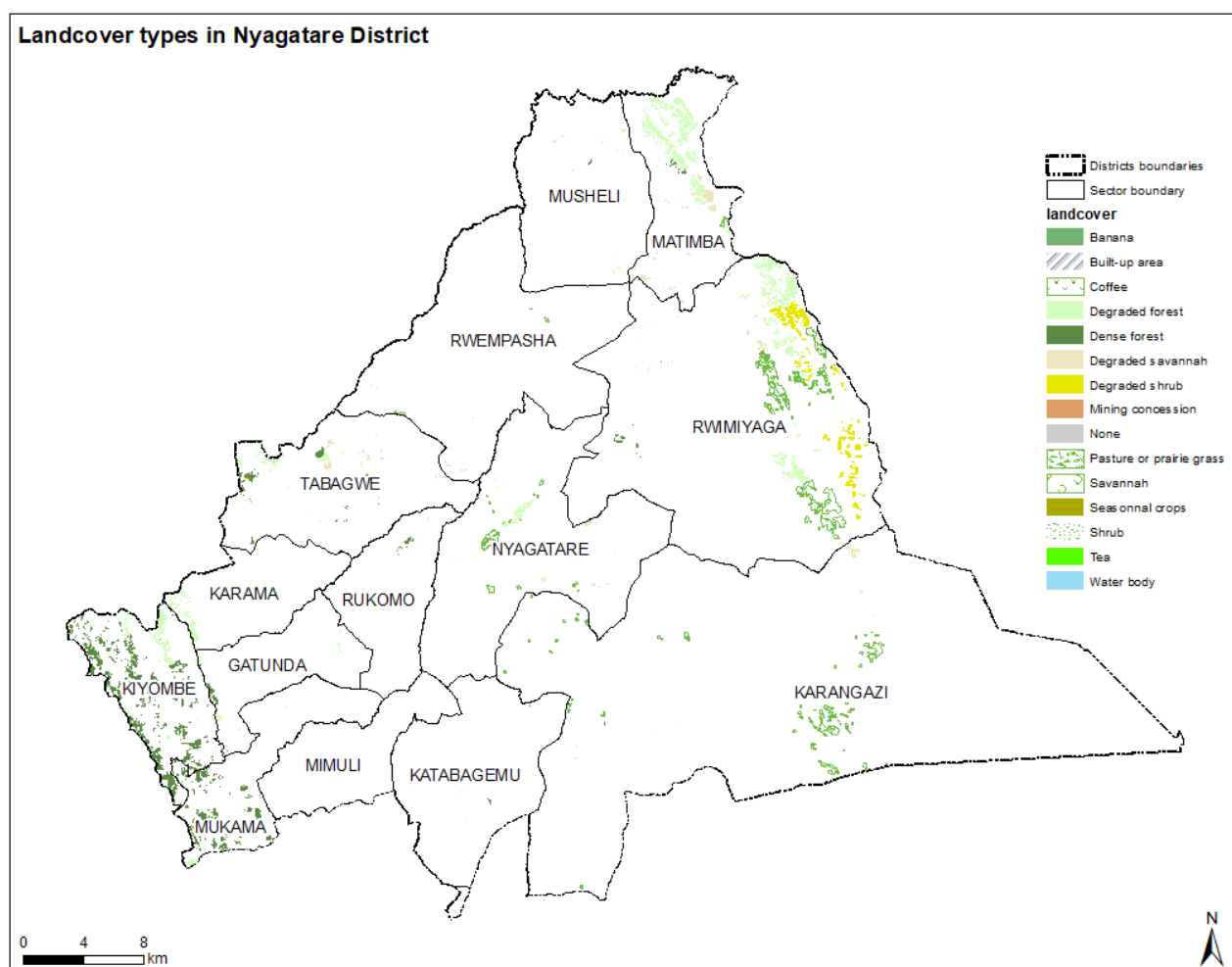
**Figure 136: Erosive features detected in Nyagatare District**

In term of land use and land cover of areas at risk in Nyagatare, the results of land cover mapping (Table 137 and Figure 137) show that 4 hectares (less than 1% of the total land at risk) are used for seasonal cropping and 1270 (29% of the total land at risk) are covered by healthy forests, **312** hectares (% of the total land at risk) are savannah. Other land cover types are degraded forests, degraded savannah that cover 2016 hectares and 365 hectares respectively.

**Table 138: Land Use and Vegetation Cover (LUVc) for land at risk in Nyagatare District**

Sector Name	Degraded forest	Degraded savannah	Degraded shrub	Dense forest	Pasture or prairie grass	Savannah	Seasonal crops	Grand Total
GATUNDA	40			46				87
KARAMA	131							131
KARANGAZI	6	39		1	287		1	335

Sector Name	Degraded forest	Degraded savannah	Degraded shrub	Dense forest	Pasture or prairie grass	Savannah	Seasonal crops	Grand Total
KATABAGEMU	0	2		5	0			7
KIYOMBE	257			1023				1280
MATIMBA	664	123		18		10		815
MIMULI	3							3
MUKAMA	30			429				459
MUSHELI	11	22		5				38
NYAGATARE	106	30			118			255
RUKOMO	5	1		21	0			28
RWEMPASHA		18			9			27
RWIMIYAGA	636	66	503	28	377	302		1913
TABAGWE	126	63		93	1		3	286
Grand Total	2016	365	503	1670	794	312	4	5664
%	36%	6%	9%	29%	14%	6%	0%	100%



**Figure 137: Land cover types in Nyagatare District**

About existing erosion control practices in Nyagatare district, Table 138 shows that only 35% of land at risk is protected by forests (1670 hectares) and savannah (312 hectares). Although still low, the highest protected sectors are Mukama with 93% of its land at risk protected, followed by Kiyombe where 80% of the total land at risk is protected and Rukomo (77% protected). The least protected sectors are Karama, Karangazi and Matimba with less than 1% of their respective land at risk. The visual interpretation of World View images did not confirm earlier findings by CROM model that there is erosion risk in Kiyombe, Rwimiyaga and Matimba sectors.

**Table 139: Erosion control practices already in place in Nyagatare District**

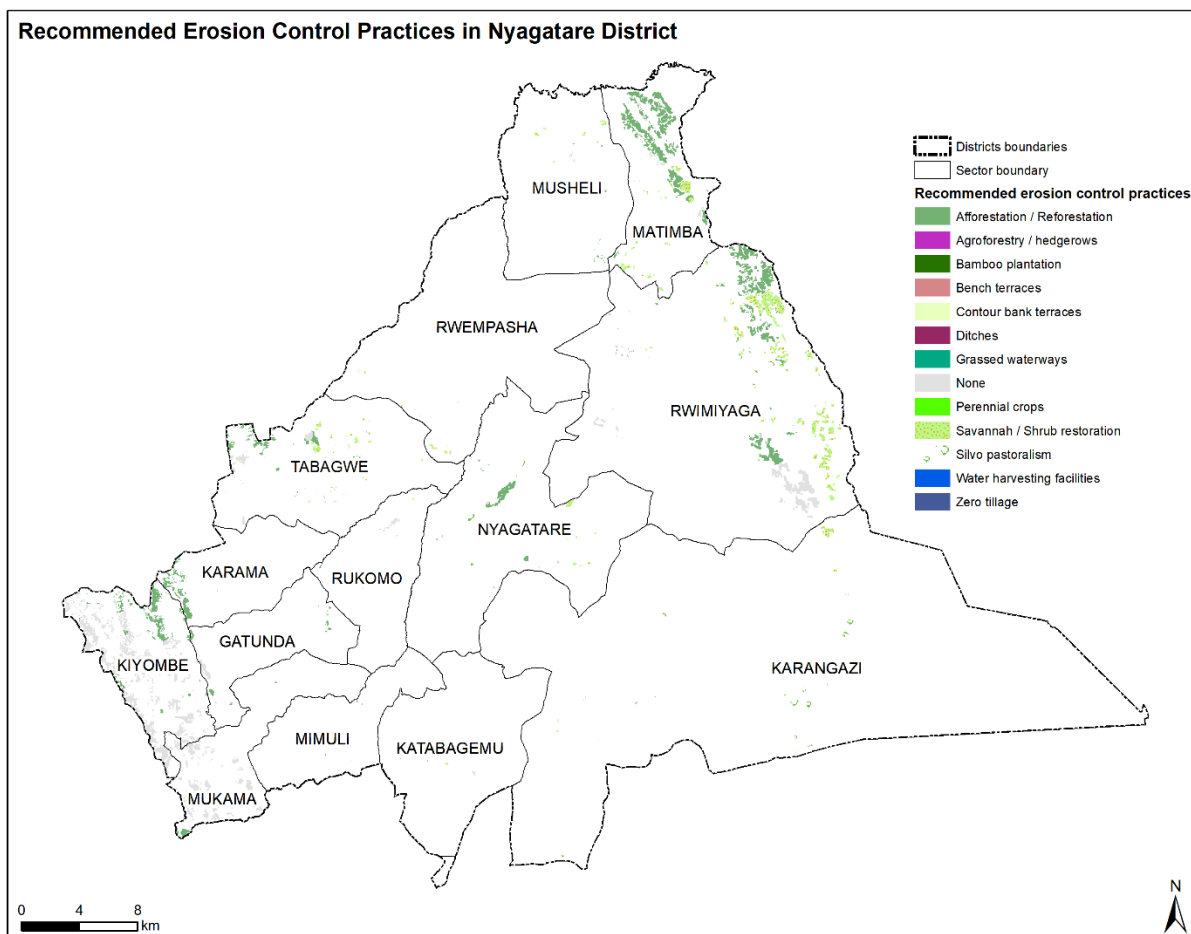
Sector Name	Erosion control in place		Total protected	None	Grand Total	% Protected
	Forest	Savannah				
MUKAMA	429		429	30	459	93%
KIYOMBE	1023		1023	257	1280	80%
RUKOMO	21		21	6	28	77%
KATABAGEMU	5		5	2	7	69%
GATUNDA	46		46	40	87	54%
TABAGWE	93		93	193	286	33%
RWIMIYAGA	28	302	330	1583	1913	17%
MUSHELI	5		5	34	38	12%
MATIMBA	18	10	28	787	815	3%
KARANGAZI	1		1	333	335	0%
KARAMA			0	131	131	0%
MIMULI			0	3	3	0%
NYAGATARE			0	255	255	0%
RWEMPASHA			0	27	27	0%
<b>Grand Total</b>	<b>1670</b>	<b>312</b>	<b>1982</b>	<b>3682</b>	<b>5664</b>	<b>35%</b>

Erosion control practices in Nyagatare District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 139 shows that about 2016 hectares (which is 36% of the total land at risk) are suitable for reforestation/afforestation, 794 hectares are silvo-pastoralism and 868 hectares of savannah and shrub that need to be rehabilitated.

**Table 140: Recommended erosion control practices in Nyagatare District**

Sector Name	Afforestation / Reforestation	Contour bank terraces	None	Savannah / Shrub restoration	Silvo pastoralism	Grand Total
GATUNDA	40		46			87
KARAMA	131					131
KARANGAZI	6	1	1	39	287	335
KATABAGEMU	0		5	2	0	7
KIYOMBE	257		1023			1280
MATIMBA	664		28	123		815

Sector Name	Afforestation / Reforestation	Contour bank terraces	None	Savannah / Shrub restoration	Silvo pastoralism	Grand Total
MIMULI	3					3
MUKAMA	30		429			459
MUSHELI	11		5	22		38
NYAGATARE	106			30	118	255
RUKOMO	5		21	1	0	28
RWEMPASHA				18	9	27
RWIMIYAGA	636		330	570	377	1913
TABAGWE	126	3	93	63	1	286
<b>Grand Total</b>	<b>2016</b>	<b>4</b>	<b>1982</b>	<b>868</b>	<b>794</b>	<b>5664</b>
<b>%</b>	<b>36%</b>	<b>0%</b>	<b>35%</b>	<b>15%</b>	<b>14%</b>	<b>100%</b>



**Figure 138: Recommended erosion control practices in Nyagatare District**

### 3.4.7. Erosion control status in Rwamagana District

Erosion risk in Rwamagana is summarised in Table 140 and presented in figure 140. Erosion risk in Rwamagana District is estimated to 13156 hectares; about 20% of the total district land are highly susceptible to erosion of which 1717 hectares are located in Mwulire sector (31% of sector land), 1446 hectares are located in Muyumbu sector (29% of sector land), 1173 hectares are located in Fumbwe (28% of the sector land), and 1176 hectares are found in Musha sector about 27% of the sector land. The least sectors are Nzige with only 242 hectares (6% of the sector land) susceptible to erosion, Rubona with 382 hectares (7%), and Kigabiro with 429 hectares, about 11% of the total sector land. As compared to other districts in Eastern Province, Rwamagana is the fifth susceptible to erosion.

**Table 141: Erosion risk per sector in Rwamagana District**

Sector name	Erosion risk					Sector land (ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total		
MWULIRE	6	59	165	1487	1717	5512	31%
MUYUMBU		18	181	1248	1446	5038	29%
FUMBWE		106	148	919	1173	4135	28%
MUSHA	2	61	310	803	1176	4294	27%
NYAKARIRO	2	31	198	1139	1370	5159	27%
GAHENGARI		41	319	1222	1582	6298	25%
KARENGE	10	8	66	1004	1088	5727	19%
MUNYAGA		19	102	591	712	4100	17%
MUHAZI		12	131	562	705	4230	17%
GISHARI		1	101	570	671	4094	16%
MUNYIGINYA	1	2	45	344	391	3024	13%
KIGABIRO		15	56	429	500	4749	11%
RUBONA		19	48	316	382	5266	7%
NZIGE			2	240	242	3999	6%
<b>Grand Total</b>	<b>22</b>	<b>392</b>	<b>1871</b>	<b>10872</b>	<b>13156</b>	<b>65627</b>	<b>20%</b>



Land areas affected by erosive features in Rwamagana District are summarized in Table 141 and the map of erosive features are presented in Figure 141. The results show that Mwulire sector is the worst affected by gullies on areas estimated to 237 hectares (14% of sector land at risk), followed by Gahengeri sector on 104 hectares (7% of sector land at risk), and Rubona sector on 19 hectares (5% of sector land at risk). These affected sectors confirm the findings of CROM model; however the reduced presence of gullies and rill erosion in Nyakaliro and Fumbwe which was originally predicted by CROM model as sectors at high risk should not read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 142 and 143. The least affected sectors are Nzige, Muyumbu, Musha, Munyiginya, Muhazi, Kigabiro, Karenge and Gishari which are not affected by any gullies nor rill erosion.

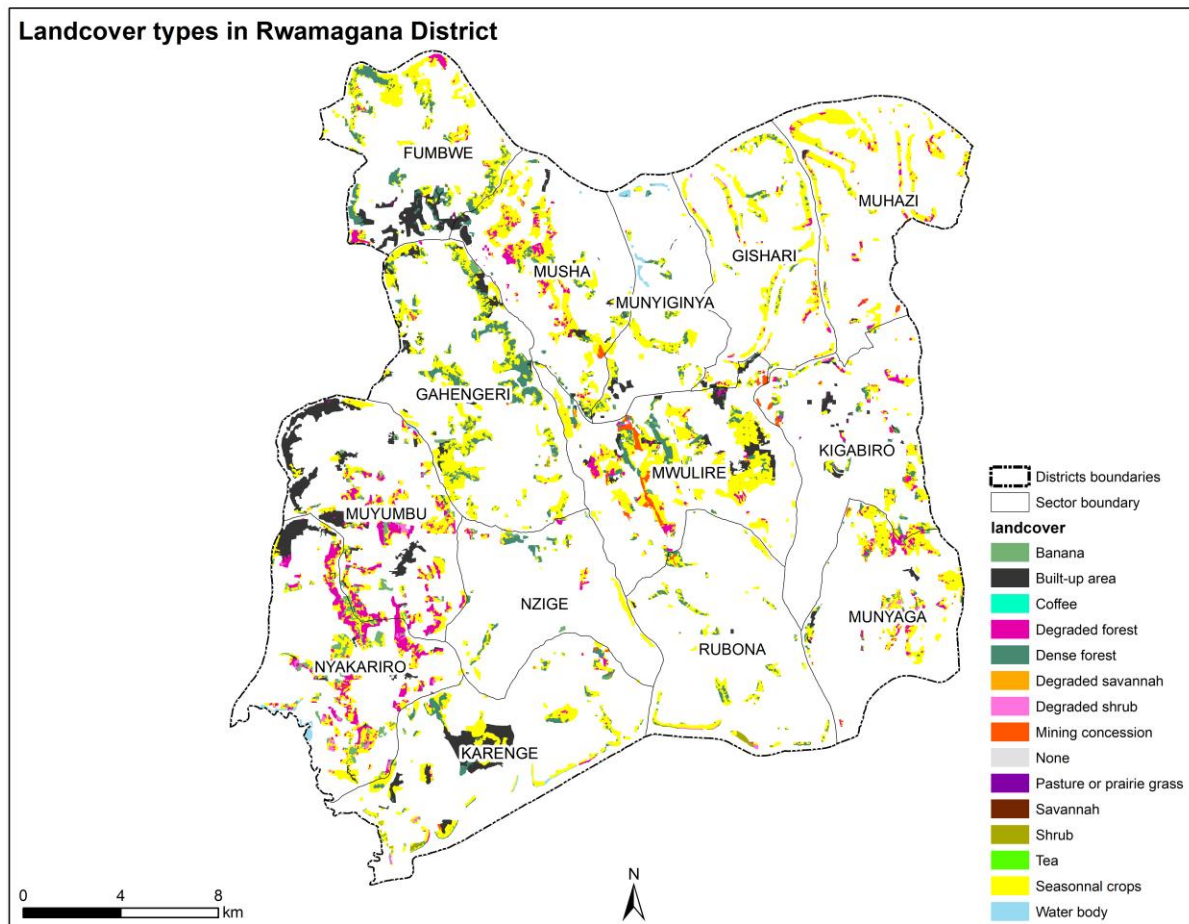
**Table 142: Erosive features and areas affected in Rwamagana District**

Sector Name	Erosion feature			Total Features	None	Grand Total	% features
	Gullies	Rill erosion	Severe gullies				
MWULIRE		2	235	237	1480	1717	14%
GAHENGGERI	104			104	1478	1582	7%
RUBONA	19			19	363	382	5%
FUMBWE		45		45	1128	1173	4%
MUNYAGA			1	1	711	712	0%
NYAKARIRO		1	1	2	1368	1370	0%
GISHARI				0	671	671	0%
KARENGE				0	1088	1088	0%
KIGABIRO				0	500	500	0%
MUHAZI				0	705	705	0%
MUNYIGINYA				0	391	391	0%
MUSHA				0	1176	1176	0%
MUYUMBU				0	1446	1446	0%
NZIGE				0	242	242	0%
<b>Grand Total</b>	<b>123</b>	<b>48</b>	<b>238</b>	<b>409</b>	<b>12748</b>	<b>13156</b>	<b>3%</b>

In term of land use and land cover of areas at risk in Rwamagana, the results of land cover mapping (Table 142 and Figure 143) show that 7880 hectares (60% of the total land at risk) are used for seasonal cropping, 1539 hectares (12% of the total land at risk) are covered by healthy forests, 1777 hectares (14% of the total land at risk) covered by built-up areas, 1171 hectares (9% of the total land at risk) are covered by degraded forests and 387 hectares of banana plantations.

**Table 143: Land Use and Vegetation Cover (LUVC) for land at risk in Rwamagana District**

Sector Name	Banana	Built-up area	Degraded forest	Degraded shrub	Dense forest	Mining and Quarries	Seasonal crops	Shrub	Water body	Grand Total
FUMBWE		241	57		286		587		2	1173
GAHENGERI	33	140	8		426		966	10		1582
GISHARI		11	31	4	59	1	566			671
KARENGE	12	347	15	6	137	7	536	14	14	1088
KIGABIRO	6	63	49	3	75	18	286			500
MUHAZI		8	57		10	11	620			705
MUNYAGA	4	27	99	15	29	2	537			712
MUNYIGINYA	3	34	0		62		251		41	391
MUSHA	3	94	118		112	11	835		2	1176
MUYUMBU	108	431	302	15	6	1	576		6	1446
MWULIRE	23	198	76	3	204	102	1112			1717
NYAKARIRO	174	178	338	38		2	607		33	1370
NZIGE	21		22		67	0	129	2	1	242
RUBONA		6		8	67	5	271	26		382
<b>Grand Total</b>	<b>387</b>	<b>1777</b>	<b>1171</b>	<b>92</b>	<b>1539</b>	<b>160</b>	<b>7880</b>	<b>52</b>	<b>99</b>	<b>13156</b>
<b>%</b>	<b>3%</b>	<b>14%</b>	<b>9%</b>	<b>1%</b>	<b>12%</b>	<b>1%</b>	<b>60%</b>	<b>0%</b>	<b>1%</b>	<b>100%</b>

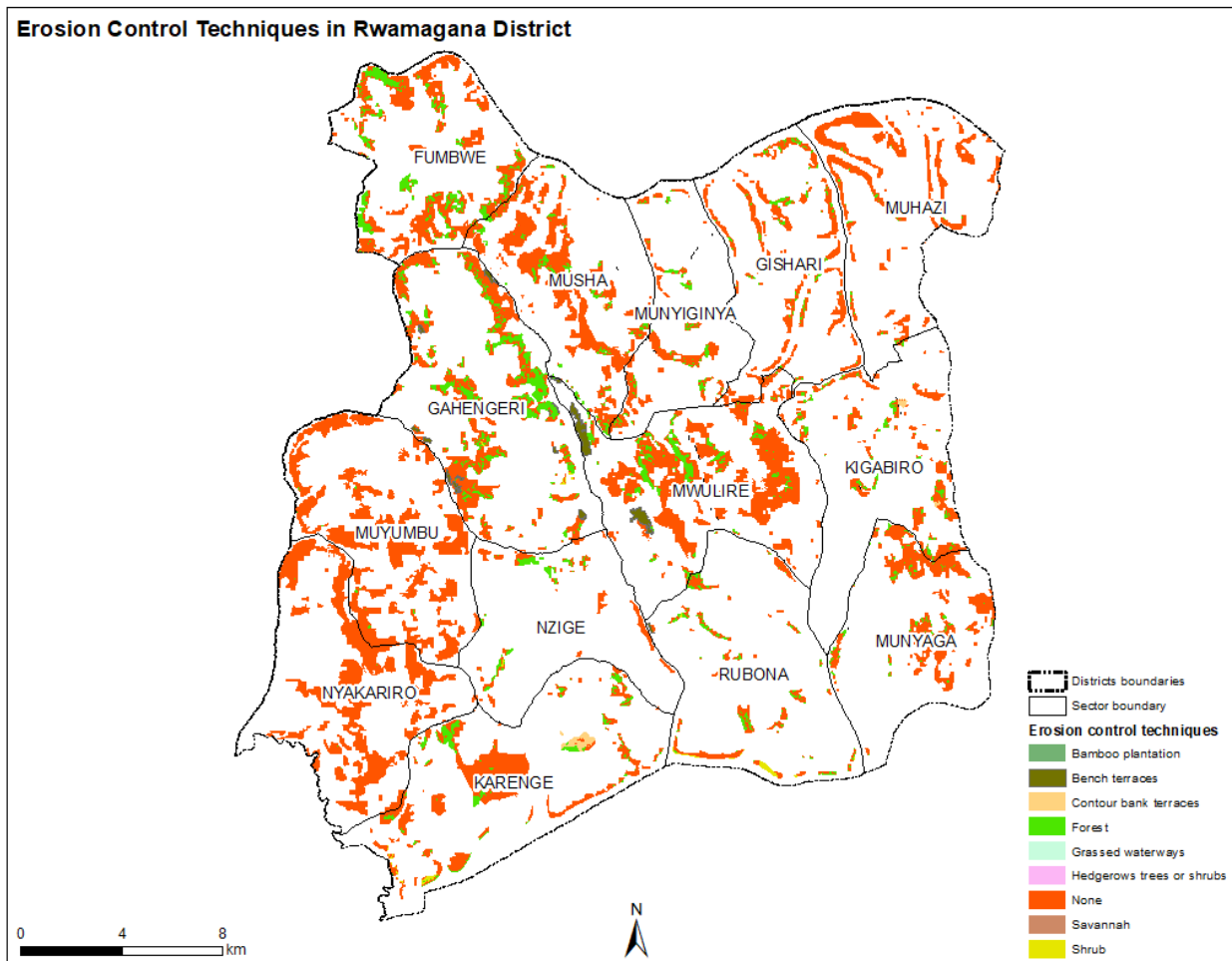


**Figure 139: Land cover types in Rwamagana District**

About existing erosion control practices in Rwamagana district, Table 143 shows that only 14% of land at risk is protected by forests (1539 hectares), contour bank terraces (69 hectares) and bench terraces (165 hectares). The highest protected sectors are Gahengeri with 31% of its land at risk protected, followed by Nzige where 29% of the total land at risk is protected and Rubona with 25% of land protected. The least protected sectors are Nyakaliro and Muyumbu with less than 1% protected in each sector, Muhazi (1%) and Munyaga (4% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Muyumbu, Musha and Nyakaliro sectors remain at moderate risk of soil erosion since more than 90% of their respective land at erosion risk are not protected.

**Table 144: Erosion control practices already in place in Rwamagana District**

Sector Name	Erosion control in place				Total protected	None	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest	Shrub				
GAHENGHERI	60		426	10	495	1086	1582	31%
NZIGE			67	2	70	173	242	29%
RUBONA	4		67	26	96	286	382	25%
FUMBWE			286		286	887	1173	24%
KARENGE		51	137	14	202	886	1088	19%
KIGABIRO		16	75		91	410	500	18%
MWULIRE	101		204		305	1413	1717	18%
MUNYIGINYA			62		62	329	391	16%
MUSHA		2	112		114	1062	1176	10%
GISHARI			59		59	613	671	9%
MUNYAGA			29		29	683	712	4%
MUHAZI			10		10	695	705	1%
MUYUMBU			6		6	1440	1446	0%
NYAKARIRO					0	1370	1370	0%
<b>Grand Total</b>	<b>165</b>	<b>69</b>	<b>1539</b>	<b>52</b>	<b>1825</b>	<b>11331</b>	<b>13156</b>	<b>14%</b>



**Figure 140: Erosion control techniques in place in Rwamagana District**

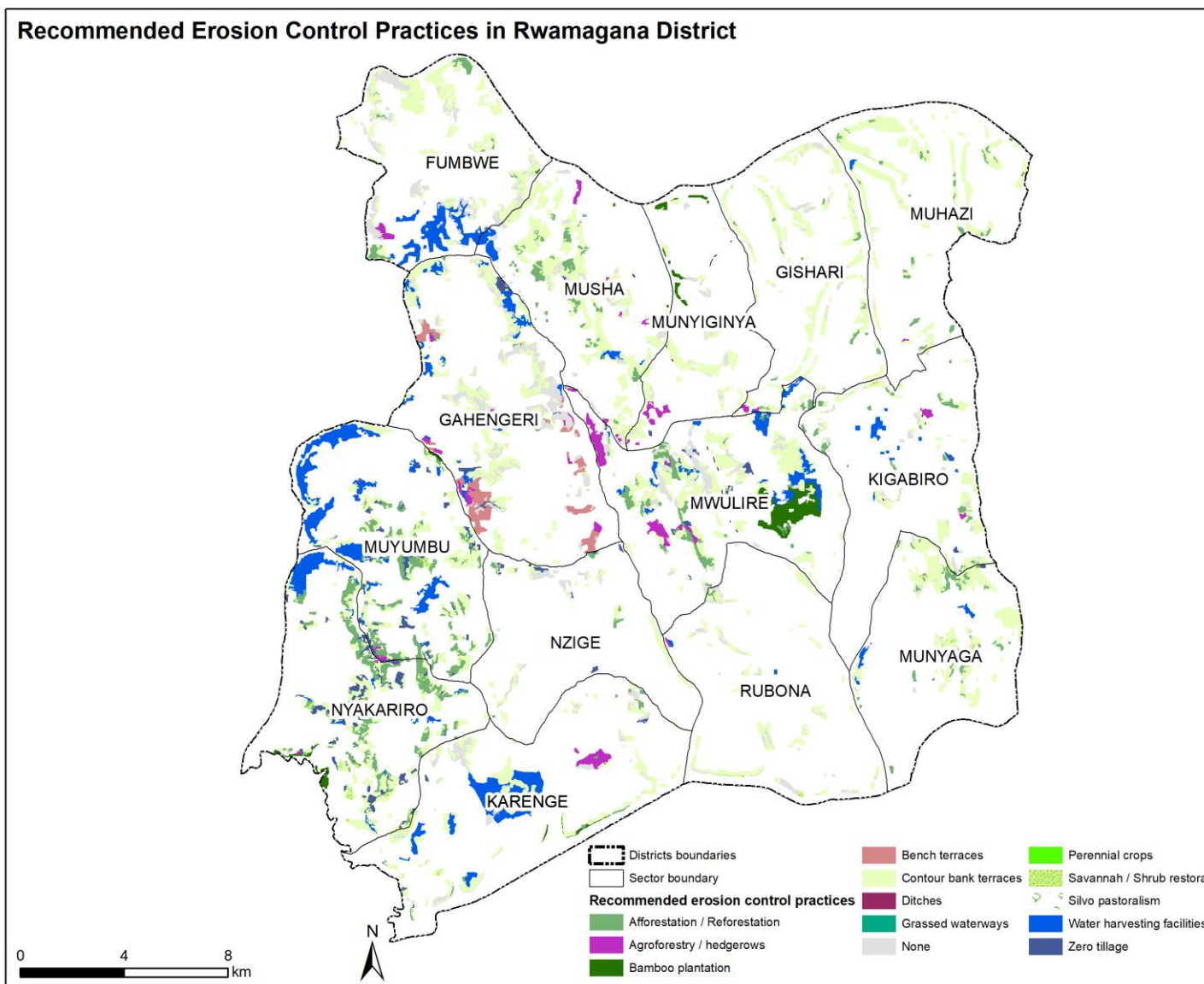
Erosion control practices in Rwamagana District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 144 shows that about 7141 hectares (which is 54% of the total land at risk) are suitable for Contour bank terraces, 350 hectares are cropland that need agroforestry/hedgerows cropping and 1339 hectares Afforestation & Reforestation. Other interventions are 337 hectares of bamboo plantations on riverbanks and closing gullies, 92 hectares of savannah and shrub restoration and 1655 hectares for water harvesting facilities.

**Table 145: Recommended erosion control practices in Rwamagana District**

Sector name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	None	Savannah / Shrub restoration	Water harvesting facilities	Zero tillage	Grand Total
FUMBWE	57	21	2		587	286		220		1173
GAHENGARI	14	52		257	652	435		140	33	1582
GISHARI	32	9			566	59	4	2		671
KARENGE	24	51	14		483	151	6	347	12	1088
KIGABIRO	67	16			286	75	3	46	6	500
MUHAZI	67	2			620	10		6		705
MUNYAGA	101		1		536	29	15	27	4	712
MUNYIGINYA	0	34	41		251	62			3	391
MUSHA	129	31	2		833	112		65	3	1176
MUYUMBU	303	9	6		567	6	15	431	108	1446
MWULIRE	179	116	235		760	204	3	187	33	1717
NYAKARIRO	339	5	34		602		38	178	173	1370
NZIGE	22		1		129	70			21	242
RUBONA	5	4			268	93	8	6		382
<b>Grand Total</b>	<b>1339</b>	<b>350</b>	<b>337</b>	<b>257</b>	<b>7141</b>	<b>1591</b>	<b>92</b>	<b>1655</b>	<b>396</b>	<b>13156</b>
<b>%</b>	<b>10%</b>	<b>3%</b>	<b>3%</b>	<b>2%</b>	<b>54%</b>	<b>12%</b>	<b>1%</b>	<b>13%</b>	<b>3%</b>	<b>100%</b>

**Note:** No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.





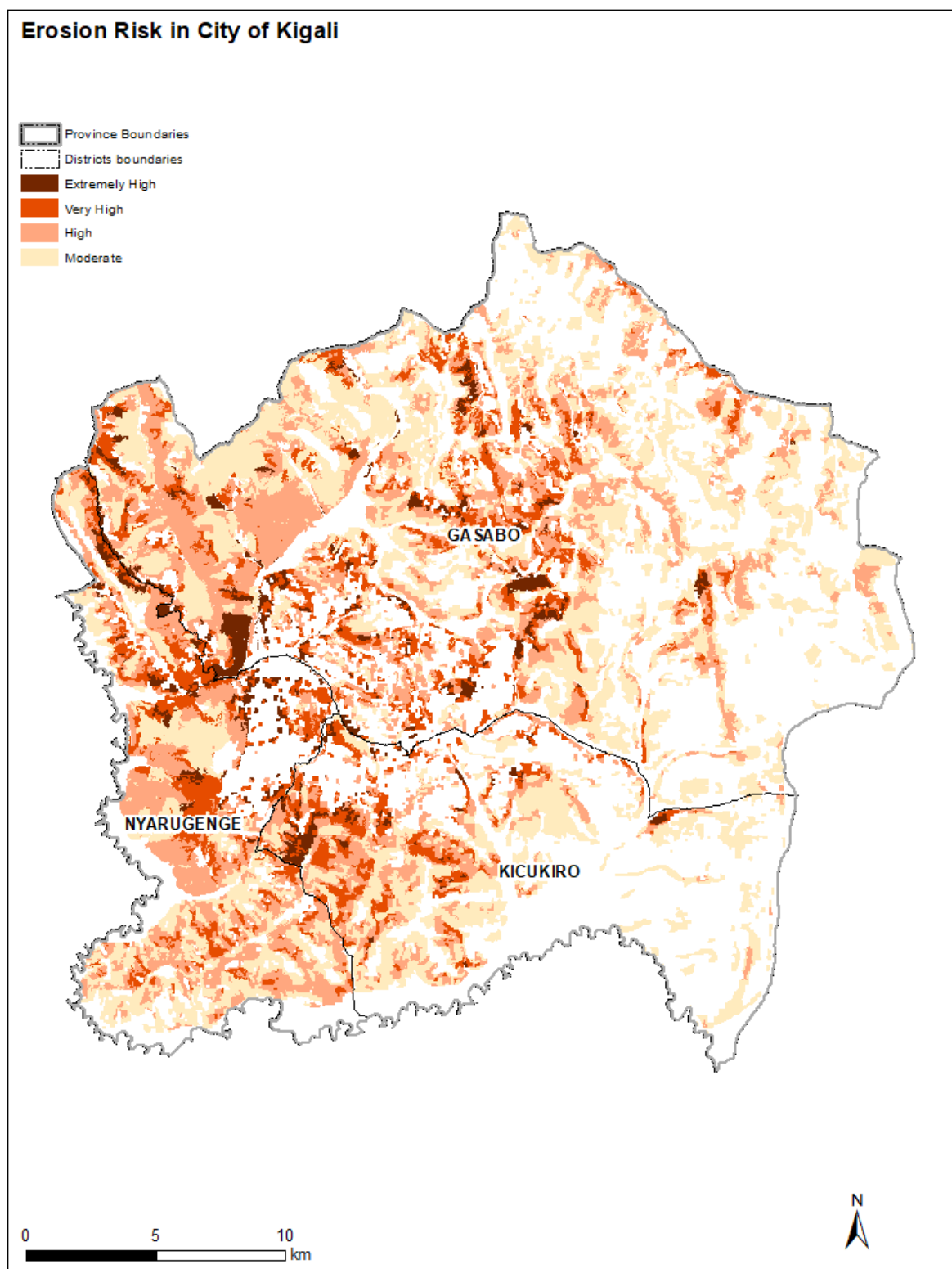
**Figure 141: Recommended erosion control practices in Rwamagana District**

### 3.5. Erosion Control Status in City of Kigali

Erosion risk in City of Kigali is summarized in table 145 and presented in figure 145. The total land at high risk of erosion in City of Kigali is about 39179 hectares (54% of the total City of Kigali). The highest amount of land at erosion risk are found in Nyarugenge District with 8781 hectares (i.e. 66% of the total district land) followed by Gasabo District with 23374 hectares (55% of the district land), and Kicukiro with 7024 hectares (42% of district land).

**Table 146: Erosion risk in City of Kigali**

District Name	Erosion risk					District land (Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total (Ha)		
NYARUGENGE	399	1683	3379	3320	8781	13395	66%
GASABO	1132	2843	7500	11899	23374	42763	55%
KICUKIRO	281	1137	1918	3689	7024	16671	42%
<b>Grand Total</b>	<b>1812</b>	<b>5663</b>	<b>12797</b>	<b>18908</b>	<b>39179</b>	<b>72829</b>	<b>54%</b>



**Figure 142: Erosion risk in City of Kigali**

3.5.1. Erosion control in Gasabo District

Erosion risk in Gasabo is summarised in Table 146 and presented in figure 146. Erosion risk in Gasabo District is estimated to 23374 hectares; about 55% of the total district land are highly susceptible to erosion of which 521 hectares are located in Gatsata sector (87% of sector land), 3233 hectares are located in Jali sector (86% of sector land), 2978 hectares are located in Jabana (82% of the sector land), and 4111 hectares are found in Bumbogo sector about 68% of the sector land. The least sectors are Rusororo with only 1392 hectares (27% of the sector land) susceptible to erosion, Rutunga with 1563 hectares (37%), and Kimironko with 429 hectares, about 38% of the total sector land. As compare to other district in City of Kigali, Gasabo is the second susceptible to erosion.

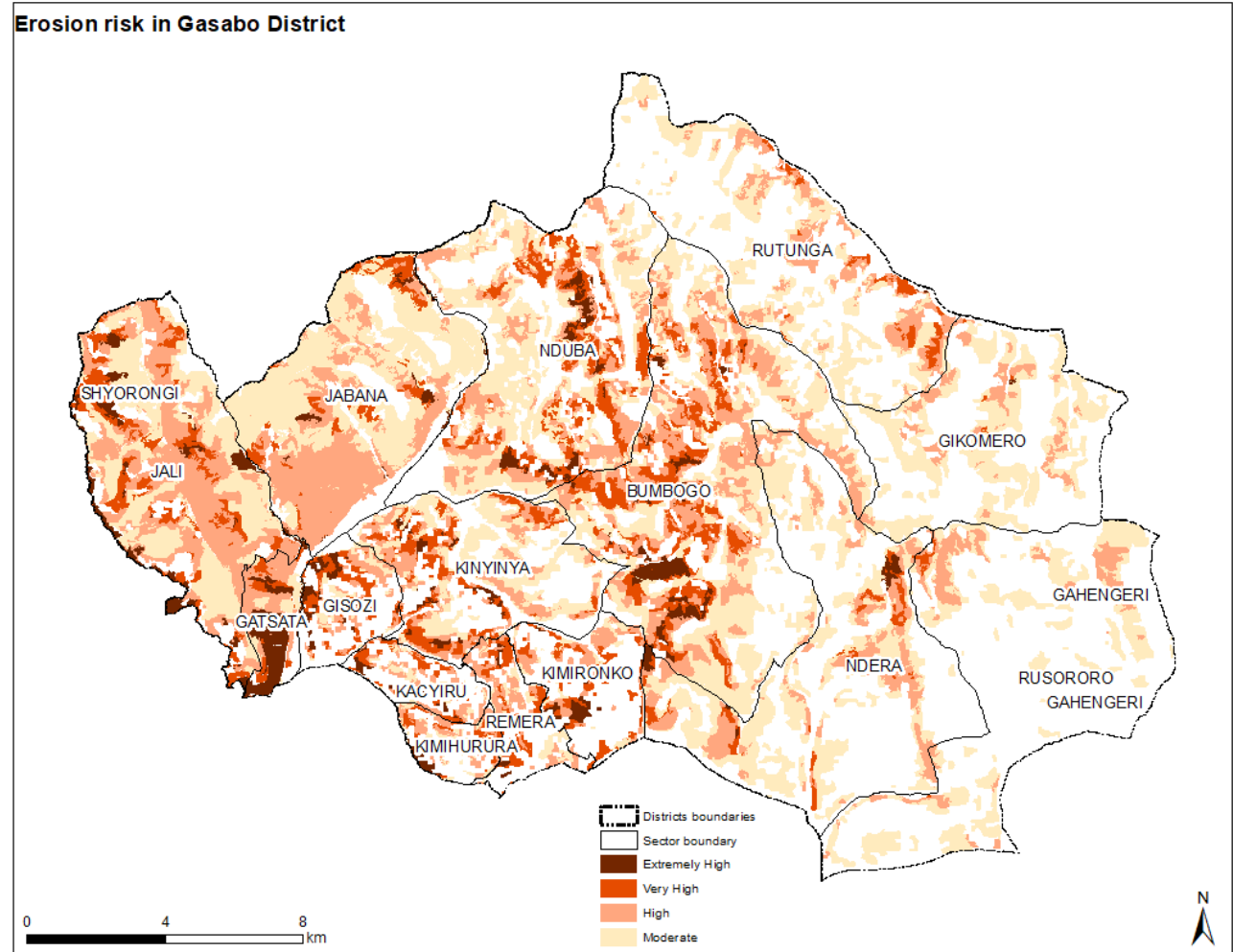


Figure 143: Erosion risk in Gasabo District

Table 147: Erosion risk per sector in Gasabo District

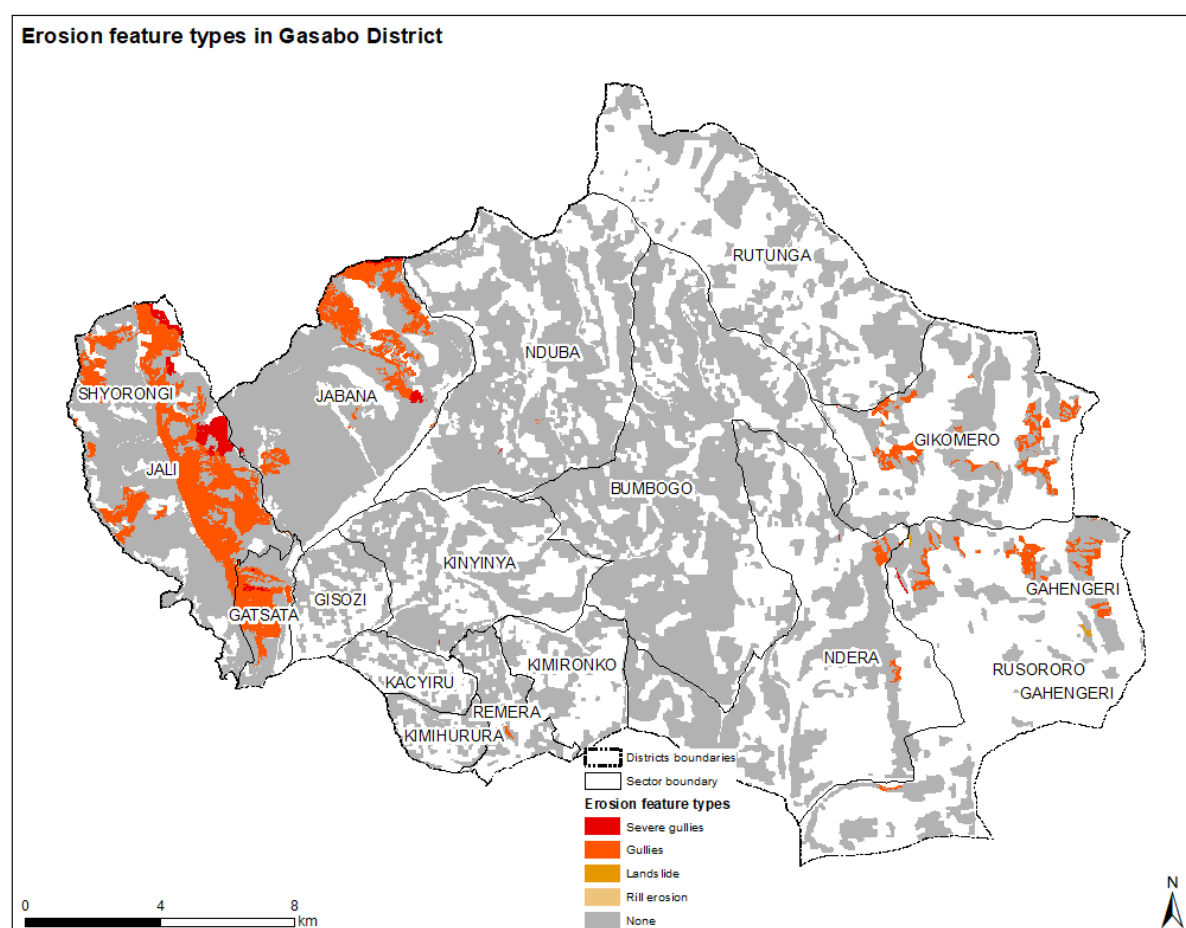
Sector Name	Erosion risk					District land (Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total (Ha)		
GATSATA	220	54	184	62	521	602	87%
JALI	224	431	1298	1280	3233	3750	86%
JABANA	48	196	1078	1656	2978	3644	82%
BUMBOGO	204	664	1398	1845	4111	6007	68%
NDUBA	132	465	813	1431	2841	4672	61%
KINYINYA	58	281	430	658	1426	2459	58%
REMERA	15	124	174	64	378	703	54%
KIMIHURURA	26	49	115	68	258	488	53%
GISOZI	80	124	126	83	414	848	49%
NDERA	56	123	600	1415	2194	5017	44%
KACYIRU	19	70	104	60	253	581	44%
GIKOMERO	2	7	229	1146	1384	3427	40%
KIMIRONKO	48	138	178	65	429	1144	38%
RUTUNGA		100	448	1014	1563	4174	37%
RUSORORO		16	325	1051	1392	5247	27%
<b>Grand Total</b>	<b>1132</b>	<b>2843</b>	<b>7500</b>	<b>11899</b>	<b>23374</b>	<b>42763</b>	<b>55%</b>

Land areas affected by erosive features in Gasabo District are summarized in Table 147 and the map of erosive features are presented in Figure 147. The results show that Gatsata sector is the worst affected by rill erosion on areas estimated to 247 hectares (48% of sector land at risk), followed by Jali with 1180 hectares (37% of sector land at risk) and Jabana with 491 hectares (16% of the sector land at risk). The presence of gullies in Jali, Jabana and Gatsata confirms the findings of CROM model; however the absence of gullies in Bumbogo, Nduba and Kinyinya which were originally predicted by CROM model as sectors at high risk should read that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis of Land cover and erosion control practices in place will demonstrate that (Table 148 and 149).

**Table 148: Erosive features and areas affected in Gasabo District**

Sector Name	Erosive features			Total Features	None	Grand Total	% features
	Gullies	Landslide	Severe gullies				
GATSATA	239		9	247	273	521	48%
JALI	1071		112	1182	2051	3233	37%
JABANA	462		29	491	2487	2978	16%
GIKOMERO	202			202	1182	1384	15%
RUSORORO	161	7	4	171	1221	1392	12%
NDERA	36			36	2158	2194	2%
REMERA	4			4	374	378	1%
RUTUNGA	0			0	1563	1563	0%
BUMBOGO				0	4111	4111	0%

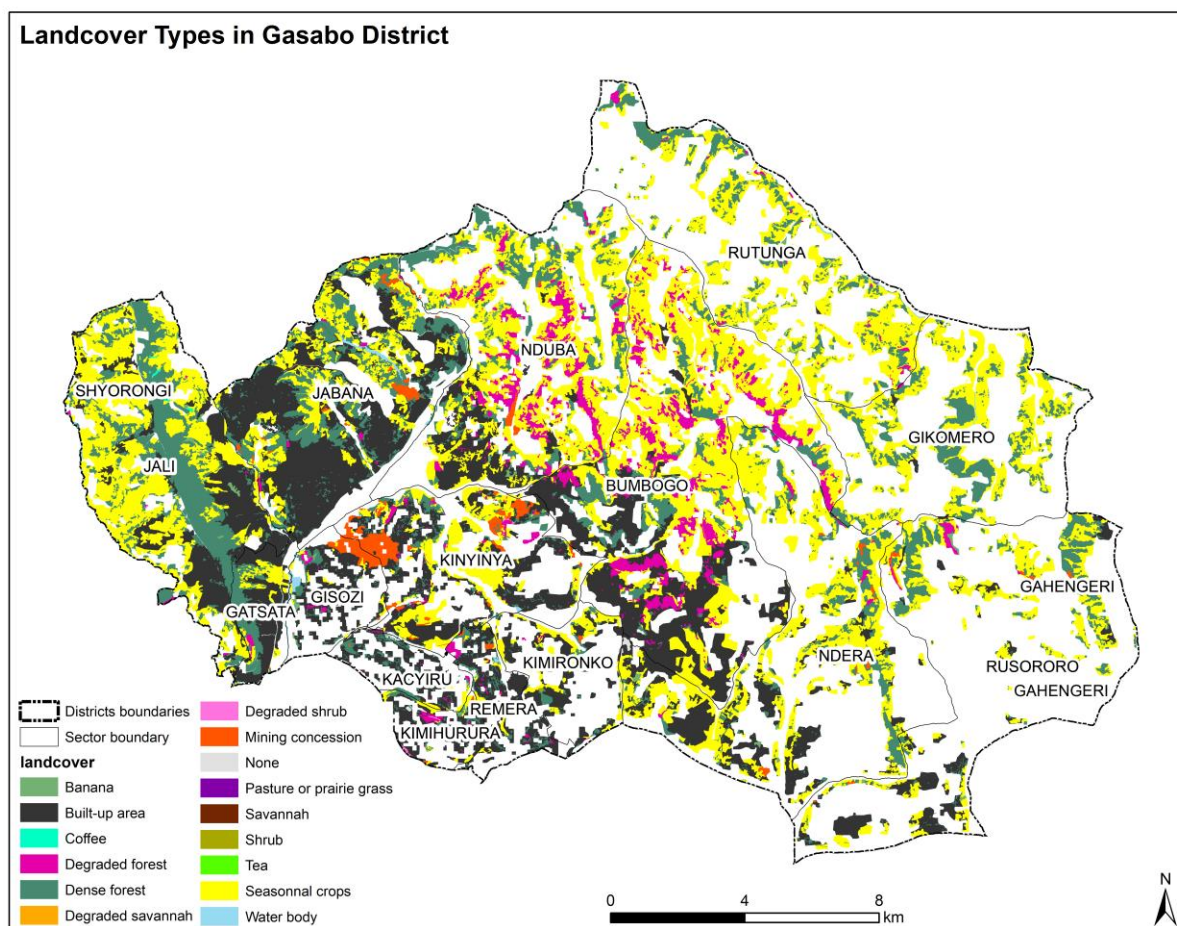
Sector Name	Erosive features			Total Features	None	Grand Total	% features
	Gullies	Landslide	Severe gullies				
GISOZI				0	414	414	0%
KACYIRU				0	253	253	0%
KIMIHURURA				0	258	258	0%
KIMIRONKO				0	429	429	0%
KINYINYA				0	1426	1426	0%
NDUBA				0	2841	2841	0%
<b>Grand Total</b>	<b>2172</b>	<b>7</b>	<b>154</b>	<b>2333</b>	<b>21042</b>	<b>23374</b>	<b>10%</b>



**Figure 144: Erosive features detected in Gasabo District**

In term of land use and land cover of areas at risk in Gasabo District, the results of land cover mapping (Table 148 and Figure 149) show that 10671 hectares (46% of the total land at risk) are used for seasonal cropping, 4360 hectares (19% of the total of the total land at risk) are covered by healthy forests and 6709 hectares (29% of the total land at risk) are covered by built-up area. In Gasabo District there are also degraded forests which cover an area of 1074 hectares (5% of the total land at risk) and banana which cover an area estimated to 119 hectares (1% of the total district land at erosion risk).





**Figure 145: Land cover types in Gasabo District**

**Table 149: Land Use and Vegetation Cover (LUVc) for land at risk in Gasabo District**

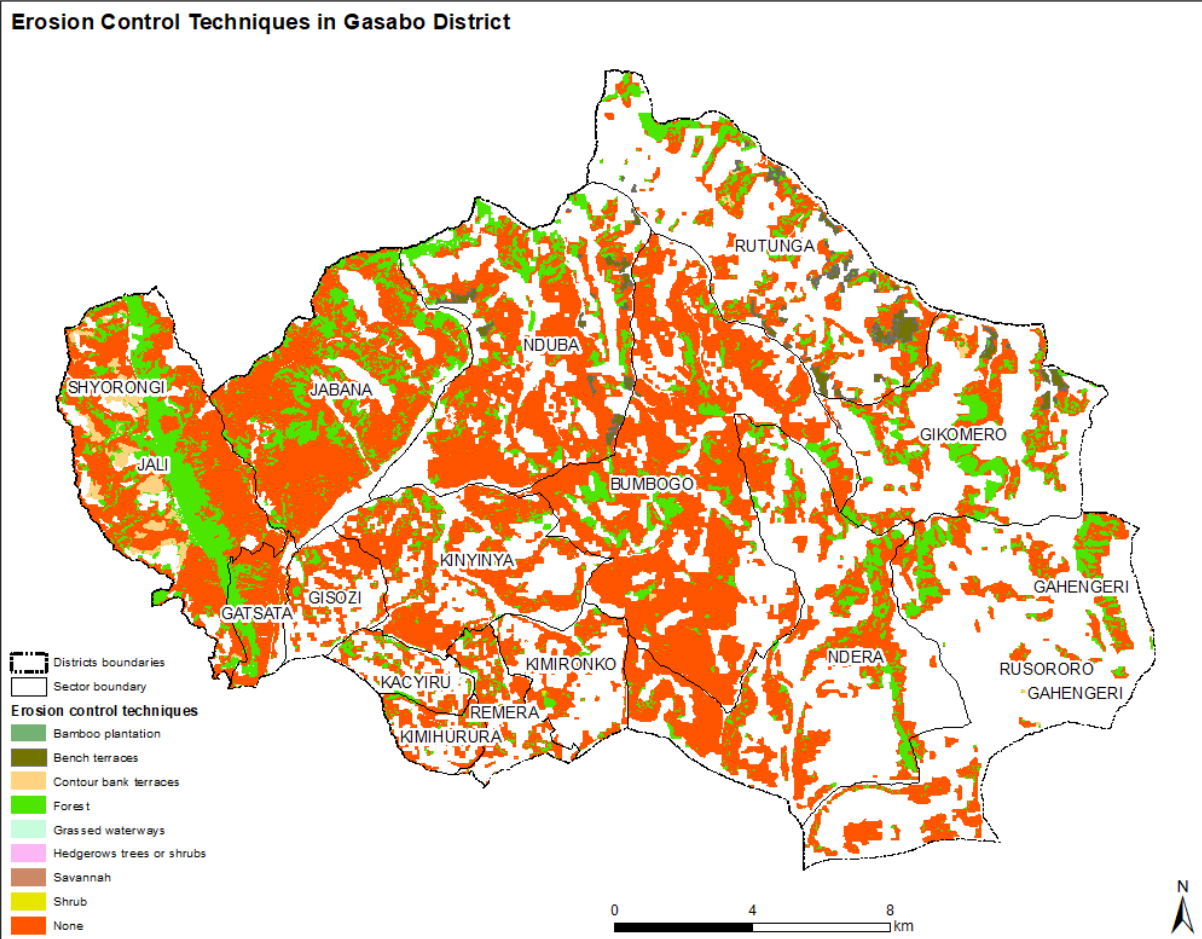
Sector Name	Banana	Built-up area	Coffee	Degraded forest	Degraded shrub	Dense forest	Mining and Quarries	None	Seasonal crops	Shrub	Water body	Grand Total
BUMBOGO		1144		519		421			2027			4111
GATSATA	3	286		9		141			76		5	521
GIKOMERO	1	12		1		431			936		1	1384
GISOZI	7	264		12		44	52		22		13	414
JABANA		1501		15		660	49		735		18	2978
JALI	21	695	6	5		927	0		1549		31	3233
KACYIRU		194		3		41			15			253
KIMIHURURA	4	170		14	6	25	1	3	34			258
KIMIRONKO		239		3		35	2		150	1		429
KINYINYA		676		33	1	88	165		461		2	1426
NDERA	13	555		20		329	23	7	1246			2194
NDUBA	24	369		381		506	22		1539			2841
REMERERA		286		15		34	5		34		3	378

Sector Name	Banana	Built-up area	Coffee	Degraded forest	Degraded shrub	Dense forest	Mining and Quarries	No	Seasonal crops	Shrub	Water body	Grand Total
RUSORORO	10	312		26		303	19		724			1392
RUTUNGA	37	2		19		375			1122		8	1563
<b>Grand Total</b>	<b>119</b>	<b>6705</b>	<b>6</b>	<b>1074</b>	<b>8</b>	<b>4360</b>	<b>338</b>	<b>10</b>	<b>10671</b>	<b>1</b>	<b>81</b>	<b>23374</b>
<b>%</b>	<b>1%</b>	<b>29%</b>	<b>0%</b>	<b>5%</b>	<b>0%</b>	<b>19%</b>	<b>1%</b>	<b>0%</b>	<b>46%</b>	<b>0%</b>	<b>0%</b>	<b>100%</b>

About existing erosion control practices in Gasabo district, Table 149 shows that only 21% of land at risk is protected by forests (4360 hectares), contour bank terraces (326 hectares), bench terraces (337 hectares). The highest protected sectors are Jali with 38% of its land at risk protected followed by Rutunga with 36% of its land at risk protected, Gikomero where 36% of the total land at risk is protected and Gatsata with 36% of land protected. The least protected sectors are Kinyinya (only 6% protected), Kimironko (8%) and Remera (9% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Bumbogo and Kinyinya sectors remain at high risk of soil erosion since more than 80% of their respective land are not protected

**Table 150: Erosion control practices already in place in Gasabo District**

Sector Name	Erosion control in place				Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Contour bank terraces	Forest	Shrub				
JALI		297	927		1224	2010	3233	38%
RUTUNGA	185	9	375		570	993	1563	36%
GIKOMERO	50	12	431		493	891	1384	36%
GATSATA			141		141	379	521	27%
JABANA			660		660	2318	2978	22%
RUSORORO		4	303		306	1086	1392	22%
NDUBA	100		506		606	2235	2841	21%
KACYIRU			41		41	212	253	16%
NDERA			329		329	1865	2194	15%
GISOZI			44		44	371	414	11%
BUMBOGO	1	4	421		427	3684	4111	10%
KIMIHURURA			25		25	233	258	10%
REMERA			34		34	343	378	9%
KIMIRONKO			35	1	36	393	429	8%
KINYINYA			88		88	1338	1426	6%
<b>Grand Total</b>	<b>337</b>	<b>326</b>	<b>4360</b>	<b>1</b>	<b>5024</b>	<b>18351</b>	<b>23374</b>	<b>21%</b>



**Figure 146: Erosion control techniques in place in Gasabo District**

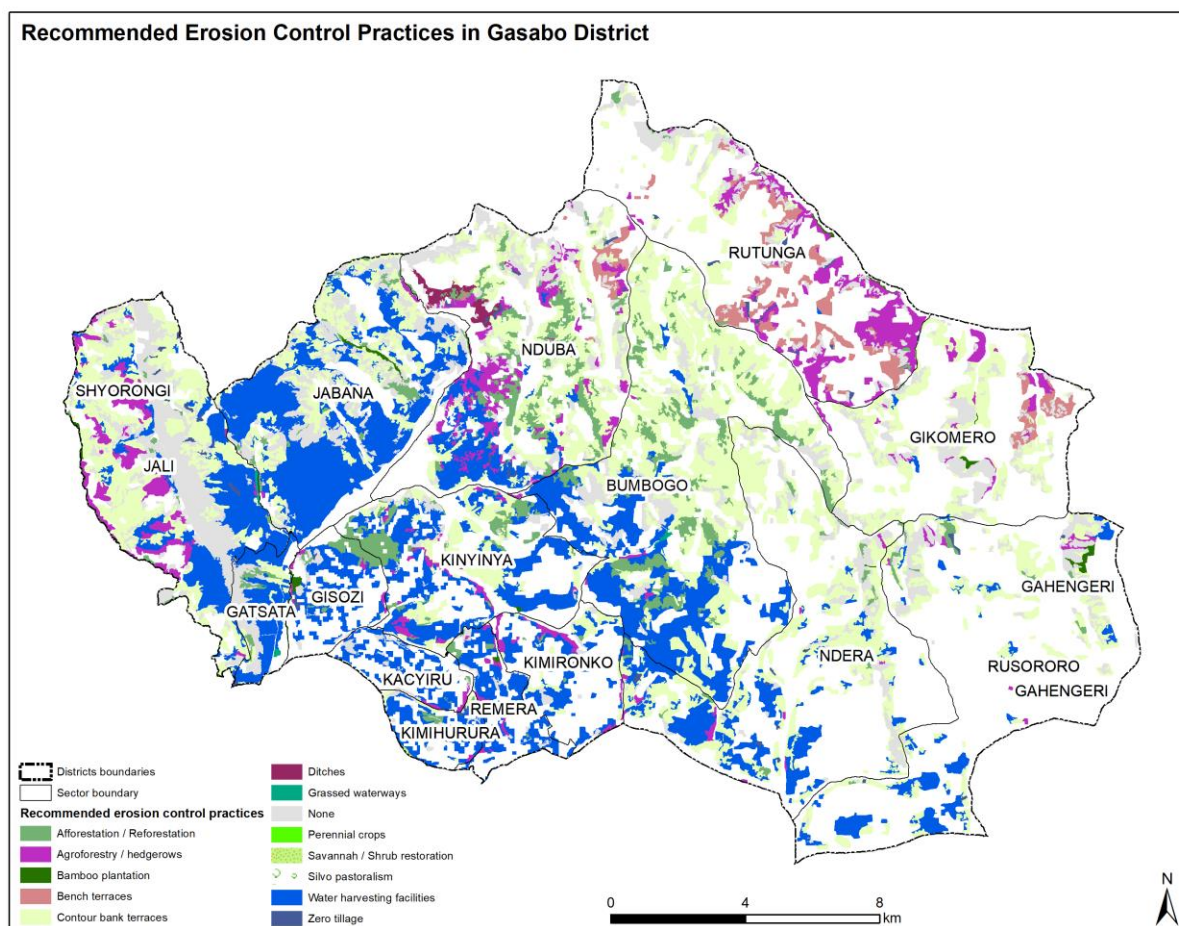
Erosion control practices in Gasabo District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 150 shows that about 8276 hectares (which is 35% of the total land at risk) are suitable for Contour bank terraces, agroforestry/hedgerows is needed on an estimated area of 1624 hectares (7%), 6715 hectares are Storm water management facilities (SWMF). Other recommended erosion control practices are afforestation and reforestation on an estimated area of 1496 hectares and 109 hectares for bamboo to close gullies and protect river banks.

**Table 151: Recommended erosion control practices in Gasabo District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Bench terraces	Contour bank terraces	Forest Ditches	Grassed waterways	None	Savannah / Shrub restoration	Water harvesting facilities	Zero tillage	Grand Total
BUMBOGO	522	16			2001		7	421		1144		4111
GATSATA	33		5		48		4	141		286	3	521
GIKOMERO	1	106	8	97	726			431		12	1	1384
GISOZI	65	18	13		4			44		264	7	414
JABANA	79	10	18		710			660		1501		2978
JALI	27	354	31		1164		8	927		695	27	3233
KACYIRU	3	14			1			41		194		253
KIMIHURURA	15	4			29			25	6	174	4	258
KIMIRONKO	6	60			89			36		239		429
KINYINYA	197	73	2		389			88	1	676		1426
NDERA	56	35	1		1199			329		561	13	2194
NDUBA	394	379		87	995	78		514		369	24	2841
REMERA	21	28	3		6			34		286		378
RUSORORO	53	29	19	0	667			303		312	10	1392
RUTUNGA	24	499	8	371	248			375		2	37	1563
<b>Grand Total</b>	<b>1496</b>	<b>1624</b>	<b>109</b>	<b>555</b>	<b>8276</b>	<b>78</b>	<b>19</b>	<b>4369</b>	<b>8</b>	<b>6715</b>	<b>125</b>	<b>23374</b>
<b>%</b>	<b>6%</b>	<b>7%</b>	<b>0%</b>	<b>2%</b>	<b>35%</b>	<b>0%</b>	<b>0%</b>	<b>19%</b>	<b>0%</b>	<b>29%</b>	<b>1%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.





**Figure 147: Recommended erosion control practices in Gasabo District**

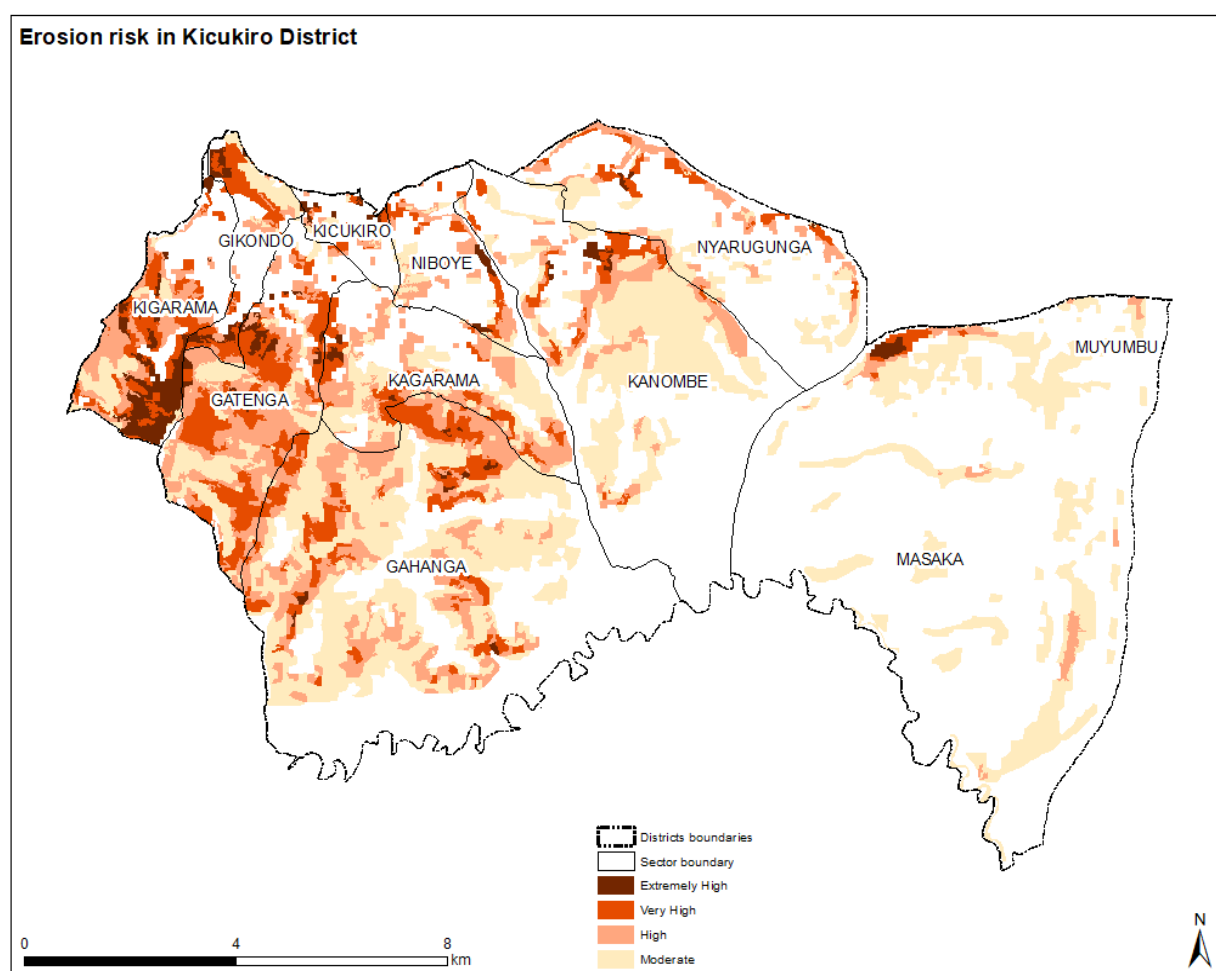
### 3.5.2. Erosion control status in Kicukiro District

Erosion risk in Kicukiro District is summarised in Table 151 and presented in figure 151. Erosion risk in Kicukiro District is estimated to 7024 hectares; about 42% of the total district land are highly susceptible to erosion of which 947 hectares are located in Gatenga sector (84% of sector land), 534 hectares are located in Kigarama sector (63% of sector land), 608 hectares are located in Kagarama (58% of the sector land). The least sectors are Masaka with only 1004 hectares (19% of the sector land) susceptible to erosion, Nyarugunga with 382 hectares (28%), and Kicukiro with 59 hectares, about 29% of the total sector land. As compared to other districts in Southern Province, Kicukiro is the third susceptible to erosion risk.

**Table 152: Erosion risk per sector in Kicukiro District**

Sector Name	Erosion risk					District land (Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total (Ha)		
GATENGA	40	304	379	224	947	1130	84%
KIGARAMA	132	139	178	84	534	777	69%
KAGARAMA	8	100	248	252	608	966	63%

Sector Name	Erosion risk					District land (Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total (Ha)		
GAHANGA	15	288	583	1235	2123	3662	58%
GIKONDO	29	88	31	54	202	351	58%
KANOMBE	14	76	198	701	988	2456	40%
NIBOYE	13	42	71	53	178	503	35%
KICUKIRO	9	18	24	9	59	213	28%
NYARUGUNGA	4	62	132	184	382	1382	28%
MASAKA	17	21	73	892	1004	5231	19%
<b>Grand Total</b>	<b>281</b>	<b>1137</b>	<b>1918</b>	<b>3689</b>	<b>7024</b>	<b>16671</b>	<b>42%</b>



**Figure 148: Erosion risk in Kicukiro District**

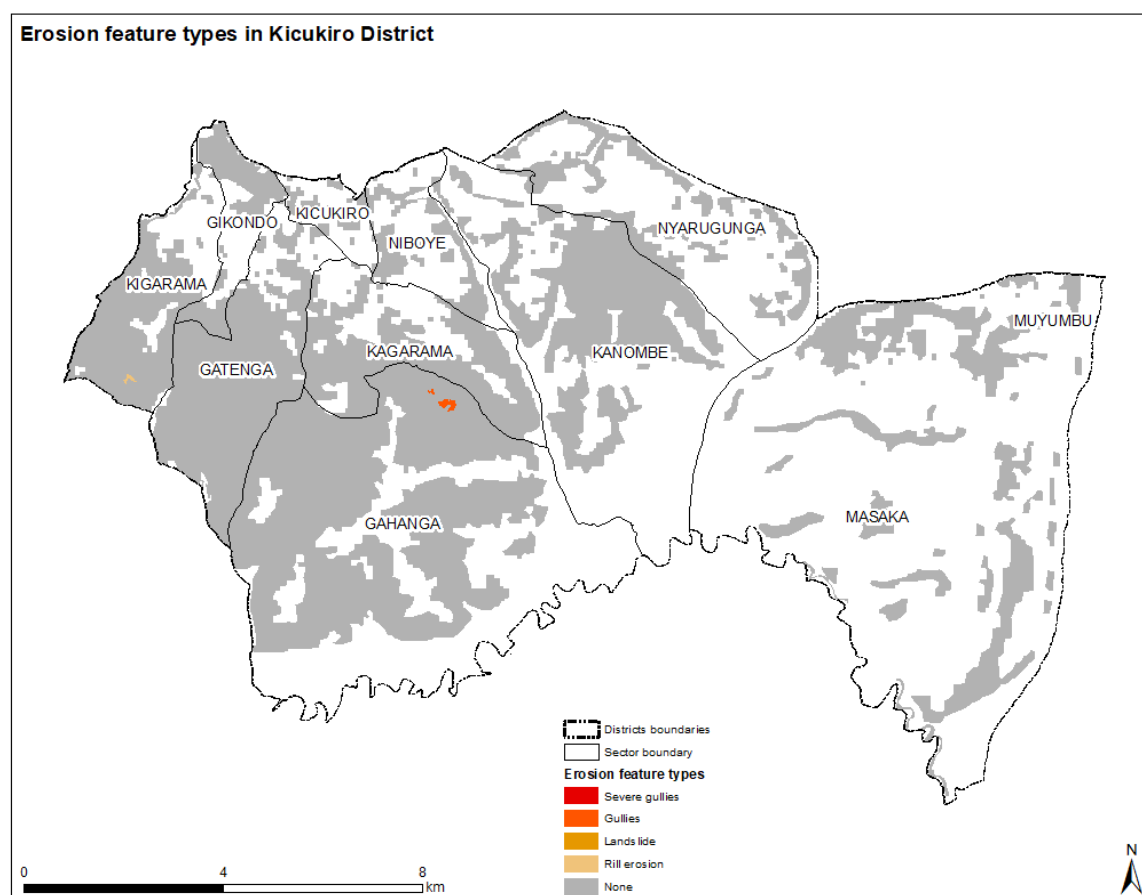
Land areas affected by erosive features in Kicukiro District are summarized in Table 152 and the map of erosive features are presented in Figure 152. The results show that Kigarama sector is the worst affected by gullies and severe gullies on areas estimated to 2 hectares (0.3% of sector land at risk), followed by Gahanga sector on 5 hectares (0.2% of sector land at risk), and Gatenga sector on less than 1 hectare



(less than 1% of sector land at risk). The presence of gullies in Kigarama and Gahanga sectors confirms the findings of CROM model.

**Table 153: Erosive features and areas affected in Kicukiro District**

Sector Name	Erosive features		Total features (ha)	None	Grand Total	% features
	Gullies	Rill erosion				
KIGARAMA		2	2	532	534	0.37%
GAHANGA	5		5	2117	2123	0.25%
GATENGA			0	947	947	0.00%
GIKONDO			0	202	202	0.00%
KAGARAMA			0	608	608	0.00%
KANOMBE			0	988	988	0.00%
KICUKIRO			0	59	59	0.00%
MASAKA			0	1004	1004	0.00%
NIBOYE			0	178	178	0.00%
NYARUGUNGA			0	382	382	0.00%
<b>Grand Total</b>	<b>5</b>	<b>2</b>	<b>7</b>	<b>7017</b>	<b>7024</b>	<b>0.10%</b>

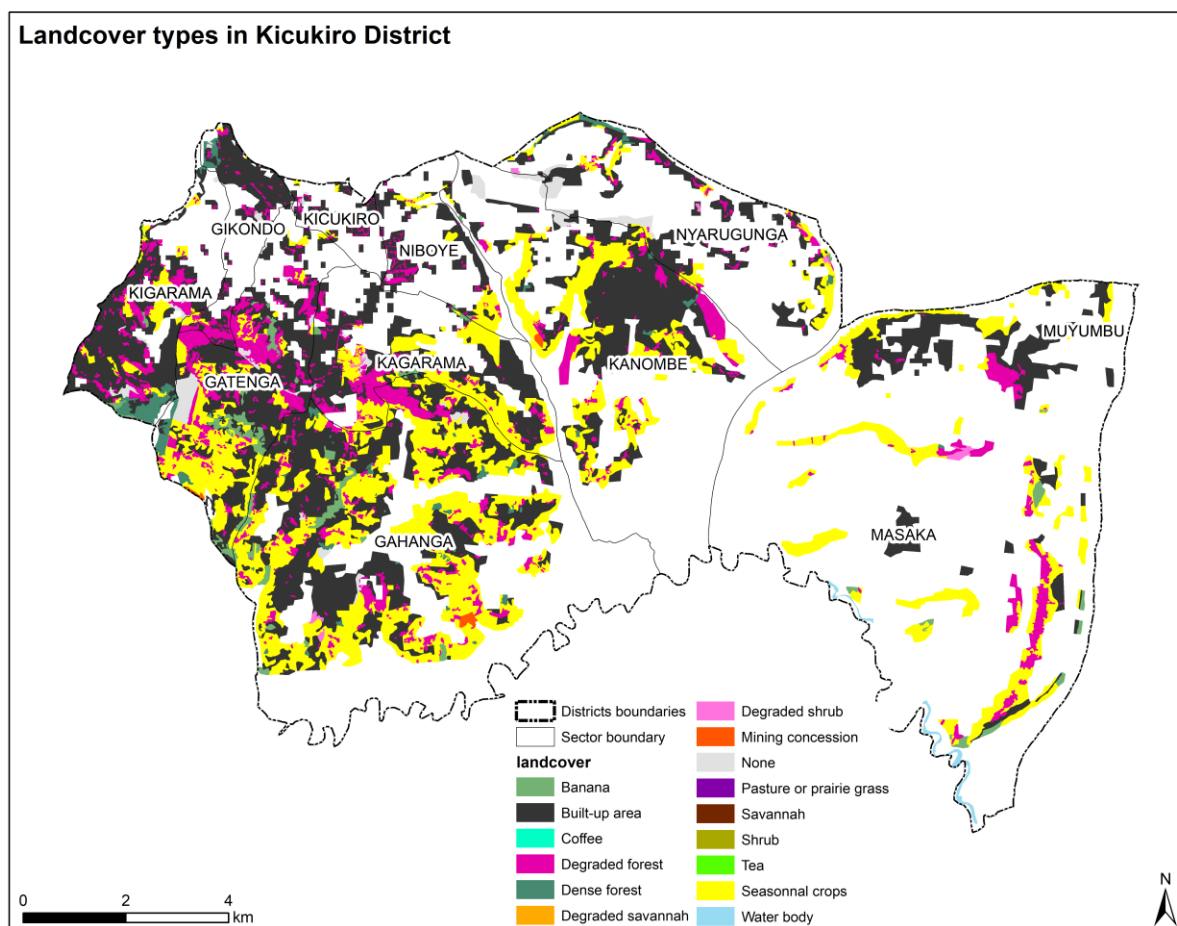


**Figure 149: Erosive features detected in Kicukiro District**

In term of land use and land cover of areas at risk in Kicukiro District, the results of land cover mapping (Table 153 and Figure 153) show that 2461 hectares (35% of the total land at risk) are used for seasonal cropping, 111 hectares (2% of the total land at risk) are covered by healthy forests, 3348 hectares (48% of the total land at risk) are covered by built-up area. and 757 hectares of degraded forests (11%)

**Table 154: Land Use and Vegetation Cover (LUVC) for land at risk in Kicukiro District**

Sector Name	Banana	Built-up area	Degraded forest	Degraded shrub	Dense forest	Mining and Quarries	None	Seasonal crops	Water body	Grand Total
GAHANGA	52	873	153	5	22	7	15	996		2123
GATENGA	50	388	186		20	3	37	263		947
GIKONDO		155	27		12		2	6		202
KAGARAMA	10	318	68	2			8	201		608
KANOMBE		514	74		6	3	26	364		988
KICUKIRO		53	2					4		59
KIGARAMA	6	336	80		36		15	61		534
MASAKA	31	370	130	8				437	27	1004
NIBOYE		119	14				3	42		178
NYARUGUNGA		221	22	4	16		33	86		382
<b>Grand Total</b>	<b>148</b>	<b>3348</b>	<b>757</b>	<b>19</b>	<b>111</b>	<b>13</b>	<b>140</b>	<b>2461</b>	<b>27</b>	<b>7024</b>
<b>%</b>	<b>2%</b>	<b>48%</b>	<b>11%</b>	<b>0%</b>	<b>2%</b>	<b>0%</b>	<b>2%</b>	<b>35%</b>	<b>0%</b>	<b>100%</b>



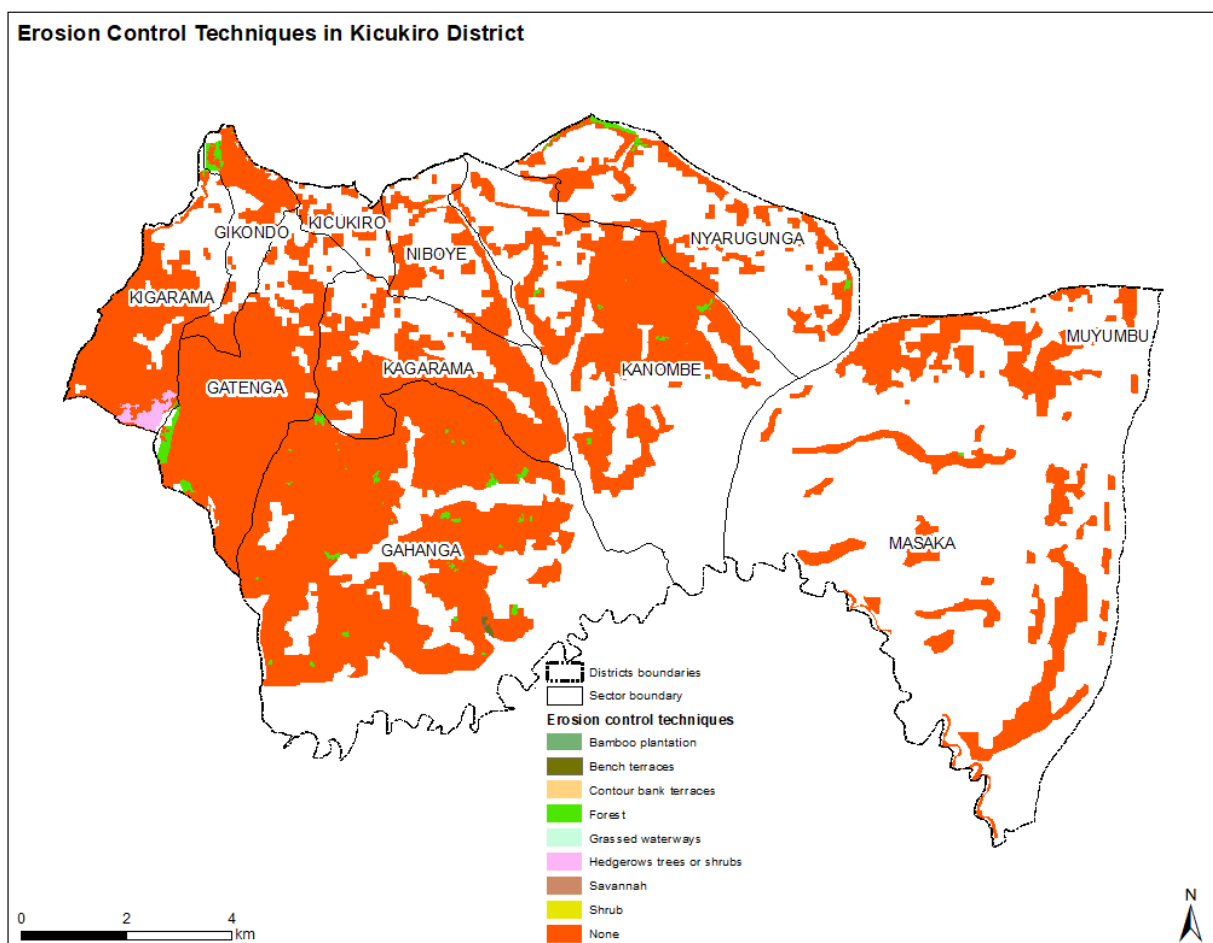
**Figure 150: Land cover types in Kicukiro District**

About existing erosion control practices in Kicukiro district, Table 154 shows that 2% of land at risk is protected by forests (76 hectares), hedgerows (36 hectares) and bench terraces (4 hectares). The highest protected sectors are Kigarama with 7% of its land at risk protected, followed by Gikondo where 6% of the total land at risk is protected and Nyarugunga with 4% of land protected. The least protected sectors are Kagarama, Masaka, Niboye and Kanombe. All these sectors have less than 1% of erosion control practices.

**Table 155: Erosion control practices already in place in Kicukiro District**

Sector Name	Erosion control in place			Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Forest	Hedgerows trees or shrubs				
KIGARAMA			36	36	498	534	7%
GIKONDO		12		12	191	202	6%
NYARUGUNGA		16		16	366	382	4%
GATENGA		20		20	926	947	2%
GAHANGA	4	22		26	2097	2123	1%
KANOMBE		6		6	982	988	1%
KAGARAMA				0	608	608	0%

Sector Name	Erosion control in place			Total protected (ha)	Unprotected (ha)	Grand Total	% protected
	Bench terraces	Forest	Hedgerows trees or shrubs				
KICUKIRO				0	59	59	0%
MASAKA				0	1004	1004	0%
NIBOYE				0	178	178	0%
<b>Grand Total</b>	<b>4</b>	<b>76</b>	<b>36</b>	<b>115</b>	<b>6909</b>	<b>7024</b>	<b>2%</b>



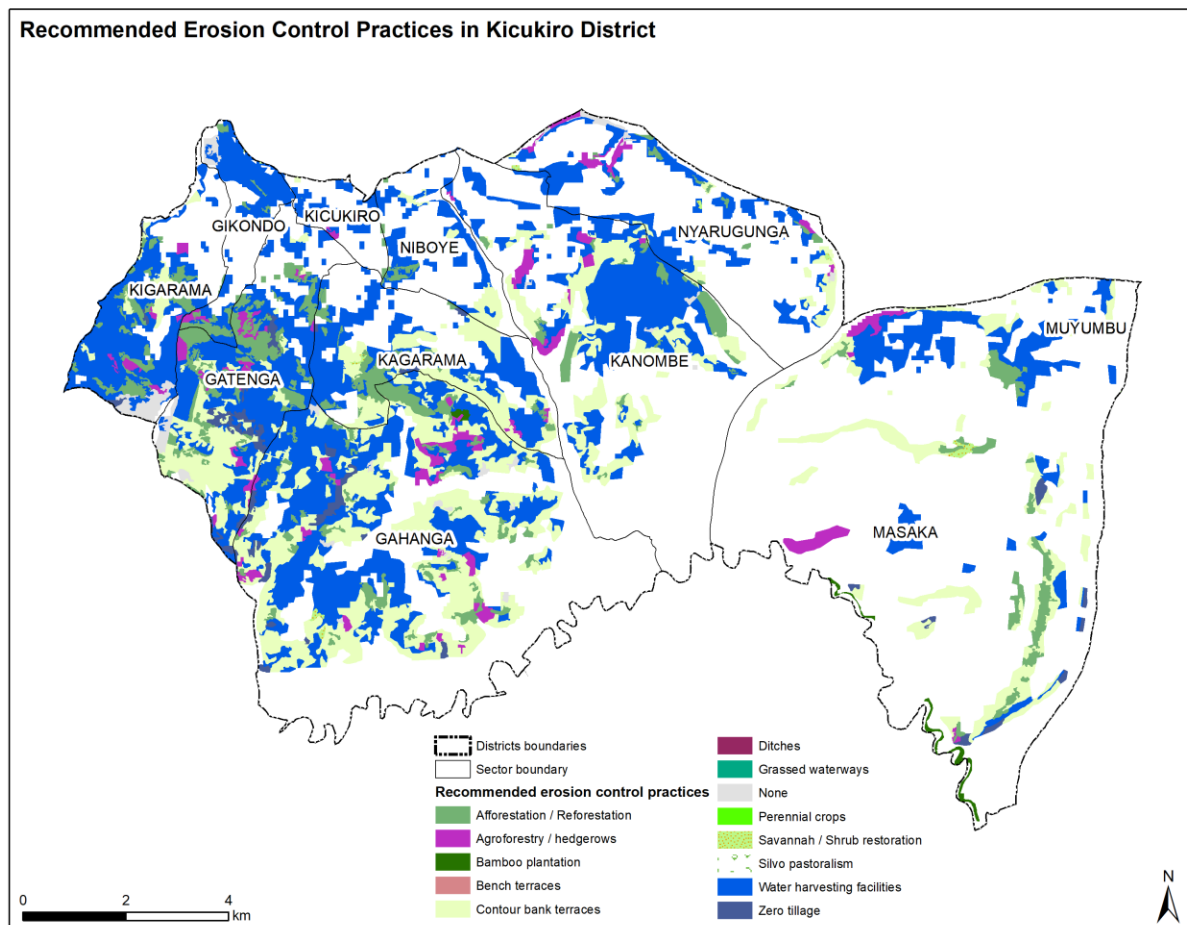
**Figure 151: Erosion control techniques in place in Kicukiro District**

Erosion control practices in Kicukiro District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 155 shows that about 2169 hectares (which is 31% of the total land at risk) are suitable for Contour bank terraces, 792 hectares are Afforestation & Reforestation. Other interventions are 289 ha for agroforestry/hedge rows, 3463 hectares of water harvesting facilities.

**Table 156: Recommended erosion control practices in Kicukiro District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Contour bank terraces	None	Savannah / Shrub restoration	Water harvesting facilities	Zero tillage	Grand Total
GAHANGA	162	89	5	907	22	5	881	52	2123
GATENGA	190	43		220	20		423	50	947
GIKONDO	27	6			12		157		202
KAGARAMA	78	5		195		2	318	10	608
KANOMBE	77	42		322	6		541		988
KICUKIRO	2	3		2			53		59
KIGARAMA	89	17		43	36		342	6	534
MASAKA	130	52	27	385		8	370	31	1004
NIBOYE	14			40			124		178
NYARUGUNGA	22	32		54	16	4	254		382
<b>Grand Total</b>	<b>792</b>	<b>289</b>	<b>32</b>	<b>2169</b>	<b>111</b>	<b>19</b>	<b>3463</b>	<b>148</b>	<b>7024</b>
<b>%</b>	<b>11%</b>	<b>4%</b>	<b>0%</b>	<b>31%</b>	<b>2%</b>	<b>0%</b>	<b>49%</b>	<b>2%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

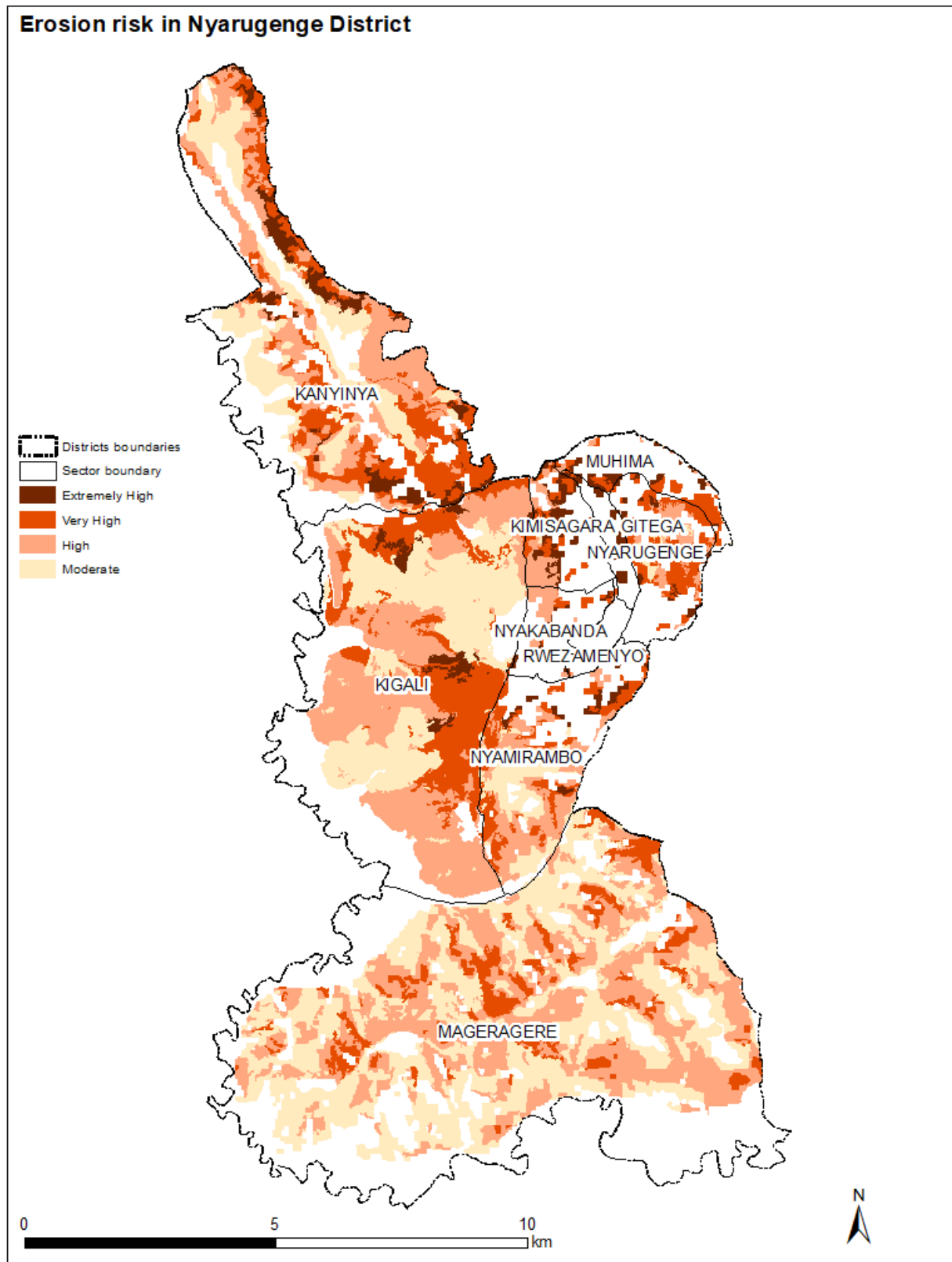


**Figure 152: Recommended erosion control practices in Kicukiro District**

### 3.5.3. Erosion status in Nyarugenge District

Erosion risk in Nyarugenge is summarised in Table 156 and presented in figure 156. Erosion risk in Nyarugenge District is estimated to 8781 hectares; about 66% of the total district land are highly susceptible to erosion of which 2299 hectares are located in Kigali sector (76% of sector land), 1724 hectares are located in Kanyinya sector (70% of sector land), 3626 hectares are located in Mageragere (66% of the sector land), and 574 hectares are found in Nyamirambo sector about 64% of the sector land. The least sectors are Rwezamenyo with only 3 hectares (3% of the sector land) susceptible to erosion, Gitega with 27 hectares (23%), Nyakabanda with 61 hectares, about 26% of the total sector land and Muhima with 80 hectares of the total sector land. As compared to other districts in City of Kigali, Nyarugenge is the first susceptible to erosion.





**Figure 153: Erosion risk in Nyarugenge District**

**Table 157: Erosion risk per sector in Nyarugenge District**

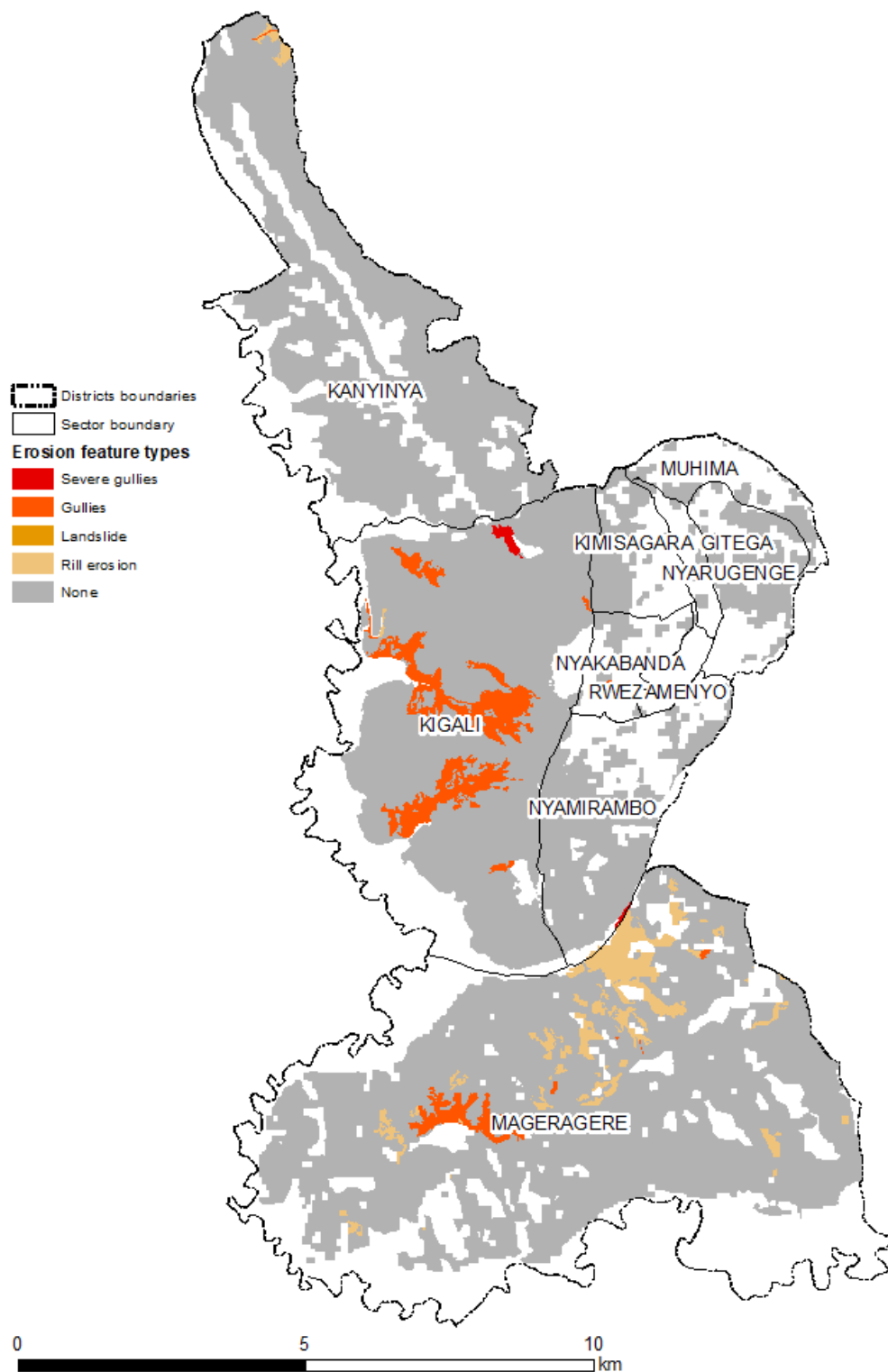
Sector Name	Erosion risk					District land (Ha)	Percentage (%)
	Extremely High	Very High	High	Moderate	Grand Total (Ha)		
KIGALI	69	516	907	807	2299	3025	76%
KANYINYA	170	452	600	503	1724	2460	70%
MAGERAGERE		337	1475	1814	3626	5491	66%
NYAMIRAMBO	29	143	226	176	574	894	64%
NYARUGENGE	20	135	58	16	230	455	51%
KIMISAGARA	56	39	59	2	156	319	49%
MUHIMA	19	52	7	2	80	292	28%
NYAKABANDA	7	9	45		61	240	26%
GITEGA	27	0			27	117	23%
RWEZAMENYO	1		1		3	103	2%
<b>Grand Total</b>	<b>399</b>	<b>1683</b>	<b>3379</b>	<b>3320</b>	<b>8781</b>	<b>13395</b>	<b>66%</b>

Land areas affected by erosive features in Nyarugenge District are summarized in Table 157 and the map of erosive features are presented in Figure 157. The results show that Kigali sector is the worst affected by gullies on areas estimated to 300 hectares (13% of sector land at risk), followed by Mageragere sector affected by rill erosion and gullies on 325 hectares (9% of sector land at risk), and Kanyinya sector on 15 hectares (1% of sector land at risk). The presence of gullies in Kigali, rill erosion in Mageragere and Kanyinya sectors confirms the findings of CROM model; however reduced presence of gullies in Nyarubaka, Musambira and Nyamiyaga and the absence of gullies in Nyamirambo, Kimisagara and Muhima sectors which were originally predicted by CROM model as sectors at high risk should not read that and this shows that CROM model did not perform well in this sectors, but rather due to the time of image acquisition, the erosive features could be observed or erosion control measures have been already taken and therefore runoffs have been reduced, thus erosive features could not be formed in this case. Further analysis will demonstrate that in Table 158 and 159. The least sectors affected by gullies and rill erosion are Rwezamenyo, Nyarugenge, Muhima, Gitega and Kimisagara where there is no erosive features observed on the recent satellite imageries.

**Table 158: Erosive features and areas affected in Nyarugenge District**

Sector name	Erosive features			Total features (ha)	None	Grand Total	% features
	Gullies	Rill erosion	Severe gullies				
KIGALI	285	3	12	300	1999	2299	13%
MAGERAGERE	74	251		325	3301	3626	9%
KANYINYA	1	14		15	1709	1724	1%
NYAMIRAMBO		1	2	3	571	574	1%
GITEGA				0	27	27	0%
KIMISAGARA				0	156	156	0%
MUHIMA				0	80	80	0%
NYAKABANDA				0	61	61	0%
NYARUGENGE				0	230	230	0%
RWEZAMENYO				0	3	3	0%
<b>Grand Total</b>	<b>361</b>	<b>268</b>	<b>14</b>	<b>643</b>	<b>8137</b>	<b>8781</b>	<b>7%</b>

### Erosion featuretypes in Nyarugenge District



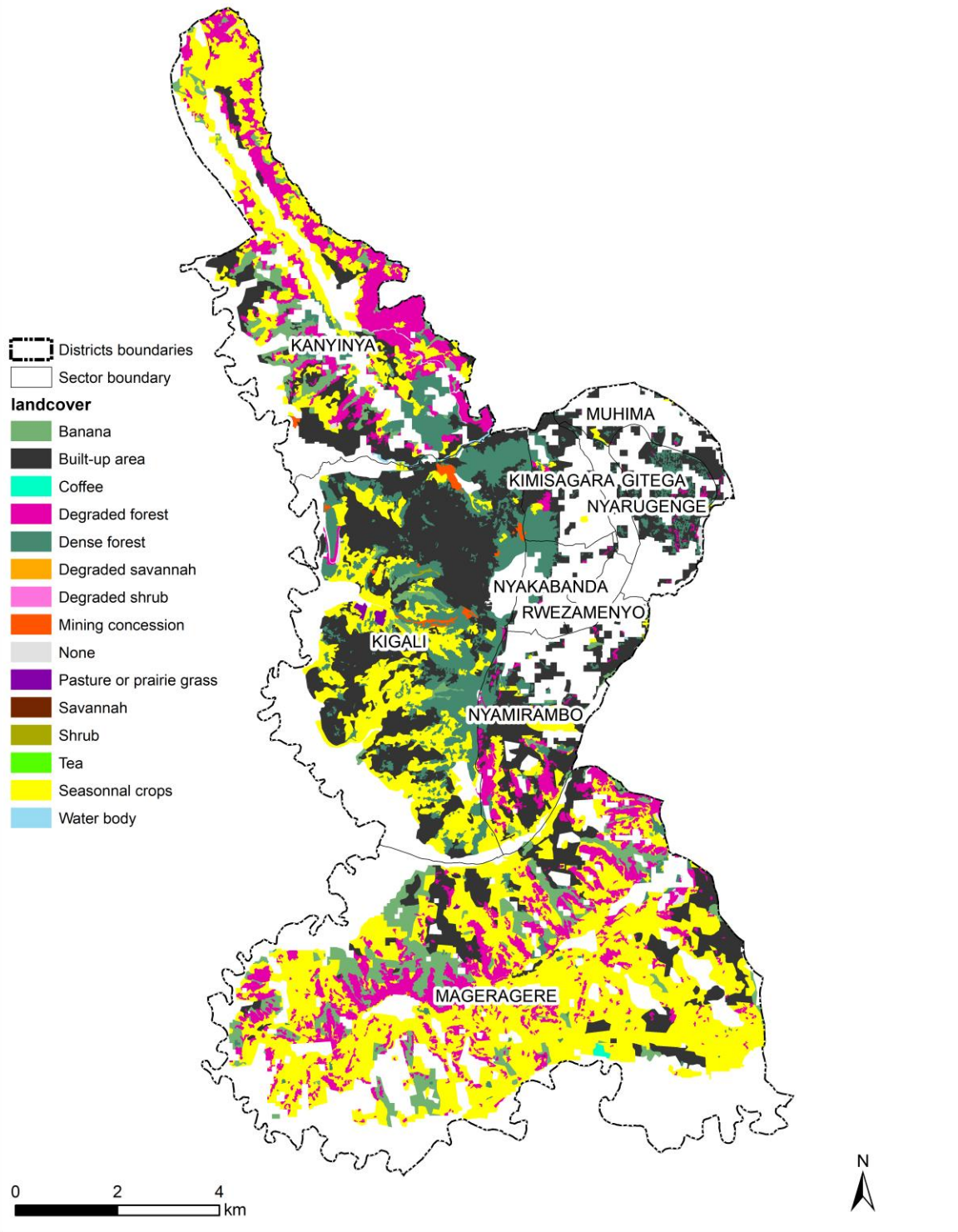
**Figure 154: Erosive features detected in Nyarugenge District**

In term of land use and land cover of areas at risk in Nyarugenge District, the results of land cover mapping (Table 158 and Figure 158) show that 3503 hectares (40% of the total land at risk) are used for seasonal cropping, 906 hectares (10% of the total land at risk) are covered by healthy forests, 2472 hectares (28% of the total land at risk) are covered by built-up areas and 664 hectares i.e. 8% are covered by Banana crop. In Nyarugenge district there are also mining and quarries sites, and coffee plantations which cover respectively 29 hectares (less than 1% of the total land at risk) and 6 hectares (less than 1% of the total land at risk).

**Table 159: Land Use and Vegetation Cover (LUVC) for land at risk in Nyarugenge District**

Sector Name	Banana	Built-up area	Degraded forest	Dense forest	Mining concession	Pasture or prairie grass	Seasonal crops	Water body	Grand Total
GITEGA		25	1	1					27
KANYINYA	179	297	475	118	3		625	27	1,724
KIGALI	35	1,028	7	550	25	12	643		2,299
KIMISAGARA		88	7	54			7		156
MAGERAGERE	438	445	574	34			2,135		3,626
MUHIMA		74	-	3			3		80
NYAKABANDA		20		42			-		61
NYAMIRAMBO	12	320	71	54			117		574
NYARUGENGE		172	6	49			3		230
RWEZAMENYO		3					-		3
<b>Grand Total</b>	<b>664</b>	<b>2,472</b>	<b>1,141</b>	<b>905</b>	<b>28</b>	<b>12</b>	<b>3,533</b>	<b>27</b>	<b>8,780</b>
<b>%</b>	<b>8%</b>	<b>28%</b>	<b>13%</b>	<b>10%</b>	<b>0.3%</b>	<b>0.1%</b>	<b>40%</b>	<b>0.3%</b>	<b>100%</b>

## Landcover types in Nyarugenge District



**Figure 155: Land cover types in Nyarugenge District**

About existing erosion control practices in Nyarugenge district, Table 160 shows that only 12% of land at risk is protected by forests (906 hectares) and Contour bank terraces (14 hectares), bench terraces (10 hectares) and shrub (2 hectares). The highest protected sectors are Nyakabanda with 68% of its land at risk protected, followed by Kimisagara where 35% of the total land at risk is protected and Nyarugenge with 24% of land protected. The least protected sectors are Rwezamenyo (any erosion feature observed), Mageragere with only 1% protected, Gitega (4% protected) and Muhima (8% protected). The visual interpretation of World View images confirms earlier findings by CROM model that Mageragere sector remain at high risk of soil erosion since more than 90% of their respective land at erosion risk is not protected.

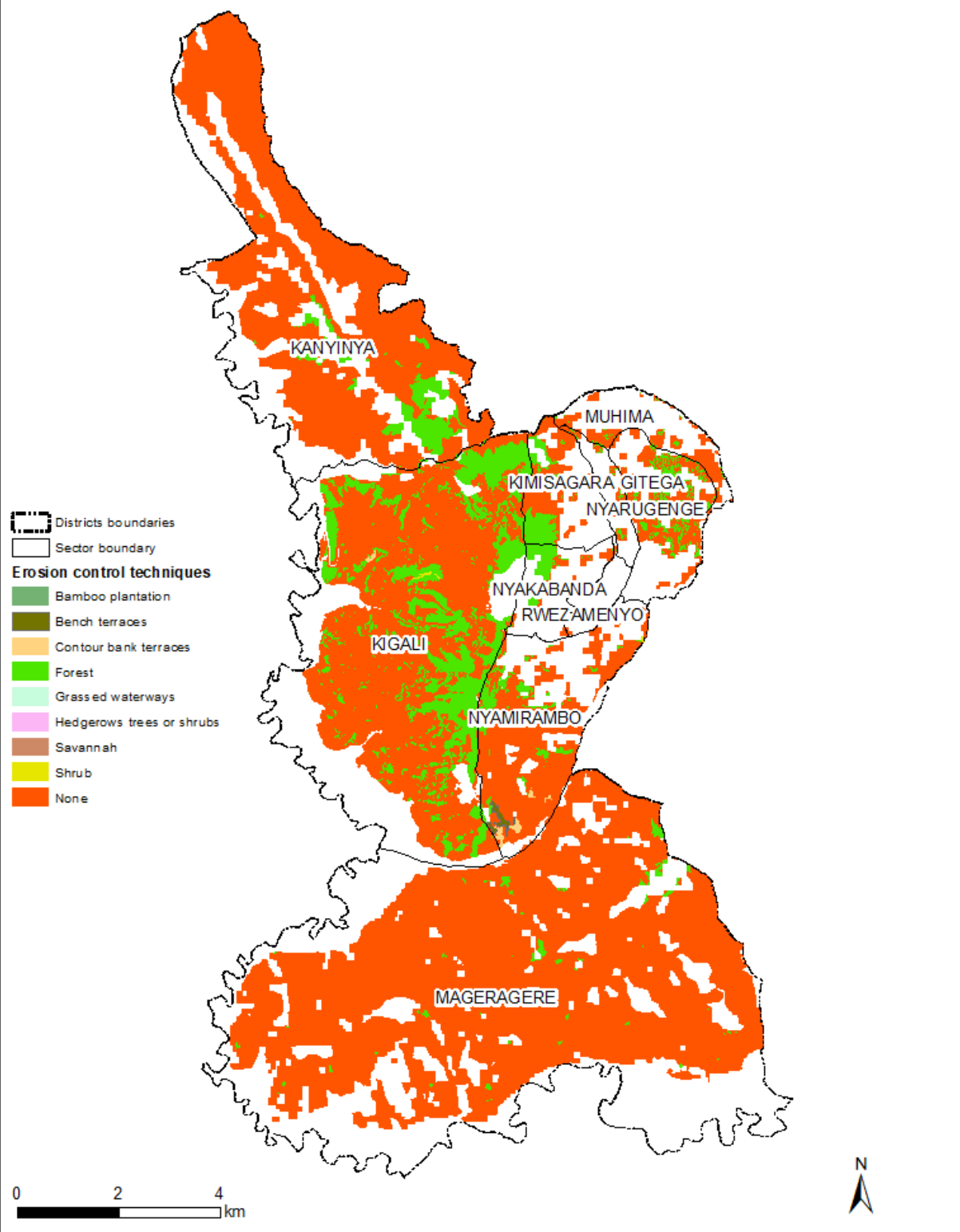
**Table 160: Erosion control practices already in place in Nyarugenge District**

Sector Name	Erosion control in place				Total protected	Non e	Grand Total	% Protected
	Bench terraces	Contour bank terraces	Forest	Shrub				
NYAKABANDA			42		42	20	61	68%
KIMISAGARA			54		54	102	156	35%
KIGALI		2	550	2	554	1,745	2,299	24%
NYARUGENGE			49		49	181	230	21%
NYAMIRAMBO	10	12	54		76	498	574	13%
KANYINYA			118		118	1,606	1,724	7%
MUHIMA			3		3	77	80	4%
GITEGA			1		1	26	27	4%
MAGERAGERE			34		34	3,592	3,626	1%
RWEZAMENYO					0	3	3	0%
<b>Grand Total</b>	<b>10</b>	<b>14</b>	<b>906</b>	<b>2</b>	<b>931</b>	<b>7,850</b>	<b>8,781</b>	<b>11%</b>

Erosion control practices in Nyarugenge District are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 161 shows that about 3303 hectares (which is 38% of the total land at risk) are suitable for Contour bank terraces, 1187 hectares are Reforestation/Afforestation and 216 hectares of cropland that need agroforestry/hedge rows cropping. Other interventions are 30 hectares for Bamboo to close gullies and protect river banks, 2,485 Ha for water harvesting infrastructures.



### Erosion Control Techniques in Nyarugenge District



**Figure 156: Erosion control techniques in place in Nyarugenge District**

**Table 161: Recommended erosion control practices in Nyarugenge District**

Sector Name	Afforestation / Reforestation	Agroforestry / hedgerows	Bamboo plantation	Contour bank terraces	Water harvesting facilities	Zero tillage/Perennial crops	Already protected	Grand Total
GITEGA	1				25		1	27
KANYINYA	481	171	28	441	305	179	118	1,724
KIGALI	43	25		616	1,028	35	552	2,299
KIMISAGARA	7	5			90		54	156
MAGERAGERE	579			2,152	445	416	34	3,626
MUHIMA	0	3			74		3	80
NYAKABANDA					20		42	61
NYAMIRAMBO	71	22	2	93	320	12	54	574
NYARUGENGE	6				175		49	230
RWEZAMENYO					3			3
<b>Grand Total</b>	<b>1,187</b>	<b>226</b>	<b>30</b>	<b>3,303</b>	<b>2,485</b>	<b>642</b>	<b>908</b>	<b>8,781</b>
<b>%</b>	<b>14%</b>	<b>2%</b>	<b>0.0%</b>	<b>38%</b>	<b>28%</b>	<b>7%</b>	<b>10%</b>	<b>100%</b>

**Note:** Grassed waterways are recommended for existing terraces which was made without waterways or with but no grasses which can cause severe gullies and destruction of bench terraces created. No-till agriculture is recommended for perennial crops on extremely high risk area while Storm water management facilities (SWMF) or water harvesting infrastructure is recommended in built-up areas. None: means no-recommendation is provided because existing erosion control measures are adequate with reference made to the total land protected. Contour banks are recommended for existing forest without ditches. Bamboos are recommended to close gullies or for riverside buffers.

## Recommendend Erosion Control Practices in Nyarugenge District

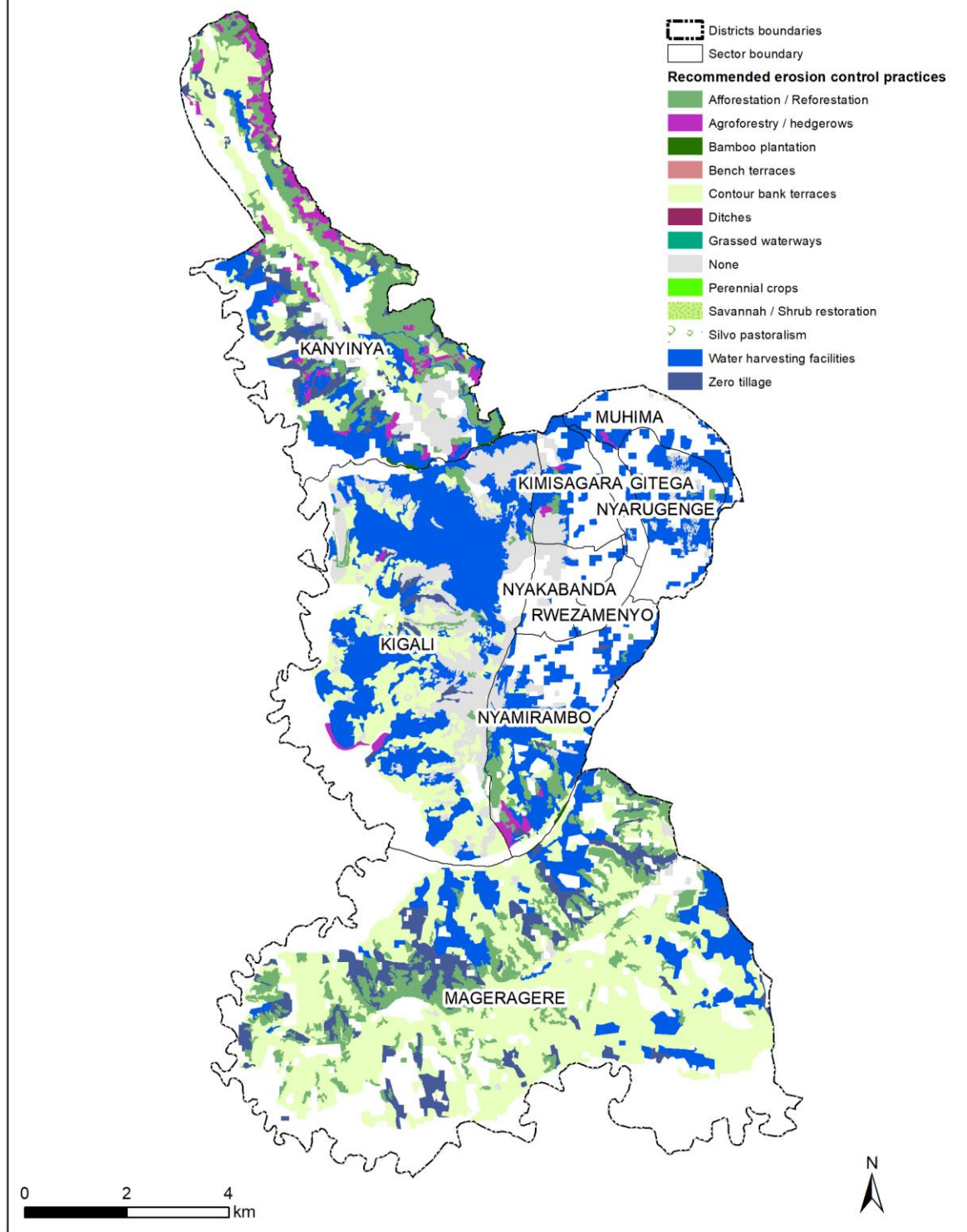


Figure 157: Recommended erosion control practices in Nyarugenge District

### 3.6. State of erosion control in the catchments and erosive hotspots

Erosion risk in the catchment is summarised in Table 162. The highest erosion risk is estimated to 230,686 hectares located in upper Nyabarongo; about 21% of the country land at risk. It is followed by Lower Nyabarongo with a total area at risk of 186,564 hectares (17% of the total national risky areas), Akanyaru with 165,122 hectares (15% of the national land at erosion risk), and Kivu basin with 126,834 hectares under risk of erosion (12% of the country land at risk). The least catchments are Rusizi with 14,927 hectares (1,4% of the country land at risk), Nyabyondo with 2,062 hectares at risk and Kiruruma with 1,335 hectares at erosion risk.

**Table 162. Erosion risk per catchment**

Catchment name	Erosion risk (Ha)				Grand Total	% catchment area
	Extremely High	Very High	High	Moderate		
Akanyaru	7,713	21,652	45,112	90,645	165,122	15%
Kiruruma	40	469	584	242	1,335	0.1%
Kivu	14,834	27,833	31,631	52,636	126,934	12%
Lower Akagera	1,188	11,083	26,717	77,242	116,230	11%
Lower Nyabarongo	13,286	39,052	59,368	74,858	186,564	17%
Mukungwa	7,887	20,570	29,122	35,860	93,439	8.6%
Muvumba	559	2,618	7,685	24,887	35,750	3.3%
Nyabyondo	165	595	863	439	2,062	0.2%
Rusizi	854	1,191	2,576	10,306	14,927	1.4%
Upper Akagera	389	5,706	25,549	76,995	108,639	10%
Upper Nyabarongo	25,123	59,879	72,050	73,633	230,686	21%
<b>Grand Total</b>	<b>72,039</b>	<b>190,648</b>	<b>301,258</b>	<b>517,743</b>	<b>1,081,688</b>	<b>100%</b>
<b>%</b>	<b>7%</b>	<b>18%</b>	<b>28%</b>	<b>48%</b>	<b>100%</b>	

Land areas affected by erosive features in the catchments are summarized in Table 163. The results show that the total catchment areas affected by erosive features are estimated to 180,919 hectares (about 16.7% of the country land at erosion risk). The upper Nyabarongo is the worst affected with 45,961 hectares affected of which 28,123 hectares are affected by rill erosion, 14,337 hectares are affected by gullies, 2,353 hectares are affected by severe gullies, while 1,148 hectares are affected by landslides. Kivu catchment area follows with 34,050 hectares affected of which 15,085 hectares are affected by rill erosion, 16,033 hectares are affected by gullies, 2,426 hectares are affected by severe gullies and 506 hectares affected by landslides. Akanyaru catchment area is also affected mostly by rill erosion (25,731 hectares) and less affected by landslides and gullies. This is opposed to the upper and lower Nyabarongo affected by gullies and landslides. The least affected catchments are Nyabyondo and Kiruruma with 252 hectares and 554 hectares respectively but it is relative to the size these two catchments.

**Table 163. Erosion feature types per catchment**

Catchment name	Erosion features currently in place (Ha)				Total affected	Not affected	Grand Total
	Landslides	Severe gullies	Gullies	Rill erosion			
Akanyaru	172	526	5,139	25,731	31568	133,554	165,122
Kiruruma	4	498	36	16	554	781	1,335
Kivu	506	2,426	16,033	15,085	34050	92,884	126,934
Lower Akagera	7	1,078	3,376	8,696	13157	103,073	116,230
Lower Nyabarongo	302	2,846	22,357	5,584	31089	155,475	186,564
Mukungwa	270	3,119	3,202	9,938	16529	76,909	93,439
Muvumba	143	100	2,904	41	3188	32,562	35,750
Nyabyondo	10	193	49	0	252	1,811	2,062
Rusizi	148	32	729	44	953	13,974	14,927
Upper Akagera	118	432	2,336	735	3621	105,018	108,639
Upper Nyabarongo	1,148	2,353	14,337	28,123	45961	184,726	230,686
<b>Grand Total</b>	<b>2,826</b>	<b>13,603</b>	<b>70,498</b>	<b>93,992</b>	<b>180919</b>	<b>900,769</b>	<b>1,081,688</b>
<b>%</b>	<b>0.3%</b>	<b>1.3%</b>	<b>6.5%</b>	<b>8.7%</b>	<b>16.7%</b>	<b>83.3%</b>	<b>100%</b>

P.S. Not affected land should not be read as Not eroded, it only means that erosive features could not be clearly observed on the Worldview satellite images

Looking at the existing erosion control practices in the catchment areas, Table 164 shows that only 26% of land at risk is protected by forests (190,312 hectares), contour bank terraces (28,916 hectares), and bench terraces (42,444 hectares). The highest protected catchment is Muvumba with 46% of its land at risk protected, other catchments are less than 30% protected which is alarming given the changing climate to more hazardous climate.

**Table 164. Erosion control status per catchment**

Catchment name	Erosion control currently in place (Ha)						Total protected (Ha)	Unprotected (Ha)	Grand Total (Ha)	% unprotected land
	Bamboo plantation	Bench terraces	Contour bank terraces	Forest	Agroforestry/hedgerow trees	Savannah/shrub				
Akanyaru	2	3,427	2,699	40,204	-	959	47,290	117,832	165,122	71%
Kiruruma		10	29	169	-	-	208	1,127	1,335	84%
Kivu		4,753	4,027	21,079	55	-	29,913	97,021	126,934	76%
Lower Akagera		2,228	1,447	5,670	-	18,707	28,052	88,178	116,230	76%
Lower Nyabarongo	10	8,161	6,406	35,477	52	44	50,151	136,414	186,564	73%
Mukungwa		10,186	3,406	11,660	17	-	25,269	68,170	93,439	73%
Muvumba		3,018	1,829	10,708	-	-	15,555	20,195	35,750	56%
Nyabyondo		58	125	329	-	-	512	1,550	2,062	75%
Rusizi		144	965	2,649	-	-	3,757	11,169	14,927	75%
Upper Akagera		1,399	483	9,293	-	948	12,123	96,516	108,639	89%
Upper Nyabarongo	0	9,169	7,501	53,074	194	-	69,938	160,748	230,686	70%
<b>Grand Total</b>	<b>12</b>	<b>42,444</b>	<b>28,916</b>	<b>190,312</b>	<b>318</b>	<b>20,657</b>	<b>282,659</b>	<b>798,919</b>	<b>1,081,688</b>	<b>74%</b>
<b>Percentage (%)</b>	<b>0.00%</b>	<b>4%</b>	<b>3%</b>	<b>18%</b>	<b>0.03%</b>	<b>2%</b>	<b>26%</b>	<b>74%</b>	<b>100%</b>	

Erosion control practices in the catchments are recommended based on existing land uses, erosion control measures already in place, and predicted erosion risk by CROM model. Table 165 shows that upper Nyabarongo presents opportunity for afforestation and reforestation on 7,058 hectares, 4,663 hectares for closing gullies and protecting river banks, 17,345 hectares of bench terraces, and a huge amount of hectares to establish contour banks for progressive terraces on 107,502 hectares and water harvesting facilities in populated areas on 11,789 hectares. Only Muvumba catchment manage to protect about 30% followed by Akanyaru (25%), followed by Akagera (21%) which still very low,

**Table 165. Recommended erosion control measures per catchment**

Catchment name	Recommended erosion control measures (Ha)										Already protected	Grand Total
	Afforestation/Reforestation	Agroforestry/Hedge rows	Bamboo plantation	Bench terraces	Contour bank terraces	Forest Ditches	Silvo pastoralism	Perennial crops	Savannah/shrub restoration	Water harvesting facilities		
Akanyaru	2,458	8,096	742	1,101	95,344	395	-	4,300	656	10,973	41,058	165,122
Kiruruma	9	35	508	9	519	-	-	-	-	108	146	1,335
Kivu	5,401	18,599	1,717	2,007	50,864	813	37	12,447	2	13,991	21,055	126,934
Lower Akagera	8,095	5,828	981	1,239	39,578	42	668	1,763	27,861	5,791	24,383	116,230
Lower Nyabarongo	8,332	19,216	1,833	4,286	90,863	872	10	7,498	323	18,265	35,067	186,564
Mukungwa	1,263	20,648	3,022	2,929	41,899	351	361	3,603	2	7,820	11,542	93,439
Muvumba	1,594	5,003	183	1,957	12,218	-	126	354	121	3,521	10,673	35,750
Nyabyondo	22	185	193	28	1,079	-	-	4	-	246	306	2,062
Rusizi	377	1,236	39	97	6,956	9	-	872	-	2,695	2,646	14,927
Upper Akagera	5,345	3,328	1,074	1,933	64,018	29	36	4,316	3,611	14,606	10,343	108,639
Upper Nyabarongo	7,058	19,224	4,663	17,345	107,502	986	-	8,495	-	11,789	53,625	230,686
<b>Grand Total</b>	<b>39,956</b>	<b>101,398</b>	<b>14,955</b>	<b>32,931</b>	<b>510,839</b>	<b>3,496</b>	<b>1,238</b>	<b>43,651</b>	<b>32,577</b>	<b>89,805</b>	<b>210,843</b>	<b>1,081,688</b>



## 4. Soil Erosion analytics

### 4.1. Erosion process in Rwanda

This study aims to contribute to the awareness by the general public of the danger that the current situation of soil erosion in Rwanda constitutes to accelerated land degradation, and hazards, and affect the national economy. The study mainly describes the effects of rainwater runoff which degrades the topsoil and evacuates the fertile land towards the valleys and swamp. The population pressure has led to farming on steep slopes, even slopes of  $45^\circ$  are often used. Their clearing triggers processes of erosion impossible to stop by the old systems erosion control, known for low slopes, already since long in operation. Hence, there is a need of a combined efforts and innovative ways to tackling erosion in Rwanda as a human security issue.

#### Runoff erosion

Erosion in Rwanda has very often been identified with the only actions by runoff. This opinion reflected in the different conservation systems, applied for a very long time (NDAYIZIGIYE, 1990)<sup>7</sup>. According to MOEYERSONS (1989)<sup>8</sup>, runoff occurs mainly by a diffuse action or in rills and, occasionally, in the form of ravines.

##### a. Gullies



**Picture 1.** Severe gullies (deep ravines) of Rurambo village, Rutagara cell, Muhanda sector in Ngororero District (Photo: Eric Bizimana, RWB, 2020)

<sup>7</sup> NDAYIZIGIYE, F., 1990. Aperçu sur les pratiques de conservation du sol et de gestion hydrique au Rwanda. Réseau Erosion (ORSTOM, Montpellier) Bull. 10: 87-97.

<sup>8</sup> MOEYERSONS, I., 1989. La nature de l'érosion des versants au Rwanda. Ann. Mus. roy. Afr. centr. Tervuren, Sc. econ., 19, 379 p.

Currently, severe gullies or deep ravines intersect many steep slopes. Also, the softened shape, especially of the convex hills of the Rurambo village for example (Ngororero district), leads to suppose that the gullying which is currently observed there results from a rupture of the balance. MOEYERSONS (1989) studied a number of these type of ravines, sometimes impressive and concluded with their anthropogenic origin: mainly by drainage pits in fields and along roads, from residential areas, which generally tends to spread laterally, concentrated and released further on steep slopes, with little or no protection. Thus are formed in a few years from the ravines that develop from these points of release towards the downstream side of the slope by "progressive" erosion (MOEYERSONS, 1991<sup>9</sup>). The development of ravines by regressive erosion has mainly been observed in axes where slope is less than 8° (in Valley mainly)

## b. Landslides

It is surprising to note that the phenomenon of mass transport in general and landslides in particular has been studied only very recently by Hussein Bizimana and Dr. Osman Sönmez<sup>10</sup> and previously by MOEYERSONS, 1989<sup>11</sup> and Nyamulinda, 1989<sup>12</sup>. However, the landslides are known problem for a long time. Geomorphic factors such as geology, topography and relief have a high influence on landslide types and occurrences in many regions of the country. The only countermeasure taken in the past was restricted to planting trees along the tracks road.



**Picture 2.** Massive landslide in Rwankuba sector of Karongi district in Western Province, on 06 May, 2018.

Landslides in Rwanda involve various forms of rapid mass transport that manifest especially in the western part of the country, including the south plateau (Huye Nyamagabe), the entire Congo-Nil ridge and the

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<sup>9</sup> MOEYERSONS, I., 1991. Ravine formation on steep slopes: forward versus regressive erosion. Some case studies from Rwanda. *Catena*, 18 (3-4): 309-324

<sup>10</sup> Hussein Bizimana and Dr. Osman Sönmez, 2015. Landslide Occurrences in The Hilly Areas of Rwanda, Their Causes and Protection Measures. *Disaster Science and Engineering* p. 1-7, 1(1), 2015

<sup>11</sup> MOEYERSONS, I., 1989-1990. Les glissements de terrain au Rwanda occidental : leurs causes et les possibilites de leur prevention. *Cahiers ORSTOM*, ser.ped., 25 (1-2): 131-150.

<sup>12</sup> Nyamulinda, F.D.K., 1989. Soil erosion and mass wasting risk in the highland area of Rwanda, Mountain Research and Development, Volume 8, N0s. 2/3, pp 173-182



Northern region. During and after the storms of the main rainy season, the different types of landslide affect especially the slopes on schistose rocks inclined at 25° or more. Each year, a number of houses and of buildings are destroyed, sometimes some roads are affected and in recent years several people have found death.

### 1°) The naturally-made landslides

The slopes of schistose-bedded hills often bear kaolin soil several meters thick and an A1 humic horizon of variable thickness between 0 and 50 cm (Picture 3). A diffuse debris sheet, including gravelly elements in quartz or quartzite, announces in red-brown layer whose thickness can reach 2 to 3 m. The latter is separated from the weathered bedrock by a very clayey layer containing an abundance of angular quartz gravels with a diameter of 0.5 to 2 cm and coarser elements (5-20 cm) in quartzite and schist. Many observations have illustrated the particular way of drainage of this profile during and after the rains: independently of the surface runoff, the presence of tunnels, cavities and large pores suggests a withdrawal of the profile at two levels. The first is located at the transition between the A1 horizon and the red-brown layer, the second in the clayey-gravelly layer above the weathered bedrock. This underground drainage at two levels is explained by a combination of textural and structural characteristics of the soil.



**Picture 3.** Landslide occurred in Mont Huye under natural conditions, Nyundo sector, Rubavu district (Photo: RBA, April 28, 2022)

### 2°) The human induced landslides.

The proliferation of the system of against erosion, for example the pits (waterfalls) created on steep slopes contributes considerably to the triggering of landslides. Indeed, the pits would somehow play the same role as the cracks introduced by the creep: they cause forced infiltration. The water is supposedly injected into the ground and reaches more quickly, from the bottom of the pits, the potential slip planes which are located especially at the lower level of underground flow. Towards the end of each major rainy season small landslides develop from these pits (Picture 3). Estimates of land loss caused by these "anthropogenic" landslides have not been yet been made but they are certainly considerable. Several researches have shown that landslides are likely to reduce when trees are planted. Roots from trees (bamboo for example) reinforce the soil through growing across failure planes, root columns acting as piles, and through limiting surface erosion<sup>13</sup>. When roots grow across the plane of potential failure there is an increase in shear strength by binding particles. The roots hold the unstable topsoil into the deeper stable layers or bedrock<sup>14</sup>.

## Proximate factors of soil erosion in Rwanda

Land use coupled with high population in Rwanda are at forefront of other drivers of soil erosion. Runoff resulting from the concentrated rooftops cause devastations. If the proposed erosion control practices are to succeed, the land use should therefore be thoroughly well planned to consider type of soil, topography and the management should be strictly followed. An important factor in the distribution of landslides is the slope gradient and mass movements only occur when a critical angle is exceeded. Mostly in Rwanda, landslides occur on slopes as high as 14° which is the lowest in all the studies<sup>15</sup>. Most of North province in Rwanda are above 45° of slope gradient, West more than 35° and South more than 25°. Water harvesting infrastructure should also be part of the human settlement projects for both individual and grouped settlements and local authorities should take this in their hands than ever before.

### 4.2. Macroeconomic cost of soil erosion for Rwanda

#### 4.2.1. Cost of productivity loss of commodity crops and effect on the Gross Domestic Product (GDP)

The costs of losses in productivity are presented per crop type Table 166. More than 745 thousand hectares of agricultural land in Rwanda (about 31% of the total country land) are potentially eroded every year. Above 3 million tonnes crop produces are estimated to be lost seasonally (6 million tonnes annually), of which 22 thousand tonnes of maize and 15 thousand tonnes of beans are estimated to be lost every season due to severe erosion (reference year: 2021A). The total economic loss in agricultural productivity due to severe erosion in Rwanda is around 37.9 billion Rwandan francs (RWf) every season.

In term of GDP, In the first quarter of 2021, GDP at current market prices was estimated to be 2,579 billion RWf <sup>16</sup>, agriculture sector contributed 27% which is about 690 billion RWf. The crop productivity loss therefore translates into a loss of about 37.9 billion RWf (5.5%) of the agricultural sector contribution to Rwanda's GDP in the first quarter 2021.

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<sup>13</sup> Birot, P., 1960. Le Cycle d'Erosion sous les Differents Climats. Batsford, London. Christiansson, C and Westerberg, L.O., 1999. Highlands in East Africa. Unstable slopes, unstable environments. *Ambio*, 18: 419-429.

<sup>14</sup> Moeyersons, J., 1988. The complex nature of creep movements on steep sloping ground in Suthern Rwanda. *Earth Surface Processes and Landforms*, 13: 511-524.

<sup>15</sup> Hussein Bizimana and Dr. Osman Sönmez, 2015. Landslide Occurrences in The Hilly Areas of Rwanda, Their Causes and Protection Measures. *Disaster Science and Engineering* p. 1-7, 1(1), 2015

<sup>16</sup> National Institute of Statistics of Rwanda (NISR). Gross Domestic Product – 2021 Q1 published on June 15, 2021.

**Table 166. Estimated seasonal productivity loss per crop using direct cost evaluation (Reference - Season 2021A) – cost of inaction in agricultural land only**

Major Crops	Total Cultivated Area (Ha)	Total Harvested Area (Ha)	Average Yield (t/ha)	Actual Productivity (t)	Area at Risk/ Eroded Areas (Ha)	Crop Productivity Loss in affected areas CPL (t)	Market price (FRW/t)	Crop Productivity Loss (in FRW)
Maize	236,642	236,642	1.60	378,627	172,110	22,030	200,000	4,406,008,455
Sorghum	33,636	33,636	1.31	44,030	24,463	2,562	400,000	1,024,725,403
Wheat	4,418	4,418	1.02	4,498	3,213	262	490,000	128,225,113
Cassava	200,313	42,284	14.22	601,278	30,753	34,985	100,000	3,498,478,275
Sweet potato	99,496	99,496	6.71	667,618	72,363	38,845	80,000	3,107,575,217
Irish potato	52,196	52,196	8.88	463,553	37,962	26,971	250,000	6,742,836,390
Bananas	280,779	105,474	10.93	1,152,409	76,711	67,052	150,000	10,057,762,880
Beans	389,149	389,149	0.67	258,784	283,028	15,057	400,000	6,022,836,535
Vegetables (tomatoes)	20,181	20,181	7.91	159,672	14,678	9,290	200,000	1,858,071,737
Soybean	27,493	27,493	0.52	14,241	19,996	829	800,000	662,896,002
Groundnuts	15,978	15,978	0.40	6,311	11,621	367	1,100,000	403,938,937
<b>TOTAL</b>	<b>1,360,281</b>	<b>1,026,947</b>	<b>54</b>	<b>3,751,021</b>	<b>746,898</b>	<b>3,235,803</b>		<b>37,913,354,944</b>

Total Agricultural area (1,475,385ha) and total harvested area (1,096,956ha) reported by NISR (SAS 2021); total affected area (797,816ha) mapped using CROM updated using WorldView satellite images; land productivity loss (LPL=0.06) calculated using Equation 1.

#### 4.2.2. Cost of topsoil loss

Due to the current land use practises, the country topography, the population pressure and the climate, the country is very susceptible to high rates of soil loss. According to W4G, 2018<sup>17</sup> that on a district level, the average of Muhanga soil loss is estimated to 46t/ha/year, Ngororero (45t/ha/year), and Gakenke (33t/ha/year) the districts with the highest levels of soil erosion. These districts are followed by Nyarugenge with an average soil loss of about 32t/ha/year; Rutsiro (32t/ha/year) and Nyamagabe (29t/ha/year). The least eroded districts are Rusizi in Western province, Rwamagana, Gatsibo, and Nyagatare districts in Eastern Province with 3-8t/ha/year soil loss. The national average is about 25t/ha/year. Considering the total area at risk of about 1,080,168 ha, 45% of the country total, discharge an average of 27 million ton of top soil lost annually. Considering the market value of topsoil in Rwanda, a proxy for soil productive capability, is between US\$34/tonne (RwF30,000) and US\$57/tonne (RwF50,000)<sup>18,19</sup>.

Based on the market value of topsoil, the annual loss is estimated to be RWf 810 billion on average, which is about one and half fold of what landscape restoration of the entire country will cost (RWf 513billion).

#### 4.2.3. Cost of soil fertility loss

Another effect of soil erosion is on soil fertility depletion and incurred cost of fertilisers. Soil erosion removes the upper fertile part of soils that contains nutrients. Other direct costs include the fertilisation applied by

<sup>17</sup> Water for Growth. 2018. Catchment-based landscape restoration opportunities mapping for Rwanda. CROM-DSS introduced in TR83, Water for Growth.

<sup>18</sup> Water for Growth. 2018. PES Scoping Study, Upper Nyabarongo catchment. Report number TR88, Water for Growth.

<sup>19</sup> Government of Rwanda (NISR, RMB). 2019. Natural Capital Accounts for Mineral Resource flows, Version 1.0. Kigali.

farmers to mitigate the fertility loss. For instance, Lugato, Paustian, Panagos, Jones, and Borrelli (2016)<sup>20</sup> estimated a soil organic carbon displacement by water erosion in EU agricultural soils of about 9–14 Mt of carbon per year and displaced organic nitrogen of 0.9–1.5 Mt/year. In case of Rwanda, considering that a ratio of soil carbon/nitrogen (C/N) ranges between 8 and 10 (an average ratio of 9) in arable land, one hectare (1ha) of agricultural field contains on average 2t C/ha/yr, and an amount of organic nitrogen is in the order of 0.2t N/ha/year. Soil erosion in many parts of Rwanda is severe with mean national rates of 250 Mg/ ha/yr<sup>2122</sup> (i.e. 25t/ha/yr). Considering 641,280 hectares affected by soil erosion, we estimate 16Mt/yr of soil displaced carrying about 1,282,560t C and 128,256t N loss per year. We apply urea and di-ammonium phosphate (DAP) in order to compensate soil nutrient loss and improve land productivity. In the substitution of Nitrogen loss with urea (with an average price of RWf 564,000/t; Reference MINAGRI subsidised price of urea in 2021) would cost a total RWf 72 billion per year to Rwandan farmers.

A consistent amount of phosphorous (P) is also displaced with sediments (by water erosion) from the topsoil. The loss of phosphorus from land to downstream rivers is in the form of dissolved phosphorus and particulate (eroded soil particles) phosphorus. When rainwater falls on soil surfaces, a portion of the phosphorus associated with the soil is dissolved in water. This phosphorus is called dissolved phosphorus. P losses by leaching are usually less than 1 kg/ha/yr. However, losses up to 3 kg/ha/yr have been measured in drain flow (Catt et al., 1998). Considering a potential of 1,923 tonnes of phosphorous displaced from 641,280 hectares of agricultural land by soil erosion and the price of P fertiliser (RWf 633,000/t as di-ammonium phosphate; Reference MINAGRI subsidised price of DAP in 2021), its substitution would cost about RWf 1,2 billion per year to Rwandan farmers. This estimation is related to the uncertain relation between plant uptake and available P from soil analysis. Those are simple examples of estimating the cost of possible fertility loss due to displacement of organic nitrogen and phosphorus in erosive areas addressing partially the replacement costs. An exhaustive estimation of soil organic carbon, organic nitrogen and phosphorous loss in Rwandan soils (and the replacement costs) requests a separate in-depth study.

#### 4.2.4. Cost of erosion control actions

On the other hand, the total cost of erosion control actions is estimated to 514 billion Rwandan francs of which 323 billion are for protection of agricultural land against soil erosion (about 60% of the total risk areas) using Bench terraces, contour bank terraces known as progressive terraces and agroforestry and hedgerows plantation on contour banks (Table 167). This will require about 10 years to complete the activity by investing about 30 billion RWf every year to protect agricultural land against excessive erosion using community approach. In doing so, we would cut the productivity losses and therefore raise additional agriculture contribution to about 5.5% GDP which are lost every season as a consequence of inaction as demonstrated in the above season 2021A exercise.

<sup>20</sup> Lugato, E., Paustian, K., Panagos, P., Jones, A., & Borrelli, P. (2016). Quantifying the erosion effect on current carbon budget of European agricultural soils at high spatial resolution. *Global Change Biology*, 22(5), 1976–1984.

<sup>21</sup> Karamage, F., Zhang, C., Ndayisaba, F., Shao, H., Kayiranga, A., Fang, X., Nahayo, L., Nyesheja, E.M., Tian, G., 2016. Extent of cropland and related soil erosion risk in Rwanda. *Sustain.* 8, 1–19.

<https://doi.org/10.3390/su8070609>

<sup>22</sup> Leigh Ann Winowiecki, Athanase Mukuralinda, Aida Bargués-Tobella, Providence Mujawamaria, Elisée Bahati Ntawuhiganayo, Alex Mugayi, Susan Chomba, Tor-Gunnar Vågen (2020). Assessing biogeochemical and human-induced drivers of soil organic carbon to inform restoration activities in Rwanda. *Soil Discussions*

<https://doi.org/10.5194/soil-2020-67>



**Table 167. Estimated costs of erosion control investments per recommended practices in different land uses.**

Recommended erosion control practices	Total erosion risk areas (Ha)	% of the total erosion risk areas	Unit cost / Ha (RWF) through private companies	Total Costs (RWF) using private companies	Unit cost / Ha (RWF) using community approach	Total Costs (RWF) using community approach
Afforestation / Reforestation	39,901	3.70%	500,000	19,950,500,000	411,000	16,399,311,000
Agroforestry / hedgerows/shrubs	101,232	9.40%	200,000	20,246,400,000	120,500	12,198,456,000
Bamboo plantation / river bank protection / closing gullies	14,915	1.40%	300,000	4,474,500,000	271,500	4,049,422,500
Bench terraces with grassed waterways	29,952	2.80%	2,665,100	79,825,075,200	2,607,800	78,108,825,600
Contour bank terraces (Progressive terraces)	510,096	47.20%	500,000	255,048,000,000	480,000	244,846,080,000
Ditches for in the forested areas	3,490	0.30%	200,000	698,000,000	270,000	942,300,000
Wooded Savannah / Shrub restoration	32,574	3.00%	200,000	6,514,800,000	411,000	13,387,914,000
Silvo pastoralism	1,237	0.10%	200,000	247,400,000	120,500	149,058,500
Water harvesting facilities/ storm water management	89,679	8.30%	1,600,000	143,486,400,000	1,600,000	143,486,400,000
Perennial crops	48	0.00%	-	-	-	-
Zero tillage (Tea, Coffee, Banana)	43,552	4.00%	-	-	-	-
<b>Total areas unprotected</b>	<b>866,676</b>	<b>80.20%</b>				
Areas already protected	210,541	19.50%	-	-	-	-
<b>Total</b>	<b>1,080,168</b>	<b>100%</b>		<b>530,491,075,200</b>		<b>513,567,767,600</b>
			<b>US\$</b>	<b>530,491,075</b>		<b>513,567,768</b>

# Conclusions and Recommendations

Globally, Rwanda is among African countries most highly vulnerable to water erosion, mainly driven by a rapidly growing population with limited economic and agricultural options on a fragile soil, steep slopes and intense rainfall. Natural resources (land, forests, and water) are under increasing pressure due to the extensive agriculture to feed a growing population, and settlement for the shelter. In fact, Rwanda is the 1st country in Africa with a population density of about 525 inhabitants per Km<sup>2</sup>. Land degradation resulting from erosion combined with other factors act to weaken the environment and affect land productivity. This vulnerability is more visible among rural areas where the consequences lead to reduced crop yields, hazardous settlements and affect the standard of living and income for rural population. Likewise, the degradation of forest landscapes due to erosion is marked by a reduction in the capacity of forests to provide goods and services.

The soil erosion by runoff is spreading more over the country and calls for actions to face it, either through prevention and or protection of land against erosion, or through actions to restore the ecological functionalities of ecosystems through awareness-raising and diversified actions to restore the productivity of degraded land and forest landscapes. In the rural and urban settlement areas, efforts are desired by living in low risk areas, combined with the adaptive shelter containing rainwater harvesting facilities, as well as storm water management infrastructure. The mapping of soil erosion control in Rwanda and the analytics provided in this report serve as basis of which all interventions required to protect land under risk of erosion should be laid on while planning adequate technical package and resources needs. The following are the recommended practices that every Rwandan should do to protect land during and after activities disturbing land at risk of water erosion:

## 1. Erosion and sedimentation problems

Adopt land management practices by changing the pattern of some human activities which accelerate soil erosion.

Soil erosion can be controlled by adopting land management practices and also by changing the pattern of some human activities which accelerate soil erosion. The most effective form of erosion control is to minimize the area of disturbance. The land disturbing activities are for example:

- 1) Quarry operations and mining. The specific issues associated with quarries and mining are storm water, overburden disposal, sediments accumulation in water streams reducing riverbeds and inducing flooding. There should be a maintenance schedule for erosion and sediment control treatments structures.
- 2) Trenching (usually for installing utility services), often occurs at the end of bulk earthworks during construction of roads, public housing (house agglomeration, schools, markets, industrial parks etc.). Topsoil and sub-soils should be stockpiled separately adjacent to the trench so that at the completion of the operation these soils can be replaced in the appropriate order and vegetation established.
- 3) Roading: The linear nature of roading poses challenges for erosion and sediment control measures. They need to be planned to ensure controls are successful.

The following practices are to be adopted by all Rwandans in order to protect the country territory against soil erosion in particular and land degradation in general.

## Minimise disturbance by retaining vegetation cover as much as possible

The most effective form of erosion control is to minimize the area of disturbance, retaining as much existing vegetation as possible. This is especially important on steep slopes or in the vicinity of water bodies, where no single measure will adequately control erosion and where receiving environments may be highly sensitive. Match land development to land sensitivity. Watch out for and avoid areas that are wet (streams, wetlands, springs), have steep or fragile soils. Analyse all the "limits of disturbance".

Earthworks will still discharge sediment-laden runoff during storms. Therefore, there is a need to construct the runoff diversion channel or bund where appropriate. This is a non-erodible channel or bund constructed for the conveyance of runoff constructed to a site specific cross section and grade design. It is done to either protect work areas from upslope runoff, or to divert sediment loaded water to an appropriate sediment retention structure.

**Establishing check dam:** Small temporary dam constructed across a channel (excluding perennial water bodies), usually in series, to reduce flow velocity. It may also retain coarse sediment. Check dams are constructed in order to reduce the velocity of concentrated flows, thereby reducing erosion of the channel. Rock check dams will trap some sediment, but they are not designed as a sediment retention measure.

**Establishing pipe drop structure (waterfall):** A temporary pipe structure or constructed flume placed from the top of a slope to the bottom of a slope. A pipe drop structure or a flume structure is installed to convey surface runoff down the face of unsterilized slopes in order to minimize erosion on the slope face.

**Benched slope:** Modification of a slope by reverse sloping to divert runoff to an appropriate conveyance system. To limit the velocity and volume and hence the erosive power of water flowing down a slope and therefore minimizing erosion of the slope face.

**Surface roughening:** Roughening a bare earth surface with horizontal grooves running across a slope or tracking with construction equipment. To aid in the establishment of vegetative cover from seed, to reduce runoff velocity, to increase infiltration, to reduce erosion and assist in sediment trapping.

## Revegetation of the excavated land

**Top soiling:** The placement of topsoil over a prepared subsoil prior to the establishment of vegetation. To provide a suitable soil medium for vegetative growth while providing some limited short term erosion control capability.

**Temporary and permanent seeding and nurseries:** The planting and establishment of quick growing and/or perennial vegetation to provide temporary and/or permanent stabilization on exposed areas. Temporary seeding is designed to stabilize the soil and to protect disturbed areas until permanent vegetation or other erosion control measures can be established.

## Protect the total area of cultivated fields by trenching and mulching which increases the infiltration capacity of the soil and reduces overland flow.

Finally, in agricultural area, in the light of current knowledge, it seems that some alternative techniques are worth trying. We are thinking here of techniques that protect the total area of cultivated fields. Different forms of mulching come into play here. Mulches are loose coverings or sheets of material placed on the surface of cultivated soil. Organic mulches also improve the condition of the soil. As these mulches slowly decompose, they provide organic matter which helps keep the soil loose. This improves root growth, increases the infiltration of water, and also improves the water-holding capacity of the soil. The application

of a protective layer of straw or other suitable material to the soil surface. To protect the soil surface from the erosive forces of raindrop impact and overland flow. Mulching assists in soil moisture conservation, reduces runoff and erosion, controls weeds, prevents soil crusting and promotes the establishment of desirable vegetation. These techniques would have resulting in a significant increase in infiltration capacity of the soil. Thus, the runoff would be prevented. On cracked soils, the water would be at the sometime forced to infiltrate in the benches between the cracks. Thus, the water supply of the potential landslide planes would be considerably delayed, which would contribute to a stabilization of the slopes in hazard.

Given the initial success of the radical earthwork method (bench terracing), it is normal to continue efforts on this plan. But some caution is called for. In order to verify the possible destabilizing effect, it would be necessary to a large number of pilot projects across the country, including slopes at risk of instability. These projects should be continued for at least about ten years before proceeding to a generalized proliferation of the system. In fact, the establishment of radical terraces and creating water retaining hole in clay soils can take a long time. The instabilities introduced by terracing may occur after ten years.

## 2. Sediment control measures

### Establishing sediment retention pond in mining and quarries operation sites as well as in construction areas

A temporary pond formed by excavation into natural ground or by construction of an embankment and remove and use water of the pond at a rate that will allow suspended sediment to settle out. To treat sediment- loaded runoff and reduce the volume of sediment leaving a site, thus protecting downstream environments from excessive sedimentation and water quality degradation.

**Sediment pit:** A temporary pit which is constructed to trap and filter water before it is pumped to a suitable discharge area. To treat sediment-laden water that has been removed from areas of excavation or areas where ponded sediment-laden water cannot drain by other means.

**Rip-Rap:** Rock pieces are piled up to create a structure called as rip-rap. These are rubble composed of a variety of rock types including limestone and granite, which are used to armour embankments, shorelines, bridge abutments, streambeds and other seaside constructions to prevent soil erosion due to concentrated runoff or other water-related causes. A limitation of riprap arises when the slopes of the considered area are greater than 2:1; the rubble becomes unstable and is itself prone to erosion. In these circumstances, gabions are used.

**Gabions:** Gabion is an Italian word gabbia meaning “cage”. The gabions are riprap encased in galvanized, steel- wire mesh cages or cylinders. These are used to stabilize slopes, stream banks, or shorelines against erosion. They are usually placed on slopes at an angle—either battered or stepped back, rather than stacked vertically. The life expectancy of gabions relies entirely on their wire frames, and premium ones have a guaranteed structural consistency of fifty years.

**Buffer strip:** These are narrow areas of land maintained in permanent vegetation to trap sediment, slow down runoff, and even control air, soil, and water quality. The root systems of the vegetation anchor soil particles together which help stop the soil from being eroded by water. They also reduce the risk of landslides and other slower forms of erosion by stabilizing stream banks.

**Works in water bodies:** Works within water bodies have a high potential for erosion and discharge of sediment. This is because work is undertaken in or near flowing water - the major cause of erosion. Flowing water causes ongoing scour and provides the transport mechanism to Allow sediment to be dispersed downstream of works. This can be done in summer time through temporary water body diversion techniques. It consists of a short term water body diversion to allow works to occur within the main channel under dry conditions. To enable water body diversion without working in wet conditions and without allowing sediment discharges into a water body.

### 3. National awareness raising and enhancing capacity of Rwandans in the path of fighting against erosion

#### Developing erosion control guide for local government and community participation

Rwanda Water Resources Board (RWB) is a government institution established by the law N° 71/2019 of 29/01/2020 with a mission to ensure the availability of enough and well managed water resources for sustainable development. To achieve this mission, RWB developed Strategic plan (2020-2030). Among outcomes of the RWB strategic plan, in its outcome four (4), Soil erosion is to be prevented, reduced and controlled and **six (6) key interventions** have been formulated to:

- Engage concerned stakeholders in the development of technical guidelines for effective erosion control and catchment protection measures based on the guidance from the updated version of CROM-DSS model (**intervention 1**).
- Implement catchment restoration measures proposed in the catchment plans to reduce soil erosion using the guidelines of CROM-DSS model (**intervention 7**).
- Support and empower local communities (e.g. landowners, farmers), including women and youth in the construction and maintenance of terraces (**intervention 11**).
- Establish pilot model sites of catchment restoration and soil erosion control measures for the farmers and communities to learn appropriate techniques and scale up good practices from the pilot (**intervention 12**).
- Prevent, reduce and control erosion hotspots (pronounced gullies) (**intervention 14**).
- Develop and disseminate erosion control-tailored toolkits, modules, brochures, and posters for all types of erosion in different districts, sectors, and cells (**intervention 18**).

The present report provides the accurate information that could serve the implementation of the above interventions especially educating Rwandan communities on concepts of erosion, causes and its effect on their livelihoods. Moreover, the study presents the magnitude of erosion on soil loss with spatially explicit erosion footprints such as rills, gullies and landslides for the communities to learn and understand that failing to do anything about it would actually cause an enormous loss of their economy through the loss of land productivity, the major source of livelihood for the majority of Rwandans. The study further proposes protective or restoration measures adapted and affordable to farmers. More stakeholder engagement is recommended to ensure concerted efforts in implementing the measures.

A centralized information system on soil erosion at RWB needs to be set up to allow a regular update of erosion control database. This system should be accessible to all stakeholders in order to fast-track the erosion control actions in different sectors uploaded for regular monitoring and reporting. RWB shall also identify dissemination team with different competences both technical and social. Information should be packaged in such way that it is understandable by layperson in erosion technical and scientific concepts. RWB would not do it alone as soil erosion is a cross-cutting issue, thus require a strong partnership to ensure the involvement of all stakeholders. Dissemination should include the use of an online Web service to view the data at the plot level details. The availability of the web-based high-resolution images and the use of online web-service can allow the distribution of the updates at the district level.

# References

- Bakker, M. M., Govers, G., & Rounsevell, M. D. A. (2004). The crop productivity–erosion relationship: An analysis based on experimental work. *Catena*, 57(1), 55–76
- Bakker, M. M., Govers, G., Jones, R. A., & Rounsevell, M. D. A. (2007). The effect of soil erosion on Europe's crop yields. *Ecosystems*, 10(7), 1209–1219.
- Battiston, L. A., Miller, M. H., & Shelton, I. J. (1987). Soil erosion and corn yield in Ontario. I. Field evaluation. *Canadian Journal of Soil Science*, 67, 731–745.
- Crosson, P. (1995). Soil erosion estimates and costs. *Science*, 269(5223), 461–465.
- De La Rosa, D., Moreno, J. A., Mayol, F., & Bonsón, T. (2000). Assessment of soil erosion vulnerability in western Europe and potential impact on crop productivity due to loss of soil depth using the Impe1ERO model. *Agriculture, Ecosystems and Environment*, 81(3), 179–190.
- Kuhlman, T., Reinhard, S., & Gaaff, A. (2010). Estimating the costs and benefits of soil conservation in Europe. *Land Use Policy*, 27(1), 22–32.
- Laurence A. Lewis, Daniel C. Clay, and Yvan M.J. Dejaegher (1988). Soil loss, agriculture, and conservation in Rwanda: Toward sound strategies for soil management
- Lal, R. (1995). Erosion–crop productivity relationships for soils of Africa. *Soil Science Society of America Journal*, 59(3), 661–667.
- Larney, F. J., Janzen, H. H., Olson, B. M., & Olson, A. F. (2009). Erosion–productivity–soil amendment relationships for wheat over 16 years. *Soil and Tillage Research*, 103(1), 73–83
- Lyles, L. (1975). Possible effects of wind erosion on soil productivity. *Journal of Soil and Water Conservation*, 30(6), 279–283.
- Magrath, W., & Arens, P. (1989). The costs of soil erosion on Java: A natural resource accounting approach. In *Environment Department Working Paper #18*. Washington, DC: The World Bank.
- Montgomery, D. R. (2007). Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, 104(33), 13268–13272.
- Oyedele, D. J., & Aina, P. O. (1998). A study of soil factors in relation to erosion and yield of maize on a Nigerian soil. *Soil and Tillage Research*, 48, 115–125.
- Pierce, F. J., Larson, W. E., Dowdy, R. H., & Graham, W. A. P. (1983). Productivity of soils: Assessing long-term changes due to erosion. *Journal of Soil & Water Conservation*, 38(1), 39–44.
- Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., ... Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science, New Series*, 267(5201), 1117–1123.
- Schumacher, T. E., Lindstrom, M. J., Mokma, D. L., & Nelson, W. W. (1994). Corn yield: Erosion relationships of representative loess and till soils in the North Central United States. *Journal of Soil and Water Conservation*, 49, 77–81.



**Annex 1. Literature review of studies estimating the agricultural productivity loss due to soil erosion by water**

<b>Reference</b>	<b>Estimation of crop yield loss due to soil erosion</b>	<b>Comments on estimation method</b>
<b>Lyles (1975)</b>	Productivity loss ~6% per 2.5 cm of soil loss	Experiments in the United States
<b>Pierce, Larson, Dowdy, and Graham (1983)</b>	2–4% productivity loss in case of severe erosion (>25 t ha <sup>-1</sup> year <sup>-1</sup> )	U.S. croplands; NRI survey
<b>Battiston, Miller, and Shelton (1987)</b>	8% productivity loss due to soil erosion	Corn yield experiments in Ontario
<b>Laurence A. Lewis, Daniel C. Clay, and Yvan M.J. Dejaegher (1988)</b>	Average seasonal soil loss was 5 t/ha (2.2 tons/acre) following variations in rainfall and topography.	Soil loss estimated by using the universal soil loss equation calibrated from field data collected on more than 19,000 fields in Rwanda.
<b>Magrath and Arens (1989)</b>	0–12% annual productivity loss in case of severe erosion	Analysis of three comparable studies in Java, Indonesia
<b>Schumacher, Lindstrom, Mokma, and Nelson (1994)</b>	8% yield reduction in cornfields with severe erosion	North Central United States experiments
<b>Pimentel et al. (1995)</b>	Severe soil erosion by water (rates of higher than 17 t ha <sup>-1</sup> year <sup>-1</sup> ) can cause a crop productivity loss of 8% annually.	Review article
<b>Crosson (1995)</b>	Productivity loss to only 0.4% per year (8% productivity loss after 20 years).	Review study based on Pimentel et al. (1995) article
<b>Lal (1995)</b>	Yield reductions due to severe erosion may range from 2% to 40%, with a mean of 8.2% for the continent.	A review of available data in African plots
<b>Oyedele and Aina (1998)</b>	Maize yield reduction of 10–17% on severely eroded	Plot experiments in Africa
<b>Van den Born, de Haan, Pearce, and Howarth (2000)</b>	9% productivity loss for maize and other grains under high erosion risk	European Union 15 countries based on ICONA 1991
<b>De La Rosa, Moreno, Mayol, and Bonsón (2000)</b>	12% reduction on crop productivity will be reached in 2100 with erosion rates of 16 t ha <sup>-1</sup> year <sup>-1</sup> .	Based on results in Andalusia region (Spain)
<b>Bakker, Govers, and Rounsevell (2004)</b>	2.7% yield decrease per decade according to findings in de-surfacing experiments; yield reductions due to	Based on data analysis (field data collection) in Europe

Reference	Estimation of crop yield loss due to soil erosion	Comments on estimation method
	soil erosion are around 4.3% per 10 cm of soil lost.	
<b>den Biggelaar, Lal, Wiebe, and Breneman (2001)</b>	Crop productivity based on past plot studies for different crops in all continents, showing negligible effects for erosion rates	Analysis of soil erosion–productivity experiments
<b>Bakker, Govers, Jones, and Rounsevell (2007)</b>	4.9% yield loss in case of 10 cm soil erosion	Based on available water capacity analysis
<b>Montgomery (2007)</b>	Soil loss rates less than 12 t ha <sup>-1</sup> year <sup>-1</sup> as tolerable for maintain the crop productivity	Based on the U.S. Department of Agriculture values
<b>Larney, Janzen, Olson, and Olson (2009)</b>	Grain yields may fall by 2.1% annually per cm of soil removal	Experiments in Alberta, Canada
<b>Nambajimana, He, Zhou, Justine, Li, Khurram, Mind’je and Nsabimana (2019)</b>	The mean annual soil losses ranges between 39.2 t ha <sup>-1</sup> y <sup>-1</sup> and 48.6 t ha <sup>-1</sup> y <sup>-1</sup> (data collected from 2000 to 2015). Rwanda’s cropland revealed that terracing could reduce the soil loss by 24.8% (from 14.6 t ha <sup>-1</sup> y <sup>-1</sup> to 11.7 t ha <sup>-1</sup> y <sup>-1</sup> ).	RUSLE model was run to quantify soil loss for Rwanda in 2000 and 2015.



