The Impact of Land Degradation on Agricultural Productivity in Nyabihu District-Rwanda, A Case Study of Rugera Sector

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Abstract— *This study looked at the impact of land degradation on agricultural productivity in Nyabihu district. Specific objectives were to assess the factors influencing land degradation in Nyabihu district, Rugera sector, the vulnerability level of land degradation and propose suitable land management conservation strategies.*

Geographical Information system (GIS) and Remote sensing data were used for the assessment of factors influencing land degradation, where Land cover (classified) maps were produced based on data extracted from google earth and cultivated slope was computed based on the Digital elevation model (DEM) of 2018 downloaded from earthexplorer.usgs.gov. GIS vulnerability assessment and classification method was used to assess level of vulnerability to soil degradation and land slide. To propose suitable land management conservation strategies practical Tools on Soil and Water Conservation measures alongside with W4GR matrix of soil and water conservation measures documents were consulted. The data collected were analyzed using ArcGIS 10.4software, and Excel; the results were presented using maps, bar graphs and tables. Based on two main factors (slope and soil depth) a conservation map and matrix were developed with proposed options of restoration and conservation of land degraded.

Keywords— land degradation, agricultural productivity, soil fertility, GIS.

I. INTRODUCTION

Land degradation in the world stands at about 85% and this is associated with soil erosion, most of which occurred since the end of World War II, causing a 17% reduction in crop productivity. The extent of soil erosion shows that it's a worldwide environmental problem with some areas such as the horn of Africa and majority of sub – Saharan region being extremely prone to erosion due to prolonged dry periods and heavy erosive rainfall, falling on steep slopes with fragile soils, causing in considerable amounts of erosion. (Abdallah, 2016)

According to Sileshi (2016), land degradation is one of the most serious environmental challenges and an issue in both developed and developing countries. However, the severity and magnitude of its impact are much more pronounced in low income countries at which the livelihood of the majority is dependent on agriculture.

It was found that land degradation was associated with soil degradation through exploitative cropping (Boardman, Poesen and Evans,2003). Soil quality decline is one of the main causes of land degradation and is considered to be responsible for 84% of the ever diminishing acreage.

According to Twagiramungu (2006), Land degradation specifically soil degradation is a major environmental problem in Rwanda, The degradation is particularly linked to hydrous erosion that affects a big portion of cultivated lands. It was assumed that the hydrous erosion reduces the capacity to feed 40 000 persons per year and causes annual losses of about 15 000 000 tons of soil.

According to Sileshi (2016), the vulnerability to land degradation needs to be assessed continually to take appropriate resource conservation measures. Therefore, the aim of this study was to assess the impact of land degradation on agriculture productivity in Nyabihu district through the integration of GIS and RS. More specifically, the study is targeted to map the spatial and temporal changes in agriculture land use and land cover, to assess soil erosion and landslide as factors of land degradation, as well as other factors that affect agricultural productivity.

It is against this background that the study assessed factors influencing land degradation, the level of land degradation, the impact of land degradation on crop production in Nyabihu district and the specific proposed land conservation measures.

This study will provide an understanding of influencing factors and level of land degradation in Nyabihu district and the relationship between land degradation and agriculture productivity. The study will significantly benefit farmers' policy makers and policy implementers in trying to enforce mitigation measures to cope with land degradation process.

The research is also proposed so that people can end up benefiting from the environment they are living in and later they contribute to the country economic advancement and the world as well. It will also be a great contributor to land management policies that will be implemented after this research by suggesting ways by which land can be protected so that agricultural productivity can be improved to sustain food security in Nyabihu district.

Findings from this research are expected to describe the evolution of the problem within a period of 5 years; hence, the impact of soil degradation on agricultural productivity in Nyabihu district; from year 2014 to 2018.

II. MATERIALS AND METHODS

This research dealt with different methods used in collecting, analyzing, processing and interpreting data on the impact of land degradation on agricultural productivity in Nyabihu district so as to obtain effective and efficient results. It includes the research design, data collection methods, data collection instruments, data quality control, procedure of data collection, data analysis and measurement of variables.

2.1 Study area and Case study profile

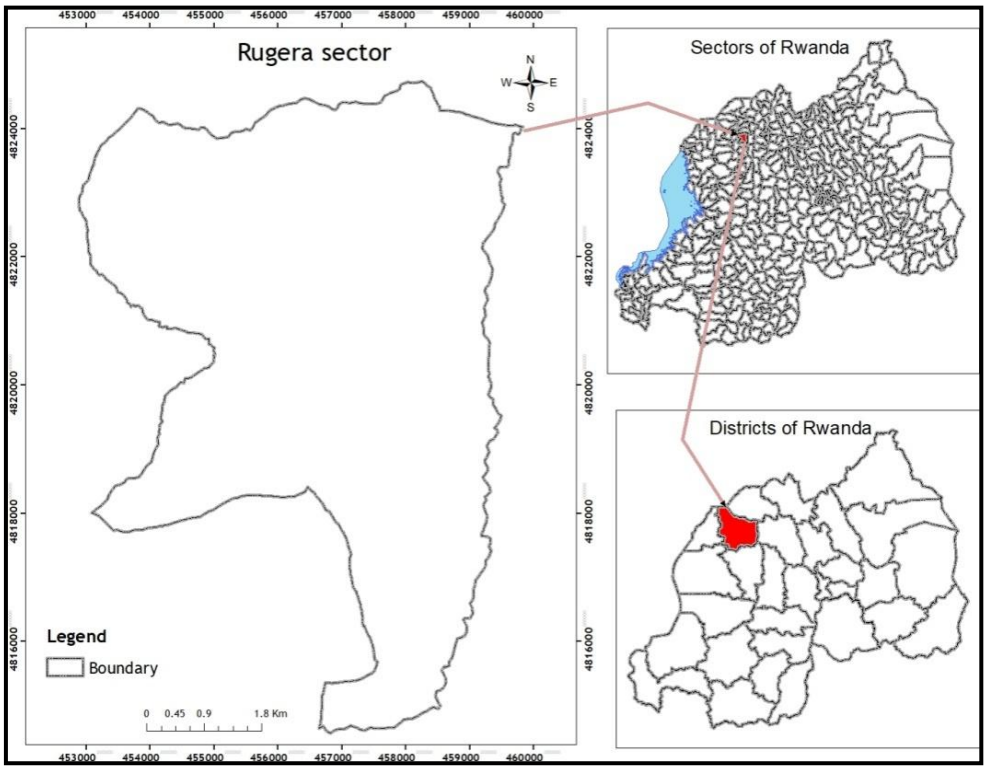

FIGURE 1: Location map of Rugera Sector, Nyabihu district from Rwanda.

Nyabihu district in general and Rugera sector in particular is characterized by heavy rainfall and low temperatures due to the effect of its elevated altitude forested land which both influences its weather patterns. The region is characterized by inceptisoils or soils of altitude, volcanic soil and alluvial soils. The soil types of the region are prone to soil erosion because of heavy rainfall; steep gradient and man's influence as well, thus land degradation.

2.2 Research design

It explains how the study is organized and implemented in details. Research design in this study, enables the conceptualization of an operational plan to undertake the various procedures and tasks necessary in the accomplishment of this study. In this study, a case study design was used with the help of GIS maps.

The case study was chosen according to the factors influencing the effects of land degradation, basing on the altitude and related factors. The effects of land degradation can be, directly or indirectly related to the geographical location of the

exposed region and the nature of the effect, according to its immediate source. GIS and RS data were acquired and processed in order to assess the factors influencing land degradation and their effects in our study area. Secondary data from past researches were consulted to discuss effects of land degradation on agricultural productivity.

2.2.1 Factors influencing land degradation

2.2.1.1 Land use and Land cover

Land cover (classified) maps were produced based on data extracted from google earth. The data were collected in the same month of January of two years of 2014 and 2017, using Smart GIS Software, the rectified image were downloaded with Geographic coordinate system, data were later projected to TM Rwanda coordinate system. With the help of Image classification tool of ArcGIS 10.4 software, the training samples were collected for each of the 3 classes of our interest. Training samples were saved as signatures which later relied on to produce classified maps. Accuracy assessments were computed from ground truthing data obtained from google earth. Using the raster to polygon tool of the same software, classified maps were converted to polygons to find its total area and the obtained values were compared to detect the change occurred in 5 years.

2.2.1.2 Slope

Slope was computed based on the DEM of 2018 downloaded from earthexplorer.usgs.gov, from 2018 DEM, the slope were calculated using Slope tool, from spatial analysis tool of ArcGIS. Raster map were converted to polygon to come up with areas of the classes of the slope.

2.2.1.3 Precipitation (P mm)

To produce a precipitation map, annually rainfall data of 2018 provided by meteo Rwanda weather stations were relied on. From ArcGIS 10.4 software, the meteo stations data with location and annual rainfall in mm were imported in software; Kriging interpolation technique from spatial analysis tools of ArcGIS 10.4 software were executed to come up with general estimation from those sample data. After all, extraction by mask tool from the same software was utilized to remain with the information of our study area.

2.2.1.4 Population density

Population density data were extracted from 2018 ESRI Rwanda Data, Data were processed in Arc GIS software and Nyabihu District population density data extracted was for the final map, and attribute table containing population density was exported in Microsoft excel for the further analysis.

2.2.2 Land degradation impact on agricultural productivity in Nyabihu district (2014-2018)

For the analysis of land degradation effects on agriculture, Irish potato production was assessed using MINAGRI data of Annual potato production (MT) from 2007 to 2017 as compiled in the study done by Emmanuel in 2018. Annual potato production from 2014 to 2017 was extracted analyzed in Microsoft Excel.

2.2.3 Land degradation Assessment

2.2.3.1 Soil loss map

Soil loss map was produced using RUSLE formula. RUSLE data of Nyabihu district were acquired from ESRI Rwanda Ltd. RUSLE stands for Revised universal soil loss equation which is computed as **A=R*K*LS*C*P**, where A stands for the annual soil loss due to erosion which is in [t/ha/year], R is the rainfall erosivity factor, K the soil erodibility factor, , LS is the topographic factor which is derived from slope length and slope gradient, C stands for the (land) cover and management factor and P which stands for the erosion control practice factor.

The study of soil loss estimation conducted in 2018 by ESRI Rwanda Ltd leading expert company in geospatial technologies covered the whole district, extraction by mask tool of spatial analyst tool of ArcGIS 10.4 software was applied to remain with the study area. Using the raster to polygon tool from conversion tools of the software mentioned above, we obtained the polygons and merged the similar one to find total areas in ha of the 5 classes that comprise the map.

2.2.3.2 Landslide

ESRI Rwanda Ltd Shape-files of landslide assessment data that covers the whole district were processed using Clip tool from Arc GIS analysis tool were utilized to remain with Rugera sector shape-files, later a field was added on attributed table to computed area for each class of the 5 classes that comprise the map.

2.2.4 Land degradation restoration, mitigation and conservation measures

2.2.4.1 Land degradation conservation measures map

ESRI Rwanda Ltd provided shape-files of proposed matrix of conservation measures from water for growth Rwanda, the data generally were for Nyabihu district. Rugera sector was extracted using extract by mask tool from Arc GIS spatial analyst tool and converted in polygons. The similar polygons were merged together to find total area for each class.

Classes extracted from map were associated with Water for Growth, (2018) report on Catchment Restoration Opportunity Mapping for Rwanda. Each identified class was associated with it proposed conservation measures using conservation measures from Water for Growth Rwanda.

2.2.4.2 Agronomic measures

Literature review on practical tools on soil and water conservation measures of REMA (2010) were used to propose land degradation agronomic conservation measures.

III. RESULTS AND DISCUSSIONS

This aimed to discuss the results of the findings and interpret data gathered in the study; the findings are based on the objectives of the study. The first section discusses the factors influencing land degradation in Nyabihu district, case study of Rugera sector. The second section discusses the impact of land degradation on agricultural productivity in Nyabihu District, finally the third section covered the assessment from crop production referring to the productivity from (2014-2018) of Irish potatoes.

3.1 Factors influencing Land degradation

3.1.1 Land Use & land cover Change

Referring to the case of Rugera sector where a land use & land cover have been altered from 2014-2017, analysis of land use & land cover change was performed referring to 3 types of land use that are Agricultural land, Forest and Built up area. The aim of the land use change detection was to analyze land use alteration that lead and influence land degradation of the area and investigating the changes in land use / land cover is very essential to take appropriate management actions.

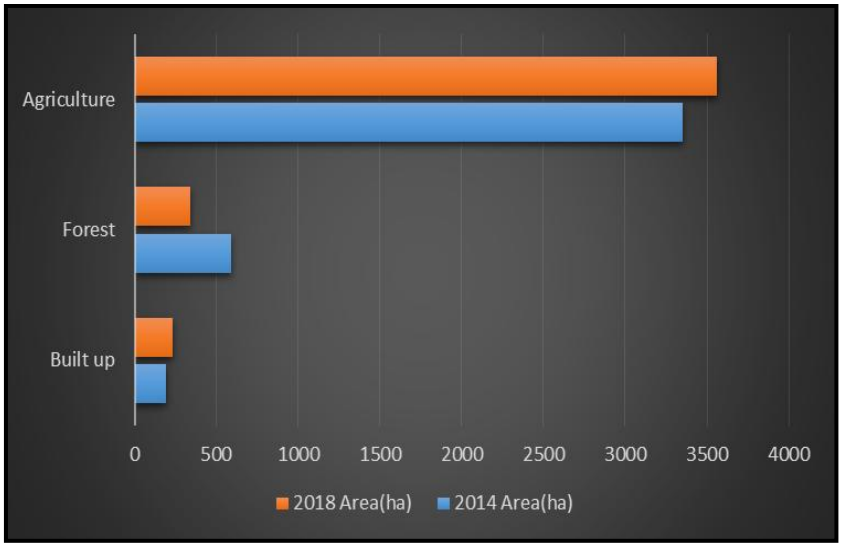

FIGURE 2: Land use & Land cover change trend.

The figures land cover &land use (2014) and land cover &land use (2017) reveal that in 2014 agriculture land increased from (81%) to (86.2%) of the total area. Area covered with forest decreased from (14.3%) to (8.2%) and built up increased from (4.6%) to (5.7%).

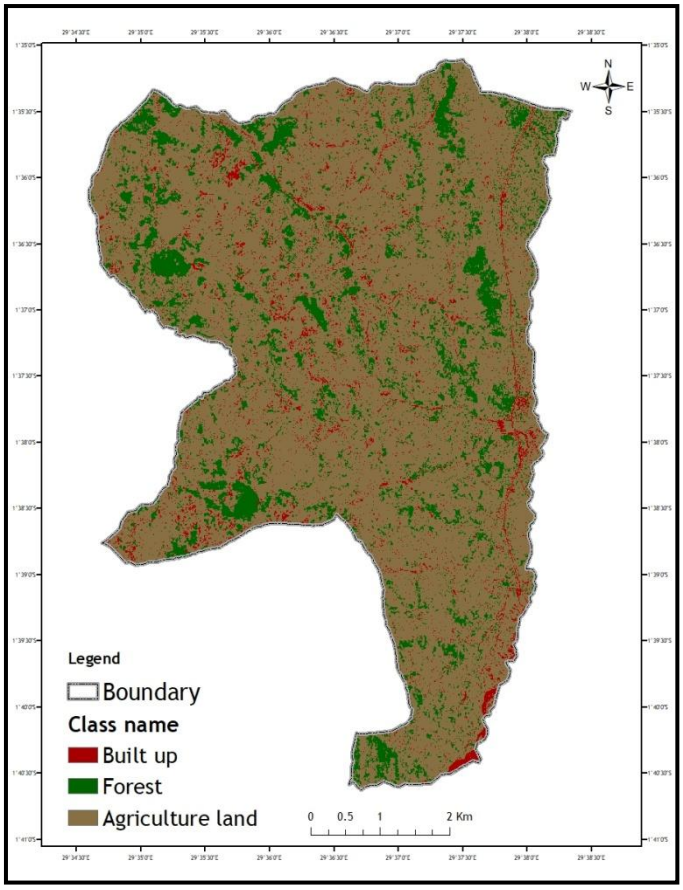

FIGURE 3: Land cover 2014
Source: Author' design

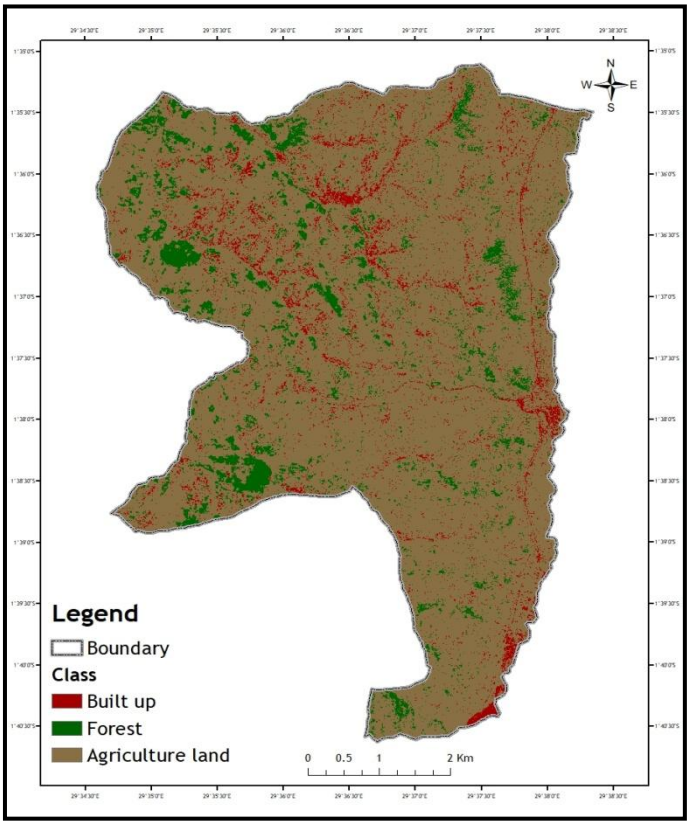

FIGURE 4: Land cover 2017
Source: Author' design

Considering the above land cover maps 2014 and 2017 land was degraded by alteration of the landscape through increasing of the area of agriculture land and built up area, and also the area occupied by forest has been reduced. The land use & land cover change have impact on agricultural productivity because the alteration land use influences the degradation of organic matter in soil. In addition, sparse forests have been reduced considerably caused the exposure of soil erosion and cause land degradation through soil degradation.

3.1.2 Cultivated sloping land

Referring to Abdallah (2016), slope factor contribute more to of land degradation through erosion, taking into consideration of our study area that has cultivated steep slope, land degradation through soil erosion is aggravated in less protected area of our study.

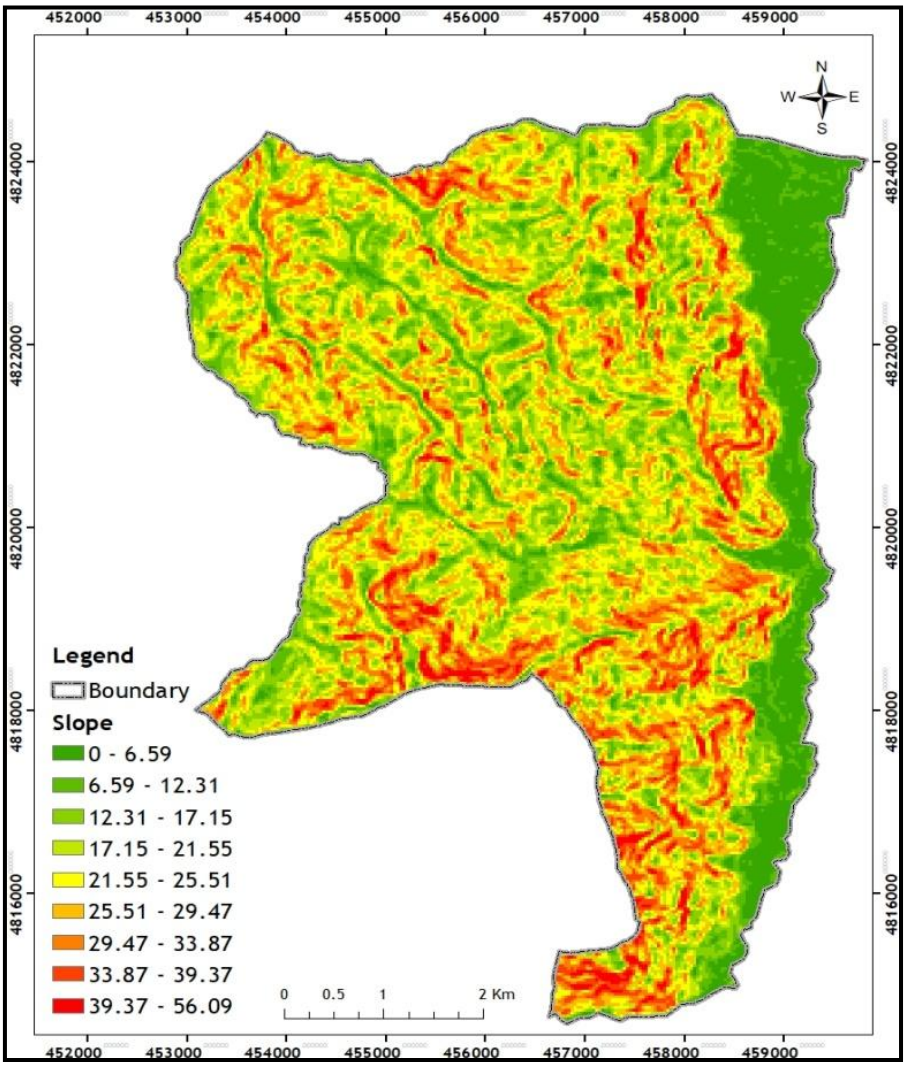

FIGURE 5: Slope map
Source: Adapted from CROM DSS data (2018)

Cultivation on steeper slopes, particularly above 30% is not recommended because it increases the vulnerability to land degradation (Sileshi, 2016). In Rwanda about 90% of the cropland is located on slopes of 5%–55%, and the soil erosion rate increased exponentially with the slope of the cropland (Karamage, Zhang, Ndayisaba, Shao, & Kayiranga, 2016). Considering our study area a big part of slope is ranging between (33%-56%) which expose the area to land degradation through soil erosion.

3.1.3 High amount of precipitation

Rainfall amount is among factors that influence land degradation, rain move soil directly, if the rain falls with sufficient intensity and the raindrop hit bare soil and breakdown soil aggregates, disperse the aggregate material. (Abdallah, 2016).

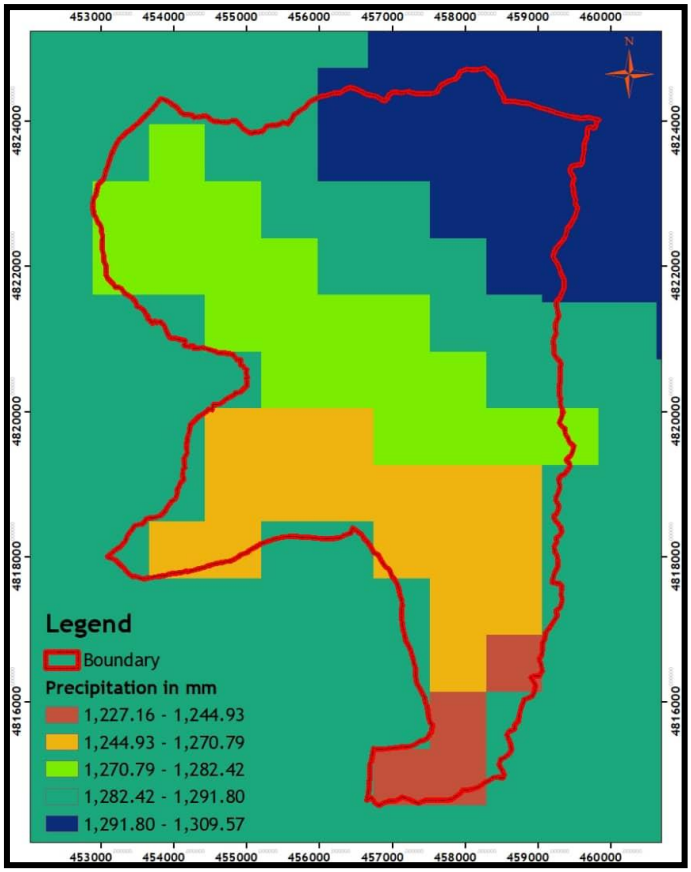

FIGURE 6: Precipitation
Source: Meteo-Rwanda (2018)

The amount of precipitation in Rugera Sector is ranging between (1227mm-1309 mm), while according to (Karamage et al., 2016), in Rwanda the average rainfall intensity is 1156 mm per year. This high amount of rainfall has impact on exposed soil and most of the time causes land degradation through soil erosion and landslide.

3.1.4 Population density

Referring to The National Institute of Statistics of Rwanda (NISR) data of 2012, the population density shows that our study area is among the 6th highest density per square km with about 589 people per km^2. A high-density rural population in our study area causes the overexploitation of agriculture land even in high sloped area ranging between (33%-56%).

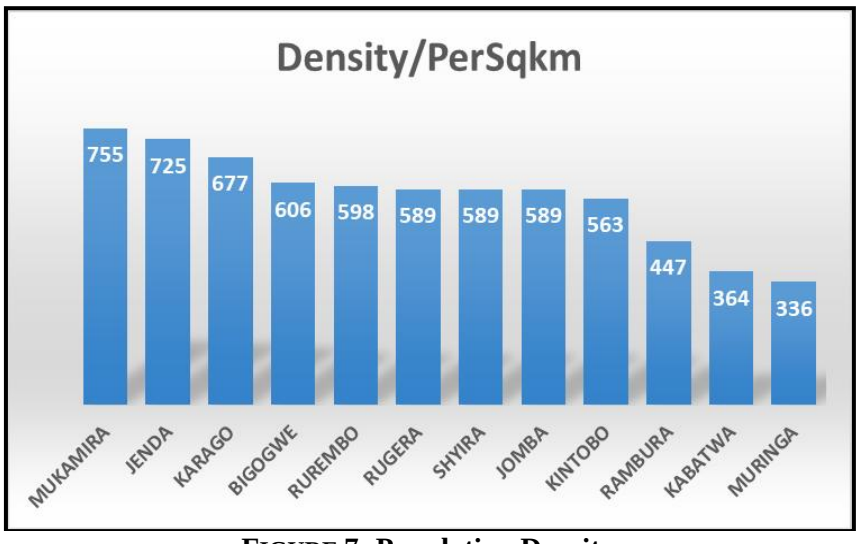

FIGURE 7: Population Density
Source: CGIS data (2012)

As stated by (Drechsel, Gyiele, Kunze, & Cofie, 2001), FAO estimates the actual supporting capacity of land ranges from 10 to 500 people/km−2, this shows that Rugera sector has exceeded the actual supporting capacity. The pressure of people on agricultural land increases cultivation of marginal soils and excessive exploitation of agricultural land will cause soon or later a severe degradation.

3.2 The impact of land degradation on agricultural productivity in Nyabihu district

The increase for demand for crop land to maintain food production is leading to agriculture in unsuitable area and cause soil erosion due to the inappropriate crop management. Land use and land cover change (2014-2017), related to increasing population and expansion of agriculture on steep slopes and unsustainable land management were the main cause of agricultural productivity decline in the area. The impact of land degradation on agriculture productivity will be explained using Nyabihu district Irish potato production trend.

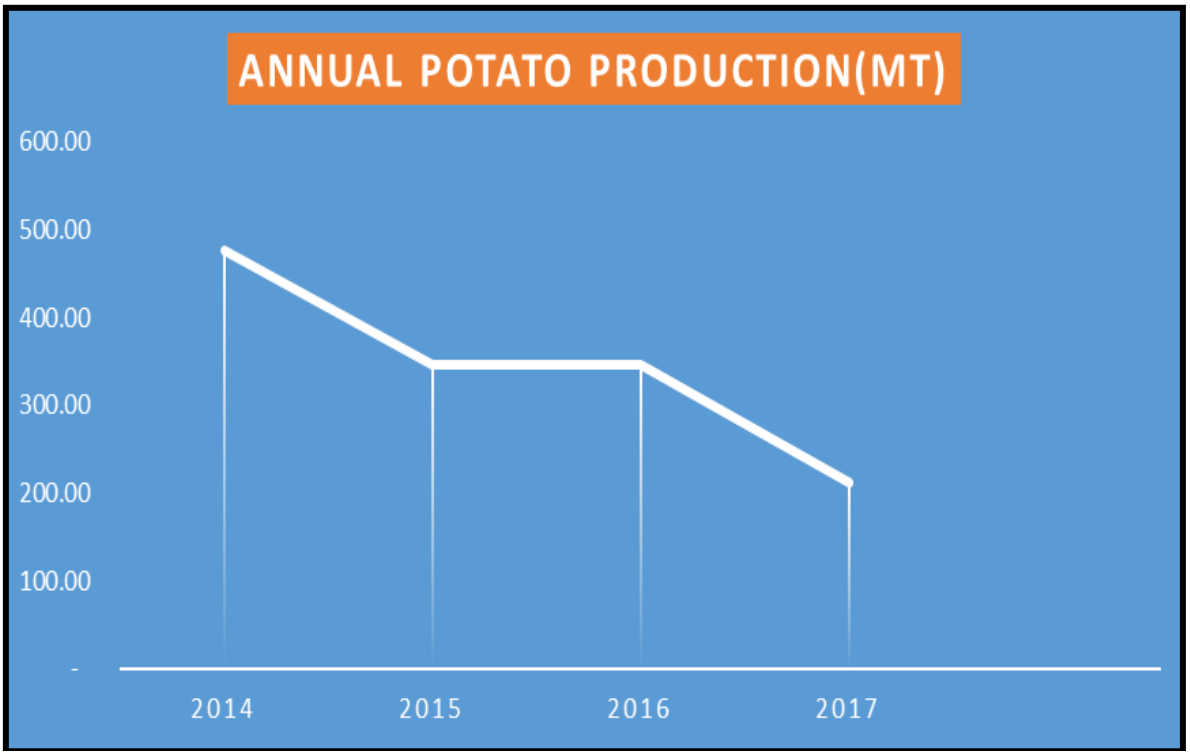

FIGURE 8: Annual irish potato production
Source:(Emmanuel, 2018)

Although according to Emmanuel (2018), the decline of annual Irish potato production was associated with factors such as pests and diseases, lack organic manure, mineral fertilizers, quality of seed, timely planting and inter-annual temperature variability. However land degradation is another influencing factor that can't be overlooked as it was identified in Rugera sector, where there are factors influencing land degradation such as land use and land cover change (2014-2017), cultivated sloping land, high amount of precipitation and high population density.

3.3 Land degradation vulnerability assessment.

The assessment of soil physical degradation is essential for the planning of land degradation restoration. GIS spatial modeling tools are efficient tools that may help decision makers to take the necessary actions to protect the most area exposed to land degradation (Ahmed Harb Rabia, 2012). Therefore this assessment will help Nyabihu district in planning of different activities to mitigate land degradation in the study area.

3.3.1 Soil erosion vulnerability

According to Kumar & Pani (2013), soil's physical degradation affects crop growth and yield by decreasing root depth, water availability and nutrient reserves. Hence, the soil erosion vulnerability assessment is a critical activity to be adopted by planners in order to reduce effects of soil degradation on agriculture productivity.

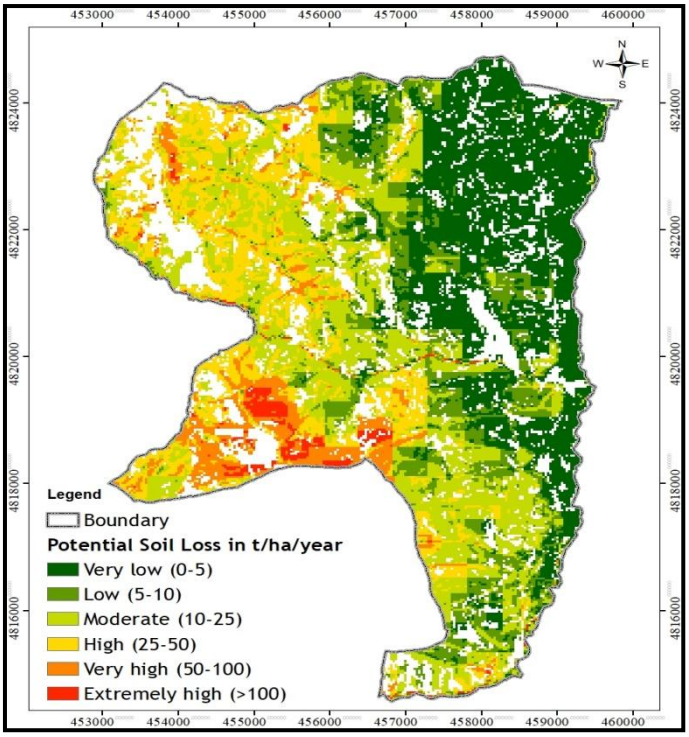

FIGURE 9: Risk to Soil Loss

Source: Adapted from CROM DSS data (2018)

Five factors (slope, land cover, rainfall, soil depth and geology) have been used to determine areas exposed to soil erosion. The soil erosion vulnerability was assessed in our study area and the vulnerability erosion maps were classified into six categories. The soil loss rate was estimated in (t ha $^{-1}$ y^{-1}) where (0-5) is considered as the area with very low soil erosion loss and (>100) is the area with high soil erosion. The soil erosion vulnerability assessment of our study area will be a contribution in soil degradation mitigation and choosing conservation measures to be adopted.

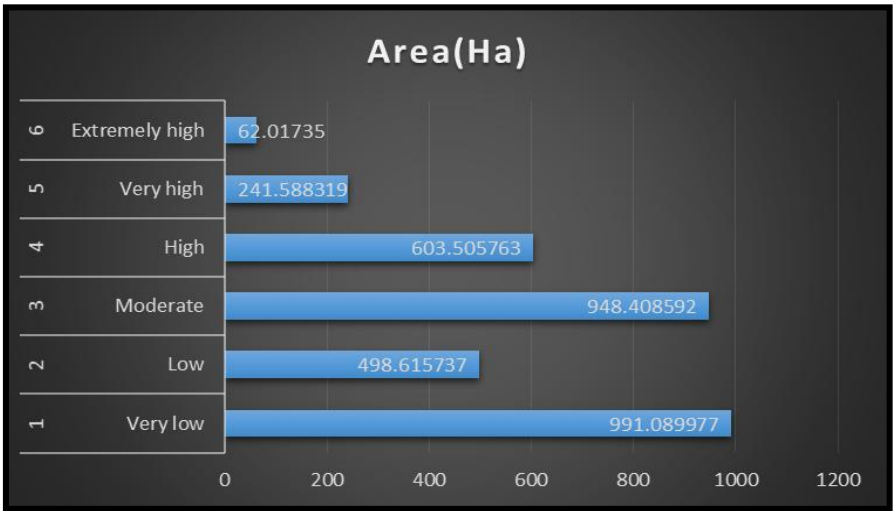

FIGURE 10: Status of Area exposed to soil erosion

According to the figure (10) about 62 ha are exposed to extremely high soil loss, 241 ha are exposed to moderate, high and extremely high soil loss and 1855ha are exposed to high soil loss. In total 2396 ha of the area are most exposed to the soil loss and need more attention for restoration and conservation measures.

3.3.2 Landslide vulnerability

Landslide vulnerability identification on agricultural may be significant for land use planning (Kroh, 2017). For the conservation of the most vulnerable areas susceptible to the landslide phenomenon, a landslide vulnerability assessment map was produced for the study area. The map is classified into five classes.

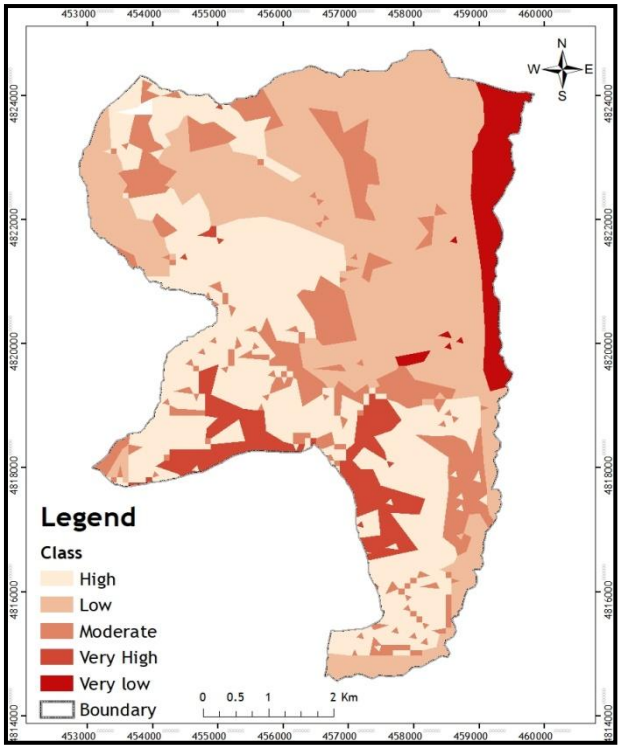

FIGURE 11: Landslide risk map
Source: Adapted from CROM DSS data (2018)

Landslide risk assessment is important in land degradation vulnerability assessment, because it helps in setting up need for restoration and conservation measures of land degradation. The identification of area exposed to landslide is also crucial while planning for restoration.

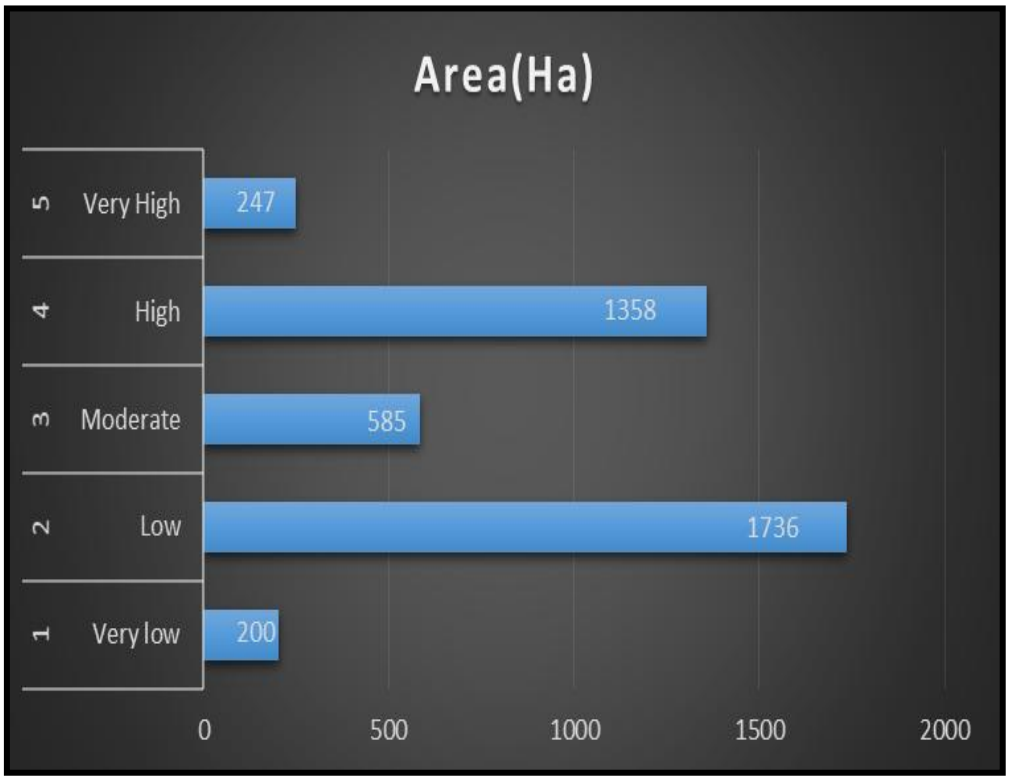

FIGURE 12: Status of Area exposed to Landslide

Considering the assessment of area exposed to landslide (Figure 12), about 2190 ha is exposed to moderate, high and very high landslide area and need restoration and conservation measures as soon as possible.

3.4 Land degradation restoration, mitigation and conservation measures

This section provides some proposed specific technical guidance for the land conservation measures. The measures proposed in this section were adopted from (REMA, 2010) and Water for growth Rwanda matrix.

3.4.1 Agronomic measures

Agronomic measures includes include mulching, crop management and agroforestry. These measures use the effect of surface covers to reduce splash erosion the splash, decreasing the velocity of runoff, and hence reducing the amount of soil loss. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy and sustainable land-use systems.

3.4.2 Water for growth Rwanda control matrix

Based on two main factors (slope and soil depth) a matrix was developed with proposed options of restoration. The matrix including classes was adapted from a previously developed conservation matrix under Land Husbandry, Water Harvesting and Hillside Irrigation Project (LWH project). From each of identified class, options of measures have been proposed.

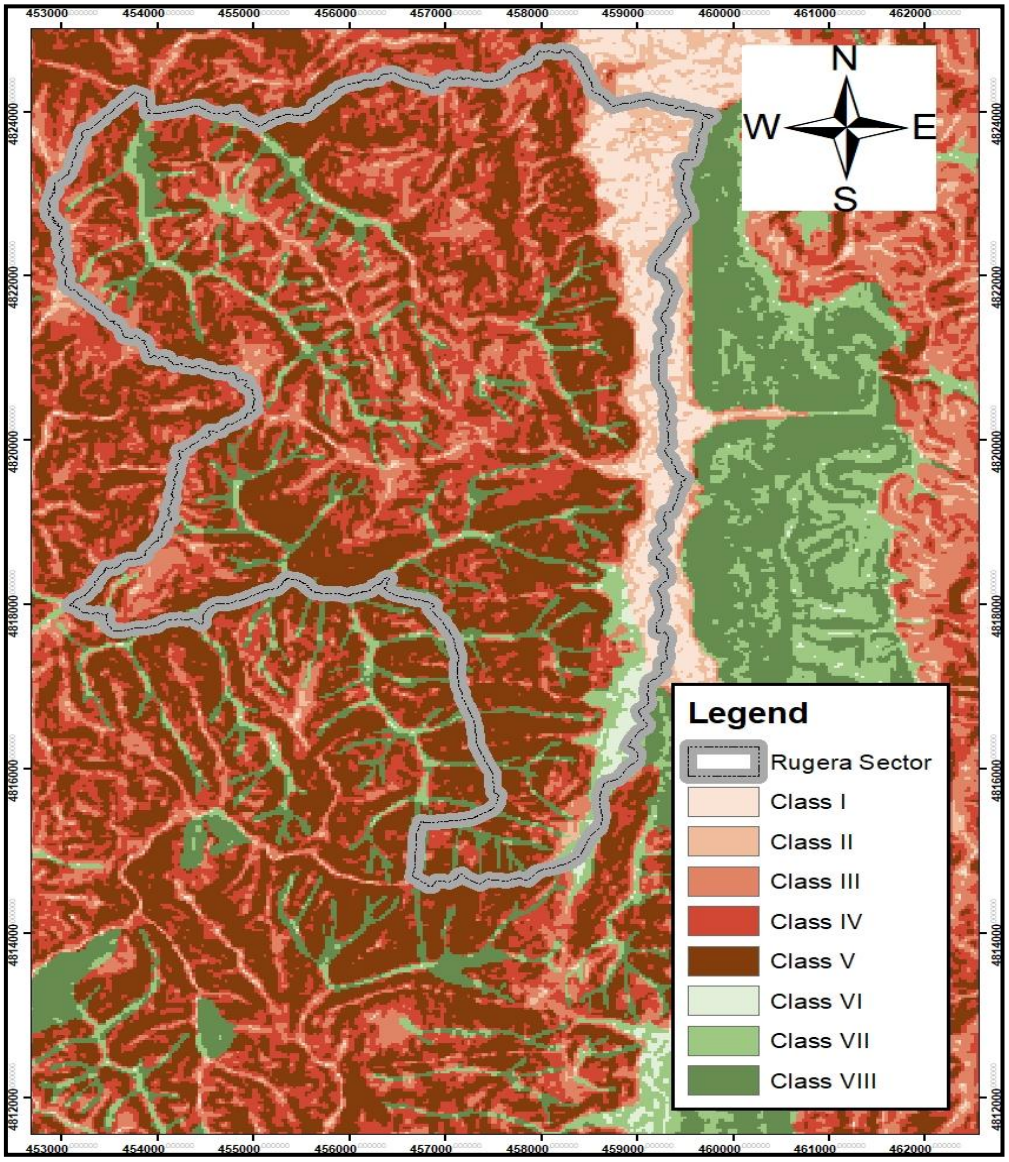

FIGURE 13: Conservation measures classification
Source: Adapted from CROM DSS data (2018)

Considering our study area we have 8 classes, for each of them, options of restoration measures have been proposed referring to proposed conservation matrix of Water for Growth Rwanda done in 2018.

TABLE 1
PROPOSED CONSERVATION MEASURES

Soil depth→ / **Land slope↓**	**1: (> 0.5m)**	**2: (≤ 0.5 m)**
1: (0-6%)	**Class I**	**Class VI**
	-Agroforestry + Contour ploughing + Alley cropping combined with grass strips	- Agroforestry + Contour ploughing + Alley cropping combined with grass strips
		- Forestation where soil depth is too limited and unsuitable for crops
		- Perennial crops, coffee, tea, banana, fruit trees
2: (6 - 16%)	**Class II**	**Class VII**
	- Progressive terraces	- Progressive terraces
	- Perennial crops, coffee, tea, banana, fruit trees	- Perennial crops, coffee, tea, banana, fruit trees
		- Forestation where soil depth is too limited and unsuitable for crops
3: (16 - 40%)	**Class III**	**Class VIII**
	- Bench terraces (or progressive) reinforced by agroforestry hedges and grass strips	- Progressive terraces / Contour bunds (4-5 m spacing between terraces) reinforced by agroforestry hedges and grass strips
	- Perennial crops, coffee, tea, banana, fruit trees	- Forestation where soil depth is too limited and unsuitable for crops
		- Perennial crops, coffee, tea, banana, fruit trees
4. (40- 60%)	**Class IV**	**Class IX**
	- Narrow cut terraces (or progressive terraces if parent material is not stable) reinforced by agroforestry hedges and grass strips	- Forestation
	- Perennial crops	
	- Forestation	
5. > 60%	**Class V**	**Class X**
	- Forestation	- Natural vegetation
	- Perennial crops	

Based on two main factors (slope and soil depth) the above table (1) is the matrix table of proposed restoration measures of land degradation in Nyabihu district, Rugera Sector. The matrix was adapted from the one developed with CROM –DSS Data from Rwanda water and Forestry Authority (RWFA) proposed options conservation of restoration.

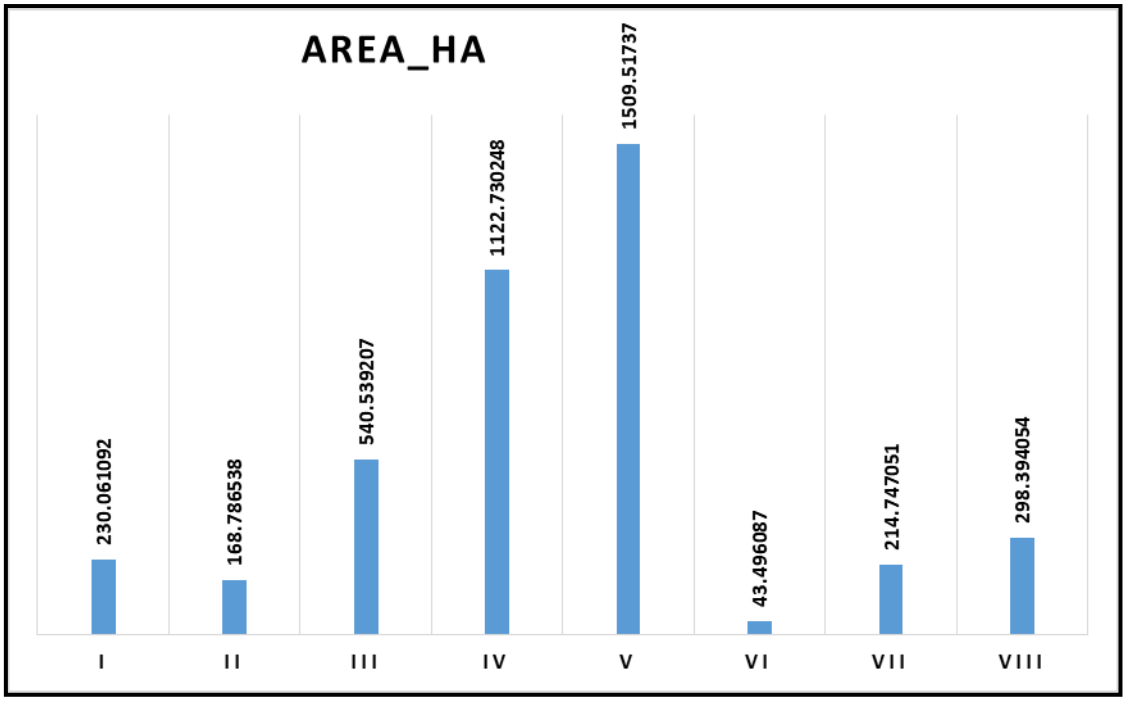

FIGURE 14: Area covered by classes

Referring to the above figure 15, a big area is covered with class five (V) with 1509.51737 Ha, followed with Class IV, III and VIII. Therefore conservation measures such as forestation of the area, planting perennial crops, narrow cut terraces or progressive terraces reinforced by agroforestry hedges and grass strips must be among the priority conservation measures of the study area.

The above table and map must be consulted by Nyabihu district, specifically Rugera sector authorities before the implementation of land conservation measures. However the implementation of most of the proposed measures are expensive (ex: Bench terrace), therefore the government should support farmers in their implementation. Concerning agronomic measures, as they are less expensive agronomist must continue the mobilization on the use of them in agriculture land.

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

From the results obtained in this study, it can be concluded that in Nyabihu district, Rugera sector land degradation is influenced by biophysical and anthropogenic factors. Those factors are land cover and land use change, high amount of precipitation and high density population cultivating sloping land. Land degradation that occurred from (2014-2018) alongside with other factors such pests and diseases, lack organic manure, mineral fertilizers, Quality of seed, timely planting and Inter-annual temperature variability had impact on agriculture productivity. From 2014, 2015, 2016, 2017 and 2018 a decline in annual crop production was observed in Nyabihu district. Land degradation through soil erosion and landslide were found to be more frequent and affecting agriculture productivity in the study area. Using GIS assessment about 2190 ha were found to be exposed to moderate, high and very high landslide and needed special attention for conservation and restoration measures, while 1855ha were exposed to moderate, high and extremely high soil loss. For effective conservation measures on land degradation the study recommends the use of both combined agronomic measures and land conservation measures adapted from proposed conservation matrix under Rwanda water and Forestry Authority (RWFA).

4.2 Recommendations

Based on the findings from the study, recommendations have been formulated to cope up with the effects of Land degradation on agriculture productivity in Nyabihu district:

- We recommend Nyabihu district all sectors deep assessment of the most vulnerable areas exposed to land degradation through erosion and landslide as most frequent hazards that contribute to the agriculture land degradation.

- While selecting conservation measures for land degradation, Nyabihu district officials must consider proposed conservation matrix under Rwanda water and Forestry Authority (RWFA).
- District agronomist in collaboration with Sectors agronomists must increase awareness and follow up on the use of land conservation agronomic measures including mulching, crop management and agroforestry as it was found to be the less expansive.
- Farmers should be involved actively in the process of land management and conservation measures in order to achieve land conservation sustainability.

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