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Expansion of Rural Settlement on High Quality Arable Land in Northern Province a Case Study of Musanze District

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Abstract

Settlement increase triggered by escalating urbanization is a critical element to the diminishing arable land globally. In Rwanda more people are concentrating in urban areas while rural population shrinks exponentially due to various factors, but unfortunately arable land continues decreasing. Rural and urban settlement especially in northern Rwanda expands into arable land, which in turn diminish high quality farmland, hence threatens food security in long-term view. However, the researches about this reduction is still insufficient. A comprehensive investigation is necessary into this important matter, which is the growing problem of agricultural land scarcity and the expansion of rural and urban communities in the Northern Province especially Kinigi sector of Musanze district. With a focus on Kinigi Sector, this research offers a detailed analysis of the complex processes at work from 2002 and 2012 and from 2012 to 2022. The results indicated that from 2002 to 2012 rural settlement has increased to 48.23% while between 2012 and 2022 increased to 98.14%, overall, this marks an increase of 49.86% from 2002 to 2022. Rural villages were largely built on high quality arable land at the beginning of the research period. thereafter, medium- and low-quality farmland was also inhabited, but to a lower degree due to the rigidity of the district.

Keywords: Expansion, rural and urban settlement, diminishing, agricultural land.

1. Introduction

The globe's fast urbanization is a result of both a major rural migration and the industrialization of the international economy. Musanze district is among the rapid growing secondary cities of Rwanda which in turn facets the impact. Recently Rwanda's population has been exponentially escalating since 2000, where between 2000 and 2012 and from 2012 and 2022 has increased to 9% and 6.37% respectively (NISR,2022). In turn this put pressure on arable land and facets its reduction, the increase of rural a and urban habitation has significantly led to the decline of arable land in Musanze district, in addition to that, large amount of high-quality farmland is prone to reduction, pointy on rural areas and urban space of the study area, as a result, food security reduces inevitably. Clarifying the reasons underlying the development of rural communities and the appropriation of arable land, especially high-quality land, is essential to ensuring regional food security (Abu Hatab et al.,2019).

Rural settlement development is presently rather stable in wealthy countries, yet it is still prone to sharp variations in developing countries. In Rwanda, it is obvious that the country's rural villages are undergoing dynamic changes, with the majority of them continuously expanding(Uwimbabazi & Lawrence, 2011). Example Kinigi in Rwanda, the rise of rural villages is attributed to several reasons, including the country's increasing urbanization. Institutional problems and human variables, such as farmers' desire to enhance living circumstances, can be used to summarize the causes of this occurrence(Umuziranenge et al., 2024). Because of the large population and limited amount of land per person in Rwanda, 72% of the country's

people view arable land as an important resource (RPHC, 2022). However, during the past 20 years, this resource has been gradually depleting due to the acceleration of economic expansion. Clearly, this development represents a serious threat to regional food security and sustainable development. It has been reported that urban expansion usually leads to the loss of high-quality arable land because the distribution of urban areas and high-quality arable land usually shares similar land conditions such as the flat terrain and having resources close to the water (C. Li et al., 2021).

Evaluating the food security of the region depends on calculating the quantity of high-quality arable land lost due to the unavoidable expansion of rural settlements in northern Rwanda pointy Musanze district(NISR et al., 2021). To achieve this, we employed an indicator that linked the expansion of rural villages to their habitation of very productive soil. We assessed the profession of superior arable land by the expansion of rural settlements using this indicator(Liu et al., 2010). Our specific goals were to:(i) report on the variation in the growth of rural Evaluating the food security of the region depends on calculating the quantity of high-quality arable land lost due to the unavoidable expansion of rural settlements in northern Rwanda pointy Musanze district(NISR et al., 2021). To achieve this, we employed an indicator that linked the expansion of rural villages to their habitation of very productive soil. We assessed the profession of superior arable land by the expansion of rural settlements using this indicator(Liu et al., 2010). Our specific goals were to: (i) assess the occupation situation in relation to the development of rural communities on arable land; and (ii) evaluate the quality of the arable land that rural communities inhabit, shedding light on the process of rural settlement expansion.

2. Description of the study area

Musanze District is one of the five districts that make up the Northern Province. Ruhondo Lake makes about 28 km^2 and the Volcano National Park covers 60 km^2 of its total 530.4 km^2 and 476,5622 total population of which 50.8% are in rural areas while 49.2% are in urban areas (NISR, 2022). The Democratic Republic of the Congo (DRC) and Volcano National Park border Musanze District on the north, while Burera District, Nyabihu District, and Gakenke District border it on the east, west, and south, respectively. Kinigi sector has tropical weather, with highlands typically seeing temperatures of 20ºC. When precipitation is sufficient all year long, it usually falls between 1,400 and 1,800 mm.

The research area is divided into two main seasons, the rainy and the dry seasons, and two smaller seasons: we have the big dry season, which runs from June to mid-September; January until the middle of March, the brief dry season; the long, rainy season runs from mid-March until the end of May. As well as from mid-September to the conclusion of the brief wet season ends in December (NISR, 2018). Regarding the physical attributes of the research region, Musanze District's soil is primarily composed of volcanic soil, which is basically rich in nutrients. The primary Musanze District's crops include corn, beans, and Irish potatoes, and wheat. These contributes 21.4% of the mean share of harvest sold country wide, this makes it the third district which has more agricultural yield in northern Rwanda (EICV3, 2011). According to 2022 PHC5, the total agricultural households is 66.3% whom are thriving in this rapid urbanizing district.

The map below shows the location of Kinigi sector located in northern province Musanze District.

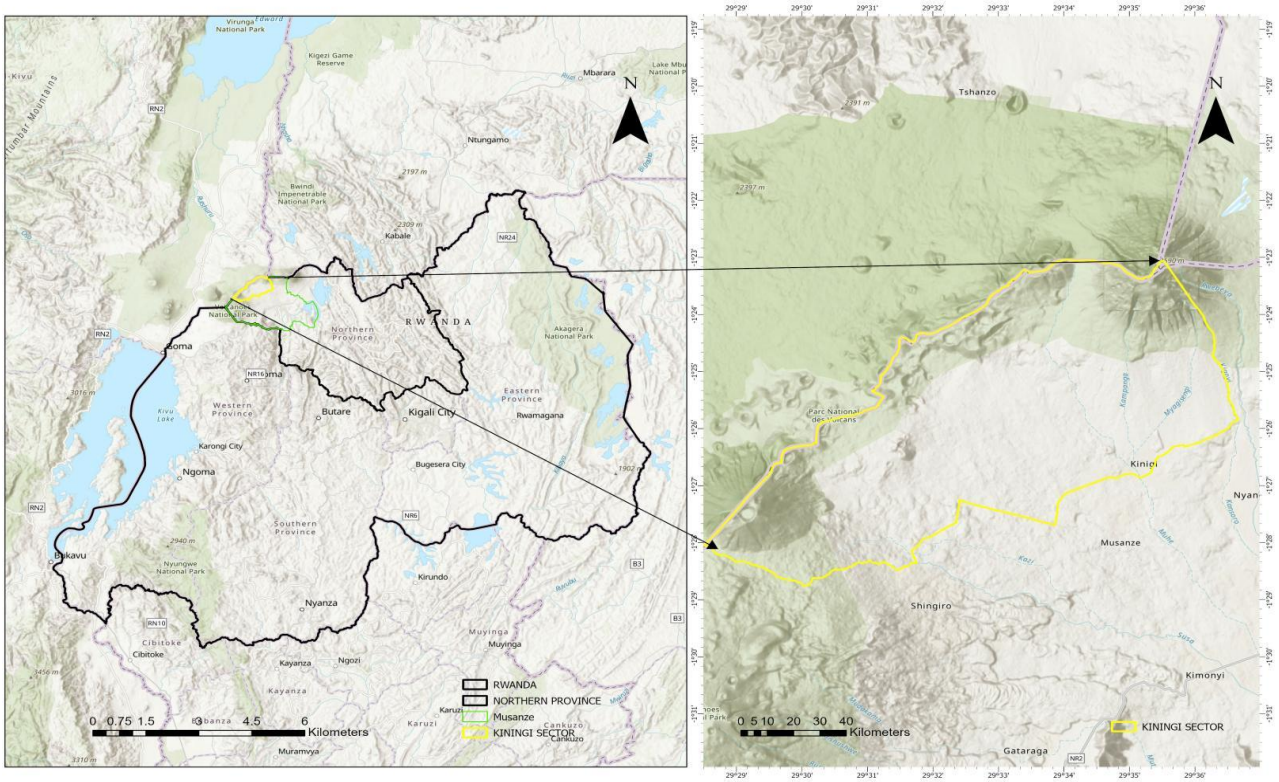


Figure 1: *The location map of Kinigi Sector in Musanze district (ArcGIS Pro 2024)*

3. Data Source

The land use maps that we generated in this study was for three periods, namely 2000, 2012 and 2022. Furthermore, the arable land quality map of Musanze district for 2000 was utilized. The land use map was generated using satellite images from USGS portal acquired through remote sensing spatial technology.

Table 1: Types of data acquire and their respective sources

Data	**Data sources**
Land use and land cover 2000,2012	https://hub.arcgis.com/datasets/6e1212160b8c434e814007b0c0b658d5/explore
Land use land cover 2022	https://livingatlas.arcgis.com/landcoverexplorer/#mapCenter=33.15500%2C5.42600%2C4&mode=step&timeExtent=2017%2C2022&year=2022&downloadMode=true
Remote sensing images	Earth Explorer (usgs.gov)

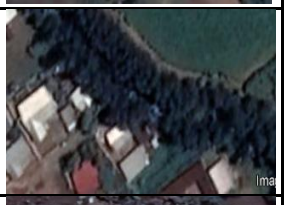
3.1 Research Methods

3.1.1 Land Use Classification

The research area's border was established using the 2000 land use map to guarantee uniformity in the area coverage. The contrast stretching approach was used to improve the black-and-white photographs from 2000, and the color image enhancement method was used to improve the color images from 2012. The land use categorization for this study was created using the 2012 reclassification of land use categories. The categorization scheme used the main land use category for 2012, with minor revisions, to reflect changes in rural communities(Gribb & Czerniak, 2015). Following that, we classified residential land in 2012 into rural settlements and other construction land based on the secondary land use category. Finally, Musanze district land use was classified as follows: arable land, woodland and grassland, water regions, urban land, rural settlements, and other construction land.

3.1.2 Validation

Table 2: *Division of land use and image interpretation (Google earth studio).*

	Land		Geographical representation	
Land use type	**Interpretation indicator**	**Geographical representation 2012**	**Interpretation indicator**	**Geographical representation 2022**
Arable land	strong indications of armament and a distribution resembling flake. The color of the green -and-white pictures is mostly either brilliant gray or black, making them quite homogeneous.		Flaky distribution in the level areas and obvious signs of agricultural fields, which are depicted in the photograph as light green.	
Forest area	Clustered distribution and represented as dark black in the black and white image		Dispersion with stripes in a constrained area, shown in the picture as deep green.	
Water area	Distributed in stripes and shown as a dark-green that is comparatively uniform in tone		dispersion that is striped and shown in the picture as dark white.	
Rural settlement	a Dispersed dispersion with a few roads and brilliant white structures		Distributed in clusters. The tiny, brilliant white rectangles are carefully spaced apart by greenery that is scattered throughout.	
Urban area	a densely populated area with none clearly identifiable roads and white and blue buildings.		a vast area with a densely populated dispersion of structures; the buildings are red and white in color and have easily identifiable roads.	
Other built-up areas	refers to land used for development, excluding urban areas and rural populations; it is characterized by a predominantly asymmetrical architecture and is depicted in dazzling white.		Plots are rectangular in shape and regularly aligned; they can be either brilliant white or red in color.	

A number of additional methods have been put forth for evaluating accuracy, including the fuzzy sets method, an error model created by Michael & al. 2022, as well as a weighted ANOVA correction method(Ezeilo, 2011). It is evident that there is no accepted technique for evaluating accuracy. Given that error matrices are widely used, we used them to evaluate the accuracy of our maps. Ground truth data, or reference data are required for the error matrix computation. Traditionally, a field survey might provide the reference data. Very high-resolution satellite pictures can be used as a source of reference data when field survey data is scarce(Zhang, 2022). We mapped the area as part of this study using satellite photos with a

spatial resolution of 2 and 10 meters, respectively, in 2000, 2012, and 2022. In order to make up for the absence of field survey data, we looked at Google Earth photos of Kinigi sector. Comparing this resolution to the satellite photos we used to map land usage, it was significantly lower.

In light of the limited availability of high-resolution images and field survey data, we developed an alternative technique to extract pertinent information in a heterogeneous manner(Adnan & Akbar, 2019). The original author individually classified the land use of the Musanze district in 2000 and 2012 using a visual interpretation approach. In general, the visual interpretation of a high-resolution satellite picture may accurately and correctly determine its true purpose(Svatonova, 2016).

The two experts have extensive backgrounds in charting the Musanze district's land usage. In particular, three specialists, including the first author, began determining the true land use of these places by visually evaluating the random points that were used to verify accuracy. The land use of the sample point was established and could be used as reference data only when the three experts' judgments were in agreement. We produced the Kinigi sector reference data in 2000.2012, 2022 using this methodology. We used the historical Google Earth pictures for 2012 with a spatial resolution of up to 0.23 m to validate the land use map(Hu et al., 2013).

We used ArcGIS Pro to produce Random locations function to produce 100 random locations in Kinigi sector in order to create reference data. Next, random spots were superimposed on Google Earth photos from 2002 to 2022. The three experts' visual evaluations were followed by a determination of the random spots' land usage. A point was removed from the reference data if the three experts could not agree on how to classify its land use. After then, a different random point was made to serve as the reference data alternative. Ultimately, the three experts' work produced 100 random reference data from 2002, and 2022.In Table 3, portions of the reference data are displayed.

We did not just concentrate on the accuracy evaluation of a single map, but also on the accuracy assessment of the modifications made to the maps, as our goal was to examine the changes among several land use maps. As a result, we created a method to gauge how accurate the modifications were. Initially, the modifications from 2000 and from 2012 to 2022 were retrieved. Then, in order to confirm their correctness within these modifications, we generated 50 random points. The same methodology was used to generate the reference data as was used to validate the maps from 2002, 2012, and 2022. Lastly, the following equation was used to evaluate the correctness of the changes:

$$\mathbf{CHA}=\frac{CRC}{TOC} \quad (1)$$

where TOC is the total number of changes, CHA is the accuracy of the changes, and CRC is the number of corrected changes.

3.1.3. An examination of how the growth of urban settlements has affected the use of high-quality arable land

Based on the land use conversion matrix, assessments may be made for the years 2000 and 2012 to 2022. The conversion matrix has been widely utilized for the investigation of dynamic land use change because it can show the quantity and direction of regional land use conversion. An indicator of high-quality agricultural consumption (IHC) may be used to examine the consumption preference for the growth of rural communities(Song et al., 2015). A trend toward the occupancy of high-quality arable land is indicated by an IHC larger than 1, and the stronger this tendency is, the higher the IHC(H. Li & Song, 2019). The following are the calculating equations:

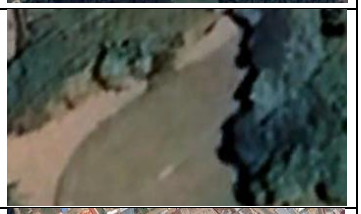
$$\mathbf{IHC}=PH_{ue}/PH_{wl} \quad (2)$$

$$\mathbf{PHue}=UE_{high}/UE_{whole} \quad (3)$$

$$\mathbf{PHwl}=TF_{high}/TF_{whole} \quad (4)$$

where UE_{high} is the area of high quality arable land occupied by rural settlement expansion, UE_{whole} is the total area of arable land occupied by rural settlement expansion, PH_{wl} is the proportion of high-quality arable land to the total arable land of Kinigi sector, TF_{high} is the area of high-quality arable land in Kinigi sector, and TF_{whole} is the total area of arable land for Kinigi sector. IHC signifies the occupation coefficient of rural settlement expansion for high-quality arable land.

***Table 3**:Parts of the reference data determined by the three experts (Google Earth Studio).*

Reference Data	2002	2012	2022
Arable Land			
Forest and Glass			
Water areas			
Rural settlement land			
Urban land			
Other construction land			

Five stages of geographical analysis were carried out in accordance with the IHC calculation formulae to get the IHC. The land use maps between 2002 and 2022 were first resampled with a 2 meter spatial resolution. Second, by overlaying land use maps from any two eras, the growth of rural communities was mapped. Third, by superimposing the increased rural settlement on top of the arable land from the first map created during the study period, the losses of arable land brought about by the growth of rural communities

were plotted. Fourth, Kinigi sector's superior arable land was located with the aid of the subsequent equation(Song et al., 2015).

$$AQR = AQp/AQa \quad (5)$$

where AQ_a is the average quality score for all arable land, AQ_p is the land quality score of parcel p, and AQR is the arable land quality rank. Kinigi's arable land quality was classified as poor, medium, or high based on AQR_s that had respective value ranges of 0-0.8, 0.8-1.2, and 1.2+(Song et al., 2015). Thus, using AQR, a high-quality land map of Musanze was produced. Finally, there was overlap between the excellent land map of Musanze and the map showing the lost arable land as a result of the growth of rural settlements. As a result, a top-notch map of the loss of arable land could be created. Equations (2)–(4) might then be used to compute the IHC.

4. Results

4.1 The Development of Rural Settlement Growth

The Kinigi sector's rural villages expanded significantly between 2000 and 2012, but at varying rates depending on the time of year. The aggregate acreage of rural settlements expanded by 48.28% between 2000 and 2012, and 92.14% from 2012 to 2022. The corresponding average annual growth rates were 48.28%. While 14ha of the rural settlements were transformed into other land use types between 2012 and 2022 (Table 2), 3165 ha of other land use types were also converted into rural settlements; arable land made up the largest percentage of these other land use categories. In terms of accessible space, the rural villages grew mostly in the form of a dispersed outward growth surrounding the initial rural settlements between 2000 and 2012 (figure 1&2). Nearly every site in the study region where rural communities were found had some evidence of outward growth.

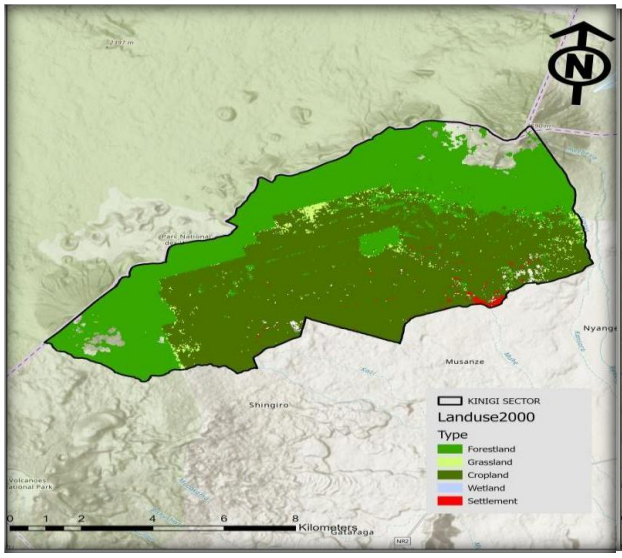


Figure 2: *Landuse landcover of Kinigi sector in 2000*

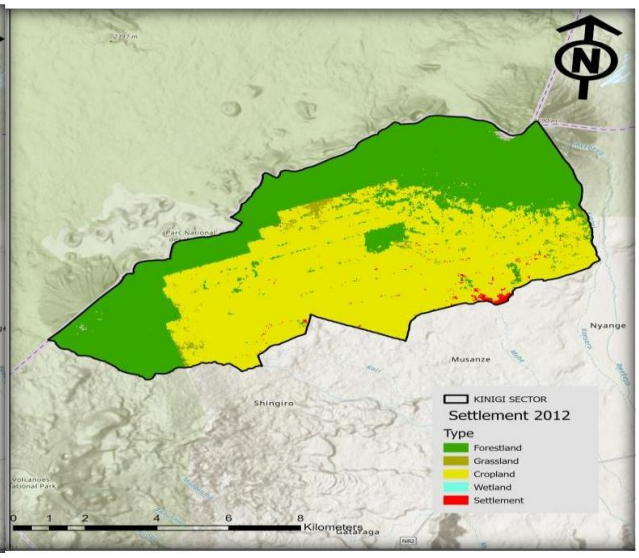


Figure 3*: Landuse landcover of Kinigi sector in 2012*

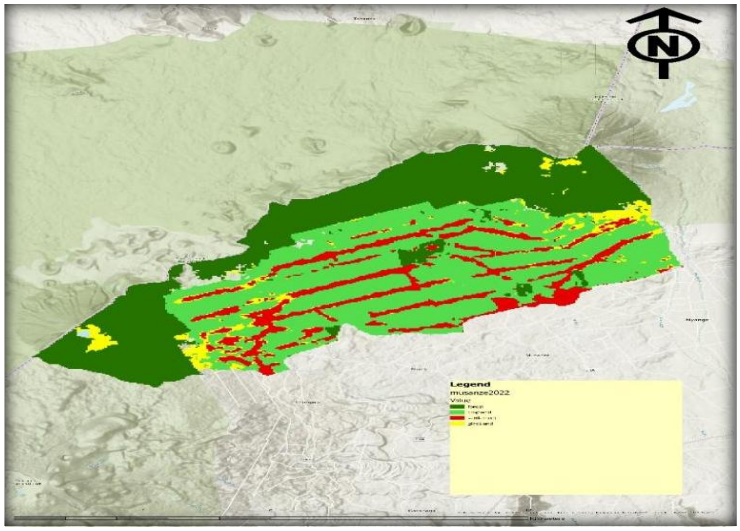


Figure 4*: Landuse landcover of Kinigi sector in 2022*

Table 4*:Conventional area matrix of Land_use types in Kinigi sector from 2000 to 2012*

Land uses	grass land	% change	cropland	% change	wetland	% change	settlement	% change	forest land	% change	% total	Total
Grass land	0	0.00%	0	0.00%	1	50.00%	1	50.00%	0	0.00%	100%	2
Cropland	5	17.24%	0	0.00%	6	20.69%	14	48.28%	4	13.79 %	100%	29
Wetland	12	15.58%	24	31.17%	0	0.00%	29	37.66%	12	15.58 %	100%	77
Settlement	81	12.16%	174	26.13%	326	48.95%	0	0.00%	85	12.76 %	100%	666
forest land	0	0	0	0	0	0	0	0	0	0	0	0

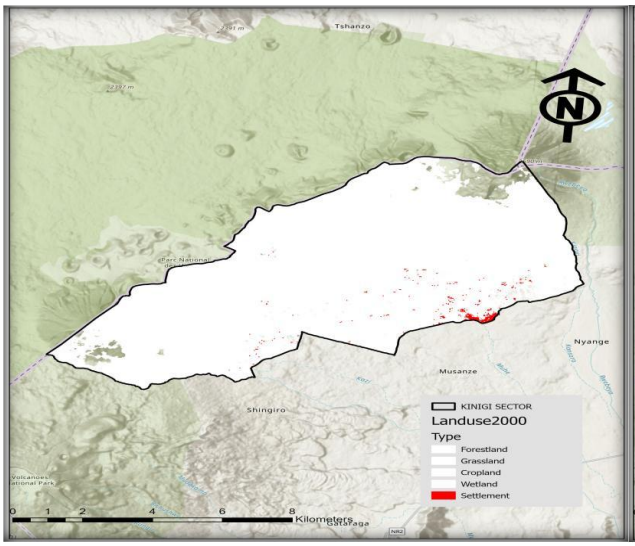


Figure 5*: Settlement of Kinigi sector in 2002*

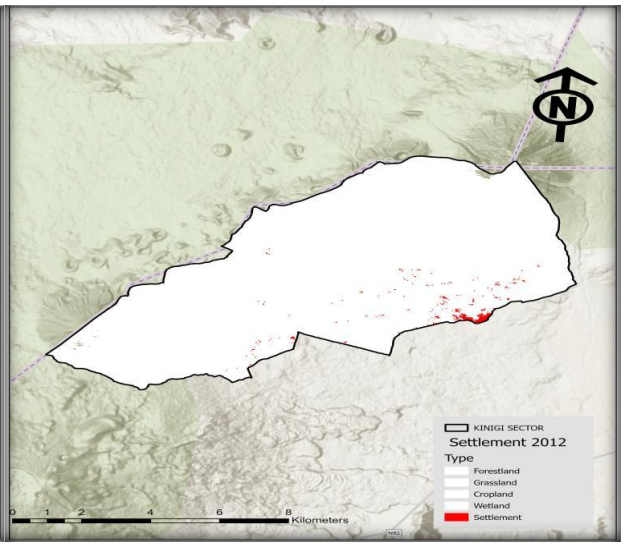


Figure 6: *Settlement of Kinigi sector in 2012*

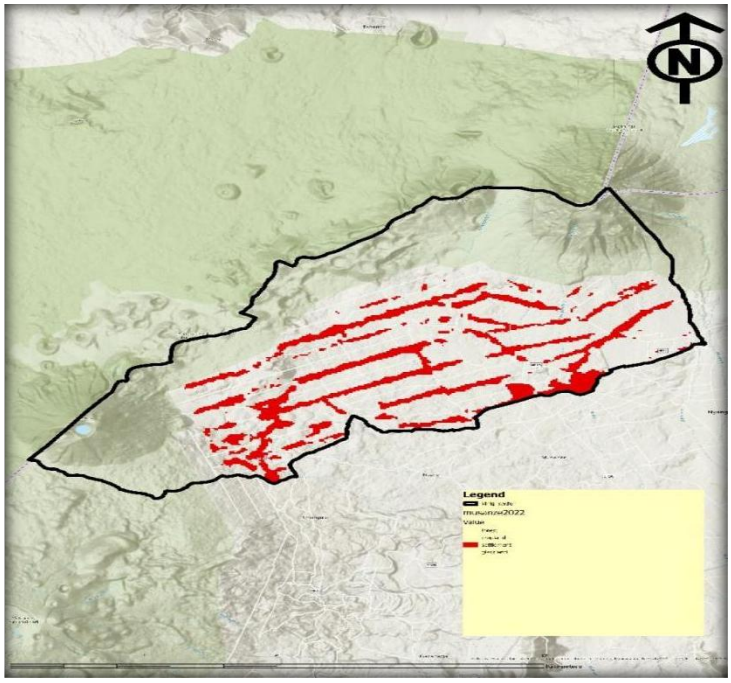


Figure 7: *Settlement of Kinigi sector in 2022*

Over the course of the research period (2000–2022), Musanze district District's total area of rural settlements expanded by 92.14%, and the percentage of arable land that was turned into rural communities made up 3165ha of the total land available. The degree of clustering of rural settlements increased dramatically by 2012, approaching the same scale as that of single rural settlements(Ephraim, 2015). In 2002, the distribution of rural settlements in the study area was relatively scattered, and the scale of individual settlements was generally small. To put it another way, compared to 2012, the periphery of rural settlement grew significantly further inward in 2022.

Table 5: Conventional area matrix of Land_use types in Kinigi sector from 2012 to 2022

Land use	Forest	%change	Crop land	%change	Grassland	%change	settlement	%change	Total%	Total change/ha
Forest	0	0.00%	316	59.29%	178	33.40%	39	7.32%	100%	533
Cropland	44	1.28%	0	0.00%	226	6.58%	3165	92.14%	100%	3435
Grassland	10	35.71%	0	0.00%	14	50.00%	4	14.29%	100%	28
Settlement	2	5.56%	5	13.89%	0	0.00%	29	80.56%	100%	36

4.3 Variations in the Distribution of Arable Land

The whole region of Kinigi sector's rural villages was studied from 2002 to 2022. The percentage of arable land being turned into rural villages accounted for 48.28% of the total land arable land available in 2002, and the sector rose by 92.14%. 2022 saw a change in the rural settlement pattern within the scale of individual settlements in the research region was typically modest and dispersed; but, by 2012, there had been a significant rise in the degree of rural village clustering, almost reaching the same scale as the number of single settlements. Stated differently, compared to 2002, the periphery of rural settlement had a significant outward expansion in 2012. Furthermore, in 2022, the periphery of a certain rural community comprised two due to the amalgamated growth of rural communities.

The decrease of arable land of inferior grade had a varied course between 2002 and 2012 (figure 6&7) as seen, the growth of rural communities in Kinigi sector on high-quality arable land was primarily lost over the years 2012 and 2022. The initial, unbroken distribution of excellent agricultural land was progressively taken over by rural communities, which essentially ate up an increasing amount of excellent arable land. Beginning in 2002 up to 2012, the growth of rural villages was primarily portrayed as an outward-diffused development with the original towns serving as its hub. According to this diffusion model, the arable land was gradually overrun and encroached upon by rural communities. Around an area with a concentration of excellent agricultural land during this time, such Kinigi sector rural villages began to grow. Between 2002 and 2012, There was more to the growth of rural communities than just outward dispersal, since several villages showed signs of combining. For example, the northern villages had a significant amount of rural settlement development and merger.

5. Discussions

The district of Kinigi sector is still rapidly being urbanized. Overall Planning of Musanze district (2022–2050) projects that 64.2% of this district's population will reside in urban areas by 2030 (NISR, 2018). However, the overall area of rural communities keeps growing in tandem with this significant shift in the distribution of the people. Improvements in the economy spurred rural inhabitants to work for more comfortable living conditions, which in turn led to a rise in the demand for rural housing and the continued growth of rural settlements, notwithstanding the institutional cause (D. Li et al., 2016). According to our research, between 2002 and 2012, Kinigi sector's rural villages were primarily located on excellent agricultural land. This occurrence can be explained by the following factors. First, based on the superior arable land map of Kinigi sector, the majority of arable land was located near rural communities. For a very long time, Kinigi sector farmers have been dependent on agricultural produce. Because of this, the farmers first constructed their homes close to fertile ground. Because there was a significant amount of organic matter present, the soil quality improved over a lengthy time of cultivation. Second, Kinigi sector's high-quality arable land is mostly located in relatively level locations, which makes it easier for new communities to grow.

The implementation of these regulations to conserve arable land was simple due to the near proximity to the metropolis (Zhong et al., 2012). As a result, these land use regulations were tightly implemented in Kinigi sector, this led to a decline in building on excellent arable land. Furthermore, the Rwandan government improved the oversight of rural constructions, which helped to limit the amount of prime arable land that was consumed by the growth of rural settlements. Musanze city people's Government issued the provisions for strengthening rural construction land use management, which mandates that the villagers carefully carry out the fundamental national policy of safeguarding arable land when erecting new homes; additionally, the recently constructed homes must adhere to the general land use planning requirements at the town level and fully utilize abandoned land and old home sites, thereby minimizing the area needed for the construction of new homes on superior arable land (Francis, 2012) .Aside from the impact of the aforementioned measures, high-quality agricultural land around rural communities in Kinigi sector were mostly taken up by rural homes, resulting in a reduction in the amount of high-quality arable land (which made up just 17.86 % of all the land that is arable). Consequently, there was an impediment to the growth of rural communities into superior arable land (Jean Pierre Bizimana, Sylvere Hategekimana, Herve Villard Habonimana, Fabrice Nkurunziza, Justin Nzayinambaho, 2016).

Rural communities occasionally took over the surrounding excellent fertile land in Kinigi sector throughout the growth phase. As a result, it is essential to inspect potential home locations in rural regions and to forbid additional habitation of excellent agricultural land. This necessitates that sensible control. There are policies in place to guarantee that rural villages may grow to a suitable size. For instance, farmers should be urged to develop their homes on the original, poor-quality property and to fully utilize vacant land, sloped wilderness, and abandoned town land; nevertheless, it should be rigorously forbidden to build new homes outside of the boundaries of rural settlements (Buckley, 2020). Strict steps should be taken concurrently to safeguard the quality of arable land. Arable land protection zones should include high-quality and medium-

quality arable land, and appropriate procedures for incentives and penalties should be developed to severely limit building on the adjacent high-quality arable land (Wei Li 1, 2, 2021). Furthermore, based on Quebec, Canada's experience protecting arable land, it's critical to establish a comprehensive framework that takes into consideration the fundamentals of arable protection. In addition, it is critical to address the broad factors required to maintain and grow a sustainable agriculture industry (Bryant, 2015).

This article uses geographical data of rural villages in 2002 and 2012 that was obtained from encrypted military remote sensing pictures. The pictures served as a guide for locating data on land use change over an extended period of time at a reasonably high quality. However, the dearth of credible reference data made it extremely difficult to validate these maps. We suggested a novel method to produce the reference data in order to address this issue. Based on this data, the land use classification's overall accuracy for the years 2002, 2012, and 2022 was evaluated correspondingly. Additionally, we suggested a method for evaluating the precision of mapped land use changes. The accuracy of these maps and the mapped changes was high.

Nonetheless, there were a lot of unknowns regarding the accuracy evaluation. In this case, the visual interpretation consistency test amongst three experts produced the reference data. Even in the event that the three experts' opinions were in agreement, the reference data categorization may be incorrect. Because of this issue, our estimate of the land use map for 2002 and 2012 may not match the real accuracy. Furthermore, we resampled the land use maps of 2002 and 2015 from 3 m to 2 m and from 30 m to 3 m, respectively, in order to evaluate the change accuracy from 2002 to 2012 and from 2002 to 2012. Additionally, these resamples may produce errors in the evaluation of change accuracy.

6. Conclusion

In this work, we analyzed the growth of rural settlements in Kinigi sector between 2002 and 2012 using sentinel 2 images. We also looked at the corresponding occupation of rural settlements on arable land, particularly those of good quality. Using the IHC, we were able to determine that, between 2002 and 2012, the majority of the rural settlement expansion took place on high-quality arable land, however between 2002 and 2012, less high-quality arable land was inhabited. On the other hand, during the latter time, arable land of medium and poor grade began to be inhabited more often. Over the course of the 20 years under study, the pace of rural settlement expansion in Kinigi sector was kept at 49.86%, and the ensuing loss of arable land is significant. Because occupying high-quality arable land was linked to cheaper construction costs and easier access to transportation, these locations have seen a significant amount of occupation throughout the growth of rural settlements. However, such occupancy can be curbed to some degree by strict land management protocols and adequate protective measures. But this calls for the right policies. In addition, the government should review and approve development plans for all new housing sites in rural areas, forbid the construction of new homes on high-quality arable land, and incorporate the results of the arable land quality assessment into the township land use planning system. On the one hand, the government should implement controls for the expansion of rural settlements and direct the development of new rural settlements.

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