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The Impact of Urban Areas Expansion on Agricultural Land Reduction from 2010 to 2022. A Case Study of Gahanga Sector, Kigali, Rwanda

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ABSTRACT
Rwanda has experienced rapid urbanization and urban sprawl in recent decades as its economy has grown and population has increased. This urban expansion has put immense pressure on the country's limited agricultural lands. This study aims to quantify the loss of agricultural land due to the encroachment of urban areas across Rwanda in Gahanga sector between 2010-2022. To achieve this aim, Documentary review and geospatial data and remote sensing satellite images, including Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) were used to classify the land use and land cover of the study area subdivided into 2010, 2016 to 2022
The result of the study indicated that built-up has grown at an estimated rate of 7.82 % in 2016 to 58.67% in 2022 and the cropland area witnessed a decline of 41.36% of Gahanga's land in only 12 years (2010 to 2022) this covers 1525.51Ha of Gahanga's total land mostly due to a tremendous augmentation in urban area. There is a definite correlation between the decrease in agricultural land and urban growth. Basing on the results of this study, there is actual urge to improve the land management knowledge and skills of the city planners to balance the increasing land demand and the loss of agricultural land.Further study be done on the ongoing monitoring and evaluation of the effects of LULC Changes on agricultural land reduction as well as the ecosystems.

Keywords: urbanization, agricultural land loss, land use/land cover change, remote sensing and GIS, Rwanda.

I. INTRODUCTION

As more people move from rural to urban areas, the world's population is becoming increasingly urbanized. Better living circumstances with developed infrastructures, employment prospects, and other opportunities are thought to be provided by towns (Cohen, B., 2006).Agriculture is a way of life that offers many communities economic benefits such as jobs, and scenic views, but the growing urbanization of the world poses a constant danger to the farming population's means of subsistence and the benefits of social amenities (Brinkley, C., 2012)

Globally, the level of urbanization is expected to rise to 67% in 2050 (Angel, S., Parent, J., Civco, D. L., Blei, A., & Potere, D, 2011). In the less developed regions, the proportion of the urban area population is expected to rise from 47% in 2011 to 64% in 2050 (Huang, K., Li, X., Liu, X., & Seto, K. C., 2019). And the impact of urban growth on agricultural land use has spread throughout the world and resulting depletion of resources, particularly agricultural lands surrounding cities (Huang, Q., Liu, Z., He, C., Gou, S., Bai, Y., Wang, Y., & Shen, M. , 2020)

It is projected that by 2050, there will be 1.2 billion urban residents in Africa alone, up from 414 million in 2011 (Vućković, M., & Adams, A. M, 2022). Sub-Saharan Africa's urbanization is changing traditional livelihood patterns and, in many cases, displacing agricultural land uses (Bonye, S. Z., Aasoglenang, T. A., & Yiridomoh, G. Y. , 2020). Since land is fixed in nature, it is believed that the rate of population expansion in both rural and urban places is not correlated with the available land especially for agriculture activities. The suburbs, which surround larger cities, are impacted by their expansion because it changes the natural resource base and puts vegetated land cover to new uses, which poses challenges to the land for agricultural and agricultural production in general (Javaid, K., Ghafoor, G. Z., Sharif, F., Shahid, M. G., Shahzad, L., Ghafoor, N., ... & Farhan, M., 2023). The uncontrolled urbanization is one of detrimental

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factors of food insecurity in Africa and governments' inefficient and reactive land-use planning policies and systems, which have aggravated the situation (van Berkum, S, 2023). Many African nations, including Ghana, Nigeria, South Africa, and Sudan, have observed that unplanned and uncontrolled urbanization is causing a large portion of the peri-urban viable agricultural lands to disappear (Carmody, P. R., Murphy, J. T., Grant, R., & Owusu, F. Y., 2023).

Like the rest of the world, East Africa is not an exception to these dynamics, the scientific investigation of consequences of land use/land cover change (LULCC) on vegetation and agriculture production the high rates of expected cropland conversion to urban is 28 and 34% in 2030 (Assede, E. S., Orou, H., Biaou, S. S., Geldenhuys, C. J., Ahononga, F. C., & Chirwa, P. W, 2023). This requires an interdisciplinary approach integrating both natural and social scientific methods, which has emerged as the new discipline of land change science The sustainability and livelihood systems of people are under risk due to the constant changes in land use and cover (LULC) across many ecosystems (Kgaphola, M. J., Ramoelo, A., Odindi, J., Mwenge Kahinda, J. M., Seetal, A., & Musvoto, C, 2023). Land is a critical resource for the livelihood of East Africans and there has been a steady decline in the size of land holdings per household (Boubacar, I., & Nene, G, 2024). East Africa's Forest cover declined by roughly 1% year between 1990 and 2015, compared to an average 2% annual rise in the human population. Tropical rain forests, tropical dry forests, tropical shrubs, tropical montane forests, and mangrove forests are the primary forest types in East Africa that have seen this decline, despite deliberate efforts to create plantation (Gbadegesin, A., Adesina, F., Orimoogunje, O., & Oderinde, F. , 2023).

Kigali, one of Africa's fastest-growing cities today, has experienced a phenomenal rate of urbanization, with residents now occupying agricultural and forest areas on the outskirts of the city (NSANGABANDI, E., & MUPENZI, C., 2020). Over the past few decades, Rwanda, particularly Kigali, have seen a rapid urban transition that has impacted LULC generally and resulted in notable changes in the country's demographic makeup and large-scale urban landscape expansion. About 11.37 million people were predicted to live in Rwanda in 2015, with 28.81% of them residing in urban areas. About 17 million people are predicted to live there by 2030, with 41.55% of them residing in cities(Li, C., Yang, M., Li, Z., & Wang, B., 2021). Over 25 million people are expected to live there by 2050, with 52 percent of them expected to reside in cities. The government has included urbanization goals in both short- and long-term strategies, but it has also given the agricultural Sector top priority in its development strategy(Simkin, R. D., Seto, K. C., McDonald, R. I., & Jetz, W. , 2022). As a result, the land cover and land use have changed due to urbanization, which has impacted agricultural output both directly and indirectly (Liu, B., Pan, L., Qi, Y., Guan, X., & Li, J, 2021).

This study intended to assess the impact of urban areas expansion on agricultural land reduction in Gahanga Sector over 12 years (2010-2022). Byinvestigating the expansion of urban area in Gahanga Sector, by investigating the agricultural land reduction in Gahanga Sector

and finally, to determine the relationship between urban expansion area and agricultural land reduction in Gahanga Sector.

II. MATERIAL AND METHODOLOGY

2.1 Description of the study area

The study focused on Gahanga Sector which is among 10 Sectors of Kicukiro District in Rwanda. Recently the population census of Gahanga in 2022 has shown 79,082 population with the total area of 36.77 km². Gahanga has an elevation of 1558 metres above the sea level. Its geographical location is at latitude of -2.0 2285 and the longitude of 30.10405 with the GPS coordinates of $02^0$01'22.26" S and $30^0$06'14.58" E. Gahanga Sector share its boundaries with Mageragere of Nyaarugenge district, Gatenga, Kagarama, Kanombe Sectors of Kicukiro district and Ntarama,Kanzeze and Mwogo Sectors of Bugesera district, Gahanga is located in the southern part of Kicukiro District with 6 cells which are Nunga, Gahanga, Kagasa, Murinja, Rwabutenge and Karembure. According to the population census of August 2012 the population of Gahanga Sector was estimated to be 27,808 people with population density of 756 people per km^2 and about 79,082 people according to 15 August 2022 census with the population density of 2,151 people/km^2,which shows an 11% annual change in population from 2012 to 2022.

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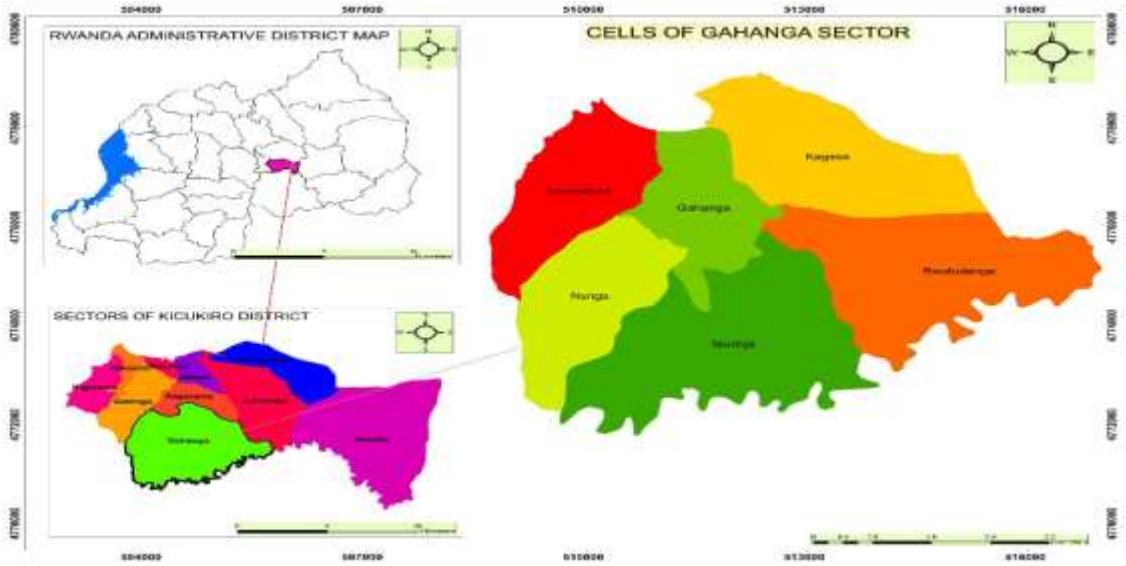

Figure 1: Map showing the location of Gahanga Sector, Kicukiro district
Source: Author's mapping in ArcGIS 10.8

2.2 Research design and data collection

We performed a critical evaluation of the literature for this study in attempt to build a theoretical framework for better comprehension and tracking the current research gap that was filled by the findings. This research consisted of using secondary data related built-up, cropland, grassland, forestland, wetland, and water body. To classify the land use and land cover of the study area subdivided into 2010, 2016 to 2022, the data were collected from geospatial data and remote sensing satellite images, including Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI). After we analyzed those data by using Geographic Information System (GIS) to produce maps of LU/LC changes.

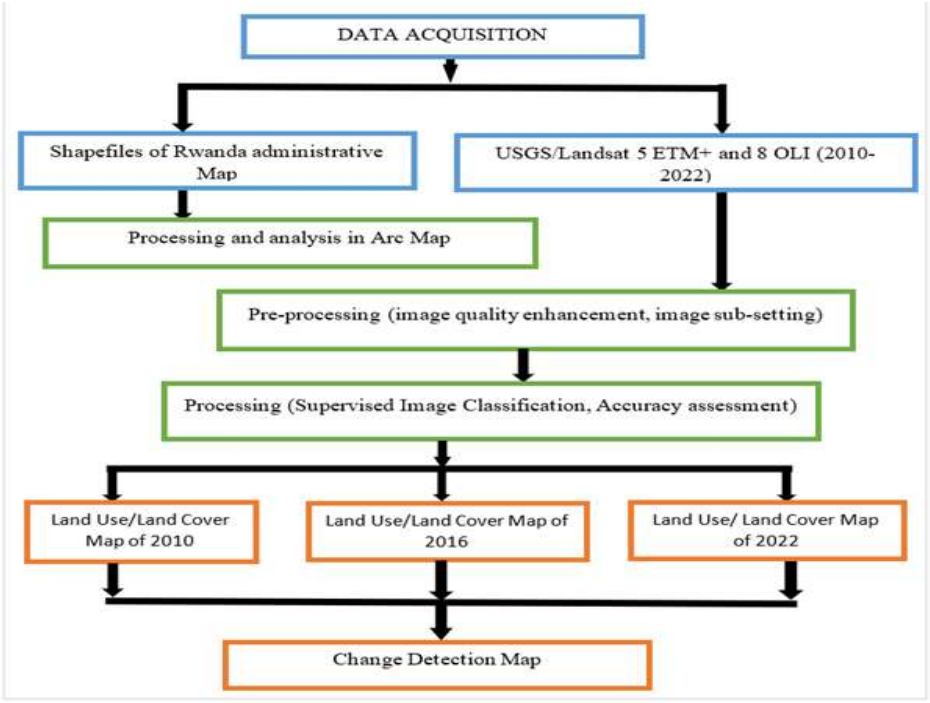

Figure 2: Flowchart of Data processing and analysis

Source: Author, 2024

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The collected data processed and analyzed through spatial analysis using ArcGIS software; the processed data exported to ArcGIS for digitizing, image classification, spatial analysis and visualization. The main analysis was done based on manual digitizing, supervised and unsupervised classifications.

In the process of unsupervised classification, to get a better result, 10 initial sub-classes were set and name with code given like urban area_1 and cropland_2. As a general rule, the number of initial classes should be at least twice larger than the number of final classes, and the adjustment was easier as the number of classes is enough. When the adjustment was completed, there were different kinds of sub classes. In the process of supervised classification, during the process of the selection of training areas, the Google Earth and land use map of unsupervised classification was used as guiding maps. Each sub class had its own name with code like agricultural land_1 and Urban area_2.

Image classification was used in classifying land cover change regarding the period of time in Gahanga Sector. The purpose of Image classification was to extract information classes from a raster image by creating the signature and digitizes a portion which had to be classified and then after each land cover had a corresponding class. The resulting raster from image classification was used to create classified maps. The supervised classification was used by selecting representative samples for each land cover class in the digital image. These sample classes called "training sites". The image classification software uses the training sites to identify the land cover classes in the entire image. The classification of land cover was based on the spectral signature defined in the training set. The digital image classification software determines each class on what it resembles most in the training site. The common supervised classification algorithms to be used in this study was the maximum likelihood classification. In this research each of the land use and land cover map was compared to the reference. The reference was prepared by considering random sample points, the field knowledge and google earth image.

III. RESULTS AND DISCUSSIONS

3.1 LULC changes in Gahanga sector 2010-2022

The magnitude of changes within the bounds of the Gahanga is succinctly and quantitatively summarized in Table 1 making it easy to comprehend the size and spatial distribution of LULC transformations especially for urban agricultural land.

LULC Classes	2010		2016		2022	
	Area in ha	%	Area in ha	%	Area in ha	%
Forest	658.8	17.8	310.05	8.4	389.3	10.6
Grassland	53.82	1.48	105.3	2.8	166.54	4.5
Cropland	**2427.93**	**65.87**	**2437.56**	**66.1**	**902.42**	**24.4**
Built –up	**0.45**	**0.012**	**288.27**	**7.8**	**2164.58**	**58.7**
Wetland	496.89	13.5	495.99	13.5	0.07	0.002
Waterbodies	47.79	1.3	48.51	1.3	62.77	1.7

Table 1: LULC changes in Gahanga sector for urban and agricultural area depiction 2010-2022

Finally, the evolution of LULC in Gahanga sector from 2010 to 2022 illustrates a notable shift from agricultural areas to urban development. Initially dominated by agricultural activities, the sector has experienced a significant transformation as urban areas have expanded, encroaching upon former agricultural lands. The transition towards urbanization has led to a reduction in agricultural areas, particularly croplands, in favor of the growth of built-up areas. This transformation underscores the changing landscape dynamics within the sector, highlighting the trade-off between agricultural sustainability and urban development.

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3.2 Spatial and Temporal LULC change of Gahanga sector for urban areas and agricultural areas extent analysis (2010 – 2016 – 2022)

The supervised image classification for Gahanga sector produced maps for LULC of the area to analyze the urbanization extent.

The change detection map uses color coded system to distinguish between different land cover types making it possible to clearly depict the extent and geographical distribution of changes that have occurred. Urbanization has changed at a high rate over time. An analysis of the LULC maps reveals a significant expansion of urban areas over the 12 years period from 2010 to 2022. Urban expansion occurred in virtually all directions, consuming sizeable areas of what had been agricultural fields, forests, and open spaces just a decade prior. The rapid and expansive urban growth over this timeframe likely placed significant pressure on the region's limited land resources.

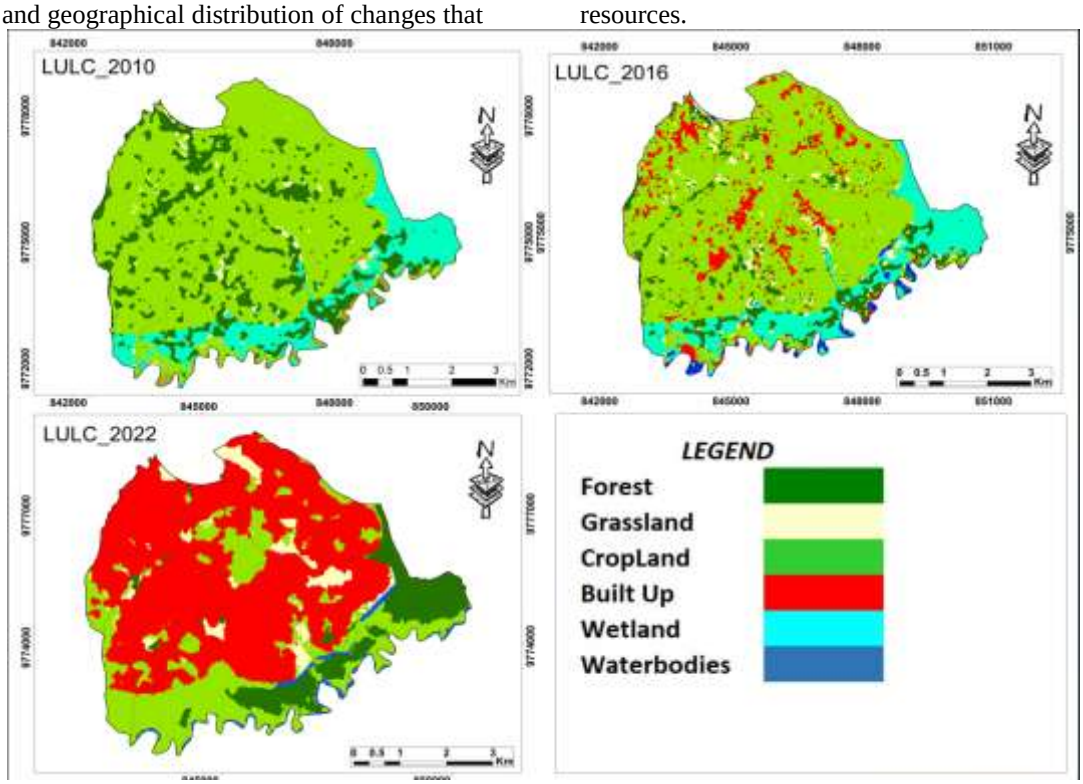

Figure III: LULC map of Gahanga 2010, 2016 and 2022 for urban areas and agricultural areas analysis.

3.3 Relationship between urban area expansion and agricultural land reduction in Gahanga Sector (2010 – 2022)

3.3.1 LULC types and their changes in area in Gahanga sector (2010 to 2022)

Generally, the LULC types in the study period gradually changed with differing rates depending on the existing socio-economic, political, and environmental situation. Based on the LULC data for Gahanga sector, a clear relationship between urban area expansion and agricultural land reduction from 2010 to 2022 has been remarkable (Figure 4). In 2010, the LULC data shows that agricultural land was the dominant land cover type, occupying a vast area of 2,427.93 ha. This highlights the sector's strong agricultural base and dependence on farming activities during that period. Conversely, the urban area was minimal, covering only 0.45 ha, indicating a predominantly rural character. However, the situation changed significantly by 2022. The urban area experienced a remarkable surge, expanding to 2,164.58 ha, an increase of over 4,800 times compared to 2010. This dramatic urban growth can be attributed to various factors, such as population growth, economic development, and urbanization trends in the area. Concurrently, the agricultural land area experienced a substantial reduction, decreasing from 2,427.93 ha in 2010 to 902.42 ha in 2022, a decline of approximately 63%. Thus, the inverse relationship between urban area expansion and agricultural land reduction is evident from the data. As the urban area expanded rapidly, it encroached upon and replaced a significant portion of the agricultural land. It is important to note that the LULC changes also affected other land cover types.

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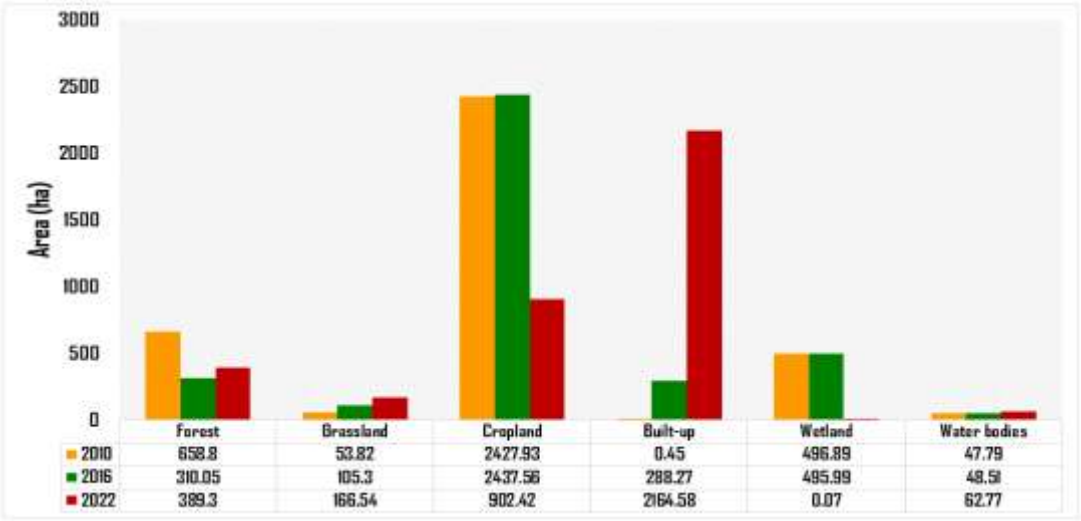
Volume 7, Issue 04 April 2025, pp: 540-548 www.ijaem.net ISSN: 2395-5252

The forest area decreased from 658.8 ha in 2010 to 389.3 ha in 2022, which could be attributed to deforestation or conversion of forested areas into urban or agricultural land. Additionally, the grassland area increased from 53.82 ha to 166.54 ha, possibly due to the conversion of agricultural or forested areas into grasslands or the establishment of recreational spaces within the urban landscape.



	Forest	Grassland	Cropland	Built-up	Wetland	Water bodies
2010	658.8	53.82	2427.93	0.45	496.89	47.79
2016	310.05	105.3	2437.56	288.27	495.99	48.51
2022	389.3	166.54	902.42	2164.58	0.07	62.77

Figure 4: LULC types and their changes in area in Gahanga sector (2010 to 2022)

3.3.2 Gain and losses (in surface area) explaining the relationship between urban area expansion and agricultural land reduction in Gahanga sector (2010 to 2022)

The calculated losses and gains (Figure 5) offer valuable insights into the relationship between urban area expansion and agricultural land reduction in Gahanga sector during the study period. The gain of 2,164.13 ha of urban land and the corresponding loss of 1,525.51 ha of cropland highlight the direct trade-off between urbanization and agricultural land preservation. As cities and towns expand to accommodate growing populations and economic activities, they often encroach upon and consume surrounding agricultural lands. This phenomenon is driven by the increasing demand for housing, commercial spaces, industrial areas, and supporting infrastructure within urban centers. The conversion of fertile agricultural lands into built-up areas is a common pattern observed in many rapidly urbanizing regions worldwide. The loss of agricultural land can have far-reaching consequences for the local and regional food systems. Reduced cropland availability can lead to a decline in agricultural productivity, potentially impacting food security, rural livelihoods, and the overall agricultural economy. Farmers may be forced to abandon their lands or seek alternative livelihood opportunities, contributing to rural-urban migration. Moreover, the loss of 496.82 hectares of wetlands further exacerbates the environmental impacts associated with urban expansion and agricultural land reduction. Wetlands play crucial roles in water purification, flood control, and supporting biodiversity, and their loss can disrupt these vital ecological functions.

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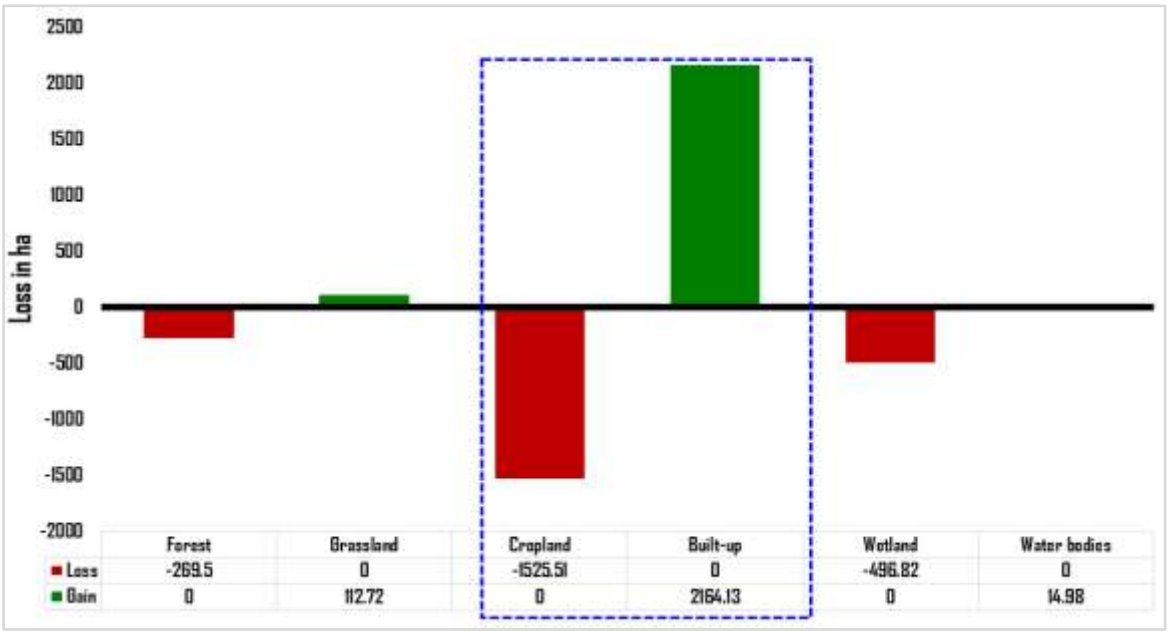

Figure 5: Gain and losses (in surface area) explaining the relationship between urban area expansion and agricultural land reduction in Gahanga sector (2010 to 2022)

3.3.3 Urban areas vs Agricultural land relationship in Gahanga sector (2010 to 2022)

It is evident that the rapid urban area expansion in Gahanga sector has come at the cost of substantial agricultural land reduction (Figure 6), as well as the loss of other valuable natural resources like forests and wetlands. This trade-off highlights the need for sustainable urban planning and policies that balance economic development, population growth, and the preservation of agricultural lands and natural ecosystems. Ultimately, achieving a harmonious balance between urban development and agricultural land preservation requires a multifaceted approach that considers environmental, economic, and social factors, ensuring sustainable and resilient communities for the future.

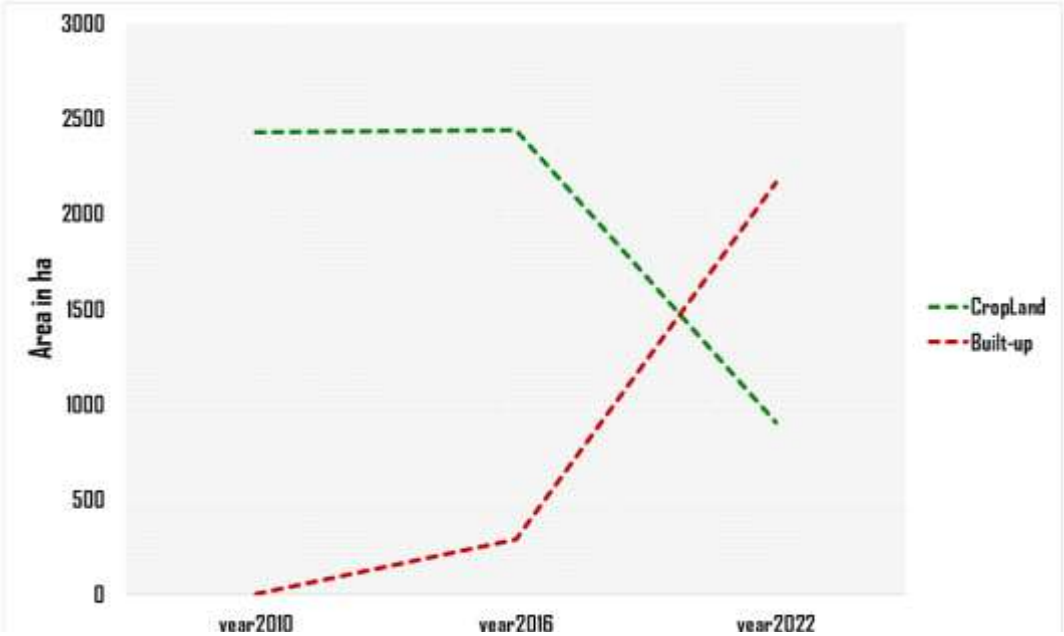

Figure 6: Urban areas vs Agricultural land relationship in Gahanga sector (2010 to 2022)

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 04 April 2025, pp: 540-548 www.ijaem.net ISSN: 2395-5252

IV. CONCLUSION

Remotely sensed data and GIS techniques were used toaccess theimpact of urban areas expansion on agricultural land reduction in Gahanga sector**.** This study shows that the LULC Changes has negative impacts on cultivated land reduction and directly and indirectly affects the agriculture production. There has been rapid conversion of cultivated land used for farming or agriculture to nonagricultural use; spatial expansion has occurred all over Gahanga Sector. The study has revealed that the study area has lost some 41.36% that covers 1525.51Ha of total land of cultivated land of Gahanga Sector to urbanization (Built-up) between 2010 and 2022. At the same time built-up has gain some 58.671 % that covers 2162.42 Ha of total land of Gahanga Sector. And it is observed that wetland land area has greatly reduced within these 12 years, wetland has lost its 13.44% of land that covers 496.82Ha due to different factors such agriculture, livestock farming, pottery…that are taking place in wetland. This result into a big challenge because urban expansion consumes agricultural land, farm lands become smaller and smaller. Consequently, farm lands cannot produce enough food hence the yield is for home consumption not providing for the market. According to the major findings of the study, which was obtained from the changes of 2010 and 2022 High Resolution images and maps shows that the extent of urban expansion over all land uses has lost over agricultural land only within 12 years of interval. This demonstrates that, the pace of urban expansion has accelerated. Generally speaking, more agricultural land is lost when cities expand more quickly. Reasonably the following mechanisms are recommended:

- To improve the land management knowledge and skills of the city planners to balance the increasing land demand and the loss of agricultural land.
- City residents should be encouraged to shift from horizontal to vertical buildings so that cultivated land is not lost in search of land for settlements.
- Agriculture practices should be modernized so that agricultural production is not affected by land use change. To boost agricultural production, we should adapt the practice of modernize the agricultural by introducing different techniques such as irrigation monoculture, use of improved and selected seeds, use of fertilizers, pesticides… so that the food production is not reduced due to the reduction of land for agriculture.
- It is advised that further study be done on the ongoing monitoring and evaluation of the effects of LULC Changes on agricultural land reduction as well as the ecosystems.

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