Rwanda Journal of Engineering, Science, Technology and Environment, Volume 5, Issue I, June 2023 / eISSN: 2617-233X | print ISSN: 2617-2321

Spatial Assessment of Urban Growth on Green Spaces in Rwanda: An insight from Rebero Mountain Landscape in Kicukiro District, City of Kigali

Alphonse Rodrigue Nshimiyimana[1], Eric Niyigena[1], Elias Nyandwi[2], Hyacinthe Ngwijabagabo[1], and Gilbert Rugengamanzi[3]

[1] Department of Spatial Planning, School of Architecture and Built Environment, College of Science and Technology, University of Rwanda, P.O. Box 3900 Kigali, Rwanda
[2] Centre for Geographic Information Systems and Remote Sensing (CGIS), College of Science and Technology, P.O. Box 3900, Kigali– Rwanda
[3] National Land Authority (NLA), P.O. Box 433, Kigali, Rwanda

***Corresponding Author: nshimiyealpha73@gmail.com**

Abstract

Green space is a crucial component of sustainable urban development that provides urban dwellers with several environmental and social benefits. This study investigates the impact of urban growth on green space management on hilly landscape using a case study of Rebero Mountain in Kicukiro District, Kigali City. The study used medium resolution satellite imagery (Landsat for 2000, 2010, and 2021) and high-resolution imagery (Quick Bird 2010 and Worldview 2 images of 2015) to assess Land Uses Land Covers (LULC) dynamics. To investigate the local community's perception on the effects of urban growth on green space, interviews were conducted. The LULC changes detection revealed a significant decrease in green space with an increase in the built-up areas. The urbanized area has been increasing from 7,422.10 Ha up to 14,730.94 Ha during the last two decades. The increasing built-up area was in parallel with reduction of green space, specifically 44 Ha (-6.7%) of urban forest and 255 Ha (-26.2%) of agricultural land, for the period between 2000 and 2021. The reduction of green cover had a negative impact on the environment, such as soil erosion and biodiversity loss. In order to support decision-makers in fostering the development of sustainable and green smart cities, a spatially explicit assessment of the availability, management, and accessibility of urban green areas is also important. Based on this research findings, the restoration of green spaces, including the need for land-use and land-cover change monitoring, practical government physical planning interventions, and an inclusive strategy for managing the city's green spaces that involves NGOs and citizens, and advocates for green city development are strongly recommended.

Keywords: Urban growth, Green space, Land use land cover dynamic, Change detection

https://dx.doi.org/10.4314/rjeste.v5i1.5

1. Introduction

Globally, human beings and nature are two inseparable components, and the linkage between them is fragilized by urban growth and development, which have increased over recent decades (Ward Thompson et al., 2016;Aram et al., 2019; Badiu et al., 2019). Unfortunately, more people are found to live in less urban green space environments due to the high level of urbanization and the spatial planning policy of densification in the twenty-first century (Wilson et al., 2011;Ritchie et al., 2018).The estimation in the United Nations-World Urbanization Prospects report of 2018 shows that urban areas are home for 55% of the world's population. In Africa, due to the high demand on natural resources brought on by rapid urbanization and population growth, many green areas, including parks, gardens, allotments, wetlands, and urban trees have degraded or faded away (Mensah, 2014;Kometa et al., 2018). The quality and quantity of green space will continue to decline as a result of the high and unexpected growth of urban areas in the developing world (Seburanga et al., 2014;Nor et al., 2017).

Green spaces is an important part of complex urban ecosystems that give environmental, aesthetic, recreational and economic benefits to the urban dwellers (Seburanga et al., 2014). It is considered to be any public outdoor space that offers amenities that provide social, health, environmental, and/or economic benefits to the community. Green spaces has been reduced based on time evolution, hence the urban growth is now considered as a major driving force of biodiversity loss (Seburanga et al., 2014).As most of people have knowledge about nature as an environment where they can rest and help them to overcome from daily stress. In fact, the society we live in we must plant trees or grass as sources of relaxation and recreation (Maas et al., 2006). In few words, Green space can be considered as vegetated land or water within or connecting an urban area which comprises natural green spaces, semi-natural habitats, green corridors, parks and gardens, playing fields, and vacant land. Green spaces are also the land uses covered by natural or man-made vegetation in constructed areas (Habimana, 2014). Those vegetation has been planted for the purpose of rising positively impacts human wellbeing (Taylor & Hochuli, 2017). During the last four decades, the urban growth in Rwanda has resulted to the decline of green space due to conversion of land use especially for accommodating the increased number of urban dwellers population. This can be shown by increase in urbanization rate as it was estimated

https://dx.doi.org/10.4314/rjeste.v5i1.5

to be 9.8% in two decades ago and increased to 17.43% by 2020. It is projected to be 35% by 2035(UNDESA, 2018). The increased urbanization result to reduction of green space as it is estimated that in 2010 the city of Kigali has 2550 Ha of natural vegetation as it lost more than 6.46 Ha of its natural forest due to increased demand of land surface to be used for other purpose including settlement and infrastructure development. This implies that green space surface has been reducing consistently with the urban growth (Seburanga et al., 2014).

In fact, a sustainable development perspective places a strong emphasis on the importance of green space, since it is regarded as one of the most crucial tools for enhancing urban sustainability. The linear components of networks known as "green ways" are programmed, planned, and managed for a variety of objectives that are consistent with the idea of a sustainable city, including ecological, recreational, cultural, aesthetically pleasing, and other factors (Karade, 2013). The Rwandan government has detailed and implemented a series of urbanization plans, policies, and regulations to orient Kigali's growth toward a sustainable green and climate resilient city in an effort to address the impacts of urban growth on the protection and management of green spaces (Manirakiza, 2012). Although earlier studies evaluated the temporal changes in urban land use in general, the specific assessment of temporal variations built-up areas with informal settlements has induced the reduction of green spaces and other important complexes of urban ecosystems (Mugiraneza, Ban and Haas, 2019). In urban green space quantity, quality, and accessibility dynamics are still missing in those studies.

Likewise, the government of Rwanda recognizes the importance of green spaces in promoting environmental sustainability, social wellbeing, and economic development, and has made significant efforts to incorporate green spaces into urban planning and development processes. In Kigali, the capital city of Rwanda, the government has developed a comprehensive urban greening program aimed at promoting the creation and maintenance of green spaces throughout the city. This program includes initiatives such as the planting of trees and shrubs along streets and in public spaces, the creation of community gardens and parks, and the development of green corridors linking different parts of the city (City of Kigali, 2021). In addition to these initiatives, the government of Rwanda established the legal frameworks to support the incorporation of green spaces into urban development. The Rwanda Environment Management

https://dx.doi.org/10.4314/rjeste.v5i1.5

Authority (REMA) has developed guidelines for environmental impact assessments (EIAs) for development projects, which include requirements for the preservation and enhancement of green spaces (REMA, 2017). To measure the extent of green spaces in urban areas in Rwanda, the government has developed a green space index (GSI) that calculates the proportion of green space within a given area of urban land. In 2020, the GSI for Kigali was 25%, reflecting the city's efforts to increase the share of green spaces in urban development (City of Kigali, 2020).

Overall, the government of Rwanda's efforts to incorporate green spaces into urban planning and development demonstrate a strong commitment to promoting sustainable, healthy, and liveable cities. Through initiatives such as the urban greening program and the development of legal frameworks and indices to support green space preservation and enhancement, Rwanda has been a model for other countries in the region in promoting sustainable urban development. With the considerable urban growth of Kigali leading to the decrease in the green spaces, this study aimed at contributing to the analysis of the spatio-temporal assessment of those spaces in Kigali city, using Rebero mountain landscape, in Kicukiro district. The study also sought to investigate the dynamics of urban growth and its impacts on green space management. Furthermore, this study approach can be applied in guiding decision-makers on the proper management of green space prior to the rapid development of Kigali city, as well as in its satellite and secondary cities.

2. Materials and Methods

2.1 Rebero Mountain Landscape Description

This study was conducted in the Kigali city on Mount Rebero landscape, in Kicukiro District. Geographically the city of Kigali is located in the Centre of the country as it lies within a latitude of 1º 57’S and on longitude 30º 04’ E. Demographically, Kigali is presently inhabited by approximately 1.2 million inhabitants. The lowest part of Kigali city is roughly 1330 m above mean sea level, and the highest hills are over 2070 m above mean sea level, with the slope of hills varying in steepness between 45 and 50 percentage rises, while the slope for valleys and wetland areas varies on inclines up to 2%. Generally, Kigali city experiences a temperate climate with two rainy periods, with the average temperature of 21° and average rainfall of 1,028 mm per year. Rebero Mountain is located in two districts of Kigali, namely Nyarugenge and Kicukiro, specifically in four sectors: Gikondo, Mageragere, Kigarama, and Gatenga, and has a surface

https://dx.doi.org/10.4314/rjeste.v5i1.5

area of 9.84 square kilometres based on its delineated boundaries. The study area (Fig.1) was once occupied by dense forest, but due to urban growth, it was degraded, cleared, and changed into settlement. The main activities that are practiced on land surface are agriculture, settlement, commercial, leisure activity, and tourism.

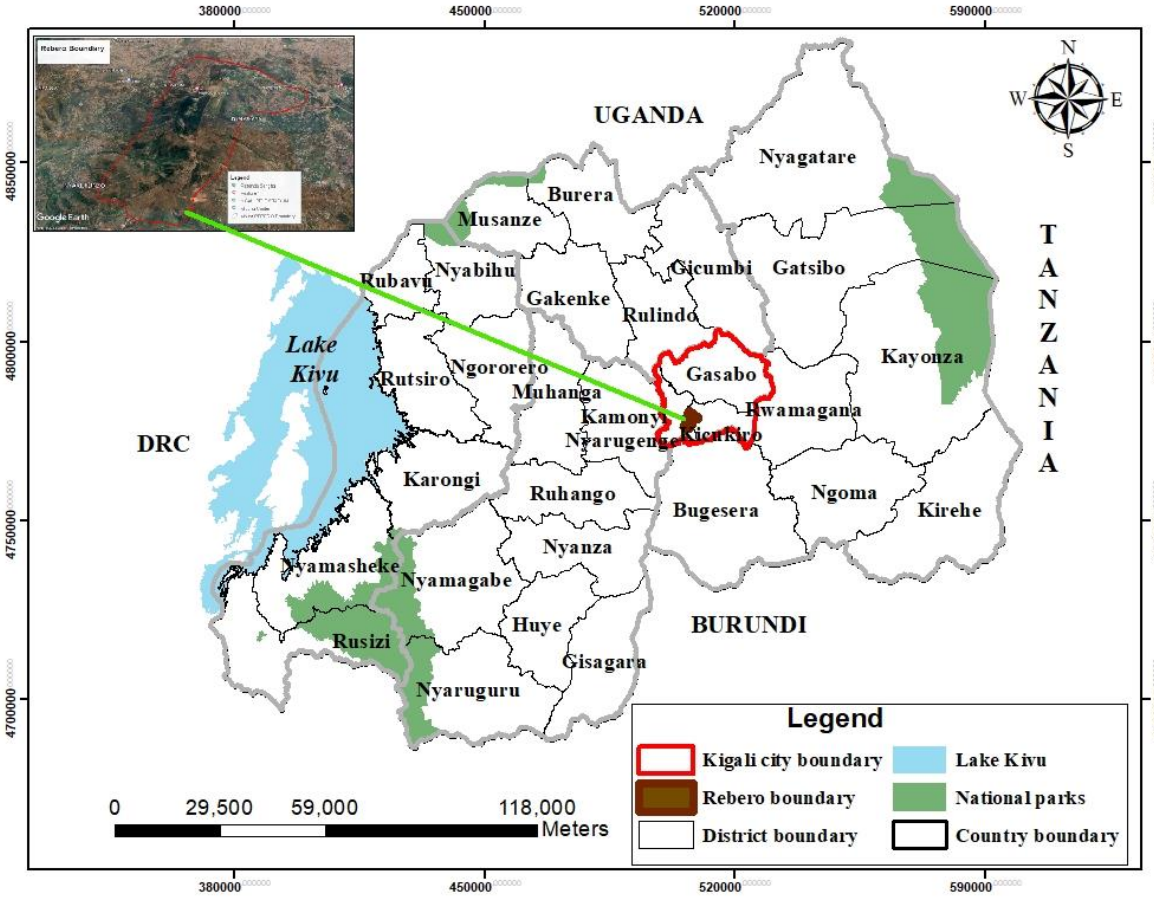

Figure1: Geographical Localisation of Study Area

2.2 Research Data Collection

Both secondary and primary data were collected and analysed in this study. The review of previous studies (books, scientific journal articles, and government reports) that are available from trustworthy sources and relevant to the study were considered for introducing urban growth and green space concepts, and supporting the results discussion.

https://dx.doi.org/10.4314/rjeste.v5i1.5

Face-to-face interviews were used to collect primary data for this research, based on this the cluster area and purposive sampling has been applied in order to select the respondents. Indeed, we group a study area into four clusters as it touches on four different sectors and each cluster stand for part of study area that touch on mentioned sector boundary and we select the interviewee to be interviewed based on the purpose and objectives of the research. With 10 people interviewed, two are local natives who live in the study area currently, six are local people who settled in the study area before 2013, and the two remaining interviewees are sector leaders in charge of agroforestry and land management. Additionally, field observations of existing land use types and anthropic activities was important for calibrating satellite imagery classification and characterizing different types of green space.

In order to perform the spatial-temporal dynamic of urban growth in Kigali city and to categorize the primary types of green space in the study region, high to medium resolution and freely accessible Landsat images were used. The satellite images used are multi-temporal Landsat 8 from Operational Land Imager (OLI) sensor, Landsat7 from Thematic mapper (TM) sensor, Landsat legacy ETM+ (1999-2003) the selected sentinel image were for 2000, 2010 and 2021 years. The satellite images selected were the ones captured from cloud free environment in late dry seasons (of July and August) for preparation of LULC and classifying different types of green space in study area. For pre-processing activity, the downloaded images were mosaicked and geo-referenced using coordinate system of WGS 1984 UTM ZONE 30N with Datum of WGS 1984 and unit stretched in meter. The subset of satellite images (2000, 2010, and 2021) on specific area of interest was performed in order to make multi-scale classifications.

2.3 Data Processing

The research design highlights the method, tool, and techniques used to assess the spatial temporal dynamics of Kigali city between 2000 and 2021, as well as the classification of the main categories of green space on Mount Rebero's landscape and the analysis of green space dynamic, as summarized in Figure 2 below.

https://dx.doi.org/10.4314/rjeste.v5i1.5

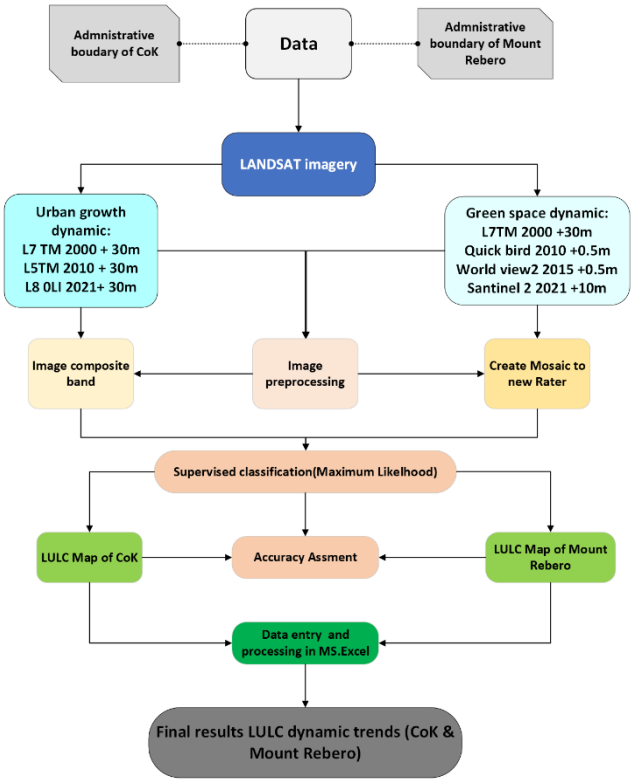

Figure 2: Analysis Framework for Remote Sensed Data (Author, 2021)

To process remote sensed data, spatial tools such as ArcGIS 10.8, Erdas imagine 2014, and ArcGIS Pro 2.8.6 was utilized. To evaluate the accuracy of results of classified image, accuracy assessment was performed. The image classification has been computed at different overall accuracy and kappa coefficient by taking 60 points for each image and overlaid it on high-resolution Google earth image. Below are formulas used to compute accuracy assessment and kappa coefficient?

$$\textbf{Overall accuracy} = \frac{\text{total number of correctly classified pixel(Diagonals)}}{\text{total number of Reference pixels}} \times 100 \quad (1)$$

$$\textbf{Kappa coffiecient} = \frac{Ts \times TCs - \sum(\text{Column total} \times \text{Row total})}{Ts^2 - \sum(\text{column total} - \text{Row total})} \quad (2)$$

$$\textbf{User accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of reference pixels in that category(the Row total)}} \times 100 \quad (3)$$

$$\textbf{Ground truth accuracy} = \frac{\text{Number of corrected classified pixels in each category}}{\text{Total number of reference pixels in that category(the column total)}} \times 100 (4)$$

https://dx.doi.org/10.4314/rjeste.v5i1.5

For raising confidence around results of classified satellite imagery, accuracy assessment and kappa coefficient was calculated.

3. Results and Discussions

3. 1. Spatial-temporal Dynamic of Urban Growth between 2000 and 2021

The LULC analysis (Fig.3) of the existing data indicate that there is such changes in land use land cover trend of Kigali city resulting to high growth of city`s Built-up area in last 21years.

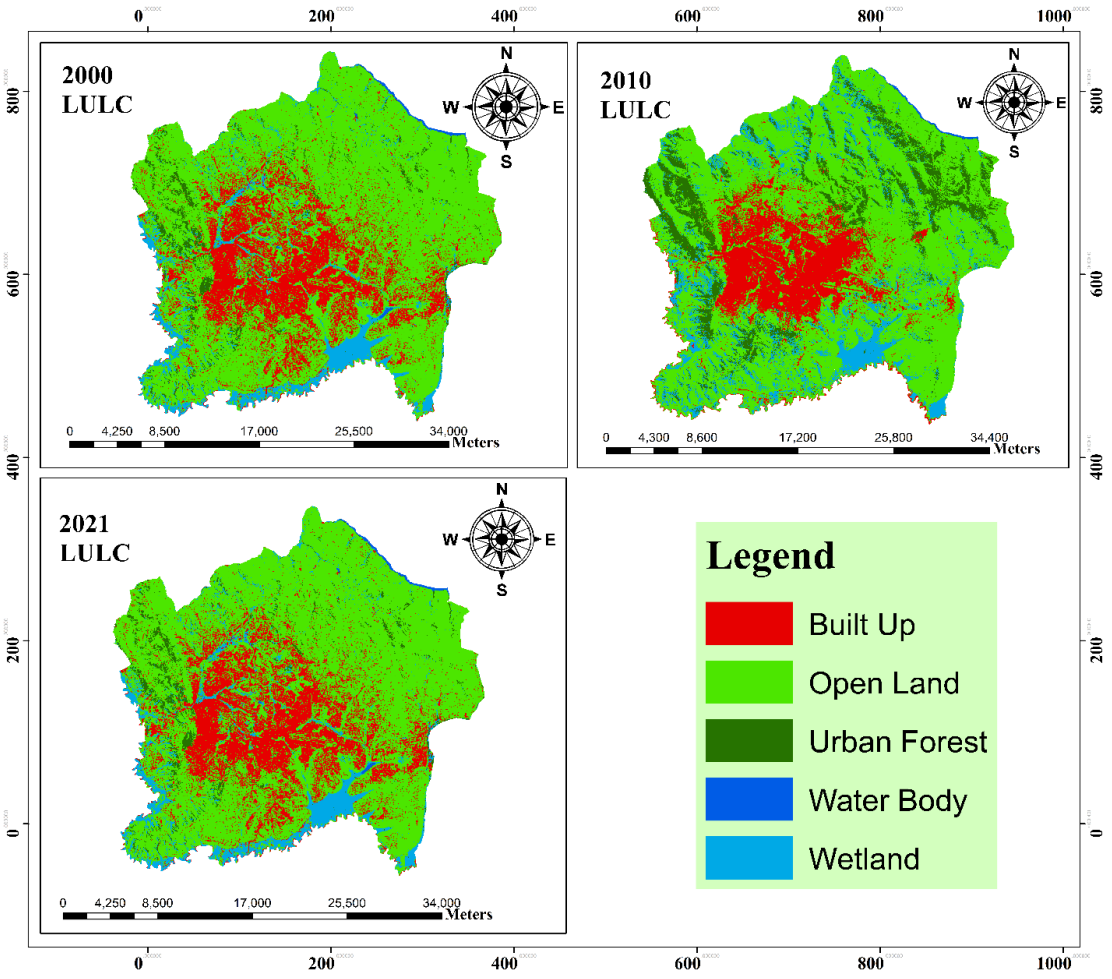

Figure 3: The city of Kigali Land Use and Land Cover Dynamics in 2000, 2010 and 2020 (USGS, 2021)

https://dx.doi.org/10.4314/rjeste.v5i1.5

The result in Fig.3 demonstrated that the rate of urban growth increased at a rapid pace regarding the surface area of built-up class, referring to the obtained results after classification, the city of Kigali has expanded rapidly from 7,422.10 ha (10.2%) up to 14,730.94 ha (20.2%) from 2000 to 2021. Approximately 7,308 ha (32.99%) of built-up area increased from 2000 to 2021over past 21years. The extent of urban growth between 2000 and 2010 was 3,556.79 ha (19.3%), while for the period of 2010 to 2021, the extent urban growth was 3,572.05ha (14.5%). This indicates that urban expansion was more intense between the periods of 2000 and 2010 than between 2010and 2021. As shown in Fig. 3, the area occupied by built-up areas gradually increased, particularly in the Kicukiro and Nyarugenge districts.

Table 3: Land Cover Change on Extent of Kigali City between 2000 and 2021

N° LULC	**LULC Classes**	**Area of coverage in hectare per Year in Hectares**			**Change in Ha**	**Change in %**
		2000	**2010**	**2021**		
1	Open Land	30787.92	46474.62	50718.79	19930.9(Increase)	24.5
2	Urban Forest	24892.17	8353.80	2312.25	-22579.9(Decrease)	-83.0
3	Wetland	9698.66	7023.20	4974.10	-4724.6(Decrease)	-32.2
4	Built Up	7422.10	10978.89	14730.94	7308.8(Increase)	33.0
5	Water Body	193.02	160.87	253.84	60.8(Increase)	13.6

The increase of residential area had an impact on other land cover classes such as urban forest and wetland. Table 3 shows that urban forests lost 16,538.37 ha (- 49.7%) between 2000 and 2010, and 6041.55 ha (-56.6%) between 2010 and 2021, while wetlands lost 2,675.46 ha (15.9%) between 2000 and 2010, and 2,049.20 ha (-17%) between 2010 and 2021.Nduwayezu, Sliuzas, & Kuffer(2016)discovered an exponentially increasing urban built-up area, highlighting that the area of built-up area has grown significantly and doubled between 1987 and 1999 and has changed gradually until 2014. In complementary with other research including the one

https://dx.doi.org/10.4314/rjeste.v5i1.5

mentioned, our findings highlight the considerable increasing of urban growth from 2000 to 2021.

In fast-growing cities, our research analyzes a variety of patterns of green space change and change sequences. The dynamics of green spaces and how they relate to ecological processes can be better understood by referring to the research findings, which highlight the decline of green space due to urban growth. This tendency might be an indication that cities all around the world especially Kigali city are increasingly focusing on preserving and constructing urban green spaces during development. Despite the value of green space, urbanization and densification are reducing and isolating the structure of green space in our research areas. Although urban green spaces are valued in Kigali and its satellite cities, there is a chance that they will be encroached upon, shrink in size, and become too isolated to sustain their environmental and social effectiveness. These researchers' findings imply that causes contributing to the loss of green space include economic expansion, population growth, urbanization, and a lack of effective urban planning, regulation, and management (Byomkesh, 2012). Even if the specific definitions of "green space" varied between researchers, they are basically the same in the instances above when they relate to vegetated areas within the urban framework. Urban built-up boundaries have been described differently in research over the years. In this type of research, some cities' built-up areas got greener.

In Rwanda, cities have only recently begun to grow, with a current urbanization rate of about 19%. Kigali is where the most of it is concentrated (Gubic & Baloi,2020). By referring to the conviviality pillar of Rwanda's urbanization strategy, this pillar emphasizes efforts to support equity and quality of life in urban settlements and the need to promote urban development at a human scale, focusing on social inclusion and cultural preservation in urban development schemes as well as the provision of adequate recreational areas, quality basic services, and environmentally safe social amenities (Habonimana et *al.*, 2015). This pillar's primary goal is to establish and sustain good relationships between individuals, groups of people, and institutions. It places special emphasis on youth, women, and children that form urban society (Jaganyi et *al*., 2018). Therefore, sustainable urban development and green space management should be connected through urbanization policies in order to strengthen the sustainability and general

https://dx.doi.org/10.4314/rjeste.v5i1.5

development of green cities, with the main aim of solving problems with urban sprawl, inadequate connectedness, specialized urban functions, inadequate distribution of social infrastructure, a lack of socioeconomic diversity, and inadequate connectivity of transport, infrastructure, and ecological networks. These guidelines are intended to safeguard and promote socioeconomic and environmental sustainability when urban growth happens through planned development, improvement, and densification of current and future areas (Michieletto, 2022).

An integral part of sustainable urban development that affects individuals is the design of sustainable cities and neighborhoods (Manirakiza, 2019). The difference in size, density, distance, shape, and spatial arrangement of landscape features between the modeled and observed urban development between 2000 and 2021 is evidence of good spatial planning on rapid urban expansion and green space (Nduwayezu, 2021). Therefore, unchecked urban growth impacts the structure and pattern of urban growth, which affects the fragmentation of green space (Baffoe, 2020). By citing SDG 11, which is dedicated to this goal and calls for “making cities and human settlements inclusive, safe, resilient, and sustainable. A specific provision on public space was incorporated in this (SDG 11.7): "By 2030, ensure that everyone has access to green spaces that are secure, inclusive, and accessible, especially for women, children, the elderly, and people with disabilities. In order to ensure that urban development addresses climate change and fosters safety, inclusivity, and public health, a number of SDG 11 targets and other SDGs are connected to useful, well-planned public spaces (Gubic and Baloi, 2019; Malonza and Ortega, 2020).

3.2. Status of Green Space at Rebero Mountain Landscape between 2000 and 2021

The results for the green space dynamic areassembled through a field observation approach and LULC classification of Mount Rebero’s image. The main categories of green space that is found on Mount Rebero are agricultural land,garden, and urban forests. The agricultural land is mainly characterized by the cultivation of seasonal crops such as cassava, beans, and maize. The Garden as green space category is mainly consisted of both public garden and private garden, road side trees, and round point. The images (Fig.4) below highlight the main categories of green space found on Mount Rebero.

https://dx.doi.org/10.4314/rjeste.v5i1.5

(a) **(b)** **(c)**

Figure 4: Green space categories on Rebero Mountain Landscape (Source:Field work, June 2021)

Spatial variation on land use and land cover trends(Fig.5), show that the urban growth dynamic has resultedin the decline of green space, specifically in thedeveloped neighborhood of Mount Rebero in Kicukiro District.

https://dx.doi.org/10.4314/rjeste.v5i1.5

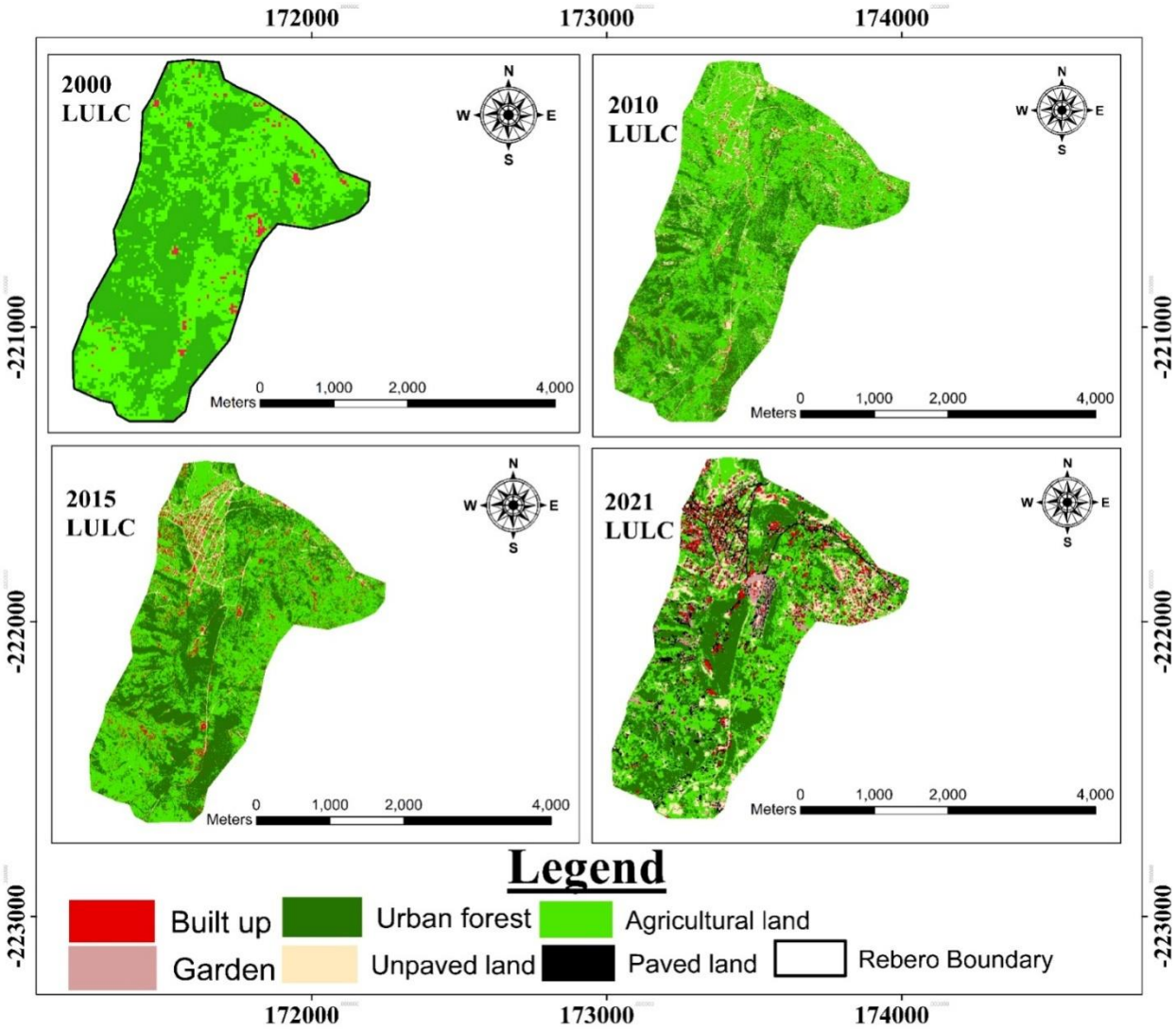

Figure 5: Quantified land use land cover dynamism on Rebero Mountain Landscape in 2000, 2010, 2015 and 2021(USGS, 2021)

The image classification output (Fig. 5) revealed that Mount Rebero is characterized by a decline in green space, particularly forest and agricultural land, with a dramatic increase in built-up area. It is critical to emphasize that the decrease in urban forest and agricultural land between 2000 and 2021 is influenced by an increase in built-up area. In 2000, the built-up area occupied 19 ha (1.9%) and increased to 56ha (7%) in 2021.

https://dx.doi.org/10.4314/rjeste.v5i1.5

Table 4: Land cover change on extent of Rebero Mountain between 2000 and 2021

N° LULC	**LULC Classes**	**Area of coverage in hectare per Year in hectares**				**Change in Ha**	**Change in %**
		2000	**2010**	**2015**	**2021**		
1	Built up	19	24	53.664	56.0	37.0	49.3
2	Urban forest	350	311	367.523	306.0	-44.0	-6.7
3	Agricultural land	614	566	523.139	359.0	-255.0	-26.2
4	Unpaved land	-	81	40.052	99.0	99.0	100.0
5	Paved land	-	-	-	101.0	101.0	100.0
6	Garden	-	-	-	64.0	64.0	100.0

The results in Table 4 indicated that there was an increase of 37 ha (49.3%) of built-up from 2000 to 2021, with a reduction of 44 ha (-6.7%) of land occupied by urban forest. As for agriculture, approximately 255 ha (-26.2%) have been reduced from a period between 2000 and 2021.Therefore, it is essential to highlight that the urban growth increase result to green space reduction due to conversion of different land use. The response from 10 sampled interviewees confirmed that green space has gradually decreased through the years. According to the interviewee, between 2000 and 2010, and again between 2010 and 2015, people began to settle in the area around Mount Rebero, and as a result, the area of green space, specifically forest, decreased significantly. This statement was also supported by the results of the Google Earth images in Fig. 6, which show the decreasing area of green space, especially urban forest and agricultural land.

The share of green space required in a certain urbanized area varies depending on the specific zoning regulations and building codes in place in the given location. Different regions and countries have different requirements and standards for the amount and distribution of green space in urban areas. For example, in the United States, the Environmental Protection Agency (EPA) recommends a minimum of 10% of a city's land area should be designated as parks and open space. In some states, such as California, there are statewide standards for park and recreation facilities that require a minimum amount of parkland per capita. Similarly, in the

https://dx.doi.org/10.4314/rjeste.v5i1.5

European Union, the Urban Green Infrastructure Strategy recommends that urban areas should have at least 15% green space coverage, with a goal of reaching 30% in the long term. Many European countries have also established minimum green space requirements for new development projects, ranging from 25-30% of the total area. In Rwanda, the Kigali Master Plan sets a target of 30% green coverage by 2020, with a focus on improving access to green spaces and public parks. Additionally, the Rwanda Building Code requires that all new development projects must include a minimum of 10% open space, including both built and unbuilt areas. In summary, the specific share of green space required over a certain area of urbanized land depends on the zoning regulations and building codes in place in the given location. However, there are a number of national and international standards and guidelines that recommend minimum levels of green space coverage for urban areas.

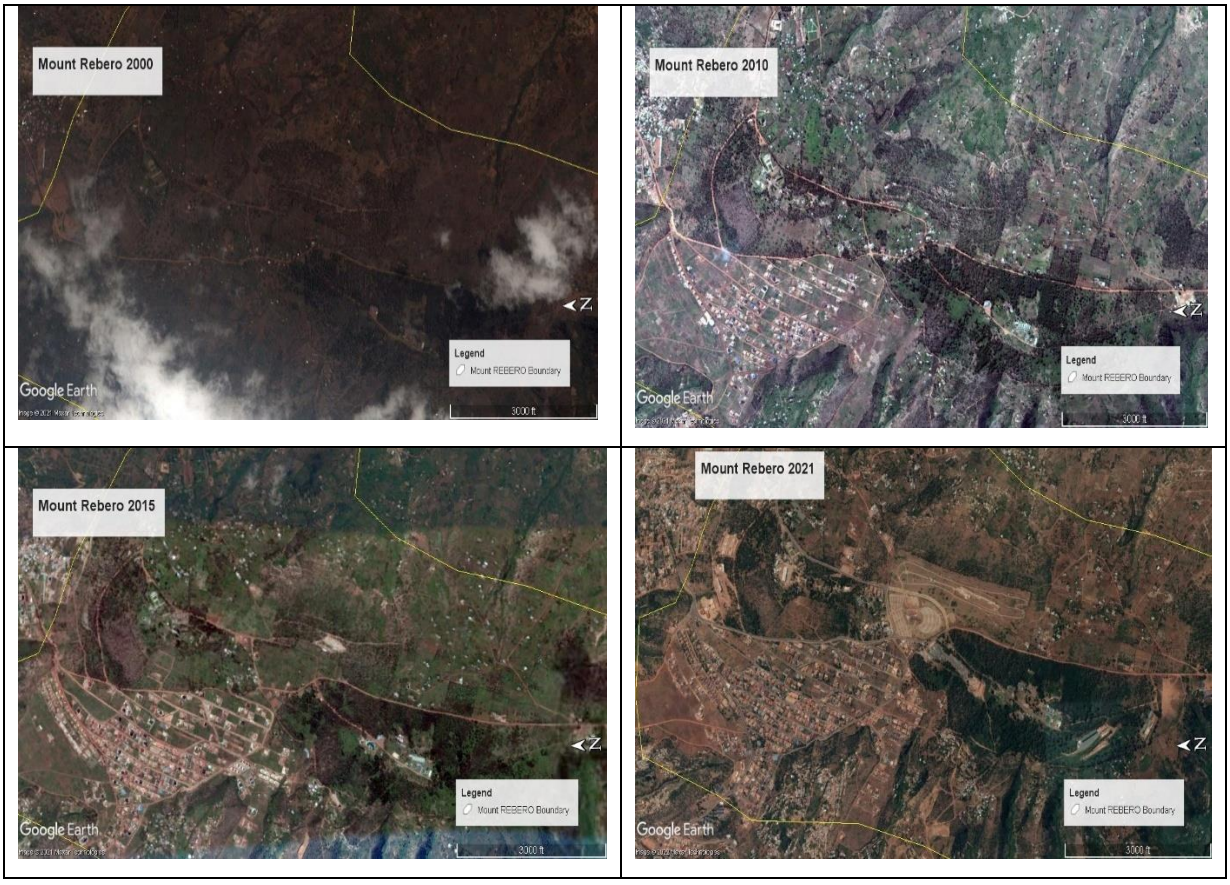

Figure 6: LULC for the Periods of 2000, 2010, 2015 and 2022 (Google earth, 2021)

https://dx.doi.org/10.4314/rjeste.v5i1.5

This decrease in green space due to the increased built-up is also highlighted by other researchers' findings, such as Kayitesi's(2019)findings on Rwampara Wetland, where it was discovered that 130 ha of built-up increased between 1987 and 2018, with a decrease of 16.3 ha of wetland during the same period. Nduwayezu et al., (2021), also revealed significant pressure fromurban growth on the natural environment, with a 14% decrease in open land between 1999 and 2018.The local community of Mount Rebero also stated that the area was once a rich niche of some animals and plants used as medicine, but that due to land use and land cover changes, some medicinal plants and indigenous trees and birds have vanished. The impact of LULC change was also depicted by Johansson et al. (2013),who found that LULC has resulted in ecosystem degradation and decreased the abundance of various species, with some even becoming extinct.Therefore, the research findings of this study are updated and complement other researchers' findings.

3.3. Loss of Rich and Dense Natural Vegetation and Induced Environmental Issues

As observed in Fig. 7, captured on the field, there are some erosion gullies as a result of a poor drainage system due to the construction of residential buildings with an improper rainwater channel system in a place that was once forested but is currently converted to other uses.

(a) **(b)**

https://dx.doi.org/10.4314/rjeste.v5i1.5

Figure 7: Poor Drainage System (on left) and Soil Erosion (on right side) (Field work, June 2021)

Regardless of having an infrastructure in place, basic infrastructure provision, poor rain water management and increase of built up area as cause of soil. This is particular notably on Mount Rebero. The higher increase of built-up space at high slope without proper drainage system as it is observed in Fig.7 result to removal of the unpaved surface of soil on lower slope.

Additionally, existing land use of Mount Rebero is mainly dominated by built up, forest as well as open space, others are rare including schools, garden, vacant land, petroleum station and telecommunication zone. According to Kigali city master plan 2020-2050, the current land use plan of Mount Rebero is in line with what updated Master plan determine on land use. However, forest and other green space amount in general decrease as increase of built up and development of infrastructure including transportation means. Thus, the map below show the current land use of Mount Rebero in Fig. 8

https://dx.doi.org/10.4314/rjeste.v5i1.5

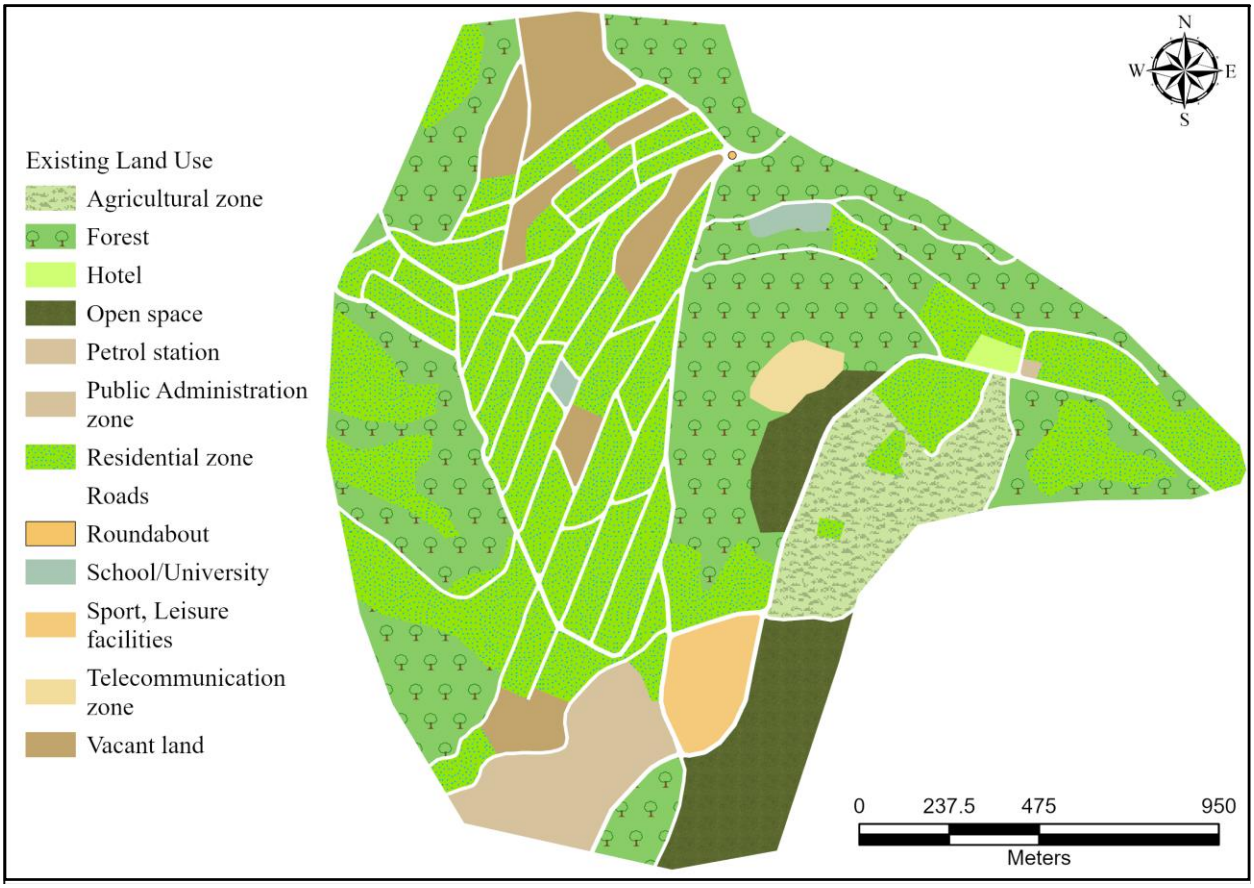

Figure 8: Existing Land Use of Rebero Mountain Landscape (Author, 2022)

Investigation of green space disparities among socio-economic categories might be possible with a finer-scale resolution of different types of green space movement. Urban agriculture, not just green areas like parks, must be considered in planning and design processes. To learn whether agricultural green space affects the directional movement of the centers, it would be helpful to isolate core urban green spaces and agricultural areas independently in future investigations. Additionally, it would be crucial to categorize the population centers according to their gender, age, and income levels in order to ascertain how they relate to the mobility of green space and economic hubs (Azunre, 2019).

Instead of just being used for enjoyment, green space should be planned in terms of ecological functions, services, and advantages. Thus, multi-functionality, local identity, history, customs, culture, social networks, and economic networks are essential components of successful planning (Hudani, 2020). The COVID-19 epidemic that started in early 2020 demonstrated the value of

https://dx.doi.org/10.4314/rjeste.v5i1.5

green spaces for urban residents' physical, emotional, and financial well-being by means of recreation in case of curfew (Bereitschaft, 2020). Therefore, rather than being centered on economics, future urban development should be centered on people and the environment. There are several benefits to having access to green space in urban areas, including the preservation of urban ecology and a place where residents can safely socialize. Thus, it is crucial to develop urban plans and policies that are focused on the needs of both people and the environment in order to establish well-planned green spaces that promote urban public health (Gubic, 2020).

This study serves as an example of the relevance of spatial structure and pattern in city development for the usage and value of green space, particularly for Rwanda as a developing country. In order to preserve and restore ecological networks and services in urban areas, strategies for future studies should concentrate on maximizing the structure of green spaces (shape, density, and connectedness) in ways that enhance their quantity and improve their distribution patterns as a suitable green area could aid in lowering the urban heat island and reducing urban warming. According to a recent study by other researchers, population density, infrastructure, and urban design were more crucial than overall population size for decreasing urban warming in tropical areas (Marcotullio, 2021). Furthermore, as was already said, it would be beneficial to investigate the effects of planning policies on the development trends of urban green spaces. Understanding the dynamics of green space dynamics at citywide sizes through different periods is crucial for improving policies to plan, monitor, and manage green space. Planning strategies may have had a mixed impact on the evolution of green space structure.

4. Conclusion

The study examined the effects of urban growth on green space management using geographic information systems (GIS) and remote sensing techniques. Indeed, many changes have occurred in Kigali city over the last 21 years, and Rebero Mountain is a key insight into this particular change. According to the image classification results, the city of Kigali has rapidly grown from 7,422.10 ha (or about 10.2% of the total) in 2000 to 14,730.94 ha (or roughly 20.2% of the total) in 2021. The vast majority of the local community's interview responses corroborated and validated the image classification findings, highlighting the significant change in urban expansion between 2000 and 2021. The decline of many green space categories and some

https://dx.doi.org/10.4314/rjeste.v5i1.5

biodiversity, such as birds and native plant species, were determined to be the effects of urban expansion on green space. Based on results, the management of green spaces has a significant impact on urban growth and its contribution to science in Rwanda and Africa. Effective green space management practices have the potential to enhance urban development while supporting scientific research and advancements. In Rwanda, the conservation and management of green spaces have been a priority for sustainable urban growth. The government has implemented various initiatives, such as the Green City Kigali project, which aims at creating the environmentally friendly and green urban spaces. Green space management plays a crucial role in urban development and scientific advancements in urban areas, as it contributes to mitigatio0n of the associated challenges. The green spaces help in promoting climate resilience, enhancing public health, and supporting scientific research on topics like urban ecology, biodiversity conservation, and sustainable urban planning. In addition, the green spaces provide valuable opportunities for scientific investigations and data collection which can inform evidence-based urban policies and strategies. More specifically, the green space supports sustainable urban development, improves environmental quality, and provides research opportunities for scientific advancements. This study therefore recommends that the city's green spaces must be restored, and effective preventative measures must be taken against afforestation. It should be done by involving the media in a concerted campaign to raise awareness of the value of the city's green spaces among city residents through radio jingles, advertorials, print media, community awareness forums, NGOs, and conservation groups. Based on this, the value of green spaces should be ingrained in the curriculum of primary, secondary, and university institutions as well as the local population to strengthen the importance of green space to society.

Moreover, governments and private landowners, who have acquired the majority of the city's green spaces over the years, should actively participate in the drive for the restoration and mitigation of the city's green spaces, so development plans should be reviewed in order to implement and adopt an approach for their restoration. Therefore, more study on environmentally friendly methods for restoring, protecting, and conserving city green spaces should be encouraged. This study had some limitations, such as a lack of high spatial and temporal resolution satellite imagery that clearly show the land cover classes focused on green space. Therefore, for accurate and reliable results, it is advised to conducting the study again

https://dx.doi.org/10.4314/rjeste.v5i1.5

using high quality imageries and utilizing the machine learning methods such as the Artificial Neutral Network, Random Forest, and Support Vector Machines with object-based tools. In addition, there is a need to conduct the same study on the impacts of urban growth on green space management in secondary cities of Rwanda.

5. References

1. Aram, F., Solgi, E., & Holden, G. (2019). The role of green spaces in increasing social interactions in neighborhoods with periodic markets. *Habitat International*, *84*, 24-32.
2. Azunre, G. A., Amponsah, O., Peprah, C., Takyi, S. A., & Braimah, I. (2019). A review of the role of urban agriculture in the sustainable city discourse. *Cities*, *93*, 104-119.
3. Badiu, D. L., Onose, D. A., Niță, M. R., & Lafortezza, R. (2019). From "red" to green? A look into the evolution of green spaces in a post-socialist city. *Landscape and urban planning*, *187*, 156-164.
4. Baffoe, G., Ahmad, S., & Bhandari, R. (2020). The road to sustainable Kigali: A contextualized analysis of the challenges. *Cities*, *105*, 102838.
5. Bereitschaft, B., & Schillers, D. (2020). How might the COVID-19 pandemic affect 21st century urban design, planning, and development? *Urban Science*, *4*(4), 56.
6. Byomkesh, T.; Nakagoshi, N.; Dewan, A. Urbanization and green space dynamics in Greater Dhaka, Bangladesh. Landsc. Ecol.Eng. 2011, 8, 45–58.
7. City of Kigali. (2020). Kigali Green City Master Plan.
8. City of Kigali. (2021). Urban Greening Program. Retrieved from https://www.kigalicity.gov.rw/index.php?id=309
9. Cioffo, G. D., Ansoms, A., & Murison, J. (2016). Modernising agriculture through a 'new'Green Revolution: the limits of the Crop Intensification Programme in Rwanda. *Review of African Political Economy*, *43*(148), 277-293.
10. Gubic, I., & Baloi, O. (2019). Implementing the new urban agenda in Rwanda: Nation-wide public space initiatives. *Urban Planning*, *4*(2), 223-236.
11. Gubic, I., & Baloi, O. (,2020). Public open space initiatives for healthier cities in Rwanda. *The Journal of Public Space*, *5*(2), 129-146.

https://dx.doi.org/10.4314/rjeste.v5i1.5

12. Habonimana, H. V., Bizimana, J. P., Uwayezu, E., Gibert3and, M., & Boerboom, L. (2015). *Spatial Multi-Criteria Evaluation for Implementation of National Urbanization Policy in Rwanda.* Paper presented at the GeoTech Rwanda 2015.
13. Hudani, S. E. (2020). The green masterplan: Crisis, state transition and urban transformation in post-genocide Rwanda. *International Journal of Urban and Regional Research*, *44*(4), 673-690.
14. Jaganyi, D., Njunwa, K., Nzayirambaho, M., Rutayisire, P. C., Manirakiza, V., Nsabimana, A., & Nduwayezu, G. (2018). Rwanda: National Urban policies and city profiles for Kigali and Huye. *79. glasgow: The GCRF centre for sustainable, healthy and learning cities and neighbourhoods (SHLC)*.
15. Johansson, T., Hjältén, J., de Jong, J., & von Stedingk, H. (,2013). Environmental considerations from legislation and certification in managed forest stands: A review of their importance for biodiversity. *Forest ecology and management*, *303*, 98-112.
16. Kabisch, N., Qureshi, S., & Haase, D. (2015). Human–environment interactions in urban green spaces—A systematic review of contemporary issues and prospects for future research. *Environmental Impact assessment review*, *50*, 25-34.
17. Karade, R. M., Kuchi, V. S., & Kabir, J. (2013, September). The role of green space for sustainable landscape development in urban areas. In *IV International Conference on Landscape and Urban Horticulture 1181* (pp. 73-76).
18. Karuppannan, S., Baharuddin, Z. M., Sivam, A., & Daniels, C. B. (2014). Urban green space and urban biodiversity: Kuala Lumpur, Malaysia. *Journal of Sustainable Development*, *7*(1), 1.
19. Kayitesi, C. (2019). Spatio-temporal analysis of urban growth and its impacts on Rwampara wetland in the City of Kigali Rwanda.
20. Kometa, S. S., Kimengsi, J. N., & Petiangma, D. (2018). Urban development and its implications on wetland ecosystem services in NDop, Cameroon. *Environ. Manag. Sustain. Dev*, *7*(1), 1-16.
21. Malonza, J. M., & Ortega, A. A. (2020). Fissures in localizing urban sustainability: the case of Rwanda. *GeoJournal*, 1-20.

https://dx.doi.org/10.4314/rjeste.v5i1.5

22. Manirakiza, V. (2012). *Urbanization issue in the era of globalization: Perspectives for urban planning in Kigali.* Paper presented at the Fourth Annual conference proceedings. Social Studies for Community Cohesion and Sustainable Development, Kigali.
23. Manirakiza, V., Mugabe, L., Nsabimana, A., & Nzayirambaho, M. (2019). City Profile: Kigali, Rwanda. *Environment and Urbanization ASIA*, *10*(2), 290-307.
24. Marcotullio, P. J., Keßler, C., Quintero Gonzalez, R., & Schmeltz, M. (2021). Urban Growth and Heat in Tropical Climates. *Frontiers in Ecology and Evolution*, *9*, 616626.
25. Mensah, C. A. (2014). Urban green spaces in Africa: Nature and challenges.
26. Michieletto, M. (,2022). Towards a sustainable urban development: the satellite city project of Kigali, Rwanda.
27. Mugiraneza, T., Ban, Y., & Haas, J. (2019). Urban land cover dynamics and their impact on ecosystem services in Kigali, Rwanda using multi-temporal Landsat data. *Remote Sensing Applications: Society and Environment*, *13*, 234-246.
28. Nduwayezu, G., Manirakiza, V., Mugabe, L., & Malonza, J. M. (2021). Urban Growth and Land Use/Land Cover Changes in the Post-Genocide Period, Kigali, Rwanda. *Environment and Urbanization ASIA*, *12*(1_suppl), S127-S146.
29. Nduwayezu, G., Sliuzas, R., & Kuffer, M. (2016). Modeling urban growth in Kigali city Rwanda. *Rwanda journal*, *1*.
30. Nor, A. N. M., Corstanje, R., Harris, J. A., & Brewer, T. (2017). Impact of rapid urban expansion on green space structure. *Ecological Indicators*, *81*, 274-284.
31. Ondieki, C., Osano, P., Getenga, Z., Mburu, J., & Gathenya, J. (2020). Green space management for sustainable urban growth in Africa: Perspectives, challenges and opportunities. Sustainable Cities and Society, 61, 102330.
32. Ritchie, H., & Roser, M. (2018). Urbanization. *Our world in data*.
33. Rwanda Environment Management Authority. (2017). Guidelines for Environmental Impact Assessment

https://dx.doi.org/10.4314/rjeste.v5i1.5

34. Seburanga, J. L., Kaplin, B. A., Zhang, Q.-X., & Gatesire, T. (2014). Amenity trees and green space structure in urban settlements of Kigali, Rwanda. *Urban Forestry & Urban Greening, 13*(1), 84-93.
35. Shahtahmassebi, A. R., Li, C., Fan, Y., Wu, Y., Gan, M., Wang, K., . . . Blackburn, G. A. (2021). Remote sensing of urban green spaces: A review. *Urban Forestry & Urban Greening, 57*, 126946.
36. Tafahomi, R., & Nadi, R. (2022). Insight into the missing aspects of therapeutic landscape in psychological centres in Kigali, Rwanda. *Cities & Health*, *6*(1), 136-148.
37. UNDESA.(2018). Worldurbanizationprospects:The2018 revision. New York, NY: United Nations Department ofEconomicandSocialAffairs*Carbon balance and management*(1).
38. Uwamwezi, V., Nyirambangutse, B., Ndoli, A., & Ntaganira, J. (2019). Assessment of urban green space patterns and quality in Kigali city, Rwanda. Cities & Health, 3(1-2), 85-98.
39. Ward Thompson, C., Aspinall, P., Roe, J., Robertson, L., & Miller, D. (2016). Mitigating stress and supporting health in deprived urban communities: the importance of green space and the social environment. *International journal of environmental research and public health, 13*(4), 440
40. Wilson, O., & Hughes, O. (2011). Urban green space policy and discourse in England under New Labour from 1997 to 2010. *Planning, Practice & Research, 26*(2), 207-228.

https://dx.doi.org/10.4314/rjeste.v5i1.5