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VISUAL MODELING OF RELATIONSHIP BETWEEN URBANIZATION AND ENVIRONMENTAL PROTECTION IN KIGALI CITY, RWANDA

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Abstract

Urban regions can expand due to migration into urban areas or increases in the human population. The aim of this study was to conduct the visual modeling of relationship between urbanization and environmental protection. This study used secondary data on the existing spatial datasets and available Landsat images on USGS to perform spatial temporal analysis of Kigali city land use over time. For three years (2000, 2010, 2022) LULC pattern were generated. Landsat 5TM for 2000, Landsat 7 ETM+, and Landsat 9 ("OLI_TIRS") with row/path 60/161, having ground resolution of 30 meters for land use and land cover mapping. Change detection analysis of 2000-2022 showed that vegetation recorded a decreased of -55.19. Forest area decreased up to -7 between 2000 and 2022 while the built up increased up to 37.7% between 2000 and 2022. However, areas under water bodies increased about 0.03 within 2000 and 2022, respectively in Kigali city. Moreover, under land cover dynamics, the predicted environmental status shows that urban land will keep on increasing under low forest occupancy and wetland and zoning water bodies will record a declining size in the City of Kigali. The results of this study suggest policy makers to reinforce the implementation of planning policies by respecting environmental and land management rules and regulations.

Keywords: Forest, Urban growth, GIS and remote sensing, Environmental protection

1. Introduction

The majority of city management systems in developing countries are beyond their capacity due to the rapid demographic change and unchecked spatial transformations. The absence of robust spatial policies, disorderly urban sprawl, and high consumption of natural resources are those cities defining characteristics [5]. The population of Kigali city is steadily growing as a result of emigration from the countryside, for example. Emigration from rural areas for employment and business opportunities is significantly higher than in other Rwandan towns [7]. One of the empirical statistical techniques, the logistic regression technique calculates the likelihood that a specific event will take place by examining the relationships between a dichotomous dependent variable and a metric or dichotomous independent variable [1, 6]. Due to its explanatory power and spatial explicitness, this technique has been claimed to be a very effective tool for land cover/use change modeling when combined with GIS and RS [4]. Visual modeling was used in this study to represent interesting objects and systems using graphical languages. Waugh [14] asserts that visual modeling enables both experts and beginners to share a common understanding of otherwise complex concepts. As a result, visual modeling can also be used to reach a group consensus. Models make it easier for designers to effectively share ideas, which speeds up deliberations and leads to a final consensus [13]. Logistic regression (LR), which aids in quantifying the contribution of the various factors driving land cover/use change, can be used to analyze potential development patterns based on trends seen in the past in order to calibrate models for land cover/use change and urban growth [3]. The goal of the current study is to create different LR models to assess the key variables affecting Kigali's development, taking into account both their historical evolution and their role in the city's development. Urbanization frequently results in deforestation, habitat loss, and freshwater removal from the environment, which can decrease biodiversity and alter the ranges and interactions of different species [2]. The study's findings can aid city decision-makers in better understanding urban planning and management of the city by helping them to describe the future urban environment. Although these policies have yet to be put into action, the rate of city growth seems to have remained constant.

2. Methodology

2.1. Study area description

Kigali is Rwanda's most important city and accounts for about 45% of Rwanda's urban population. It started in 1907 under the advice of Dr. Richard Kant, the first European resident of Rwanda. Kigali is the capital and largest city of Rwanda. It is geographically located at the heart of Rwanda with latitude $1^0$43’20” S - $2^0$10’00” S and longitude $30^0$0’0” E - $30^0$16’40” E. The city is built on numerous hills, sprawling across four ridges with valleys in between. The commercial centre is located on one of these ridges with the administrative canter on the other. It is comprised of 35 Sectors i.e. (15 in Gasabo, 10 in Kicukiro and 10 in Nyarugenge).

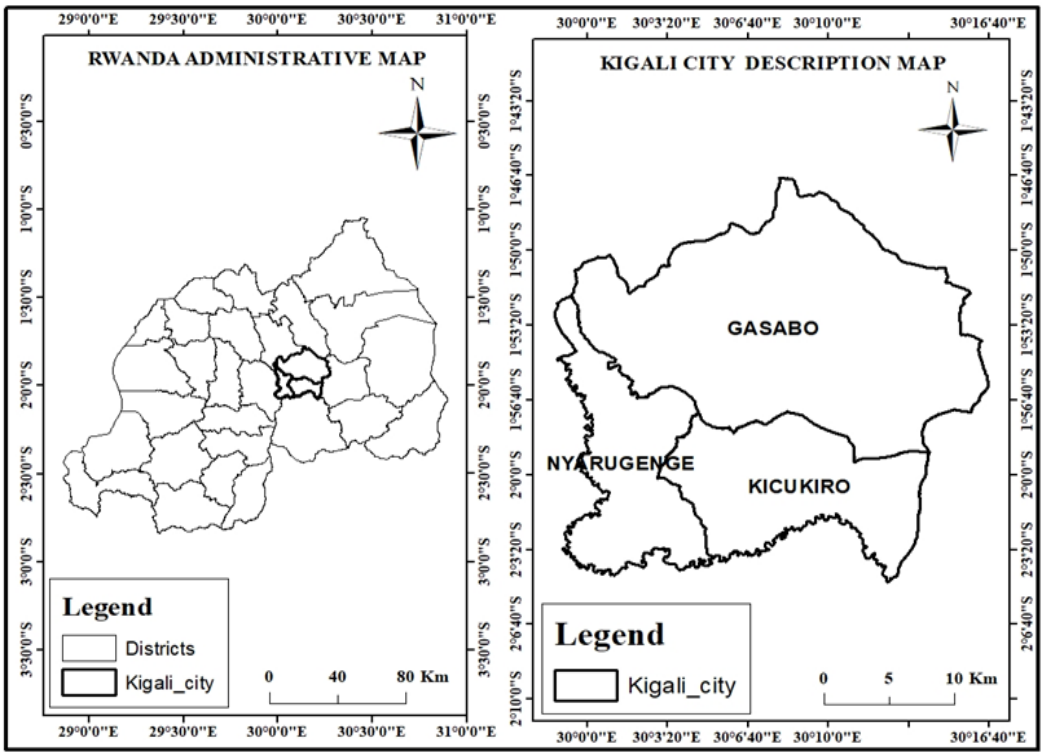


Figure 1. Geographical location of Kigali city

Kigali's growth under Belgian rule was very slow and contained primarily on the top of the hill. When Rwanda became independent on July 1, 1962, Kigali remained a small village with mainly administrative functions. Between 1962 and 1984, Kigali's population and urban area expanded rapidly. Population grew at around 16 per cent from around 6,000 people to nearly 160,000 and the built area expanded also to 15 square Kilometer. Nowadays, Kigali city has come of age-as the capital of Rwanda and made phenomenal strides. It is a city that has not just survived, but has prevailed and has grown into a modern metropolis-a heart of the emerging Rwandan economy and a pride of every Rwandan. Kigali is the capital city of Rwanda, seat of government and main economic canter. It has a surface area of 376 km^2. It is also the primary city, concentrating around 67% of the total urban population in the country; it has a fast growing population of at least one million inhabitants.

2.2. Data Collection and analysis

To achieve this research, the Landsat9 OLI & Landsat 7 ETM plus imagery for different season were used for this study and multi-temporal images was obtained as follows: 2000-2022.

Landsat 7 ETM plus were downloaded from USGS web platform (www.earthexplorer.usgs.gov/).The map of study area was created from the shape file of administrative boundary of Rwanda as well as from Rwanda geoportal in order to produce map of the study area and later the satellite imageries was clipped with the administrative boundary of study area. The detail information of landsat9 and Landsat7ETM plus.

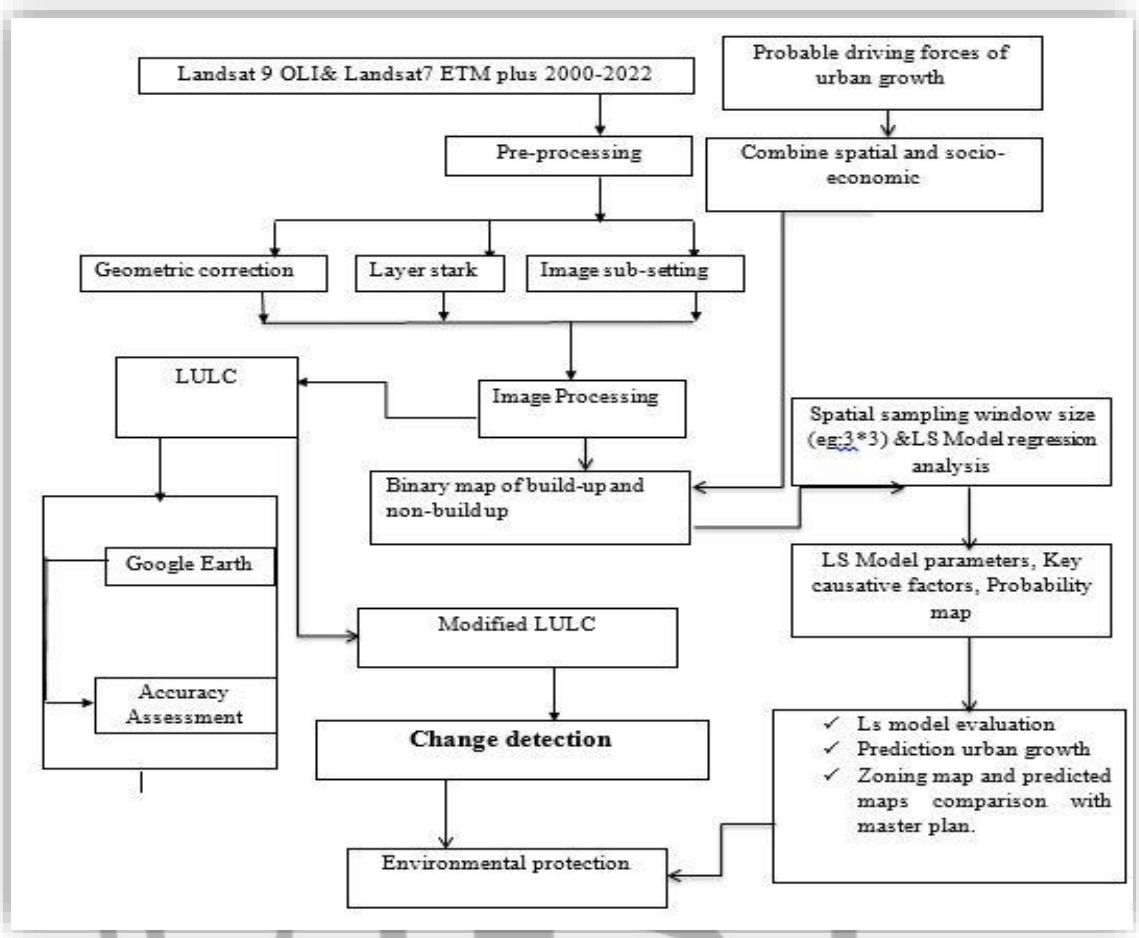


Figure 2: Methodological Framework

This study used secondary data, including existing literature, existing spatial datasets and available Landsat images on USGS source were required to perform spatial temporal analysis of Kigali city land use over time. The authors employed secondary data on detecting the change in land use land cover directly to environmental protection using satellite data in the range of 2000-2022.Image classification was implemented after generating training samples, and the images were classified by classification using maximum likelihood. The classification was in four classes: Built-up, bare land, vegetation, and forest land. After Classification, a post classification comparison to detect the change in land use land cover of Kigali City was performed. Another important step is to build a logistic regression model of Kigali City's urban growth patterns. Time series analysis and modelling are performed using three different Landsat imagery from 2000 to 2022.

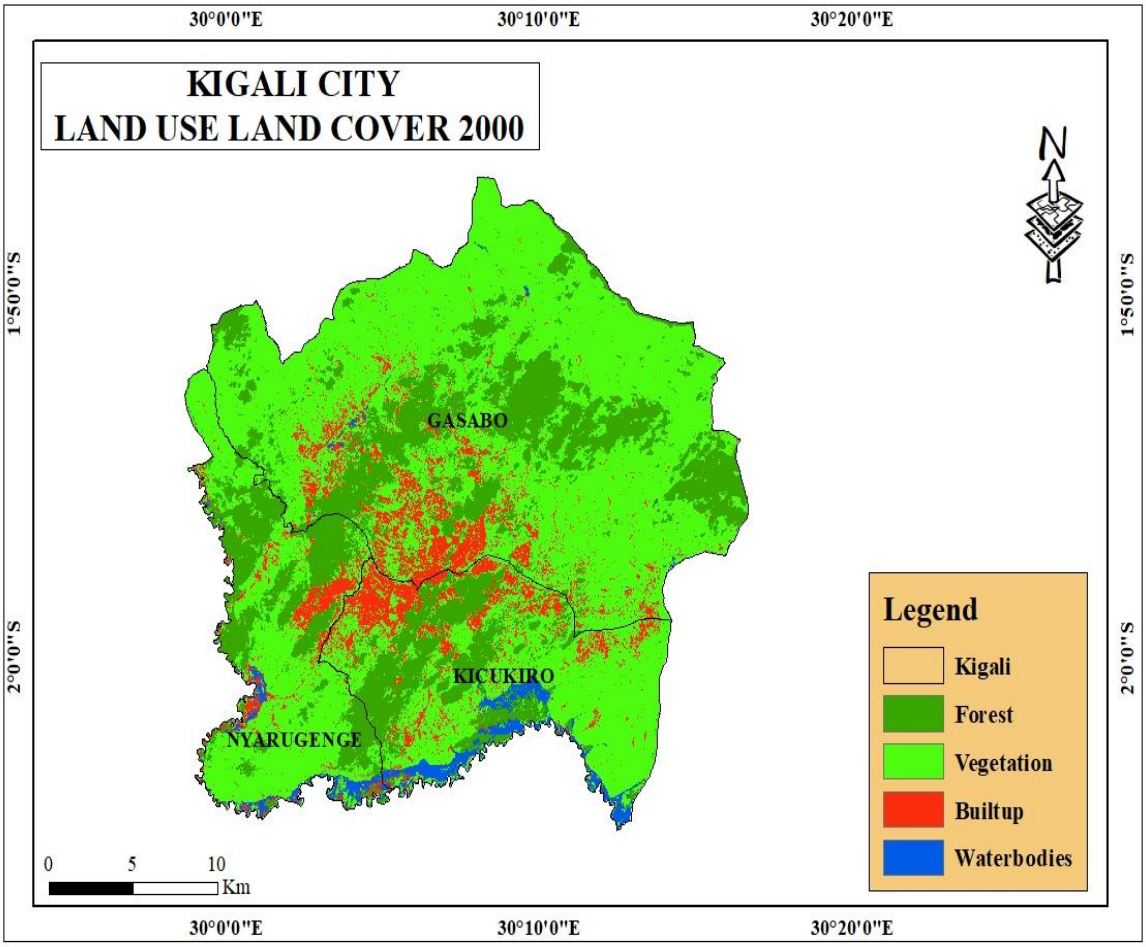
3. Results

3.1. 2000,2010 and 2022 Land Use and Land Cover patterns

Land use statistics and transition matrix have been important information to analyse the relationship between urbanization and environmental protection strategic using visual modelling. Supervised

classification used for different land use land covers in Kigali city class's features was vegetation, forest, built-up, and water body. Lastly, the analysis on what the proposed land use plan of Kigali city under environmental. Monitoring land use/land cover changes is of great importance in order to assess the impact of environmental protection.

As shown in Figure 3, the built-upland was mainly concentrate din the central part of City of Kigali. In addition, the same Figure 3 shows that the land under vegetation cover was still at an advanced proportion in 2000 over the City of Kigali. This is dominantly localized within Gasabo District compared to the record of Nyarugenge and Kicukiro Districts,



Figures 3: Land use and land cover 2000

The results detailed in Table 1 show that the major land use /land cover class in 2000 was vegetation occupying 62.6 %, the forest was 25.1 %, water body was 2.4 %, built-up was 9.9 %. These results show that the forest and vegetation was very high compared to other land use /land cover in 2000.

Table 1. Area and percentages of Land use land cover 2000

Class	Area in ha	Percentage
Forest	18297.5	25.1
Vegetation	45721.4	62.6

Built-up	7250.5	9.9
Water bodies	1717.2	2.4
Total	72986.6	100

The spatial distribution of LULC in 2010 as demonstrated in Figure 4 shows that vegetation area recorded a declining rate mainly due to the registered extending built-up land within Kicukiro district. In addition, based on the results indicated in Figure 4, it is noticed that forestland decreased over the entire City of Kigali compared to its 2000 occupancy in (see Figure 3).

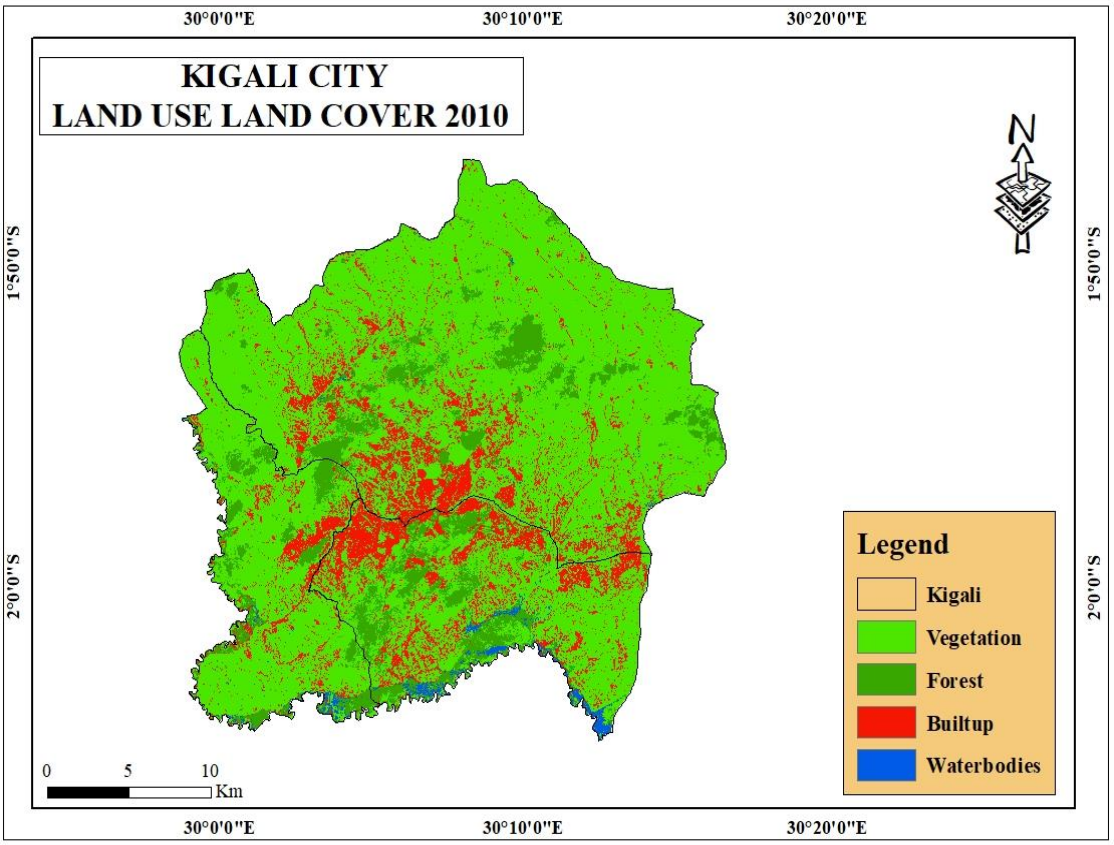


Figure 4. Land use and Land cover 2010

With regarding the change son land cover in 2010, the results in Table 2 show that Vegetation areas was the most dominant LULC class where it occupied 73% (53,278.8 ha) of total Kigali city area. Built-up is the second LULC class where it occupied 14.90% which equals to 10872.6 ha of Kigali city total area. Forest land was the third LULC class in 2010 where it occupies 11.04 %, out of 8058.2 total area of Kigali city, Water bodies land covered 1.06%.

Table 2. Area and percentages of Kigali city 2010

Class	Area in ha	Percentage
Vegetation	53278.8	73.00
Forest	8058.2	11.04

Built-up	10872.6	14.90
Water bodies	777.0	1.06
Total	72986.6	100

The results in Figure 5 reveal that compared the built-up land of 2000 and 2010 (Figures 3 and 4), in 2022, the area under built-up recorded a considerable expansion. This is likely associated to the decreasing forest land noticed in 2022 (Figure 5) compared to its previous period namely 2000 and 2010 which also reveal a declining trend but not at the similar speed as that of 2022.

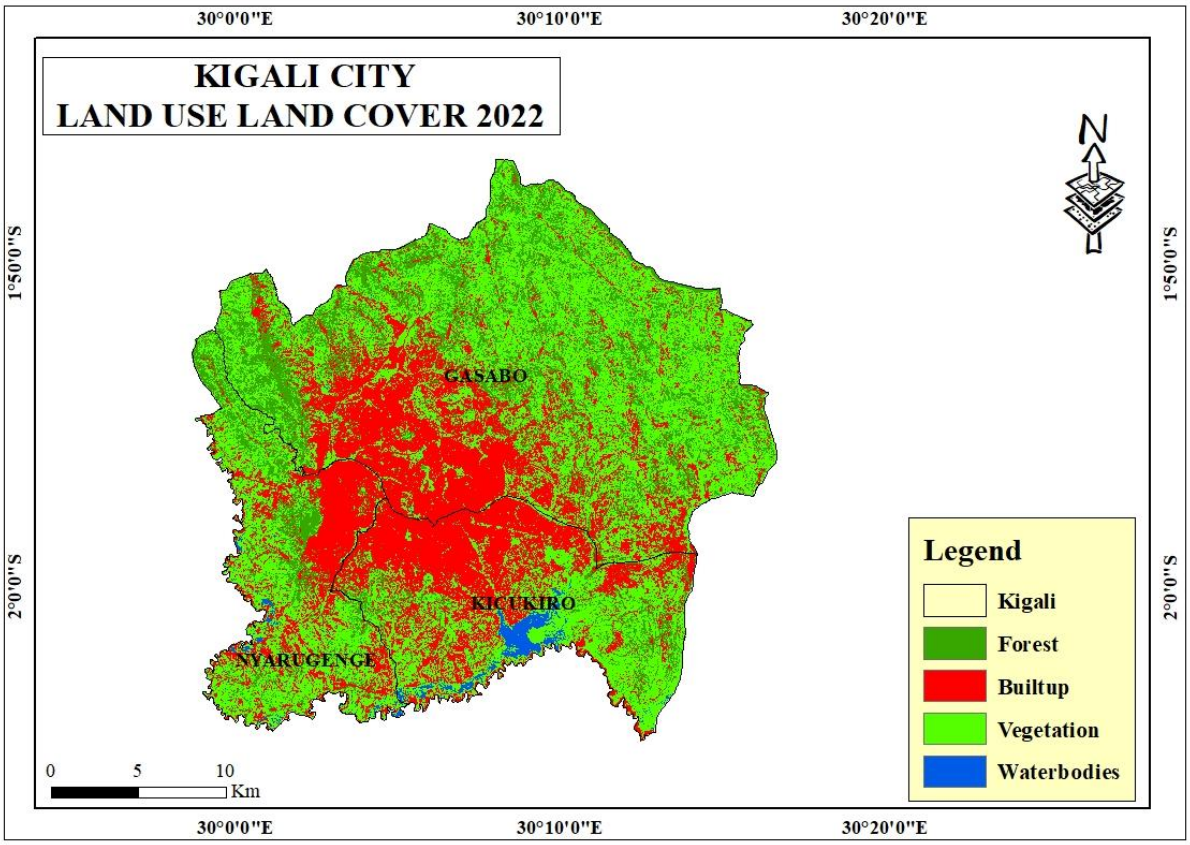


Figure 5: Land use and land cover of Kigali city2022

Finally, as indicated in table 3, built up area occupy 32.70%, forest occupy 21.9%, vegetation occupies the biggest area than other land cover classes at 44.79% and Water bodies occupy 1.31%.

Table 3. The size of each land cover type, Area and percentage 2022

Class	Area in ha	Percentage
Forest	15467.6	21.19
Built-up	23868.6	32.70
Vegetation	32691.9	44.79

Water bodies	958.4	1.31
Total	72986.6	100

3.2. Change Detection of 2000 to 2022

According to Rensink (2002) the various algorisms have been developed for change detection, analysis the common used in this research. The change detection procedures can be grouped under three broad headings characterized by the data transformation procedures and the analysis techniques used to delimit areas of significant changes, image enhancement, multi-date data classification and comparison of two independent land cover classifications.

For this study, the authors performed a land use change analysis to determine how land use was used from the year 2000 to 2022. Thus, the quantity of land use/land cover change was further analysed per classes in term of gains, losses and unchanged area of land use in vegetation land, built up land, forest and water land occupation. Therefore, the results in terms of change detection within the considered research period range (2000, 2010 to 2022) are shown in Figure 6 below.

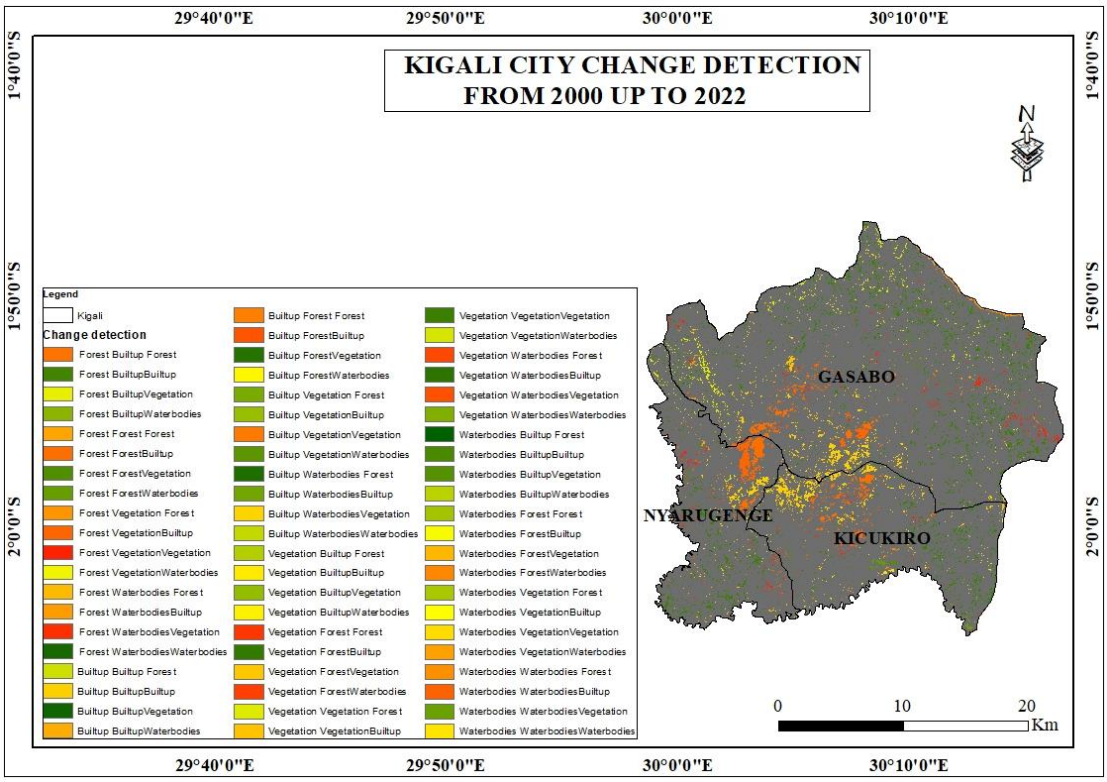


Figure 6. Show change detection Map of 2000-2022

The findings of the study in Table 4 indicate the Change detection analysis of 2000-2022 where vegetation decreased up to -55.19 between 2000 and 2022. The forestland recorded a decrease of -7 between 2000 and 2022 while the built up increased up to about 37.7% between 2000 and 2022. However, waterbodies increased about 0.03 in the years 200 and 20222 across the City of Kigali.

Table 4. Chang detection area from 2000 up to 2022

Class	Area in ha	Percentage	Area in ha	Percentage	Area in ha	Percentage	Area(ha)change in 2000-2022	% change in 2000-2022
Forest	18298	25.1	8058.2	11.04	15467.6	21.19	-5228.3	-7.13
Vegetation	45721	62.6	53278.8	73	32691.9	44.79	-40249.3	-55.19
Built-up	7250.5	9.9	10872.6	14.9	23868.6	32.7	27490.7	37.7
Water bodies	1717.2	2.4	777	1.06	958.4	1.31	-18.2	0.03
Total	72986.6	100	72986.6	100	72986.5	100.0		

3.3. Prediction of Environmental status under land cover dynamic in City of Kigali

In order to predict environmental protection status in the City of Kigali, the authors referred to the National Land Use and Development Master Plan (NLUDMP). The NLUDMP is a nationwide sectorial document aiming at guiding the optimal use of land with the main target of (i) finding the best balance sheet based on spatial and economic analysis; (ii) generating specific guidelines for implementation; (iii) designing a new and sites. Overcrowding, pollution, and the urban squalor associated with factories were major concerns that led city officials and planners to consider the need for functional separation of uses.

To produce the predicted environmental protection status in Kigali City, the authors utilized all the periodical land use and land cover maps 2000,2010 and 2022, respectively along with the map of Change detection. The predicted environmental status in Figure 7 shows that urban land will keep on increasing under low forest occupancy. However, it can be detected that both wetland and zoning water bodies will record a declining size in the City of Kigali.

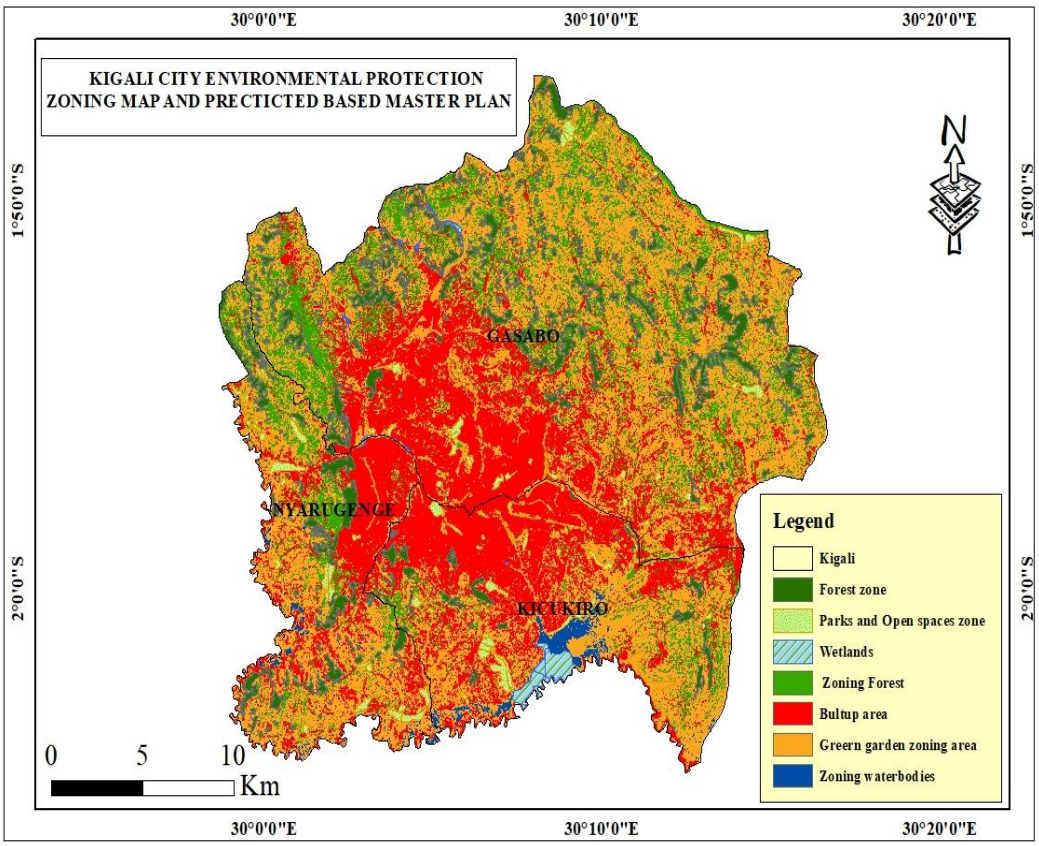


Figure7: Environmental protection zoning and predicted based master plan

4.Conclusion

The objective of this study was to conduct the visual modeling of relationship between urbanization and environmental protection. This study used secondary data on the existing spatial datasets and available Landsat images on USGS to perform spatial temporal analysis of Kigali city land use within the period of 2000, 2010 and 2022. The Change detection analysis showed that from 2000 to 2022, the vegetation decreased up to -55.19 and forest decreased at -7 between 2000 to 2022, respectively. In addition, the results show that built-up land predominantly increased at about 37.7% between 2000 and 2022 while water bodies increased at 0.03 within the considered period of study (2000-2022) in Kigali city. Furthermore, the predicted environmental status under land cover paters in Kigali city reveal that urban land will keep on increasing under low forest occupancy. However, it can be detected that both wetland and zoning water bodies will record a declining size in the City of Kigali. Finally, in order to ensure sustainable land management and environmental protection, policymakers are recommended to reinforce the implementation of planning policies by respecting environmental and land management rules and regulations.

Acknowledgements

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