

# Examining Rate of Built-Up Areas on the Vegetation Cover along River Riara Riparian within Kiambu Town, Kenya

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## Abstract

Urban river riparian spaces and their natural systems are valuable to urban dwellers; but are increasingly affected and ruined by human activities and in particular, urbanization processes. In this research, land sat and sentinel satellite imagery apt for change detection in vegetation cover, both landsat and sentinel imagery, covering the period between 1970 and 2021 in epochs of 1973, 1984, 1993, 2003, 2015 and 2021 years were used to establish the correlation between vegetation cover and built-up area along River Riara river reserve. The images were analysed to extract the built-up areas along the river reserve, including the buildings, and the rate of human settlements, which influenced vegetation cover. Normalized Difference Built-Up Index (NDBI) and Normalized Difference Vegetation Index (NDVI) were computed using the Short-Wave Infrared (SWIR) and the Near Infra-Red (NIR) bands to show the rate of change over the years. Results indicate NDVI values were high, compared to NDBI values along river Riara in the years 1973 and 1993 implying that there was more vegetation cover then. However, in the year 2021, the NDVI indicated the highest value at 0.88, with the complementary NDBI indicating the highest NDBI value at 0.47. This represents a significant increase in built-up areas since 2015 more than in previous epochs. Either, there was a significant increase in NDBI values, from 0.24 in 1993 to 0.47 in 2021. More so, the R-squared value at 0.80 informed 80% relationship between NDBI and NDVI values indicating a negative correlation.

## Keywords

Ecological Conservation, Urban Riparian Reserves, Vegetation Cover Index, Built-Up Area Index, NDVI, NDBI

## 1. Introduction

Many cities and urban areas, by design, have developed along rivers running through them mainly because of transportation services they afford. As a result of urbanisation processes, river-city interfaces are increasingly becoming intricate demanding “give-and-take” interventions (Bott et al., 2019). On the one hand, the urbanised areas appear to squeeze the river edge, reducing the natural green vegetation cover and diminishing their capability to deliver ecosystem amenities. Some commonly witnessed effects of cleared natural vegetation include surplus runoff and heavy pollution loads (Strayer & Findlay, 2010). Nature on the other hand can boisterously obliterate towns through flooding events of the same rivers. Recurrent urban river flooding harms urban infrastructure and functions.

Over the last two centuries, urbanization processes have caused adverse changes in urban riverine vegetation crucial to drainage systems and hydrology (Zaharia et al., 2016). River ecosystems, including their structure and function, particularly in developing countries, are increasingly undergoing rapid encroachments by human activities negatively reducing natural vegetation cover. The challenge is particularly grave in urban regions since cities, owing to their nature, influence the entire river ecosystem and water cycle. Increased populations demand increased production, which is tied to increased resource consumption. This production-consumption cycle includes drawing water input for domestic and industrial consumption, and emitting domestic and industrial effluent, including chemicals, into the same rivers. When such effluent finds its way to the urban rivers' ecosystems, it greatly alters their natural vegetation cover status.

Disturbances in urban river natural vegetation and ecosystem are prevalent in both developing and developed economies of the world. According to Koskey (2011), the only arguable disparities would be the magnitude at which the riverine vegetation cover is affected by introduction of new land uses, and the effectiveness of the statutory agencies and strategies deployed by individual urban riparian areas to mitigate these effects through vegetation restorative approaches (Wagner & Hagan, 2000).

Brundtland Report introduced the concept of sustainable development, and there has been a lot of research focused on urban sustainability (Qi et al., 2013). The Worlds Cities Report (UN Habitat, 2016) indicates that existing land use and land cover form of urban development along urban rivers are unsustainable, affecting human wellbeing and health, and ultimately impacting the limits of social-ecological benefits such as recreational urban rivers ecosystems services. Alberti et al. (2003), observes that the value of urban rivers landscape and natural vegetation cover in addressing their ecosystem services is often disregarded during urban planning and design processes. Similarly, Bulent (2013) echoes the fact that more often than not urban river vegetation landscape features are reflected on after creation of the built environment. In the study area, solid waste is visibly openly dumped along with the riparian reserves of Riara River, greatly affecting the vegetation cover and quality. Secondly, there is evidence of pres-

ence of incompatible economic land uses that subsequently lead to defoliation of vegetation cover.

Therefore, this study's main objective was to examine the rate of built-up areas on vegetation cover change along the river Riara riparian within Kiambu town, Kenya. This objective was formulated in the context of rapid urbanization witnessed in the study area and the growing need for ecological conservation and management.

## 2. Study Area, Materials and Methods

### 2.1. Study Area Description

The natural study situs lies at the heart of Kiambu Town, the administrative capital of Kiambu county located North East of Nairobi City at  $1^{\circ}10'0''S$ ,  $36^{\circ}50'0''E$ , and about 1720 m above sea level 13 Km from Nairobi City as shown in **Figure 1**



**Figure 1.** Study area in the national context.

below. The section of the river under study abuts Kiambu prison on the west, Kiambu Institute of Science and technology to the east, Riverside Estate to the north and Kiambu sub-county offices to the south. Spines roads crosscutting the study area are Kiambu road at the Kirigiti-Kamiti road junction as well as the Kiambu-Karuri road. In the regional context, the study area lies along within the tropics as shown in **Figure 2** below.

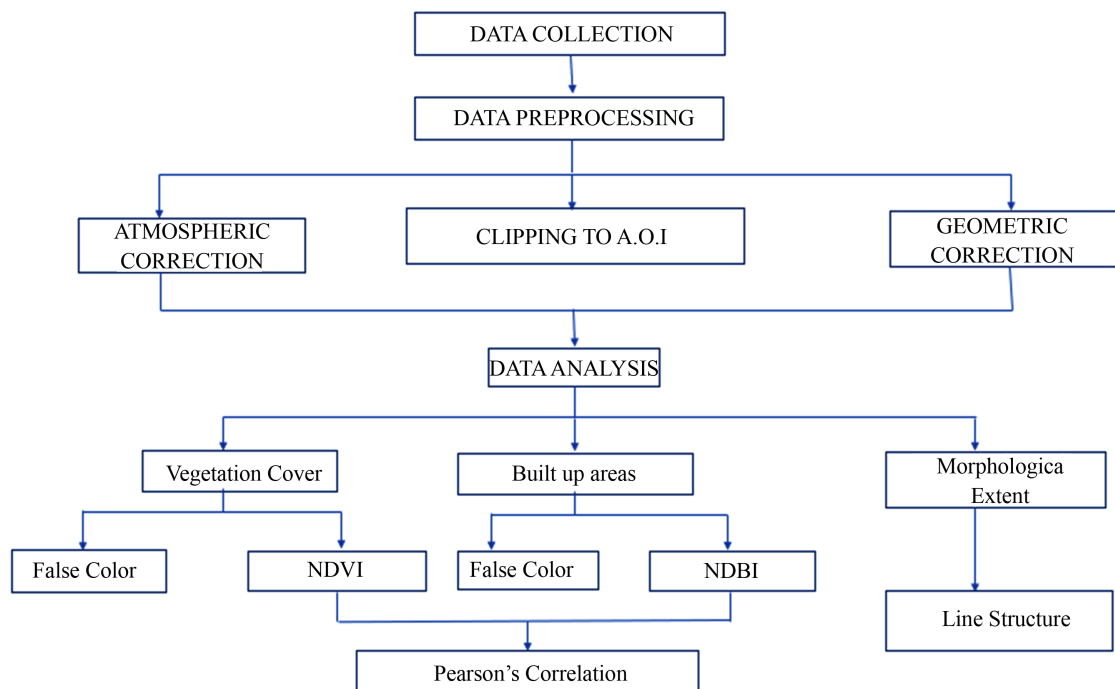
## 2.2. Materials and Methods

The flow chart indicated in **Figure 3** below demonstrates the structure of processes engaged in analysis and deriving empirical data of land cover vegetation changes in the study area.

Satellite imagery was necessary and most apt for change detection in the study area. Landsat and sentinel imageries were used. The time epochs cover the period between 1970 and 2021 as shown in **Table 1** below.



**Figure 2.** Study area in the strategic locational context.



**Figure 3.** Conceptual framework, displaying the methodological flow of processes.

**Table 1.** Time epochs, the year when the images were collected, and the satellite platforms.

Time Epoch	Year selected	Satellite platform
1970-1980	1973	Landsat 1
1980-1990	1984	Landsat 4 and 5 TM
1990-2000	1993	Landsat 5 TM
2000-2010	2003	Landsat 7 ETM
2010-2020	2015	Sentinel 2 MSI
2020-2030	2021	Sentinel 2 MSI

### 2.3. Land Use Change on River Riara Riverine Ecosystem from the Years 1973 to 2021

This study aimed at investigating the impact of development and emerging built-up areas on the vegetation cover along River Riara over 50 years period. Therefore, it was essential to compute the vegetation cover change compared to the built-up areas' development over the period.

Remotely sensed images are used to detect land cover changes in urban and urban areas to define urbanization process rate. However, this approach has been developed over time, founded on Normalized Difference Built-up Index (NDBI) to program the process of mapping built-up areas prioritizing the exceptional spectral response of built-up areas and added land covers. Therefore, emerging Built-up areas are successfully mapped out through arithmetic management of re-coded Normalized Difference Vegetation Index (NDVI) and NDBI images derived from satellite images (Nikrouz & Mahdi, 2017).

#### Vegetation cover

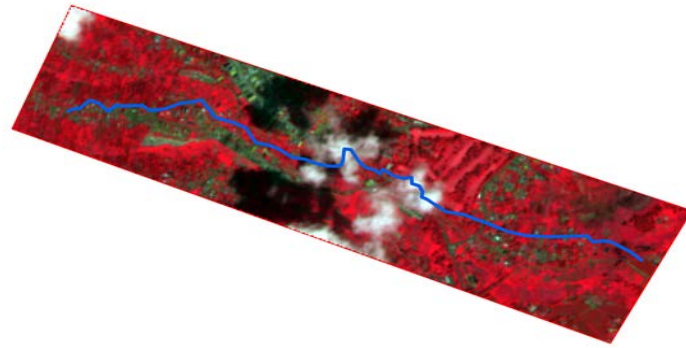
Vegetation cover change entailed the rate of change in plants and tree specimens along the river between the year 1970 and 2021. To determine the changes, false colour composites of the satellite imageries were developed, and Normalized Differences in Vegetation Indices were computed. In the images, the Near Infrared (NIR), Red and Green bands were used for extracting vegetation values.

#### *False Colour Composite*

The false colour composite for vegetation cover was obtained by stacking and arranging the bands in the format 5, 4, 3 (5 represents the NIR band, 4 represents Red in the visible section of the Electromagnetic spectrum, and 3 represents green). Vegetation often has a high reference usually seeming red in colour, with the red showing an accumulation in vegetation as shown in **Figure 4** below, indicating year 2003 false colour composite, and **Figure 5**, same year NDVI values respectively.

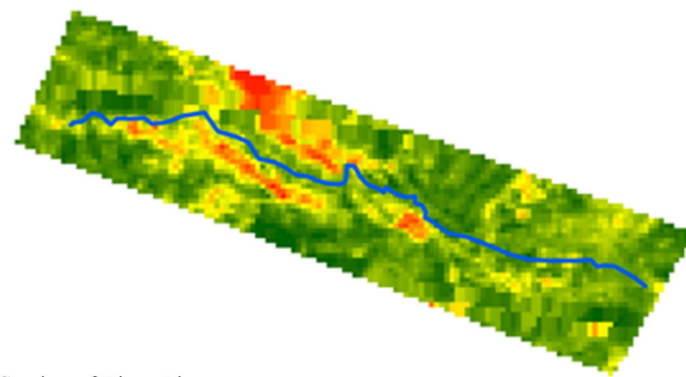
#### ✓ *Normalized Difference Vegetation Index (NDVI)*



The NDVI computation was done to determine the degree of vegetation accumulation along the river in the specific years. Its formula varied among the images since the satellites store different information in separate bands. For



**Figure 4.** 2003 False colour composite.

2003 NDVI Image



Section of River Riara   
 High: 0.876744  
 Low: 0.0780878

**Figure 5.** 2003 NDVI.

instance, in Landsat 8, NIR is found in band 5 but it is stored in band 4 in Landsat 7. However, the formula is consistent for all satellite missions.

Whereby, 
$$= \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$
, in all satellite missions including Landsat and sentinel.

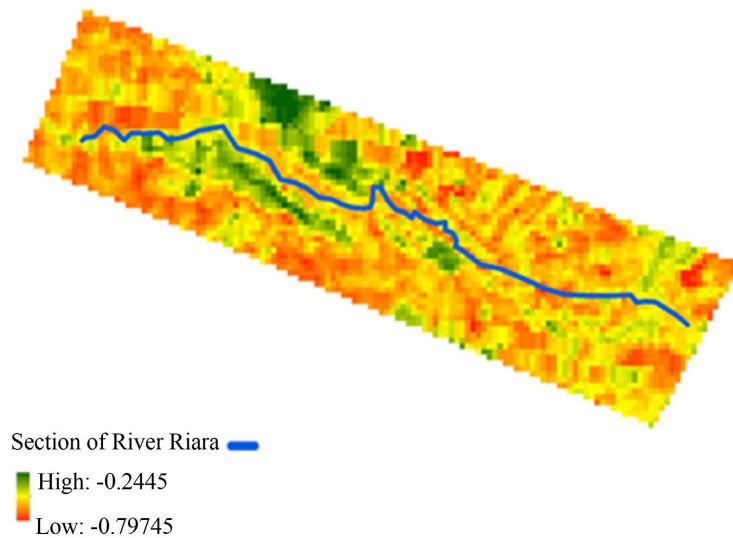
#### **Built-up areas**

The images were analysed to extract the built-up areas along the river. These included the buildings, and the rate of human settlements emerging that led to the reduction in vegetation cover. Normalized Difference Built-Up Index (NDBI) was computed to realize the rate over the years. In this computation, the Short-Wave Infrared (SWIR) and the NIR band were used as illustrated in **Figure 6** below, depicting NDVBI computation for the year 2003.

Whereby, 
$$= \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}}$$
, in all satellite imageries.

#### **R Squared Correlation**

After acquiring, the NDVI and NDBI values, the Pearson's coefficient was used to determine the correlation between the rate of built-up areas and vegetation



**Figure 6.** NDBI computation for the 2003 image.

cover. It would help to determine the impact of increase in built-up areas on vegetation cover along river Riara. The Pearson's correlation coefficient investigated the linear relationship between the two variables, NDVI and NDBI.

Whereby,

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}$$

$r$  = coefficient of correlation;

$x_i$  =  $x$  variable in the computation, the NDVI values;

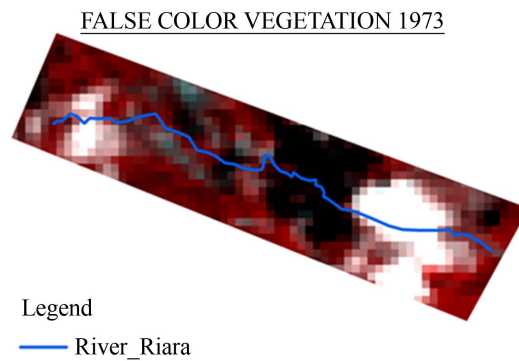
$\bar{x}$  = mean of the  $x$  variable values;

$y_i$  = the  $y$  variable, NDBI value;

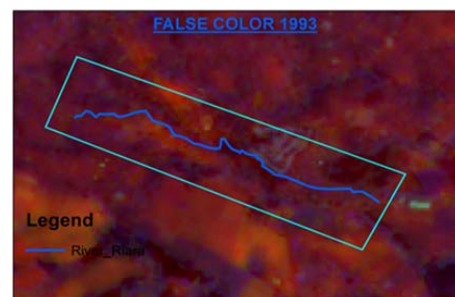
$\bar{y}$  = mean of the  $y$  variable values.

#### False Color Composites

**Figure 7** and **Figure 8** below represent the false colour composites for Landsat 1 images in 1973 and 1993. They appear blurry because Landsat 1 had 80 m spatial resolution and zooming in to the area of interest distorts the resolution. In **Figure 8**, the white represents cloud cover captured during the image collection. However, it is essential to note that both figures are dominated by the red colour. It represents vegetation cover. While generating the false colour composites for vegetation, the Near Infrared (NIR), Red, and green bands were used in the process. Often, vegetation has high reflectance in the NIR, while healthy vegetation has high visibility in the Red visible section of the electromagnetic spectrum. Therefore, the combination of NIR, Red, and Green, was effective in displaying the vegetation extent along river Riara in the years 1973 and 1993. Little built-up areas are visible in the images implying that there was more vegetation cover compared to build-up areas.



**Figure 7.** 1973 False colour composite.



**Figure 8.** 1993 False colour composite.

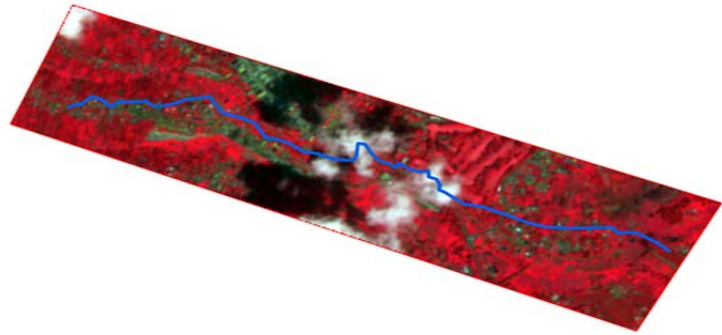
**Figure 9** and **Figure 10** below represent false colour composites for 2003, and 2015 respectively. In these images, there is a better resolution since Landsat 4 Thematic Mapper (TM) for 2003 and Sentinel 2 MSI for 2015 imagery was used. Landsat 4 TM has 30 metres resolution, while Sentinel 2 has 10 metres spatial resolution. In 2003, the red colour representing vegetation cover is dominant, but there are noticeable built-up areas along the river. Between 2003 and 2015, there is significant increase in built-up areas as seen in the 2015 false colour composite. There are more built-up areas along the river than vegetation cover

Similarly, **Figure 11** and **Figure 12** below represents false colour composites for 2015 and 2021 respectively. They illustrate that between that periods, there has not been an increase in the built-up areas along river Riara.

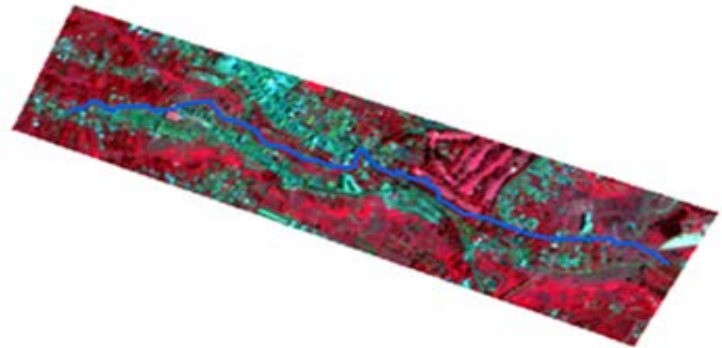
### 3. Results

**Figure 5** and **Figure 13** and **Figure 14** show the NDVI for 2003, 2015, and 2021 while **Figures 15-17** show resultant NDBI respectively. In the NDVI images, the green colour represents areas with high amounts of vegetation while the red colour represents areas with low amounts of vegetation implying that these are the built-up areas. The amount of vegetation was approximately 98.5666 acres, measured from the QGIS software. It amounts to 83.53% of the total areas. NDBI was calculated from the same images within a GIS to determine built-up areas. The green colour represents the points where the NDBI values were high, showing that these were the built-up areas. Hence, it was possible to track as the change occurred between 1993 and 2021.

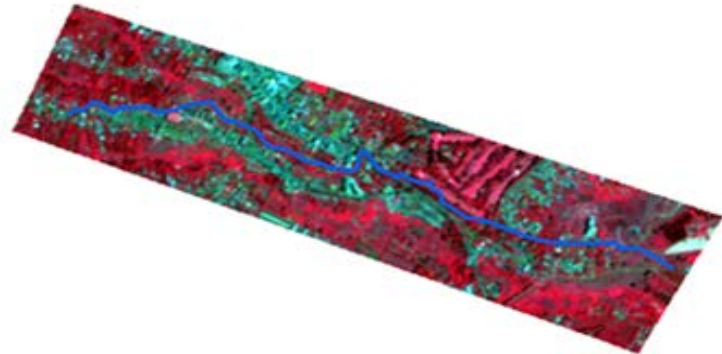




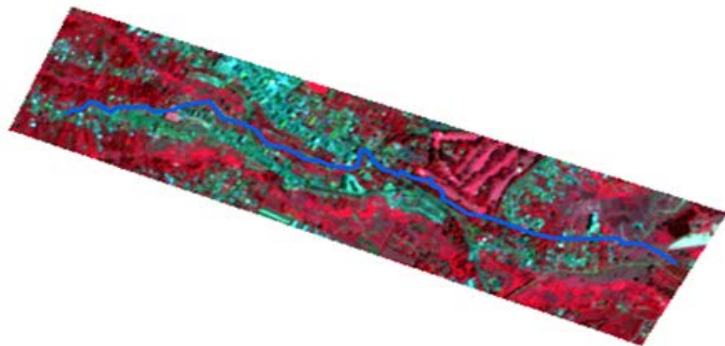
**Figure 9.** 2003 false colour image.



**Figure 10.** 2015 false composite.

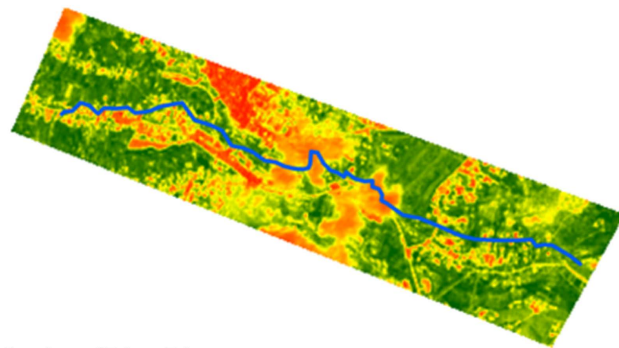


**Figure 11.** 2015 false colour composite.



**Figure 12.** 2021 false colour composite.

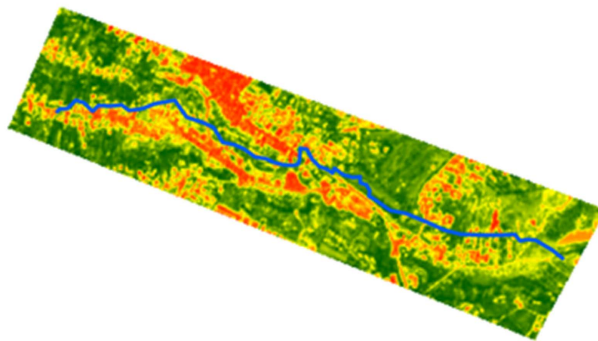
2015 NDVI Image



Section of River Riara —  
High: 0.848388  
Low: -0.030479

**Figure 13.** 2015, NDVI.

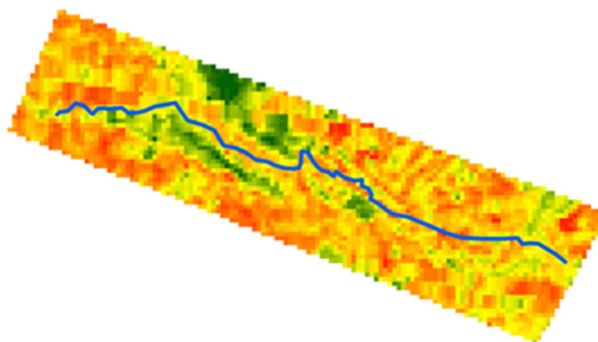
2021 NDVI Image



Section of River Riara —  
High: 0.888645  
Low: 0.101573

**Figure 14.** 2021, NDVI.

2003 NDBI Image



Section of River Riara —  
High: -0.2445  
Low: -0.79745

**Figure 15.** 2003, NDBI.

2015 NDBI Image

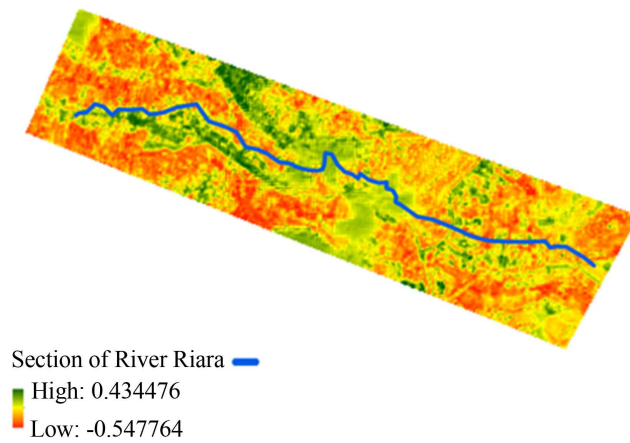


Figure 16. 2015, NDBI.

2021 NDBI Image

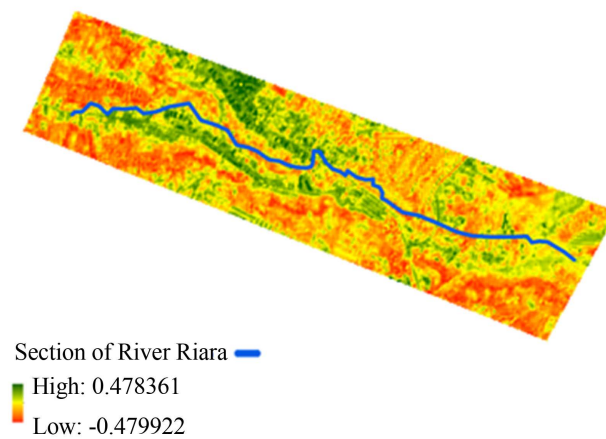
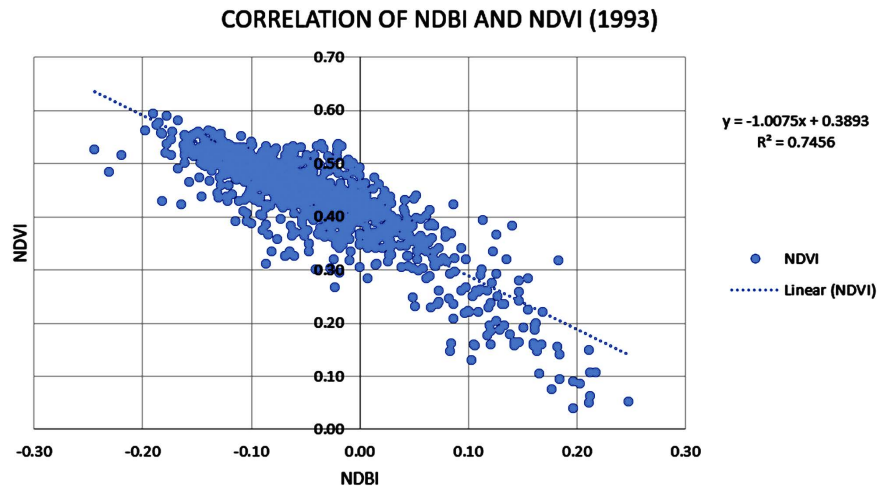


Figure 17. 2003, NBVI.

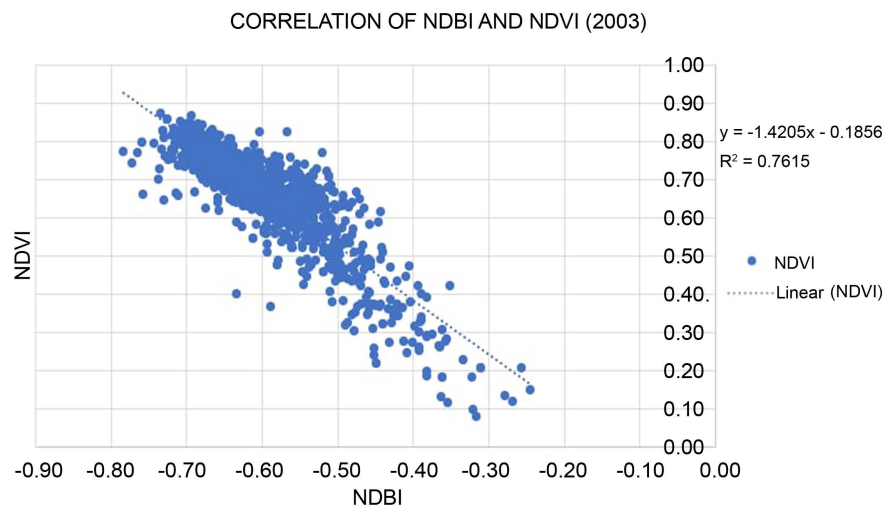
### Normalized Difference Vegetation Index (NDVI) and Normalized Difference Building Index (NDBI) and their correlation

The colour is dominant across the area of interest, and along the river. It means that in 1993, there were large volumes of vegetation. In the year 1993 NDBI, is the subsequent NDBI image for 1993 and the highest value is 0.29 represented by the green colour. The colour is less intense compared to red showing that there were minimal built-up indices along the river at this time. **Figure 18** below shows the R-squared value of correlation between NDVI and NDBI for the year 1993 at 0.7456. It means that there was 74.56% influence between vegetation and Built-Up area. The gradient is negative showing that variables are negatively correlated whereby an increase in Built-up areas leads to a decrease in the Vegetation along the river as indicated.

**Figure 19** below representing 2003 NDVI, had the highest NDVI values as 0.7615 represented by the green colour. This shows that vegetation cover was still



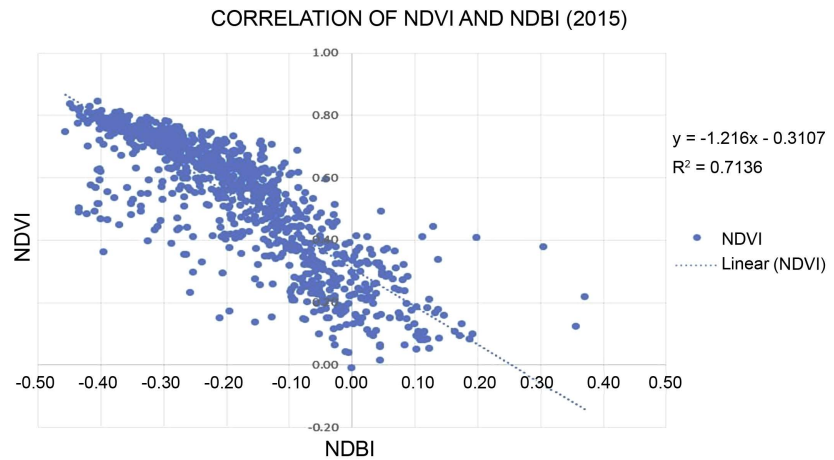
**Figure 18.** Correlation of NDBI and NDVI (1993).



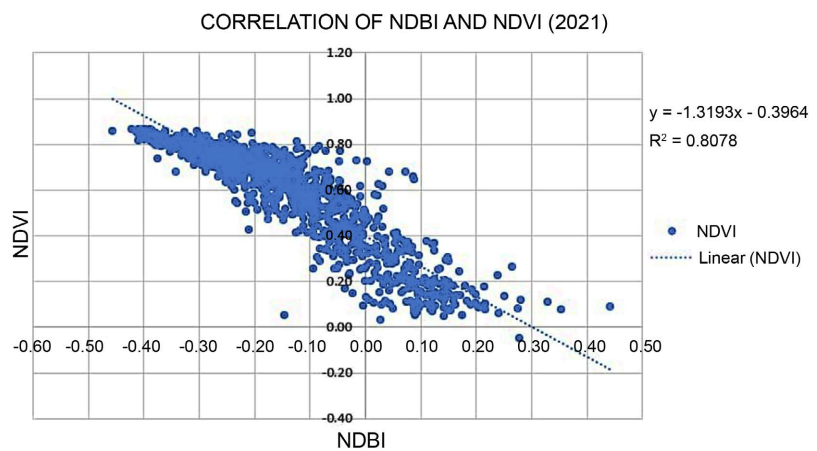
**Figure 19.** Correlation of NDBI and NDVI (2003).

high similar to 1993. The values increased by 71.6%, implying a similar increase in vegetation cover in the area. The subsequent NDBI image shows that the highest NDBI value was 0.24 implying that there were minimal built-up areas and no significant development had occurred in the area of interest.

**Figure 20** shows the NDVI image for 2015. The value is 0.7136 represented by the green colour. Compared to the 2003 image, it appeared that there was an increase in the red colour, which shows areas with low NDVI. There was a 4% decrease in NDVI. More so, the vegetation acreage had also reduced to 94.62336 acres, implying a 3.9867% decrease in vegetation. Therefore, it means that there has been an increase in the built-up areas by 55%, and the 3.94 acres lost in vegetation can be accounted for in built-up areas, meaning a reduction in vegetation cover in the area of interest and along the river. This shows that the R-squared value was 0.71 implying a 71% influence between the variables. A negatively sloping gradient shows that the variables are negatively correlated where an increase in built-up areas led to a decrease in vegetation in the area of interest.



**Figure 20.** Correlation of NDVI and NDBI (2015).



**Figure 21.** Correlation of NDVI and NDBI (2021).

**Figure 21** below depicting the year 2021 NDVI, presents the highest value as 0.8078. However, the complementary NDBI image has the highest value NDBI value as 0.47. It means that has been a significant increase in built-up areas since 2015. Sentinel 2 imagery was used for this year. The measured acreage for vegetation cover within a GIS amounted to 88.8994 acres. It implies that, from the initial acreage, there was a 7% decrease in vegetation cover along the river reserve as correlated for the year 2021.

#### 4. Conclusions

On the onset, the study finds River Riara section within Kiambu town is threatened by human activities mainly through conversion of riparian reserves for economic activities decreasing the natural vegetation riparian zone capacity. The combination of NIR, Red, and Green in the years 1973 and 1993 revealed little built-up areas. The year 2021 NDVI findings, however, indicated a high value at 0.88 value. However, the complementary NDBI image had the highest value NDBI value at 0.47. This shows that there has been a significant increase in built-up areas from 2015 to 2021. The measured acreage for vegetation cover within a

GIS software amounted to 88,8994 acres. Therefore, this implies, from the initial acreage, there was a 7% decrease in vegetation cover along the river. A comparison between 1993 land cover images and that of 2021 reveals a significant increase in built-up areas. It is represented by a significant increase in NDBI values, from 0.24 in 1993 to 0.47 in 2021. More so, the R-squared value in 0.80 shows that there was 80% relationship between NDBI and NDVI values. The R-squared value was 0.71 implying a 71% influence between the variables. Resultantly a negatively sloping gradient generated revealed that the variables are negatively correlated where an increase in built-up areas led to a decrease in vegetation along River Riara riparian zone.

On the other hand, riparian physical river vegetation cover and processes are increasingly seen as vital components for creating and maintaining riparian ecosystems' benefits. Consequently, their understanding, as well as linkages and feedbacks with ecology and hydrology, are assuming crucial importance for river riparian vegetation cover management and restoration. Finally, the vegetation cover and built-up area characterization of the Riara River Riparian Zone over time can be explained within the historical, ecological and human values context of riparian ecosystems.

## 5. Recommendations

In a systems approach, the urban rivers' riparian vegetation cover variables established in the study should not be perceived in seclusion. Rather, these attributes are parts of a whole where the riparian zone vegetation cover and its underlying factors are its main components. The development of an integrated framework for determination, use and management of riparian vegetation cover quality therefore should be developed, through elaborate public participation, aiming towards an integrated manner, incorporating different elements that define and determine the riparian zones in a changing and often turbulent urban land use environment.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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