BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

Journal of Environmental & Earth Sciences
https://ojs.bilpublishing.com/index.php/jees

ARTICLE

Urbanisation Footprints and the Distribution of Air Quality in Nairobi City, Kenya

Maurice O Oyugi*

Department of Architecture and Building Science, University of Nairobi, Kenya

ARTICLE INFO

Article history
Received: 25 May 2021
Accepted: 4 August 2021
Published Online: 31 August 2021

Keywords:
Urbanisation
Urban morphology
Air quality
Development density
Land use
Biomass index

ABSTRACT

Various postulations on the relationship between urban morphology and air quality are qualitative. This fails to establish the strength of the contributions of each morphological parameter in the spatial distribution of the air quality. It is this gap in knowledge that this study sought to fill by modelling the correlation existing between the urban morphological variables of development density, land uses, biomass index and air quality values of Nairobi city. While 30 development zones of the city constituted the target population, IKONOS satellite imagery of the city for the year 2015 was utilised in establishing the development densities, land uses and biomass index. The parameters were transformed into numerical surrogates ranging from 1 to 10 with lower values accorded to zones with low biomass index, the highest development density, noxious land uses, high gaseous concentrations and *vice-versa.* Pearson's correlation coefficients (r), coefficients of determination (R), *t*-tests and the Analysis of Variance (F-tests) with levels of significance being 95% were used to determine the strengths, significances and consistencies of the established relationships. The study established that development density is the most significant morphological variable influencing the distribution of air quality. This is followed by biomass index and to a weaker extent, land uses.

1. Introduction

Nairobi has witnessed high urbanisation rate as the city's population grew from 270,000 to 4,397,073 between the years 1963 and 2019, respectively. This represents approximately 4.7% annual growth rate compared to 3.5% per annum for major African cities [1,2]. This has been occasioned by modest national economic growth, high rural-urban migration and natural population increase rates as well as favourable physiographical base of the city, which apart from providing excellent sources of building materials has also lowered the construction costs [3]. Over the years, the increasing urban population has been accommodated through urban sprawl, with built-up areas expanding into the natural vegetation, causing ecological disruptions. Since urbanization is a major factor in global warming and climate modification, cities with high urbanisation rates such as Nairobi are associated with the same. The establishment that global warming and climate change is exacerbated by urbanisation and greenhouse gas (GHG) emissions has heightened studies on the correlations between urbanisation footprints of development densities, land uses, biomass index and the urban environmental quality parameters such as the urban heat islands, air quality, climate change and global warming. The urban morphological attributes notably;

**Corresponding Author:*
Maurice O Oyugi,
Department of Architecture and Building Science, University of Nairobi, Kenya;
Email: Maurice.oyugi@uonbi.ac.ke

DOI: https://doi.org/10.30564/jees.v3i2.3289

development densities, building configurations, street orientations and widths, man-made structures and green belts attenuates wind velocity within the canyons and the urban canopy layers, consequently affecting the dispersal and concentration of the air pollutants.

Land uses, building configurations and the distribution of development densities within an urban area influences the transportation mode used in the city as well as the city's energy consumption and GHG emissions. This is because proximity of homes and concentration of services coupled with provision of efficient public transportation accentuated by compact urban development encourages walking, cycling and use of mass transportation instead of private motor vehicles. This consequently leads to decline in fossil fuel consumption per capita. However, this is complicated by the fact that urban centres are industrial hubs and GHG emissions coming from industries outstrip those from the transportation sector. Overall, empirical evidence shows that cities are responsible for 75% of global energy consumption and 80% of GHG emissions. Compact developments induce usage of less energy for heating. For example, households in the United States of America living in single-family detached housing consume 35% more energy for heating and 21% more energy for cooling as compared to households living in other forms of housing due to urban heat island effect [4].

As corroborated by energy usage differentials in four urban spatial structures notably; mono-centric, polycentric, composite (multiple-nucleic) and urban village models, distribution of land uses equally influences the GHG emissions. In the mono-centric cities, most economic activities and amenities are concentrated in the Central Business District (CBD). This promotes usage of public transportation, for most commuters travel from the suburbs to the CBD. In the polycentric cities, few jobs and amenities are located in the centre and most trips are made from suburb to suburb. Therefore, a large number of possible travel routes exist, but with few passengers per route. This makes public transportation expensive to operate thus private means of transportation become convenient options for users.

The composite (multiple-nucleic) urban form manifesting a dominant centre with many jobs located in the suburb's minor centres is the most common urban spatial structure. In the model, most trips from the suburbs to the CBD are made using public transportation, while trips from suburb to suburb are made using private modes of transportation. This necessitates the need for both public and private modes of transportation. The urban village model is utopian and is a creation of the urban master plans. In this scenario, urban areas contain many business centres and a commuter travel to the centre closest to them, granting more opportunities to walk and cycle to work. This model is ideal for it requires less transportation due to the reduced distances to work. This lowers the energy usage and the GHGs emission. Therefore, the more the urban spatial structure encourages public transportation, the more it leads to less emission of GHGs and *vice versa*. The above annunciations corroborate the correlation between urban morphology, GHG emissions and air quality. However, the relationship is moderated by the quantity and quality of vegetation, which are carbon sinks within the urban landscape. According to Klaus *et al.* [5], polluted air accumulates in the built up areas due to convergence of air into the areas during the day for such areas are warm and acts as urban heat islands. At night, this is replaced by cool fresh air from adjacent cold neighbourhoods. It is therefore evident that urban air quality and surface temperature values is determined by urban structures, anthropogenic and physical process.

The effect of urbanisation on global warming and climate change has raised challenges to sustainable urbanization and efforts have been made to postulate theories and models explaining the relationships, with majority being descriptive rather than quantitative. However, it is quantitative models facilitated by geospatial techniques, which have a niche in aiding the validation of the correlation. The geospatial techniques further provide an efficient and effective method to the analysis and modelling of the urban air quality distribution with morphological variations as well as building an understanding on the contributions of urbanization, expanding industrialization and problems associated with high-density developments to global warming and climate change. This is imperative in aiding the formulation of urban environmental policies geared towards mitigating the ravages of global warming and climate change [2,6]. Inasmuch as there is concurrence among the scholars that there is a significant relationship existing between urban morphology and air quality, the fundamental question is to what extent is an individual morphological parameter determining the distribution of air quality within a city. It is this gap in knowledge that this study sought to fill by quantitatively modelling the relationship existing between the urban morphological variables of development density, land uses, biomass index and the air quality values of Nairobi city.

The study which was guided by the hypothesis that there is a significant relationship existing between urban morphology and the air quality establishes the strength of the relationships existing between and among the

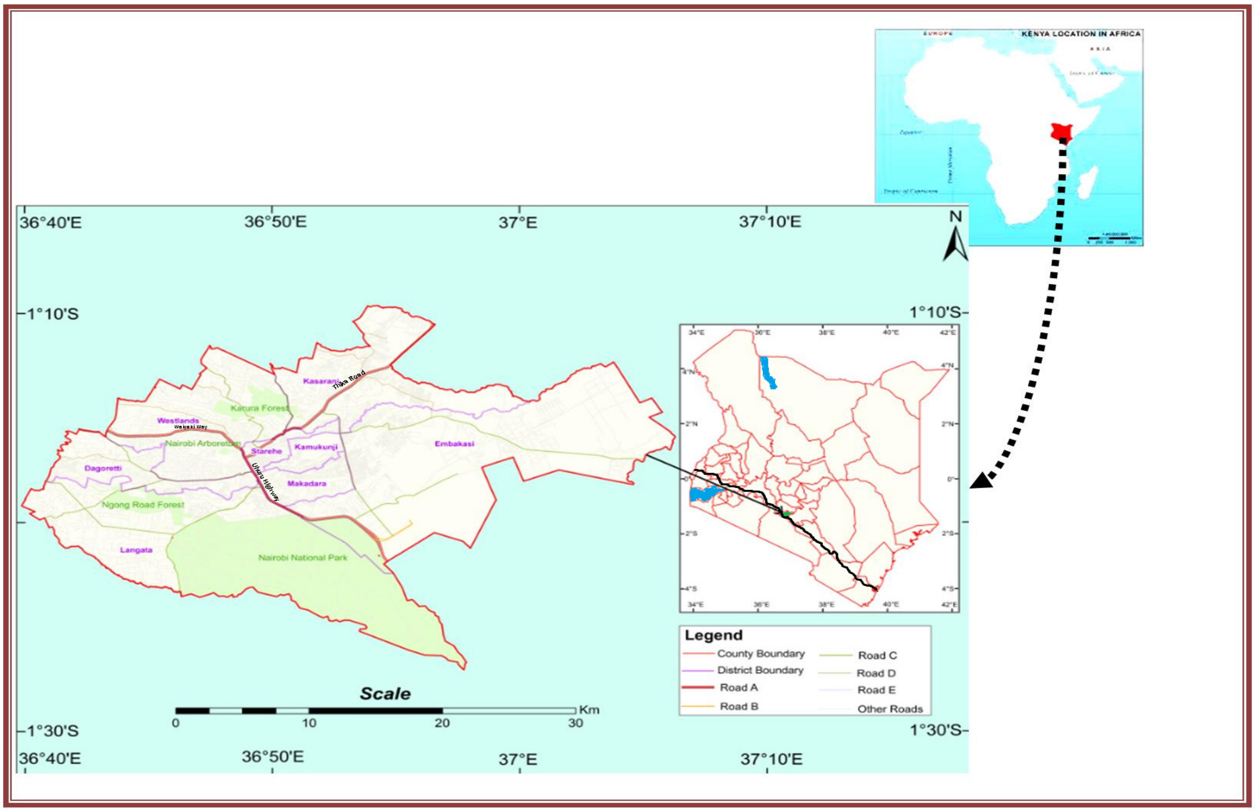

Figure 1. Location of the Study Area

urban morphological parameters of development density, land uses and biomass index and the air quality values of Nairobi city as derived from geospatial and *in-situ* measurements. This gives credence to urbanisation as a significant factor in global warming and climate change. To fulfil the aim of the study, wind velocity in the city was assumed constant throughout the year. Therefore, the distribution and the concentrations of the air pollutants within the city are only influenced by the amounts of the pollutants emitted by the point and mobile sources.

2. Methods and Materials

The study adopted both descriptive and quantitative designs to explain how air quality is distributed over Nairobi city and factors influencing the phenomenon. The study covered the entire Nairobi City County bounded by longitudes 36^0 40’ and 37^0 10’E and latitudes 1^0 09’ and 1^0 28’S covering an area of approximately 716 km^2 (Figure 1). While the independent variables of the study were urban morphological parameters of development density, land uses and biomass index, the dependent variable of the study was air quality (concentrations of carbon dioxide, sulphur dioxide, nitrogen dioxide and the suspended particulate matter) values. Biomass index was considered in this study as a morphological parameter because vegetation influences air quality through filtration, recycling and attenuation of wind velocity to influence the distribution of air pollutants [7,8]. However, the study did not consider water vapour, methane and ozone gases which are integral aspects of GHGs and the main drivers of global warming and climate change because the concentration of water vapour in the city is presumed to be uniform and determined by precipitation levels and not the anthropogenic activities. The ozone and methane gases are stratospheric layer gases thus could not be considered in this study, which relied on instruments whose validity and reliability are only guaranteed in the troposphere. The gases considered in the study are by-product of transportation and industrial fossil fuel combustion whose concentrations are subject to increase with urbanisation. Apart from the gases having noxious venom effect on human, animals and plants’ health, the ability of the gases to form acid rain makes them destructive to vegetation, soil, construction materials and water bodies.

Building configuration exemplified by higher building densities and skyscrapers influence urban environmental quality through loss of natural vegetation alongside attenuation of wind velocity. This restricts air pollutants to urban canyons thus impeding pollution dispersal. Despite the significant role the building configuration plays in

DOI: https://doi.org/10.30564/jees.v3i2.3289

the determination of the urban air quality, it was not included in the study because the analysis of the building configuration requires up-to-date aerial photographs as opposed to satellite remote sensing utilised by the study. The constraint was in the acquisition of up-to-date aerial photographs of the city as the existing photographs are out-dated and provides incomplete spatial coverage of the city. Another limitation to the study was lack of air quality measuring stations in the city whose data could be utilised. This necessitated the use of *in-situ* approach for data capture, which is time consuming and expensive in terms of human resource involved, laboratory analysis and the cost of hiring the air samplers. Studies of this nature require more point data to support interpolation of the air quality values in the city.

2.1 Target Population and Sampling Procedures

All the 30 development zones prescribing development densities and land uses as detailed out by the Nairobi City County Government constituted the target population. Except for the air quality, sampling was not undertaken for the biomass index, development density and land uses.

2.2 Assessment of Development Density and Land Use Variations

Pre-processed and rectified multi-spectral IKONOS imagery of Bands 2, 3 and 4, covering the city together with the development-zoning map procured from the Nairobi City County Government were used for land use and development density analysis. The study area had to be extracted from the IKONOS imagery for the procured imagery covered the city and its environs. The analysis of development densities was undertaken through polygonisation of the developed surfaces from the extracted imagery. This was further overlain to development-zoning boundaries. The development densities were computed through aggregating areas of developed surfaces within a zone as a ratio of the zone's area. The computed densities for the 30 zones were further transformed into numerical (nominal) values ranging from 1 to 10. Since high development densities compromises air quality as compared to low densities, high development density zones were assigned low (1) numerical values while low density zones were assigned high (10) numerical values and spatially presented.

Visual image interpretation technique utilising the nine elements notably; shape, size, shadows, site, tone, texture, pattern, height and association was used to analyse land use distribution within the city and the identified land uses polygonised into a map. To assess the accuracy of the established land uses, random ground truthing aided by a hand-held GPS was undertaken. As informed by implications of the land uses on air quality, the identified land uses were assigned nominal values ranging from 1 to 10. Land uses such as industrial users known to compromise the air quality were assigned the lowest nominal values while forests and parks known for the enhancement of air quality were assigned higher nominal values. To arrive at a nominal value for a development zone based on land uses, proportion of a zone's area under different land uses were multiplied by the assigned nominal value of the land use and aggregation of the same undertaken per zone. This information is spatially presented inform of a map. This is similar to the procedure postulated by Nichol *et al* [9] when undertaking the assessment of urban environmental quality of Hong Kong city.

2.2.1 Determination of Biomass Index

Vegetation influences urban air quality due to its ability to purify the air and attenuate wind flow. However, it has been established that the biomass component of the vegetation is the most significant determinant of the degree to which vegetation influences ecosystem purification and energy flow. Remote sensing techniques for mapping urban vegetation parameters such as the total green spaces and the percentage of tree canopy combines higher resolution infrared imageries such as IKONOS, GEO-EYE, QUICK-BIRD with aerial photography and fieldwork. Although such methods are expensive, they present the best option for the medium resolution satellite imageries such as SPOT and Landsat lacks spatial details to detect fragmented urban vegetation [10]. As noted by Fung and Siu [11] who used Normalised Difference Vegetation Index for the assessment of Hong Kong city's vegetation change over time, Landsat imagery is only useful in conducting generalised surveys of green spaces and vegetation vigour, but fails to discriminate the vegetation type. The above being the case, IKONOS imagery as augmented by the zoning map of the city was utilised in facilitating the computation of the biomass index.

The clipping of the area constituting the city was undertaken from the multi-spectral IKONOS imagery upon which classification and polygonisation of the vegetation types were undertaken. To facilitate the computation of the Biomass Index (VD), the development zone boundaries were overlain on the generated vegetation cover map. The index for individual vegetation type was computed using equation 1 adopted from Nichol *et al* [9].

 DOI: https://doi.org/10.30564/jees.v3i2.3289

$$\%VD = 100\ \frac{W_v L_v}{L} / \sum W_v \quad (1)$$

Where: -

VD: Biomass Index

Wv : Weighting for each vegetation type *v;*

L$_v$: Area covered by a vegetation type *v* in a zone;

L: Total Area of a zone.

Averaging of biomass index for the development zones were undertaken and converted into numerical values ranging from 1 to 10 (Table 1). In acknowledging that vegetation covers with high biomass index impact positively on air quality, development zones with high average biomass index values were assigned higher (10) nominal values and *vice-versa* and spatially presented.

Table 1. Vegetation Weightings

Type	Weighting	Description
Short grass	0.2	Green grass lower than 0.5 m
Tall grass	0.4	Green grass higher than 0.5 m
Shrub	0.6	Short and woody plant with woody (non-green) stems from the base
Small Tree	0.7	Woody plant with trunk diameter < 0.3 m
Large Tree	0.9	Woody plant with trunk diameter > 0.3 m

Source:Adopted from Nichol *et al* [9]

2.3 The Assessment of the Spatial Variations of Air Quality within the City

Air sampling was undertaken to establish the concentrations of SPM, carbon dioxide, sulphur dioxide and nitrogen dioxide gases within the city. For the purposes of collecting air samples, sample sites were established through regular systematic point technique which involved the subdivision of the city into regular grids each measuring 8.0 square kilometres. Systematic random sampling technique of three grid intervals in all the directions was thereafter utilised in deciding the grid cells from whose centres air samples were picked [12]. Additionally, the coordinates of the sample sites were established using ArcGIS 10.5 Software. The identification of sample sites was done through hand held GPS. A total of 240 sample sites were established and air samples collected for laboratory analysis using Spectrex PAS-500 hand held air samplers. Granted that some zones such zone 20A (Karura Forest), 20G (Nairobi National Park), 20F (Jomo Kenyatta International Airport) and 20J (Ngong Forest) among others are homogeneous in terms of development densities and land uses, few samples were taken from the zones despite their larger sizes. Therefore, apart from the size of a development zone, decision on the number of sampling sites established per zone was further influenced by development densities and the heterogeneity of the land uses.

Laboratory readings for the gaseous concentrations were made for each sampled grid and averages computed by gas type per zone (Table 2). This was further converted into nominal values ranging from 1 to 10 with aggregate and average nominal values of the same computed per zone. Low gaseous concentrations were assigned higher (10) nominal values and *vice-versa*. Therefore, zones with high average gaseous concentration nominal values corresponded to zones of better air quality. The study adopted spatial interpolation technique, which relies on Geographical Information System to generate continuous surfaces from point measurements. The technique is premised on *Tobler's First Law of Geography* which states that *"The closer two points are, in space the more likely the points are similar and influence each other"*. As informed by simplicity, accuracy and sensitivity to clustering and presence of outliers, Inverse Distance Weighting (IDW) technique of

Table 2. Form Used for Recording Air Quality Values

Development Zones	Average Carbon Dioxide Values	Carbon Dioxide Nominal Values	Average Nitrogen Dioxide Values	Nitrogen Dioxide Nominal Values	Average Sulphur Dioxide Values	Sulphur Dioxide Nominal Values	Average Suspended Particulate Matter Values	Suspended Particulate Matter Nominal Values	Total Air Quality Nominal Values	Average Air Quality Nominal Value
1										
2										
3										
4										
.										
20J										

DOI: https://doi.org/10.30564/jees.v3i2.3289

spatial interpolation was used in modelling the distribution of the gaseous concentrations into continues surfaces. In this technique, the weights of the measurements diminish as a function of distance, hence the name Inverse Distance Weighted technique [13]. While the results of the computations are presented in tabular format, the various gaseous concentrations are spatially presented using ArcGIS 10.5 Software.

2.4 Air Quality Model for the City

To arrive at a model explaining the spatial distribution of air quality in the city based on morphological variables under consideration, nominal values ranging from 1 to 10 were used (Table 3).

Bivariate and multivariate models were used in establishing the strengths of the relationships existing between the variables. This was done through the computation of the correlation coefficients (r) of the relationships. To determine the significance of the relationships and consistencies of the same, *t*-test and ANOVA were undertaken with levels of significance (α) and confidence being 5% and 95% respectively. In this endeavour, SPSS Software was used for statistical analysis. The correlation coefficients and the coefficients of determinations were calculated using *Pearson's Product Moment Correlation Coefficient Index* stated as function 2.

$$r = \frac{\sum[X-\dot{x}][Y-\dot{y}]}{\sqrt{\sum[X-\dot{x}]^2}\sqrt{\sum[Y-\dot{y}]^2}} \quad \text{...} (2)$$

Where: -

r = Correlation Coefficient

X = The Independent Variables

ẋ = The Mean of the Independent Variables

Y = The Dependent Variables

ẏ = The Mean of the Dependent Variables

The study concludes that there is no relationship existing between the variables if the established correlation coefficient (r) is zero. Similarly, if the correlation coefficient (r) value was established at between 0 and either -0.5 or 0.5, then it's concluded that there is a weak relationship existing between the variables. While the study concludes that there is fairly significant relationship existing between the variables if the established correlation coefficient (r) was either -0.5 or 0.5, the study concludes that there is a moderately significant relationship existing between the variables under consideration if the established correlation coefficient (r) ranges from either -0.5 to -0.7 or 0.5 to 0.7. Correlation coefficient (r) values ranging from either -0.7 to -1.0 or 0.7 to 1.0 are considered very significant.

Regression Models were established through equations 3, 4 and 5.

$$(\grave{Y} - \dot{y}) = \frac{(r)\delta Y[X-\dot{x}]}{\delta X} \quad \text{...} (3)$$

Where: -

Ỳ = Estimated Dependent Variable

r = Correlation Coefficient value

X = The Independent Variables

ẋ = The Mean of the Independent Variables

Y = The Dependent Variables

ẏ = The Mean of the Dependent Variables

δY = The standard deviation of the dependent

Table 3. Table Used for Correlating Air Quality with Urban Morphological Variables

Development Zones	Air Quality Nominal Values	Land Use Nominal Values	Development Density Nominal Values	Biomass Index Nominal Values
1				
2				
.				
.				
.				
.				
.				
.				
20J				

variables (Y)

δX = The standard deviation of the Independent variables (X)

The δY and δX are computed as:

$$\delta Y = \frac{\sqrt{\sum[Y-\acute{y}]^2}}{n-1} \quad \text{.......} (4)$$

$$\delta X = \frac{\sqrt{\sum[X-\acute{x}]^2}}{n-1} \quad \text{.......} (5)$$

Hence the regression model is stated as function 6

$$\Upsilon = a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 \text{..............} + \acute{\varepsilon} \quad \text{.......} (6)$$

Where:

Υ = The urban air quality value

X_s= The independent variables

a_s = Coefficient of determinations of the independent variables

$\acute{\varepsilon}$ = The error term

The tests of significance of the established correlations were undertaken using *t*-test stated as either function 7(a) or 7(b).

$$t = \frac{r}{\sqrt{[1-r^2/n-2]}} \quad \text{.......} (7a)$$

Or

$$t = \frac{(r)[\sqrt{n-2}]}{\sqrt{[1-r^2]}} \quad \text{.......} (7b)$$

Where:

t = The calculated *t*-value

r = Correlation Coefficient Index

n = Sample Size

With level of significance (α) being 0.05 and the degree of freedom (df) being n-2, null (H_0) hypothesis was rejected if the calculated-*t* value was greater than the critical -*t* value. The ANOVA or the F-test facilitated the decisions as to whether the witnessed correlations occurred by chance or not (Table 4).

Table 4. The Analysis of Variance (ANOVA)

Source of Variation	Degree of Freedom	Sum of the Squares	Mean of the Squares
Accounted for by the Regression Line (SSR)	1	SSR =$\sum(\dot{Y}-\acute{y})^2$	SSR/1 SSR =$\sum(\dot{Y}-\acute{y})^2$
Accounted for by the Residuals (SSE)	n-2	SSE = $\sum(Y-\dot{Y})^2$	SSE/n-2 SSE = $\frac{\sum(Y-\dot{Y})^2}{n-2}$
Accounted for by the Mean (SST)	n-1	SST = $(Y-\acute{y})^2$	Nil

Source:Hammond and McCullagh [14].

The F-values were calculated using either function 8(a) or 8(b).

$$F = \frac{SSR/1}{SSE/n-2} \quad \text{.......} (8a)$$

Or

$$F = \frac{\sum(\dot{Y}-\acute{y})^2}{\sum(Y-\dot{Y})^2/n-2} \quad \text{.......} (8b)$$

With level of significance (α) being 0.05 and degree of freedom being n-2, the null hypothesis (H_0) was rejected if the calculated F-value was greater than the critical F-value.

2.5 Quality Assessment – Validity and Reliability

Validity of the information obtained in the study was safeguarded by pre-testing of data collection instruments, training of the Field Assistants on appropriate use of the instruments as well as proper data entry, particularly the data obtained through *in-situ* measurements. Equally, secondary information particularly the satellite imageries used in the study were procured from internationally accredited organisations notably from the United States Geological Survey (USGS) while the development zoning map and other allied maps were sourced from Nairobi City County Government and the Survey of Kenya. Reliability was achieved in the study by ensuring that the instruments used for *in-situ* measurements were granted equal exposure time. This was further accentuated by training of Research Assistants on accurate data capture and entry.

3. Results and Discussions

3.1 The Morphological Attributes of the City

Urban morphology, which is an embodiment of development densities, land uses, biomass index and building configurations among others affects urban air quality by attenuating wind circulation and generation of GHGs, consequently accentuating the concentration of air pollutants to heighten global warming and climate change. This realisation has brought forth the concept of urban sustainability, which incorporates ecological rationalisation in urban design and development. The concept has further provoked scholars to seek new models for redesigning the urban places. In this endeavour, four models of urban sustainability notably; neo-traditional development, urban containment, compact city and eco-city are currently being implemented in the cities. These models are based on seven main design concepts notably; the compactness, sustainable transportation, density, mixed land uses, diversity, passive solar design and greening.

DOI: https://doi.org/10.30564/jees.v3i2.3289

3.1.1 The Land Uses of Nairobi City

The study established that by the year 2015 wetlands, parks and other recreational spaces, forests, commercial developments, airport land, industrial and residential developments, quarry land, urban agriculture, water bodies and riparian reserves, railway land, public purpose (educational institutions, hospitals and governmental offices) and undeveloped lands were the major land uses in the city (Table 5, Figure 2). Sizes of various land uses are computed in square kilometres per development zone (Table 6). This is collectively done with the computation of aggregate nominal values of the zones based on land uses and further spatially presented (Table 7, Figure 3).

Residential Land-Uses

Residential land-uses consisting of high, medium and low density habitations occupied 204.65 km^2 or 28.56% of the city's land. Even though this study did not dichotomise the residential land uses into these categories, high density residential developments consisting of areas with over 10,000 people per square kilometre are generally located in the north-eastern, south-eastern and south-western parts of the city as exemplified by Kariobangi, Dandora, Mathare, Kibera and Mukuruu neighbourhoods among others. As compared to low density residential neighbourhoods such as Karen, Muthaiga, Runda, Lavington, Kileleswa and Spring Valley which are inhabited by between 3,000 to 6,000 people per square kilometre, high density neighbourhoods are inadequately served by sanitation and drainage facilities making them environmental squalors. Most of the residential neighbourhoods in the city fall under medium density developments inhabited by between 6,000 to 10,000 people per square kilometre as exemplified by Langata, Kilimani, Embakasi and Buru-Buru neighbourhoods among others (See Appendix I for the development zones where the mentioned neighbourhoods fall).

The urban housing needs in Kenya is estimated at

Table 5. Proportions of Land Uses in the City by the Year 2015

	Land Uses	Area (km^2)	Percentages
1.	Residential Developments	204.65	28.56
	Industrial Developments		
2.	Secondary Industrial Developments	24.15	3.37
	Quarry Land	2.93	0.41
3.	**Commercial Developments**	41.29	5.76
	Transportation and Public Purpose Developments		
4.	Airport Land	17.44	2.43
	Railway Land	2.20	0.31
5.	**Public Purpose Lands:** Government Institutions, Hospitals, Schools, Universities, Colleges, Prisons and Military Barrack	20.97	2.93
	Recreational and Ecological Conservation Areas		
6.	Parks and Other Recreational Spaces	138.44	19.32
	Forests	26.45	3.69
	Wetlands	0.94	0.13
7.	**Public Utilities**		
	Water Bodies, Domestic and Waste Water Treatment Plants	3.81	0.53
	Deferred Land Uses		
8.	Urban Agriculture and Riparian Reserves	112.64	15.72
	Undeveloped Land	120.77	16.85
Total		716.22	100.00

200,000 units per annum, but only 30,000 units are being developed, resulting in an annual deficit of over 170,000 [15]. As accentuated by rapid urbanisation and inadequate budgetary provisions, the public and private sectors have not kept pace with the increasing demand. This has exposed the sector to market forces which are not sensitive to the needs of the middle and low-income cohorts, hence the continued mushrooming of informal settlements. This has further been exacerbated by lag in the expansion of housing infrastructure and serviced land, low purchasing power of the majority households, restrictive by-laws, inadequate access to housing finance and land policy allowing manipulation in tenure. Therefore, tackling housing deficit in the city requires reviewing policies which alienates the majority from accessing land.

Informal settlements in Nairobi have gradually grown since 1902 when European settlers appropriated large tracts of land in the environs of the city, consequently displacing indigenous inhabitants. While the colonialists made little provision for accommodating Africans in Nairobi, Africanisation policy after independence led to more Africans migrating into the city, consequently leading to the emergence of the informal settlements. According to Shihembesta [16], Kenyatta's administration allowed immigrants who could not find accommodation in the existing formal low-cost housing estates to put up temporary structures within the city as long as these structures were not too close to the CBD. Most of the houses in the informal settlements are single roomed with occupancy of over 6 inhabitants. This is not healthy for housing units having more than 2.5 people per habitable room are considered overcrowded [15]. In most cases, the informal settlements are established on flood plains, steep slopes, river banks and areas adjacent to sewers and dump sites where the inhabitants are increasingly exposed to health risks and disasters. Since slum demolition is justified by the Public Health Act (Cap 242), the inhabitants of such neighbourhoods are constantly under eviction threats and harassment.

Industrial Activities

Quarrying and manufacturing activities dominate the city's industrial sector. The need to enhance income and to reduce walking distance to the employment zones informed the *Nairobi Metropolitan Growth Strategy of 1973* which recommended restrictions on expansion of the then-existing industrial areas, but encouraged developments of additional seven secondary industrial areas next to residential neighbourhoods of Komarock, Ruaraka, Kariobangi, Dandora, off Mombasa road, North Airport road and off Outer Ring road (Figure 2). Since then, the city has witnessed expansion of industrial land

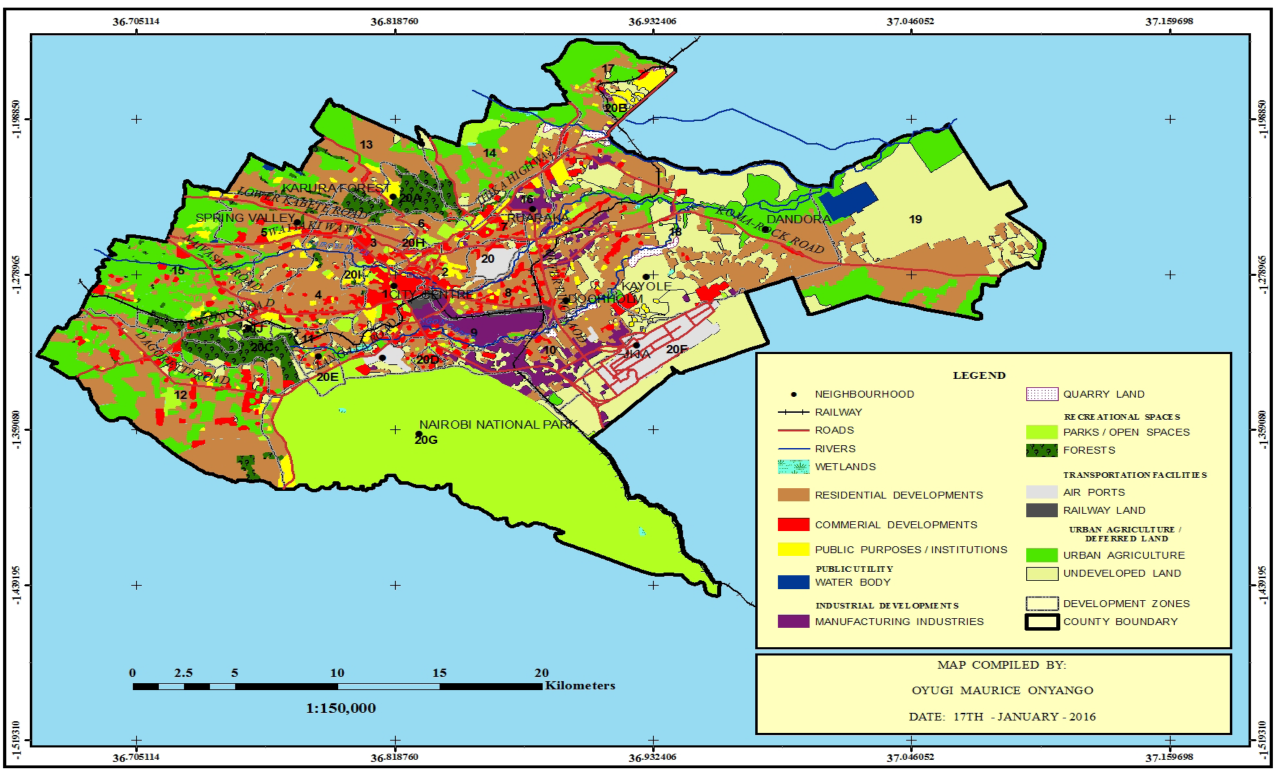

Figure 2. Land Uses of Nairobi in the Year 2015.

DOI: https://doi.org/10.30564/jees.v3i2.3289

uses which by the year 2015 stood at approximately 24.15 km^2 or 3.37% of the city's land. However, the industrial land uses are concentrated in the southern and eastern parts of the city; off and along Mombasa road, Kariobangi, Ruaraka, Dandora, Komarock, North Airport road and off Outer Ring road neighbourhoods. As attributed to vibrant construction industry, which has hiked the demand for building stones, quarrying has emerged with greater environmental concern in the city, particularly in the eastern and north-eastern neighbourhoods such as Kahawa, Kayole, Mwiki, Kasarani, Njiru and Ruai. By the year 2015, the land use occupied approximately 2.93 km^2 or 0.41% of the city's land. Apart from reducing the air quality through exacerbating smoke and dust pollutions as well as reducing aesthetic value of the human settlements, the explosives used in quarrying is a major source of noise pollution in the neighbourhoods where the quarries are situated.

Commercial and Service Centres

Apart from the commercial activities in the CBD, the *Nairobi Metropolitan Growth Strategy of 1973* recommended the development of seven other satellite commercial centres next to the industrial areas, which were proposed by the strategy. The strategy further recommended implementation of new housing schemes with at least a commercial centre. Currently, commercial land uses occupy approximately 41.29 km^2 or 5.76% of the city's land. These include the CBD, Westlands, Capitol Hill, Ngara areas, Eastleigh, Buru-Buru and Dagoretti Corner among others.

Public Purpose Land-Uses

Institutional land uses which are spread across the city include airports, airfields, railway land and institutions such as the hospitals, schools, universities, colleges, prisons and military barracks. Collectively these land uses occupy approximately 40.61 km^2 or 5.67% of the city's land.

Recreational and Ecological Conservation Areas

Parks and other Recreational Spaces

The city's biodiversity which is carbon sinks, moderators of urban micro-climates and provider of support to environmental education and biodiversity conservation programmes are constantly threatened by land fragmentation, degradation, overexploitation and pollution. The city's biodiversity has been sustained by favourable local ecological conditions such as high altitude, rainfall and fertile soils. The major parks and recreational spaces in the city include the Nairobi National Park, City Park and other minor recreational spaces such as the Uhuru Park, Jamhuri and Jeevanjee Gardens as well as Nyayo, Kasarani and City stadia which collectively occupy 138.44 km^2 or 19.32% of the city's land.

Forests

Nairobi city which was established on a mosaic landscape consisting of open grasslands, forests, woodlands and swamps has since been modified by anthropogenic activities with only small pockets of natural vegetation still remaining. Today the forests notably; Nairobi Arboretum, Karura, Ngong, Ololua and Dagoretti forests which have continued to play crucial roles as micro-climate moderators and water towers for the rivers within the city occupy 26.45 km^2 or 3.69% of the city's land. Karura forest is the water tower for Thigiri, Karura, Ruaraka and Gitathura rivers dissecting the northern parts of the city. The forest also supports plantation and indigenous trees which are sources of timber for domestic furniture and wood carvings. While Ngong forest which consists of planted and indigenous trees as well as grasslands was excised between the years 1963 to 1994 leaving it highly fragmented, the biodiversity of Ololua forest is under threats occasioned by mining activities. The Nairobi Arboretum has mainly been used for trials of plant species introduced in the country [17]. Illegal loggings targeting high-value tree species and allocations of parts of City park, Karura and Ngong forests to private developers have degraded and reduced the city's forests cover. In addition, implementation of the 60-meter wide southern by-pass road through Ngong forest has led to clearance of approximately 30 hectares of forest cover. This is likely to affect the city's air quality and microclimatic conditions [18]. The reduction of the forest cover has also been occasioned by weak enforcement of laws protecting the forests and budgetary constraints in the institutions responsible for forest management. For instance, the previous Forest Act (Cap.385) authorised the minister in charge of forests to gazette and/or de-gazette forest reserves without consultations. However, the Forest Act of 2005 has made the process more stringent [19].

Water Bodies and Wetlands

Apart from the rivers, other water bodies and wetlands in Nairobi are the Ruai waste water treatment plant and Nairobi dam. While water bodies cover approximately 3.81 km^2 or 0.53% of the city's land, wetlands cover approximately 0.94 km^2 or 0.13% of the city's land.

DOI: https://doi.org/10.30564/jees.v3i2.3289

Continued discharge of untreated waste water and surface run-offs from municipal, industrial and agricultural land uses have increasingly polluted and eutrophicated the water bodies and wetlands. For example, Nairobi dam which was constructed in 1953 with a surface area and storage capacity of 350,000 m^2 and 98,000 m^3 respectively is currently shallow with an average depth of 2.76 metres. The reduction in the depth is attributed to silting of the dam as occasioned by inflow from the Ngong river and other surface run-offs from the Kibera settlement. While the water hyacinth, which has clogged the dam, has prevented recreational sailing and fishing which were the intended purposes for the construction of the dam, the scenario has further been complicated by the reclamation of sections of the dam for agricultural purposes through dumping of the solid wastes.

Agricultural and Deferred Land Uses

Urban agriculture has continued to manifest in the city through livestock rearing, cultivation of crops, fodder and horticulture as well as tree nurseries. Approximately 112.64 km^2 or 15.72% of land in Nairobi is under agriculture, with farming activities taking place along railway and road reserves, within flood plains and backyards of low density residential neighbourhoods, unutilized industrial plots and in the peri-urban areas where land holdings are large enough to accommodate cultivation and livestock rearing. While urban agriculture presents opportunities for alternative livelihood, it has adverse environmental impacts notably; upsurge of zoonotic diseases and chemical poisoning. Unattended livestock consume industrial effluents contaminated with heavy metals, which often end up in the food chain. Farmers in Nairobi also block open sewers to irrigate their crops, and thus predispose consumers of such products to pathogens and contamination with heavy metals. Chicken, goats and cattle reared in the informal settlements and urban peripheries contribute to waste volumes in form of dung. Kenya is lacking policies on urban agriculture yet she is a signatory to the *Harare Declaration of 2003* on urban and peri-urban agriculture in Eastern and Southern Africa, which recommends enactment of policies integrating urban agriculture into the urban economies. Moreover, this is contrary to the stipulations of the National Land Policy and County Government Act of 2012, which advocates for multi-functional urban land uses. This has led to undesirable farming practices such as diversion of sewage, deliberate bursting of water pipes to harness water for irrigation, illegal invasion of open-spaces and conversion of the same into gardens [20].

The undeveloped land which covers approximately 120.77 km^2 or 16.85% of the city are commercial, residential and industrial properties not developed by the owners. The spatial concentration of the parcels in the eastern and north-eastern parts of the city is attributed to the share certificate tenure system under which the majority of these properties belong. This tenure system involves land acquisition through joint purchase by the land buying companies, cooperatives, trusts, societies and self-help groups, which thereafter issue share certificates to the members. However, land speculations by these organizations make them hold the tenure documents for long at the detriment of the members who end up lacking documents to facilitate the approvals of their proposed developments by the city authority. Under such circumstances, land remains undeveloped for long periods - a phenomenon which is further compounded by individuals and companies who have bought land in these neighbourhoods for speculations.

3.1.2 Development Density and Biomass Variations within the City

Development densities vary across the city. For instance, CBD (Zone 1) and Eastlands (Zones 7, 8, 16 and 20) have the highest densities of 56.71%, 57.67%, 57.02%, 53.87% and 53.81% respectively. However, there are marked differences even within the same zone. For example, Zone 11 comprising of Kibera, Ayany, Olympic, Fort Jesus and Karanja neighbourhoods collectively have a density of 33.06% while Kibera neighbourhood; an informal settlement within the zone has a higher density of 87% (Table 8, Figure 4). Since high densities reduces the vegetation cover, such neighbourhoods experience high concentrations of air pollutants. Even though air purification abilities of the vegetation are influenced by vegetation type and density, it is the biomass component, which significantly influences the same. Findings on biomass index and aggregate morphological variations in the city are herein presented (Table 9, Figure 5, Table 10, Figure 6).

DOI: https://doi.org/10.30564/jees.v3i2.3289

Table 6. Land Uses in Square Kilometres by Zones

Development Zones	Wetlands	Parks and Other Recreational Spaces	Forests	Commercial Developments	Airport Land	Industrial Developments	Residential Developments	Quarry Land	Undeveloped Land	Urban Agriculture	Water Body	Railway Land	Public Purposes	TOTAL
1	0.00	1.12	0.08	4.27	0.00	0.00	1.41	0.00	0.08	0.00	0.00	0.01	1.14	8.10
2	0.00	0.46	0.00	2.30	0.13	0.01	3.01	0.00	0.35	0.00	0.00	0.05	0.99	7.28
3	0.00	0.38	0.06	1.85	0.00	0.00	3.52	0.00	0.01	0.00	0.00	0.00	0.37	6.20
4	0.00	0.81	0.59	3.07	0.00	0.00	14.45	0.00	0.48	0.19	0.00	0.00	1.23	20.82
5	0.00	0.03	0.82	1.68	0.00	0.00	11.20	0.00	0.46	3.40	0.00	0.00	1.56	19.16
6	0.00	1.20	0.73	0.47	0.00	0.00	3.73	0.00	0.21	0.00	0.00	0.00	0.39	6.75
7	0.00	0.16	0.01	1.45	0.00	0.13	1.62	0.00	0.25	0.00	0.00	0.00	0.42	4.03
8	0.00	0.25	0.00	2.47	0.46	1.25	4.67	0.00	0.33	0.00	0.00	1.00	0.34	10.76
9	0.00	0.50	0.00	1.81	0.02	7.07	2.20	0.06	0.37	0.14	0.00	0.99	0.15	13.31
10	0.31	2.25	0.02	2.95	2.24	8.28	11.56	0.65	9.14	1.62	0.00	0.00	0.76	39.78
11	0.00	0.36	0.63	0.47	0.00	0.00	1.36	0.00	0.29	0.15	0.00	0.00	0.09	3.34
12	0.00	1.03	1.31	5.08	0.00	0.00	31.70	0.00	1.48	18.96	0.05	0.00	0.98	60.59
13	0.00	0.00	2.55	0.33	0.00	0.00	14.80	0.00	0.30	9.18	0.26	0.00	0.86	28.27
14	0.24	2.09	1.47	0.98	0.00	0.00	11.41	0.26	2.00	9.89	0.00	0.00	0.74	29.08
15	0.00	0.61	1.71	2.24	0.00	0.00	8.73	0.00	0.33	25.45	0.07	0.00	1.50	40.64
16	0.00	0.00	0.08	0.31	0.00	1.75	0.99	0.00	0.41	0.24	0.00	0.00	0.63	4.40
17	0.00	0.13	0.00	0.62	0.00	0.19	4.94	0.66	1.83	9.41	0.00	0.00	2.19	19.97
18	0.14	0.62	0.00	6.52	0.02	3.80	42.21	1.30	38.13	15.66	0.04	0.16	3.00	111.60
19	0.00	0.00	0.00	0.00	0.00	0.00	21.91	0.00	41.59	16.27	3.39	0.00	0.00	83.15
20	0.00	0.00	0.00	0.70	2.45	0.00	1.09	0.00	0.25	0.00	0.00	0.00	0.00	4.49
20A	0.00	0.01	6.33	0.14	0.00	0.00	2.31	0.00	0.35	0.16	0.00	0.00	0.83	10.13
20B	0.00	0.00	0.00	0.01	0.00	0.06	0.32	0.00	0.07	0.47	0.00	0.00	0.58	1.51
20C	0.03	0.31	7.21	0.71	0.00	0.00	2.14	0.00	1.02	1.00	0.00	0.00	0.00	12.46
20D	0.00	0.21	0.00	0.48	0.00	0.00	0.52	0.00	0.15	0.00	0.00	0.00	0.00	1.36
20E	0.00	1.69	0.00	0.00	0.00	0.00	0.38	0.00	0.18	0.00	0.00	0.00	0.05	2.30
20F	0.00	0.16	0.00	0.07	12.12	0.42	0.05	0.00	19.19	0.00	0.00	0.00	0.06	32.07
20G	0.21	122.55	0.11	0.07	0.00	1.20	1.72	0.00	1.28	0.39	0.00	0.00	1.34	128.87
20H	0.00	0.44	0.00	0.04	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.11	0.91
20I	0.00	0.19	0.10	0.04	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.63	1.29
20J	0.00	0.86	2.64	0.15	0.00	0.00	0.07	0.00	0.24	0.06	0.00	0.00	0.04	4.05
Total	**0.94**	**138.44**	**26.45**	**41.29**	**17.44**	**24.15**	**204.65**	**2.93**	**120.77**	**112.64**	**3.81**	**2.20**	**20.97**	**716.68**

Table 7. Land Use Nominal Values

Development Zones	Wetlands (9.0)	Parks and Other Recreational Spaces (8.0)	Forests (10.0)	Commercial Developments (3.0)	Airport Land (4.0)	Industrial Developments (1.0)	Residential Developments (2.0)	Quarry Land (1.0)	Undeveloped Land (7.0)	Urban Agriculture (6.0)	Water Body (6.5)	Railway Land (4.5)	Public Purposes (5.0)	Total (Zonal) Nominal Values
1	0.00	1.11	0.10	1.58	0.00	0.00	0.35	0.00	0.07	0.00	0.00	0.00	0.71	3.91
2	0.00	0.51	0.00	0.95	0.07	0.00	0.83	0.00	0.33	0.00	0.00	0.03	0.68	3.39
3	0.00	0.49	0.10	0.90	0.00	0.00	1.13	0.00	0.02	0.00	0.00	0.00	0.30	2.94
4	0.00	0.31	0.29	0.44	0.00	0.00	1.39	0.00	0.16	0.06	0.00	0.00	0.29	2.94
5	0.00	0.01	0.43	0.26	0.00	0.00	1.17	0.00	0.17	1.07	0.00	0.00	0.41	3.52
6	0.00	1.43	1.09	0.21	0.00	0.00	1.11	0.00	0.22	0.00	0.00	0.00	0.29	4.34
7	0.00	0.32	0.01	1.08	0.00	0.03	0.81	0.00	0.43	0.00	0.00	0.00	0.52	3.19
8	0.00	0.19	0.00	0.69	0.17	0.12	0.87	0.00	0.21	0.00	0.00	0.42	0.16	2.82
9	0.00	0.31	0.00	0.41	0.01	0.53	0.33	0.01	0.19	0.06	0.00	0.33	0.05	2.23
10	0.07	0.45	0.01	0.22	0.23	0.21	0.58	0.02	1.61	0.24	0.00	0.00	0.10	3.73
11	0.00	0.86	1.88	0.42	0.00	0.00	0.81	0.00	0.62	0.26	0.00	0.00	0.13	4.99
12	0.00	0.14	0.22	0.25	0.00	0.00	1.05	0.00	0.17	1.88	0.01	0.00	0.08	3.78
13	0.00	0.00	0.90	0.04	0.00	0.00	1.05	0.00	0.07	1.95	0.06	0.00	0.15	4.22
14	0.07	0.57	0.50	0.10	0.00	0.00	0.78	0.01	0.48	2.04	0.00	0.00	0.13	4.70
15	0.00	0.12	0.42	0.17	0.00	0.00	0.43	0.00	0.06	3.76	0.01	0.00	0.18	5.15
16	0.00	0.00	0.17	0.21	0.00	0.40	0.45	0.00	0.65	0.33	0.00	0.00	0.71	2.92
17	0.00	0.05	0.00	0.09	0.00	0.01	0.49	0.03	0.64	2.83	0.00	0.00	0.55	4.70
18	0.01	0.04	0.00	0.18	0.00	0.03	0.76	0.01	2.39	0.84	0.00	0.01	0.13	4.41
19	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	3.50	1.17	0.26	0.00	0.00	5.47
20	0.00	0.00	0.00	0.47	2.19	0.00	0.48	0.00	0.38	0.00	0.00	0.00	0.00	3.52
20A	0.00	0.01	6.25	0.04	0.00	0.00	0.46	0.00	0.24	0.10	0.00	0.00	0.41	7.50
20B	0.00	0.01	0.00	0.01	0.00	0.04	0.43	0.00	0.34	1.86	0.00	0.00	1.91	4.60
20C	0.03	0.21	5.79	0.17	0.00	0.00	0.34	0.00	0.57	0.48	0.00	0.00	0.00	7.60
20D	0.00	1.24	0.00	1.07	0.00	0.00	0.76	0.00	0.76	0.00	0.00	0.00	0.00	3.83
20E	0.00	5.87	0.00	0.00	0.00	0.00	0.33	0.00	0.54	0.00	0.00	0.00	0.12	6.86
20F	0.00	0.04	0.00	0.01	1.51	0.01	0.00	0.00	4.19	0.00	0.00	0.00	0.01	5.77
20G	0.02	7.61	0.01	0.00	0.00	0.01	0.03	0.00	0.07	0.02	0.00	0.00	0.05	7.81
20H	0.00	3.89	0.00	0.12	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.63	5.34
20I	0.00	1.15	0.76	0.09	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	2.46	4.98
20J	0.00	1.69	6.51	0.11	0.00	0.00	0.04	0.00	0.42	0.09	0.00	0.00	0.05	8.89

DOI: https://doi.org/10.30564/jees.v3i2.3289

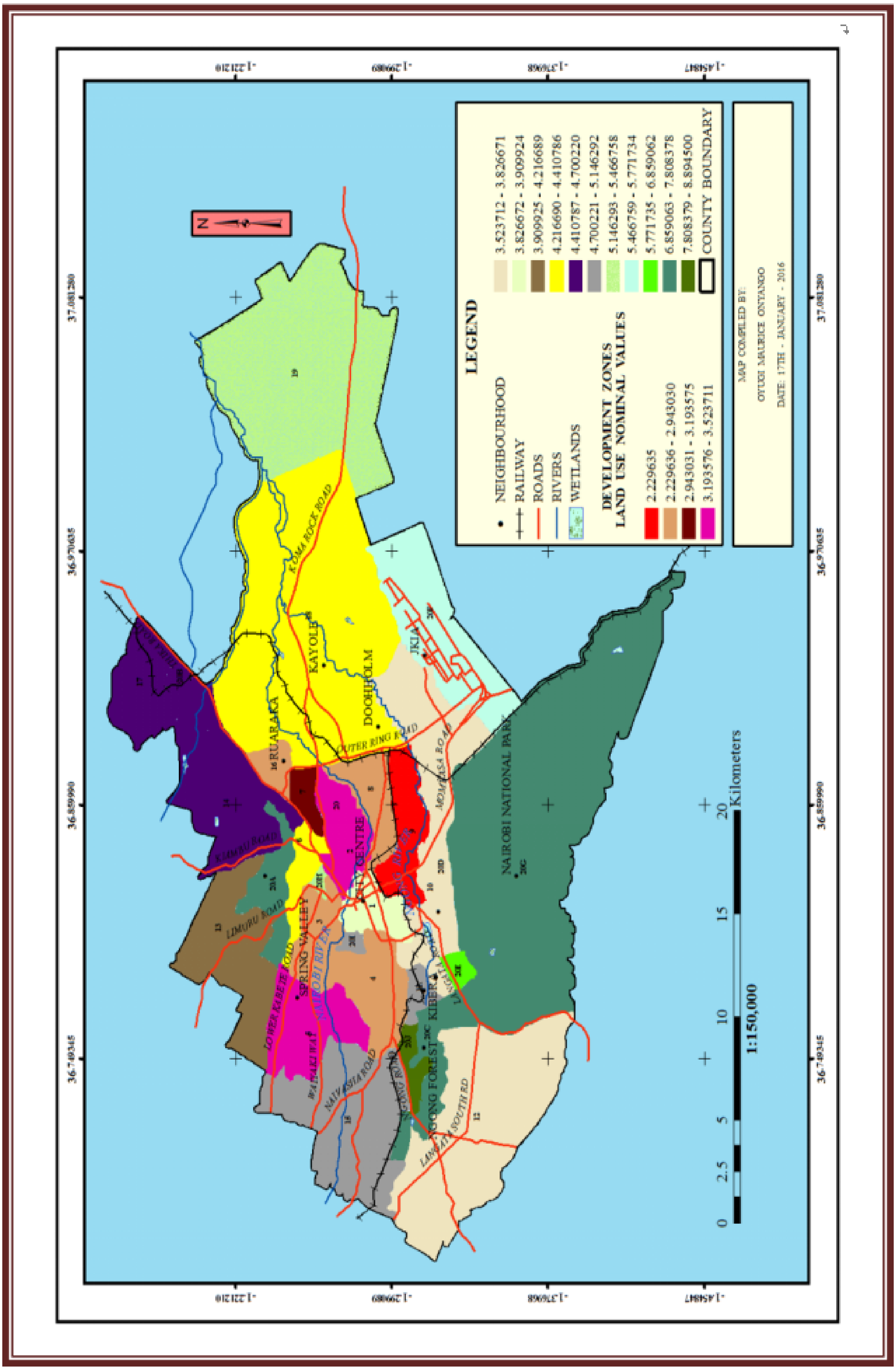

Figure 3. The Spatial Distribution of Land Use Nominal Values

Table 8. Nominal Values for the Development Densities in the City

Development Zones	Built-Up Land Uses by Areas (km^2)						The Zone's Total Land Areas (km^2)	Actual Built Up Spaces - Areas (km^2)	Development Density (%)	Development Density Nominal Value
	Commercial Developments	Airport Land	Industrial Developments	Residential Developments	Railway Land	Public Purposes				
1	4.27	0.00	0.00	1.41	0.01	1.14	8.10	4.59	56.71	4.5
2	2.30	0.13	0.01	3.01	0.05	0.99	7.28	3.59	49.32	5.5
3	1.85	0.00	0.00	3.52	0.00	0.37	6.20	3.01	48.56	5.5
4	3.07	0.00	0.00	14.45	0.00	1.23	20.82	5.84	28.04	7.5
5	1.68	0.00	0.00	11.20	0.00	1.56	19.16	4.49	23.45	8.0
6	0.47	0.00	0.00	3.73	0.00	0.39	6.75	1.15	17.05	8.5
7	1.45	0.00	0.13	1.62	0.00	0.42	4.03	2.32	57.67	4.5
8	2.47	0.46	1.25	4.67	1.00	0.34	10.76	6.14	57.02	4.5
9	1.81	0.02	7.07	2.20	0.99	0.15	13.31	8.90	66.88	3.5
10	2.95	2.24	8.28	11.56	0.00	0.76	39.78	16.49	41.47	6.0
11	0.47	0.00	0.00	1.36	0.00	0.09	3.34	1.10	33.06	7.0
12	5.08	0.00	0.00	31.70	0.00	0.98	60.59	10.05	16.58	8.5
13	0.33	0.00	0.00	14.80	0.00	0.86	28.27	4.00	14.14	9.0
14	0.98	0.00	0.00	11.41	0.00	0.74	29.08	3.28	11.29	9.0
15	2.24	0.00	0.00	8.73	0.00	1.50	40.64	4.36	10.73	9.0
16	0.31	0.00	1.75	0.99	0.00	0.63	4.40	2.37	53.87	5.0
17	0.62	0.00	0.19	4.94	0.00	2.19	19.97	4.19	20.96	8.0
18	6.52	0.02	3.80	42.21	0.16	3.00	111.60	28.17	25.24	8.0
19	0.00	0.00	0.00	21.91	0.00	0.00	83.15	10.95	13.17	9.0
20	0.70	2.45	0.00	1.09	0.00	0.00	4.49	2.42	53.81	5.0
20A	0.14	0.00	0.00	2.31	0.00	0.83	10.13	0.92	9.04	9.5
20B	0.01	0.00	0.06	0.32	0.00	0.58	1.51	0.54	35.87	6.5
20C	0.71	0.00	0.00	2.14	0.00	0.00	12.46	1.00	8.03	9.5
20D	0.48	0.00	0.00	0.52	0.00	0.00	1.36	0.64	47.50	5.5
20E	0.00	0.00	0.00	0.38	0.00	0.05	2.30	0.22	9.69	9.5
20F	0.07	12.12	0.42	0.05	0.00	0.06	32.07	7.58	23.63	8.0
20G	0.07	0.00	1.20	1.72	0.00	1.34	128.87	1.69	1.31	10
20H	0.04	0.00	0.00	0.32	0.00	0.11	0.91	0.18	19.77	8.5
20I	0.04	0.00	0.00	0.33	0.00	0.63	1.29	0.35	27.30	7.5
20J	0.15	0.00	0.00	0.07	0.00	0.04	4.05	0.09	2.23	10.0

 DOI: https://doi.org/10.30564/jees.v3i2.3289

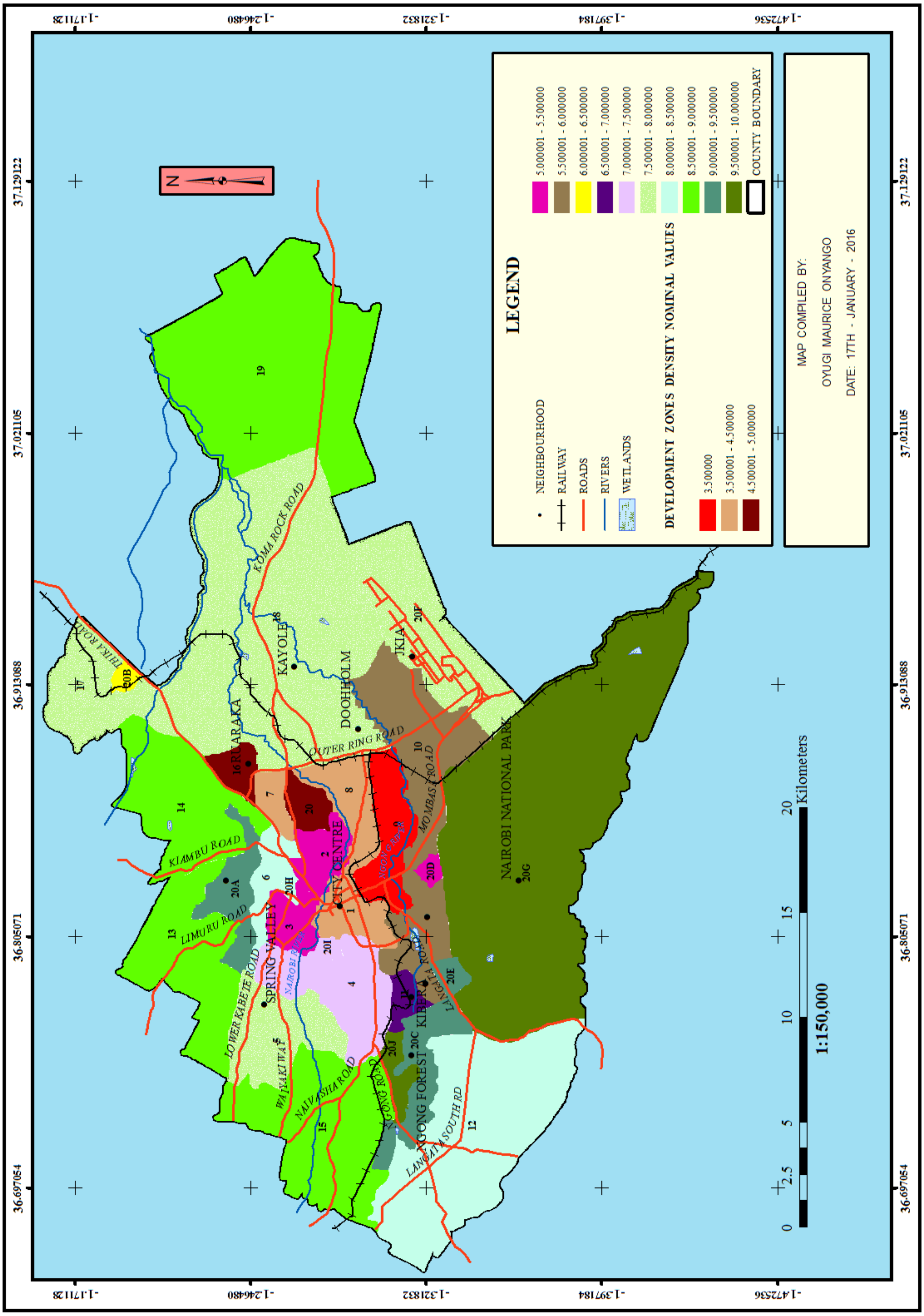

Figure 4. The Distribution of Development Density Nominal Values

Table 9. Biomass Variations within the City

Development Zones	Vegetation Categorization in the Un-built Spaces and Weightings						Actual Built Up Spaces (km^2)	Un-Built Spaces or the Open-Land (km^2)	The Zone's Total Land Areas (km^2)	The Zonal Aggregate Biomass Index (VD) (%)	The Biomass Index Nominal Value (Scale to 10: Aggregate VD/10)
	Wetlands (0.3)	Parks and Other Recreational Spaces (0.8)	Forests (1.0)	Quarry Land (0.1)	Undeveloped Land: Short grass (0.2) / Tall grass (0.4) / Shrub (0.6) / Small Tree (0.7)	Urban Agriculture (0.5)					
1	0.00	11.07	0.99	0.00	19.93	0.00	4.59	3.51	8.10	31.98	3.20
2	0.00	5.06	0.00	0.00	24.39	0.00	3.59	3.69	7.28	29.46	2.95
3	0.00	4.91	1.04	0.00	30.98	0.00	3.01	3.19	6.20	36.94	3.69
4	0.00	3.12	2.85	0.00	44.99	0.47	5.84	14.98	20.82	51.43	5.14
5	0.00	0.14	4.30	0.00	38.01	8.88	4.49	14.67	19.16	51.34	5.13
6	0.00	14.26	10.87	0.00	37.98	0.00	1.15	5.60	6.75	63.11	6.31
7	0.00	3.18	0.13	0.00	15.29	0.00	2.32	1.70	4.03	18.60	1.86
8	0.00	1.87	0.00	0.00	16.26	0.00	6.14	4.62	10.76	18.12	1.81
9	0.00	3.04	0.00	0.04	11.15	0.51	8.90	4.41	13.31	14.74	1.47
10	0.23	4.52	0.04	0.16	20.87	2.03	16.49	23.28	39.78	27.86	2.79
11	0.00	8.59	18.84	0.00	13.19	2.20	1.10	2.24	3.34	42.81	4.28
12	0.00	1.37	2.16	0.00	33.73	15.65	10.05	50.54	60.59	52.90	5.29
13	0.00	0.00	9.01	0.00	30.42	16.24	4.00	24.28	28.27	55.67	5.56
14	0.25	5.74	5.04	0.09	24.46	17.01	3.28	25.80	29.08	52.58	5.26
15	0.00	1.19	4.22	0.00	14.53	31.32	4.36	36.28	40.64	51.25	5.13
16	0.00	0.00	1.72	0.00	15.58	2.73	2.37	2.03	4.40	20.03	2.00
17	0.00	0.52	0.00	0.33	11.18	23.57	4.19	15.78	19.97	35.60	3.56
18	0.04	0.45	0.00	0.12	23.54	7.01	28.17	83.43	111.60	31.15	3.12
19	0.00	0.00	0.00	0.00	31.60	9.78	10.95	72.20	83.15	41.38	4.14
20	0.00	0.00	0.00	0.00	27.71	0.00	2.42	2.07	4.49	27.71	2.77
20A	0.00	0.09	62.45	0.00	18.75	0.81	0.92	9.21	10.13	82.09	8.21
20B	0.00	0.12	0.00	0.00	19.83	15.46	0.54	0.97	1.51	35.41	3.54
20C	0.08	2.11	57.91	0.00	16.16	4.03	1.00	11.46	12.46	80.29	8.03
20D	0.00	12.36	0.00	0.00	14.82	0.00	0.64	0.71	1.36	27.18	2.72
20E	0.00	58.73	0.00	0.00	6.76	0.00	0.22	2.08	2.30	65.49	6.55
20F	0.00	0.39	0.00	0.00	37.94	0.00	7.58	24.49	32.07	38.33	3.83
20G	0.05	76.07	0.09	0.00	1.82	0.15	1.69	127.18	128.87	78.19	7.82
20H	0.00	38.93	0.00	0.00	22.10	0.00	0.18	0.73	0.91	61.03	6.10
20I	0.00	11.55	7.57	0.00	35.49	0.00	0.35	0.94	1.29	54.61	5.46
20J	0.00	16.90	65.06	0.00	7.10	0.72	0.09	3.96	4.05	89.78	8.98

DOI: https://doi.org/10.30564/jees.v3i2.3289

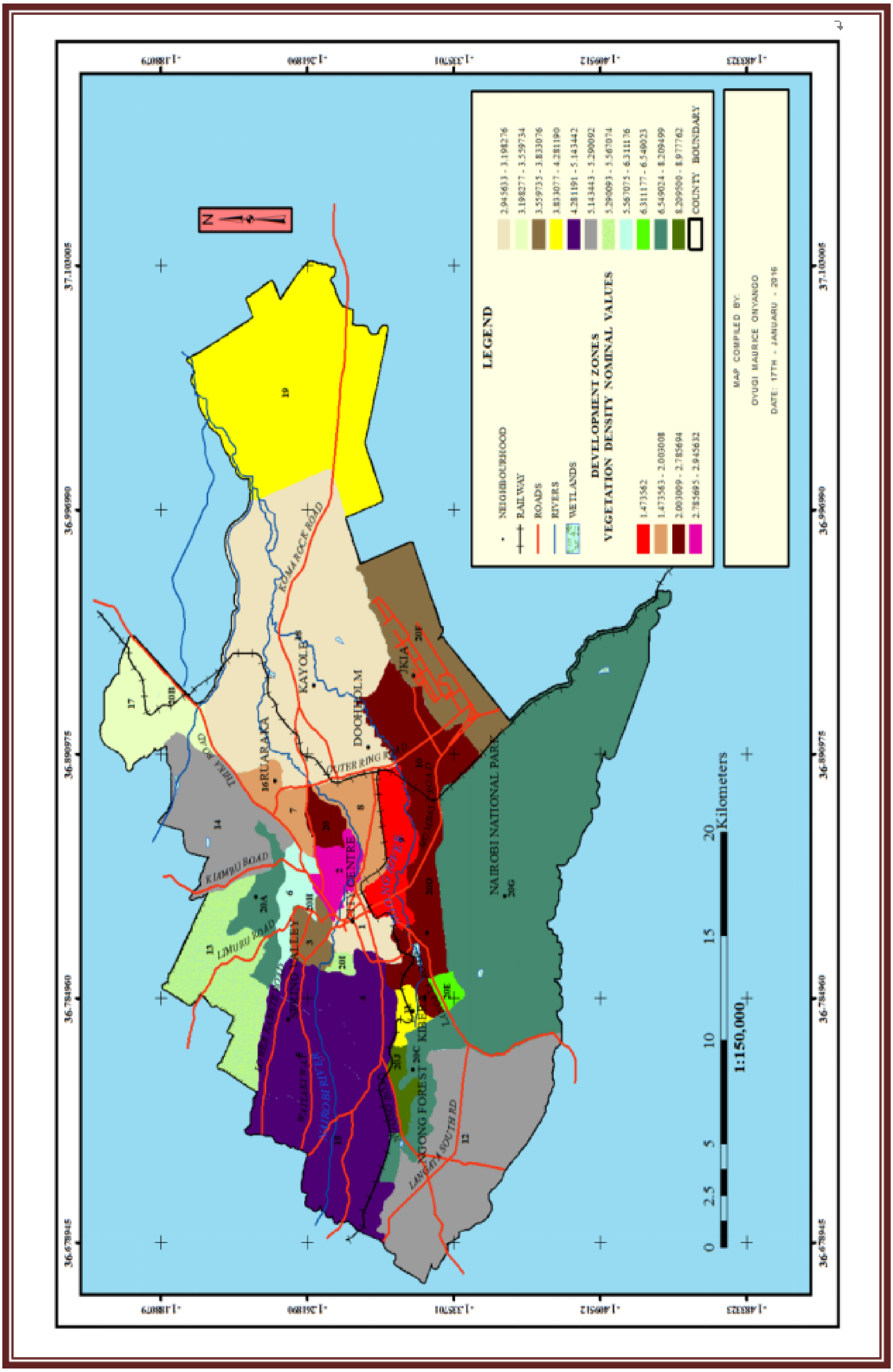

Figure 5. The Spatial Distribution of Biomass Values

Table 10. Morphological Variations within the City

Development Zones	Urban Form Nominal Values		Biomass Index Nominal Values (VDNV)	Aggregate Urban Morphology Nominal Values (DDNV+LUNV+VDNV)	Average Urban Morphology Nominal Values (DDNV+LUNV+VDNV)/3
	Development Density Nominal Value (DDNV)	Land Use Nominal Values (LUNV)			
1	4.5	3.91	3.20	11.61	3.87
2	5.5	3.39	2.95	11.84	3.95
3	5.5	2.94	3.69	12.14	4.05
4	7.5	2.94	5.14	15.58	5.19
5	8.0	3.52	5.13	16.65	5.55
6	8.5	4.34	6.31	19.15	6.38
7	4.5	3.19	1.86	9.56	3.18
8	4.5	2.82	1.81	9.13	3.04
9	3.5	2.23	1.47	7.20	2.40
10	6.0	3.73	2.79	12.51	4.17
11	7.0	4.99	4.28	16.27	5.42
12	8.5	3.78	5.29	17.57	5.86
13	9.0	4.22	5.57	18.78	6.26
14	9.0	4.70	5.26	18.96	6.32
15	9.0	5.15	5.13	19.27	6.42
16	5.0	2.92	2.00	9.93	3.31
17	8.0	4.70	3.56	16.26	5.42
18	8.0	4.41	3.12	15.53	5.18
19	9.0	5.47	4.14	18.60	6.20
20	5.0	3.52	2.77	11.29	3.76
20A	9.5	7.50	8.21	25.21	8.40
20B	6.5	4.60	3.54	14.64	4.88
20C	9.5	7.60	8.03	25.13	8.38
20D	5.5	3.83	2.72	12.04	4.01
20E	9.5	6.86	6.55	22.91	7.64
20F	8.0	5.77	3.83	17.60	5.87
20G	10.0	7.81	7.82	25.63	8.54
20H	8.5	5.34	6.10	19.94	6.65
20I	7.5	4.98	5.46	17.94	5.98
20J	10.0	8.89	8.98	27.87	9.29

 DOI: https://doi.org/10.30564/jees.v3i2.3289

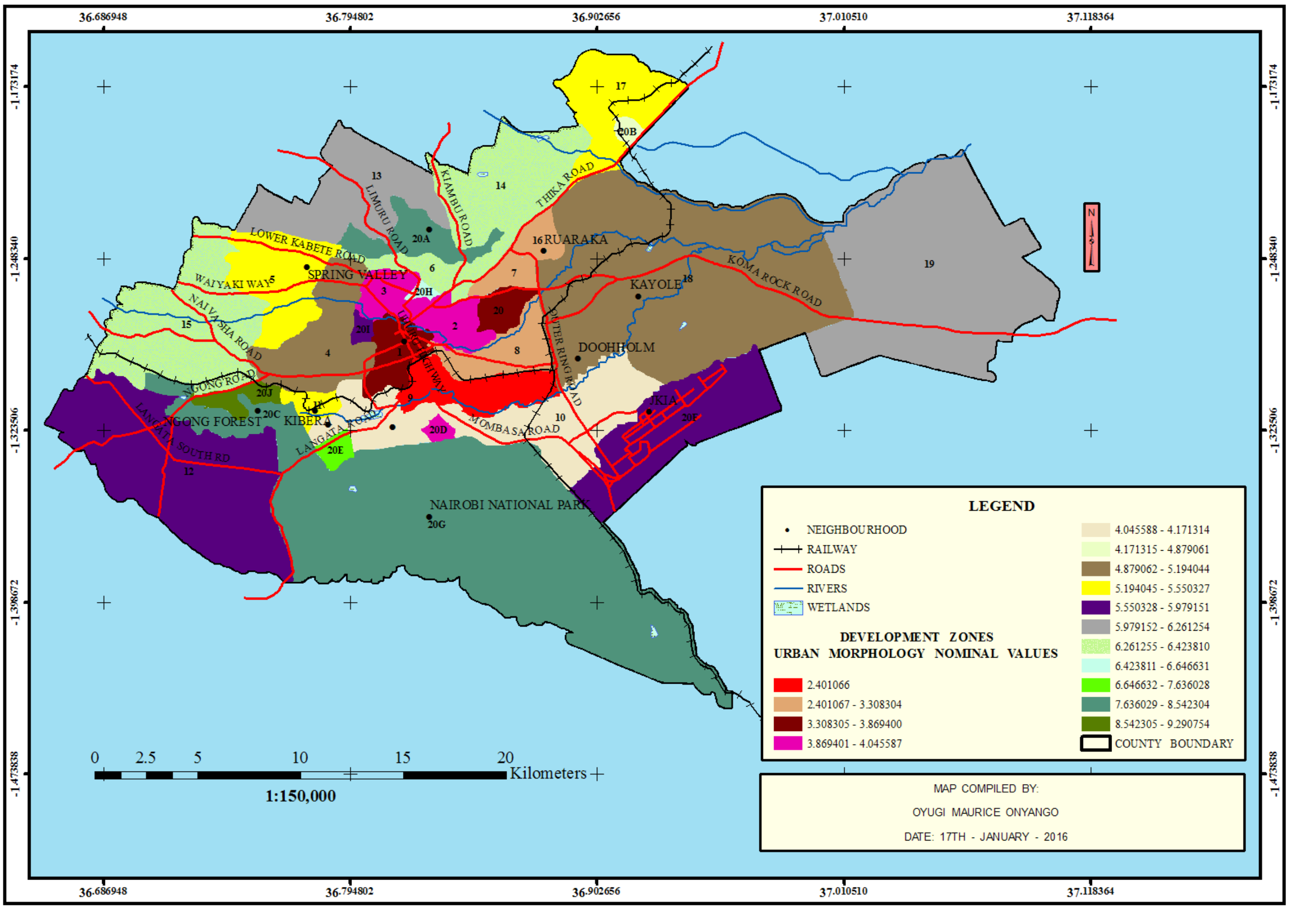

Figure 6. Spatial Distribution of Urban Morphological Values

3.2 Air Quality Distribution in the City

High urbanisation and improved economic growth rates as well as inadequate public transportation in African cities have contributed to increased vehicular volume and GHG emissions. Currently, out of the 8.5 million registered vehicles in Kenya, approximately 5.0 million operate within Nairobi and its environs. This has heightened traffic snarl and air pollution in the city, making Nairobi rank fourth globally in transportation problems. Should the trend continue, the number of vehicle trips would increase by 148% in the year 2025 while the average speed will reduce from 35 km/hour to 11 km/hour [21]. Motor vehicles emit GHGs, suspended particulate matter and Sulphur dioxide which react with sunlight to deplete the ozone layer. These pollutants also have health effects manifesting in chest congestion, coughs, phlegm, sore throats and asthmatic attacks [22,23]. Of all these pollutants, $SPM_{2.5}$ which is a complex mixture of solid and liquid organic and inorganic particles less than or equal to 2.5 μm in diameter is of particular significance on climate change and health effects. Their small sizes enable them to penetrate deeply into the lungs where they exert adverse effects such as lung and heart diseases as well as exacerbating post-neonatal infant mortality [24,25].

There is a marked gradual decrease in gaseous concentrations from the CBD, industrial areas and satellite commercial centres in the city, which are employment zones experiencing increased vehicular volume, heightening the concentration of air pollutants (Table 11). This is complicated by the high development densities characterising the neighbourhoods, which has depleted the vegetation cover as well as attenuating wind velocity, consequently reducing purification ability of the ecosystem and pollutants' dispersal. Carbon dioxide is the widest spread air pollutant within the city followed by nitrogen dioxide, sulphur dioxide and SPM respectively (Figures 7 to 10).

Table 11. Average Air Concentrations and Nominal Values by Development Zones

Development Zones	Average Carbon Dioxide Values (ppm)	Carbon Dioxide Nominal Values	Average Nitrogen Dioxide Values (ppb)	Nitrogen Dioxide Nominal Values	Average Sulphur Dioxide Values (ppb)	Sulphur Dioxide Nominal Values	Average Suspended Particulate Matter Values (μg/m^3).	Suspended Particulate Matter Nominal Values	Total Air Quality Nominal Value	Average Air Quality Nominal Values
1	375.33	1.333	21.87	4.333	1.40	5.000	43.72	7.000	17.666	4.417
2	375.16	1.333	24.08	3.667	1.36	5.000	41.88	7.000	17.000	4.250
3	268.42	4.667	12.93	7.000	0.80	7.667	23.36	8.333	27.667	6.917
4	324.03	3.000	11.68	7.333	0.67	8.333	12.48	9.333	27.999	7.000
5	199.48	7.000	6.32	9.000	0.37	9.667	7.57	10.000	35.667	8.917
6	234.17	5.667	12.58	7.000	0.80	7.667	18.03	9.000	29.334	7.334
7	318.51	3.000	21.46	4.333	1.47	4.667	55.38	6.000	18.0	4.500
8	398.68	1.000	29.32	1.667	1.81	3.000	84.29	3.667	9.334	2.334
9	401.97	1.000	28.97	2.000	1.82	3.000	78.62	4.000	10.0	2.500
10	362.63	2.000	27.61	2.333	1.76	3.333	76.64	4.333	11.999	3.000
11	358.55	2.000	13.64	6.667	0.84	7.333	11.65	9.333	25.333	6.333
12	135.57	8.667	6.62	9.000	0.36	9.667	10.80	9.667	37.001	9.250
13	124.55	9.333	4.60	9.667	0.37	9.667	8.51	9.667	38.334	9.584
14	189.89	7.333	11.33	7.333	0.81	7.667	27.18	8.333	30.666	7.667
15	174.45	7.667	7.29	9.000	0.44	9.333	12.60	9.333	35.333	8.833
16	263.74	4.667	17.35	5.667	1.24	5.667	49.03	6.333	22.334	5.584
17	210.28	6.333	10.68	7.667	0.72	8.000	21.97	8.667	30.667	7.667
18	260.83	5.000	16.33	6.000	1.21	5.667	51.32	6.333	23.0	5.750
19	202.16	6.667	11.15	7.667	0.57	8.667	32.43	7.667	30.668	7.667
20	371.94	1.667	26.71	2.667	1.72	3.333	73.53	4.333	12.0	3.000
20A	145.38	8.667	6.73	9.000	0.49	9.000	11.59	9.333	36.0	9.000
20B	201.79	6.667	8.66	8.333	0.76	7.667	17.05	9.000	31.667	7.917
20C	237.67	5.667	7.54	8.667	0.50	9.000	10.80	9.667	33.001	8.250
20D	361.00	2.000	25.15	3.000	1.55	4.333	51.22	6.333	15.666	3.917
20E	272.34	4.667	13.65	6.667	0.86	7.333	10.41	9.667	28.334	7.084
20F	278.58	4.333	21.94	4.333	1.27	5.333	68.30	5.000	18.999	4.750
20G	247.04	5.333	19.47	5.000	0.94	7.000	44.59	6.667	24.0	6.000
20H	290.37	4.000	16.37	6.000	1.03	6.667	24.30	8.333	25.0	6.250
20I	333.16	2.667	15.39	6.333	0.85	7.333	18.96	8.667	25.0	6.250
20J	282.26	4.333	7.34	9.000	0.49	9.000	12.55	9.333	31.666	7.917

DOI: https://doi.org/10.30564/jees.v3i2.3289

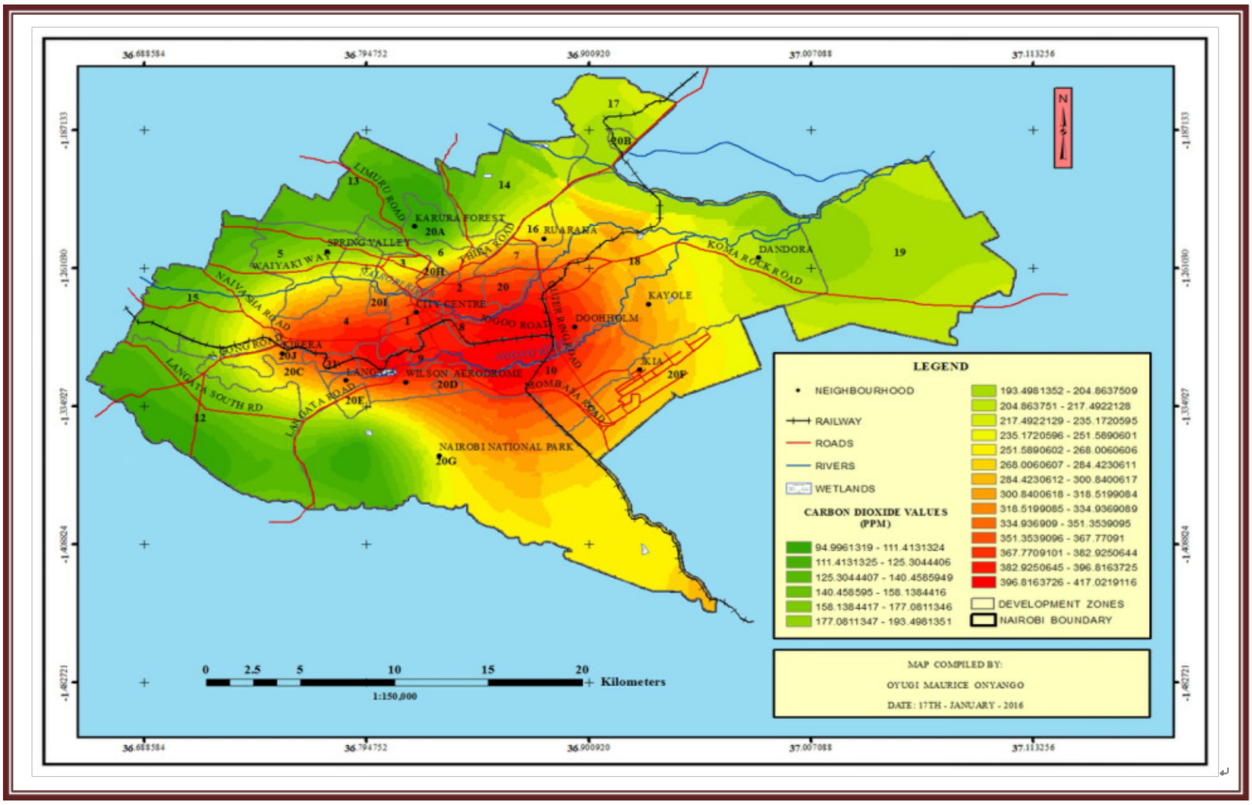

Figure 7. The Distribution of Carbon Dioxide Concentration Values in the City

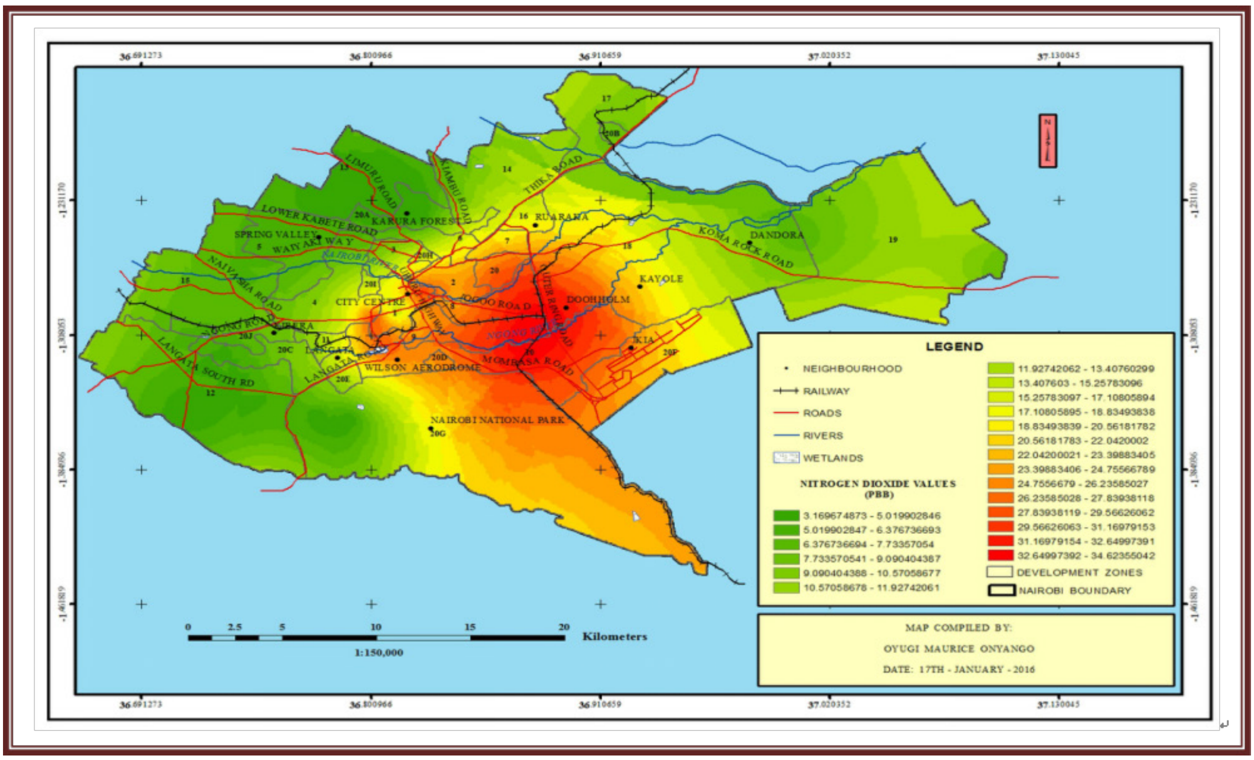

Figure 8. The Spatial Distribution of Nitrogen Dioxide Concentration Values in the City

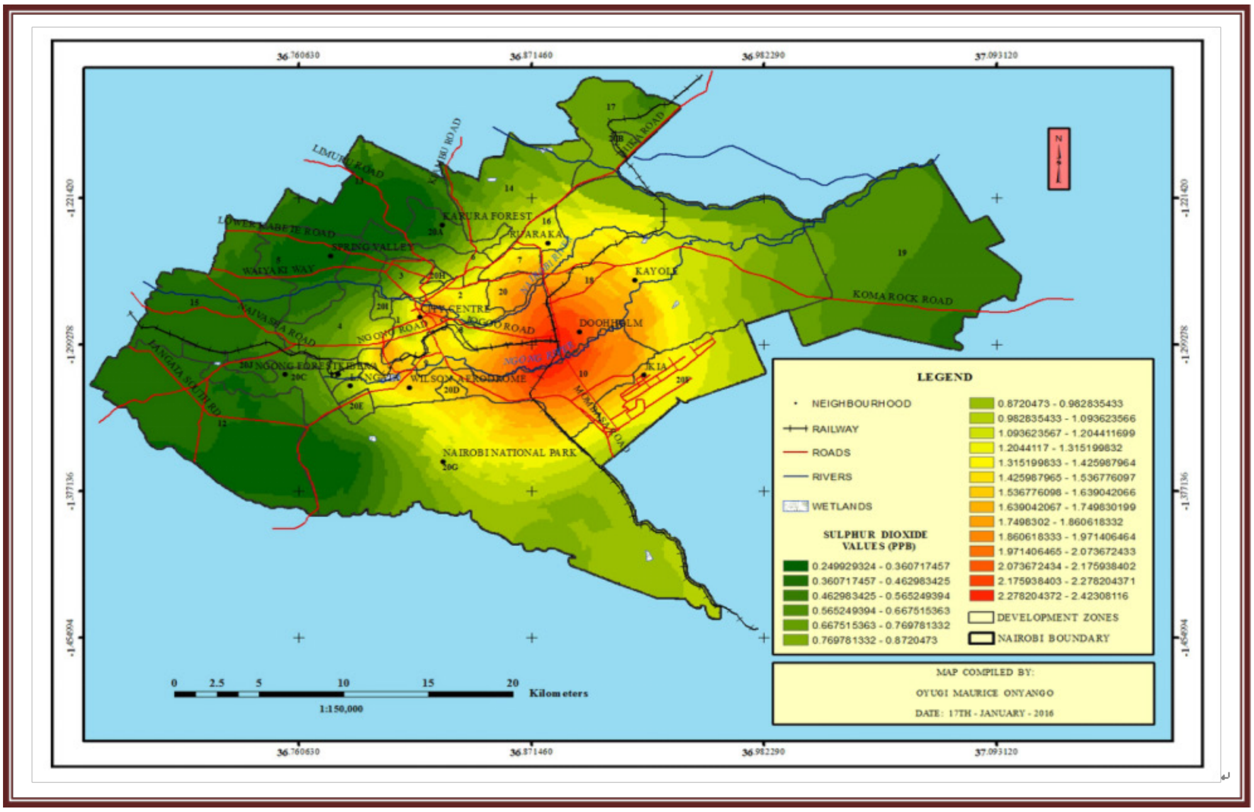

Figure 9. The Distribution of Sulphur Dioxide Concentration Values in the City

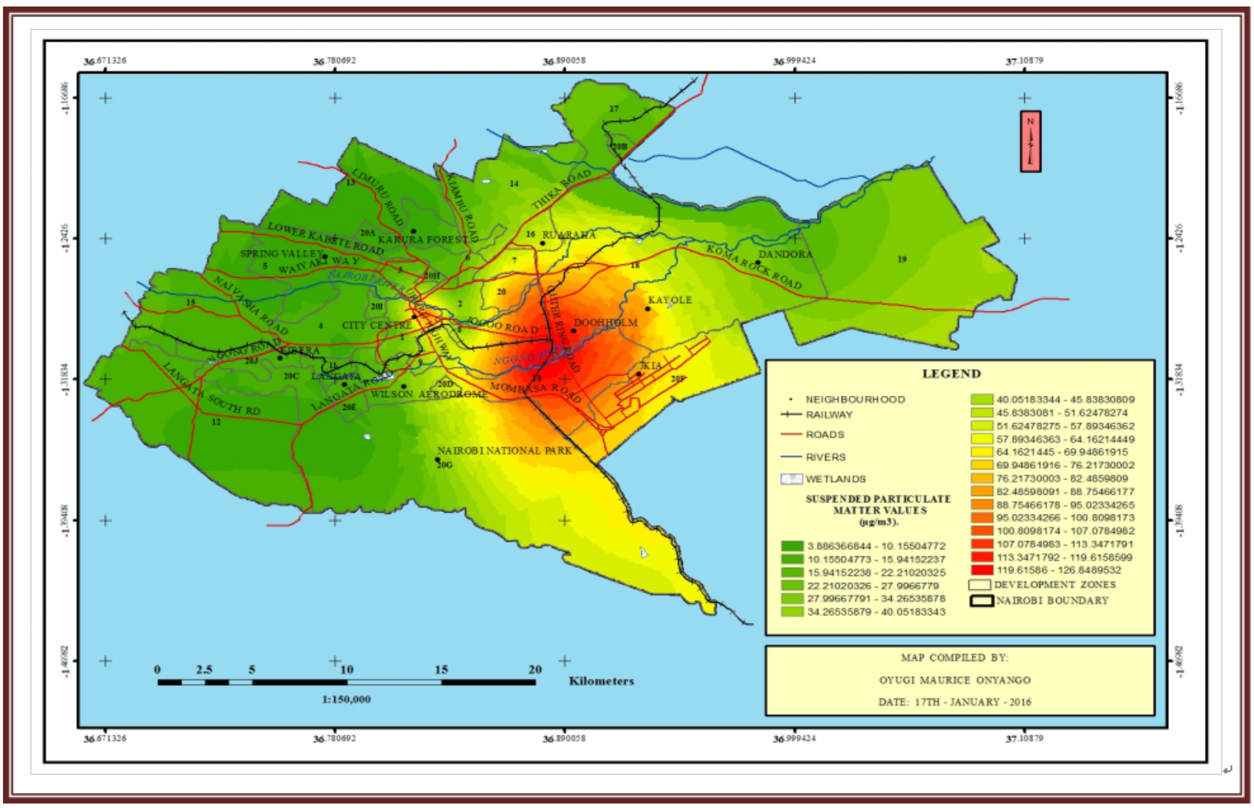

Figure 10. The Distribution of the Suspended Particulate Matter Concentration Values

Distributed under creative commons license 4.0 DOI: https://doi.org/10.30564/jees.v3i2.3289

The Relationship between Urban Air Quality and Morphological Parameters

Urban morphological parameters of development density, land use and biomass index were utilised in establishing the relationship existing between urban morphology and air quality (Table 12). Results of the *Pearson's Product Moment Correlation Coefficient Indexes* of the relationships existing between and among the various morphological variables and air quality is also presented (Table 13). As earlier stated, the study was informed by the hypothesis that there exist significant relationships among the urban morphological variables under consideration as well as between the urban morphological variables and air quality. To demonstrate the intra-linkages existing between the morphological parameters, analysis of the relationship existing between

Table 12. The Morphological and Air Quality Attributes of the Development Zones

Development Zones	Air Quality Nominal Values (Y)	Urban Form Nominal Values		Biomass Index Nominal Values (VDNV) (X_3)	Urban Morphology Nominal Values (DDNV+LUNV +VDNV)	Average Urban Morphology Nominal Values (DDNV+LUNV +VDNV)/3
		Development Density Nominal Values (DDNV) (X_1)	Land Use Nominal Values (LUNV) (X_2)			
1	4.42	4.5	3.91	3.20	11.61	3.87
2	4.25	5.5	3.39	2.95	11.84	3.95
3	6.92	5.5	2.94	3.69	12.14	4.05
4	7.00	7.5	2.94	5.14	15.58	5.19
5	9.00	8.0	3.52	5.13	16.65	5.55
6	7.33	8.5	4.34	6.31	19.15	6.38
7	4.50	4.5	3.19	1.86	9.55	3.18
8	2.33	4.5	2.82	1.81	9.13	3.04
9	2.50	3.5	2.23	1.47	7.20	2.40
10	3.00	6.0	3.73	2.79	12.51	4.17
11	6.33	7.0	4.99	4.28	16.27	5.42
12	9.25	8.5	3.78	5.29	17.57	5.86
13	9.58	9.0	4.22	5.57	18.78	6.26
14	7.67	9.0	4.70	5.26	18.96	6.32
15	8.83	9.0	5.15	5.13	19.27	6.42
16	5.58	5.0	2.92	2.00	9.92	3.31
17	7.67	8.0	4.70	3.56	16.26	5.42
18	5.75	8.0	4.41	3.11	15.53	5.18
19	7.67	9.0	5.47	4.14	18.60	6.20
20	3.00	5.0	3.52	2.77	11.29	3.76
20A	9.00	9.5	7.52	8.21	25.21	8.40
20B	7.92	6.5	4.60	3.54	14.64	4.88
20C	8.25	9.5	7.60	8.03	25.12	8.38
20D	3.92	5.5	3.83	2.72	12.04	4.01
20E	7.08	9.5	6.86	6.55	22.91	7.64
20F	4.75	8.0	5.77	3.83	17.60	5.87
20G	6.00	10.0	7.81	7.82	25.63	8.54
20H	6.25	8.5	5.34	6.10	19.94	6.65
20I	6.25	7.5	4.98	5.46	17.94	5.98
20J	7.92	10.0	8.89	8.98	27.87	9.29

the development density and land use was undertaken. While the first analysis focused on the relationship with land use as the dependent variable, the second analysis focused on the relationship with development density as the dependent variable. In both the cases, the relationship existing between the two variables was established to be strong with correlation coefficient (r) values of -0.788 while the calculated *t*-values and critical *t*-values are 6.767 and 2.048 respectively. However, there is a slight difference in the calculated F-values for the two relationships as occasioned by differences in the regression models expressing the relationships. For the relationship in which the development density is the independent variable, the calculated F-value was established to be 45.798 compared to a critical F-value of 4.20. This had a slight difference from the relationship in which land use was the independent variable in which the calculated F-value was established to be 45.793 compared to a critical F-value of 4.20. This confirms that the relationship existing between the two variables is consistently significant (Table 14).

As corroborated by a correlation coefficient (r) value of -0.871, calculated and critical *t*-values of 9.392 and 2.048 respectively, with a corresponding calculated F-value of 88.216 compared to a critical F-value of 4.20, the relationship existing between development density and biomass index is confirmed to be very significant and consistent. Similarly, a correlation coefficient (r) value of 0.840, a calculated *t*-value of 8.185 compared to the critical *t*-value of 2.048, corresponding to a calculated F-value of 66.992 compared to a critical F-value of 4.20, the relationship existing between land use and the biomass index is confirmed to be very significant and consistent.

Table 13. Correlation Matrix Variables

Variables	Air Quality	Development Density	Land Uses	Biomass Index
Air Quality	1.000	-0.775	0.446	0.684
Development Density	-0.775	1.000	-0.788	-0.871
Land Uses	0.446	-0.788	1.000	0.840
Biomass Index	0.684	-0.871	0.840	1.000

There is a strong negative relationship existing between development density and air quality. This is corroborated by a correlation coefficient (r) value of -0.7751 and a calculated *t*-value of 6.492 compared to a critical *t*-value of 2.048. While the calculated F-value for the relationship is 42.149, the critical F-value is 4.20. This confirms that the relationship existing between the two variables is not occurring by chance. Contrary to the above, land uses and air quality present a weak relationship evidenced by a correlation coefficient (r) value of 0.446 and a calculated *t*-value of 2.638 compared to a critical *t*-value of 2.048. The calculated and critical F-values for the relationship are 6.961 and 4.20 respectively. This is attributed to the transboundary nature of the air pollutants spreading through the wind, thus a neighbourhood surrounded by noxious land uses will still experience low air quality. Granted that the correlation coefficient (r) value for the relationship existing between the biomass index and air quality is 0.684, the study confirms that the relationship is moderately significant as corroborated by the calculated *t*-value of 4.956 compared to a critical *t*-value of 2.048. Since the calculated F-value of the relationship is 24.56 compared to a critical F-value of 4.20, the relationship existing between biomass index and air quality is significant and consistent.

The study further established a consistently moderate relationship existing between urban form (aggregation of development density and land use nominal values) and air quality. This is confirmed by a correlation coefficient (r) value of 0.657, a calculated *t*-value of 4.614, a calculated F-value of 21.291 with a corresponding critical F-value of 4.20. The study also established a moderately significant correlation existing between urban morphology (aggregation of development density, land use and biomass index nominal values) and air quality as evidenced by a correlation coefficient (r) value of 0.682. While the significance of the relationship is confirmed by a calculated *t*-value of 4.937 compared to a critical *t*-value of 2.048, the consistency of the relationship is confirmed by a calculated F-value of 24.373 compared to a critical F-value of 4.20. To facilitate the determination of the strengths of the relationships existing between morphological variables and air quality, regression models depicting the relationships were established. In addition to other statistical attributes, the relationship existing between urban form elements and air quality is represented by regression equation 9.

$$\acute{Y} = -0.490X_1 - 2.202X_2 + 50.015 \quad (9)$$

Where: -

$\acute{Y}$ = The estimated air quality values

X_1 = Development density values

X_2 = Land use nominal values

While the calculated *t*-value attributed to the development density in the model is 6.241, the calculated *t*-value attributed to land uses is 2.422, the calculated *t*-value attributed to error term is 7.944 and the calculated F-value is 27.670. This corroborates the significant role the development density plays in the determination of the spatial distribution of the air quality within the city as compared to land uses.

  DOI: https://doi.org/10.30564/jees.v3i2.3289

Table 14. Relationships Existing Between and among the Morphological Variables and Air Quality

Statistical Elements	Relationship Variables			
	Development Density and Air Quality	**Development Density and Land Use**	**Land Use and Air Quality**	**Biomass Index and Air Quality**
Correlation Coefficients	-0.7751	-0.788	0.446	0.684
Coefficients of Determination (r^2 or R)	0.6008	0.621	0.199	0.467
Calculated t - Value	6.492	6.767	2.638	4.956
Critical t - Value	2.048	2.048	2.048	2.048
Regression Model	**Y = -0.085X + 8.8316**	**Y = -0.068X + 6.6709**	**Ỳ = 0.567X + 3.682**	**Ỳ = 0.711X + 3.089**
ANOVA or the F- Test Value	42.149	45.798	6.961	24.56
Critical F - Value	4.20	4.20	4.20	4.20
	Relationship Variables			
	Development Density and Biomass Index	**Land Use and Development Density**		**Land Use and Biomass Index**
Correlation Coefficients	-0.871	-0.788		0.840
Coefficients of Determination (r^2 or R)	0.759	0.621		0.705
Calculated t-Value	9.392	6.767		8.185
Critical t - Value	2.048	2.048		2.048
Regression Model	**Y = -0.9193X + 72.639**	**Y = -9.1227X + 72.03**		**Y = 10.262X - 2.3316**
ANOVA or the F- Test	88.216	45.793		66.992
Critical F - Value	4.20	4.20		4.20
	Relationship Variables			
	Urban Form and Air Quality	**Urban Morphology and Air Quality**		
Correlation Coefficients	0.657	0.682		
Coefficients of Determination (r^2 or R)	0.432	0.465		
Calculated t-Value	4.614	4.937		
Critical t - Value	2.048	2.048		
Regression Model	**Y = 1.6346X +5.6937**	**Y = 1.0857X + 7.3336**		
ANOVA or the F- Test	21.291	24.373		
Critical F - Value	4.20	4.20		

 DOI: https://doi.org/10.30564/jees.v3i2.3289

The relationship existing between the urban morphological parameters of development density, land use, biomass index and air quality represented by model 10 reveals varying levels of significance.

$$\acute{Y} = -0.389X_1 - 3.060X_2 + 0.174X_3 + 43.123 \qquad (10)$$

Where: -

Ý = The estimated air quality values

X_1 = Development density values

X_2 = Land use nominal values

X_3 = Biomass Index values

Other statistical parameters in the relationship are: -

t_1 = The calculated *t*-value attributed to development density which is 3.978

t_2 = The calculated *t*-value attributed to land uses which is 2.654

t_3 = The calculated *t*-value attributed to biomass index which is 2.992

t_4 = The calculated *t*-value attributed to error term which is 5.835

F = Calculated F-value of the relationship which is 20.544

It is therefore evident that development density is the most significant determinant of air quality distribution in the city, followed by biomass index and land uses. Since the calculated *t*– value attributed to error term in the model is significant, it implies that there are some variables which were not considered in the study but are determinants of the spatial distribution of the air quality in the city.

4. Conclusions and Recommendations

The study, which finds impetus on the effects of urbanisation on global warming and climate change, provides a niche for the development of a unifying model explaining the correlation existing between urbanisation, urban morphology, air quality, global warming and climate change. Indeed, the study establishes that the most significant urban morphological variable influencing the spatial distribution of air quality is development density followed by biomass index and to a weaker extent, land uses. This is because urban developments deplete vegetation cover leading to increased impervious surfaces such as buildings and roads, consequently lowering the purification ability of the ecosystem. Further, increased development leads to urban sprawl, which increases vehicular volume to exacerbate GHGs, suspended particulate matter and sulphur dioxide emissions. This makes cities a major contributor to global warming and climate change. High development densities also influence urban air quality through attenuation of wind velocity, restricting air pollutants in the narrow canyons, leading to the concentrations of the same. Through a combination of shading, evaporative cooling effects and photosynthetic processes, vegetation mitigates urban neighbourhoods against air pollution and heating effects generated by the developments. This makes development density and biomass index imperative morphological parameters determining the distribution of urban air quality.

The study further establishes that the air quality distribution in the city can broadly be dichotomised into four broader categories namely; the northern and western, southern, eastern and the central parts of the city, which significantly corresponds to the development density, industrial and transportation networks as well as vegetation distribution. Since red volcanic soils, which characterises the northern and western parts of the city, are rich in nutrients and humus contents, they support healthy natural and exotic vegetation, which are carbon sinks and purifier to other GHGs. The southern and eastern parts of the city which are characterised by low-lying plains and black cotton soils with low nutrient contents are dominated by sparse vegetation covers such as the disturbed bushes, shrubs, perennial grasses and under storey trees which are not effective purifier of gases. Therefore, the presence of forest reserves to the northern and western parts of the city coupled with low development densities characterising the regions have acted in concert towards the achievement of relatively better air quality. This contrasts with the central, southern and eastern parts of the city, which are characterised by sparse vegetation covers, high development densities and dominance of land uses such as transportation, industrial developments and quarries, which compromises the air quality. Therefore, the study concludes that development density has acted in concert with biomass index, physiographical, climatological and pedological factors to influence the distribution of the air quality within Nairobi city.

5. Recommendations

The achievement of sustainable urban air quality requires implementation of multiple strategies and techniques, which are known to work within the standard practice of urban environmental planning and management. Such strategies include promotion of green infrastructure, implementation of appropriate development densities, tightening up legislations on protection of urban ecosystems such as the green belts, gardens, trees and implementation of sustainable industrial and transportation networks. Urban environmental management further requires a new environmental contract encompassing civil society, public and private sector participations. This should build on the strengths of planning and other environmental management strategies, which give

  DOI: https://doi.org/10.30564/jees.v3i2.3289

encouragement to local and regional institutional capacity building, behavioural change and innovation. For the achievement of sustainable air quality in Nairobi city, the study recommends the following:

(1) Enhancement of Vegetation Cover within the City

The vegetation cover enhances air quality, however this is negated by the urban sprawl characterising the eastern and southern parts of the city. Therefore, to achieve sustainable air quality, measures such as the implementation of appropriate development policies geared towards increasing the vegetation cover should be prioritised. Such policies should entail tightening up legislations protecting urban ecosystems, minimisation of land fragmentations and urban sprawl through up-scaling sky lines, increments of plot coverages, ratios and minimum plot sizes for developments as well as strict enforcement of density standards inclusive of spelt out number of trees to be planted per acreage of plot. In accordance with the provisions of Environmental Impact Assessment Regulations of 2003, all the proposed developments within the city that are likely to compromise the air quality should be subjected to Environmental Impact Assessment.

(2) Expansion and Regular Maintenance of the Urban Infrastructure

Increased frequencies of sewer blockages and bursts indicate that developments in the city have surpassed the capacity of the existing infrastructure. Therefore, for the city to continue supporting the growing population through re-densification which control urban sprawl, there is need for expansion and regular maintenance of the existing water reticulation, sewer and road networks.

(3) Enhancement of Air Quality through Creation of Monitoring Stations and Enactment of Appropriate Transportation and Industrial Development Policies

Industries and motor vehicles emits GHGs, sulphur dioxide and suspended particulate matter, which apart from lowering the urban air quality also makes cities major contributors of global warming and climate change. Therefore, the Nairobi City County Government should formulate policies, standards and legislations for the reduction of air pollution in the city. The policies should include popularisation of public transportation, non-motorised modes of transportation, limiting the number of vehicles coming into the city and development of arterials which supports rapid vehicular flow for it has been established that vehicles emit more GHGs, sulphur dioxide and suspended particulate matter when their speeds are low. The focus should further be placed on industrial and commercial districts characterised by vehicular concentration and high density developments, which apart from depleting the vegetation cover also restricts the dispersal of air pollutants, leading to increased concentrations of the same. Policy measures such as decentralisation of industrial and commercial districts should be pursued. For this to be implemented, there is need for frequent air quality monitoring which can be achieved through establishment of network of stationary air quality monitoring stations and frequent mobile air quality monitoring along road transects.

(4) Instituting Geospatial, Information and Communication Technologies (GICTs) in Urban Planning and Growth Management in line with the Recommendations of Sustainable Development Goals (SDGs)

In undertaking reviews of development plans geared towards the development of compact city, cognisance should be taken of land use suitability. This is impetrative in protecting the fragile ecologies notably the forests and riparian reserves against the encroachment by anthropogenic activities which in turn exacerbates flood disasters, leading to loss of life and property. However, the above can effectively be undertaken if the County Government institute the utility of ICT and geospatial techniques as planning tools which is in line with the SDGs' stipulations.

(5) Multi-Sector Partnership Approach to Air Quality Management

Despite the constitutional stipulations on the involvement of the citizens in the development plan formulation and implementation, current urban development paradigms operational in the city are not participatory and various development agents feel left out in the process. Therefore, in the evolution and review of development plans, the people and various development agents should be brought on board. This makes it easy for development agents to understand issues entailed in the plan and to take charge in implementing the same. This requires enactment of policy framework on partnership building as well as registering neighbourhood associations and empowering the same to undertake self-driven development control and air quality compliance monitoring.

 DOI: https://doi.org/10.30564/jees.v3i2.3289

References

[1] Government of Kenya (2019). Population and Housing Census Surveys. Nairobi, Government Printer.

[2] United Nations (2014). World Urbanization Prospects, the 2014 Revision: Highlights. United Nations, New York.

[3] Oyugi, M.O (2018). Modelling the Effects of Urban Morphology on Environmental Quality of Nairobi City, Kenya. Ph.D Thesis, School of Environmental Studies, University of Eldoret, Kenya.

[4] Satterthwaite, D (2008). "Cities' contribution to global warming: Notes on the allocation of greenhouse gas emissions", *Environment and Urbanization,* 20(2).

[5] Klaus, D., Jauregui, E., Poth, A., Stein G and Voss, M (1999). "Regular Circulation Structures in the Tropical Basin of Mexico City as a consequence of the Heat Island Effect", *Erdkunde* 53: 231-243.

[6] Oyugi, M.O (2020). "Trends in Urban Morphological Data Capture: A Review of Theoretical Perspectives on Utility of Geospatial Technology", *Indones.J.Urban.Environ.Technol*, 3(2), 177 – 208.

[7] Wagrowski, D. M and Hites, R. A (1997). "Polycyclic aromatic hydrocarbon accumulation in urban, suburban and rural vegetation", *Environ. Sci. Technol.,* 31: 279-282.

[8] Dwyer, J. F., MacPherson, G. E., Schroeder, H. W and Rowntree, R. A (1992). "Assessing the Benefits and Costs of the Urban Forest", *J. Arboricult.* 18(5) 227-234.

[9] Nichol J., Man S.W., Fung, C and Leung, K.K. M (2006). "Assessment of Urban Environmental Quality in A Subtropical City Using Multispectral Satellite Images", *Environment and Planning B: Planning and Design* 33(1): 39-58.

[10] Nowak D.J., Stevens, J.C., Sisinni, S.M and Luley, C.J (2002). "Effects of urban tree management and species selection on atmospheric carbon dioxide". *Journal of Arboriculture* 28(3):113-122.

[11] Fung, T and Siu, W.L (2001). "Environmental quality and its changes, an analysis using NDVI", *Intern. J. Remote Sensing*, 22: 305-334.

[12] Franzen, D. W (2011). "Collecting and Analyzing Soil Spatial Information Using Kriging and Inverse Distance". In David E.C and Shanahan J. F (Eds), GIS Applications in Agriculture. Boca Raton, FL: CRC Press.

[13] Li, J and Heap, A.D (2008). "A review of spatial interpolation methods for environmental scientists", *Geosciences*, Vol.137.

[14] Hammond, R and McCullagh, P (1978). Quantitative Techniques in Geography: An Introduction. Clarendon, Oxford University Press.

[15] Kusienya, C.M (2004). "The Mathare 4A experience and the Kenya Slum Upgrading Programme". Kenya country paper presented at the workshop on *The Perpetuating Challenge of Informal Settlements,* 8th -10th November 2004, University of Witwatersrand, Johannesburg.

[16] Shihembesta, L.U (1989). Urban Development and Dwelling Environments. Brief Notes on Dandora, Kariobangi, and Eastleigh. International Workshop on Housing. Ku-Leuven, UNCHS-PGCHS-HRDU.

[17] JICA (2005a). The Study on Master Plan for the Nairobi Metropolitan Area in Republic of Kenya: Ministry of Roads and Public Works, Ministry of Local Government/Japanese International Cooperation Agency (JICA), Nairobi.

[18] JICA (2005b): Nairobi Urban Transport Strategy, Ministry of Public Works, Ministry of Transport/City Council of Nairobi/JICA, Nairobi.

[19] Gachanja, M. (2005). "Forest Law Enforcement and Governance - The Case of Kenya". Paper Prepared for the Regional Workshop on the *African Forest law Enforcement and Governance (AFLEG) Process,* 24th - 25th February 2003, IUCN, Nairobi.

[20] Ayaga, G., Kibata G, Lee-Smith D., Njenga M and Rege, R (2004). "Policy Prospects for Urban and Peri-urban Agriculture in Kenya." Proceedings of the Workshop on *"Urban Harvest",* 15 July, 2004, CIP and International Livestock Research Institute (ILRI), Nairobi, Kenya.

[21] Irungu, K.Z (2017). Decongesting Nairobi- Urban Transportation Challenges. Roads Department, Republic of Kenya.

[22] Hedley, A.J., Wong, C.M.., Lam, T.H., McGhee, S and Ma, S (2003). "Air quality in Hong Kong and the impact of pollution on health 1988-1997". In McGranahan, G and Murray, F. (Eds.), Air Pollution and Health in Rapidly Developing Countries, Earthscan, London.

[23] Schwela, D., Haq G., Huizenga C., Han W.J., Fabian, H and Ajero, M (2006). Urban Air Pollution in Cities; Status, Challenges and Management. Earthscan, London.

[24] Woodruff, T.J., Parker, J.D and Schoendorf , K.C (2006). "Fine particulate matter (PM2.5) air pollution and selected causes of postneonatal infant mortality in California". *Environmental Health Perspectives* 105: 608-612.

[25] Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K and Thurston, G.D (2002). "Lung cancer, cardiopulmonary mortality and long-term exposure to fine particulate air pollution", *J. American Medical Association*, 287(9):1132-1141.

DOI: https://doi.org/10.30564/jees.v3i2.3289

APPENDIX

DEVELOPMENT ZONES OF NAIROBI

Zone	Areas Covered	Zone	Areas Covered
1	Central Business District (CBD/Upper Hill Area	2	Eastleigh Pumwani/California Ziwani/Starehe
3	Westlands Parklands' City Park Estate/Upper Parklands	4	Spring Valley Riverside Drive Kileleshwa Kilimani Thompson Woodley
5	Upper Spring Valley Kyuna Loresho Lavington/Bernard Estate		
6	Muthaiga New Muthaiga	7	Mathare/Mathare North/Lower Huruma Kariobangi/Korogocho Dandora
8	**Old Eastlands** Shauri Moyo/Maringo/Bahati Kaloleni/Makongeni Mbotela/Jericho/Jerusalem Kariobangi Lt/Industrial Mathare North Lt/Industrial Kariobangi Lt/Industrial	9	**Industrial Area** Nairobi West/Madaraka South 'B'/South 'C' Nairobi Dam/Ngummo Highview/Magiwa Golf Course/Langata Estates
10	Southlands Otiende/Ngei 1&2 Onyonka/Masai Jonathan Ngeno/Villa Franca Imara Daima/Tassia Fedha/Avenue/Embakasi Village	11	**Special Scheduled Area (Kibera Slums)** **National Housing Corporation (NHC) Estates** • Ayany • Olympic • Fort Jesus • Karanja Road
12	Karen/Langata	13	Gigiri/Kitisuru/Ridgeways Garden Estate Safari Park/Balozi Housing
14	Roysambu Thome Marurui	15	Dagoretti • Riruta • Kangemi • Mutuini • Waithaka • Ruthimitu • Uthiru
16	Baba Dogo Ngumba/Ruaraka	17	Githurai 44&45 Zimmerman Kahawa West
18	**Kasarani** • Clayworks • Clay City • Sports View • Mwiki • Njiru • Ruai	19	**Special Scheduled Area** • Githurai Kimbo • Wendani • Kahawa Sukari

 DOI: https://doi.org/10.30564/jees.v3i2.3289

Zone	Areas Covered		Zone	Areas Covered
20	**Public/Strategic Reserved Areas (Gazetted)** • State House • JKIA Airport • Wilson Airport • Military Sites o Military Airbase Eastleigh o DoD Headquarters o Kahawa Barracks o Langata Barracks o Defence College, Karen o Forces Memorial Hospital		20g	**Recreational and Forests** • City Park • Arboretum • Ngong Forest • Karura Forest **National Game Park** **Stadia** • Moi Sports Complex, Kasarani • City Stadium • Nyayo Stadium Uhuru Park Central Park Uhuru Park Central Park Uhuru Gardens

DOI: https://doi.org/10.30564/jees.v3i2.3289