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Assessment of Normalized Difference Vegetation Index (NDVI) of Port Harcourt Metropolis and Environs, from 1986 to 2018: Implication to Urban Greening and Management

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ABSTRACT

In the past 33 years, population and urbanization in Port Harcourt metropolis and environs has resulted to rapid vegetal removal and alteration of its urban green surface. This paper examines Normalized Difference Vegetation Index (NDVI) of Port Harcourt metropolis and environs from 1986 to 2018 using algorithm of the Google Earth Engine (GEE) from Geographic Information Systems (GIS). The results show that in 1986, with population of 757,022 persons, NDVI recorded lowest value of -0.08 and highest value of 0.43 ranging 0.5; NDVI was observed to be thickly visible at the east, north and western segments of the city showing dense vegetal cover at Rumuekini and Oyigbo segments. In 2003, with population of 1,143,103 persons, NDVI was between 0.53 and -0.10 ranging0.63 with high density at the north-eastern section (Rumuekeni) north-western section (Oyigbo), east and south-eastern sections (Okirika). Also, in 2018, NDVI was between 0.043 and -0.06 with a range of 0.49, shifted its concentration to the north-eastern section (Oyigbo) and south-eastern segment (Okirika) with population of 3,095,342 persons having the highest loss of the city greening. Thus, it is established that there is rapid and intense decline of vegetal cover on the city green surface areas. It is therefore recommended that policy makers and development practitioners implement tree planting and urban greening in Port Harcourt metropolis and environs to intervene the thermal discomfort and hazards possible in the city.

Keywords: *NDVI, Urbanization, GIS, Urban Greening, Biophysical Component, Evapotranspiration, Temperature, Land Use Land Cover*

INTRODUCTION

Normalized Difference Vegetation Index (NDVI) information is very important in managing urban greening and the thermal environment. On daily basis, there is constant alteration of biophysical components of the environment in the form of vegetal removal, environmental degradation and atmospheric pollution [1]. The alterations have caused rise in environmental temperature and energy imbalance [2]. Normalized Difference Vegetation Index (NDVI) is an index in Remote Sensing (RS) which quantifies vegetation amount in a given area by measuring the difference between near-infrared (NIR) that vegetation severely reflects and Red Light (R) which the vegetation absorbs. When NDVI value is negative, it signifies likely presence of water, if close to +1 it means possible dense green leaves and close to zero means likely absence of green leaves which could be urban area [3]. Thus, urbanization has affected the values of NDVI in cities as urban area occupies only 2% of the total global surface area, but hosting over 50% of the human population [4] [5]. The process of urbanization has resulted to massive removal of vegetation from urban surfaces and replacing them with urban fabrics capable of increasing the thermal fluxes thereby resulting to human heat discomfort in the city area. Removal of vegetation accelerates Land Surface Temperature (LST) at the inner city and reduces Land Surface Emissivity (LSE) especially at the rural fringes [6].

Since 1960, thermal energy fluxes and temperature of cities as a result of modification of Land Use Land Cover (LULC) have given researchers serious concern [7]. Studies show that vegetation through photosynthesis and transpiration can reduce temperature and increase humidity, thus play a role in regulating temperature of the environment and urban heat island effect [8]. The process of modifying vegetal land scope through deforestation and urbanization will affect the temperature of surface areas, solar radiation, heat storage and releases, evapotranspiration, wind turbulence at the canopy layer and cloud formation. Accumulation of these phenomena effects in a larger scale the global climate change over time and space used in radiation budge and heat balance for climate models [9].Vegetal modification in a city will result to lose of water quality, increased pollution, more energy consumption and health hazards [10] [11].

Data acquired through space borne satellite remote sensing and Geographic Information System (GIS) has facilitated the assessment several spatial phenomena on the earth surface and their changes [12]. GIS technology is a platform that provides flexible environment for entering, analyzing and displaying digital data from various sources in urban changes and database development. Any feature on the earth surface is capable of emitting thermal radiation at different wavelengths. Thus, emissivity as the spectra radiance of a grey body to that emitted by a blackbody at the same temperature has been of great use in the study of urban vegetal cover and management [13]. However, land surface emissivity has helped in the process of retrieving land surface temperature and NDVI from thermal infrared data of the Satellite origin [14].

Port Harcourt is a fast growing coastal city in Nigeria as urbanization and high industrial activities are modifying the biophysical components of the city by replacing them with urban pavement materials such as roads, buildings and general concrete infrastructures of man [15]. Rural sites are converted to residential areas, farmlands are turned industrial sites and recreational areas are converted to building sites. The city center has dense concentration of buildings due to population rise [16] [17]. Port Harcourt urbanization has raised the city temperature with attendant human discomfort. The pressure exerted by the growing population on various land uses is noticeable in the city [11] [15] [18]. This study therefore analyzes the spatio-temporal vegetal pattern using NDVI approach of Port Harcourt city from 1986 to 2018 in order to understand the variation of the city greening with rising urbanization challenges as well as foster solutions to the scourging heat disaster common in the cities of the World.

MATERIALS AND METHODS

Description of Study Area

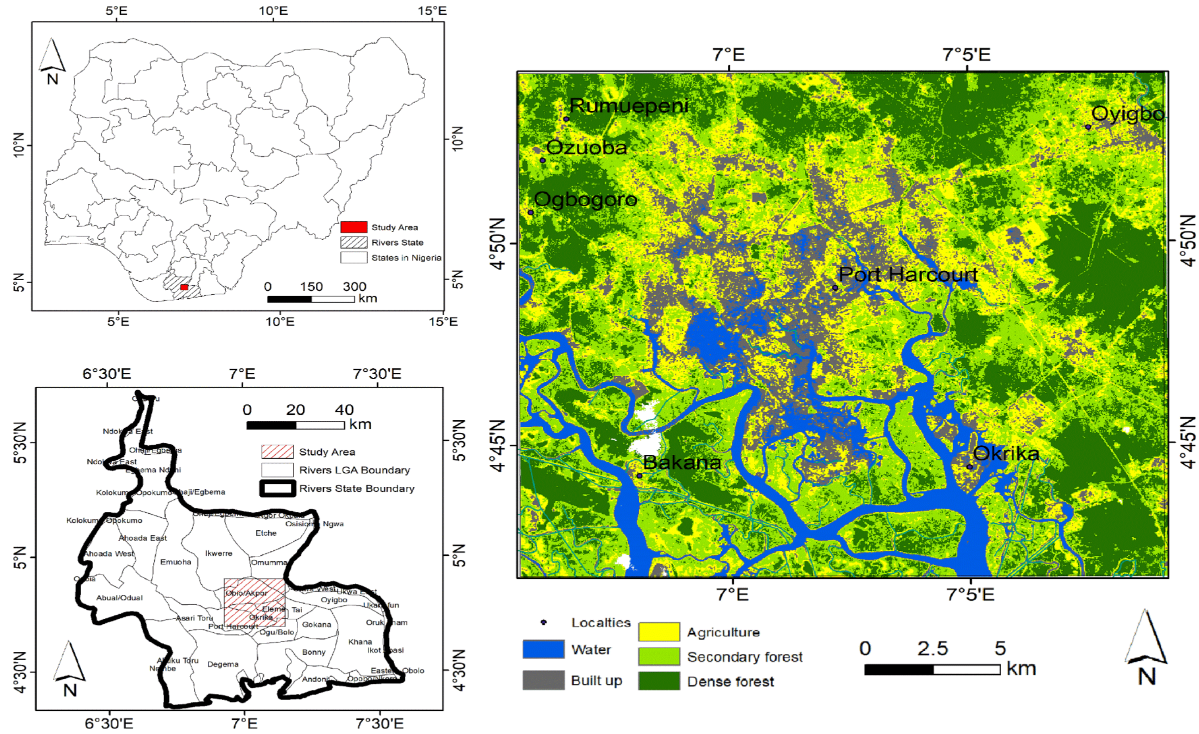

Figure1. *Study Area (Port Harcourt Metropolis and Environs)*

Source: *Nwaerema, Ologunorisa, Nwagbara and Ojeh, 2019.*

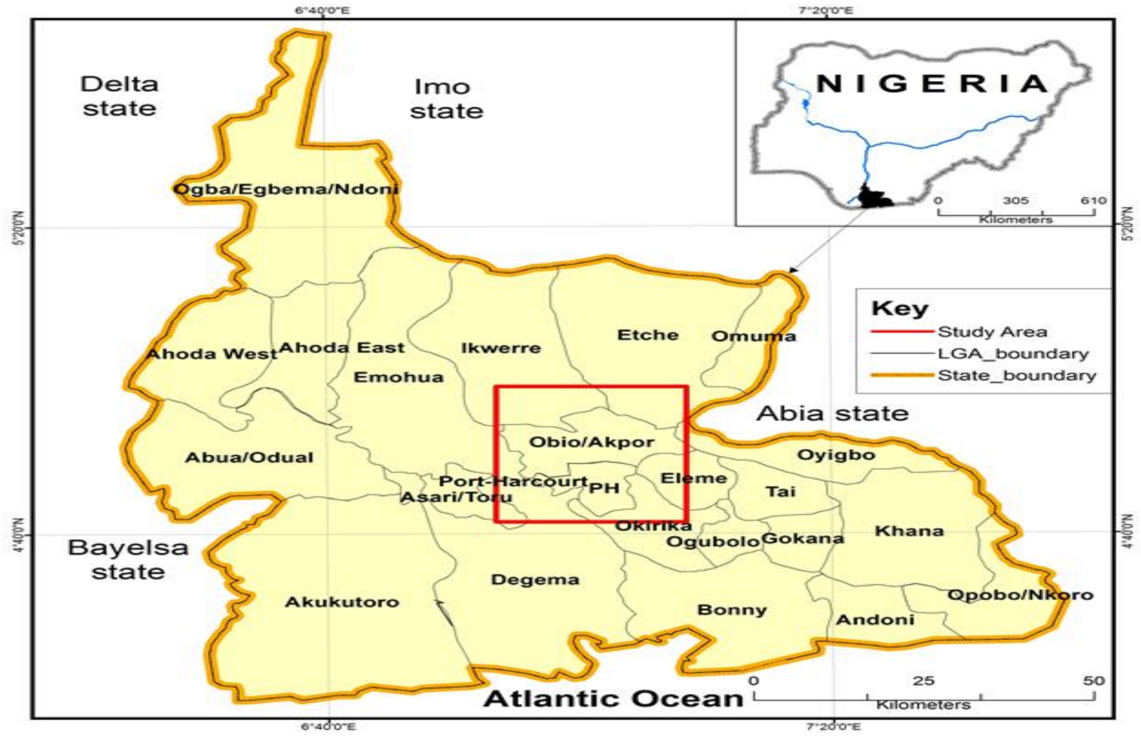

Figure2. *Rivers State showing Port Harcourt Metropolis and Environs*

Source: *Nwaerema et al., 2019*

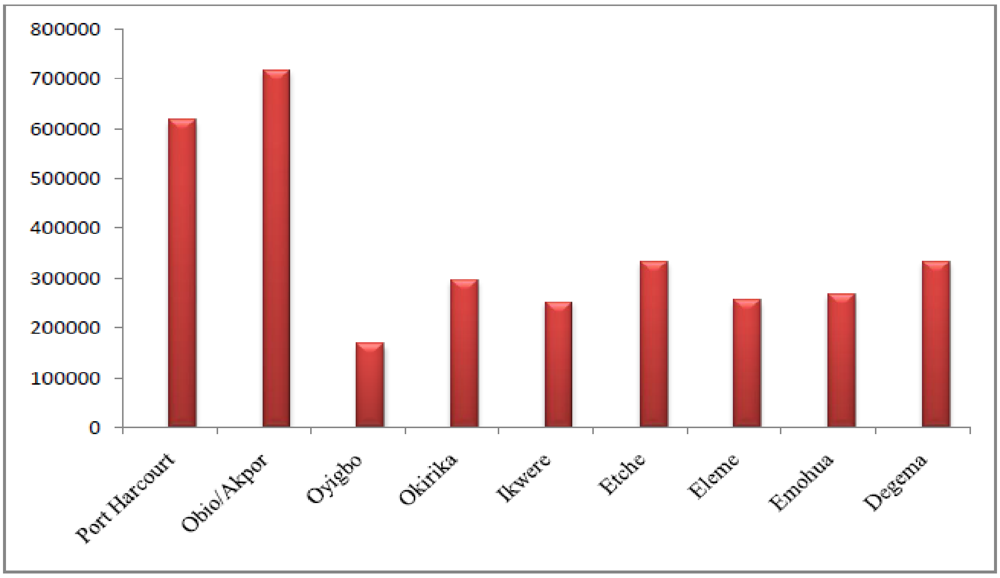

Figure3: *Population of Port Harcourt City and surrounding LGAs*

The study area description was adopted in a related work on the geo-spatial dynamics of land surface temperature of Port Harcourt metropolis and environs [19]. Port Harcourt metropolis and environs is located within the longitudes of 70’E and 70’5 E and the latitudes 4045’N and 4050 N (Figure 1). The main Local Government Areas (LGA) that make up Port Harcourt metropolis and environs are Obio/Akpor and Port Harcourt City LGAs; Eleme, Degema, Oyibo, Emohua, Etche, Okirika and IkwereLGAs as extended LGAs surrounding the main city (Figure 2). Port Harcourt city and environs is the largest metropolitan city in the Niger Delta region of Nigeria with population of 3,095,342 persons in 2018 (Figure 3).The city is a coastal settlement close to the Atlantic Ocean in the Niger Delta region of Nigeria (Figure 2). As a city located to the coastal environment of the Atlantic Ocean, both land and sea breezes moderate the thermal characteristics of the city. The harmattan wind is common during December and January propelled by the north-easterly trade winds across the Inter-Tropical Convergence Zone

(ITCZ). The peak of relative humidity averages 80% in April through September but low in the dry season between January to March [20] [21]. Rainfall is usually high between April to October with volumes of 2000mm to 2500mm [18]. Average peak temperature is 32°C in core dry season of January to March and in the wet season is 26°C in the month of July [19]. The cloud thickness is 6 oktas during the wet season which gradually drops during the dry season and the mean wind velocity is 0-3m/s [19] [20] [21]. The climatic characteristics and location of Port Harcourt metropolis and environs gave birth to the thick vegetation cover and biophysical conditions as well as the rapid urbanization process.

Methods of Data Collection

The author has adopted the previous methods of [17]. These methods of satellite data retrieval use Google Earth Engine (GEE). Satellite data were retrieved and analyzed using the algorithm for extracting LST from Lands at 5, 7 and 8 thermal infrared sensors as it applies to surface emissivity sources from the Google Earth Engine (GEE) which is an advanced earth science data and analysis platform which allows the estimation of LST products from any part of the globe, covering the time period from 1986, 2003 and 2018. GEE approach makes satellite data retrieval easily accessible and quickly downloaded. The Landsat 5, 7 and 8 satellites are fixed with thermal infrared radiometers useful for Land Surface Temperature (LST) estimation. The retrieval pathways are as bellow in Table1.

Table1: *Details of Landsat Data Retrieved*

Dates of Retrieval	Satellite/Sensor	Reference System/Path/Row
01/01/16 - 30/01/16	GEE/Landsat 5/7/8	AoI
01/01/02 – 30/01/02	GEE/Landsat 5/7/8	AoI
01/01/86 – 30/01/86	GEE/Landsat 5/7/8	AoI

Source: *Nwaerema et al., 2019*

In order to establish reliability and consistency of the data, the Single Channel (SC) algorithm was applied to estimate emissivity of different locations. Landsat 8 that carries two thermal bands for data consistency. The Landsat 5 archive extends from March 1984 to May 2012, the Landsat 7 archive extends from May 1999 to present and the Landsat 8 archive from April 2013 to present day [21].

The SC algorithm technique was applied to analyze the three Landsat thermal infrared observations. Google cloud computing servers generates the LST estimation with direct access to the GEE satellite data catalogue. By adopting the SC technique, the LST (TS) was calculated from the radiance-at-the-sensor in a single band using the radiative transfer equation below:

$$B \ (LST) = Lsen - Lup - \tau \cdot \ (1-\varepsilon). \ \ Ldown\pi \ \tau \cdot \ \varepsilon \text{ --------------------------------- } \quad (1)$$

Where B denotes Planck function, Lsen represents the radiance-at-the-sensor, Lup means the thermal path radiance, Ldown is the down welling irradiance, ε signifies the surface emissivity and τ is the atmospheric transmissivity. In Equation (1) the Lup, Ldown and τ were established to calculate the LST. They were also heavily dependent on the total water vapour in an atmospheric column (Perceptible Water (PW), which was easier to determine with the use of satellite data and LST estimation.

$$L\,ST = Y\left[{}^{1}\!/_{\in} . (\psi_1 . L_{sen} + \psi_2 + \psi_3)\right] + \grave{o} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where

$$Y = \left[\frac{C_2 . L_{sen}}{T_b^2} \ . \ \left[(\lambda^4 . \ L_{sen})/C_1 + {}^{1}\!/_{\lambda}\right]\right] - 1 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\grave{o} = -y . L_{sen} + Tb \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$\psi = C . \begin{cases} PW^2 \\ PW \\ 1 \end{cases} \rightarrow$$

$$\begin{Bmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \end{Bmatrix} \begin{Bmatrix} C_{11} & C_{12} & C_{13} \\ C_{12} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{Bmatrix} . \begin{Bmatrix} PW_2 \\ PW \\ 1 \end{Bmatrix} \ldots\ldots\ldots\ldots \quad (5)$$

Where Planck's constant valuec1 is 1.19104 × 108 W µm4 m−2 sr−1 and C2 is 14,387.7 µm K; λ is the central wavelength of the thermal band of the Landsat sensor in question; Lsen in W sr−1 m−2 µm−1; Tb is the brightness temperature in Kelvin; C is the coefficients table, with cij derived by simulations using different atmospheric profiles and ψx is the coefficients weighted with PW.

In order to achieve the product of the Landsat Thermal Radiance-at-Sensor, the level 1T (precision Ortho-corrected) products for each Landsat stage provided by the USGS were ortho rectified images of the thermal infrared radiance-at-the-sensor. The satellite products are image collections of the Landsat GEE catalogue. These images at the collection points possess digital number values, converted to radiance-at-sensor by GEE function using scaling factors. However, Landsat thermal bands have varied spatial resolutions with high reliability among different Landsat sensors as the derived products were re sampled by the USGS up to 30m × 30m using cubic convolution re sampling method [22].

As the Planck function was directly inverted, the brightness temperature was estimated. The GEE catalogue possesses image collection of Landsat top-of-the-atmosphere (TOA) brightness temperature. The Landsat brightness temperature product in the GEE catalogue contains cloud cover information which can be derived using the Fmask approach. The Fmask has remained a good method for spotting clouds, cloud shadows, water surfaces and others in Landsat imagery. The brightness temperature and information on the clouds, cloud shadows and water surfaces were used for image collections. The Landsat surface reflectance was available through the GEE catalogue, in the form of image collections. The red and near-infrared bands were used for the calculation of the NDVI, which was needed in order to estimate the NDVI-based emissivity and LST [23].

Emissivity was introduced for LST estimation, since error in emissivity of 1% can result to noticeable errors in the LST to the value of 1 K depending sensor setting, climatological and geographical conditions of the area. For this reason, three different sources of emissivity of ASTER and MODIS in GEE and NDVI-based emissivity estimated from Landsat red and near-infrared data. The reason was to test their strengths and weaknesses to compare their impact on the LST retrieval for different land types, corresponding to different landscapes and ecosystems. Fraction of vegetation cover (FVC) was estimated using Equation (6), by assuming the NDVI threshold for non-vegetated (NDVInonveg) and vegetated (NDVIveg) surfaces to be 0.18 and 0.85, respectively. Emissivity was estimated using Equation (7), assuming a reference emissivity for non-vegetated (εnonveg) and vegetated surfaces (εveg) to be 0.97 and 0.99, respectively. The NDVI-based emissivity product was of 30m × 30m spatial resolution, matching exactly the Landsat thermal data [23]. The following formulas were applied:

$$\mathrm{FVC} = \left[\frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{nonveg}}}{\mathrm{NDVI}_{\mathrm{veg}} - \mathrm{NDVI}_{\mathrm{nonveg}}}\right] 2 \quad \ldots\ldots\ldots\ldots \quad (6)$$

$$\epsilon = \epsilon_{\mathrm{nonveg}} \;.\; (1 - \mathrm{FVC}) + \epsilon_{\mathrm{veg}} \,.\, \mathrm{FVC}\ldots \quad (7)$$

RESULTS AND DISCUSSION

The Normalized Difference Vegetation Index (NDVI) of GIS origin is an indicator used to analyze whether the target or observed location contains green vegetation or not. Normalized Difference Vegetation Index quantifies vegetation by measuring the difference between near-infrared which vegetation strongly reflects and red light which vegetation absorbs. NDVI varies between -1.0 and +1.0 of different vegetal density with +1 as high vegetal cover. It expresses pattern and trends of vegetal cover over a period of time [24]

In 1986 (Figure 4 and Table 2), NDVI recorded lowest value of -0.08 and highest value of 0.43 ranging 0.51indicating the second highest vegetal cover period in the epoch. NDVI was thickly visible at the east, north and western segments of the city showing that Rumuekini and Oyigbo segments in this period had low urbanization pressure. The southern areas of Bakana and Okirika had intense concentration of urbanization expressed in the NDVI values of vegetation cover. The city center had greater level of vegetal cover with suspected water bodies draining into the city. Notwithstanding the water prone terrain and drainage systems of the southern part of the city, urbanization spread was intense in Bakana and Okirika areas. Urbanization and its surface modifications were in the south-western direction. However, this period experience vegetation cover close to the city center.

In 2003 (Figure 5 and Table 2), NDVI was between 0.53 and -0.10 ranging 0.63 with high density at the north-eastern section (Rumuekeni) north-western section (Oyigbo), eastern and south-eastern section (Okirika) indicating the highest range of vegetal cover in the study period. The city center had sparse vegetal cover as industrialization activities had taken over natural land uses and farmlands. In this year, land modification spread to the northern part along Rumuekini and Oyigbo segments as the southern segments of Bakana and Okirika slowed in urbanization pressure. The west and eastern segments of the city had spots of developed lots of lands replacing natural vegetal lands. The urban pressure was expressed in the replacement of biophysical components by urban fabrics. This year experience increased disappearance of vegetation in the inner city and across different spots of the city surface areas.

In 2018 (Figure 6 and Table 2), NDVI was between 0.043 and -0.06 with a range of 0.49 concentrating on north-eastern section (Oyigbo) and south-eastern segment (Okirika) showing the least value in the study years. Port Harcourt inner city in this year had expanded with intense replacement of natural vegetal surfaces with urban fabrics extended to the rural fringes. Vegetation at the inner city was scarce. The northern segments of Rumuekini and Oyigbo had been taken over by intense urbanization pressure. Vegetation had disappeared beyond Rumuekini and Oyigbo indicating that these areas would experience serious thermal energy effects. Also, the southern sections of Bakana and Okirika had received intense pressure of vegetal removal extending to the water bodies. The eastern segment showed limited natural vegetation yet with severe urban pressure. The inner city and extended rural fringes had received near zero greening showing poor greening and management. In a study on urbanization and vegetation degradation across the world's metropolises, the results indicated spatio-temporal vegetal degradation rapidly taking place in the cities across the world and vegetal decline was noticeable in different periods according to different stages of urbanization which is in tandem with the pattern of Port Harcourt metropolis and environs changing vegetal density over the past 33 years [25]. Also, study was conducted using GIS in Uyo city, the result showed that swamp vegetation, mixed vegetation and forest are the most affected natural land uses as they were replaced by sparse built-up, dense built-up and borrow pit resulting from the consequences of urbanization and intense economic activities of the city population the same way vegetal surface of Port Harcourt city is replaced by urban fabrics due to dense population [26].

Another investigation was carried out in Indianapolis, USA to know the changes of biophysical variables due to urbanization induced LULC changes, the result showed general trend of pixel responding to land-use-land-cover changes as dense vegetation cover and high surface cover were replaced by areas of high temperature, sparse vegetation cover and low surface moisture conditions [27]. This establishes the possibility that Port Harcourt area is replacing its natural vegetation showing that high temperature rise is possible.

In all, NDVI (vegetal cover) increased from the inner city to the rural outskirts. In other words, NDVI is low in the inner city. From 1986 to 2018, Port Harcourt metropolis and environs had experienced tremendous and rapid development, expanding by clearing vegetation toward the rural environment thereby intensifying thermal heat concentration in the inner city. The density of vegetation in a specific area will contribute to the degree of UHI operation in that site. Thus, the inner city of Port Harcourt as observed is facing constant loss of urban greening thereby pushing NDVI to the far rural fringes.

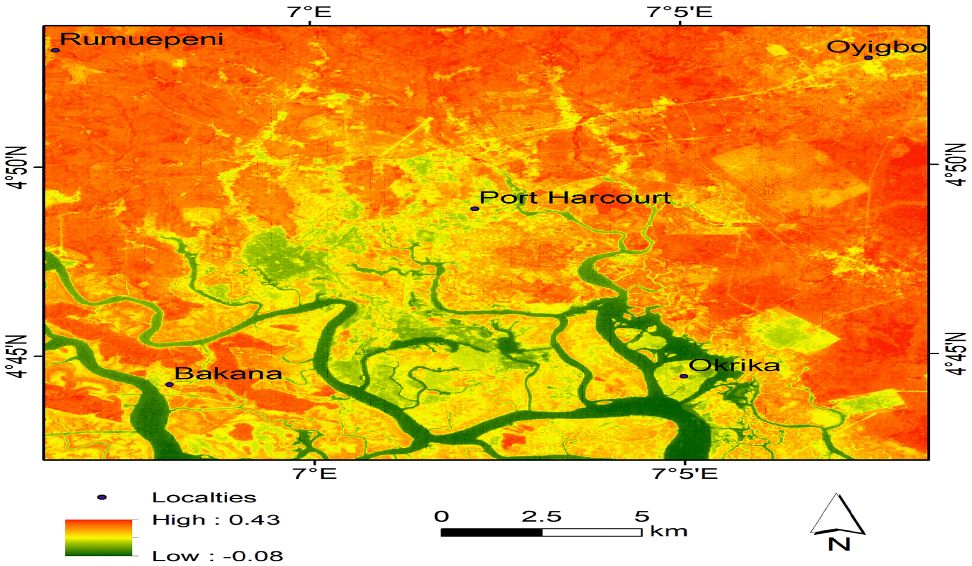

Figure4. *Normalized Difference Vegetation Index (NDVI) of Port Harcourt Metropolis and Environs, 1986*

Source: *Author, 2018*

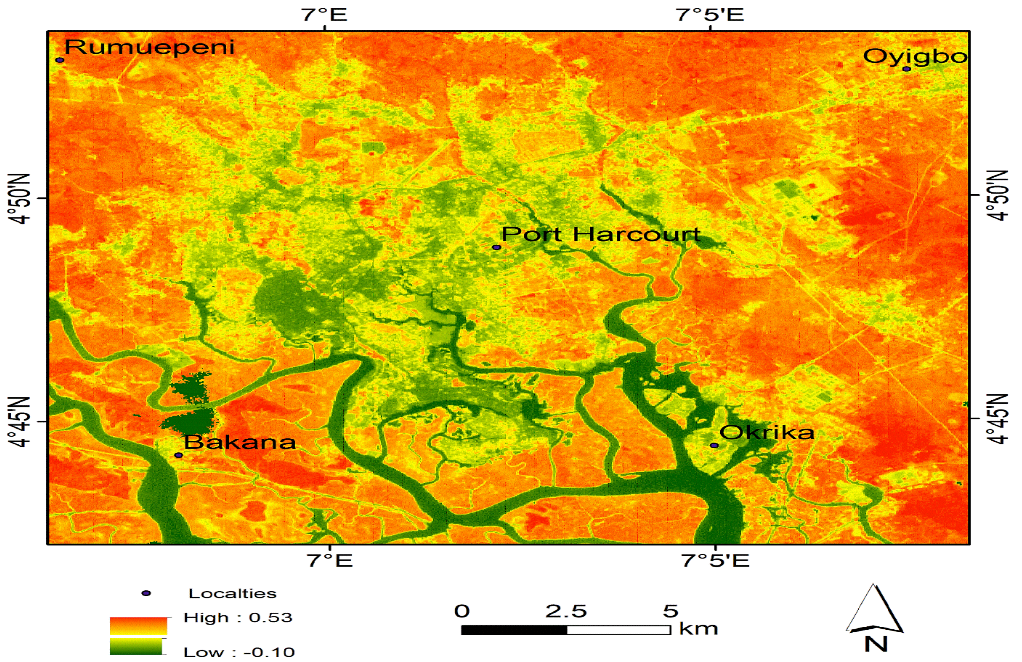

Figure5: *Normalized Difference Vegetation Index (NDVI) of Port Harcourt Metropolis and Environs, 2003*

Source: *Author, 2018*

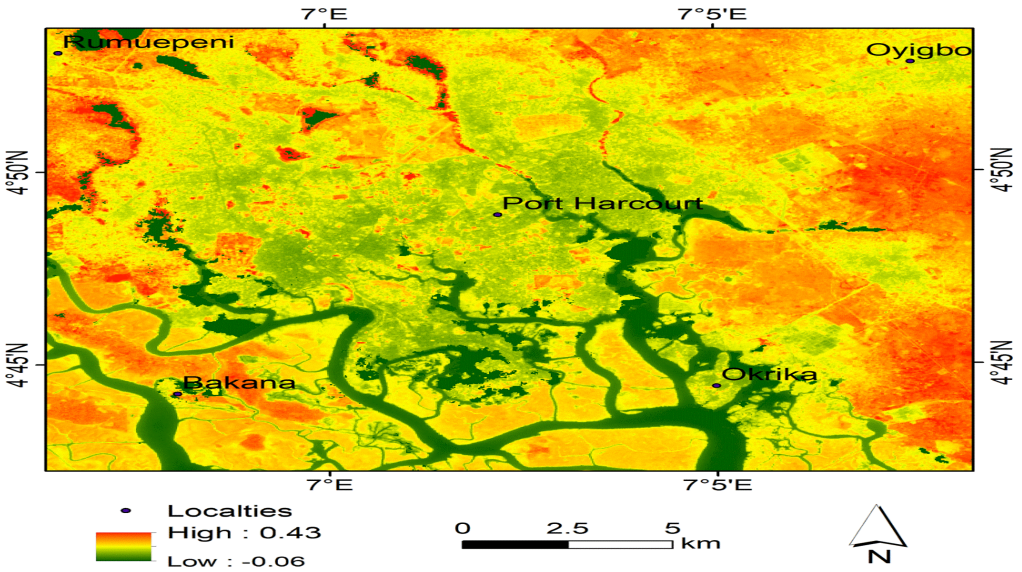

Figure6: *Normalized Difference Vegetation Index (NDVI) of Port Harcourt Metropolis and Environs, 2018*

Source: *Author, 2018*

Table 2: *Area Concentration and Direction of NDVI over the Study Years*

Year	NDVI Level	NDVI Range	Area Concentration and Direction of NDVI
2018	0.43 – (-0.06)	0.49	North-eastern segment (Oyigbo) and south-eastern segment (Okirika).
2003	0.53 – (-0.10)	0.63	North-eastern segment (Rumuekeni) north-western segment (Oyigbo), eastern and south-eastern segments (Okirika).
1986	0.43 – (-0.08)	0.51	Northern segment (Rumuekeni/Oyigbo), eastern and south-eastern segment (Okirika).

Source: *Author, 2018*

The population of Port Harcourt area was projected for the years under study [28]. The trend of population and NDVI (Figures 7 and 8) in 1986 was 757,022 persons with NDVI range of 0.51. In 2003 the population was 1,143,109 persons with NDVI range of 0.63 and in 2018 the population rose to 3,095,342 persons with NDIV range of 0.49.

The period of 2019 had the least vegetal and surface area greening due to rapid urbanization. Increased population has reduced the city green in gas a result of increased urban pavement materials and human activities. Normalized difference vegetation index of Port Harcourt metropolis and environs since 1986 to 2019 has been integrated in the performance of population of people altering the vegetal characteristic of the city environment.

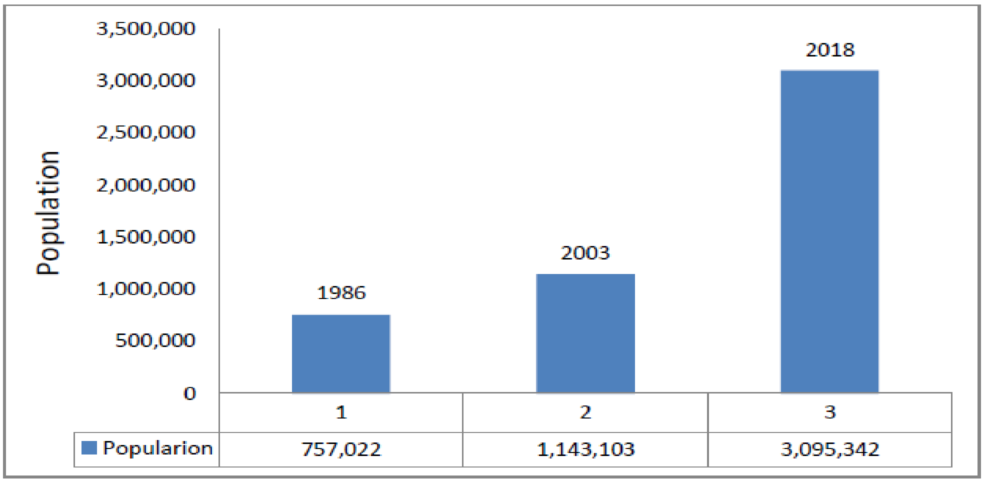

Figure7. *Population of Port Harcourt in 1986, 2003 and 2018*

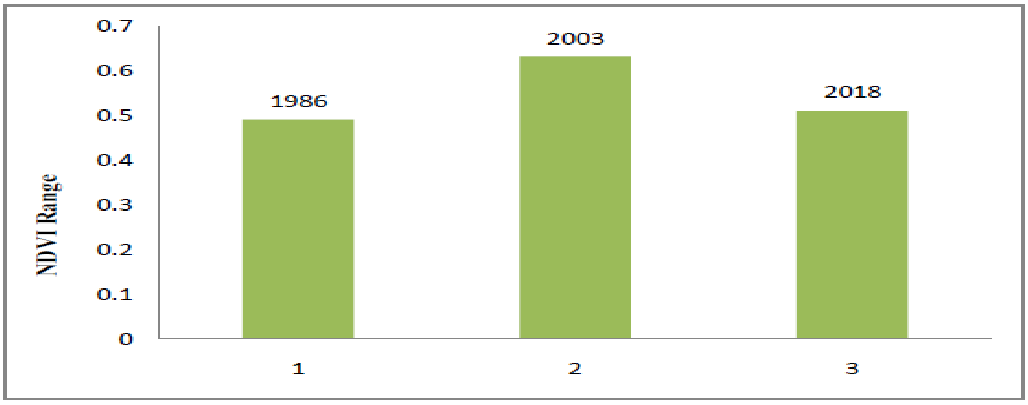

Figure8. *NDVI Range of Port Harcourt Metropolis and Environs in 1986, 2003 and 2018*

CONCLUSION

GEE as a remote sensing technique is a vital tool in the investigation of urban greening. In the last 33 years Normalized Difference Vegetation Index (NDVI) of Port Harcourt metropolis and environs has reduced from 0.63 to 0.49 with a variation of 0.14 and current population of 3,095,342 persons. Thus, NDVI from 1986 to 2018 has remained dynamic from one section of the city to another characterized by changes in human development activities across the city surface. The current situation indicates that the entire city surface has undergone intensive vegetal removal especially the northern sections of Rumuekini and Oyigbo indicating areas with poor greening which are vulnerable to heat disaster. It is therefore recommended that policy makers and development practitioners implement tree planting and greening in order to ameliorate the possible occurrence of heat related ailments in Port Harcourt city and rural fringes.

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