World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Spatio-temporal variations of climate change and urban heat island in Port Harcourt, Rivers State, Nigeria (Implications on Physical Planning)

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World Journal of Advanced Research and Reviews, 2025, 25(01), 2296-2304

Publication history: Received on 16 December 2024; revised on 25 January 2025; accepted on 28 January 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.25.1.0274

Abstract

One of the most worrisome environmental challenges facing the globe today is the issue associated with the impacts of climate change most especially on the urban environment. The variations in climatic condition of cities in developing world today as experienced over time cannot be overemphasized. This study investigated the spatio-temporal variations of climate change and urban heat island, taking into cognizance its implications on physical planning in Port Harcourt Rivers State. The study adopted the qualitative design approach and data were obtained from secondary sources. Remotely sensed data from USGS Earth Explorer and Landsat OLI/TIRS data for 2015 and 2024 with minimal cloud cover were obtained. A comparative analysis using ArcGIS was carried out to show spatial patterns and Land Surface Temperature change in the study area. The Land Surface Temperature change was calculated using TOA, BT, emitted radiance wavelength, and Land Surface Emission with an extension in ArcGIS software. The Land Surface Temperature analysis in 2015 and 2024 revealed a significant increase in temperature. Impervious surface analysis using NDVI indicated a rise in built-up areas over the years. The relationship between impervious surface and Land Surface Temperature highlighted the impact of urbanization on temperature changes. The study therefore recommended strategies like increasing urban greenery, using cool roofs and pavements, urban planning and design improvements, energy efficiency measures, urban regeneration and watershed management as preventive and mitigative measures.

Keywords: Climate Change; Urban Heat Island; Normalized Difference Vegetation Index; Land Surface Temperature

1. Introduction

Among others, the most threatening environmental challenges confronting human race today in the world view are the issues of greenhouse effect, ozone layer depletion and climatic variation. This is most pronounced in industrial regions of the world where air pollution has been eminent. Climate change, which is responsible for the stimulation of several environmental problems today become a challenging issue, and to address this, the United Nations Framework Convention on Climate Change was adopted and singed by 162 countries in 1992 at the Rio Earth Summit. Climate change is a long-term shift in global or regional climate patterns occasioned by anthropogenic activities which results to ozone layer depletion, emission of greenhouse gases, excessive removal of vegetations and massive urban expansion without recuse to the ambient quality of the environment. The Intergovernmental Panel on Climate Change (IPCC, 2014) explained that climate change is a change in the state of the climate that can be identified by changes in the mean and/or the variability of its characteristics, and which continues for a long time, typically decades or longer.

The climate of Africa, Nigeria and perhaps Port Harcourt have been extremely hotter than ever. Heat waves has become a threat to human health both urban and rural dwellers within and at the periphery of the city. Urban Heat Island (UHI) became very pronounced in the city because of air pollution, compacted settlements, high rise building, pavement areas, uncoordinated development and the subsequent disappearance of green vegetations (Aybars, 2022). These built-up

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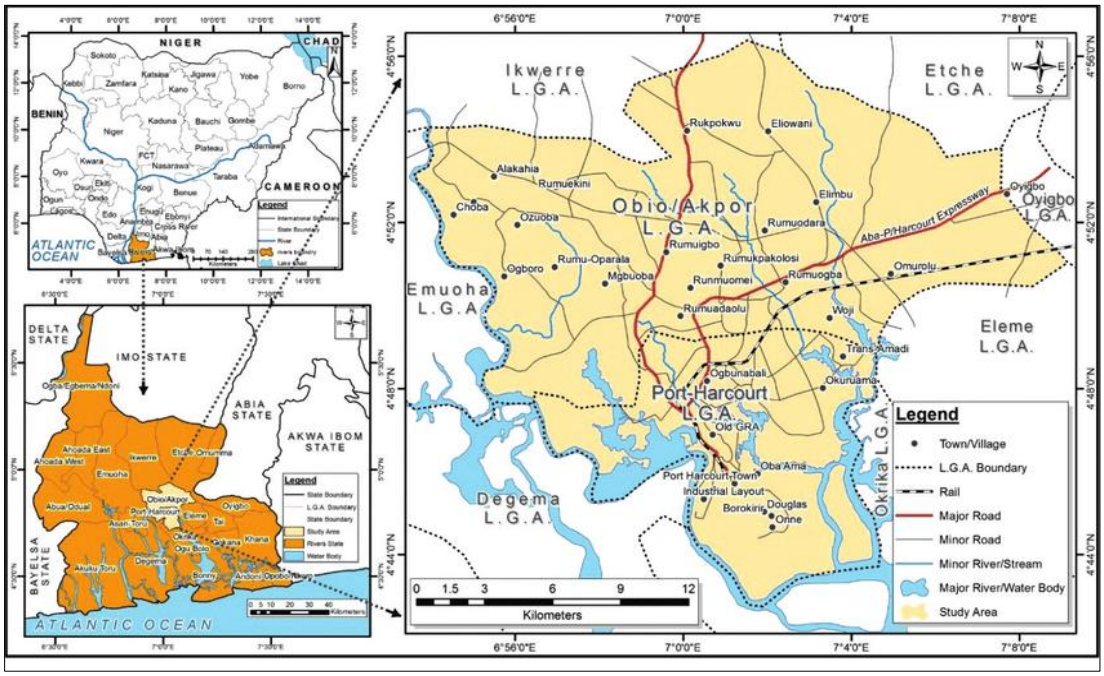
areas trapped the incoming short-wave radiation from the sun at noon time and re-radiate it back as long wave radiation at night. Greenhouse gases and atmospheric aerosols trapped the long wave radiation within the earth atmosphere thereby increases the heat capacity of the surrounding environment. The effects of Urban Heat Island (UHI) are a significant consequence of urbanization, causing higher temperatures in urban areas compared to rural areas (Dergachev, 2023). The implications of this scenario on physical planning and the vulnerable population in the study area cannot be overemphasized.

Physical planning aimed at ensuring that the elements of the physical environment are properly arranged, preserved and conserved. It also ensures that development is orderly without any forms of compromise to the wellbeing and sustainability of the environment. City planning that incorporates the concept of resilient cities become imperative in dealing with current environmental challenges most especially the issues surrounding climate change and urban heat island (Akue, 2018). Because resilient cities could absorb, recover and prepare for future shocks, the physical planning approach must employ its techniques when planning the urban environment. Physical planners must employ the smart cities revolution approach with model analytical techniques provided by urban big data to solving issues related to urban dynamics, urban heat island and climate change in our built environment as the issue of environmental degradation and urban decay becomes pertinent in our national and international discuss. Hence this study assesses the spatio-temporal variation in climate change and urban heat island in Port Harcourt and the implication on physical planning.

1.1. Study Area

Port Harcourt is the capital city of Rivers State in Nigeria, and a growing metropolitan area in the heart of the Niger Delta region. The city lies along the Bonny River, an eastern tributary of the lower Niger, 41 miles (66km) upstream from the Gulf of Guinea located in Nigeria Niger Delta area (Oyegun, 2007). It is located approximately on latitude 4^0 17' 98" – 4^0 47' 21" E and longitude 6^0 09' 99' – 6^0 59' 55" N of the Greenwich Meridian (Oyegun, 2007). The study area features a tropical monsoon climate with lengthy and heavy rainy season and very short dry season. The average temperatures typically range from 25°C (77°F) to 28°C (82°F). Warmest Months fall within February to April, with average high temperatures around 30°C (86°F) to 32°C (90°F). While the Coolest Months are July to September, with temperatures slightly lower, averaging around 25°C (77°F) to 27°C (81°F). It has a unique relief. The relief is low – lying and the rivers are influenced by tidal fluctuation. The drainage system of the study area is structurally controlled on the coastal lowlands, and it is mainly dendritic in pattern on the shoreline zone (Umeuduji & Aisuebeogun, 1999).



Source: GIS Lab Department of Urban and Regional Planning Rivers state University.

Figure 1 Study Area Showing Port Harcourt city and Obio/Akpor LGAs

2. Literature

2.1. Climate change variability

Climate change variability refers to the fluctuations and changes in the earth's climate system over time, which can occur naturally or be influenced by human activities. Changes in climate variability can have significant impacts on biological systems including agriculture, forestry, and human health. (IPCC, 2013) noted that the global temperatures have risen by about $1^{o}c$ since the late 19^{th} century. Climate variation has resulted to extreme weather events such as heat waves, droughts, heavy rainfall, excessive sunshine that will results to other environmental problems (IPCC, 2012). Studies by the Intergovernmental Panel on Climate Change (IPCC) have shown that there is increase in see level by about 15-20 cm since 1900 (IPCC, 2013).

2.2. Causes of Climate Change

Climate change refers to major changes in temperature, rainfall, snow, or wind patterns lasting for decades or longer. According to Nyashilu, Kiunsi & Kyessi (2024), climate change has been affecting human beings in the world. Both human-made and natural factors contribute to climate change. Cities situated on coastal areas are the most vulnerable to the impacts of climate change, notably extreme weather events such as intensive heat waves, flood, sea level rise, and tropical storms. Climate change leads to the loss and damage of socioeconomic and livelihood activities, infrastructures, and ecosystems in cities (Hakovirta, 2024). In urban areas, climate change becomes a threat to human habitation as a result of un-controlled urbanisation with massive deforestation. The phenomenon of climate change has led to the increase of energy consumption for cooling and weather stability (Nyashilu et al, 2024).

Human activities have increased the amount of greenhouse gases in the atmosphere. Although, credible amount of greenhouse gases is necessary for life to exist on earth, they trap heat in the atmosphere, keeping the planet warm and in a state of equilibrium. But this natural greenhouse effect is being strengthened as human activities (such as the combustion of fossil fuels and the burning of hydrocarbons) add more of these gases to the atmosphere, resulting in a shift in the Earth's equilibrium (Thornton, Ericksen, Herrero, & Challinor, 2014).

Human causes include burning fossil fuels, incomplete combustion from automobiles, hydrocarbon emission via gas flaring, illegal refining of crude oil, wastes combustion, cutting down forests, and developing land for farms, cities, and roads. These activities all release greenhouse gases into the atmosphere that interfere with the short-wave radiation and perhaps increase the amount of heat generated during the long wave re-radiation. Natural causes include changes in the Earth's orbit, the sun's intensity, the circulation of the ocean and the atmosphere, cloud contribution, volcanic activity, thunder strike and wildfire.

Table 1 Various Prevalent Causes of Climate Change

S/N	**Factors**	**Description**
1	Fossil fuels	Gases such as carbon dioxide and methane trap heat in the Earth's atmosphere. They are mostly created by humans burning fossil fuels – coal, oil, wood and natural gas (Fahey et al., 2017).
2	Increasing livestock farming	Industrial farming and ranching release huge levels of methane and carbon dioxide into the atmosphere. Farming contributes forty percent of the methane and twenty percent of the carbon dioxide to worldwide emissions (Fahey et al., 2017).
3	Deforestation	Deforestation to use wood for building materials, paper and fuel increases global warming in two ways: the release of carbon dioxide during the deforestation process and the reduction in the amount of carbon dioxide that forests can capture (USGCRP, 2014).
4	Fluorinated gases	These particularly damaging gases are emitted from equipment and products such as commercial and industrial refrigerators, air-conditioning systems and heat pumps. Such emissions have a very strong warming effect, up to 23,000 times greater than that of carbon dioxide (USGCRP, 2014).
5	Fertilisers containing nitrogen	Fertilisers containing nitrogen produce nitrous oxide emissions, which increase the warming effect on the Earth's atmosphere. The use of nitrogen-rich fertilizers increases the amount of heat cropland can store. Nitrogen oxides can trap up to 300 times more heat than carbon dioxide. Sixty-two percent of nitrous oxide released comes from agricultural by-products

6	Power Plants	Forty percent of carbon dioxide emissions stem from electricity production. Ninety-three percent of the electric industry emissions result from burning coal. Municipal and medical waste incineration account for two-thirds of mercury emissions (Fahey et al., 2017).
7	Oil Drilling	Burn-off from the oil drilling industry impacts the carbon dioxide released into the atmosphere. Fossil fuel retrieval, processing and distribution account for roughly eight percent of carbon dioxide and thirty percent of methane pollution (Fahey et al., 2017).
8	Permafrost	The melting of permafrost releases tons of trapped greenhouse gases which further speeds up the melting of more permafrost. Scientists calculate that approximately five hundred gigatons of carbon is trapped in the Siberian permafrost alone. A single gigaton equals one billion tons (USGCRP, 2014).
9	Transportation	EPA reports state that thirty-three percent of emissions come from the transportation of people and goods (Cunningham, 2018).
10	Natural Gas Drilling	Touted as a cleaner fuel source, natural gas drilling causes massive air pollution; the hydraulic fracturing technique used to extract natural gas from shale deposits pollutes ground water sources as well.
11	Garbage	As trash breaks down in landfills, it releases methane and nitrous oxide gases. Approximately eighteen percent of methane gas in the atmosphere comes from waste disposal and treatment.
12	Volcanic Eruption	Volcanoes expel large quantities of carbon dioxide when they erupt. Volcanoes have an overall small effect on global warming and an eruption causes a short-term global cooling as ash in the air reflects greater amounts of solar energy.

Source: (Fahey et al., 2017).

2.3. Impact of Climate Change on the Urban Environment

Climate change has many elements, affecting biological and human systems in different ways. The considerable spatial heterogeneity of climate change impacts has been widely studied; global average temperature increases mask considerable differences in temperature rise between land and sea and between high latitudes and low; precipitation increase is very likely in high latitudes, while decreases are likely in most of the tropics and subtropical land regions (Change, 2007). Climate change can lead to the phenomenal of urban heat island a situation where urban areas experienced higher temperatures increasing heat. The heat capacity of the surrounding environment became very high causing heat waves and heat related illnesses and death (Taha, 1997). Climate change has resulted to extreme weather changes where urban areas becomes more vulnerable. Urban flooding has become the most treating events in cities damaging infrastructures and destroying essential services (IPPC 2014)

2.4. Urban Heat Island, Causes and Effects

Urban Heat Island (UHI) is one of the most serious difficulties that humans have faced in the twenty-first century resulted due to urbanization and industrialization. The experience of an Urban Heat Island (UHIs) is recognized as rising air temperatures (AT) in cities compared to air temperatures in their rural area (Jabbar, Hamoodi, & Al-Hameedawi,2023) due to Land use or land cover changes. When cities replace the natural land cover with high concentrations of heat-absorbing pavements, buildings, and other surfaces, the UHI phenomenon arises which is a type of air pollution that contributes to global warming. Urban heat islands are primarily created by the increasing use of land surfaces that trap heat in urban areas, for example, pavement areas, high rise buildings, asphalt roads and other heat absorbing structures. This have become an increasing concern because of rapid urban growth since the mid-twentieth century (Jabbar, et al, 2023). The main causes of UHI are the vast amounts of heat generated by urban structures, compacted buildings, pavement areas, and the increased heat generated from automobile used (Shalaby, 2011). The UHI could be viewed as a global issue that impedes the functioning and habitability of cities and urban ecosystems (Mohajerani, Bakaric & Jeffrey-Bailey, 2017). The direct effects of UHI on urban habitations include reduction in environmental quality, exacerbation of thermal discomfort, and acceleration of heat related public health problems while an extreme cases of UHI events can significantly contribute to global warming and high mortality (Nwakaire, Onn, Yap, Yuen & Onodagu,2020).

2.5. Physical Planning and Climate Change

Over the years, physical planning has been seen as playing a critical role in determining and delivering sustainable development through the revisions of Planning Policy Guidance on the scope and intent of the land-use planning system

and a new approach to planning which addressed environmental concerns can be developed and endorsed at national and local levels (Campbell, 2006). Land use planning can be employed to find a balance between competing and sometimes contradictory uses while promoting sustainable land use options (Metternicht, 2017). The land-use planning system provides the key framework for managing development and the use of our land in ways which take into account the sustainable use of our natural resources through zoning regulations, planning standards and by promoting or encouraging nature-based solutions for climate change in cities, the use of renewable energy in new developments and reducing the use of non-renewable resources (and emissions) to mitigate greenhouse gases. Physical planners in collaboration with policy makers can implement regenerative strategies for neighbourhoods such as a neighbourhood green spaces initiative to reduce urban heat effects. Integration of Climate mitigation strategies in Environmental Impact Assessment as guidelines to environmental significant project should be encouraged. Urban planning strategies such as green revolution, green infrastructures, urban forestry, and climate resilient design can help in curbing climate change effects in cities.

3. Methodology

This study adopted the longitudinal research design using the qualitative research approach. Data was collected basically from remote sensing imageries and analysed using GIS application techniques. Remotely Sensed data was downloaded from USGS Earth Explorer. Landsat 8 OLI/TIRS data was downloaded for the years 2015 and 2024, with 0-30% cloud cover. The shape file of the study area was digitized from Open Street Map to show the boundary area. Landsat 8 Data was further analysed to prepare the Land Surface Temperature (LST) and Normalised Difference Vegetation Index (NDVI) maps. The following steps were initiated in the process.

3.1. Land Surface Temperature (LST) using Landsat 8 Data and GIS Software ArcGis10.41

The Landsat image was converted to Top of Atmosphere Radiance (TOA) using radiance rescaling factor, the thermal infrared digital numbers were converted to TOA spectral Radiance as shown below:

$$L\lambda = ML*Qcal+AL-Oi$$

Where $L\lambda$= TOA spectral radiance (watts/(m2*sr*μm))
ML = Radiance Multiplicative Band Number
AL = Radiance Add Band Number
QCal = Quantitated and Calibrated Standard Product Pixels Value (DN)
Oi = Correlation of Value for Band 10 = 0.29

3.2. Conversion to TOA Brightness Temperature (BT)

The spectral radiance data was converted to TOA BT using the thermal constant values in meta data file employing the formula: BT = K2/Ln (K1/ $L\lambda$+1).

3.3. Normalized Difference Vegetation Index (NDVI)

The NDVI is a standardized vegetation index which is calculated using near infrared (Band 5) and Red (Band 4) bands. NDVI = (NIR-RED)/ (NIR +RED).

3.4. Land Surface Emissivity (LSE)

LSE is the average emissivity of an element of the surface of the earth calculated from NDVI values: PV= ((NDVI-NDVI min)/ NDVI max-NDVI min))2

Where,
PV= Proportion of Vegetation
NDVI = DN Values from NDVI Image
NDVI min= Minimum DN Values of the NDVI Image
NDVI max = Maximum DN Values of the NDVI Image
E= 0.004 * PV + 0.986

3.5. Land Surface Temperature

The Land Surface Temperature is a radiative temperature which is calculated using TOA BT, wavelength of emitted radiance, and Land Surface Emission.

$$LST = BT/1+ (\lambda*BT/c2) *Ln (E)$$

Here c2= 14388μmk

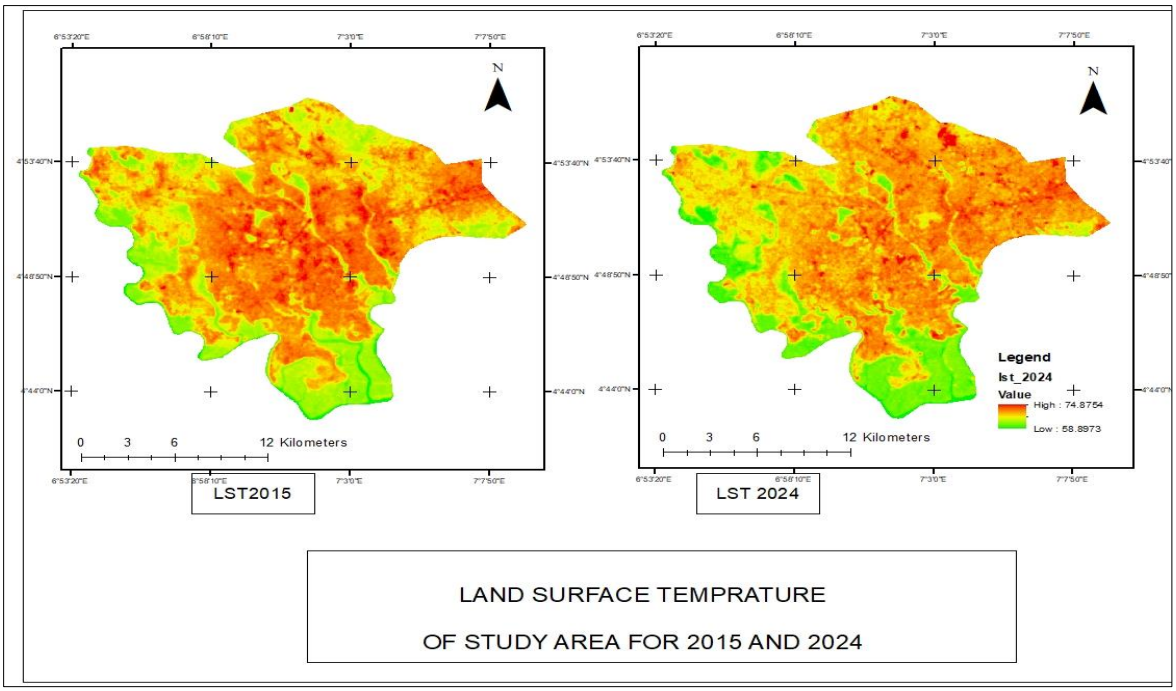
The values of ƛ for Landsat 8 for band 10 is 10.8.

The analysed data is thus presented as NDVI and LST maps.

4. Results and Findings.

4.1. Land Surface Analysis

The Land Surface Temperature Analysis as shown in fig.2 revealed that Land Surface Temperature of Port Harcourt city in the year 2015 and 2024 for the month of February which is usually one of the hottest months in the year has increased significantly with a mean temperature of 47ºc in 2015 and 55ºc in 2024. This implies that there is a significant increase in the mean temperature between 2015 and 2024 at a turn of 8ºc



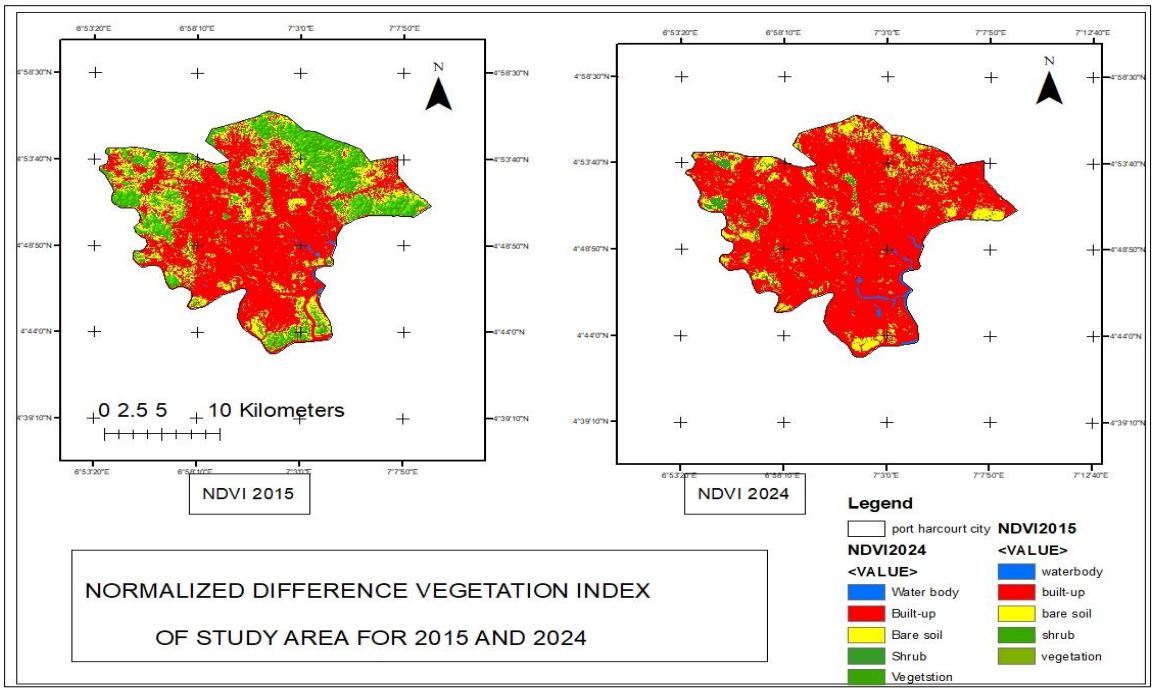
Source: researchers' analysis 2024

Figure 2. LST Map of the study area 2015 and 2024

4.2. Impervious Surface Analysis

The impervious surface was generated from the Normalized Difference Vegetation Index (NDVI) using the index 0.015 to 0.14 to represent built up areas. The NDVI for 2015 as shown in fig. 3 revealed that the percentage of impervious surface was approximately 78% of the total study area with a mean index value of 0.09, while the NDVI of 2024 had a mean index value of 0.13 with 93% of the total land surface as built-up areas.

The Urban Heat Island (UHI) effect results from land cover transformations, such as the replacement of natural vegetation with impervious surfaces like concrete and asphalt, leading to negative impacts like increased energy consumption, air pollution, greenhouse gas emissions, and compromised environmental conditions affecting human health and comfort. Port Harcourt City has not been left out of this trend. Normalized Difference Vegetation Index data of 2015 and 2024 shows significant changes in Port Harcourt's Land Cover which in turn has caused an increase in the Land Surface temperature with a mean value of 47ºc in 2015 and 55ºc in 2024. This is as a result of increasing rate of physical and structural development that has the propensity of trapping the shortwave radiation and increase the rate of long wave re-radiation at night. Built-up areas become pronounced driving out green areas leaving the land surface vulnerable to the effects of direct heat.



Source: researchers' analysis 2024

Figure 3 Normalized difference vegetation index map of the study area for 2015 and 2024

However, there is a relationship between Impervious Surface and Land Surface Temperature.

The Normalized Difference Vegetation Index (NDVI) map and the Land Surface Temperature (LST) map shows that there is a significant relationship between land surface temperature and land cover change. This is more evident as an increase impervious or urbanized areas has a significant impact on the Land surface temperature of the study area. This is because urbanisation shape the land surface exposing it to direct heat from the sun. This of course causes serious temperature variation which is more active in less vegetative zone.

5. Conclusion

One of the most worrisome environmental challenges facing the globe today is the impacts of climate change most especially on the urban environment. As urbanisation becomes eminent with all its attendant changes on land-use and land surface, the impacts arising from the incident of climate change becomes pronounced in cities. Human activities have increased the eventuality of climate change with its concomitant effects on the urban environment where urban heat island becomes more pronounced. The findings of this study have shown that there is a significant increase in the mean temperature between 2015 and 2024 at a turn of 8^{o}c. The analysis of the NDVI for 2015 as shown in fig. 3 revealed that the percentage of impervious surface was approximately 78% of the total study area with a mean index value of 0.09, while the NDVI of 2024 had a mean index value of 0.13 with 93% of the total land surface as built-up areas. This has dramatically shown the extent of climate change over time in the study area

Recommendations

The following are some of the common mitigation and preventive measures:

- **Increasing Urban Greenery:** Planting more trees and creating green spaces such as parks, green roofs, and vertical gardens to enhance carbon sequestration and provide shading.
- **Cool Roofs and Pavements:** Using materials with higher albedo for roofs and pavements can reflect more sunlight and absorb less heat.
- **Urban Planning and Design:** Designing cities to improve airflow, incorporating more open spaces, and reducing the density of high-rise buildings can help mitigate the phenomenon of Urban Heat Island
- **Energy Efficiency Measures:** Reducing energy consumption and enhancing the efficiency of buildings and transportation can lower the anthropogenic heat produced in urban areas.

- **Water Management:** Incorporating water features and improving water management to enhance the cooling effects of evaporation. Taking note of watershed management.
- Urban regeneration through the promotion of environmental sustainability, promoting sustainable urban practices and reducing environmental degradation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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