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Urban Heat Island and its Implication for Energy Consumption across Selected Cities in the Niger Delta

Mmom, Prince Chinedu. and Lawal, Olanrewaju
Department of Geography and Environmental Management, Faculty of Social Sciences, University of Port Harcourt
*Corresponding author's email: prince.mmom@uniport.edu.ng

Abstract
Urban Heat Island (UHI) intensification is a critical environmental and socioeconomic challenge associated with urbanization. This study investigates UHI effects in Port Harcourt, Uyo, and Asaba, cities in Nigeria's Niger Delta region, over a three-year period (2019-2021). Using Landsat imagery and Surface Urban Heat Island Intensity (SUHII) indices, the study quantifies land surface temperature (LST) variations and evaluates population exposure to heat stress. Results reveal significant spatial and temporal variations in LST, with urban centers experiencing higher temperatures. SUHII analysis highlights dense urban zones as hotspots of heat intensity, with substantial population exposure to high-risk areas, particularly in Port Harcourt (416,921 individuals), Uyo (167,469), and Asaba (65,393). The study further establishes a link between UHI intensification and increased energy demand for cooling, exacerbating energy shortages and greenhouse gas emissions. These findings underscore the urgent need for sustainable urban planning strategies, including green infrastructure and energy-efficient practices, to mitigate the effects of UHI and support climate resilience.

Keywords: *Urban Heat Island, Niger Delta, Land Surface Temperature, Energy Consumption, Urbanization*

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1. Introduction

Urban heat intensification, commonly known as the Urban Heat Island (UHI) effect, is an increasingly pressing issue in many regions across the globe. UHIs occur when urban areas experience substantially higher temperatures than their rural surroundings due to human activity, land use changes, and the presence of heat-absorbing materials like asphalt and concrete (Jabbar et al., 2023). The Niger Delta in Nigeria, particularly cities such as Port Harcourt, Uyo, and Asaba, has seen significant urbanisation in recent years, exacerbating the UHI effect in this already climate-vulnerable region.

The growing intensity of the UHI effect across cities has led to various environmental and socioeconomic challenges. Among these challenges is the increase in energy consumption as residents attempt to combat the rising urban temperatures, especially during peak heat periods. This paper examines the intensification of UHI in Port Harcourt, Uyo, and Asaba over three years (2019-2021) and creates an index useful for accessing the potential for increased energy consumption across the urban environment.

2. Materials and methods

To model UHI in the cities of Port Harcourt, Uyo, and Asaba, Landsat imageries were collated for three years (2019-2021). Land surface temperature (LST) was calculated using the method proposed by Avdan and Jovanovska (2016). The Surface Urban Heat Island Intensity (SUHII) was computed using the method proposed by Hsu et al. (2021). The method was adapted by selecting a reference rural area near each city and subtracting the LST for this reference rural area from the LST for the urban areas LST. SUHII intensity was classified into five distinct categories using the Jenks natural break algorithm (Jenks, 1967), and population exposure to UHI was calculated using gridded population data of 2020 (WorldPop, 2020).

3. Results

3.1 Land surface temperature (LST) and UHI

The study revealed notable variations in LST across the cities of Port Harcourt, Uyo, and Asaba between 2019 and 2021. These variations reflect both spatial and temporal differences in surface temperatures, influenced by urbanisation and human activity. In Uyo, the average LST ranged from 22.2°C to 29.9°C, while Port Harcourt recorded a broader range from 19.8°C to 30.5°C. Asaba experienced the highest temperatures, with LST values ranging from 20.0°C to 32.5°C (Figure 1a-c).

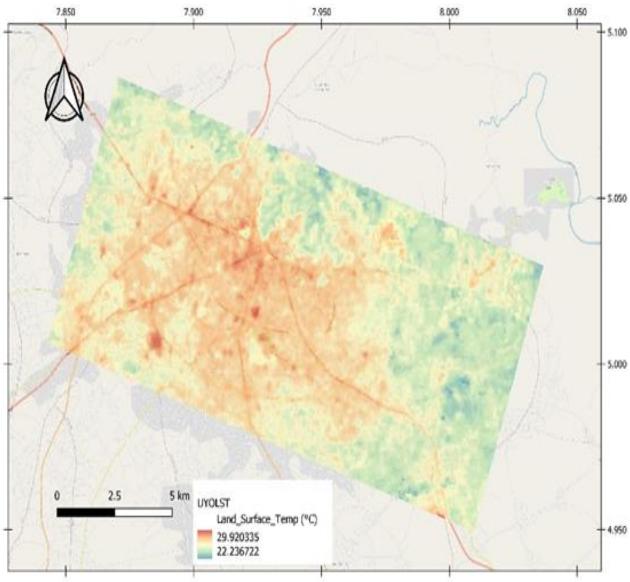

Fig. 1a: LST for Uyo and environs

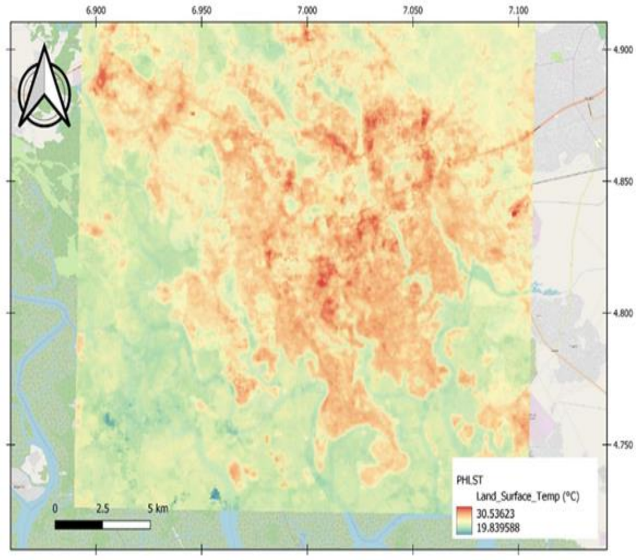

Fig. 1b: LST for Port Harcourt and environs

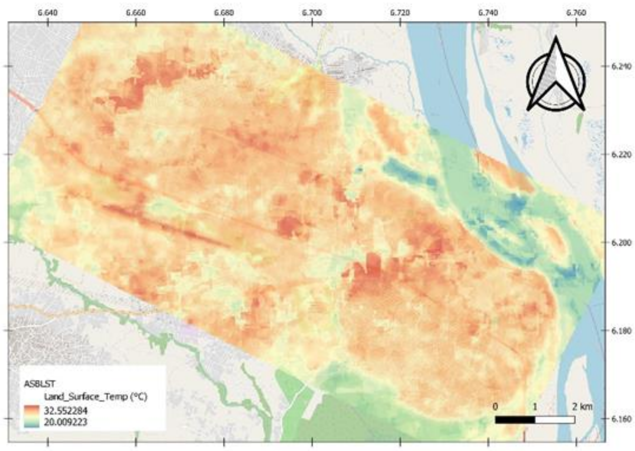

Fig. 1c: LST for Asaba

These temperature ranges highlight the presence of significant heat stress, particularly in densely populated city centres and neighbourhoods. These urban areas, characterised by high human activity and the prevalence of heat-absorbing materials like concrete and asphalt, consistently experienced higher temperatures. The combination of urban density and land use patterns underscores the escalating heat intensity in these cities.

3.2 Analysis of surface urban heat island intensity (SUHII)

The SUHII analysis showed that considerable variations exist across the cities. In Asaba, SUHII values ranged from -5.5 to 6.9, indicating that some places are cooler than the reference rural area while others are considerably warmer. Similarly, Port Harcourt's SUHII varied from -6.1 to 4.5, while Uyo recorded values between -3.6 and 3.9 (Figure 2a-2c).

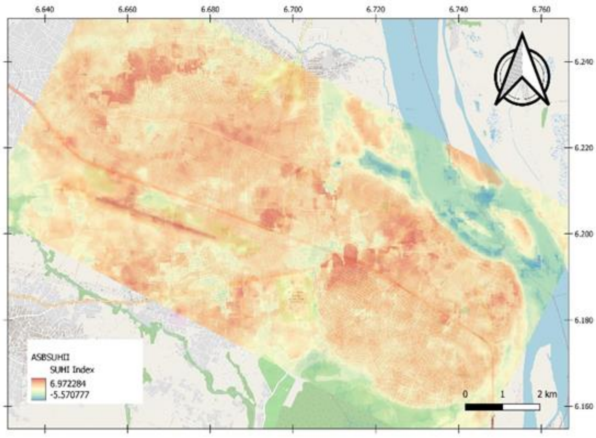

Fig. 2a: SUHI index for Asaba

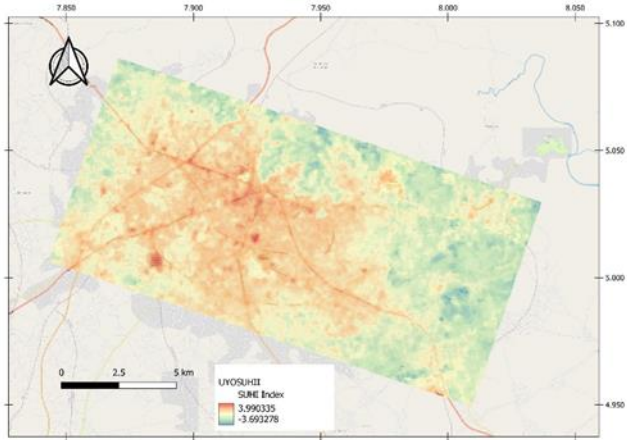

Fig. 2b: SUHI index for Uyo

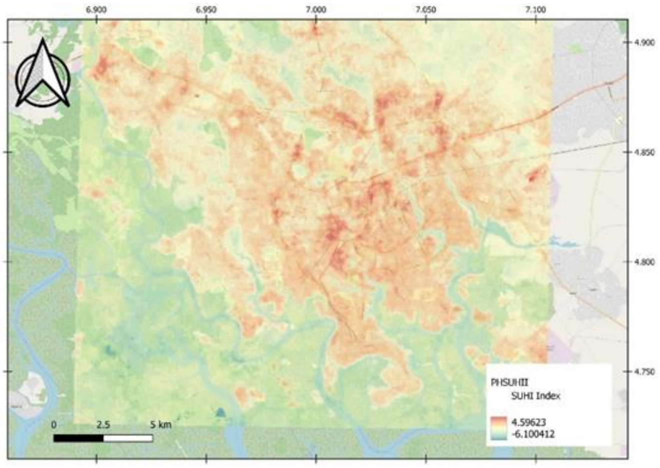

Fig. 2c: SUHI index for Port Harcourt

While some areas exhibited cooler than reference heat intensity (negative SUHII values), the majority of urban neighbourhoods had higher temperature intensity compared to their rural surroundings, signalling a pronounced UHI effect. Dense urban areas in Port Harcourt and Uyo recorded the highest UHI intensities, falling into Class 5 (Figure 3a -c), which denotes the most severe heat stress. Less urbanised regions, by contrast, generally have lower SUHII, reflecting a lesser degree of heat stress.

3.3 Population exposure

The assessment of population exposure to high SUHI showed that the number of people living in Class 5 SUHII zones—the areas most affected by heat—was significant across the three cities. An estimated total of 416,921, 167,469, and 65,393 individuals reside in the high-risk areas across Port Harcourt, Uyo and Asaba, respectively.

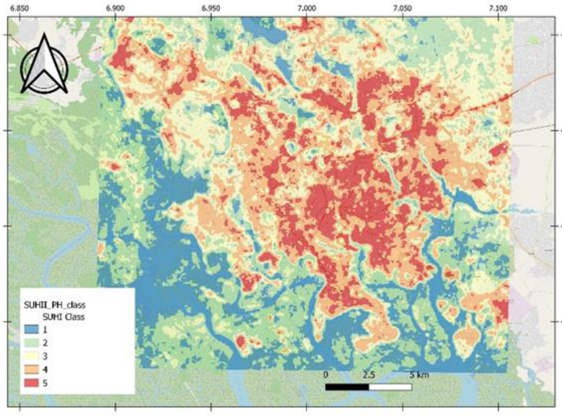

Fig. 3a: UHI Class for Port Harcourt

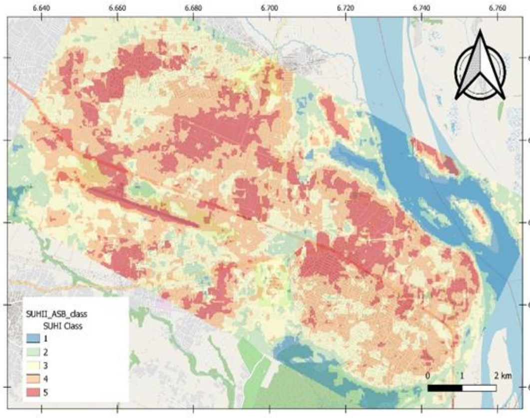

Fig. 3b: UHI Class for Asaba

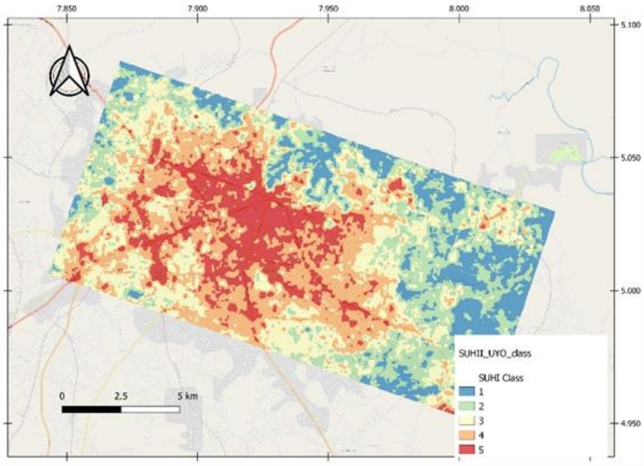

Fig. 3c: UHI Class for Uyo

These findings established that a substantial portion of the urban population is living in zones characterised by high heat stress. As urbanisation continues and temperatures rise, the increasing population exposure to UHI effects highlights the need for targeted interventions to reduce heat intensity and its detrimental impacts on public health and urban energy consumption.

4. Implications for energy consumption

Increased energy consumption to cool indoor spaces leads to higher greenhouse gas emissions, as electricity generation in the country relies to some extent on the combustion of fossil fuels. This creates a feedback loop where the rising temperatures due to the UHI effect increase energy demand, which in turn leads to more emissions and further climate change impacts. The spatial and temporal variability in LST and SUHII values highlights the localised nature of UHI effects. For instance, in Asaba, where LST values peaked at 32.5°C and SUHII reached 6.9, energy demand for cooling is likely more pronounced than in Uyo or Port Harcourt, which recorded comparatively lower maximum LST and SUHII values.

High heat stress zones, especially in urban centers, are indicative of increased cooling energy consumption, aligning with findings from Li et al. (2019), who reported a median increase of 19.0% in cooling energy use due to UHI effects. Similarly, the high exposure of populations to Class 5 SUHII zones, such as in Port Harcourt with 416,921 individuals, suggests significant energy demand for cooling systems to maintain indoor thermal comfort. This aligns with Hirano and Fujita (2012) observation that UHI effects intensify cooling energy consumption in urban centers, although residential areas might experience seasonal energy savings during cooler months. The intra-city variations in UHI impacts, where urban centers experience the most severe heat stress, resonate with Santamouris et al. (2015), who found that peak electricity demand can rise by up to 4.6% for every degree of temperature increase. The findings underscore the disproportionate energy burden placed on densely populated and highly urbanised zones, highlighting the need for targeted energy efficiency measures.

In addition, the SUHII provide an opportunity to identify areas with varying impacts on energy consumption, particularly related to cooling needs. As the UHI effect worsens, the demand for electricity for air conditioning and other cooling technologies increases dramatically. The increased cooling demand is likely to put a strain on the national grid and potentially increase the demand for fossil fuels for power-generating sets. This not only leads to higher energy costs for individuals but also exacerbates issues related to energy shortages and power outages.

5. Conclusion

This study's findings underscore the growing urban heat stress in the Niger Delta region, particularly in Port Harcourt, Uyo, and Asaba. The significant population exposure to high UHI intensity zones highlights the urgent need for adaptive strategies to mitigate the effects of UHI intensification. The increasing LST and UHI intensification observed across these cities are indicative of broader climate change and rapid urbanisation trends that require immediate action. From an energy consumption standpoint, the UHI effect is likely to lead to rising energy demand, particularly for cooling technologies. This increased demand places additional strain on the national energy infrastructure and contributes to higher costs for residents and businesses. The findings call for sustainable urban planning measures, such as the expansion of green spaces, the use of reflective building materials, and improved energy efficiency, to mitigate the impacts of urban heat.

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