

Quantification of the Influence of Wind Speed on Diurnal Urban Heat Island Across Climatic Belts in Nigeria

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ABSTRACT

This study investigates the influence of wind speed on diurnal urban heat islands (UHI) across climatic belts in Nigeria using meteorological and remote sensing data analysis. Remote sensing techniques were utilized to collect data such as LST, GPS ground truth points, MODIS & Landsat images, and wind speed data from NASA spanning 20 years (2003-2022). The UHI intensity was calculated by determining the temperature difference between urban and rural areas. Statistical regression analysis was employed to quantify the influence of wind speed on UHI, considering other meteorological variables as potential confounding factors. The results indicate that wind speed slightly increased the UHI intensity in selected cities during the dry season and decreased it during the rainy season between 2003 and 2022. However, the correlation coefficient between wind speed and UHI intensity was found to be insignificant ($r = .093$, $p < .706$), suggesting a minimal direct influence of wind speed on UHI variations. These findings contribute to a better understanding of UHI dynamics in Nigeria and have implications for urban planning and climate resilience strategies in the region.

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Introduction

The Urban Heat Island (UHI) phenomenon, characterized by significantly warmer urban areas compared to their surrounding rural environment, has garnered global recognition as a crucial element of wind and climate dynamics [1]. Extensive research from various countries, including the USA, South Korea, Indonesia, India, and China, has underscored the prevalence of UHI in urban settings, particularly during dry periods like summer [2-5]. Studies have elucidated specific UHI dynamics, revealing nocturnal diurnal reinforcement of heat islands and distinct temperature changes before sunrise and after sunset [6]. These findings elucidate the composition of the Surface Urban Heat Island (SUHI), primarily driven by anthropogenic heat sources and impervious surface coverage [7].

Nigeria, characterized by diverse climatic belts, offers a unique context for studying UHI dynamics [8]. The UHI effect in Nigeria is not only influenced by urbanization but also by climatic variability across different regions of the country [8]. Of particular importance is the role of wind speed in moderating urban temperatures, with high wind speeds facilitating heat dispersion and low wind speeds exacerbating the UHI effect [9]. Despite significant research on UHI in Nigerian cities like Lagos, Abuja, and Kano, there remains a notable gap in understanding how wind speed influences diurnal

UHI patterns across different climatic regions in the country [10].

Addressing this gap is crucial for informing effective urban planning strategies and enhancing climate resilience in Nigeria. In light of the aforementioned research context, this study aims to investigate the influence of wind speed on diurnal urban heat islands across climatic belts in Nigeria. By examining the interplay between wind speed and UHI dynamics in different climatic regions, this research seeks to contribute to a deeper understanding of urban climate processes in Nigeria and inform evidence-based urban planning strategies aimed at mitigating heat-related risks and enhancing urban resilience in a changing climate context.

Materials and Methods

Study Area

The study focuses on Nigeria, a country located in West Africa, bordered by Benin to the west, Niger to the north, Chad to the northeast, and Cameroon to the east. To the south, it is bordered by the Gulf of Guinea, providing access to the Atlantic Ocean. Nigeria's geographic coordinates range from approximately 4° to 14° North latitude and 3° to 15° East longitude, spanning a total area of around 923,768 square kilometers [11]. The country encompasses diverse climatic zones, including tropical rainforests in the south, savannas and woodlands in the central regions, and arid and semi-arid conditions in the north, influenced by the West African monsoon system and the intertropical convergence zone (ITCZ) [12]. This geographic and climatic diversity makes

Nigeria an ideal location for studying the influence of cloud cover on diurnal variations of the urban heat island phenomenon across different climatic belts. The study focuses on eight (8) major urban areas across different climatic belts: Tropical Wet Climate (Lagos & Port Harcourt), Tropical Savanna (Abuja & Enugu), Hot Semi-Arid (Kano, Kastina & Maiduguri) and Montane (Jos) in Nigeria.

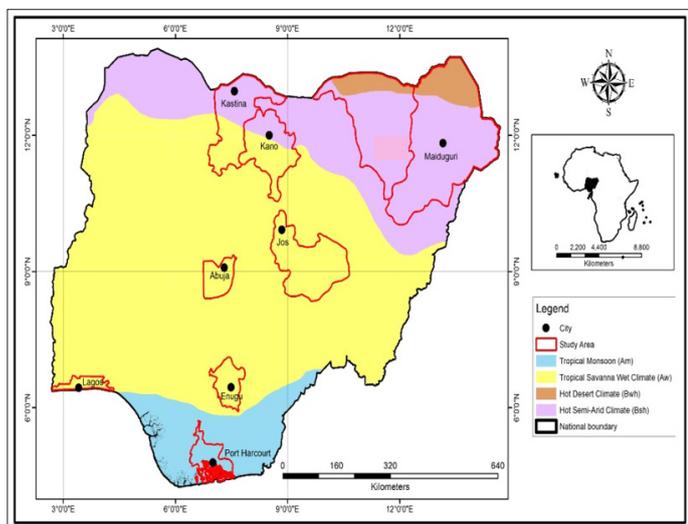


Figure 1: Study Area showing the Four Climatic Belts of Nigeria

Source: Dept of Geography Cartography Laboratory, Uniport. 2023

Meteorological Data

Satellite imagery from MODIS is utilized to identify wind speed on diurnal (day and night) urban heat islands across climatic belts and surface temperatures over urban areas in Nigeria. Land use/land cover data are also incorporated to assess urbanization patterns. Ground-based meteorological observations, including temperature, humidity, wind speed, and solar radiation, are collected from stations located within urban areas and surrounding regions across different climatic zones.

The temperature difference between urban and rural areas is calculated to determine UHI intensity. Spatial and temporal

variations in UHI intensity are analyzed.

The difference in temperature between urban and rural regions at a given time is known as UHI intensity (UHII). The non-urban points must be located outside of the built-up urban region or any surface that has been altered by constructions (asphalt, cement, etc.) since this site has traditionally been linked with a rural area. Hence, the UHII was calculated for every hour of the day from 2003 to 2022 according to the following equation:

$$\Delta T_i = T_{Urb} - T_{Rur} \text{ (mean)} \quad (1)$$

Where ΔT_i represents the UHII,

T_{Urb} is the 2 m temperature for each urban grid point and

T_{Rur} (mean) is the 2m temperature averaged over the rural grid points.

Additionally, to find associations between local WTs and urban overheating (UO), and have a clearer view of these associations, we have used also the higher 5% of daily maximum ΔT_i for both daytime and nighttime.

However, the city bounds are frequently erroneous since the urban continuum occasionally lacks distinct boundaries, suggesting a shift toward normally rural land usage [13]. In our case, the rural area is represented by the rural classes of CORINE (coordination of information on the environment) covering grassland, cropland, shrub-land, woodland, broadleaf forest and needleleaf forest (<https://land.copernicus.eu/pan-european/corine-land-cover>). More specifically, according to the land-sea mask, land area receives value 1 and is represented by the land classes of CORINE, sea area receives missing value NaN and is represented by the sea classes of CORINE, while according to the rural-urban mask, the rural area receives value 1 and is represented by the rural classes of CORINE, the urban area receives missing value NaN and is represented by the urban classes of CORINE.

Regression analysis is performed to quantify the influence of wind speed on the UHI, considering other meteorological variables as potential confounding factors.

Table 1

Land Surface Temperature	Moderate Resolution Imaging Spectroradiometer (MODIS) https://ladsweb.modaps.eosdis.nasa.gov/	2003-2022	8 Days 1km Gridded	Land Surface Temperature Distribution
Wind Speed	NASA's GMAO/MERRA-2 (GEOS 5) https://power.larc.nasa.gov/data-access-viewer/	2022-2023	-	Monthly Daily Wind Speed Distribution Data.
GPS Coordinate	Field W Ork	2022	-	Ground Truth Data For Change Detection

Source: Researcher's FieldWork, 2023

Results and Discussion

The Influence of Wind Speed on the Urban Heat Island in Nigeria between January and July 2003 to 2022

The trend analysis of wind speed influence on the Urban Heat Island at 10 meters above sea level over the eight (8) selected cities in Nigeria for the months of January and July between 2003 and 2022 are presented in Figure 2 – 8. However, it was observed that the wind speed trend, observed in Abuja, Kano, Lagos, Jos, Port Harcourt, Maiduguri and Enugu cities were slightly increased at

the rate of 0.018m/s, 0.010m/s, 0.001m/s, 0.036m/s, 0.0002m/s, 0.010m/s and 0.020m/s during the dry season and reduced at the rate of -0.007m/s, -0.001m/s, -0.009m/s, -0.005m/s, -0.011m/s, -0.005m/s and -0.018m/s during the rainy season respectively (Figure 2-8) while Katsina experienced a 0.021m/s increase in the dry season and a 0.002 m/s during the rainy season (Figure 9).

Based on the foregoing, all the eight cities across the climatic belts witnessed increased wind speed during the dry season and decreased wind speed during the rainy season except for Katsina. The city of Jos, had the highest increase in wind speed while Port Harcourt had the lowest between January 2003 and 2022 (Dry season) during the period under study. On the other hand, Kano had the highest increase in wind speed while Port Harcourt recorded the lowest in July between 2003 and 2022 (Rainy season) during the period under study.

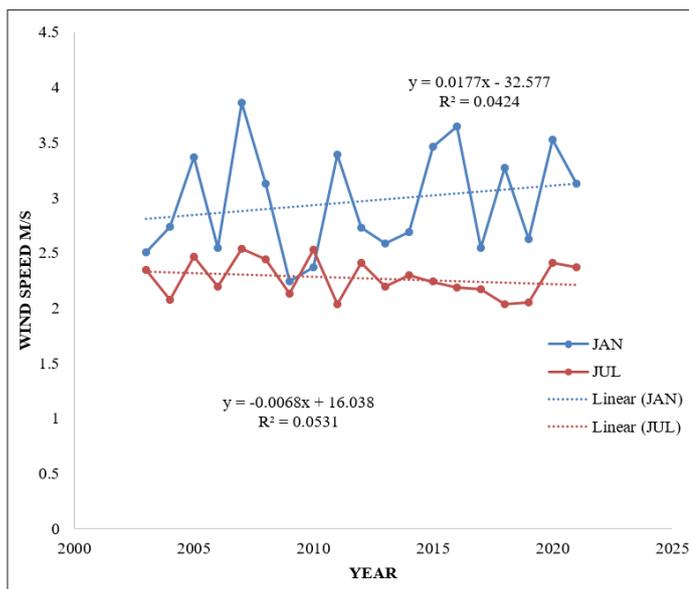


Figure 2: Seasonal Variation of Wind Speed of Abuja

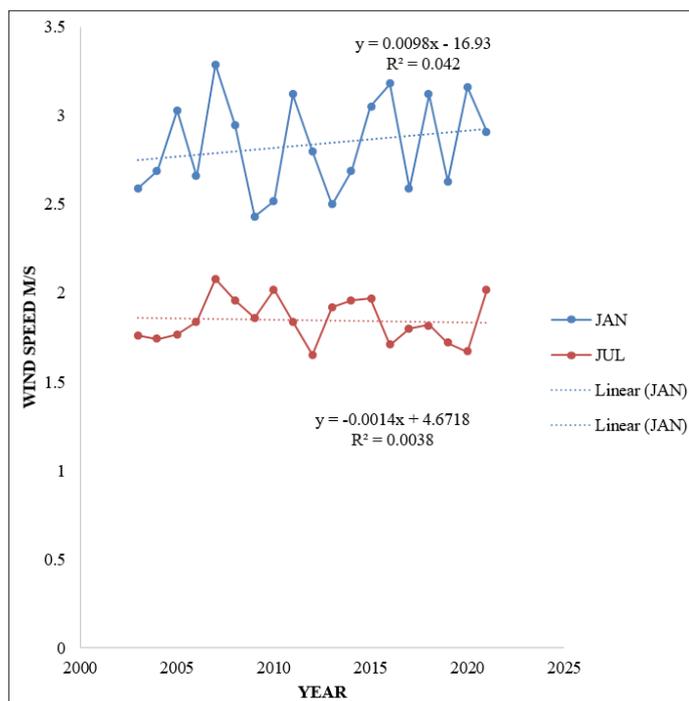


Figure 3: Seasonal Variation of Wind Speed of Kano

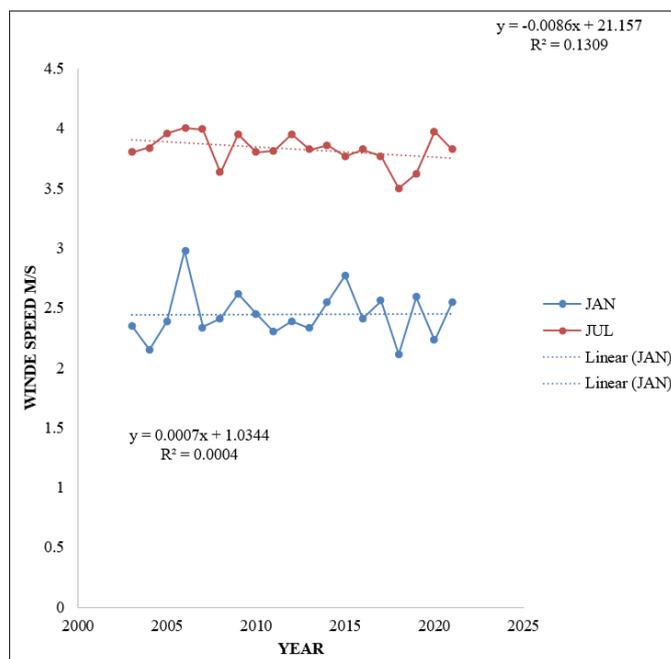


Figure 4: Seasonal Variation of Wind Speed of Lagos

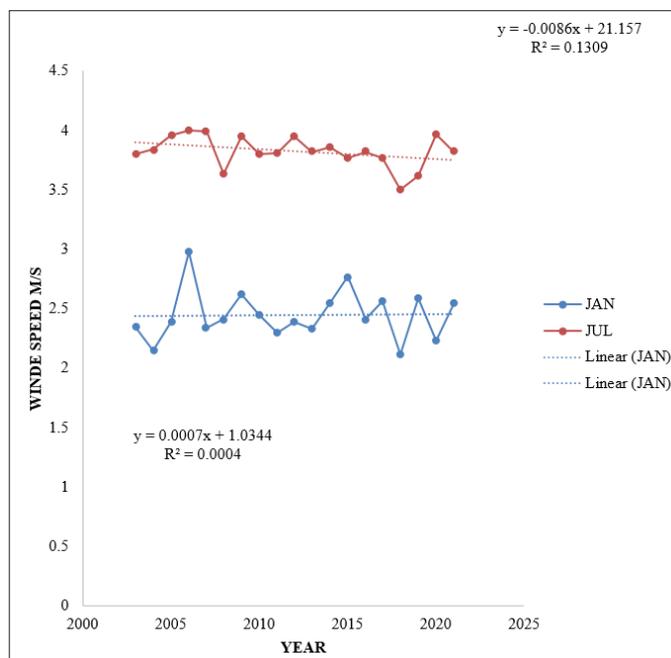


Figure 5: Seasonal Variation of Wind Speed in Jos

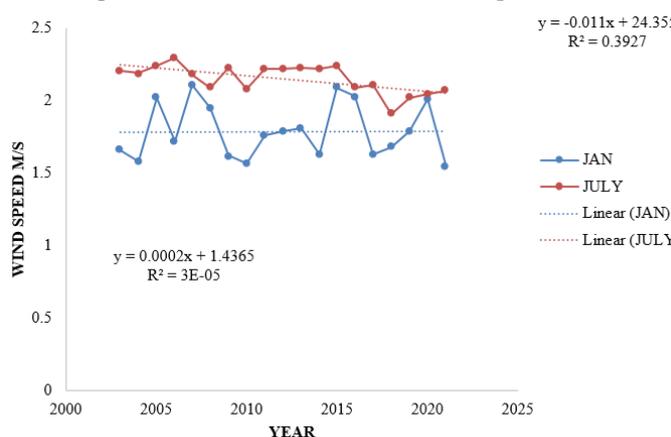


Figure 6: Seasonal Variation of Wind Speed in Port Harcourt

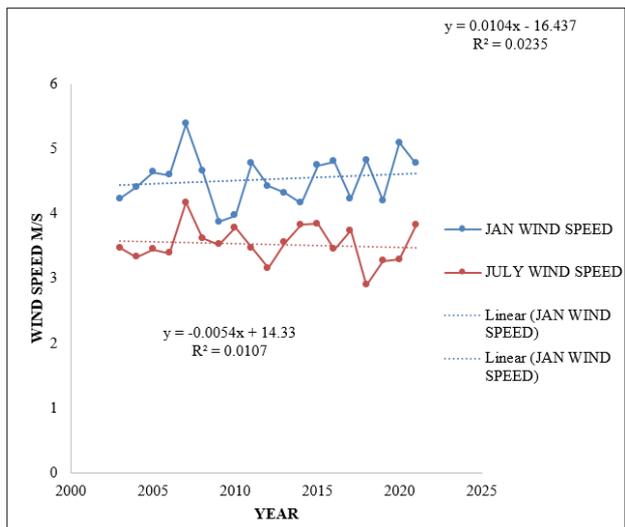


Figure 7: Seasonal Variation of Wind Speed in Maiduguri

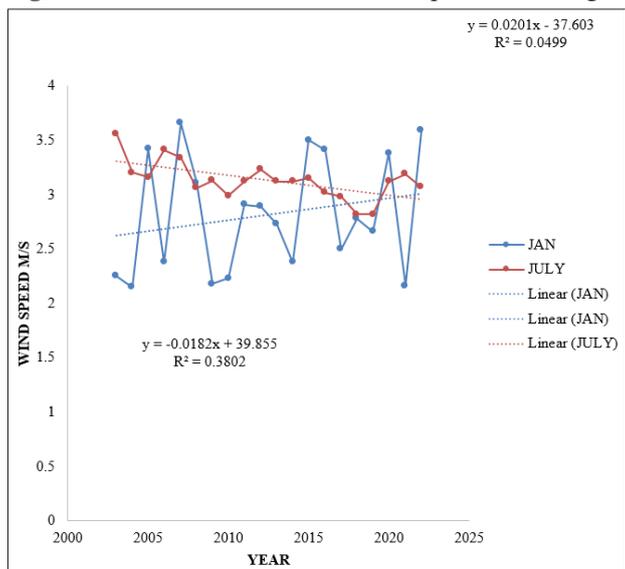


Figure 8: Seasonal Variation of Wind Speed in Enugu

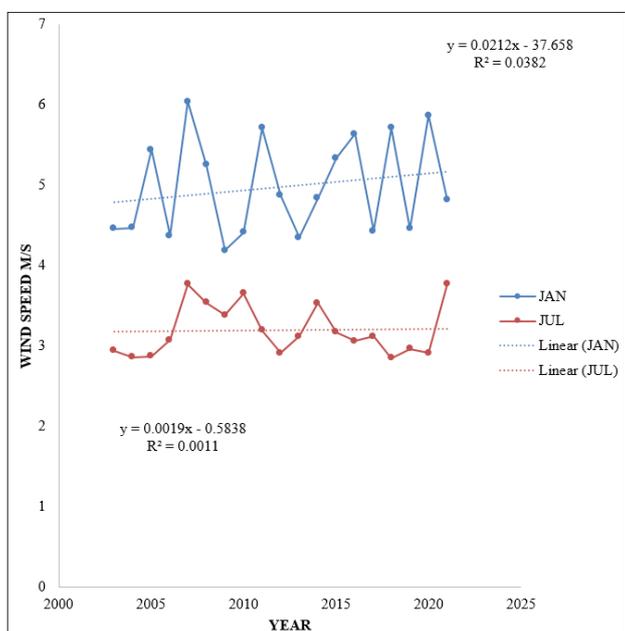


Figure 9: Seasonal Variation of Wind Speed in Katsina

Hypothesis: There is no significant relationship between Wind on UHI from 2003 to 2022.

Table 1: Correlation Coefficient between the influence of wind speed on UHI between 2003 and 2022

Correlations		Wind Speed	UHI
Wind Speed	Pearson Correlation	1	.093
	Sig. (2-tailed)		.706
	N	19	19
UHI	Pearson Correlation	.093	1
	Sig. (2-tailed)	.706	
	N	19	19

** . Correlation is significant at the 0.01 level (2-tailed).

Source: Researcher’s fieldwork 2023.

Table 1 shows the Correlation coefficient between the influence of wind speed on UHI between 2003 and 2022. The correlation coefficient of the influence of wind speed on UHI between 2003 and 2022 was insignificant at ($r=.093$, $p<.706$). This means, wind speed accounted for 0.865% of the variance in the UHI in the study area.

Discussion of Findings

The research conducted between 2003 and 2022 in various cities across Nigeria examined the relationship between wind speed and the Urban Heat Island (UHI) effect. The study provided insights into how wind patterns impact temperature variations during dry and rainy seasons in cities such as Abuja, Port Harcourt, Lagos, Jos, Kano, Katsina, and Maiduguri. This discussion aims to relate these findings to other research in the field of UHI and wind influence in different geographical locations and time frames.

Previous studies have explored the connection between wind speed and UHI in various global settings. Research by in Australian Cities found that increased wind speeds correlated with reduced UHI intensity [10]. This aligns with the observed trend in Port Harcourt, Nigeria, where higher dry season wind speeds were associated with a potential opportunity for UHI mitigation through strategic urban planning interventions.

Contrarily, studies by Allegrini et al., (2019) conducted in European cities suggested that decreased wind speeds contributed to exacerbating UHI effects. This finding resonates with the observations in Abuja, Nigeria, where reduced wind speeds during both dry and rainy seasons could pose challenges in mitigating UHI, necessitating tailored urban planning strategies.

The mixed wind speed trends observed in Lagos during different seasons resonate with the findings of Bassett et al., (2020) in coastal cities, indicating that fluctuating wind patterns can result in varying impacts on UHI intensity and, subsequently, public health. This emphasizes the importance of adaptable measures to address potential heat-related issues in such regions.

Moreover, the declining wind speeds and their implications observed in Jos, Kano, Katsina, and Maiduguri correspond to the findings of Muhammad et al. (2020) in arid regions, highlighting the increased energy demands for cooling systems due to reduced natural ventilation, thus emphasizing the urgency of implementing energy-efficient solutions in these areas. The findings of this research in Nigeria regarding the influence of wind speed on UHI

effects align with and contribute to the existing body of knowledge on UHI in various geographical regions globally. The variations in wind speed trends observed across different seasons and cities underscore the need for tailored urban planning strategies and adaptable measures to address the potential impacts on public health and energy demands in mitigating UHI effects. Further studies incorporating a broader geographical scope and long-term observations could enhance our understanding of the intricate relationship between wind patterns and UHI dynamics across diverse urban landscapes [14-17].

Conclusions

This comprehensive investigation sheds light on the complex interplay between wind speed and diurnal urban heat island (UHI) dynamics across climatic belts in Nigeria. Through the integration of meteorological data collection, remote sensing analysis, and statistical regression techniques, this study has elucidated key insights into the factors influencing UHI intensity in Nigerian cities.

The findings reveal that wind speed plays a nuanced role in modulating UHI patterns, with slight increases observed in UHI intensity during dry seasons and decreases during rainy seasons across selected cities in Nigeria. However, the correlation analysis suggests that the direct influence of wind speed on UHI variations is minimal, highlighting the multifaceted nature of UHI dynamics and the potential confounding effects of other meteorological variables.

Inspite the insignificant correlation, the study underscores the importance of considering wind speed as a contributing factor in UHI studies, particularly in urban planning and climate resilience efforts. By better understanding the mechanisms driving UHI dynamics, policymakers and urban planners can develop targeted strategies to mitigate heat-related risks and enhance urban livability in Nigerian cities.

Furthermore, the integration of remote sensing technology with ground-based meteorological observations demonstrates the utility of multi-disciplinary approaches in studying complex urban phenomena. Leveraging remote sensing data for spatial and temporal analysis provides valuable insights into urban environmental processes, facilitating evidence-based decision-making for sustainable urban development.

In conclusion, this study contributes to the growing body of knowledge on UHI dynamics in Nigeria and emphasizes the need for continued research to unravel the intricate interactions between meteorological factors, land use patterns, and urban microclimates. By advancing our understanding of UHI dynamics, we can better adapt to the challenges of urbanization and climate change, ultimately fostering more resilient and sustainable cities in Nigeria and beyond.

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