EJSIT
European Journal of Science, Innovation and Technology
ISSN: 2786-4936
www.ejsit-journal.com
Volume 5 | Number 1 | 2025

Assessing Thermal Climate and Key Climatic Factors Influenced by Solar Radiation in the Niger Delta

Chinonso Stanley Lawrence, Vincent Ezikornwor Weli, Meelubari Barinua Kpang
Department of Geography and Environmental Management,
Faculty of Social Sciences, University of Port Harcourt, Nigeria

ABSTRACT

The Niger Delta, a critical ecological zone in Nigeria, faces significant environmental challenges due to its complex network of creeks, rivers, and mangrove swamps. Among these challenges, the thermal climate—characterized by temperature variations and influenced by climatic factors—plays a pivotal role in the region's environmental health, agricultural productivity, and human well-being. This study employs a longitudinal correlational research design to assess thermal climate patterns and the influence of solar radiation on key climatic factors in the Niger Delta over an extended period (2014-2023). The analysis reveals that surface air temperatures across the region consistently range from approximately 24°C to 27°C, reflecting the region's tropical climate. Variations in temperature extremes among the states are evident, with Delta and Cross River experiencing minimum temperatures of 24.4°C and 24.1°C, respectively, while Edo and Ondo record maximum temperatures of 27.9°C and 27.3°C. These variations are influenced by local factors such as elevation, air pollution levels, proximity to water bodies, and vegetation cover, which play a critical role in temperature regulation. The mean surface air temperature across the states shows a relatively consistent range between 25.5°C and 26.3°C, while the standard deviation indicates varying degrees of temperature variability. The Mann-Kendall test for surface air temperature trends across the region reveals predominantly positive tau values, indicating an overall increasing temperature trend. However, statistical significance varies across states, with some regions, like Cross River, showing significant warming trends, while others do not, suggesting the impact of localized environmental and land use factors on temperature dynamics. This study provides a comprehensive analysis of the thermal climate in the Niger Delta, highlighting the region's consistent warmth and the importance of understanding local variations for climate adaptation and resilience planning. The findings have significant implications for agriculture, energy, and public health, emphasizing the need for tailored climate mitigation and adaptation strategies that address the unique climatic conditions of each state within the Niger Delta.

Keywords: Thermal Climate, Niger Delta, Solar Radiation, Climate Change, Trend Analysis

INTRODUCTION

In recent years, rapid urbanization and industrial development have intensified concerns about aerosol particles and their effects on the global climate system, as highlighted by studies from Aslam et al. (2024), Chen et al. (2023), Gautam et al. (2022a), and Shang et al. (2023). These particles directly influence atmospheric stability and climate variability by interacting with solar radiation and affecting cloud formation and the water cycle (Dong et al., 2023b). Aerosols, which include airborne solids and liquids, originate from a variety of sources such as natural dust, volcanic ash, mist, clouds, haze, sea salts, human-made aerosols, oceanic sulfides, industrial sulfates, soot (black carbon), and organic matter. These particles undergo diverse chemical and physical processes that affect air quality, as explored by Bisht et al. (2022) and Dong et al. (2023a). The radiative forcing of aerosols, shaped by the type and presence of particles, significantly influences their impact on climate. Black Carbon (BC), a type of absorbing aerosol, has varying warming effects across different regions of the planet (Everett et al., 2022; Hu et al., 2020). Additionally, atmospheric dust particles contribute to warming by absorbing radiation, which alters the propagation of both short and long-wave radiation (Kok et al., 2023).

The Niger Delta Region, one of the most significant ecological zones in Nigeria, is characterized by its complex network of creeks, rivers, and mangrove swamps. This region is not only a vital hub for Nigeria’s oil and gas industry but also a center of significant environmental challenges. Among these challenges, the thermal climate—defined by temperature variations and related climatic factors—plays a crucial role in determining the region's environmental health, agricultural productivity, and overall human well-being.

Solar radiation is a primary driver of the Earth's climate system, influencing temperature, weather patterns, and the distribution of energy across the planet. In the context of the Niger Delta, solar radiation's interaction with the atmosphere is further complicated by the presence of air pollution, largely stemming from industrial activities, gas flaring, and artisanal refining of crude oil. These pollutants can attenuate solar radiation, altering the thermal climate and potentially exacerbating environmental issues such as heat stress, ecosystem degradation, and public health concerns.

Understanding the influence of solar radiation on the thermal climate in the Niger Delta is crucial for effective environmental management and sustainable development in the region. This study aims to provide a comprehensive assessment of the thermal climate and key climatic factors influenced by solar radiation, considering the unique environmental and socio-economic conditions of the Niger Delta.

Furthermore, the thermal climate of any region is largely governed by the amount and distribution of solar radiation it receives. In the Niger Delta region, solar radiation not only drives the temperature patterns but also plays a significant role in influencing other climatic factors such as humidity, wind patterns, and precipitation. However, the increasing levels of air pollution in the region, resulting from industrial activities and widespread artisanal refining, have raised concerns about the potential attenuation of solar radiation and its impact on the thermal climate.

This study seeks to explore the intricate dynamics between solar radiation and the region's thermal climate. The research investigates how variations in solar radiation, influenced by factors such as air pollution, affect temperature, humidity, and other climatic elements. It also examined the implications of these changes for the environment and local communities, particularly in terms of agricultural productivity, human health, and overall environmental sustainability.

By focusing on the Niger Delta, a region with a unique combination of ecological, industrial, and socio-economic characteristics, this study aims to contribute to the broader understanding of how human activities and environmental factors interact to shape local climates. The findings are expected to inform policy-making and environmental management strategies aimed at mitigating the adverse effects of climate change and promoting sustainable development in the Niger Delta region.

In their study, Haigh et al. (2010) examined the essential role of solar irradiance in influencing the thermal structure and composition of Earth's atmosphere. They emphasized that incoming solar radiation is crucial in shaping the thermal and chemical properties of the atmosphere. Ultraviolet radiation triggers chemical reactions, particularly those that produce stratospheric ozone, and significantly heats the middle atmosphere. On the other hand, visible and near- infrared radiation primarily warms the lower atmosphere and Earth's surface. Thus, the spectral composition of solar radiation is vital in determining atmospheric structure and surface temperature, with the atmosphere's response to changes in solar irradiance closely linked to its spectral distribution.

The researchers used daily measurements of the solar spectrum collected by the Spectral Irradiance Monitor (SIM) instrument aboard the Solar Radiation and Climate Experiment (SORCE) satellite since April 2004. They observed unexpected spectral changes during the declining phase of the solar cycle, with a larger-than-expected decline in ultraviolet radiation, partially offset by an increase in visible radiation. Haigh et al. (2010) showed that these spectral shifts led to a notable decrease in stratospheric ozone below 45 km, while there was an increase above this altitude.

To corroborate their findings, the researchers employed a radiative-photochemical model to simulate the observed ozone variations. Their results aligned with contemporary measurements from the Aura-MLS satellite, though it was challenging to attribute these changes solely to solar effects within the study's short timeframe. Additionally, using SIM data, Haigh et al. (2010) revealed that solar radiative forcing of surface climate was out of phase with solar activity, indicating complex dynamics within the Earth-atmosphere system.

While the study illuminated the spectral variations in solar irradiance and their impact on atmospheric ozone and climate, Haigh et al. (2010) called for further observational evidence to validate their findings. The study presented intriguing possibilities regarding the effects of solar variability on atmospheric temperature, challenging existing assumptions. Overall, the research offered valuable insights into the complex interactions between solar irradiance, atmospheric composition, and climate, highlighting the intricate nature of Earth's climate system and the need for ongoing investigation into solar influences on atmospheric dynamics.

Yang et al. (2017) explored the relationship between microclimate environments, park usage, and human behavior in the urban area of Umeå, Sweden, which has a subarctic climate. The researchers highlighted the importance of outdoor microclimates in determining the quality of outdoor spaces, particularly in regions like Sweden, where people highly value summer for outdoor activities due to the long, harsh winters.

Despite the preference for outdoor activities during the summer, few studies had previously examined the impact of microclimate conditions on the use of outdoor spaces like parks, especially in subarctic climates. Yang et al. (2017) aimed to address this research gap by studying how microclimate conditions affect park usage and human behavior in Umeå. The study employed various methods, including observations of naturally occurring behavior, structured interviews based on specially designed questionnaires, and measurements of objective microclimate parameters. These parameters included air dry bulb temperature, relative humidity, wind speed, solar radiation, and globe temperature.

The findings provided important insights into the relationship between microclimate conditions and human behavior in Umeå. Despite the subarctic climate, 49% of residents preferred higher solar radiation even under "slightly warm" Thermal Sensation Vote (TSV) conditions, indicating a strong expectation for solar radiation. This suggests that residents in Umeå have adapted to the subarctic climate and prefer sunny conditions, even when the temperature is only slightly warm.

Additionally, the study found that residents, who are accustomed to the subarctic climate, exhibited different behavioral patterns compared to non-locals. This underscores the importance of considering local climate adaptation when studying human responses to microclimate environments. Overall, Yang et al. (2017) offered valuable insights into the interplay between microclimate environments, park usage, and human behavior in Umeå, Sweden. Their findings enhance the understanding of how outdoor spaces are used in subarctic climates and highlight the importance of considering both objective microclimate measurements and subjective human responses in urban planning and design.

MATERIALS AND METHODS

This study utilized a longitudinal correlational research design to explore the relationships between variables over an extended timeframe without altering them. By examining the complex interplay between air pollution-induced solar radiation attenuation and its impact on the thermal climate in the Niger Delta Region, the research focuses on understanding whether higher levels of air pollution are significantly linked to decreased solar radiation and how variations in solar radiation affect thermal climate parameters. The study's sampling strategy involves selecting the nine states within the Niger Delta Region (Figure 1) to ensure comprehensive data representation. It includes various settings—urban, industrial, and rural—to capture a broad range of air pollution types and intensities and their effects on solar radiation.

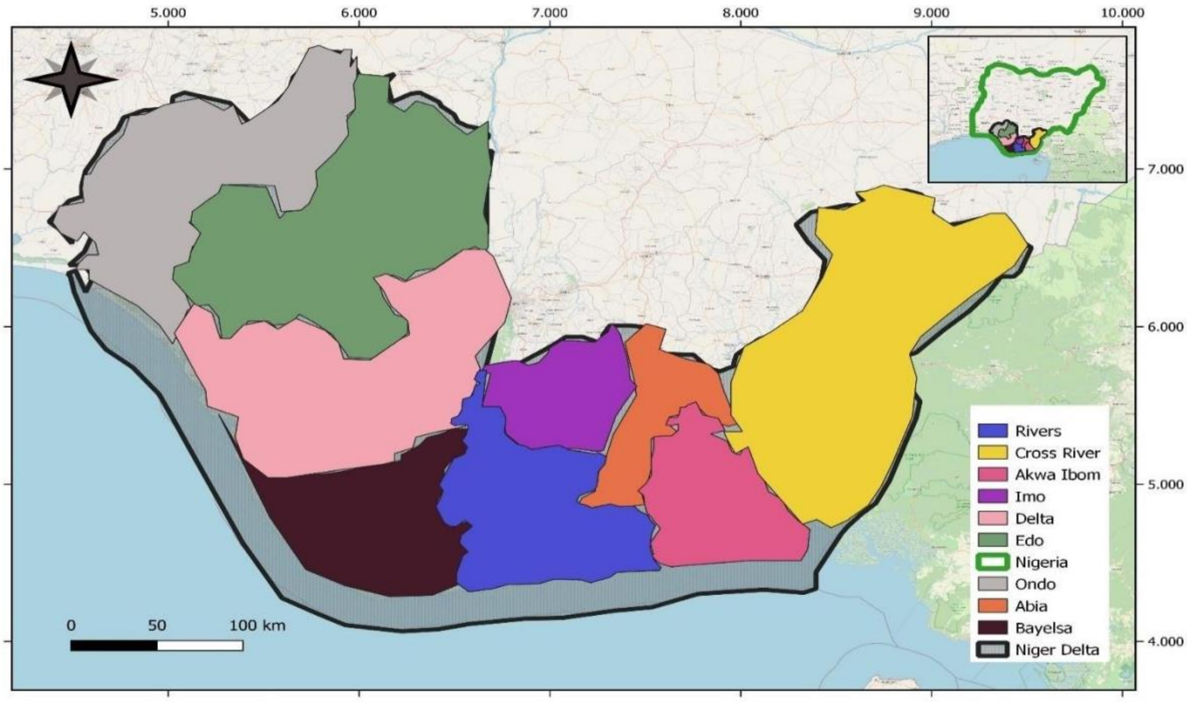

Figure 1: Study Area
Source: Researcher's work 2024

The Niger Delta's unique geography, characterized by diverse ecosystems such as mangrove swamps, creeks, and rivers, makes it an ideal location for studying the complex interactions between solar radiation, air pollution, and thermal climate. The variability in environmental conditions and human activities across the region adds depth to the study, enhancing its relevance and applicability. Therefore, the Niger Delta States have been selected as the study area due to the recent increase in artisanal refining activities, highlighting the importance of investigating solar radiation attenuation and its effects on the thermal climate.

This study employed both secondary data and the MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications, Version 2) reanalysis dataset, covering the years 2014 to 2023. The secondary data included historical records on air quality parameters such as temperature, humidity, CO_2, and NO_2. MERRA-2, developed by NASA's Global Modelling and Assimilation Office (GMAO), is a globally gridded dataset that offers a consistent record of various atmospheric variables. It integrates observational data with advanced numerical modeling to provide detailed information on solar radiation, air quality, and meteorological variables at high spatial and temporal resolutions over an extended period.

The combination of secondary data with the MERRA-2 dataset allowed for a comprehensive examination of the relationships between air pollution, solar radiation, and thermal climate. The secondary data were used to validate and enhance the analysis, ensuring a robust and well- rounded study. This research primarily relied on reanalysis data, focusing on the MERRA-2 dataset, recognized for its detailed and synthesized representation of atmospheric variables. MERRA-2, produced by NASA's GMAO, provides an extensive record of atmospheric parameters, including solar radiation, air quality indicators, and meteorological variables. The dataset's high spatial and temporal resolutions facilitated an in-depth exploration of atmospheric conditions in the Niger Delta region.

MERRA-2 offers data at various temporal resolutions, ranging from hourly to monthly averages, enabling a detailed analysis of diurnal and seasonal patterns. Its high spatial resolution ensures accurate representation of atmospheric variations across the Niger Delta. The collation process involved extracting specific variables related to solar radiation, air pollution, and thermal climate from the MERRA-2 dataset, including surface solar radiation, aerosol concentrations, temperature, humidity, and wind speed.

The selected study period from January 1, 2014, to December 31, 2023, is scientifically significant for analyzing the impact of air pollution on solar radiation in the Niger Delta region. This decade marks a critical phase for understanding the trends and impacts of both natural and human activities on atmospheric composition and solar radiation levels. The Niger Delta has undergone substantial industrial and economic growth over the last decade, accompanied by increased emissions from oil extraction, gas flaring, and the rise of artisanal refining. The latter, an informal and often illegal process, has become widespread in the region, contributing significantly to air pollution due to the unregulated burning of crude oil. Studying this period provides a comprehensive analysis of how heightened industrial activity, particularly artisanal refining, correlates with changes in air quality and solar radiation levels.

Advancements in atmospheric monitoring and satellite technology during this period, including the availability of high-resolution data from the MERRA-2 Reanalysis dataset, have enabled more accurate and detailed analysis of atmospheric pollutants and their impacts on solar radiation. This technological progress enhances the study's reliability, allowing for a precise assessment of pollutants from both industrial sources and artisanal refining activities.

A decade-long period provides a robust dataset long enough to identify significant trends and patterns while being recent enough to ensure data continuity and relevance. This timeframe minimizes short-term variabilities and anomalies, offering a clearer view of underlying trends in air pollution and solar radiation. The period from 2014 to 2023 includes multiple seasonal cycles and interannual variations, allowing for a detailed analysis of how seasonal changes and yearly anomalies in air pollution levels affect solar radiation. This comprehensive temporal coverage is essential for understanding the dynamics of air pollution and its impact on solar energy receipt over time, especially in the context of the rise of artisanal refining.

In examining the thermal climate in the Niger Delta Region, this study analyzed land surface temperature data obtained from the MERRA-2 dataset. The surface air temperature variable (air surface temperature) was utilized, and data retrieved for the period from January 1, 2014, to December 31, 2023, using the GES DISC Sub setter within the defined region (1.67, 3.437, 15.029, 15.39). The analysis included descriptive statistics for each state, providing insights into the thermal characteristics of the region. Furthermore, a trend analysis using the Mann- Kendall test was conducted to identify any discernible patterns or shifts in the thermal climate over the specified timeframe.

RESULTS AND DISCUSSION

Results

Surface Air Temperature Across States in the Niger Delta Region

Table 1 reveals valuable insights into the climatic conditions of each state and the overall variability in temperature within the region from 2014 to 2023. Results reveals that, on average, the surface air temperatures across all states in the Niger Delta Region range from approximately 24°C to 27°C. This indicates that the region experiences relatively warm temperatures throughout the year, which is consistent with its tropical climate.

When examining the minimum and maximum temperatures recorded in each state, it is evident that there is variation in temperature extremes across the region from 2014 to 2023. For instance, the minimum temperature recorded in Delta state is 24.4°C, while in Cross River state, it is slightly lower at 24.1°C. Conversely, the maximum temperature recorded in Edo state is 27.9°C, which is slightly higher than the maximum temperature recorded in Ondo state at 27.3°C. This variation in temperature extremes underscores the influence of local factors such as elevation, air pollution level, proximity to water bodies, and vegetation cover on temperature regulation within each state, which buttresses the findings of Chen et al. (2018), that air pollution significantly impacts atmospheric stability, shaping the vertical distribution of temperature and moisture which influences weather phenomena at local and regional scales.

The mean and standard deviation (2014 to 2023) of surface air temperature provide additional insights into the central tendency and variability of temperatures within each state. Across all states, the mean of surface air temperature ranges from approximately 25.5°C to 26.3°C, indicating a relatively consistent average temperature across the region. However, the standard deviation ranges from approximately 0.78°C to 0.90°C, suggesting varying degrees of variability in temperature within each state. States with higher standard deviations, such as Cross River and Bayelsa, experience greater fluctuations in temperature compared to states with lower standard deviations, such as Imo and Ondo.

Table 1: Descriptive Statistics of Surface Air Temperature Across States in the Niger Delta Region (2014 to 2023)

States	Sample size (N)	Minimum (°C)	Maximum (°C)	Mean (°C)	Std. Deviation (°C)
Ondo	120	23.6	27.3	25.5	0.82
Edo	120	23.9	27.9	25.8	0.85
Delta	120	24.4	27.6	26.1	0.83
Bayelsa	120	24.7	27.9	26.3	0.88
Rivers	120	24.7	27.8	26.2	0.82
Imo	120	24.5	27.4	26.1	0.78
Abia	120	24.5	27.6	26.0	0.82
Akwa Ibom	120	24.6	27.8	26.2	0.83
Cross River	120	24.1	27.7	25.7	0.90

Source: Researcher's Analysis 2024

Thermal Climate Across the Niger Delta Region

The results of the Mann-Kendall test for surface air temperature in various states or regions shown in Table 2 reveals insights into the thermal climate captured by surface air temperature. Across the regions analyzed, there are notable variations in trends and statistical significance. tau, a measure of trend strength and direction, indicates predominantly positive values, suggesting an overall increasing trend in surface air temperature over the study period. However, the magnitude of tau varies across states, indicating differences in the rate of temperature change. Significance levels (sl) associated with the Mann-Kendall test provide further context, with higher p-values (> 0.05) suggesting that observed trends are not statistically significant for most regions. In contrast, Cross River, exhibit a p-value, indicating a statistically significant trend.

The total number of data pairs (S) used in the analysis varies across regions, reflecting differences in sample sizes. Meanwhile, the test statistic (D) measures the number of concordant and discordant pairs in the data series, contributing to the calculation of the tau value. Additionally, the variance of S (varS) provides insight into the variability or spread of the data series within each region.

In the broader context of examining the thermal climate captured by surface air temperature, these results suggest nuanced patterns across different regions. While some regions demonstrate statistically significant increasing trends in land surface temperature, others do not exhibit such trends. This variability may stem from local climatic conditions, land use patterns, or other factors influencing land surface temperature dynamics. This finding gives credence to that of Haigh et al. (2010), which provided valuable insights into the dynamic interplay between solar irradiance, atmospheric composition, and climate, underscoring the complexity of Earth's climate system and the importance of continued investigation into solar influences on atmospheric dynamics.

Table 2: Mann Kendall Test Results for Surface Air Temperature Across States in the Niger Delta

Variable	tau	sl	S	D	Var S
Ondo	-0.0056	0.92951	-40	7140	194366.7
Edo	-0.02633	0.671448	-188	7140	194366.7
Delta	0.02577	0.678077	184	7140	194366.7
Bayelsa	0.050844	0.411586	363	7139.5	194365.7
Rivers	0.046779	0.450055	334	7140	194366.7
Imo	0.046499	0.45278	332	7140	194366.7
Abia	0.105882	0.086801	756	7140	194366.7
Akwa Ibom	0.070868	0.252018	506	7140	194366.7
Cross River	0.121008	0.05029	864	7140	194366.7

Source: Researcher's Analysis 2024

Discussion

The findings of this study provide a detailed understanding of the climatic conditions and temperature variability in the Niger Delta region. The consistent warmth observed throughout the year, as indicated by the surface air temperature range, reflects the region's tropical climate. This has significant implications for sectors such as agriculture, energy, and public health, influencing crop growth, energy consumption, and the incidence of heat-related illnesses.

Temperature extremes vary across states, highlighting the impact of local factors like elevation, proximity to water bodies, and vegetation cover on temperature regulation. Recognizing these factors is essential for effective climate adaptation and resilience planning, as they can guide decisions on infrastructure development, urban planning, and natural resource management. The mean and standard deviation of surface air temperature provide insights into the central tendency and variability of temperatures within each state. States with higher standard deviations experience greater temperature fluctuations, indicating a need for adaptive measures to reduce climate-related risks and impacts, particularly in vulnerable communities.

The Mann-Kendall test results for air surface temperature offer additional insights into the thermal climate by revealing temperature trends. Some regions show statistically significant warming trends, while others do not, suggesting localized variations influenced by land use patterns and environmental changes. This highlights the importance of region-specific climate mitigation and adaptation strategies that consider the unique temperature dynamics in different areas. The differences in sample sizes and test statistics across regions reflect variations in data availability and distribution, underscoring the need to address data gaps and enhance monitoring systems to improve understanding of temperature trends and support evidence-based climate policy and planning.

In the context of existing literature, Haigh et al. (2010) discussed the critical role of solar irradiance in shaping Earth's atmosphere and its effects on temperature variability. Their research emphasized the impact of spectral changes during the declining phase of the solar cycle on atmospheric composition and temperature distribution. While their study focused on broader atmospheric dynamics, the findings resonate with the observed patterns of temperature variability in the Niger Delta, illustrating the complex relationship between solar radiation and thermal climate.

Furthermore, Yang et al. (2017) investigated the relationship between microclimate environments and human behavior in a subarctic climate, highlighting how individuals respond to varying levels of solar radiation. Although conducted in a different climatic context, their findings underscore the importance of solar radiation in shaping human behavior. Integrating these insights into the discussion enhances our understanding of the interactions between solar radiation, microclimate conditions, and human responses, offering valuable perspectives for developing climate adaptation strategies in diverse environmental settings.

CONCLUSION AND RECOMMENDATIONS

In conclusion, this study provides a comprehensive analysis of the thermal climate and key climatic factors influenced by solar radiation in the Niger Delta region. The findings underscore the region's consistent warmth throughout the year, characteristic of its tropical climate, and reveal significant implications for various sectors, including agriculture, energy, and public health. The observed temperature variability across different states highlights the influence of local environmental factors such as elevation, water bodies, and vegetation cover, which play a crucial role in temperature regulation.

The study also demonstrates the importance of understanding these local variations for effective climate adaptation and resilience planning. The Mann-Kendall test results indicate that while some areas exhibit significant warming trends, others do not, suggesting that localized factors and land use changes play a significant role in shaping temperature dynamics. This calls for tailored climate mitigation and adaptation strategies that consider the unique climatic conditions of each region within the Niger Delta.

By linking the study's findings with existing literature, the complex interplay between solar radiation, atmospheric conditions, and temperature variability has been further elucidated, emphasizing the importance of region-specific strategies to address the impacts of climate change. The study also highlights the need for enhanced data collection and monitoring systems to better understand and predict climatic trends in the region. Overall, this research contributes valuable insights into the thermal climate of the Niger Delta, offering guidance for policymakers, urban planners, and other stakeholders in developing effective strategies to mitigate the impacts of climate change and enhance the region's resilience to future climatic challenges.

ACKNOWLEDGEMENT

I am deeply grateful for the exceptional guidance and support provided by my supervisors, Prof. V. E. Weli and Dr. Kpang Meelubari. Their dedication and expertise have been pivotal in bringing this study to fruition.

My profound gratitude also goes to my loving wife, Mrs. Grateful Lawrence, I find it challenging to put into words how much your unwavering support means to me. You have truly exemplified the adage that "he who finds a wife, finds a good thing."

My heartfelt thanks go to my mother Mrs. Lilian Nkwoma Lawrence, who sponsored my academic pursuit from infancy to my undergraduate level. Finally, I would like to thank the managing Director of Ikosh Nigeria Limited and his beloved wife Mr. & Mrs. Nelson Oluwamuyiwa Kosile for their continuous financial support towards me.

REFERENCES

Aslam, R. W., Shu, H., Tariq, A., Naz, I., Ahmad, M. N., Quddoos, A., Javid, K., Mustafa, F., & Aeman, H. (2024). Monitoring land use change in Uchhali and Khabeki wetland lakes, Pakistan using remote sensing data. *Gondwana Research, 129*, 252–267. https://doi.org/10.1016/j.gr.2023.12.015

Chen, B., Hu, J. & Ghosh, B.K. (2024). Finite-time tracking control of heterogeneous multi-AUV systems with partial measurements and intermittent communication. *Science China Information Sciences*, *67*, 152202. https://doi.org/10.1007/s11432-023-3903-6

Dong, W., Zhao, J., Qu, J., Xiao, S., Li, N., Hou, S., & Li, Y. (2023b). Abundance matrix correlation analysis network based on hierarchical multihead self-cross-hybrid attention for hyperspectral change detection. *IEEE Transactions on Geoscience and Remote Sensing*, *61*, 1–13. http://dx.doi.org/10.1109/TGRS.2023.3235401

Everett, J. T., Newton, E. N., & Odum, M. M. (2022). A Review of Progress in Constraining Global Black Carbon Climate Effects. *Earth Systems and Environment*, *6*(4), 771-785. https://doi.org/10.1007/s41748-022-00313-1

Gautam, S., Elizabeth, J., Gautam, A. S., Singh, K., & Abhilash, P. (2022a). Impact assessment of aerosol optical depth on rainfall in Indian rural areas. *Aerosol Science and Engineering*, *6*, 186–196. https://doi.org/10.1007/s41810-022-00134-9

Haigh, J.D., Winning, A., Toumi, R., & Harder, J.W. (2010). An influence of solar spectral variations on radiative forcing of climate. *Nature*, *467*, 696-699. https://doi.org/10.1038/nature09426

Hu, K., Zhao, D., Liu, D., Ding, S., Tian, P., Yu, C., ... & Ding, D. (2020). Estimating radiative impacts of black carbon associated with mixing state in the lower atmosphere over the northern North China Plain. *Chemosphere*, *252*, 126455. https://doi.org/10.1016/j.chemosphere.2020.126455

Kok, J. F., Storelvmo, T., Karydis, V. A., Adebiyi, A. A., Mahowald, N. M., Evan, A. T., ... & Leung, D. M. (2023). Mineral dust aerosol impacts on global climate and climate change. *Nature Reviews Earth & Environment*, *4*(2), 71-86. https://doi.org/10.1038/s43017-022-00379-5

Shang, K., Xu, L., Liu, X., Yin, Z., Liu, Z., Li, X., Yin, L., & Zheng, W. (2023). Study of Urban Heat Island Effect in Hangzhou Metropolitan Area Based on SW-TES Algorithm and Image Dichotomous Model. *SAGE Open*, *13*(4), 21582440231208852. https://doi.org/10.1177/21582440231208851

Yang, B., Olofsson, T., Nair, G., & Kabanshi, A. (2017). Outdoor thermal comfort under subarctic climate of north Sweden–A pilot study in Umeå. *Sustainable Cities and Society*, *28*, 387-397. https://doi.org/10.1016/j.scs.2016.10.011