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Time-Series Analysis of Temperature Difference Between Neighbouring Days (TDN) across Southern Nigeria for Radiowave Applications using ARIMA Model

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ABSTRACT

This paper examines Temperature Difference between Neighbouring Days (TDN) as a high-quality indicator of short-term variability of temperature and its impact on atmospheric conditions in southern Nigeria. The analysis used daily surface temperature data from six cities, based on eight years of records from the European Centre for Medium-Range Weather Forecasts (ECMWF) for southern Nigeria. Warri and Lagos had the lowest values of TDN, which may be explained by the fact that the presence of the Atlantic Ocean may moderate the values and contribute to a better thermal stability and more predictable radio-wave propagation. Onitsha and Akure on the other hand, experienced the highest TDN values, indicating the existence of stronger day-to-day temperature changes. In quantitative terms, the standard deviation of TDN in Onitsha was about 84% greater than that in Lagos and 55% greater than that in Warri, suggesting that the potential environmental instability is significantly higher and that the possibility of signal losses and multipath interference is significantly higher. The data on temperature were used to characterize the temporal patterns of TDN using an ARIMA (1,0,1) model. The high AR (1) coefficients in Warri and Port Harcourt (-0.4241 and -0.3810, respectively) are an indication that there was a consistent and predictable behaviour in temperature, whereas weaker temporal correlation found in the inland cities is consistent with their greater variability. The outcomes of these studies emphasize the applicability of TDN to analyze the short-term variations in temperature and illustrate its applicability in climate analysis and telecommunications planning.

Keywords: TDN, temperature fluctuation, mean temperature, signal reliability, southern Nigeria

Introduction

The average kinetic energy of particles within an object or space is described by its temperature. Atmospheric temperature consequently describes the degree of kinetic activities of particles within different layers of the atmosphere. Its size is mainly depending on the time of day and location, and its variation is highly impacted by various other atmospheric factors and phenomena (Adediji *et al.*, 2015). These include solar radiation, the amount of moisture in the atmosphere, the height and layer of the spot inside the atmosphere, and the location of the spot on the earth's surface in relation to the equator. The kind and thickness of the cloud, the type of land surface, and the proximity to or distance from big bodies of water, such as rivers,

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lakes, and seas, are additional determinants (Kayode *et al*., 2019). Finally, in many parts of the world, the distribution and intensity of rainfall have a significant impact on the daily and seasonal temperature profiles. In addition to influencing several physicochemical processes in the atmosphere, temperature change also has a role in the operation of numerous biological processes and organisms (Ashidi *et al*., 2019). Similarly, numerous wireless radio propagation processes are influenced by variations in temperature, while functioning as a veritable parameter for evaluating weather and climatic dynamics (Ashidi *et al*., 2020).

Another important temperature-related physical phenomenon frequently exploited for weather and climate characterisation is the temperature difference between neighboring days (TDN). TDN refers to the shift in the average temperature from one day to the next, as stated by Lin *et al*. (2013), Cheg *et al*. (2014), and Ma *et al*. (2019). Weather describes the atmospheric conditions at a particular moment and place, while climate represents the long-term trends of weather in a specific area. Although interconnected, weather and climate are essentially separate concepts (Lin *et al*., 2013; Agada *et al*., 2023). Studies have revealed that weather has a direct impact on ecosystems inside the troposphere, the lowest atmospheric layer, and on human activities (Guo *et al*., 2011; Cheng *et al*., 2014). Numerous study works have evaluated numerous temperature indicators, such as daily mean temperature, maximum and lowest temperatures, apparent temperature, and the diurnal temperature range (DTR) (Zhan *et al*., 2017). However, there hasn't been much research done in this region of the world to investigate TDN for weather and climate studies. Consequently, this work explores the time series analysis of TDN across chosen sites in Southern Nigeria using ARIMA model.

Nigeria's atmospheric and climatic variability has been the subject of recent studies, and there is growing interest in knowing how temperature variations impact radio wave propagation and atmospheric stability in various places. Agada *et al*. (2023) underlined that Nigeria comprises a range of meteorological and ecological zones, each distinguished by unique weather patterns. Their research studied the links among diverse climatic conditions throughout Nigeria, particularly highlighting the impact of dry winds from the north and east. The study looked at factors such wind speed, solar radiation, relative humidity, precipitation, and daily air temperature using meteorological data from NASA. According to their statistical study, the two main variables influencing the nation's weather patterns are wind speed and air temperature.

Podbregar *et al*. (2024) evaluated the influence of temperature changes on phase stability in a radio-frequency (RF) phase-stabilization system via an optical fiber link. They discovered that the system maintained constant phase performance with minor temperature changes (≤0.1 °C/s), with phase fluctuations around 0.3 ps. Larger temperature fluctuations, however, resulted in delays of up to 5 ps, suggesting that significant thermal changes may jeopardize signal stability. The study underscores the need for improved system designs to enable reliable phase-stable RF distribution under real-world temperature circumstances.

Using a radar system in a controlled climate chamber, Mahendran *et al*. (2024) investigated the effects of temperature and humidity variations on electromagnetic wave propagation in the 68–92 GHz frequency range. Their findings demonstrated that both environmental factors affect the dielectric properties of air, resulting in detectable phase shifts in the signals; phase variations were detectable under both varying temperature at constant humidity and varying humidity at constant temperature. The study confirmed that even small atmospheric changes can have a significant impact on high-frequency wave propagation.

Adediji and Iwaotan (2025) used ERA-Interim reanalysis data to investigate how temperature affects radio duct formation in coastal Nigeria. They estimated modified refractivity and its gradient to determine ducting conditions, finding higher gradients during the wet season and smaller gradients during the dry season. Temperatures of 26°C or above were linked to ducting occurrences, which mostly happened between December and February. In Port Harcourt, slopes reached −13 M-units/km. Their

findings reveal that coastal temperature conditions greatly influence radio duct development, which can trap signals and change propagation characteristics. Future research could take into consideration hybrid or non-linear time-series models to better capture complex temperature dynamics in tropical climates, even though the ARIMA (1,0,1) model successfully captures temporal dependencies in TDN and offers insight into daily temperature variability. Specifically, ARIMA assumes linear relationships and may not fully account for seasonal patterns, non-linear trends, or sudden abrupt shifts in temperature. As a result, predictions based solely on ARIMA could underestimate extreme fluctuations that strongly influence atmospheric refractivity and radiowave propagation.

This work attempts to give a thorough examination of TDN and its relationship with surface temperature in southern Nigeria, taking into account the importance of temperature variability in determining atmospheric refractivity and radio signal behaviour. By merging TDN computations with local meteorological data, the research attempts to increase knowledge of how day-to-day temperature fluctuations affect air stability and radio-wave propagation in tropical areas.

2.0 Materials and Method

The investigation was carried out over six different locations in southern Nigeria as illustrated in Figure 1. Surface temperature data for these places was acquired from the European Centre for Medium-Range Weather Forecasts (ECMWF), a respected research institution. Because local weather stations frequently lack consistent, gap-free, and quality-controlled coverage throughout all research locations, TECMWF data was chosen. Its long-term daily temperature records are useful for evaluating TDN over numerous years. Furthermore, ECMWF data has been rigorously validated in tropical climate and radio propagation investigations, ensuring reliability for this research. The dataset covered daily averaged surface temperature values for the period of 7 years from January 1, 2010, to December 31, 2017, spanning a total of 8 years. The data had a spatial resolution of 0.25° by 0.25°. Figure 2 shows the comparison of surface temperature profile obtained from the archive of ECMWF with in-situ measured for year 2016.

Computation of TDN

We used the following formula, which is given by Lin *et al*. (2013) and Ma *et al*. (2019), to calculate the temperature difference between neighboring days (TDN).:

$$TDN_i = T_i - T_{i-1} \quad (1)$$

where:

- TDN_i represents the temperature difference between day i and the previous day i-1.
- T_i is the average temperature on day i,
- T_{i-1} is the average temperature on day i−1.

The **mean temperature (mean T)** for each location was determined using the equation:

$$Mean\ T = \frac{1}{n}\sum_{i-1}^{n} T_i \quad (2)$$

where:

- n is the number of days,
- T_i is the daily temperature for day i.

In addition, **standard deviation (σ)** was calculated using the standard statistical formula:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i-1}^{n} (T_i - Mean\ T)^2} \quad (3)$$

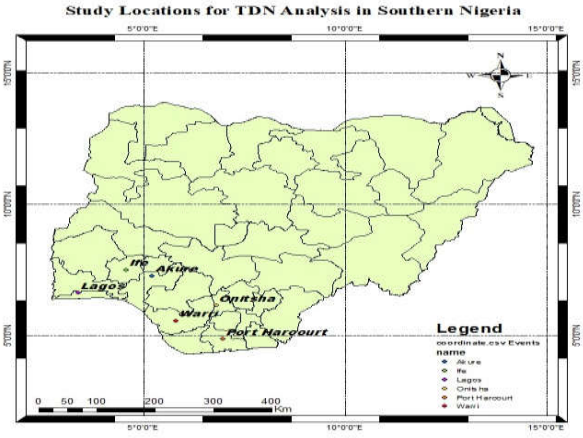

Figure 1: Map showing the study locations. Source: ARC Map 10.7.1

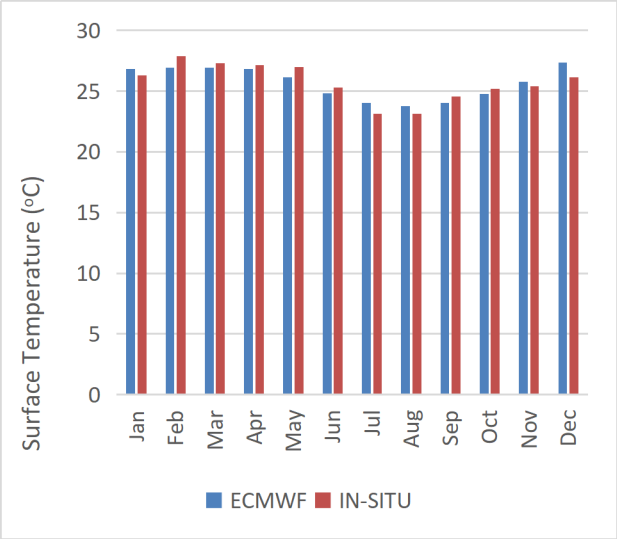

Figure 2: Monthly mean profile of surface temperature obtained in-situ against ECMWF

Spatial Distribution of TDN across location

To analyze the spatial distribution of TDN across the six study locations, a simplified Moran's I (Eqn. 4 below) spatial autocorrelation analysis was done using the mean TDN values and estimated physical closeness between the cities. A binary spatial weight matrix was developed, assigning a value of 1 to neighboring cities and 0 otherwise, based on relative coastal and inland locations (Lat and Long Coordinate). Using the Moran's I method, we found a value of 0.44, suggesting significant positive spatial autocorrelation. The findings that coastal towns (Port Harcourt, Warri, and Lagos) have lower TDN values whereas inland cities (Onitsha, Akure, and Ife) have more variability are supported by this investigation, which has consequences for telecommunications design and radio signal stability.

$$I = \frac{N}{\sum i \sum j w_{ij}} \frac{\sum i \sum j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum (x_i - \bar{x})^2} \quad (4)$$

N is number of locations under studied, x_i *and* x_j are TDN values for locations i and j, $\bar{x}$ represents mean TDN and w_{ij} are spatial weight between locations i and j.

Statistical Tools Used

For the analysis of the gathered data, numerous statistical tools were applied to examine and explain the temperature differences and related characteristics. Descriptive statistics were employed to summarize key metrics, such as the mean, median, standard deviation, and variance, offering insight into the central tendency and variability of the TDN values. Correlation analysis was employed to analyze the link between TDN and other temperature indicators, while trend analysis assisted to discover temporal patterns in temperature fluctuation across the study period. Various graphical forms, including line graphs, bar charts, and box plots, were applied to visually show temperature changes across the different sites throughout time.

Python was used for more complex statistical calculations, such as correlation and trend analyses, whereas Microsoft Excel was used for basic data management and descriptive statistics. The statistical results, which are presented in Tables 1, 2, and 3 as well as Figures 1 through 9, were guaranteed to be accurate and understandable by the use of these software tools.

Results and Discussion

Table 1 displays the descriptive statistics for temperature deviation from normal (TDN) across various sites in southern Nigeria during the past eight years. In Akure, the maximum recorded temperature is 5.7K, while the minimum is -6.9K. Ife has a maximum temperature of 6.6K and a low of -8.1K. Lagos has a lowest temperature of -1.2K and a high temperature of 3.1K. Onitsha and Port Harcourt both have a maximum temperature of 7.3K and a minimum of -5.7K. Warri's temperature records indicate a minimum of -3.9K and a maximum of 4.1K. Ife, Onitsha, and Port Harcourt all show a significant range of 14.7K, but the range of computed TDN values gradually drops from Ife (14.7K) to Warri (8K). This broad range in the latter three locations may be related to urban heat island effects or seasonal temperature changes, which result in noticeable daytime heating and quick overnight cooling (Aremu *et al.*, 2017). Deforestation and increased urbanization are two causes that may make this variability worse. Conversely, Warri's fairly limited TDN range of 8K suggests more stable temperature conditions, possibly affected by its coastal vicinity, which helps reduce major temperature variations through the ocean's thermal inertia (Singh *et al.*, 2024). Over the previous eight years, Akure has showed a

prominent TDN value of -0.2K, in contrast to the other five sites, which predominantly feature a TDN value of 0K. This tiny disparity may arise from local environmental considerations, such somewhat milder evening temperatures or reduced urban heat, particularly when contrasted to more densely populated areas like Lagos and Onitsha, where heat retention is more prominent (Anyakoha, 2007).

Table 2 displays the results of the mean T for the complete period under consideration, i.e., 2922 days or 8 years. The mean T rises from Warri to Akure. The mean T is 297.6K in Warri, 298.0K in Port Harcourt, 298.4K in Lagos, 298.4K in Onitsha, and 298.5K and 298.5K in Ife and Akure, respectively.

Table 1: Descriptive statistics for TDN

Location	Akure	Ile-Ife	Lagos	Onitsha	Port Harcourt	Warri
Mean	0.0007532	0.0003423	-0.0004108	0.0015406	0.0015406	0.0001712
Standard Error	0.0186564	0.0180501	0.0111974	0.0205824	0.0205824	0.0132611
Standard Deviation	1.0083077	0.9755433	0.6051773	1.1123995	1.1123995	0.7167158
Sample Variance	1.0166844	0.9516848	0.3662396	1.2374326	1.2374326	0.5136815
Kurtosis	4.3311895	4.7565757	2.3577105	5.3370084	5.3370084	2.6208301
Skewness	0.1685283	0.0190004	-0.251388	0.5161305	0.5161305	-0.1792432
Range	12.6	14.7	6.3	13	13	8
Minimum	-6.9	-8.1	-3.2	-5.7	-5.7	-3.9
Maximum	5.7	6.6	3.1	7.3	7.3	4.1
Sum	2.2	1	-1.2	4.5	4.5	0.5
Count	2921	2921	2921	2921	2921	2921

Table 2: Mean temperature and TDN for all the locations

Location	Akr	Ife	Lag	Oni	PhC	War
Mean Temp (K)	298.5474	298.429	298.1252	298.3846	297.9893	297.628
Mean TDN (K)	-0.00105	-0.00095	-0.00028	-0.00119	-0.00039	-0.00011

The outcomes of Table 2 are shown in Figure 3. Here, Akure is just a little above Ife in terms of the highest temperature fluctuation for 8 years, which may be attributed to some climatic variability in Akure (Akpootu *et al*., 2024). Also, the least temperature fluctuation across all the places happens in Warri, which is lagger due to the fact that it is positioned close to the coast (Egbinola and Amobiochukwu, 2013; Omotoso *et al*., 2021). According to Table 3 and Figure 4, the mean TDN rose in the negative direction from Warri to Onitsha. The mean TDNs for Warri, Lagos, and Port Harcourt are -0.00011K, -0.00028K, and -0.00039K, respectively. Furthermore, Ife, Akure, and Onitsha had mean TDNs of -0.00095K, -0.00105K, and -0.00119K, respectively. Onitsha and Warri show the greatest and lowest temperature changes among the six sites, respectively, according to Figure 3, which summarizes the findings in Table

3.

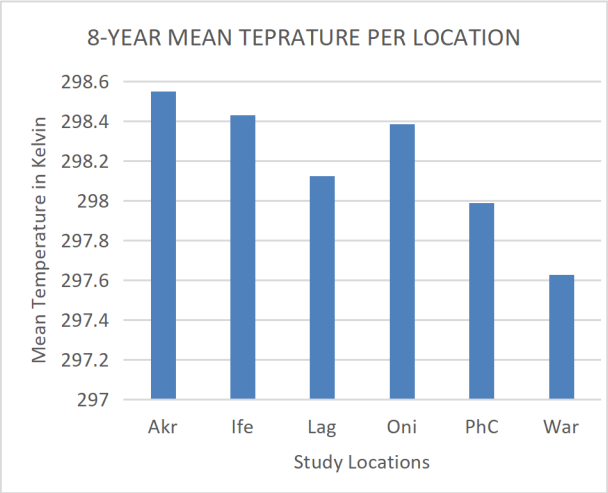

Figure 3: Mean temperature for all the locations

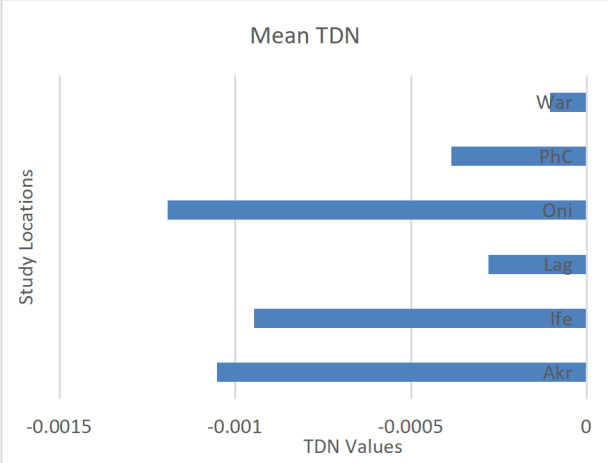

Figure 4: Mean TDN in Kelvin for all the locations

The distribution of temperature difference (TDN) values throughout the areas under study is shown in Figure 5 as a box plot, also called a whisker plot. The center 50% of the data for each site is represented by each box, which shows the interquartile range (IQR) of the TDN values. The median value is indicated by the line inside the box. The boxes' widths show how TDN values vary, with certain places such Ife and Onitsha showing a wider variation than others, like Warri.

TDN for the six locations—Akure (A), Ife (B), Lagos (C), Onitsha (D), Port Harcourt (E), and Warri (F)—is displayed in Figure 6 (A-F) during a period of roughly 2500 days. Daily temperature variations are represented by TDN values, which might affect atmospheric and environmental dynamics, especially when it comes to radio signal transmission (Usman *et al*., 2020).

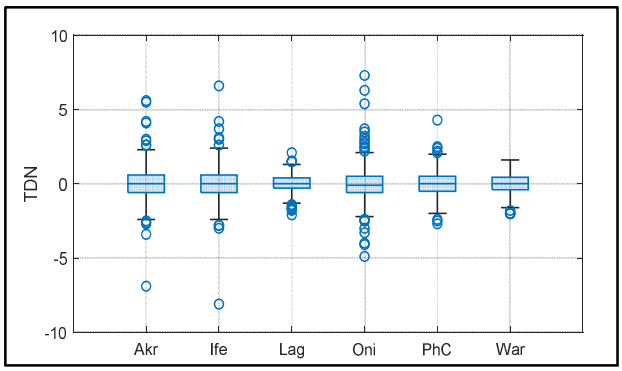

Figure 5: Box plots showing TDN distribution

TDN readings in Akure (6A) vary greatly, frequently peaking and falling to levels above +6 and below -6. This shows significant temperature swings across successive days, possibly due to its inland location where temperatures can fluctuate more rapidly without the stabilizing influence of big water bodies (Elijah *et al*., 2021; Falodun *et al*., 2021). According to Rahman and Nasher (2024) and Usman *et al*. (2024), such fluctuation may damage the quality of radio transmissions by creating frequent variations in atmospheric density, which affects signal propagation and may lead to signal fading. Similarly, Ife (6B) shows substantial oscillations, though with slightly lower extremes than Akure, indicating moderately rapid temperature changes. Additionally, these changes can make radio signal conditions less stable (Ojo *et al*., 2024).

Lagos (6C) exhibits a more stable TDN pattern, primarily fluctuating between -4 and +4. Because of its closeness to the Atlantic Ocean, this coastal city's daily temperature fluctuations are probably mitigated, leading to a more constant atmospheric refractive index that can sustain consistent radio signal transmission (Adeniji *et al*., 2021). With repeated peaks and troughs resembling those of Akure, Onitsha (6D) shows more extreme TDN values, indicating significant daily temperature variations. Located in a riverine location, Onitsha may suffer temperature variability impacted by both land and water, leading to air instability that could disrupt radio

wave propagation through enhanced multipath fading (Omotoso *et al*., 2021).

Port Harcourt (6E) and Warri (6F) show modest TDN patterns, with swings mainly within -4 to +4. As coastal and riverine cities, they benefit from neighboring water bodies that help regulate daily temperature variations. This relative consistency in TDN suggests more stable air conditions, which would facilitate dependable radio signal transmission. However, infrequent TDN spikes could momentarily impact signal strength due to rapid atmospheric changesThe overall finding shows that cities with significant TDN fluctuation, like Onitsha and Akure, are more vulnerable to atmospheric circumstances that could impair radio signal transmission (Nwokolo *et al*., 2022). Sharp day-to-day temperature variations can alter air density and refractivity, leading potential signal deterioration (Obiegbu and Anene, 2023). On the other hand, areas with more consistent TDN values, such as Lagos, Port Harcourt, and Warri, have more conducive environments for continuous radio signal transmission. This investigation underlines the impact of local climatic conditions on communication infrastructure, especially in locations where radio signals are crucial or broadcasting or telecommunications (Usman *et al*., 2024).

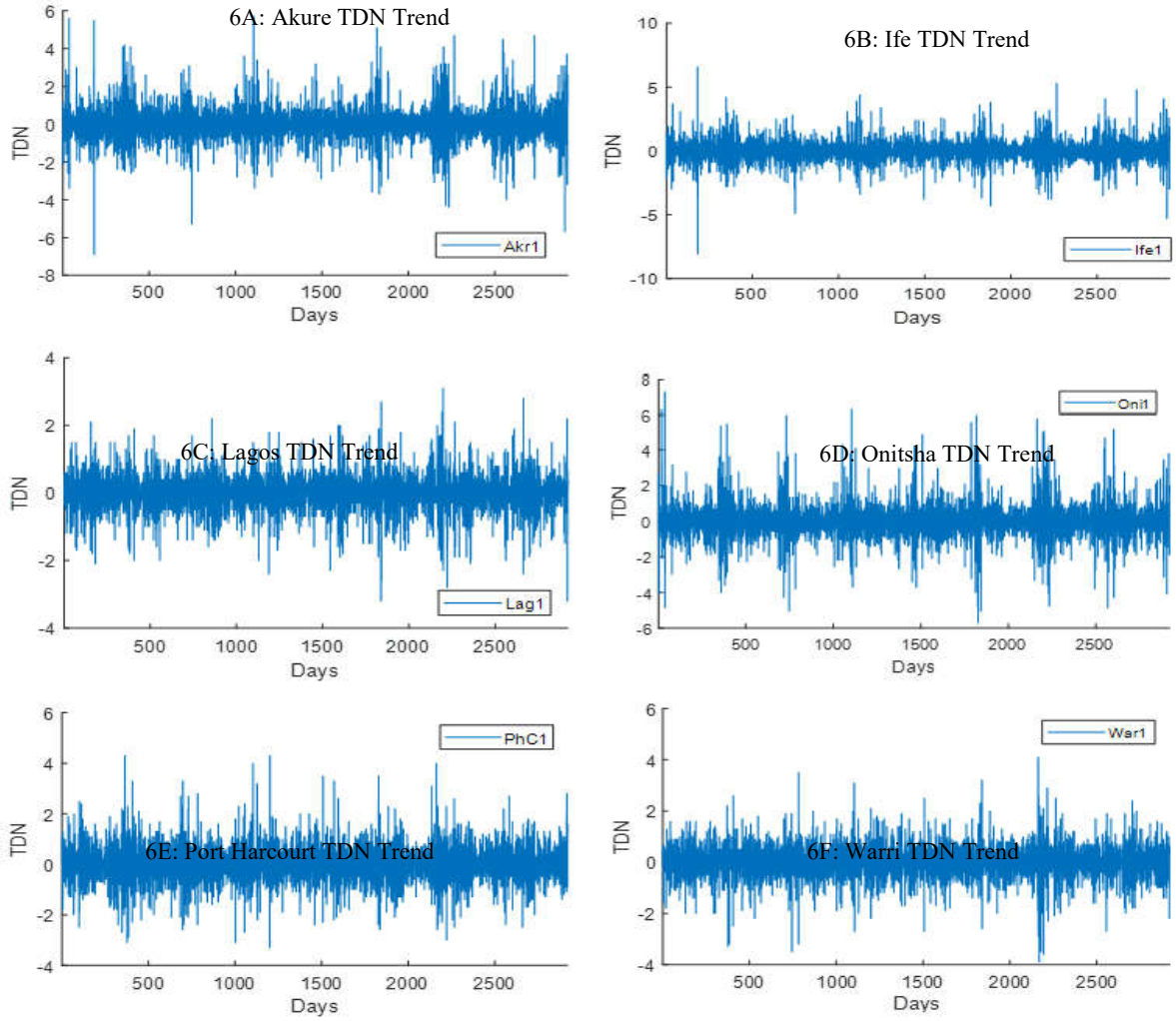

Figure 6: Time series graph for Akure (A), Ife (B), Lagos (C), Onitsha (D), Port Harcourt (E) and Warri (F)

Figure 7 illustrates the yearly average Temperature Difference between Neighboring Days (TDN) across the study locations. The yearly mean TDN values for each site are shown in this chart, which highlights variations in daily temperature variance between the cities. Ife (IFE)

shows the most noticeable peaks during the study period, especially in 2012 and 2015, when mean TDN values surpass 0.015 K and -0.015 K, respectively. This shows that Ife has significant temperature fluctuation, perhaps due to distinct local environmental or geographic factors that lead to frequent and notable day-to-day temperature shifts (Singh *et al*., 2024). This variability can impact radio signal propagation, as fluctuating temperatures alter atmospheric refractivity, potentially leading to increased signal fading or multipath interference (Manga and Kalu, 2024; Ojo *et al.,* 2024).

For example, TDN levels in Port Harcourt (PHC) and Warri (WAR) are comparatively steady over time, with little variation and near zero. Because moderate temperature variations cause fewer disturbances in air density and refractivity, this stability suggests more consistent atmospheric conditions that facilitate dependable radio signal transmission (Ukhurebor *et al*., 2020). Due to its maritime environment, which lessens dramatic temperature swings, Lagos (LAG) also exhibits considerable stability, with TDN values close to zero (Adeyemi and Ogodo, 2024). Akure (AKR) and Onitsha (ONI) demonstrate substantial variability, with noticeable peaks and valleys, particularly in 2012 and 2014. These patterns reflect periods of higher day-to-day temperature change, possibly due to seasonal transitions or regional weather events (Adedayo, 2016).

Similar to Ife, these variations may result in less predictable air conditions, which could make it difficult to maintain reliable radio signal quality. The TDN research suggests that Ife suffers the largest temperature variations among the cities, perhaps contributing to more unstable conditions for radio signal propagation (Falodun *et al*., 2019). Port Harcourt, Warri, and Lagos, with more constant TDN values, are projected to offer superior circumstances for steady signal transmission (Ukhurebor *et al*., 2020). This finding is useful for telecommunications planning, since places with high TDN fluctuation may need additional equipment to counteract signal deterioration owing to atmospheric changes (Elijah *et al*., 2021).

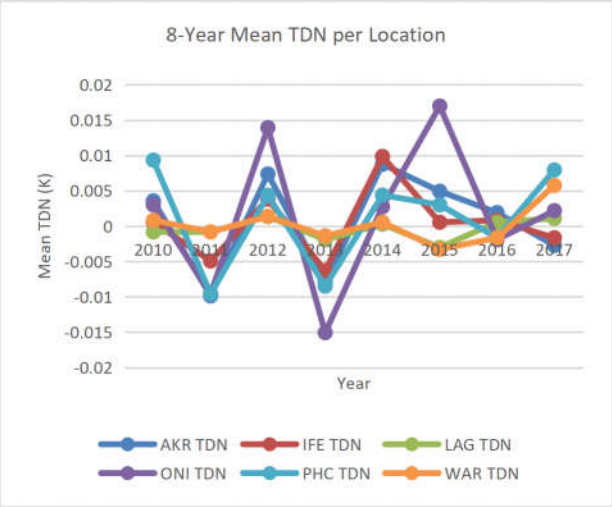

Figure 7: A plot of mean TDN for all the locations per year

Figure 8 illustrates that the ARIMA model used to estimate daily temperature differences (TDN) between surrounding days generally fits well across the study locations. This model efficiently captures short-term dependencies, as evidenced by the large AR (1) and MA (1) parameters in Table 3, revealing that TDN values are influenced by recent values and past forecast errors (Akpootu *et al*., 2024; Manga and Kalu, 2024). The AR (1) and MA (1) coefficients were significant at $p < 0.05$, suggesting that the TDN values from the previous day have a significant impact on the temperatures of the next day. Instead of depending only on descriptive trends, this illustrates the resilience of temporal dependencies.

The constants, however, are not statistically significant, which suggests no underlying baseline trend in TDN. Variance estimates show differing levels of fluctuation across locations, with Onitsha and Akure experiencing greater variability than Lagos and Warri. While the residuals indicate occasional periods of increased variability, suggesting that the model may overlook some complex patterns (Rahman and Nasher, 2024), it remains effective for short-term pattern prediction, though additional factors like environmental or seasonal influences may be involved (Jafarian-Namin *et al.,* 2024).

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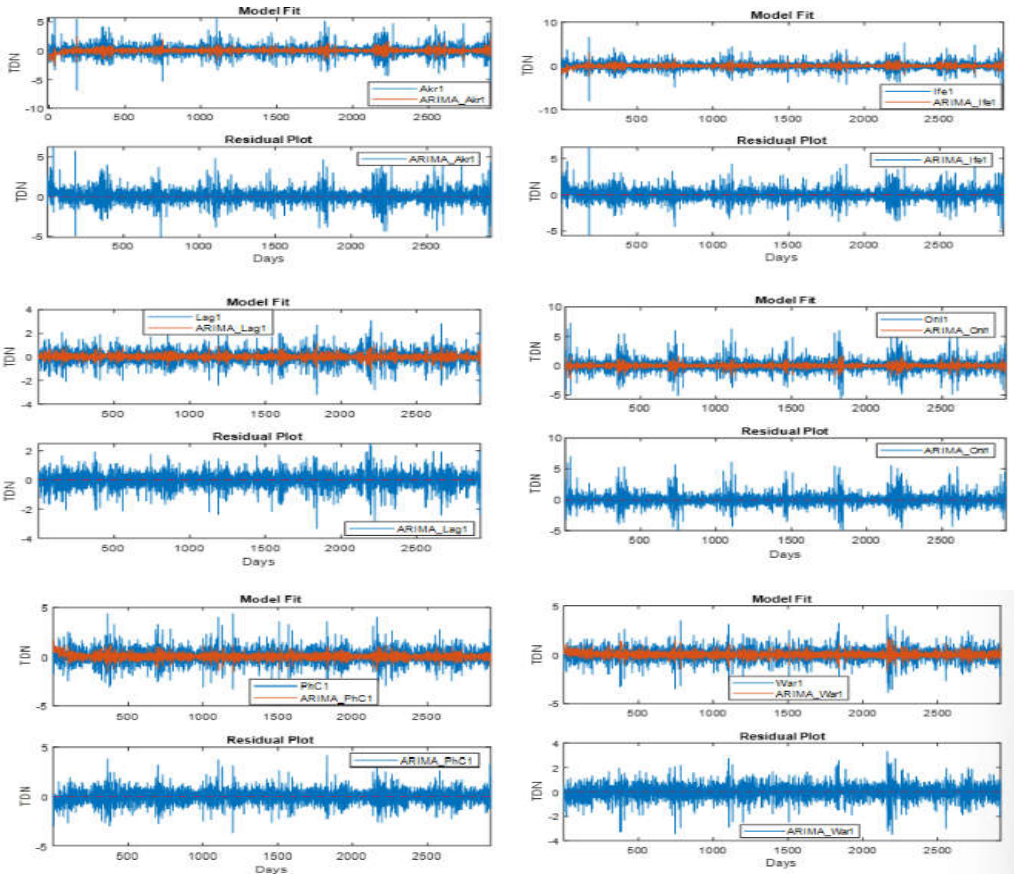

Figure 8: ARIMA Model Fit

Table 3: ARIMA Model Parameter estimate for TDN

Location	Parameter	Value	Stand err	T statistic	P-value
Akure	Constant	0.0003	0.0003	0.8172	0.4138
Ife		0.0003	0.0003	0.7959	0.4261
Lagos		-0.0000	0.0000	-1.1414	0.2537
Oni		-0.0000	0.0000	-0.0345	0.9725
PhC		-0.0002	0.0002	-0.6197	0.5354
Warri		-0.0001	0.0001	-0.7067	0.4798
Akure	AR{1}	-0.3609	0.0119	-30.2472	0.0000
Ife		-0.3867	0.0114	-33.9770	0.0000
Lagos		-0.3724	0.0129	-28.7636	0.0000
Oni		-0.3192	0.0096	-33.1550	0.0000
PhC		-0.3810	0.0137	-27.7909	0.0000
Warri		-0.4241	0.0131	-32.2660	0.0000
Akure	MA{1}	-0.9818	0.0031	-320.9815	0
Ife		-0.9807	0.0030	-323.8883	0
Lagos		-0.9998	0.0010	-966.5206	0
Oni		-1.0000	0.0066	-151.1082	0
PhC		-0.9830	0.0032	-304.7062	0
Warri		-0.9930	0.0022	-445.0383	0
Akure	Variance	0.9347	0.0137	68.2077	0
Ife		0.8629	0.0133	65.0440	0
Lagos		0.3192	0.0059	54.1609	0
Oni		1.1038	0.0168	65.5918	0
PhC		0.5905	0.0112	52.5946	0
Warri		0.4297	0.0076	56.5428	0

Table 4: Goodness of fit parameters for TDN ARIMA model

Measure	Akr	Ife	Lag	Oni	PhC	War
AIC (e+03)	8.1002	7.8667	4.9620	8.5858	6.7587	5.8301
BIC (e+03)	8.1241	7.8906	4.9860	8.6097	6.7827	5.8540

Conclusion

Over the course of eight years, this study examined TDN values in six southern Nigerian cities: Warri, Lagos, Port Harcourt, Ife, Akure, and Onitsha. It was found that Warri and Lagos consistently had the lowest TDN, possibly due to the Atlantic Ocean's cooling influence, while Onitsha, Akure, and Ife showed higher TDN, reflecting greater daily temperature fluctuations. While higher TDN in inland cities may increase multipath interference and signal fading, indicating the need for more robust telecommunications infrastructure, lower TDN in coastal cities suggests more constant atmospheric refractivity, which favors radio signal transmission. The ARIMA (1,0,1) model adequately captured temporal trends and persistence in temperature fluctuations, while it implies linearity and may not fully account for seasonal or abrupt non-linear shifts in TDN. Limitations of this work include reliance on ECMWF reanalysis data with 0.25° × 0.25° spatial resolution, which may have smoothening effect on local microclimatic fluctuations. Also, the linear ARIMA model may not capture all complex atmospheric dynamics. Future study should examine merging TDN with radio refractivity indices or real-time signal observations for better predictive modeling of radio-wave propagation. Incorporating intraday temperature changes and non-linear modeling methodologies could further expand understanding of short-term atmospheric effects on telecommunications.

Data Availability

Data used for this research can be made available upon reasonable request.

Conflict of Interest

The authors declared no conflict of interest.

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