Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v35(s).2026.690
Volume 35(S), 2026

Wavelet Coherence Between Large-Scale Climate Indices and Precipitation Variability over Nigeria (1961–2021)

Adeola Johnson and Silas Ayodeji Idowu

Department of Physics Electronics, Federal University of Technology, Akure, Nigeria

*Corresponding Author's Email: ayodejisilas313@gmail.com

Keywords:
Wavelet Coherence,
Climate Teleconnections,
Precipitation Variability,
Atlantic Meridional Mode,
Nigeria

Submitted: 30 July 2026

Accepted: 03 Sept. 2026

Published: 02 July 2026

ABSTRACT

Precipitation variability across Nigeria is strongly modulated by remote climate teleconnections, yet existing studies rarely examine multi-index interactions across localized time–frequency scales. This study applies wavelet coherence and cross-wavelet phase analysis to examine the relationships between six large-scale climate indices — the Atlantic Meridional Mode (AMM), Atlantic Multidecadal Oscillation (AMO), North Atlantic Oscillation (NAO), Niño 3.4 (NINA), Pacific Decadal Oscillation (PDO), and Southern Oscillation Index (SOI) — and monthly precipitation across Nigeria's five climatic zones (Sahel, Sudan savannah, Guinea savannah, tropical rainforest, and coastal) from 1961 to 2021. Monthly rainfall data were extracted from the ERA5 reanalysis across twenty-five representative locations, and spatial correlation structures were mapped using ordinary kriging interpolation. The AMM exhibited the strongest and most persistent coherence with precipitation across all five zones, concentrated predominantly at near-annual periodicities (~0.0625 – 0.125), identifying it as the primary large-scale driver of Nigerian rainfall variability. The AMO and NAO demonstrated intermittent, seasonally gated coherence; Niño 3.4 displayed distinct anti-phase coherence at 2–8-year periodicities concentrated in the tropical rainforest zone; while the PDO and SOI exhibited weak, inconsistent associations. Spatially, negative correlations for the AMM, AMO, and NAO strengthened toward the southern coastline, whereas Niño 3.4 showed an inland-to-coastal gradient of increasingly negative correlation. These findings demonstrate the priority of the AMM for seasonal rainfall forecasting in Nigeria and provide zone-specific empirical evidence to support agricultural planning and water resource management.

INTRODUCTION

Rainfall over Nigeria is governed not only by local convective and orographic processes but also by large-scale, remotely forced patterns of atmospheric and oceanic variability collectively known as climate indices. Indices such as the Atlantic Multidecadal Oscillation (AMO), the Atlantic Meridional Mode (AMM), the North Atlantic Oscillation (NAO), the Niño 3.4 index, the Pacific Decadal Oscillation (PDO), and the Southern Oscillation Index (SOI) track basin-scale anomalies in sea-surface temperature and sea-level pressure that modulate the position and strength of the Intertropical Convergence Zone (ITCZ) and the West African monsoon (Gbode et al., 2019). Because these indices operate across a wide range of time scales from interannual El Niño–Southern Oscillation (ENSO) cycles to multidecadal Atlantic modes their influence on precipitation is rarely constant in time, which limits the diagnostic value of conventional correlation or trend analysis and motivates a time–frequency approach.

Wavelet analysis addresses this limitation by decomposing a time series into localized time–frequency components, making it possible to identify not only whether two variables are related but also the specific periodicities and epochs at which the relationship is strongest (Torrence & Compo, 1998). Wavelet coherence extends this to bivariate analysis, quantifying the local correlation between two time series across time and scale and recovering their phase relationship (Grinsted et al., 2004). This framework has proved useful for examining hydro-climatic teleconnections (Xu, 2018) and has already been applied within West Africa: Adepitan and Falayi (2019) used wavelet analysis to show that the influence of climate indices on Nigerian rainfall and temperature is concentrated at specific, non-stationary frequencies; Baidu et al. (2017) found that rainfall variability over neighbouring Ghana reflects both local and regional teleconnection influences; and Loua et al. (2019) reported significant frequency-dependent coupling between precipitation and surface temperature at Conakry, Guinea.

A growing body of work has linked individual indices to Nigerian and West African rainfall. The AMM has been identified as the primary source of interannual tropical Atlantic variability, sustained by a wind–evaporation–sea surface temperature feedback that shifts the West African monsoon (Xia et al., 2023), and Diatta et al. (2020) showed that Atlantic teleconnections, including the AMM, dominate rainfall variability across West Africa at multi-decadal time scales, in contrast with the shorter-period influence of intraseasonal oscillations. The NAO has been linked to European precipitation through a well-established north–south dipole (Tsanis & Tapoglou, 2018; Tatli & Menteş, 2019), with Khedimallah et al. (2020) reporting robust positive NAO–rainfall correlations of 60–84% across North African basins; within Nigeria, Okorie (2021) found that NAO influence on south-eastern rainfall is seasonally dependent and strongest during the dry season. ENSO-related indices show region-specific effects: Umar and Kehinde (2020) linked long-term rainfall decline in southern and south-western Nigeria to ENSO phase, while Emmanuel (2022) showed that El Niño intensifies dry-season conditions in Guinea and the Sahel but that La Niña consistently enhances precipitation across the wider region. Complementary studies using extreme-precipitation indices have documented an intensification of heavy rainfall across Nigeria's climatic zones over recent decades (Dike et al., 2020; Audu et al., 2021), a decline in seasonal and annual totals in the north (Ogunrinde et al., 2022), and a shift toward wetter conditions in the north-east but drier conditions in the south-east under future emission scenarios (Shiru & Park, 2020).

Despite this progress, most existing Nigerian studies examine a single climate index, a single station or region, or focus on precipitation trends rather than the time–frequency structure of the index–rainfall relationship. Comparative, multi-index assessments spanning all of Nigeria's climatic zones over a multi-decadal record remain scarce, and the spatial structure of the index–rainfall relationship across the country has not been systematically mapped. This study addresses that gap by jointly evaluating the wavelet coherence between six climate indices (AMM, AMO, NAO, Niño 3.4, PDO, SOI) and precipitation across twenty-five locations spanning Nigeria's five climatic zones over sixty years (1961–2021), and by mapping the spatial correlation structure across the country. The specific objectives are to (i) characterize the wavelet coherence between each climate index and precipitation across Nigeria's climatic zones; (ii) identify the periodicities at which each index and precipitation are most strongly coupled; and (iii) assess the spatial correlation structure of each index–precipitation relationship across the country. In addressing these objectives, the study identifies which of the six indices carries the greatest practical value for seasonal rainfall prediction in Nigeria and provides zone-specific evidence relevant to agricultural planning, water resource management, and climate adaptation policy in Nigeria and the wider West African region.

MATERIALS AND METHODS

Study Area

Nigeria lies in West Africa between latitudes 4°N–14°N and longitudes 3°E–15°E, bordering the Gulf of Guinea to the south and extending through savannah, rainforest, plateau, and Sahelian terrain toward the Sahara in the north (Ojegbile et al., 2023). The dry season (November–March) is dominated by dry, dust-laden harmattan winds from the Sahara, while the rainy season (April–October) brings abundant rainfall to the southern and central regions, driven principally by the seasonal migration of the ITCZ (Ibebuchi & Abu, 2023). Rainfall declines sharply from south to north: coastal and Niger Delta locations receive over 2,000–4,000 mm annually, whereas the northern Sahel receives only 500–750 mm, concentrated between June and September (World Bank Climate Change Knowledge Portal, 2021; Mobolade and Pourvahidi, 2020). Following Ragatoa et al. (2019), the country is here partitioned into five climatic zones Sahel, Sudan savannah, Guinea savannah, tropical rainforest, and coastal each represented by five sampling locations (Figure 1).

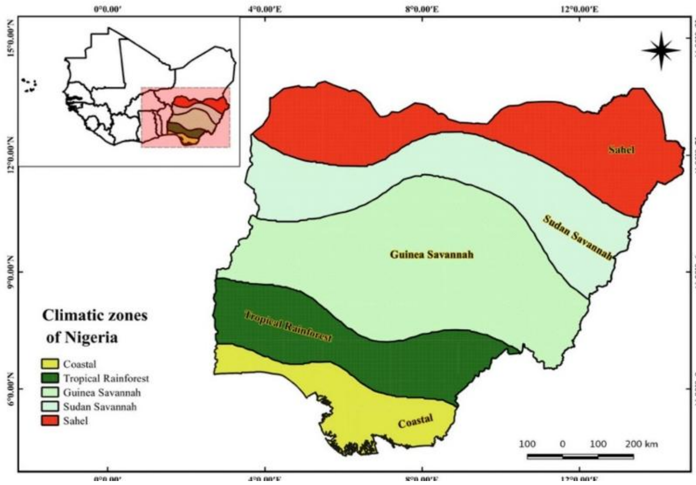

Figure 1: Climatic Zones of Nigeria used in this Study (Adapted from Ragatoa et al., 2019)

Data

Monthly precipitation data for 1961–2021 were obtained from the ERA5 reanalysis produced by the European Centre for Medium-Range Weather Forecasts, at a spatial resolution of 0.25° × 0.25°, and extracted for twenty-five locations grouped into the five climatic zones described above. Six climate indices were used: the Atlantic Multidecadal Oscillation (AMO) and Atlantic Meridional Mode (AMM), both obtained from NOAA's Earth System Research Laboratory (Enfield et al., 2001); the North Atlantic Oscillation (NAO) and Southern Oscillation Index (SOI), obtained from the Climate Prediction Center of the U.S. National Weather Service (Shi et al., 2020); the Niño 3.4 index (denoted NINA throughout), representing sea-surface temperature anomalies in the east-central equatorial Pacific and serving as a standard measure of ENSO phase (Li et al., 2021); and the Pacific Decadal Oscillation (PDO), obtained from NOAA's National Centers for Environmental Information. The PDO was included alongside the other five indices because its decadal-scale modulation of North Pacific sea-surface temperature has been shown to interact with ENSO-related teleconnections that extend into the Atlantic and West African sector (Fan et al., 2024), making it a relevant, if secondary, candidate driver of Nigerian rainfall variability alongside the Atlantic- and ENSO-based indices. The AMO reflects multidecadal North Atlantic sea-surface temperature anomalies that influence rainfall across North America, Europe, and North Africa (World Climate Service, 2021), while the AMM captures interannual tropical Atlantic variability sustained by a wind–evaporation–sea surface temperature feedback in which wind anomalies lead sea-surface temperature anomalies by approximately two months (Xia et al., 2023). The NAO quantifies the sea-level pressure gradient between the Icelandic Low and Azores High (Abdelkader & Yerdelen, 2022), and the PDO describes decadal-scale sea-surface temperature variability in the North Pacific north of 20°N (Fan et al., 2024).

Data Analysis

Wavelet coherence was used to quantify the localized correlation between each climate index and precipitation in time–frequency space (Grinsted et al., 2004). For two time series x and y, the wavelet coherence coefficient is defined as

$$R^2(\alpha,\tau) = \frac{\left|S(\alpha^{-1}W_{xy}(\alpha,\tau))\right|^2}{\left[S(\alpha^{-1}|W_x(\alpha,\tau)|^2)\cdot S(\alpha^{-1}\left|W_y(\alpha,\tau)\right|^2)\right]} \qquad (1)$$

where $R^2(\alpha, \tau)$ ranges from 0 (no coherence) to 1 (perfect coherence), α is the wavelet scale, τ is the localized time index, $W_{xy}(\alpha, \tau)$ is the cross-wavelet transform of the precipitation and index series, W_x and W_y are their individual wavelet transforms, and S is a smoothing operator applied in both scale and time to produce a consistent, non-degenerate coherence estimate (Grinsted et al., 2004; Torrence & Compo, 1998). Statistical significance of coherence was assessed against a red-noise background using Monte Carlo methods, and the cone of influence the region affected by edge effects was computed and excluded from interpretation in all wavelet plots. The phase relationship between each index and precipitation was recovered from the argument of the cross-wavelet transform and is displayed as arrows on the coherence plots: arrows pointing right indicate an in-phase relationship, arrows pointing left indicate an anti-phase (inverse) relationship, and arrows pointing up or down indicate intermediate lead–lag relationships. All wavelet computations were performed using the MATLAB implementation of Grinsted et al. (2004), employing the Morlet wavelet as the analyzing basis function throughout, consistent with standard practice for geophysical time series (Torrence & Compo, 1998). The ERA5 reanalysis and climate index records used in this study contained no missing values over the 1961–2021 period, so no gap-filling procedure was required. Within each climatic zone, the five sampling locations were selected to represent the zone's geographic extent as delineated by Ragatoa et al. (2019), spanning its latitudinal and longitudinal range.

To complement the time–frequency analysis, Pearson correlation coefficients between each climate index and monthly precipitation were computed across all twenty-five observation points. The spatial structure of these correlation fields was interpolated and mapped across Nigeria using Ordinary Kriging with a spherical semivariogram model implemented in ArcGIS 10.8 (Geostatistical Analyst). Semivariogram parameters (nugget, sill, and range) were fitted using weighted least squares, and interpolation accuracy was assessed via leave-one-out cross-validation (evaluating root-mean-square standardized error) to ensure reliable continuous surface representation across the five climatic zones, allowing the geographic pattern of each index's influence to be examined independently of the temporal wavelet analysis.

RESULTS AND DISCUSSION

Wavelet Coherence Between Precipitation and Climate Indices

Wavelet coherence was computed between precipitation and each of the six climate indices at every location, grouped by climatic zone. Across all five zones, the AMM showed the most extensive and consistent coherence with precipitation, concentrated in a frequency band corresponding to an approximately annual periodicity (normalized frequency 0.0625–0.125) and, more weakly, at longer periods (frequency 0.0078–0.0156). Figure 2 illustrates this pattern for the Sahel zone, where strong, statistically significant coherence recurs at the same time–frequency locations across all sampled sites, with arrows indicating a consistent phase relationship. The AMO and NAO showed comparatively intermittent coherence with precipitation: both indices exhibited episodes of significant coherence, generally with a mixed or antiphase relationship, but these episodes were shorter-lived and less consistent across locations within a zone than those found for the AMM. The Niño 3.4 index showed generally weak coherence with precipitation in the Sahel, Guinea, and Sudan zones, but a distinct anti-phase coherence band emerged in the tropical rainforest zone at the 2–8-year period (Figure 3), consistent with the interannual time scale of ENSO. The PDO produced episodic, zone-dependent coherence in-phase in the coastal, Guinea and tropical zones and anti-phase in the Sahel and Sudan zones while the SOI showed the weakest and most spatially inconsistent coherence of the six indices, with significant bands confined to short segments of the record in the coastal and tropical zones only. A synthesis of the dominant coherence characteristics for each index is given in Table 1.

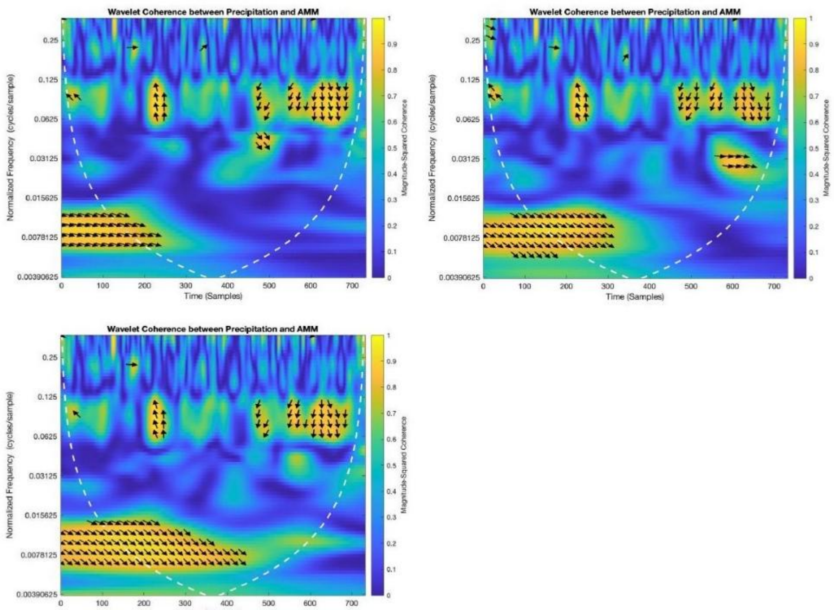

Figure 2: Wavelet Coherence Between Precipitation and the Atlantic Meridional Mode (AMM) at Three Representative Locations in the Sahel Zone. The Thick Black Contour Encloses Regions of Coherence Significant at the 5% Level Against Red Noise; the Cone of Influence (Shaded/Dashed Curve) Marks the Region Affected by Edge Effects. Arrows Indicate Phase: Right = In-Phase, Left = Anti-Phase, Up/Down = Intermediate Lead–Lag

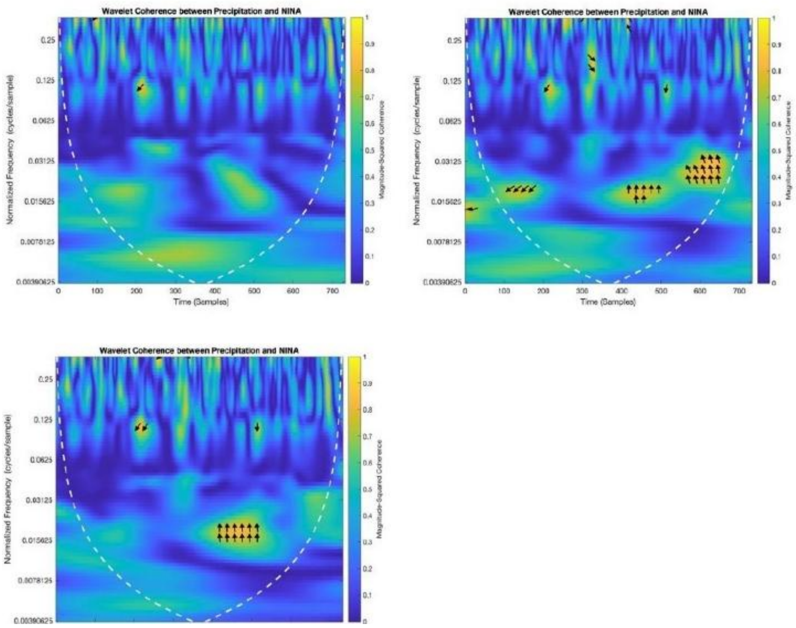

Figure 3: Wavelet Coherence Between Precipitation and the Niño 3.4 Index (NINA) at Three Representative Locations in the Sahel Zone, Shown for Comparison with Figure 2. Coherence with NINA is Markedly Weaker and Less Consistent than with the AMM at these Same Locations

Table 1: Summary of Wavelet Coherence Characteristics Between Precipitation and Each Climate Index Across Nigeria's Climatic Zones

Index	**Dominant coherence band**	**Consistency across zones**	**Zone(s) of strongest coherence**	**Dominant phase relationship**
AMM	~0.0625–0.125 (annual); weaker at 0.0078–0.0156	High — present in all five zones	All zones, most extensive in Sahel and Sudan	Consistent within zone; in-phase to mixed
AMO	0.0078–0.0156 and 0.0625–0.125 (episodic)	Low — short-lived, location-dependent	Coastal and Guinea (partial)	Mixed / anti-phase
NAO	0.0625–0.25 (episodic)	Low — sign and timing vary by zone	Sahel (uniform but alternating)	Antiphase in Guinea, Sudan, Tropical
NINA (Niño 3.4)	0.0156–0.0625 (2–8 yr, ENSO band)	Moderate — concentrated in one zone	Tropical rainforest	Anti-phase
PDO	0.0625–0.125 (episodic)	Moderate — zone-dependent sign	Sahel/Sudan (anti-phase); Coastal/Guinea/Tropical (in-phase)	Zone-dependent
SOI	0.0156–0.0625 (short segments)	Very low	Coastal and Tropical (partial)	Weak / inconsistent

These results are consistent with, and extend, prior wavelet-based evidence from the region. Diatta et al. (2020) similarly found that Atlantic-basin teleconnections dominate West African rainfall at multi-decadal to interannual scales, in contrast to the shorter intraseasonal influence of the Madden–Julian Oscillation, matching the broad, persistent AMM coherence found here. The comparatively weak and inconsistent NAO coherence contrasts with the strong NAO–rainfall coupling reported for North Africa by Khedimallah et al. (2020) and for Europe by Tsanis and Tapoglou (2018) and Tatli and Menteş (2019), suggesting that the NAO's influence weakens and becomes less spatially coherent as its Atlantic-sector signal propagates toward tropical West Africa; this is consistent with the seasonally restricted NAO influence on south-eastern Nigerian rainfall reported by Okorie (2021). The concentration of Niño 3.4 coherence in the tropical rainforest zone, and its anti-phase relationship with precipitation, corroborates Umar and Kehinde (2020), who linked El Niño phases to drier conditions in southern Nigeria via warm Atlantic sea-surface temperature anomalies, and is broadly consistent with the region-specific ENSO teleconnection patterns described for West Africa by Emmanuel (2022).

3.2 Spatial distribution of precipitation–index correlation

The spatial pattern of the precipitation–index correlation, obtained through kriging interpolation of the pointwise Pearson correlations, is shown in Figures 4–9 and summarized in Table 2. The AMM (Figure 7) and AMO (Figure 8) both show a similar spatial signature: correlation with precipitation is negative across most of the country and strengthens toward the southern coastline, particularly in the south-west, while weakening and in places reversing sign — toward the northern Sahel. The NAO (Figure 5) shows the same south-to-north weakening of its (negative) correlation with precipitation, with the strongest negative influence confined to the coastal and part of the tropical rainforest zone and negligible influence in the far north. The Niño 3.4 index (Figure 9) shows uniformly negative correlations at every location, but with a distinct south–north gradient of increasingly negative values toward the southern coastline, indicating that ENSO's association with increased rainfall in southern West Africa is strongest along the coast and weakens inland. The PDO (Figure 6) shows a spatially patchy correlation structure with no clear latitudinal gradient, while the SOI (Figure 4) shows the weakest and most spatially uniform correlation of the six indices, consistent with its minimal role identified in the wavelet analysis.

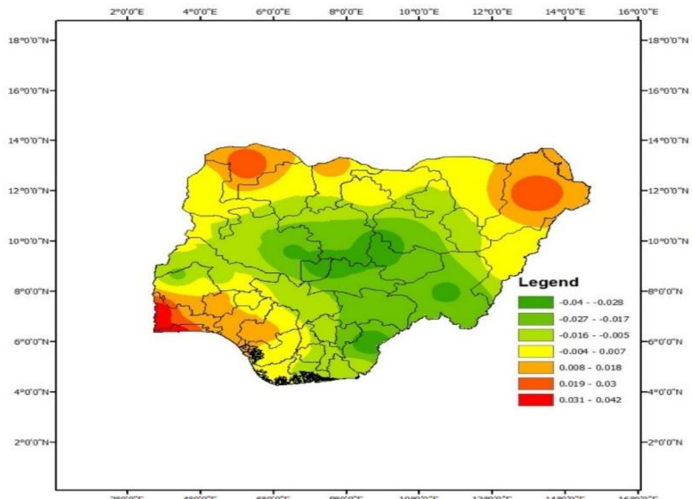

Figure 4: Spatial Correlation Between the Southern Oscillation Index (SOI) and Precipitation Across Nigeria

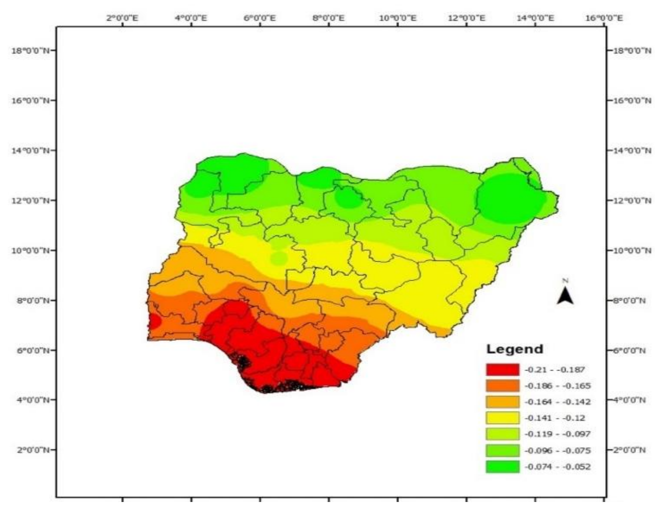

Figure 5: Spatial Correlation Between the North Atlantic Oscillation (NAO) and Precipitation Across Nigeria

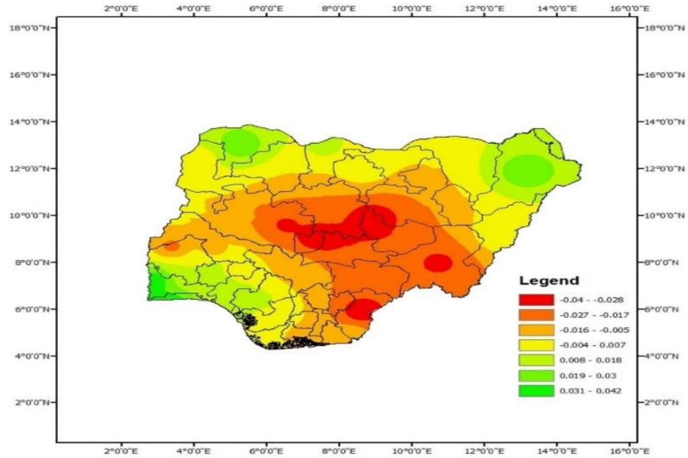

Figure 6: Spatial Correlation Between the Pacific Decadal Oscillation (PDO) and Precipitation Across Nigeria

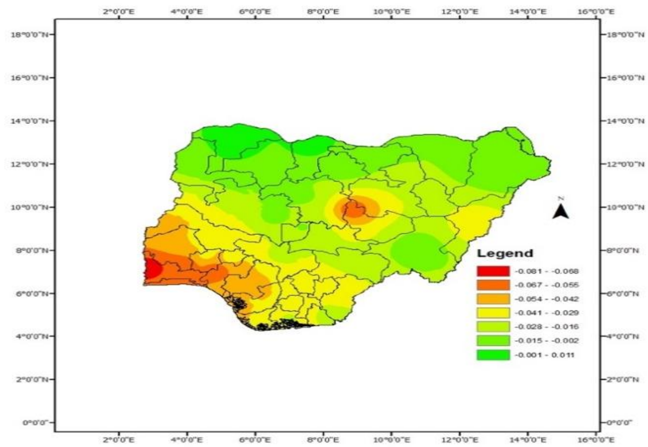

Figure 7: Spatial Correlation Between the Atlantic Meridional Mode (AMM) and Precipitation Across Nigeria

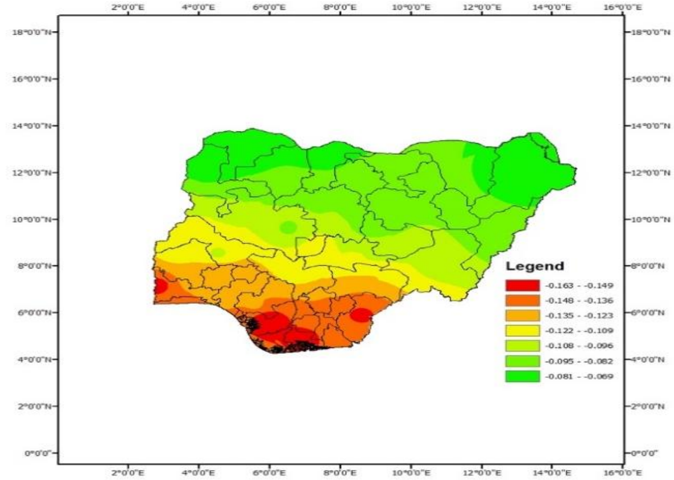

Figure 8: Spatial Correlation Between the Atlantic Multidecadal Oscillation (AMO) and Precipitation Across Nigeria

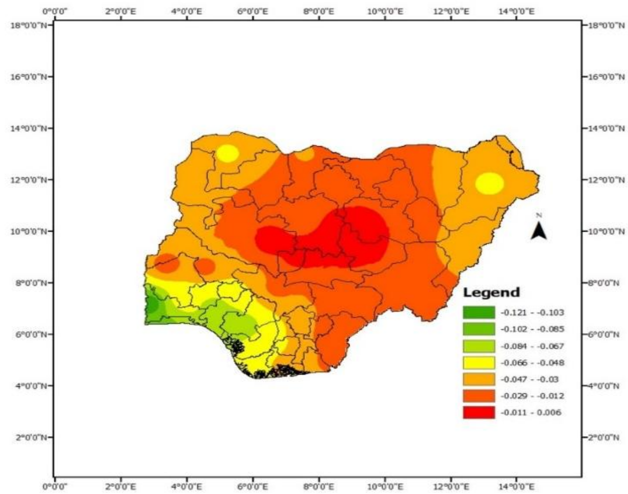

Figure 9: Spatial Correlation Between the Niño 3.4 Index (NINA) and Precipitation Across Nigeria

Table 2: Summary of the Spatial Correlation Structure Between Each Climate Index and Precipitation Across Nigeria

Index	Sign of correlation	Spatial gradient	Zone of strongest influence
SOI	Weak, mixed sign	Minimal — spatially near-uniform	None distinct
NAO	Negative	Strengthens southward	Coastal / tropical rainforest
PDO	Weak, mixed sign	Patchy, no clear gradient	Central Guinea savannah (localized)
AMM	Negative	Strengthens southward	South-west coastal
AMO	Negative	Strengthens southward	South and south-west
NINA (Niño 3.4)	Negative (uniform)	Increasingly negative southward	Southern coastline

Discussion

Mechanisms and Implications

The convergent evidence from the wavelet and spatial analyses the AMM as the most persistent and geographically extensive driver, with AMO and NAO acting as secondary, regionally confined influences and ENSO acting as a coastal-to-tropical modulator is physically consistent with the wind–evaporation–sea surface temperature mechanism through which the AMM operates. Because the AMM is sustained by a positive feedback in which tropical Atlantic wind anomalies precede sea-surface temperature anomalies by about two months (Xia et al., 2023), its influence propagates efficiently into the West African monsoon system and imprints an annual-to-interannual signal on rainfall that is detectable across all of Nigeria's climatic zones, from the Sahel to the coast. The weaker and more spatially confined NAO and AMO signals are consistent with these indices' primary domain of influence lying further north and east, over the North Atlantic and Europe (Lindsey & Dahlman, 2009), such that their imprint on West African rainfall is a secondary, seasonally gated teleconnection rather than a first-order driver. The concentration of ENSO's influence along the southern coastline and in the tropical rainforest zone is consistent with a mechanism operating through Gulf of Guinea sea-surface temperatures and the strength of the West African monsoon flow, which weakens with distance from the coast.

These findings carry direct implications for rainfall prediction and climate adaptation in Nigeria and the wider West African sub-region. Because the AMM shows the most consistent and spatially extensive coherence with precipitation, it represents the most promising single predictor for statistical or hybrid seasonal rainfall forecasts across Nigeria, complementing the extreme-precipitation trend evidence already reported by Dike et al. (2020) and Audu et al. (2021) and the projected rainfall declines in southern and south-eastern Nigeria under future emissions scenarios (Shiru & Park, 2020). The distinct role of ENSO in the tropical rainforest and coastal zones suggests that seasonal forecasts for these areas should give particular weight to Niño 3.4 phase, consistent with the ENSO-linked rainfall decline documented for southern Nigeria by Umar and Kehinde (2020). For agriculture, the wet-season rainfall reductions and drought intensification already documented across northern and central Nigeria (Ogunrinde et al., 2022; Isa et al., 2023) imply that AMM-informed seasonal outlooks could usefully be incorporated into planting-calendar advisories, while the weak and inconsistent PDO and SOI signals found here suggest these two indices offer limited independent predictive value for Nigerian rainfall and should be assigned lower priority in operational forecasting relative to the AMM. More broadly, water resource planning, flood and drought early-warning systems, and climate adaptation strategies for agriculture across Nigeria and West Africa stand to benefit from explicitly incorporating the zone-specific index sensitivities identified here, rather than treating climate-index influence on rainfall as spatially uniform across the country.

CONCLUSION

Wavelet coherence analysis of six climate indices and precipitation across Nigeria's five climatic zones over 1961–2021 identifies the Atlantic Meridional Mode as the dominant driver of Nigerian rainfall variability, showing strong and consistent coherence at near-annual periodicities across every zone examined. The Atlantic Multidecadal Oscillation and North Atlantic Oscillation exert a comparatively minor and intermittent influence, with no consistent effect across cycles or regions. The Niño 3.4 index primarily affects precipitation in the tropical rainforest zone, with strong coherence at the 2–8-year ENSO band, while the Pacific Decadal Oscillation shows sporadic, zone-dependent correlations and the Southern Oscillation Index exerts the weakest influence of the six indices considered. Spatially, the negative influence of the AMM and AMO on rainfall is most pronounced along the southern coastline, NAO correlations are weakest in the northern interior, and the Niño 3.4 index shows a south–north gradient of strengthening negative correlation.

These results support prioritizing the AMM in the development of statistical and hybrid seasonal rainfall prediction models for Nigeria, while recognizing that ENSO phase carries particular relevance for the tropical rainforest and coastal zones. Regional climate models, applied at finer spatial resolution than achieved here, would help resolve the localized mechanisms underlying these teleconnections, and extending the analysis to additional reanalysis and station-based precipitation datasets would help quantify the uncertainty in the correlation estimates reported here. Future work should also examine interactions among the six indices, since compounding or offsetting effects between, for example, the AMM and ENSO could modulate the net rainfall response in ways not captured by single-index coherence analysis. Given the demonstrated influence of the AMM, its incorporation into operational seasonal forecasting, and the communication of AMM-informed outlooks to stakeholders in agriculture, water resource management, and disaster risk reduction, would represent a practical, evidence-based step toward strengthening climate adaptation capacity in Nigeria and the wider West African region.

ACKNOWLEDGEMENT

The authors thank the Department of Physics, Federal University of Technology, Akure, for institutional support during this study.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

SOURCES OF FUNDING

This research received no dedicated external grant funding.

DATA AVAILABILITY STATEMENT

ERA5 precipitation data are freely available from the Copernicus Climate Data Store (https://cds.climate.copernicus.eu). Climate index data are freely available from NOAA's Earth System Research Laboratory (https://psl.noaa.gov) and the Climate Prediction Center (https://www.cpc.ncep.noaa.gov). Derived correlation and coherence outputs are available from the corresponding author upon reasonable request.

REFERENCES

Abdelkader, M., & Yerdelen, C. (2022). Hydrological drought variability and its teleconnections with climate indices. Journal of Hydrology, 605, 127290. https://doi.org/10.1016/j.jhydrol.2021.127290

Adepitan, J. O., & Falayi, E. O. (2019). Variability changes of some climatology parameters of Nigeria using wavelet analysis. Scientific African, 2, e00017. https://doi.org/10.1016/j.sciaf.2018.e00017

Audu, M. O., Ejembi, E., & Igbawua, T. (2021). Assessment of spatial distribution and temporal trends of precipitation and its extremes over Nigeria. American Journal of Climate Change, 10(3), 331–352. https://doi.org/10.4236/ajcc.2021.103016

Baidu, M., Amekudzi, L. K., Aryee, J. N. A., & Annor, T. (2017). Assessment of long-term spatio-temporal rainfall variability over Ghana using wavelet analysis. Climate, 5(2), 30. https://doi.org/10.3390/cli5020030

Diatta, S., Diedhiou, C. W., Dione, D. M., & Sambou, S. (2020). Spatial variation and trend of extreme precipitation in West Africa and teleconnections with remote indices. Atmosphere, 11(9), 999. https://doi.org/10.3390/atmos11090999

Dike, V. N., Lin, Z. H., & Ibe, C. C. (2020). Intensification of summer rainfall extremes over Nigeria during recent decades. Atmosphere, 11(10), 1084. https://doi.org/10.3390/atmos11101084

Emmanuel, I. (2022). Linkages between El Niño-Southern Oscillation (ENSO) and precipitation in West Africa regions. Arabian Journal of Geosciences, 15, 623. https://doi.org/10.1007/s12517-022-09942-2

Enfield, D. B., Mestas-Nuñez, A. M., & Trimble, P. J. (2001). The Atlantic Multidecadal Oscillation and its relationship to rainfall and river flows in the continental U.S. Geophysical Research Letters, 28(10), 2077–2080. https://doi.org/10.1029/2000GL012745

Fan, L., Wang, Y., Cao, C., & Chen, W. (2024). Teleconnections of atmospheric circulations to meteorological drought in the Lancang–Mekong River Basin. Atmosphere, 15(1), 89. https://doi.org/10.3390/atmos15010089

Gbode, I. E., Adeyeri, O. E., Menang, K. P., Intsiful, J. D. K., Ajayi, V. O., Omotosho, J. A., & Akinsanola, A. A. (2019). Observed changes in climate extremes in Nigeria. Meteorological Applications, 26(4), 642–654. https://doi.org/10.1002/met.1791

Grinsted, A., Moore, J. C., & Jevrejeva, S. (2004). Application of the cross wavelet transform and wavelet coherence to geophysical time series. Nonlinear Processes in Geophysics, 11(5–6), 561–566. https://doi.org/10.5194/npg-11-561-2004

Ibebuchi, C. C., & Abu, I.-O. (2023). Rainfall variability patterns in Nigeria during the rainy season. Scientific Reports, 13, 8914. https://doi.org/10.1038/s41598-023-34970-7

Isa, Z., Sawa, B. A., Abdussalam, A. F., Ibrahim, M., Babati, A. H., Baba, B. M., & Ugya, A. Y. (2023). Impact of climate change on climate extreme indices in Kaduna River basin, Nigeria. Environmental Science and Pollution Research, 30(31), 77689–77712. https://doi.org/10.1007/s11356-023-27821-5

Khedimallah, A., Meddi, M., & Mahé, G. (2020). Characterization of the interannual variability of precipitation and runoff in the Cheliff and Medjerda basins (Algeria). Journal of Earth System Science, 129, 55. https://doi.org/10.1007/s12040-020-01385-1

Li, J., Garshick, E., Huang, S., & Koutrakis, P. (2021). Impacts of El Niño-Southern Oscillation on surface dust levels across the world during 1982–2019. Science of the Total Environment, 769, 144566. https://doi.org/10.1016/j.scitotenv.2020.144566

Lindsey, R., & Dahlman, L. (2009, August 30). Climate variability: North Atlantic Oscillation. NOAA Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-variability-north-atlantic-oscillation

Loua, R. T., Bencherif, H., Mbatha, N., Bègue, N., Hauchecorne, A., Bamba, Z., & Sivakumar, V. (2019). Study on temporal variations of surface temperature and rainfall at Conakry airport, Guinea: 1960–2016. Climate, 7(7), 93. https://doi.org/10.3390/cli7070093

Mobolade, T. D., & Pourvahidi, P. (2020). Bioclimatic approach for climate classification of Nigeria. Sustainability, 12(10), 4192. https://doi.org/10.3390/su12104192

Ogunrinde, A. T., Oguntunde, P. G., Akinwumiju, A. S., Fasinmirin, J. T., Olasehinde, D. A., Pham, Q. B., Linh, N. T. T., & Anh, D. T. (2022). Impact of climate change and drought attributes in Nigeria. Atmosphere, 13(11), 1874. https://doi.org/10.3390/atmos13111874

Ojegbile, B. M., Okolie, C. J., Omogunloye, O. G., & Abiodun, O. E. (2023). The dynamics of ERA5 and GNSS-derived precipitable water vapour in the climatic zones of Nigeria. Nigerian Journal of Environmental Sciences and Technology, 7(2), 372–394. https://doi.org/10.36263/nijest.2023.02.0429

Okorie, F. C. (2021). North Atlantic Oscillation and rainfall variability in south-eastern Nigeria: A statistical analysis of a 30-year period. Journal of Atmospheric Science Research, 4(4). https://doi.org/10.30564/jasr.v4i4.3843

Ragatoa, D. S., Ogunjobi, K. O., Klutse, N. A. B., Okhimamhe, A. A., & Eichie, J. O. (2019). A change comparison of heat wave aspects in climatic zones of Nigeria. Environmental Earth Sciences, 78, 130. https://doi.org/10.1007/s12665-019-8112-8

Shi, L., Zhang, J., Yao, F., Zhang, D., & Guo, H. (2020). Temporal variation of dust emissions in dust sources over Central Asia in recent decades and the climate linkages. Atmospheric Environment, 222, 117176. https://doi.org/10.1016/j.atmosenv.2019.117176

Shiru, M. S., & Park, I. (2020). Comparison of ensemble projections of rainfall from four bias correction methods over Nigeria. Water, 12(11), 3044. https://doi.org/10.3390/w12113044

Tatli, H., & Menteş, Ş. S. (2019). Detrended cross-correlation patterns between North Atlantic oscillation and precipitation. Theoretical and Applied Climatology, 138(1–2), 387–397. https://doi.org/10.1007/s00704-019-02827-7

Torrence, C., & Compo, G. P. (1998). A practical guide to wavelet analysis. Bulletin of the American Meteorological Society, 79(1), 61–78. https://doi.org/10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2

Tsanis, I., & Tapoglou, E. (2018). Winter North Atlantic Oscillation impact on European precipitation and drought under climate change. Theoretical and Applied Climatology, 135(1–2), 323–330. https://doi.org/10.1007/s00704-018-2379-7

Umar, A. T., & Kehinde, M. O. (2020). Relationship of El Niño/Southern Oscillation to rainfall patterns in Nigeria. FUDMA Journal of Sciences, 4(2).

World Bank Climate Change Knowledge Portal. (2021). Nigeria climate data: Historical. https://climateknowledgeportal.worldbank.org/country/nigeria/climate-data-historical

World Climate Service. (2021, October 11). What is the Atlantic Multi-decadal Oscillation? https://www.worldclimateservice.com/2021/10/11/atlantic-multi-decadal-oscillation/

Xia, F., Zuo, J., Sun, C., & Liu, A. (2023). The Atlantic Meridional Mode and associated wind–SST relationship in the CMIP6 models. Atmosphere, 14(2), 359. https://doi.org/10.3390/atmos14020359

Xu, J. (2018). Wavelet regression: An approach for undertaking multi-time scale analyses of hydro-climate relationships. MethodsX, 5, 561–568. https://doi.org/10.1016/j.mex.2018.05.005