*FUDMA Journal of Sciences (FJS)*
*ISSN online: 2616-1370*
*ISSN print: 2645 - 2944*
*Vol. 10 No. 23, December, 2026, pp 253 – 259*
*DOI:* https://doi.org/10.33003/fjs-2026-1023-6549

# Hydroclimatic Variability and Near-Surface Soil Moisture Trends at Six Locations in South-South Nigeria, 2000–2025

***[1]Benjamin Evi Idisi, [2]Asiafa James Oscar, [3]Agwor Nicholas Emamezi and [4]Amara Ethel Uzor-Totty**

[1]Department of Environmental Management, Southern Delta University, Ozoro, Delta State, Nigeria.
[2]Department of Building Technology, Southern Delta University, Ozoro, Delta State, Nigeria.
[3]Department of Environmental Management, Southern Delta University, Ozoro, Delta State, Nigeria.
[4]National Root Crops Research Institute, Umudike, Km 8 Umuahia–Ikot Ekpene Road, Umuahia, Abia State, Nigeria.

*Corresponding authors' email: benjamin.idisi86@gmail.com

**Received:** 08 Sept. 2026
**Accepted:** 16 Nov. 2026
**Published:** 16 Nov. 2026

**ABSTRACT**
In this study the monthly and annual 2-m air temperature, precipitation and 0–7 cm volumetric soil moisture were validated for six selected coordinate locations within Akwa Ibom, Bayelsa, Cross River, Delta, Edo and Rivers states in the South-South Nigeria from January 2000 to December 2025. The 1,872 location-month records were retrieved from the Open-Meteo Historical Weather API, with the model ERA5 option. Annual temperature and soil moisture were the mean of the monthly values and annual precipitation was the sum of the monthly totals. Theil–Sen slopes and tie-adjusted Mann–Kendall tests were used, and alternative serial-dependence methods explored as sensitivity analyses. The temperature increased at a rate of 0.0480 °C year$^{-1}$ (conventional p = 1.22 × 10−7) as summarised by the equal weight composite; this is not an area weighted regional estimate and is simply a summary of the six sampled locations. The slope of annual precipitation was positive but not significant (2.85 mm year -1, p = 0.724).The soil-moisture slope was negative −0.000636 m³ m−3 year−1 and significantly negative at conventional Mann–Kendall significance level (p = 0.038) and mixed indications for dependence sensitive procedures. The maximum values of mean temperature (28.40 °C) occurred in February while the maximum values of precipitation (342.33 mm month$^{-1}$) and shallow soil moisture (0.4666 m³ m$^{-3}$) occurred in September. Results show a strong warming signal, no evidence for a monotonic annual precipitation signal, and soil moisture in shallow soils with varying degrees of signal depending on the method used.

**Keywords:** South-South Nigeria, Hydroclimatic Variability, ERA5, Precipitation, Air Temperature, Soil Moisture, Mann–Kendall test, Theil–Sen estimator, Serial Dependence

## INTRODUCTION

Air temperature, precipitation and soil moisture are interrelated, but distinct, aspects of the hydroclimatic system. Precipitation provides the water to the land surface, temperature represents the near surface thermal conditions and shallow soil moisture incorporates the timing of precipitation with infiltration, drainage, evaporation, transpiration and storage in the shallow soil. Their interactions are dependent on the temporal scale and environmental settings, thus the annual rainfall totals cannot be directly used as proxy of soil-water availability (Galvincio et al., 2024; Oguntunde et al., 2017; Xi et al., 2023). South-South Nigeria includes coastal plains and mangroves, freshwater swamps, river floodplains, agricultural landscapes and urban centres in Akwa Ibom, Bayelsa, Cross River, Delta, Edo and Rivers states. Given the same amount of rainfall, the response of the land surface moisture may vary due to soil type, vegetation type, drainage and water-table conditions. In addition to rainfall amounts, the timing and distribution of rainfall are also important, as some sites may experience waterlogging during the wet season but suffer from moisture stress during the dry season (Ayanlade & Howard, 2019; Hassan et al., 2020; Akinbobola et al., 2023). The temperature and precipitation data observed in Nigeria and Niger Delta region have been recorded to be spatially and temporally varying with the estimates varying with location, period of observation, data source, and the method of analysis (Salami et al., 2014; Animashaun et al., 2023; Akinbobola et al., 2023 and Abubakar et al., 2025). In situ soil-moisture measurements that can be collected continuously are still scarce in many wetland and riverine areas. The temporally consistent estimates can be obtained from reanalysis and satellite products, but their performance has been found to depend on the variable definition, land cover and local validation (Gbode et al., 2023; Lal et al., 2022; Thamaga et al., 2022). Temporal serial dependence also needs to be taken into account for trend inference. Estimated trend magnitude, conventional statistical significance and robustness to alternative dependence assumptions should be reported separately, since conventional Mann–Kendall p-values might be miscalibrated if annual observations are autocorrelated. Also, spatial interpretation is of equal importance: each single coordinate for a state is a measure at a sampled point, not an area-weighted state average and the mean of six point series is a summary of sampled points and not an area-weighted estimate for a geopolitical zone.

The dynamics of climate variability and soil-moisture have been previously investigated by the author group in South-South Nigeria during 2000-2020. Idisi et al. (2024a) evaluated regional climate variability and soil-moisture dynamics while Idisi et al. (2025a) assessed hydroclimatic drivers with CHIRPS precipitation, ERA5 temperature, and SMAP/AMSR-E soil-moisture datasets, and Idisi et al. (2025b) presented the temporal soil-moisture trends and associated relationships with precipitation and temperature. The present study differs in: Months within the 2000-2025

timeframe were retrieved through the Open-Meteo Historical Weather API using the ERA5 model option, the six coordinates were explicitly identified, and the present study was focussed on the evaluation of the trend-inference sensitivity for alternative treatments of serial-dependence. These differences apply with respect to the analytical design, and any commonality in source data, code or derived data products should be determined via a direct data-lineage comparison prior to publication. The aim of this research underscores hydroclimatic variability and trends in near-surface soil moisture for six representative locations in South-South Nigeria for the period 2000-2025 and assess the robustness of estimating the trends with two different approaches for dealing with temporal serial dependence.

## Literature Review

### *Hydroclimatic Variability and Soil Moisture*

Temperature is complementary environmental indicator to precipitation and soil moisture. Temperature and rainfall have been reported to vary significantly both spatially and temporally in Nigeria (Edokpa, 2020; Animashaun et al., 2023; Akinbobola et al., 2023; Abubakar et al., 2025). Yearly precipitation amounts can mask shifts in rainfall patterns such as timing, intensity and dry spell duration (Salami et al., 2014). In addition, infiltration, evapotranspiration, vegetation, soil properties and drainage also affect soil moisture, so that the shallow soil-moisture series should not be understood as a direct measurement of agricultural drought and impacts on crops (Oguntunde et al., 2017; Olisa et al., 2023; Xi et al., 2023).

### *Reanalysis Data and Statistical Inference*

Reanalysis products offer a temporally consistent estimate from model data in regions with few station data and the quality of the reanalysis is variable depending on the variable, location and temporal scale. Evaluation of ERA5 data in West Africa reveals strengths and persistent limitations, notably with regards to precipitation extremes and long-term trends (Gbode et al., 2023; Thamaga et al., 2022). The validation results for the ERA5-Land soil-water layers highlighted the lack of independent observations; however, they do not validate the separate point series of Open-Meteo ERA5 used here (Lal et al., 2022; Olisa et al., 2023). In environmental analysis, the trend estimation by Mann–Kendall tests and Theil–Sen slopes has been well established (Mann, 1945; Kendall, 1975; Sen, 1968) and the effects of temporal dependence on trend estimation are adjusted by serial-correlation corrections and/or pre-whitening approaches (Hamed & Rao, 1998; Yue & Wang, 2004).

### *Relationship to Earlier Studies and Research Contribution*

The present study is not the first to assess the hydroclimatic variability or soil moisture in South-South Nigeria. The previous studies by the author group are based on 2000–2020 with varying combinations of gridded precipitation, temperature and soil moisture products (Idisi et al., 2024a, 2025a, 2025b). The current study extends the time series through 2025, details six coordinate-level extractions and pays particular attention to the sensitivity of soil-moisture trend inference to alternative serial-dependence procedures. The comparison is thus not methodological and temporal, but is a claim that the region underlying this topic is not explored. Although not done in this analysis, Peiro et al. (2024) further demonstrates the benefits of combining precipitation and soil-moisture data to map the environment. However, a formal comparison of the source data and the output is still required to show any overlap.

## MATERIALS AND METHODS

### Study Area and Spatial Sampling

The analysis uses one coordinate in each of the six South-South states: Akwa Ibom (5.05° N, 7.93° E), Bayelsa (4.92° N, 6.27° E), Cross River (5.96° N, 8.33° E), Delta (5.53° N, 6.00° E), Edo (6.34° N, 5.63° E) and Rivers (4.85° N, 6.92° E). The coordinates are point extractions and do not necessarily reflect a spatial average for the six states. There are coastal and inland environments, low lying terrain, dense drainage and wetland ecosystem (Hassan et al., 2020).

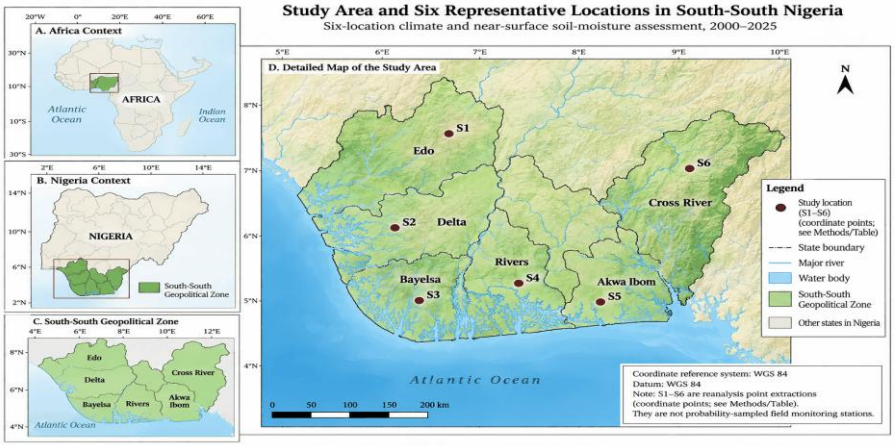



Figure 1: Study-area Context and Six Selected Coordinate Locations in South-South Nigeria

For each variable, the six-location composite was calculated as the unweighted arithmetic mean of the six coordinate-specific annual values. Each sampled point therefore contributes one-sixth of the composite, irrespective of state area, population, coastline length or the number of reanalysis grid cells in a state. The composite is descriptive of the six selected locations and must not be interpreted as a spatially representative or area-weighted estimate for South-South Nigeria.

### Data Source and Variables

The source was found to be the archive endpoint of the Open-Meteo Historical Weather API (https://archive-api.open-meteo.com/v1/archive) and the ERA5 model was explicitly chosen by setting models=era5. Temperature_2m_mean,

precipitation_sum and soil_moisture_0_to_7cm_mean are the documented daily-variable identifiers corresponding to the study variables. The reproducible request is based on latitude and longitude of each point,start_date=2000-01-01,end_date=2025-12-31, daily=temperature_2m_mean,precipitation_sum,soil_moisture_0_to_7cm_mean, models=era5, and timezone=UTC. The six coordinate pairs are given in section 3.1. The Open-Meteo API gives only Daily and Hourly data and does not have a native 312 months series; to this end, monthly data should be calculated by averaging Daily temperature and soil-moisture means data within each calendar month period and by summing Daily precipitation data within each calendar month period. Processed tables for the 312 months have been included in the files submitted, but original full query urls, raw daily API responses, and the extraction times and API response metadata have not. So the request and the monthly aggregation specification above is a reproducible extraction pathway; however the authors have to compare it to the original extraction log and scripts before any claim that they exactly reproduce the original extraction can be made. Data is from the ERA5 output of the Open-Meteo Historical Weather API and not from ERA5-Land. There are 1,872 location-month records (312 months × six locations) in the working dataset. Structural checks indicated that there were 312 monthly records at each location, that there were no missing values in the three target variables, and that the location–month keys were unique. No imputation or gap filling of missing values was done to the working tables accordingly. These checks verify table completeness and not necessarily the accuracy of the reanalysis estimates at the sample locations.

**Temporal Aggregation and Composite Construction**

The 2-m temperature data and soil-moisture data at the top layer (0–7 cm) should be represented by the daily mean value over the calendar month, while the daily precipitation data should be summed to provide the monthly precipitation. The supplied 312-month working tables are described as monthly means for temperature and soil moisture as well as monthly totals for precipitation, but the daily records and the processing scripts are not supplied and the within-month aggregation step could not be re-executed independently. For every site/calendar year, annual air temperature and annual soil moisture (0-7cm) were calculated as the average of the 12 calendar year months. The annual precipitation was computed by adding the 12 months. Thus the monthly climatology was determined by averaging each calendar month of data from the 26-year period at each location, and then averaging the six locations. The composite value for the annual six-location was calculated from the six point values for each variable in each year by taking the unweighted mean. This procedure does not apply spatial interpolation, state-polygon averaging or area weighting and provides equal influence to each selected coordinate. The composite temperature, precipitation and soil-moisture values in 2000 were 26.028 °C, 2,327.43 mm and 0.40916 $m^3$ $m^{-3}$, respectively; corresponding 2025 values were 27.250 °C, 2,523.93 mm and 0.41426 $m^3$ $m^{-3}$. These endpoint contrasts are a descriptive hazard, and should not be used in place of trend estimates. A positive endpoint difference of the soil moisture and a negative Theil–Sen slope might exist as the latter is the median of each pair of annual changes.

**Trend Estimation**

For each annual time series, the magnitude of the monotonic trend was estimated using the Theil–Sen estimator, calculated as the median of all possible pairwise slopes (Sen, 1968):

**Theil–Sen Slope Estimator**

$\beta = \text{median}\ [(y_j - y_i) / (j - i)]$, for all $i < j$

Where $\beta$ represents the estimated annual trend magnitude, $y_i$ and $y_j$ denote the observed annual values at time indices i and j, respectively, and $j - i$ represents the elapsed time between observations.

The statistical significance of monotonic trends was assessed using the Mann–Kendall test (Mann, 1945; Kendall, 1975). The test statistic (S) was calculated as:

**Mann–Kendall Test Statistic**

$S = \Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} \text{sign}\ (y_j - y_i)$

Where n is the number of annual observations, and the sign function is defined as:

Sign $(\theta) = +1$, when $\theta > 0$

Sign $(\theta) = 0$, when $\theta = 0$

Sign $(\theta) = -1$, when $\theta < 0$

Tied observations contributed zero to the Mann–Kendall statistic. The variance of S was adjusted for tied observations using the tie-correction term:

**Tie-Adjusted Variance**

$\text{Var}(S) = [n(n-1)(2n+5) - \Sigma_{k=1}^{g} t_k(t_k - 1)(2t_k + 5)] / 18$

Where g represents the number of groups of tied observations and $t_k$ denotes the number of observations in the kth tied group. A continuity correction of ±1 was applied when standardising S to obtain the Z statistic:

$Z = (S - 1) / \sqrt{\text{Var}(S)}$, when $S > 0$

$Z = 0$, when $S = 0$

$Z = (S + 1) / \sqrt{\text{Var}(S)}$, when $S < 0$

Trend significance was evaluated at the 5% significance level using two-tailed tests. Conventional 95% confidence intervals for the Theil–Sen slope estimates were reported separately and were not adjusted for temporal serial correlation. The submitted analytical records did not identify the software package, version or exact computational algorithm used to derive the slope confidence limits; consequently, these intervals are interpreted as conventionally estimated rather than serial-correlation-adjusted confidence intervals.

**Serial-Dependence Sensitivity Analysis**

The lag-1 autocorrelation of each annual series was used as a measure of serial dependence, as well as comparing conventional Mann–Kendall inference with a number of sensitivity procedures. These included Hamed–Rao-type variance corrections that were based on a significance-selected lag rule, fixed lag 1, and fixed lags 1-3, as well as trend-free pre-whitening (TFPW) and heteroskedasticity-and-autocorrelation-consistent (HAC) regression tests with lag-1 and lag-3 covariance estimates. Variance of the Mann–Kendall statistic is also adjusted for serial dependence by using Hamed–Rao corrections (Hamed & Rao, 1998) and fixed-lag variants test sensitivity to lag specification. TFPW provides an estimated serial component after detrending which helps to avoid removal of part of the trend by the pre-whitening. HAC Inference offers sensitivity checking based on regression, and is not a modified Mann–Kendall test. Lag-selection threshold, autocorrelation estimator, TFPW restoration sequence, HAC kernel and finite-sample correction are not preserved at the code level of the source files. The methods are simply considered to be a sensitivity

profile; no procedure is chosen after the data have been collected because of having the smallest p-value.

**Reproducibility and Data Limitations**

Monthly and annual working tables were inspected for counts of records and missing values in the table and for unique location–month keys. This means that the processed series and statistical output should be archived with the recreated API metadata, the actual scripts for extraction and aggregation, and the statistical code and files to generate the figures. In addition, there is a need for independent comparison with meteorological stations or with in-situ or compatible satellite soil-moisture observations, neither of which was done in this study.

## RESULTS AND DISCUSSION

**Air Temperature**

There is a distinct trend of warming in the 6-location temperature composite of the annual series. The composite temperature Theil–Sen slope was +0.047998 °C year$^{-1}$ (conventional 95% slope interval: +0.036616 to +0.058893 °C year$^{-1}$; conventional tie-adjusted Mann–Kendall p = 1.22 × 10$^{-7}$). The positive trend persisted and was highly significant with the dependence-sensitive procedures reported in Table 1. There was a high degree of persistence in the data as shown by the lag-1 autocorrelation of 0.816. The uniform positive trend and the statistical significance of the trends found in the procedures tested provide a strong indication of a warming tendency in these sampled series, and that is not necessarily due to one single physical reason.

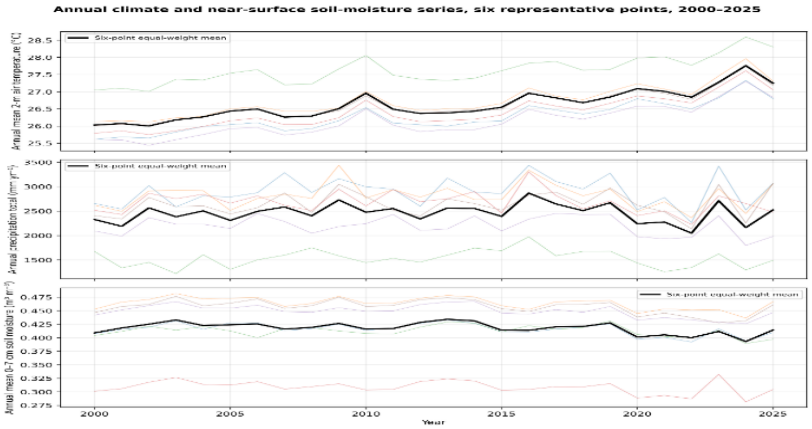



Figure 2: Annual Temperature, Precipitation and 0–7 cm Soil Moisture at the Six Sampled Locations and the Equal-weight Composite, 2000–2025

This positive temperature change is in the same direction as the temperature change in the wider Nigeria as seen by Animashaun et al., (2023) and Edokpa (2020). Urban thermal studies in the Niger Delta also show that there has been a change in the land-surface temperature but satellite land-surface temperature is not the 2-m air temperature, it's not the same variable (Ayanlade & Howard, 2019). When humidity, radiation and wind are similar, warmer air can lead to higher evaporative demand in the atmosphere, but this was not examined here. The observed slope is a statistical description and not one that justifies attributing any individual warming to greenhouse forcing or to urbanisation and/or land-cover change.

**Precipitation**

The composite annual precipitation Theil–Sen slope was +2.853 mm year-1 with a conventional 95% slope interval of -10.139 to +14.542 mm year-1 and a conventional Mann–Kendall p value of 0.724. Monotonous trend was not detected by the Hamed–Rao-style and TFPW and HAC sensitivity tests as well. This does not mean that there was no change in rainfall behaviour, it simply means that a monotonic evolution of the annual totals was not observed. Year-to-year aggregation may mask changes in seasonal distribution, wet season onset, event intensity, extreme rainfall or variability within the year, which can only be seen from monthly/daily analysis. The lack of significant trend in annual precipitation aligns with the spatial variations observed in hydroclimatic studies over Nigeria (Salami et al., 2014, Akinbobola et al., 2023, and Abubakar et al., 2025). These processes are not captured by annual amounts of rainfall, and flood exposure is a function of event rainfall, antecedent wetness, river stage, drainage capacity, and land cover and coastal conditions. Similarly, agricultural water planning needs to be based on information on intra-seasonal rainfall and crop water demand.

**Near-Surface Soil Moisture**

The composite slope (0-7cm) of the soil moisture Theil–Sen trend of the soil moisture was found to be −0.000636 m³ m−3 year−1. The conventional Mann–Kendall test showed nominal level (p = 0.038) and the fixed-lag Hamed–Rao-type tests gave p-values of about 0.081 (lag 1) and 0.066 (lags 1–3). Smaller p-values were obtained when HAC procedures were used instead of TFPW procedures. The spectrum of the results suggests that the interpretation of the results is dependent on how serial dependence is treated. The negative slope is thus described as an estimated tendency towards drying and not evidence of a clear drying trend. The autocorrelation at lag-1 was 0.468. Furthermore, the composite soil-moisture value in 2025 (0.41426 m³ m-³) was higher than the value in 2000 (0.40916 m³ m-³), showing how a fitted median slope and a difference between two endpoints characterizes two different aspects of a non-monotonic series. It is important to recognize that a negative near surface slope alone does not define agricultural drought nor does it provide a causal mechanism. The 0–7 cm horizon is sensitive to recent precipitation, surface evaporation and vegetation uptake while the deeper soil horizons may have varying persistence and seasonal behavior. Together with near-surface products, root-zone products, in-situ probes and crop/vegetation indicators would allow the assessment to be extended to agricultural drought and ecosystem stress.

**Seasonal Climatology**

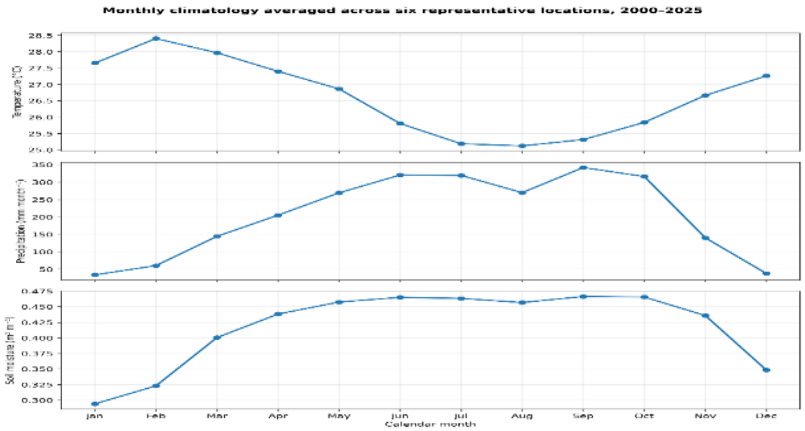



Figure 3: Monthly Climatology of 2-m Air Temperature, Precipitation and Shallow Soil Moisture Across the Six Sampled Locations, 2000–2025

The highest mean temperature occurred in February (28.40 °C) and the lowest in August (25.12 °C). September recorded the highest monthly precipitation (342.33 mm month-1), while the lowest was recorded in January (34.09 mm month-1) with high amount of precipitation in June, July and October. Mean 0–7 cm soil moisture was also highest in September (0.4666 $m^3 m^{-3}$) and lowest in January (0.2941 $m^3 m^{-3}$). Co-seasonality is physically reasonable, but this does not imply that all soil moisture is regulated by precipitation; other factors, such as drainage, soil parameters, vegetation, storage and atmospheric demand also play a role in shallow soil moisture, and were not included as explanatory covariates.

**Spatial Differences and Statistical Sensitivity**

The six sample points had positive temperature slopes (0.0405 to 0.0517 °C year-1). The sign of the precipitation slopes was not consistent and slopes were not statistically significant at the sample points. Slopes for soil-moisture were all negative, but nominal significance as determined by location and the fixed-lag dependence correction weakened for several locations. These are exploratory, point level comparisons that are not state-wide estimates, nor should the multiple location-variable tests be considered independent confirmatory tests. The six coordinates constitute a fixed comparative design but do not adequately capture the variety of environments in the states or through the geopolitical zone. The equal weight composite is not an area weighted spatial mean, but rather each sampled coordinate provides the same contribution. Further limitations of the study include the use of model-derived data, the lack of independent local validation of data, and lack of retention of the metadata and analysis scripts of the API requests. From a management perspective, the results suggest that integrated monitoring of temperature, rainfall and soil moisture might be possible but not the declaration of regional drought. Ideally, future studies should integrate denser spatial sampling, meteorological stations, soil-moisture probes, root-zone measurements, vegetation indicators and event-scale hydrological variables.

**Table 1: Trend Estimates and Serial-Dependence Sensitivity for the Six-Location Equal-Weight Composite. HR = Hamed–Rao-Style Variance Correction; TFPW = Trend-Free Pre-Whitening; HAC = Heteroskedasticity-And-Autocorrelation-Consistent Regression Test. Conventional Sen-Slope Intervals Are Not Serial-Correlation-Adjusted**

| Variable | Sen slope/year | Conventional 95% slope interval | MK p | HR lag 1 p | HR lags 1–3 p | TFPW p | HAC lag 1 p | Raw lag-1 r |
|---|---|---|---|---|---|---|---|---|
| Air temperature | 0.047998 | 0.036616 to 0.058893 | 1.223e-07 | 1.053e-05 | 2.661e-09 | 1.481e-07 | 4.914e-09 | 0.816 |
| Annual precipitation | 2.852632 | -10.139394 to 14.541667 | 0.7243 | 0.6983 | 0.7544 | 0.9814 | 0.9672 | -0.117 |
| 0–7 cm soil moisture | -0.000636 | -0.001168 to -0.000109 | 0.03827 | 0.08075 | 0.0665 | 0.009531 | 0.01909 | 0.468 |

**Table 2: Location-Specific Trend Estimates and Fixed Lag-1 Serial-Dependence Sensitivity Results. Each Location Represents One Coordinate Point**

| Location | Temperature Sen slope (p; HR1 p) | Precipitation Sen slope (p; HR1 p) | Soil-moisture Sen slope (p; HR1 p) |
|---|---|---|---|
| Akwa Ibom | 0.048373 (p=5.89e-08; HR1=1.91e-06) | 8.5188 (p=0.454; HR1=0.33) | -0.00057326 (p=0.0473; HR1=0.0796) |
| Bayelsa | 0.047991 (p=4.6e-08; HR1=2.73e-06) | 2 (p=0.791; HR1=0.776) | -0.00070573 (p=0.0383; HR1=0.0606) |
| Cross River | 0.040463 (p=2.39e-06; HR1=0.000155) | 0.4 (p=0.86; HR1=0.883) | -0.00036132 (p=0.29; HR1=0.392) |
| Delta | 0.051098 (p=2.78e-08; HR1=4.22e-06) | -7.5714 (p=0.27; HR1=0.218) | -0.00062531 (p=0.113; HR1=0.0563) |
| Edo | 0.051738 (p=7.53e-08; HR1=1.29e-05) | -4.476 (p=0.508; HR1=0.539) | -0.00091329 (p=0.0106; HR1=0.0406) |
| Rivers | 0.045266 (p=4.6e-08; HR1=1.66e-06) | 9.4778 (p=0.252; HR1=0.114) | -0.00076377 (p=0.058; HR1=0.124) |

**CONCLUSION**

The study analyzed the temperature, precipitation and soil moisture (0–7 cm) of six selected points in South-South Nigeria from 2000 to 2025 with monthly data sourced from reanalysis data through the application of non-parametric trend analysis techniques. Results show a strong positive temperature trend at about 0.048°C/year, but no statistically significant monotonic trend in annual precipitation and soil moisture trends that are either negative and may or may not be statistically significant, depending on how serial

dependence is handled. There are also indications from seasonal analysis that maximum temperature is experienced in February and maximum precipitation and shallow soil moisture in September. The results offer valuable information on hydroclimatic changes, but are constrained by the availability of only six point locations, were based on the model, and were not independently validated and have uncertainty in the soil-moisture trend interpretation. Future studies should include more detailed spatial sampling, other meteorological and soil moisture data, root-zone measurements, and other hydrological parameters. Environmental-management agencies should implement an integrated system of climate and soil-moisture monitoring and avoid drawing inferences about the regional drought or causes of drought without supporting data.

**REFERENCES**

Abubakar, M. L., Ahmed, M. S., Ashiru, U.-K. A., Ahmed, M., Mohammed, R. Z., & Abdussalam, A. F. (2025). Assessment of spatiotemporal rainfall variability over the Niger Delta region, Nigeria: Implications for water resource management. *Hydrological Sciences Journal*, *70*(10), 1571–1584. https://doi.org/10.1080/02626667.2025.2496279

Akinbobola, A., Lawal, K. A., & Ologunorisa, T. E. (2023). Spatiotemporal variability of rainfall as an evidence of changing climate over the Nigerian Niger Delta. *Ghana Journal of Geography*, *15*(2), 212–238. https://doi.org/10.4314/gjg.v15i2.9

Animashaun, I. M., Oguntunde, P. G., Olubanjo, O. O., & Akinwumiju, A. S. (2023). *Analysis of variations and trends of temperature over Niger central hydrological area, Nigeria, 1911*–2015. Physics and Chemistry of the Earth, Parts A/B/C, 131, Article 103445. https://doi.org/10.1016/j.pce.2023.103445

Ayanlade, A., & Howard, M. T. (2019). Land surface temperature and heat fluxes over three cities in Niger Delta. *Journal of African Earth Sciences*, *151*, 54–66. https://doi.org/10.1016/j.jafrearsci.2018.11.027

Edokpa, D. A. (2020). Variability in the long-term trends of rainfall and temperature over southern Nigeria. *Journal of Geography, Meteorology and Environment*, *3*(1), 15–41.

Galvincio, J. D., de Queiroga Miranda, R., & da Luz, G. G. (2024). Use of soil moisture as an indicator of climate change in the SUPer system. *Hydrology*, *11*(5), Article 65. https://doi.org/10.3390/hydrology11050065

Gbode, I. E., Babalola, T. E., Diro, G. T., & Intsiful, J. D. (2023). Assessment of ERA5 and ERA-Interim in reproducing mean and extreme climates over West Africa. *Advances in Atmospheric Sciences*, *40*(4), 570–586. https://doi.org/10.1007/s00376-022-2161-8

Hamed, K. H., & Rao, A. R. (1998). A modified Mann–Kendall trend test for autocorrelated data. *Journal of Hydrology*, *204*(1–4), 182–196. https://doi.org/10.1016/S0022-1694(97)00125-X

Hassan, I., Kalin, R. M., Aladejana, J. A., & White, C. J. (2020). Potential impacts of climate change on extreme weather events in the Niger Delta part of Nigeria. *Hydrology*, *7*(1), Article 19. https://doi.org/10.3390/hydrology7010019

Idisi, B. E., Deekor, T. N., & Lawal, O. (2024a). Climate variability and soil moisture dynamics in the South-South region of Nigeria. *International Journal of Advanced Academic Research*, *10*(11), 1–18. https://doi.org/10.5281/zenodo.14193268

Idisi, B. E., Ogbereyivwe, O., & Ogbevire, E. (2025a). Hydroclimatic drivers of soil moisture decline in South-South Nigeria: Implications for sustainable agriculture. *Frontiers in Sustainable Science and Technology*, *2*(2), 68–85. https://doi.org/10.69930/fsst.v2i2.560

Idisi, B. E., Essaghah, A. E. A., & Lawal, O. (2025b). Temporal trends in soil moisture and their linkages to precipitation and temperature variability in South-South Nigeria. *Nigeria Journal of Oil, Gas and Engineering Technology Research*, *3*(1), 88–122. https://nijoget.org/img/zuma.pdf

Kendall, M. G. (1975). *Rank correlation methods* (4th ed.). Charles Griffin.

Lal, P., Singh, G., Das, N. N., Colliander, A., & Entekhabi, D. (2022). Assessment of ERA5-Land volumetric soil water layer product using in situ and SMAP soil moisture observations. *IEEE Geoscience and Remote Sensing Letters*, *19*, 1–5. https://doi.org/10.1109/LGRS.2022.3223985

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica*, *13*(3), 245–259. https://doi.org/10.2307/1907187

Oguntunde, P. G., Lischeid, G., Abiodun, B. J., & Dietrich, O. (2017). Analysis of long-term dry and wet conditions over Nigeria. *International Journal of Climatology*, *37*(9), 3577–3586. https://doi.org/10.1002/joc.4938

Olisa, C. O., Akinloye, K. F., Idisi, E. B., & Eludoyin, O. S. (2023). Comparative assessment of physicochemical properties of soil in different ecological zones of Western Niger Delta, Nigeria. *Scholarly Journal of Science and Technology Research & Development*, *2*(6), 1–19. https://www.ijaar.org/articles/sjstrd/v2n6/sjstrd262.pdf

Open-Meteo. (n.d.). Historical weather API documentation. https://open-meteo.com/en/docs/historical-weather-api

Peiro, Y., Volpe, E., Ciabatta, L., & Cattoni, E. (2024). High-resolution precipitation and soil moisture data integration for landslide susceptibility mapping. *Geosciences*, *14*(12), Article 330. https://doi.org/10.3390/geosciences14120330

Salami, A. W., Mohammed, A. A., Abdulmalik, Z. H., & Olanlokun, O. K. (2014). Trend analysis of hydro-meteorological variables using the Mann–Kendall trend test: Application to the Niger River and the Benue sub-basins in Nigeria. *International Journal of Technology*, *5*(2), 100–110. https://doi.org/10.14716/ijtech.v5i2.406

Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, *63*(324), 1379–1389. https://doi.org/10.1080/01621459.1968.10480934

Thamaga, K. H., Dube, T., & Shoko, C. (2022). Advances in satellite remote sensing of the wetland ecosystems in Sub-

Saharan Africa. *Geocarto International*, *37*(20), 5891–5913. https://doi.org/10.1080/10106049.2021.1926552

Xi, X., Zhuang, Q., Kim, S., & Gentine, P. (2023). Evaluating the effects of precipitation and evapotranspiration on soil moisture variability within CMIP5 using SMAP and ERA5 data. *Water Resources Research*, *59*(5), Article e2022WR034225. https://doi.org/10.1029/2022WR034225

Yue, S., & Wang, C. Y. (2004). The Mann–Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resources Management*, *18*, 201–218. https://doi.org/10.1023/B:WARM.0000043140.61082.60

©2026 This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International license viewed via https://creativecommons.org/licenses/by/4.0/ which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is cited appropriately.