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Hydroclimatic Variability and Near-Surface Soil Moisture in South-South Nigeria: An ERA5-Land Assessment of Selected Years, 2000–2020

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ABSTRACT
Soil moisture is an essential part of the hydrological cycle and connects the atmospheric forcing with the land-surface processes and influences the agricultural productivity, wetland functioning and environmental resilience. This study was conducted to assess the spatial and temporal trends of near surface air temperature, daily precipitation and top layer (0–7cm) volumetric soil moisture across South South Nigeria using the ERA5-Land Hourly reanalysis dataset and zonal statistics in Geographic information system (GIS) for 08 selected reference years (2000, 2003, 2006, 2009, 2012, 2015, 2017 and 2020). One metre of total precipitation per hour was converted into millimetres and then the daily rainfall depth (mm day-1) was calculated and averaged annually over the reference years before values were aggregated. The regional mean air temperature for each sampled year ranged from 24.68 °C in 2012 to 25.48 °C in 2020 and the difference between the first and last years is +0.75 °C (+3.03%). Inter-sample fluctuations in mean daily precipitation were large with no consistent direction (with a maximum in 2015 of 4.18 mm day^{-1}, and a minimum in 2020 of 3.31 mm day–1 compared to 2000 of 3.42 mm day–1, giving an endpoint difference of −3.22%). Modelled mean top-layer soil moisture rose from 0.315 m^3/m^3 in 2000 to 0.325 m^3/m^3 in 2009 and 2012 before declining to 0.305 m^3/m^3 in 2020 (−6.15% relative to the peak).

INTRODUCTION

The effects of climate variability, and the modification of land-surface conditions, are key issues in environmental management, especially in low-lying deltaic areas where water availability, ecological stability and human livelihoods are all closely linked. These coupled dynamics are complemented by near-surface air temperature, precipitation and soil moisture as complementary hydroclimatic indicators: air temperature controls the exchange of energy with the atmosphere and evaporative demand, precipitation provides meteoric water to the land surface, and soil moisture represents the balance between water inputs, drainage losses, and pore-water storage in the upper soil profile (Muñoz-Sabater et al., 2021; Xi et al., 2023). Analysis of these three variables together gives a more diagnostic base to assess land-surface environmental conditions than analysis of any individual climatic parameter alone. Soil moisture plays a critical role in the atmosphere–land interaction by controlling infiltration and surface runoff generation, evapotranspiration, water uptake by plants, and the partitioning of available surface energy into sensible and latent heat fluxes (Xi et al., 2023). Most importantly, soil-water content is not necessarily directly and immediately

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related to the total amount of precipitation. Instead, its spatial and temporal patterns are influenced by rainfall timings, intensities, and frequencies, combined with the atmospheric evaporative demand, vegetation cover, drainage network density, topography, and inherent soil physico-chemical properties (Olisa et al., 2023; Xi et al., 2023). With the Soil Moisture Active Passive (SMAP) and ERA5 observations, Xi et al. (2023) showed that soil-moisture variability is differently influenced by precipitation and evapotranspiration on various time scales, which supports our thinking that considering soil moisture as a variable is essential along thermal and rainfall indicators and not precipitation as a direct proxie of soil-water availability. The South-South geopolitical region of Nigeria comprising of Akwa Ibom, Bayelsa, Cross River, Delta, Edo and Rivers States, accommodates Niger Delta and surrounding coastal plains and is one of the most ecologically diverse and economically important landscape in West Africa. The region is characterised by the presence of barrier islands, mangrove swamps, freshwater swamp forests, wide networks of rivers and creeks, floodplains and fast-growing urban centres, which support agriculture, artisanal and industrial fisheries, hydrocarbon infrastructure and millions of inhabitants (Hassan et al., 2020; Olisa et al., 2023). Olisa et al. (2023) reported significant differences in soil texture, soil organic matter and soil water holding properties within each of the different ecological zones across the Western Niger Delta region, highlighting the influence of soil edaphic heterogeneity on land-surface moisture. At the same time, the region is experiencing a heightened hydro-climatic risk, such as the occurrence of extreme rainfall events, frequent riverine and coastal flood, and thermal anomalies in the urban areas (Akinbobola et al., 2023; Akue et al., 2025; Hassan et al., 2020). The results of the empirical studies carried out in Nigeria reveal the great difference in thermal regime and rainfall between the different ecological zones and the different observation periods, so, physical variables and spatial scales must be distinguished. Animashaun et al., (2023), identified substantial multi-decadal warming trends in long-term station data at the Niger Central Hydrological Area (1911–2015), while spatial heterogeneity in land-surface temperature (LST) and urban heat island intensity (UHI) due to land-cover changes were identified by Ayanlade and Howard (2019) and Akue et al., (2025) in urban remote-sensing assessments at Port Harcourt, Warri, and Benin City. Satellite derived LST however measures radiometric skin temperature which is physically distinct from the air temperature measured at the near surface (2 m) and using both as a proxy to each other can lead to erroneous climate interpretation at a regional scale (Ayanlade & Howard, 2019). Likewise, investigations of precipitations in river sub-basins of Nigeria and the Niger Delta region reveal that the trends are not monotonic at the national level but there are high spatial non-uniformity and interannual variability (Akinbobola et al., 2023; Edokpa et al., 2023; Ibebuchi & Abu, 2023; Salami et al., 2014). Salami et al. (2014) illustrated how non-parametric trend testing was helpful in continuous station series in the Niger and Benue sub-basins, whereas Ibebuchi and Abu (2023) and Akinbobola et al. (2023) highlighted the spatial disparities observed over the Niger Delta under the influence of circulation patterns during the rainy season and localised convective variability. An assessment of the coupled atmospheric and land-surface dynamics in South-South Nigeria is limited by the few monitoring networks of in-situ meteorological and soil-moisture data and their lack of temporal and spatial continuity. To fill this observation gap, modern land-surface reanalysis products assimilate meteorological observations into physically consistent land-surface models to generate a spatially continuous gridded fields. In particular, the high resolution (0.25 ° × 0.25 °) estimates of 2 m air temperature, accumulated precipitation and multi-layer volumetric soil water derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5-Land reanalysis are available in a unified modelling framework (ECMWF, n.d.; Muñoz-Sabater et al., 2021). Reanalysis outputs are not an observationally based field dataset at each grid cell, but rather a model-constrained estimate and therefore independent benchmarking is still important. Lal et al. (2022) compared the ERA5-Land volumetric soil-water estimates with in-situ networks and SMAP retrievals at the global scale, and found that overall it shows good skill in capturing the moisture dynamics at the regional scale, though is sensitive to soil hydraulic parameterisation at the local scale. In addition, continuous improvement in soil data fusion, including the integration of ERA5-Land with observations from SMAP's Level-4 data (Wang et al., 2026), and the creation of long-term soil-moisture products for Africa suitable for drought monitoring (Maidment et al., 2026), further highlights the operational benefits of ERA5-Land and the need for careful definition of the soil-layer depth and validation limits. While there has been increasing research on the climate variability in Nigeria, a knowledge gap exists in the South-South region that is the spatial distribution and multi-year behaviour of near-surface air temperature, daily precipitation and top-layer soil moisture across all six states of Nigeria, in a single, spatially harmonised reanalysis framework. Previous research has been either on a city-by-city basis or on hydrological basins (Akinbobola et al., 2023; Animashaun et al., 2023; Ayanlade & Howard, 2019), or has involved remote sensing vegetation indices to monitor localised petroleum impacted landscapes (Wekpe & Idisi, 2024) or extreme weather projections (Hassan et al., 2020). Beyond this, the present study is based on a spatial and temporal descriptive baseline of zonal distributions and endpoint changes at multi-year intervals with discrete years

between 2000-2020, prior to assuming causal relationships between soil-moisture decline and driver response, as Idisi et al. (2025) did in a companion study.

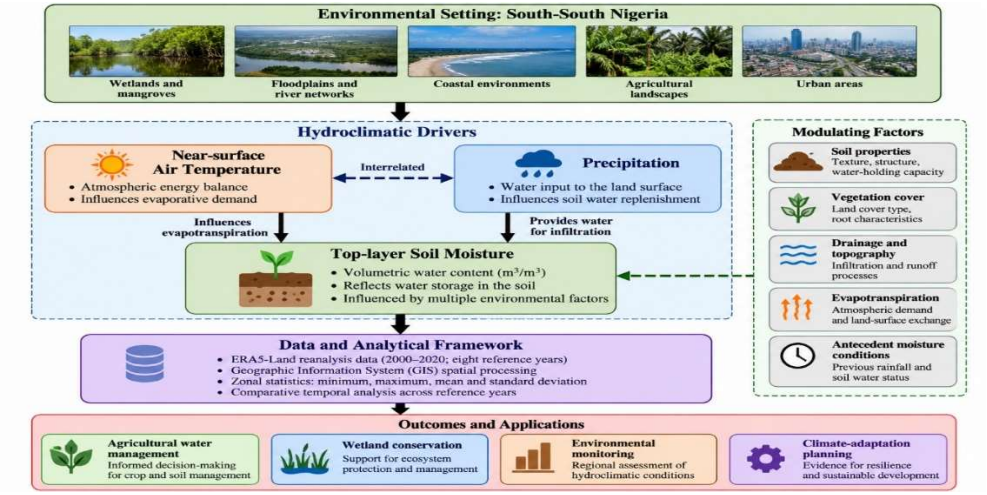


Figure 1. Conceptual framework for the descriptive assessment of hydroclimatic variability and near-surface (0–7 cm) soil moisture across South-South Nigeria. *Source: Authors' conceptualisation, adapted from Muñoz-Sabater et al. (2021) and Xi et al. (2023)*

To organise this descriptive evaluation, the conceptual framework between the atmospheric thermal and precipitation forcing and the top layer volumetric soil moisture over the heterogeneous landscapes of South-South Nigeria is presented in Fig. 1. In this context, near surface air temperature and daily precipitation are complementary hydroclimatic indicators, and top layer (0-7cm) volumetric soil moisture is the near surface Land Surface Water Status that is influenced by edaphic, topographic and vegetative conditions (Muñoz-Sabater et al., 2021; Xi et al., 2023). Significantly, the framework is not a causal attribution model, but is an organisational one used for multi-variable descriptive comparison. The study sought to determine the spatiotemporal variability of near surface air temperature, precipitation and top layer soil moisture in South South Nigeria from 2000-2020 (8 years) using ERA5-Land data.

MATERIALS AND METHOD

Study Area

The study covers the South-South region of Nigeria which comprises of six states namely: Akwa Ibom, Bayelsa, Cross River, Delta, Edo and Rivers. The zone is located on the Atlantic coast of Nigeria stretching from latitudes 4°21'43.2"N to 7°40'52.8"N and longitudes 5°8'42"E to 9°30'7.2"E covering an area of about 84,587 km^2 within and around the Niger Delta basin and the coastal and lowland rainforest zones. The relief is generally low level (most of the deltaic plain has a relief of less than 25 m asl), and is criss-crossed by many rivers, tidal creeks, estuaries, freshwater swamps and coastal mangrove ecosystems which give way to undulating rainforests and highland fringes in northern Edo State and eastern Cross River State. Seasonal migration of Intertropical Discontinuity (ITD) controls the regional climate, resulting in humid tropical monsoonal and equatorial climate with long wet season from March to October (with a short wet season break in August) and short dry season from November to February during the influence of dry continental Harmattan winds. The mean annual rainfall values vary from about 2000 mm in the northern inland areas to more than 4000 mm along the coastal sections in Bayelsa and Rivers States. The hydroclimatic conditions present in the region help to support intensive agriculture, fisheries, wetland biodiversity, petroleum operations and rapidly growing urban settlements making the region highly sensitive to changes in the distribution of rainfall, thermal regime, and near surface soil-water availability (Hassan et al., 2020; Olisa et al., 2023).

Data Extraction, Temporal Sampling, and Variable Preparation

The European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5-Land Hourly reanalysis data (ERA5-Land hourly data from 1950 till present) was accessed from the Copernicus Climate Change Service (C3S) Climate Data Store (CDS) in the format of gridded atmospheric and land-surface fields. The ERA5-Land is the result of forcing the Hydrology-Tiled ECMWF Scheme for Surface Exchanges over Land (HTESSEL) land-surface model with downscaled ERA5 atmospheric fields and it provides physically consistent, spatially continuous environmental estimates at the native horizontal grid resolution of 0.1° × 0.1° (around 9 km × 9 km at tropical

latitudes). The main NetCDF data was downloaded in April 2026 and was pre-processed using Python programming before being extracted spatially and analysed zonally, using ArcGIS 10.5. Three complementary variables were derived and used for analysis: near surface air temperature (temperature_2m), total precipitation (total_precipitation), and upper layer volumetric soil water (volumetric_soil_water_layer_1) with their physical definition and the unit in which they are measured summarized in Table 1.

Table 1: Specifications of ERA5-Land Reanalysis Variables Analysed in the Study

Environmental Variable	ERA5-Land Parameter Name	Physical Definition & Vertical Level	Reported Unit
Near-surface air temperature	*temperature_2m*	Air temperature at 2 m above the land surface	°C
Daily precipitation	*total_precipitation*	Accumulated liquid and frozen water reaching the surface, averaged as daily rainfall depth	mm day^{-1}
Top-layer soil moisture	*volumetric_soil_water_layer_1*	Volumetric water content of the upper 0–7 cm topsoil layer	m^3/m^3

Source: ECMWF ERA5-Land Hourly reanalysis dataset (0.1° × 0.1° native resolution).

Temporal Sampling Design*:* This baseline investigation used a multi-year reference snapshot design with eight individual years of observations within the 21-year observation window (2000, 2003, 2006, 2009, 2012, 2015, 2017 and 2020). This sampling strategy has intervals of a regular 3-year period, and with the inclusion of 2017 to bridge the temporal transition that occurs at the end of the decade between 2015 and 2020, it is a computationally convenient, spatially harmonised regional baseline, consistent with the temporal sampling frame of the authors' larger environmental monitoring programme in South-South Nigeria. Temperature_2m fields, provided in kelvin (T_K), were transformed to degree Celsius (T_°C) with the standard thermodynamic offset relation: T_°C = T_K − 273.15 (1)

Each calendar year, all near-surface air temperature rasters were then averaged together to create annual mean rasters of the near-surface air temperature in the converted hourly layers. Total_precipitation in ERA5-Land Hourly archive corresponds to the amount of liquid and frozen water (rainfall and snow) that has reached the Earth's surface and is expressed as the cumulative depth in metres (P_m) which is accumulated continuously over each 24-hour daily forecast cycle (ECMWF, n.d.). The 24-hour cumulative precipitation depth at the end of each UTC day was extracted and then converted from metres (P_m) to millimetres (P_mm) through linear metric scaling, which leads to physically unambiguous rainfall metrics: P_mm = P_m × 1000 (2)

Daily depths of precipitation (in mm day-1) were then averaged over all the calendar days of each reference year (365 days in non-leap years, 366 days in leap years 2000, 2008/2012 and 2020) to create annual mean daily precipitation rasters. By explicitly specifying the reported metric as annual mean daily rainfall depth (mm day -1), the full physical meaning of the reported values is provided, e.g., the range of reported values between 3.13 and 4.18 mm day -1 is equivalent to an annual mean rainfall depth, averaged over space, of about 1,142 and 1,526 mm year -1 over the six-state domain.

Soil-Layer Vertical Specification: The ERA5-Land product called "volumetric_soil_water_layer_1" (in m^3/m^3) was used to quantify the near-surface soil-water status, which refers to the liquid water volume per m3 of soil in the topsoil (0–7 cm) of the four-layer soil column in HTESSEL (Muñoz-Sabater et al., 2021). Averaging was performed over time for each reference year to provide annual mean topsoil moisture rasters. Layer 1 only resolves the upper 0-7 cm soil horizon and represents moisture dynamics in the upper soil layers, which are influenced by the immediate hydration of the soil by the atmosphere via infiltration and evaporation at the surface, and not water storage in the deeper part of the root zone in layers 2-4 (7-289 cm) (Lal et al., 2022; Maidment et al., 2026).

Spatial Processing, Zonal Statistics, and Validation Disclosure

Data was analyzed and mapped spatially and regionally using ArcGIS version 10.5. The administrative polygon of the South-South geopolitical zone of Nigeria which includes the States of Akwa Ibom, Bayelsa, Cross River, Delta, Edo and Rivers States were downloaded from open-access Nigerian administrative boundary vector datasets from the Nigerian National Population Commission (NPC) and OpenStreetMap. To make the boundary data and the ERA5 Land dataset spatially compatible for the further processing, the data were referenced to a common geographic coordinate reference system, WGS 1984. The annual mean rasters were then clipped by the South-South regional boundary to limit the analysis to the area of the study. Using the Zonal Statistics as Table tool in ArcGIS 10.5, spatial statistics were extracted for the regions. It used an unweighted raster-cell inclusion method, in which all 0.1° × 0.1° grid cells whose centroids were located within the South-South regional boundary were included in the calculations. n is the number of eligible grid cells. Four descriptive spatial statistics were calculated for each hydroclimatic variable for each sampled reference year: the regional minimum, regional maximum, arithmetic spatial mean ($\bar{X}$), and spatial standard deviation (SD).

The arithmetic spatial mean was obtained with the following equation (3):

$\bar{X} = (1/n) \times \Sigma X_i$, for i = 1 to n (3)

The standard deviation of the spatial data was determined by applying Equation (4):

$SD = \sqrt{[(1/n) \times \Sigma (X_i - \bar{X})^2]}$, for i = 1 to n (4)

In the equation, X_i is the annual mean value of the variable in raster grid cell i, $\bar{X}$ is the arithmetic mean of the values in all the included grid cells and n is the number of grid cells whose centroids are in the South-South regional boundaries. Note that the spatial standard deviation presented in this study is not the same as interannual temporal variability.

The SD quantifies the spatial variation of the annual mean values among the grid cells for the study region (all 6 states) for a given reference year. It thus reflects the level of spatial diversity of a variable in the region for a time period, not the changing values of the variable from one year to the next. The relative endpoint percentage change (ΔX%) was computed according to Equation (5) to evaluate the net change from the first sampled reference year (2000) to the last one sampled (2020):

$\Delta X\% = [(X_{2020} - X_{2000}) / X_{2000}] \times 100$ (5)

Where X_{2000} and X_{2020} are the spatial mean for the region for the year 2000 and 2020 respectively.

Percentages are positive when there is an increase in the regional mean between the two sampled years, and negative when there is a decrease in the regional mean. This is a point based measure of relative change and, in itself, cannot determine whether there is a continuous temporal trend or not during that period and what the direction of that trend is or whether its statistical significance exists. Reanalysis Validation Limitation: No synoptic gauge data from the Nigerian Meteorological Agency (NIGMET) and/or satellite soil-moisture retrieval data from the SMAP or SMOS satellites were used to validate the ERA5-Land estimates over the study area. Therefore, all reported values are unvalidated land-surface reanalysis estimates with locally varying accuracy, depending on the accuracy of the ECMWF atmospheric forcing and soil hydraulic parameterisations (Lal et al., 2022; Muñoz-Sabater et al., 2021). The end-to-end analytical workflow is summarised in figure 2, and consists of six stages.

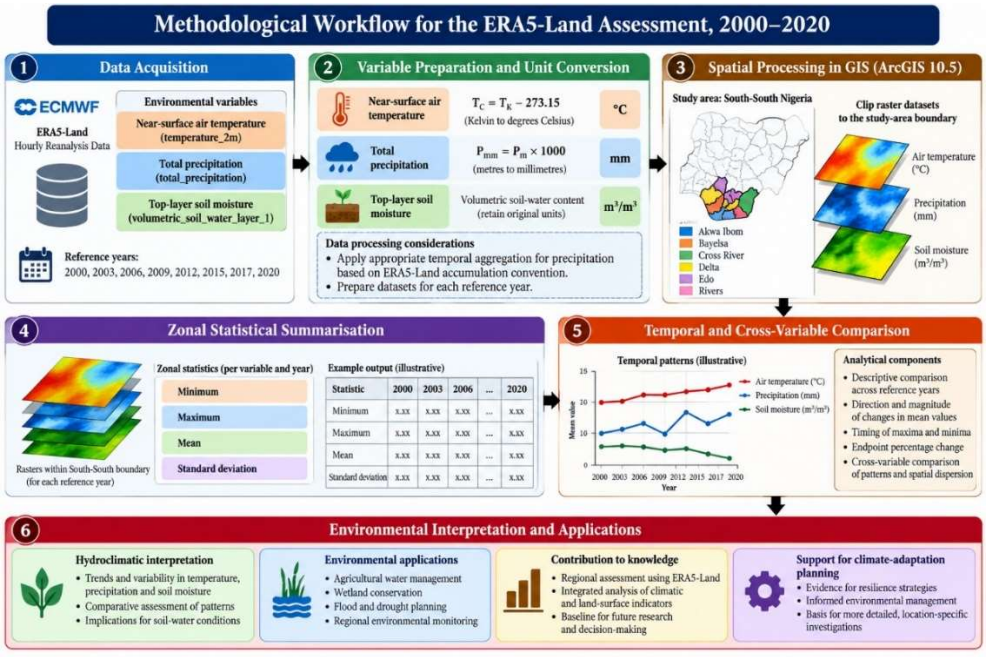


Figure 2: Six-stage methodological workflow for extracting, aggregating, and comparing ERA5-Land hydroclimatic and top-layer soil-moisture variables across South-South Nigeria (2000–2020). *Source: Authors' methodological design (2026)*

RESULTS AND DISCUSSION

Spatiotemporal Variation in Near-Surface Air Temperature

Table 2 shows the regional zonal statistics of the near-surface (2 m) air temperature for the eight sampled reference years. The spatial mean air temperature in the region rose from 24.73 °C in 2000 to 25.48 °C in 2020, a difference of +0.75 °C (or +3.03 % relative to 2000). But, movement through intervening reference years was not monotonic. Mean temperature rose from 24.73 °C in 2000 to 24.97 °C in 2003 and 25.13 °C in 2006, dipped slightly to 25.05 °C in 2009, and reached its lowest sampled value of 24.68 °C in 2012 before increasing successively through 25.03 °C in 2015 and 25.35 °C in 2017 to its peak of 25.48 °C in 2020. Regional cell maxima and minima exhibited parallel trajectories: cell maxima rose from 27.59 °C in 2000 to 28.38 °C in 2020 (with a trough of 27.47 °C in 2012),

while cell minima shifted from 21.87 °C in 2000 to 22.57 °C in 2020.

Table 2. Zonal Summary Statistics for Near-Surface (2 M) Air Temperature (°C) Across South-South Nigeria by Reference Year

Statistic (°C)	2000	2003	2006	2009	2012	2015	2017	2020
Minimum	21.87	22.17	22.28	22.26	21.89	22.19	22.48	22.57
Maximum	27.59	27.77	27.99	27.84	27.47	27.86	28.21	28.38
Spatial Mean	24.73	24.97	25.13	25.05	24.68	25.03	25.35	25.48
Spatial SD	2.86	2.80	2.85	2.79	2.79	2.83	2.87	2.90

Note: Spatial SD denotes spatial standard deviation across grid cells within the South-South zone in each year. Source: Authors' zonal analysis of ERA5-Land Hourly reanalysis data.

Results must be interpreted as either endpoint comparisons (descriptive) or formal statistical trend detection. The increase in the spatial mean in 2020 by +0.75 °C compared with 2000 is in the same direction as the overall warming signal observed over the hydrological basins of Nigeria (Animashaun et al., 2023) and from global ERA5-Land thermal assessments (Muñoz-Sabater et al., 2021), but an endpoint difference over eight non-contiguous reference years is not sufficient to demonstrate a statistically significant long-term warming trend. The interannual synoptic variability in thermal conditions over the Niger region is exemplified by the 2012 cooler anomaly that has been associated with widespread cloudiness and major flood events throughout the Niger basin. Moreover, the spatial SD was very narrow ranging between 2.79 °C in 2009 and 2012 and 2.90 °C in 2020, indicating the relatively consistent geographical thermal gradient between cooler highland margins (Northern Cross River/Edo States) and warmer coastal and urbanised lowlands (Akue et al., 2025; Ayanlade & Howard, 2019). While Ayanlade and Howard (2019) and Nwaerema et al. (2019) found sharper localised warming in Port Harcourt, Warri and Benin City, Ayanlade and Howard (2019) used satellite derived LST and Nwaerema et al. (2019) used satellite-derived air temperatures, both represent urban canopy skin heating, while ERA5-Land 'temperature_2m' represents air temperature smoothed over ~9 km grid cells at 2 m.

Spatiotemporal Variation in Daily Precipitation

The mean daily precipitation showed strong inter-sample variability, but no monotonic directional change (Table 3), unlike the air temperature. Regional mean daily rainfall declined from 3.42 mm day^{-1} in 2000 to 3.13 mm day^{-1} in 2003, rose to 3.57 mm day^{-1} in 2006 and 4.12 mm day^{-1} in 2009, dropped to 3.34 mm day^{-1} in 2012, and peaked at 4.18 mm day^{-1} in 2015 before declining through 3.95 mm day^{-1} in 2017 to 3.31 mm day^{-1} in 2020. The difference between the 2000 and 2020 endpoints is modest (−0.11 mm day −1 or −3.22%) and the large multi-year fluctuations of more than 1.0 mm day −1 between the dry and wet reference years mask this. Grid-cell maxima varied widely from 5.14 mm day^{-1} in 2012 to 7.01 mm day^{-1} in 2015, whereas grid-cell minima ranged between 1.04 mm day^{-1} (2003) and 1.55 mm day^{-1} (2012).

Table 3: Zonal Summary Statistics for Mean Daily Accumulated Precipitation (Mm Day^{-1}) Across South-South Nigeria by Reference Year

Statistic (mm day^{-1})	2000	2003	2006	2009	2012	2015	2017	2020
Minimum	1.45	1.04	1.32	1.35	1.55	1.34	1.22	1.23
Maximum	5.39	5.22	5.82	6.88	5.14	7.01	6.68	5.38
Spatial Mean	3.42	3.13	3.57	4.12	3.34	4.18	3.95	3.31
Spatial SD	0.98	1.05	1.12	1.38	0.90	1.42	1.36	1.05

Note: Precipitation values represent annual averages of 24-hour daily accumulated precipitation (mm day $^{-1}$). Spatial SD reflects across-cell spatial dispersion within each year. Source: Authors' zonal analysis of ERA5-Land Hourly reanalysis data.

The oscillating precipitation regime noted in the sampled years is consistent with regional climatological studies, which have shown that Nigerian rainfall is characterized by high interannual and spatial variability, but a lack of secular trend (Akinbobola et al., 2023; Edokpa et al., 2023; Ibebuchi and Abu, 2023; Salami et al., 2014). Interestingly, the events with the largest spatial mean precipitation (SMPs) also had the largest spatial standard deviations (SSD) and the largest minimum maximum precipitation differences including in 2009 (4.12 mm day−1 with SSD of 1.38 mm day−1), in 2015 (4.18 mm day−1 with SSD of 1.42 mm day−1) and in 2017 (3.95 mm day−1 with SSD of 1.36 mm day−1). The pattern suggests that years with wetter samples were dominated by greater spatial variations with

higher rainfall along the coastal regions (Bayelsa, Rivers and Akwa Ibom) and lower rainfall along the northern inland regions (northern Edo), which align with the coastal to inland moisture gradient observed by Akinbobola et al. (2023) and Ibebuchi and Abu (2023). On the other hand, 2012 had a lower annual mean daily rainfall (3.34 mm day-1) and the lowest spatial dispersion (SD = 0.90 mm day-1) and shows that severe deltaic flooding like the Niger Delta Flood of 2012 can be caused by a high concentration of sub-seasonal storm clusters, as well as elevated annual mean daily precipitation from upstream river discharge (Hassan et al., 2020).

Spatiotemporal Variation in Top-Layer (0–7 cm) Soil Moisture

This study quantifies the spatial and temporal variation in soil moisture in the top layer of the soil (0–7 cm) for georeferenced digital elevation model data. The two phases of description of the modeled top layer (0 to 7 cm) volumetric soil moisture for the sampled years showed a gradual wetting during the initial years followed by lower soil moisture during the last reference years (Table 4). Regional mean soil moisture increased steadily from 0.315 m^3/m^3 in 2000 to 0.320 m^3/m^3 in 2003 and 0.322 m^3/m^3 in 2006, reaching a plateau of 0.325 m^3/m^3 in both 2009 and 2012. Since then, average top-layer soil moisture content has decreased in 2015 and 2017 to 0.315 m3/m3, and to its lowest sampled level in 2020 at 0.305 m3/m3. The 2020 mean represents a net endpoint difference of −0.010 m^3/m^3 (−3.17%) relative to 2000, and a reduction of −0.020 m^3/m^3 (−6.15%) relative to the 2009–2012 peak. The sequence of grid-cell minima was similar, with a rise from 0.170 m^3/m^3 in 2000 to 0.180 m^3/m^3 in the years 2009–2015, and a fall to 0.160 m^3/m^3 in 2020, with grid-cell maxima close to saturation (0.450 to 0.470 m^3/m^3) through all the sampled years.

Table 4: Zonal Summary Statistics for Top-Layer (0–7 Cm) Volumetric Soil Moisture (M^3/M^3) Across South-South Nigeria by Reference Year

Statistic (m^3/m^3)	2000	2003	2006	2009	2012	2015	2017	2020
Minimum	0.170	0.170	0.174	0.180	0.180	0.180	0.170	0.160
Maximum	0.460	0.470	0.470	0.470	0.470	0.450	0.460	0.450
Spatial Mean	0.315	0.320	0.322	0.325	0.325	0.315	0.315	0.305
Spatial SD	0.084	0.087	0.085	0.084	0.084	0.078	0.084	0.084

Note: Values represent ERA5-Land volumetric_soil_water_layer_1 (0–7 cm depth). Spatial SD denotes within-year spatial dispersion across grid cells. Source: Authors' zonal analysis of ERA5-Land Hourly reanalysis data.

The decrease from 0.325 to 0.305 m3/m3 after 2012 is not necessarily to be interpreted without cautious inference. The lower values in 2015, 2017, and 2020 reflect a difference in sampled observations, and not necessarily a sustained regional drying trend, since the analysis samples discrete reference years, rather than a continuous time-series of observations for either years or seasons. Moreover, the spatial standard deviations were still high in all years (0.078–0.087 m^3/m^3), indicating that mangrove/freshwater swamp cells with persistently high water saturation levels (up to 0.470 m^3/m^3) and upland savanna/rainforest soils with lower water saturation levels (0.160–0.180 m^3/m^3) exhibited ecological soil-property gradients reported by Olisa et al. (2023). Furthermore, ERA5-Land layer 1 (0–7 cm) is quickly varying with respect to both the atmospheric boundary conditions and modelled soil hydraulic conductivity, and hence cannot be directly extrapolated to deeper root-zone water storage without multi-layer or satellite-assimilated data (Maidment et al., 2026; Wang et al., 2026).

Cross-Variable Behaviour and Environmental Management Implications

Combining all three variables (Table 5) shows that over the period of years sampled, near surface air temperature, daily precipitation and top-layer soil moisture did not develop parallel or synchronous courses. The top layer soil moisture had the greatest regional mean (0.325 m3/m3) in years 2009 and 2012, which had the largest and lowest annual mean daily rainfall (4.12 mm day-1 and 3.34 mm day-1) respectively, but the air temperature was relatively moderate in both years (25.05 °C and 24.68 °C, respectively). In 2015, however, the daily precipitation was the highest sampled mean (4.18 mm day-1) and the maximum (7.01 mm day-1), while the mean soil moisture for the top layer was the lowest (0.315 m3/m3) and the air temperature the highest (25.03 °C), whereas in 2020, the highest sampled mean air temperature (25.48 °C) coincided with the lowest sampled mean top-layer soil moisture (0.305 m3/m3).

Table 5: Synthesis of Principal Descriptive Findings across the Eight Reference Years (2000–2020)

Variable & Metric	Initial Year (2000)	Peak / Extremum Value (Year)	Final Year (2020)	Net Endpoint Difference (2000–2020)	Observed Descriptive Pattern
Mean air temperature (°C)	24.73	25.48 (2020)	25.48	+0.75 °C (+3.03%)	Higher endpoint value with 2012 trough (24.68 °C)

Mean precipitation (mm day^{-1})	3.42	4.18 (2015)	3.31	−0.11 mm day^{-1} (−3.22%)	Pronounced non-monotonic fluctuation
Max cell precipitation (mm day^{-1})	5.39	7.01 (2015)	5.38	−0.01 mm day^{-1} (−0.19%)	Highest spatial peak in 2015; lowest in 2012 (5.14)
Mean soil moisture (m^3/m^3)	0.315	0.325 (2009, 2012)	0.305	−0.010 m^3/m^3 (−3.17%)	Early rise to 2009–2012 plateau, then lower values
Min cell soil moisture (m^3/m^3)	0.170	0.180 (2009–2015)	0.160	−0.010 m^3/m^3 (−5.88%)	Lowest spatial minimum recorded in 2020

Source: Compiled from Tables 2–4 (ERA5-Land Hourly reanalysis zonal statistics).

This uncoupling (e.g., 2015 yielded the highest mean daily precipitation of 4.18 mm day-1 and lowest soil-moisture mean of 0.315 m3 m-3 compared with 0.325 m3 m-3 for 2012) physically illustrates that soil moisture in the near-surface layer cannot be determined solely from precipitation amounts (Xi et al., 2023). The amount of surface soil-water storage is a function of the partitioning of rainfall (infiltration versus rapid surface runoff during intense convective storms), atmospheric evaporative demand, antecedent wetness, vegetation canopy interception and soil drainage capacity, as Xi et al. (2023) demonstrated. Although in 2020, endpoint air temperature was higher (25.48 °C) and top-layer soil moisture was lower (0.305 m3/m3), the physical feasibility of these two circumstances, such as increased evaporative demand or changing land use (Akue et al., 2025; Ofordu et al., 2022), were not explored in this descriptive framework, as evapotranspiration, land-use change, and fluxes of surface energy were not explicitly modeled. This baseline assessment does not aim to quantitatively assess hydroclimatic drivers of soil-moisture variation, as was done in Idisi et al. (2025). From an environmental management point of view these findings have three practical implications for South Nigeria. First, regional hydroclimatic monitoring agencies should include soil-moisture indicators in their monitoring instead of only measuring rainfall, and temperature. Second, water management and crop scheduling for agriculture in the topsoil of 0–7 cm, especially for shallow-rooted rain-fed crops, should consider spatial variability across ecological zones and not use regional average (Olisa et al., 2023). Third, operational monitoring frameworks in the Niger Delta should combine the spatially continuous reanalysis data (ERA5-Land) with synoptic observations on the ground with satellite soil moisture products (Lal et al., 2022; Maidment et al., 2026; Wang et al., 2026) and non-parametric trend tests (e.g., Mann–Kendall and Sen's slope) for continuous, annual records to differentiate persistent trends in the climate from interannual fluctuations.

CONCLUSION

In this study, near-surface (2 m) air temperature, mean daily accumulated precipitation, and top layer (0-7 cm) volumetric soil moisture data derived from the ERA5-Land were descriptively analysed in a spatial and temporal context over the six states of South-South geopolitical zone of Nigeria for eight reference years ranging from 2000 to 2020. The empirical results indicate some rather different and non-synchronous trends of the three hydroclimatic variables. The air temperature at the end of the observation period (25.48 °C in 2020) was higher than the initial baseline (24.73 °C in 2000); the difference between the end point and the initial baseline was +0.75 °C (+3.03%) with an anomaly of cooling in 2012 (24.68 °C). Mean daily precipitation showed strong inter-sample variation and no clear direction over time, with the highest value of 4.18 mm day-1 in 2015 and the lowest in 2020 (3.31 mm day-1, an endpoint difference of -3.22% compared to 2000, which was 3.42 mm day-1). Spatial dispersion increased significantly across wetter reference years. At the same time, modelled top-layer soil moisture rose from 0.315 m^3/m^3 in 2000 to a peak of 0.325 m^3/m^3 in 2009 and 2012, and then dropped to 0.305 m^3/m^3 in 2020 (-6.15% from the peak). These opposite trends illustrate that near-surface soil-water state in deltaic areas is not correlated with precipitation amounts and a multi-variable integrated hydroclimatic monitoring is required. However, the findings of this evaluation will be subject to the methodological limits of the evaluation. The observed endpoint differences are not statistically significant long-term climatic trends, do not reflect causal physical mechanisms (like evapotranspiration forcing or land-cover change), or do not reflect deeper root-zone moisture availability across heterogeneous local soil types due to the analysis relying on eight discrete reference years, descriptive spatial zonal statistics, and ERA5-Land reanalysis estimates. Future studies should be conducted to build on this regional baseline: uninterrupted annual and seasonal time-series should be analysed; formal non-parametric trend and change-point tests (e.g. Mann–Kendall test and Sen's slope estimator) should be applied; reanalysis outputs should be compared against independent synoptic meteorological gauges and multi-satellite soil-moisture retrievals; and explicit land-surface and evapotranspiration fluxes should be incorporated to improve agricultural water management, wetland conservation, and climate-adaptation planning in the Niger Delta.

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