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Decoding Togo's Rainy Season: Historical Trends and Future Shifts under Variability and Changes Using CORDEX-Africa Models

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Abstract

This study combines historical analysis (1981-2024) and future projections (2020-2040) to assess seasonal rainfall patterns in Togo, focusing on the May–October rainy season. Using the multi-model mean from the CORDEX-Africa program, data were processed and analyzed in Python, with statistical tests applied to evaluate mean differences, relative changes, and their significance. Historical results reveal a single, well-defined rainy season peaking in August (230.92 mm on average), preceded and followed by an extended dry season from November to April with rainfall typically below 30 mm. Annual precipitation averages around 1500 mm but exhibits strong interannual variability influenced by ENSO events and the West African monsoon system. Spatial analysis shows August as the most challenging month to model accurately, with lower R^2 (0.79) and higher RMSE (41.57 mm) due to localized heavy rainfall. Projections for 2020-2040 indicate distinct north-south gradients, with significant increases in rainfall in northern regions during July-August and deficits in the south from July to October, highlighting contrasting flood and drought risks across the country.

Keywords

Togo, Seasonal Rainfall, CORDEX-Africa, Climate Projections, Spatial Variability

1. Introduction

Rainfall variability is a critical driver of environmental, social, and economic change in many regions worldwide [1] (Awode *et al.*, 2025). It plays a central role in proactive planning and resilience-building in the face of climate-related risks, particularly in economies dependent on agriculture, water resources, and urban infrastructure [2] (Gilmont *et al.*, 2018). Seasonal and interannual fluctuations in rainfall directly influence agricultural productivity, water availability, and flood risk, with cascading effects on food security, economic stability, and public health [3]. Understanding rainfall trends and patterns is therefore essential in highly vulnerable regions to support the development of adaptive strategies that mitigate the impacts of such variability on livelihoods and ecosystems [4].

Rainfall distribution is inherently variable in both space and time, often reflecting the influence of topographic and climatic controls. For example, studies in Ethiopia show that seasonal and interannual rainfall variability is partly modulated by the North Atlantic Multidecadal Oscillation (NAO), with pronounced regional differences: the northern and northwestern areas exhibit declining rainfall trends, whereas eastern areas show increases, particularly in summer [5] In Mexico, rainfall patterns are influenced by nonstationary climate oscillations such as the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), which can trigger abrupt seasonal shifts—underscoring the need for adaptive water resource management [6].

Across Africa, rainfall variability in regions such as the Sahel and the Guinea Coast is often linked to opposing rainfall anomalies in adjacent areas, forming complex dipole patterns influenced by sea surface temperature variations, particularly in the Atlantic [6]. In East Africa, seasonality varies from unimodal to bimodal regimes, with equatorial areas experiencing semiannual peaks and southern regions exhibiting a single rainy season, reflecting the interplay between tropical and subtropical climatic drivers [7]. In West Africa, the Atlantic Multidecadal Oscillation (AMO) is a key long-term driver of rainfall variability, modulating both monsoon strength and moisture transport [8] [9].

In the tropics, including Togo, rainfall variability is shaped by the combined effects of global and regional climate drivers such as ENSO and AMO [10] [11]. In Togo, as in much of West Africa, these climatic influences contribute to a distinct seasonal cycle, with a pronounced rainy season from April to October and a dry season from November to March [12]. The rainy season is typically marked by intense, and sometimes torrential, rainfall that is vital for crop production and groundwater recharge but also heightens the risks of flooding, soil erosion, and waterborne diseases [13].

This seasonal rhythm is a defining feature for agricultural planning, urban water management, and infrastructure resilience [14]. The national environmental report [15] identifies floods, droughts, delayed rainfall, high temperatures, and strong winds as major climate-related hazards. While drought affects most of the country except for the coastal zone which faces additional risks from sea level rise, flooding has become increasingly severe, causing significant material damage and loss of life. Key socio-economic sectors such as agriculture, livestock rearing, agricultural marketing, and horticulture are particularly vulnerable to these risks [16].

Despite the growing challenges faced by local populations in adapting to current climate variability, the absence of comprehensive governmental policies addressing future climate change impacts further exacerbates vulnerability, particularly in rural areas. This highlights the urgent need for evidence-based adaptation strategies tailored to local contexts.

In Togo, studies assessing the future impacts of climate change on precipitation patterns remain limited, and detailed analyses of seasonal rainfall evolution are scarce. With the increasing availability of Regional Climate Model (RCM) outputs through initiatives such as the Africa-CORDEX program, there is an opportunity to generate more precise and locally relevant projections. However, the performance of individual RCMs can vary depending on the variable and region considered, and a good historical simulation does not necessarily ensure reliable future projections. To address these uncertainties, a multi-model ensemble approach is recommended, as it helps to capture a wider range of possible futures and improve the robustness of projections [17].

In this study, we examine both recent observations and future projections of the rainy season (May-October) across Togo, using the mean of eight RCMs provided by the Africa-CORDEX program. These models offer relatively high spatial resolution (10 - 100 km), which is essential for capturing the climatic heterogeneity across the country. The main objective is to assess the spatial and temporal evolution of rainy season precipitation, providing policymakers with scientific evidence to support informed climate adaptation planning.

2. Materials and Methods

In this section, Study area, Methods, and Data Collection, Site Selection, Optimization and Simulation Tools are described.

2.1. Study Area

The Republic of Togo, located in West Africa along the Gulf of Guinea, extends from latitudes 6˚N to 11˚N (**Figure 1**). It shares its borders with Ghana to the west, Benin to the east, and Burkina Faso to the north. The country's southern coastline stretches for 56 kilometers along the Gulf of Guinea. Encompassing a total area of 54,600 km^2, Togo exhibits a diverse topography, characterized by undulating hills in the northern regions, a central plateau in the south, and a low-lying coastal plain interspersed with extensive lagoons and marshlands [18]. Togo faces significant socio-economic challenges, with approximately 69% of rural households currently living below the poverty line. The nation's climate transitions from tropical in the south to savanna in the north. Rainfall patterns in the southern regions follow a bimodal distribution, with the first rainy season extending from mid-March to late July and the second occurring from early September early to mid-November. Conversely, the northern regions experience a single rainy season, typically from May to October [18]. During the dry season, spanning from November to March, Togo is influenced by the Harmattan, a dry and dusty trade wind originating from the northeast, which brings cooler temperatures and arid conditions. Additionally, the northern regions are periodically affected by droughts.

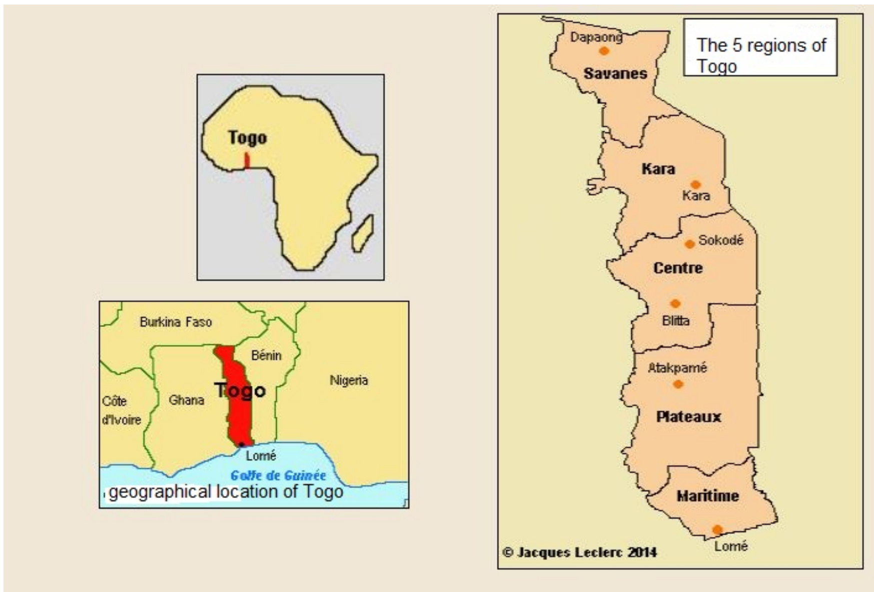

Figure 1. Study area.

2.2. Data Sources, Methods and Materials

This study utilizes two primary data sources. The first source consists of outputs from the CORDEX program, which provides simulations from a set of Regional Climate Models (RCMs) covering different regions worldwide. The CORDEX model domains are detailed at http://wcrp-cordex.ipsl.jussieu.fr/images/pdf/cordex_regions.pdf. For this analysis, datasets from the Africa-CORDEX domain were accessed via the Earth System Grid Federation at https://esgf-data.dkrz.de/projects/esgf-dkrz/. These datasets have undergone quality control procedures to ensure reliability.

All CORDEX Africa RCMs operate on a rotated pole coordinate system with a spatial resolution of approximately 0.44˚ longitude by 0.44˚ latitude, corresponding to a quasi-uniform grid size of about 50 km × 50 km across the equatorial domain (**Table 1**). The RCMs simulate climate dynamics based on Representative Concentration Pathway (RCP) scenarios, with detailed descriptions of their physical parameterizations and driving General Circulation Models (GCMs) provided by Nikulin *et al.* (2018) [19]. Among the driving GCMs are CNRM-CERFACS-CNRM-CM5 (CNRM), ICHEC-EC-EARTH (ICHEC), and MPI-M-MPI-ESM-LR (MPI), which have been thoroughly evaluated in previous studies (Nikulin *et* *al.*, 2018). These CORDEX data have also been employed in prior research over the Mono Basin [18].

Table 1. Used climatic models, global model under which they are run (column 1), their Institute of origin (column 2), their short name (column 3) and RCM model Name (column 4).

Global Model Name	Institute ID	Model Short Name	RCM Model Name
GFDL-ESM2M	NOAA-GFDL	NOAA	SMHI-RCA4
NorESM1-M	NCC	NCC	SMHI-RCA4
MPI-ESM-LR	MPI-M	MPI	SMHI-RCA4
MIROC5	MIROC	MIROC	SMHI-RCA4
IPSL-CMA5-MR	IPSL	IPSL	SMHI-RCA4
EC-EARTH	ICHEC	ICHEC	KNMI-RCAMO22T
CNRM-CM5	CRNM-CERFACS	CNRM	SMHI-RCA4
CanESM2	CCCma	CCCMA	SMHI-RCA4

The second data source consists of observed rain records obtained from the National Meteorological Agency of Togo (Météo Togo) for the period 1980-2024. These observations cover stations spatially distributed across the country. To ensure consistency with model outputs, the observational data were regridded onto a common 50 km spatial grid [18].

The correlation coefficient (R), root mean square error (E), and standardized standard deviation (SD) were used to analyze the accuracy and deviation between the simulated and observed data, which were quantified as follow:

$$\mathrm{R}=\frac{\frac{1}{N}\sum_{i=1}^{N}\left(f_n-\overline{f}\right)\left(r_n-\overline{r}\right)}{\sigma_f\sigma_r}$$

$$\mathrm{E}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(f_n-r_n\right)^2}$$

$$\mathrm{SD}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(f_n-\overline{f}\right)^2}$$

where, r_n and f_n are the simulated and observed data respectively. σ_r and σ_f are the standard deviation of r_n and f_n. The simulated data were more accurate when the R was closer to 1. Similarly, when the E and SD were closer to the observation point on the x-axis, smaller deviations between the simulated and observed data were presented.

The relative changes from the reference period are assessed as shown by equation below:

$$\mathrm{I}=\left(\frac{\mathrm{FF}-\mathrm{HIST}}{\mathrm{HIST}}\right)\cdot 100$$

where FF and HIST represent respectively the mean for the near future (2021-

2040) and the historical or reference period (1981-2010). These methods have been used over Mono Basin by Batablinle *et al.* (2018) [18] and Lawin *et al.* (2019) [20].

The analysis was conducted using Python, an open-source programming language widely applied in climate and hydrological research for its robust data processing, statistical analysis, and visualization capabilities. Python's scientific libraries—such as **xarray**, **numpy**, **pandas**, and **matplotlib** were employed to handle climate datasets, perform spatial and temporal aggregation, and generate the projection maps. This computational approach ensured reproducibility, flexibility in processing large datasets, and the ability to integrate multiple Regional Climate Model (RCM) outputs from the Africa-CORDEX archive into a multi-model ensemble for improved projection reliability.

3. Results and Discussion

3.1. Results

3.1.1. Analysis of Seasonal Variability, Spatial Patterns, and Estimation Accuracy of Nationwide Annual and Monthly Precipitation in Togo

Rainfall variability exerts a significant influence on water management, agriculture, and hydrological regimes in Togo. **Figure 2** presents both the average monthly rainfall pattern and the annual rainfall trends, providing insights into the seasonal distribution and interannual fluctuations of precipitation across the country.

The analysis of average monthly rainfall in Togo over the 1983-2023 period reveals a rainfall regime characterized by a single, well-defined rainy season, peaking in August. From November to April, rainfall remains very low, often below 30 mm, marking a prolonged dry season. Beginning in May, a rapid increase in precipitation is observed, reaching its maximum in August with over 230 mm, before gradually declining towards November. This pattern reflects the seasonal migration of the Intertropical Convergence Zone (ITCZ) and has a direct influence on the country's agricultural calendar.

In parallel, the examination of annual rainfall trends between 1983 and 2024 highlights a pronounced interannual variability around an average of 1500 mm/year. Certain years, such as 1990 and 2000, record significant surpluses, whereas others, notably 1998 and 2014, show marked deficits. Although no strong linear trend is immediately evident, a slight downward tendency can be observed after the mid-2000s. This variability, influenced by regional and global climate drivers such as ENSO events and oscillations within the West African monsoon system, poses considerable challenges for food security and sustainable water resource management.

Table 2 shows that precipitation variability across the wettest months of the year remains relatively low, with a constant coefficient of variation (CV) of 15% from May to October. This indicates a relatively uniform rainfall distribution during the main rainy season, reducing uncertainty for agricultural activities and water resource planning. May records an average of 122.13 mm, marking the effective onset of the rainy season. Rainfall then increases steadily through June (181.52 mm) and July (203.26 mm), peaking in August with 230.92 mm, before declining to 187.22 mm in September and dropping sharply to 98.85 mm in October.

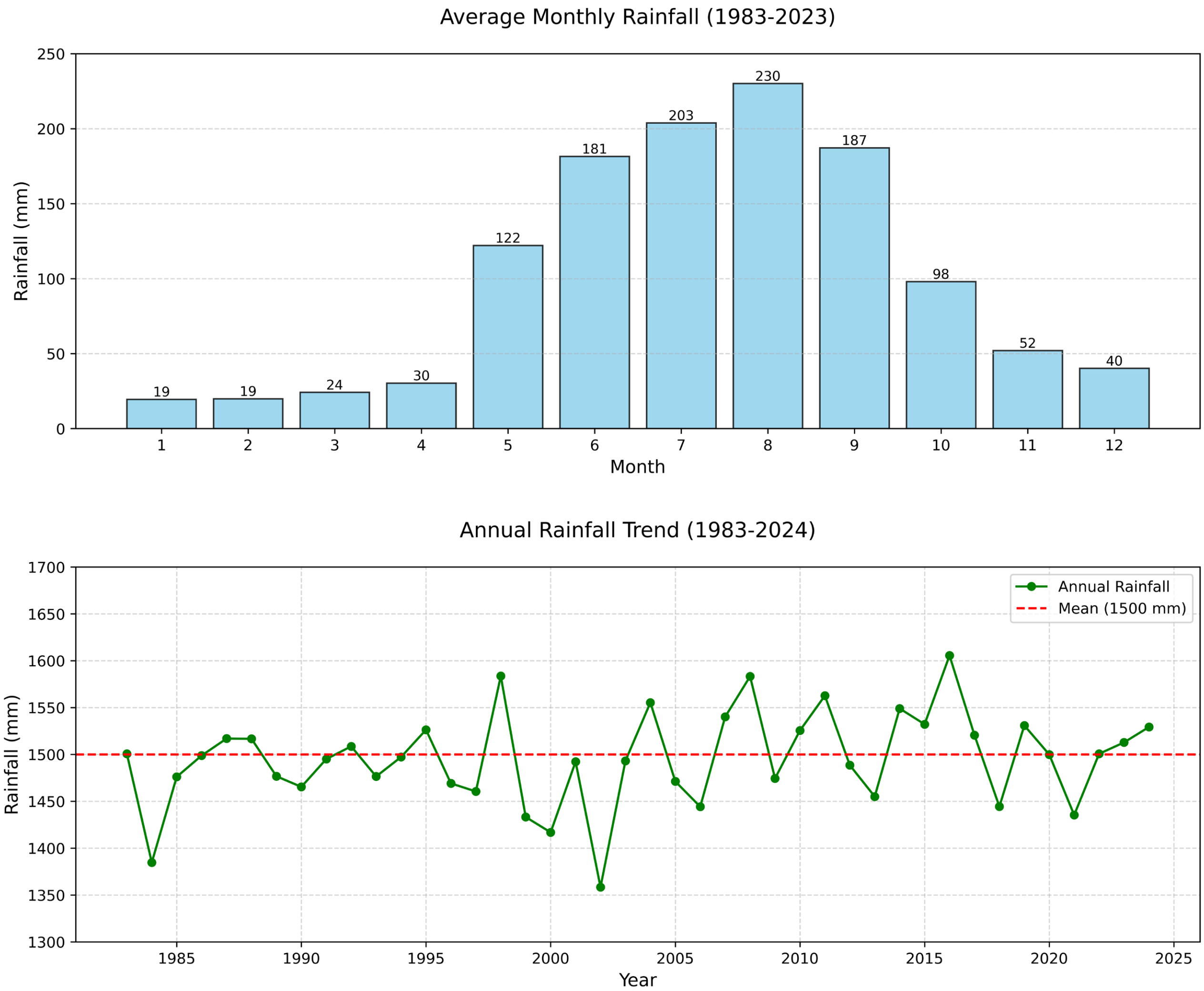

Figure 2. Monthly and annual average rainfall in Togo (1983-2024).

Table 2. Analysis of descriptive statistics, seasonal variability, and model accuracy for nationwide monthly precipitation in Togo.

Month	Average	Max	Min	SD	CV%	R^2	Me	RMSE
May	122.13	158.77	85.49	18.32	15.0	0.88	0.42	21.98
June	181.52	236.03	127.01	27.26	15.0	0.82	−0.15	32.71
July	203.26	264.27	142.25	30.49	15.0	0.91	0.67	36.59
August	230.92	300.23	161.61	34.64	15.0	0.79	−0.83	41.57
September	187.22	243.41	131.03	28.08	15.0	0.85	0.24	33.70
October	98.85	128.51	69.19	14.82	15.0	0.93	−0.56	17.79

Although variability remains stable, spatial and temporal differences are still evident. The highest maximum values are observed in August (300.23 mm), followed by July (264.27 mm), reflecting strong convective activity during the peak monsoon. Conversely, October's lower average (98.85 mm) marks the retreat of the rainy season.

From a modelling perspective, interpolation accuracy varies by month. The highest R^2 values are recorded in October (0.93) and July (0.91), indicating strong agreement between observed and estimated values, whereas August shows a relatively lower R^2 (0.79), suggesting more complex spatial rainfall patterns during the peak season. The RMSE values are lowest in October (17.79 mm) and highest in August (41.57 mm), confirming that the latter month is more challenging to model due to localised heavy rainfall events.

Overall, the rainfall regime is typical of a tropical monsoon climate, with a well-defined peak in August and consistently low variability during the rainy season. Understanding this distribution is essential for optimizing crop calendars, managing hydrological systems, and anticipating potential flooding risks in peak months.).

3.1.2. Rainy Season Projection in Togo (May to October)

The series of maps provides a detailed projection of the mean monthly precipitation across Togo during the rainy season from May to October, based on the CORDEX Africa mean model. To begin with, the spatial distribution highlights a latitude range roughly between 6.1˚N and 11.1˚N, and longitude from −0.15˚ to 1.8˚E, allowing us to observe how rainfall varies geographically within the country (**Figure 3**). Looking at the precipitation scale, values range from about 4.5 mm/day in the driest areas to 9.5 mm/day in the wettest regions, represented by colors from deep blue to dark brown.

Focusing first on May (Month 5), rainfall is generally moderate to high in the central and southern parts of Togo, indicating the onset of the rainy season concentrated mainly in the southern half. Meanwhile, the northern regions experience relatively low precipitation levels. Moving into June (Month 6), precipitation intensifies particularly in the south-central areas, yet northern areas remain relatively dry, suggesting a gradual northward progression of the rains but maintaining a clear south-to-north gradient.

By July (Month 7), a notable increase in rainfall occurs in central and northern regions, marking the spread of the peak rainy season further north, although the southern parts see a slight decrease compared to June. Continuing into August (Month 8), precipitation remains high in central and northern areas, with some of the highest recorded values during the season, while the southern region experiences moderate rainfall. This pattern indicates that August likely corresponds to the peak intensity of the rainy season across much of Togo.

Subsequently, in September (Month 9), rainfall begins to diminish in the northern and southern areas but remains elevated in the central regions, signaling the start of the rainy season's retreat. Finally, in October (Month 10), precipitation significantly decreases across the south and center, with minimal rainfall in the north, reflecting the transition toward drier conditions and the end of the rainy season.

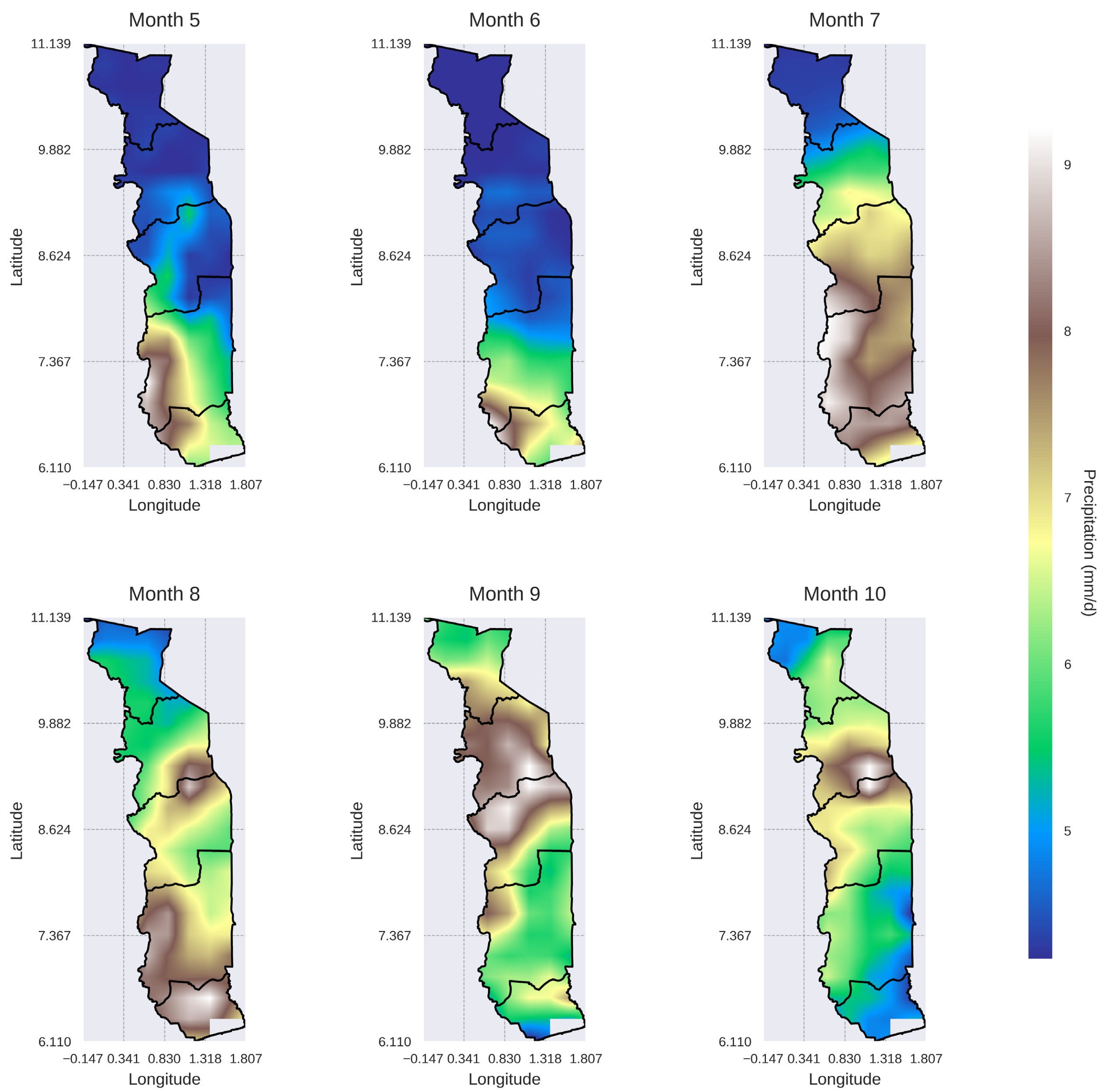

Figure 3. Projected rainfall patterns in Togo during the 2020-2040 rainy season (May to October).

In summary, the projection maps depict a classic West African monsoon progression: rainfall initiates in the south, advances northward to peak around August, and then gradually recedes by October. Overall, the spatial and temporal distribution of precipitation aligns well with known seasonal dynamics and climate patterns observed in Togo.

3.1.3. Projected Climate Trends for Togo (2020-2040) Based on CORDEX-Africa Mean Model

This 2020-2040 projection for Togo, derived from the multi-model mean of CORDEX-Africa simulations, shows relative (%) changes in precipitation from May to October compared to the 1983-2024 reference period (**Figure 4**). The results highlight pronounced seasonal and spatial contrasts across the latitudinal (6˚N - 11˚N) and longitudinal (0˚ - 1˚E) gradients, reflecting the seasonal dynamics of the Intertropical Convergence Zone (ITCZ) and its differentiated regional impacts.

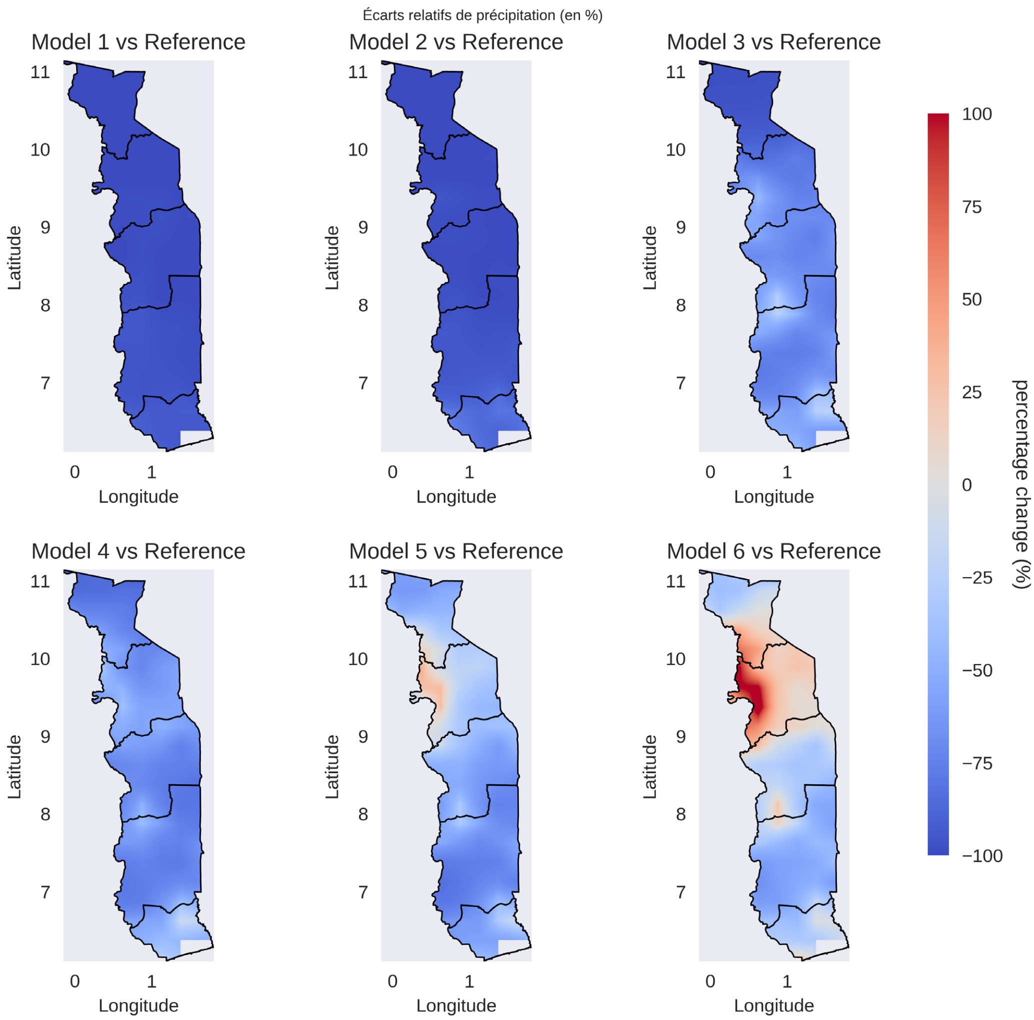

Figure 4. Percentage of future projected changes (relative to the 1983-2024 baseline).

In May, the onset of the rainy season remains relatively stable, with deviations limited to ±5% in most areas. A localized increase of about +10% is projected near 8˚N/0˚, indicating micro-scale geographical variations. In June, precipitation is projected to increase more generally by +10% to +15%, with the most notable anomalies around 9˚N/1˚E, likely linked to an earlier and more intense arrival of the West African monsoon.

By July, the projection indicates a marked north-south contrast: the northern latitudes (10˚N - 11˚N) experience significant increases (+20% to +25%), while the south (6˚N - 7˚N) shows a slight decline (−5%). This shift reflects the northward displacement of the ITCZ, reducing rainfall in the southern part of the country. In August, the strongest projected anomaly appears at 10˚N/0˚ (+30%), while a decrease (−10%) is found at 7˚N/1˚E. Such concentration of rainfall in the north suggests the likelihood of intense, localized storm events.

In September, anomalies return closer to reference values (±5%), except at 8˚N/0˚, where a sustained increase of +15% persists. This indicates a transitional phase in the rainy season, although localized flood risks remain. By October, the projection shows a generalized decrease in precipitation (−10% to −15%), marking the end of the rainy season, except for 9˚N/1˚E, where rainfall levels remain stable.

Overall, the multi-model mean projection confirms a strong north-south gradient: northern regions (10˚N - 11˚N) are likely to experience substantial rainfall increases, while southern areas are expected to face persistent deficits. Recurrent "hotspots" near 8˚N/0˚ and 10˚N/0˚ appear particularly sensitive to climate variability and change. These trends have important implications: in the north, projected rainfall increases in July-August raise the risk of flooding, while in the south, declines from July to October heighten drought vulnerability.

To adapt to these projected conditions, targeted climate monitoring should focus on the 8˚N - 11˚N belt, agricultural calendars should be revised to incorporate drought-tolerant crop varieties in the south and improved drainage in the north, and further high-resolution studies should assess the influence of land-use change on rainfall variability.

3.2. Discussion

Togo exhibits notable regional climatic variability, with a traditionally bimodal rainfall regime observed in the southern part of the country, characterized by two distinct rainy peaks annually. In contrast, the majority of the territory particularly the central and northern regions is dominated by a unimodal rainfall pattern, featuring a single well-defined rainy season from May to October. However, our recent analyses based on monthly precipitation series indicate a progressive transformation of this bimodal regime into a near-unimodal pattern on a national scale. This shift reflects a homogenization of the rainfall cycle, with the gradual disappearance of the second rainfall peak in the south, thereby aligning the southern region's climatic characteristics more closely with those of the central and northern parts of the country.

Our analysis (1983-2024), combined with projections for 2020-2040, complements and expands upon earlier studies conducted over the 1961-2001 period [21] (The previous study highlighted a general decline in annual precipitation across nearly all agro-ecological zones in Togo, identifying the Maritime Region as the driest and Kouma-Konda as the wettest, with an average annual rainfall of 1714 mm. June was reported as the wettest month, and the Mann-Kendall test revealed a statistically significant downward trend in annual rainfall.

In contrast, our study leverages higher spatial and temporal resolution data, employing a multi-model ensemble from the CORDEX-Africa program and advanced statistical methods implemented in Python. While confirming substantial interannual and seasonal variability, we additionally observe the marked transformation of the southern region's bimodal rainfall regime into a predominantly unimodal pattern across the entire country a phenomenon less evident in earlier analyses. Moreover, our projections indicate contrasting spatial trends, with increasing rainfall in northern Togo and decreasing precipitation in the south, suggesting more complex dynamics than the broad declining trend previously documented.

These differences likely reflect recent shifts in large-scale climate drivers such as ENSO and the Atlantic Multidecadal Oscillation, as well as methodological improvements that better capture localized extremes and variability [22]. The implications for water resource management and agriculture remain critical: whereas earlier findings emphasized risks associated with persistent precipitation deficits and drought, our results highlight the necessity of adapting to spatially differentiated changes and the gradual loss of bimodality, which impacts traditional agricultural calendars [2]. In sum, integrating historical observations with contemporary data and future projections offers a more nuanced and comprehensive understanding of rainfall variability in Togo. This enhanced perspective is vital for developing effective climate resilience strategies and ensuring food security in the face of evolving climatic conditions.

4. Conclusion

By integrating the CORDEX-Africa multi-model mean with Python-based statistical analysis, this study provides a robust assessment of past and future rainfall dynamics in Togo. The stable variability within the rainy season offers a degree of predictability for agricultural and water management planning, yet localized extremes-particularly in August-present persistent modelling and infrastructural challenges. Projections for 2020-2040 relative to 1983-2024 reveal an intensification of rainfall in the north during peak months, increasing flood risks, and concurrent declines in the south, raising drought vulnerability. These findings underscore the need for spatially differentiated adaptation strategies: enhancing drainage infrastructure in the north, promoting drought-tolerant crops in the south, and expanding high-resolution observational networks nationwide. Overall, the characterization of seasonal, spatial, and projected rainfall variability provides a critical foundation for evidence-based climate adaptation policies in Togo.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Awode, A.E., Adewumi, J.R., Obiora-Okeke, O. and Komolafe, A.A. (2025) Analysis

of Rainfall Variability and Extreme Events in South-Western Nigeria: Implications for Water Resource Management and Climate Resilience. *Bulletin of the National Research Centre*, **49**, Article No. 31. https://doi.org/10.1186/s42269-025-01324-4

[2] Gilmont, M., Hall, J.W., Grey, D., Dadson, S.J., Abele, S. and Simpson, M. (2018) Analysis of the Relationship between Rainfall and Economic Growth in Indian States. *Global Environmental Change*, **49**, 56-72. https://doi.org/10.1016/j.gloenvcha.2018.01.003

[3] Kinda, S.R. and Badolo, F. (2019) Does Rainfall Variability Matter for Food Security in Developing Countries? *Cogent Economics & Finance*, **7**, Article 1640098. https://doi.org/10.1080/23322039.2019.1640098

[4] Balogun, I.I., Sojobi, A.O. and Oyedepo, B.O. (2016) Assessment of Rainfall Variability, Rainwater Harvesting Potential and Storage Requirements in Odeda Local Government Area of Ogun State in South-Western Nigeria. *Cogent Environmental Science*, **2**, Article 1138597. https://doi.org/10.1080/23311843.2016.1138597

[5] Bekele-Biratu, E., Thiaw, W.M. and Korecha, D. (2018) Sub-Seasonal Variability of the Belg Rains in Ethiopia. *International Journal of Climatology*, **38**, 2940-2953. https://doi.org/10.1002/joc.5474

[6] Álvarez-Olguín, G. and Escalante-Sandoval, C.A. (2017) Modes of Variability of Annual and Seasonal Rainfall in Mexico. *JAWRA*, *Journal of the American Water Resources Association*, **53**, 144-157. https://doi.org/10.1111/1752-1688.12488

[7] Broman, D., Rajagopalan, B., Hopson, T. and Gebremichael, M. (2019) Spatial and Temporal Variability of East African Kiremt Season Precipitation and Large-Scale Teleconnections. *International Journal of Climatology*, **40**, 1241-1254. https://doi.org/10.1002/joc.6268

[8] Crétat, J., Harrison, S.P., Braconnot, P., d'Agostino, R., Jungclaus, J., Lohmann, G., *et al.* (2024) Orbitally Forced and Internal Changes in West African Rainfall Interannual-to-Decadal Variability for the Last 6000 Years. *Climate Dynamics*, **62**, 2301-2316. https://doi.org/10.1007/s00382-023-07023-y

[9] Mohino, E., Janicot, S. and Bader, J. (2010) Sahel Rainfall and Decadal to Multi-Decadal Sea Surface Temperature Variability. *Climate Dynamics*, **37**, 419-440. https://doi.org/10.1007/s00382-010-0867-2

[10] Oguntunde, P.G., Abiodun, B.J. and Lischeid, G. (2011) Rainfall Trends in Nigeria, 1901-2000. *Journal of Hydrology*, **411**, 207-218. https://doi.org/10.1016/j.jhydrol.2011.09.037

[11] Okonkwo, C., Demoz, B., Sakai, R., Ichoku, C., Anarado, C., Adegoke, J., *et al.* (2015) Combined Effect of El Niño Southern Oscillation and Atlantic Multidecadal Oscillation on Lake Chad Level Variability. *Cogent Geoscience*, **1**, Article 1117829. https://doi.org/10.1080/23312041.2015.1117829

[12] Todmal, R.S. (2024) Intensity, Frequency and Coverage of Hydro-Meteorological Droughts and Agriculture in the Semi-Arid Basins of Maharashtra (India). *Climatic Change*, **177**, 1-24. https://doi.org/10.1007/s10584-024-03794-3

[13] Animashaun, I.M., Oguntunde, P.G., Akinwumiju, A.S. and Olubanjo, O.O. (2020) Rainfall Analysis over the Niger Central Hydrological Area, Nigeria: Variability, Trend, and Change Point Detection. *Scientific African*, **8**, e00419. https://doi.org/10.1016/j.sciaf.2020.e00419

[14] Zaveri, E.D., Damania, R. and Engle, N. (2023) Export Diversification from an Activity Perspective: An Exploration Using Occupation Data. The World Bank. https://doi.org/10.1596/1813-9450-10463

[15] Republic of Togo (2007) National Adaptation Programme of Action (NAPA) to Climate Change. Ministry of Environment and Forestry.

[16] Nutsukpo, D.K., Jalloh, A., Zougmoré, R.B., Nelson, G.C. and Thomas, T.S. (2013) Ghana. In: Jalloh, A., Nelson, G.C., Roy-Macauley, H., Thomas, T.S. and Zougmoré, R., Eds., West *African Agriculture and Climate Change*: *A Comprehensive Analysis*, International Food Policy Research Institute (IFPRI), 141-172.

[17] Batablinlè, L., Lawin, E. and Agnidé, S. (2018) Africa-Cordex Simulations Projection of Future Temperature, Precipitation, Frequency and Intensity Indices over Mono Basin in West Africa. *Journal of Earth Science and Climatic Change*, **9**, 1-12.

[18] Lamboni, B., Emmanuel, L.A., Manirakiza, C. and Djibib, Z.M. (2019) Variability of Future Rainfall over the Mono River Basin of West-Africa. *American Journal of Climate Change*, **8**, 137-155. https://doi.org/10.4236/ajcc.2019.81008

[19] Nikulin, G., Jones, C., Giorgi, F., Asrar, G., Büchner, M., Cerezo-Mota, R., *et al.* (2012) Precipitation Climatology in an Ensemble of Cordex-Africa Regional Climate Simulations. *Journal of Climate*, **25**, 6057-6078. https://doi.org/10.1175/jcli-d-11-00375.1

[20] Emmanuel, L.A., Batablinlè, L., Célestin, M. and Hodabalo, K. (2019) Future Extremes Temperature: Trends and Changes Assessment over the Mono River Basin, Togo (West Africa). *Journal of Water Resource and Protection*, **11**, 82-98. https://doi.org/10.4236/jwarp.2019.111006

[21] Ndiaye, P.M., Bodian, A., Diop, L. and Djaman, K. (2017) Sensitivity Analysis of the Penman-Monteith Reference Evapotranspiration to Climatic Variables: Case of Burkina Faso. *Journal of Water Resource and Protection*, **09**, 1364-1376. https://doi.org/10.4236/jwarp.2017.912087

[22] Olaniyan, E., Afiesimama, E., Oni, F. and Lawal, K.A. (2015) Simulating the Daily Evolution of West African Monsoon Using High Resolution Regional Cosmo-Model: A Case Study of the First Half of 2015 over Nigeria. *Journal of Climatology & Weather Forecasting*, **3**, Article 1000142. https://doi.org/10.4172/2332-2594.1000142