

Spatial and temporal variation in precipitation in Togo

Abstract

Precipitation is one of the important variables in hydrological cycle and has important application in both irrigated and rainfed agricultural crop production. Better understanding of spatio-temporal variability of precipitation across Togo is important and useful for water users and most agricultural activities. Thus, the objective this study was to analyze the spatial and temporal variation in monthly and annual precipitation across Togo for the period of 1961-2001. Monthly precipitation data was provided by the national direction of meteorology. The performed analysis revealed a decline in annual total precipitation across almost all agro-ecological zones in Togo with the Maritime Region revealed as the driest. Kouma-Konda received the greatest 40 year average annual precipitation in the country with 1714mm. June was the wettest month across Togo. The greatest coefficient of variation (82%) in monthly precipitation was registered in January for the study period. Water management implications could be generated from this study, especially for rural and urban agricultural production zones. Mann Kendall's test was used to understand the temporal variation in precipitation over the period of 40 years. Decreasing trends in annual precipitation are likely to have significant impacts across Togo, where rainfed agriculture is widely practiced. On the other hand, persistent and progressive precipitation deficits are likely to cause recurrent drought and destroy plant cover, increase evapotranspiration, increase surface albedo and, affect other aspects of the water and energy balance.

Keywords: Rainfall, Variation, Spatio-temporal, Togo

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Introduction

Reduction in seasonal precipitation is becoming recurrent, and many countries are concerned by the concept of climate change. Global surface temperature has increased by $0.74 \pm 0.18^\circ\text{C}$ from 1906 to 2005 and it is projected that annual average runoff and water availability will decrease from 10 to 30% by the middle of 21st century.¹ Climate change has resulted in extreme drought condition in some parts of the world and flooding in other parts.² Several studies have reported a drastic decrease in the principal climatic variable, precipitation, in Africa.³⁻⁷ Furthermore, it has been reported that most environmental changes in Africa are related to changes in precipitation.^{8,9} Observed that one of the most important contrasts in rainfall is the multi-decadal persistence of anomalies over northern Africa.¹⁰ Identified several changes in the general atmospheric circulation that have accompanied the shift to drier conditions in West African Sahel.¹¹ Recent studies have revealed that the seasonal development of the tropical rain belt over Africa is driven by several factors of the general atmospheric circulation, which in turn, controls the location and characteristics of the inter-tropical convergence zone (ITCZ).⁹⁻¹⁴ This atmospheric circulation is believed to generate and maintain wave disturbances that modulate the precipitation field. Found the Tropical Easterly Jet (TEJ) as one of the most intense circulation features over Africa and they concluded that the TEJ may be a critical factor in the development of the rainy season and the overall climate in West Africa as opposed to the traditional belief of seasonal movements of the ITCZ.¹⁵ Suggested that the indirect effects of anthropogenic sulfate may have contributed to the drying of the Sahel in North Africa.¹⁶ A few studies in Togo revealed precipitation deficit since 1970.¹⁷⁻²¹ Validated the hypothesis of sensible decrease in water resources in West Africa since the beginning of the 1970s.²²⁻²⁵ Reported that in non-Sahelian West Africa,

the rainfall regime began to change around 1966 in Senegal and Guinea Bissau, and then in Guinea, Mali, Burkina Faso, and the northern part of Benin.²⁶ The Ivory Coast, Togo, the south of Benin, Cameroon and the Central African Republic have been affected by changes in precipitation patterns to various degrees. Variability in annual rainfall is characterized by the reduction in annual total precipitation, event frequency disorganization, occurrence of in-season drought when crops are at their critical growth stage (reproductive phase) which usually coincides with the highest evapotranspiration (ET) demand and the severity of the dry period. Reported that rainfed agriculture constitutes at least 97% of agriculture in all West African countries. In Togo where staple food production is not irrigated, particular attention has to be given to precipitation patterns in time and space for better cropping season determination to optimize soil water storage and in season precipitation for crop production.²⁷ In addition, planting date for several crops need to be (re)adjusted according to the shifting of seasonal precipitation patterns over time. Furthermore, spatial analysis of long-term trends in precipitation can help identify areas that are experiencing an increase in the magnitude and frequency of high precipitation events which can generate abundant runoff and result in flood conditions, so that appropriate water and land management practices can be adopted to mitigate these effects. It can also help identifying areas that are experiencing severe drought for resilience and adaptation to climate change strategies development. Since the majority of agriculture in Togo is rainfed, precipitation patterns and distribution need to be investigated to enhance the short and long-term sustainability of crop production as well as the economy of the country. The objective of this study was to evaluate the spatial and temporal variation of monthly and annual average precipitation across Togo for deriving eventual impact on water resources availability and water management planning in rainfed and irrigated agriculture.

Materials and methods

Study area : The study was conducted for Togo, West African country located between latitude 6° 11'41.35", 11°00'22.82", between longitude 0°14'27.79", 1°37'9.37". Togo is surrounded by Ghana at west, Benin Republic at East, Burkina-Faso at the north and by Atlantic Ocean at the south, with total coverage area of 56,000km² stretched over 600 km along the meridian 1 (North-south), and 50 km along the east-west. The Republic of Togo has a consolidated weather station network with about one hundred weather stations under the supervision of the National Direction of Meteorology (Figure 1). Thirty weather stations, representing the most agro-climatic zones of the country were considered in this research due to the unavailability or poor functionality of measurement equipment at some weather stations. Daily rainfall records were collected at all stations from 1961 to 2001. The normal distribution of the data was tested through the skewness coefficient that varied from -0.057 and 0.167 and falling within the reference range of [-0.5, 0.5].²⁸ Data are therefore normally distributed. Monthly means and standard deviations were calculated at all stations over the study period. Considering the extensive rainfed agriculture in Togo and the recent variation in climate, spatial and temporal information on precipitation would be very useful and contribute to overall improvement, planning and management of the water resources for agricultural production, natural resources management, ecological and hydrological water balance analysis.

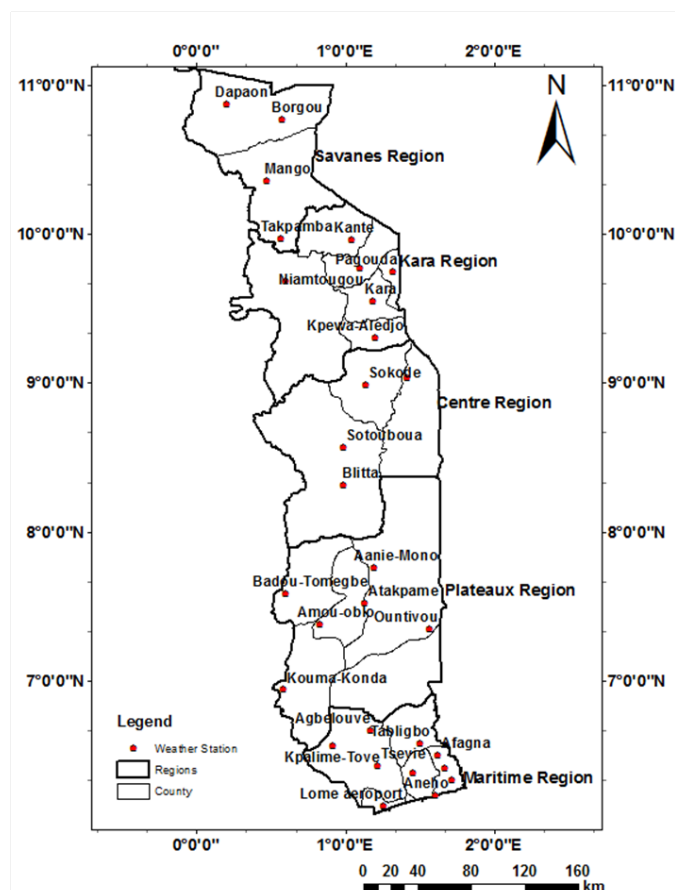


Figure 1 Study area and location of all weather stations used in the interpolation process.

Mapping spatial variation in the monthly rainfall across Togo: The predicted values of monthly and total annual rainfall based on 40 years of historical data were computed using the spline interpolation (Radial Basis Function) method which is an advanced, computationally

intensive, geostatistical estimation method.^{29,30} Spline interpolation is a deterministic interpolation method that fits a mathematical function through input data to create a smooth surface. The functions allow users to decide between smooth curves or tight straight edges between measured points. It can generate the accurate surfaces from only few sampled points. Each station is omitted in turn from the estimation of the fitted surface, and the mean square error is calculated. The mean square error calculations are repeated for a range of values of a smoothing parameter, and the value that minimizes the mean square error is used to determine the optimum smoothing. This process is called minimizing the generalized cross-validation (GCV) or “leave one out” technique. In spline interpolation, surface is achieved through weights (γ_j) and number of points (N). We used regularized spline with maximum of five and minimum of three neighboring stations. The weight parameter defines the weight of the third derivatives of the surface in the curvature minimization. A higher weight creates a smoother gridded surface. We used the following spline function:³¹

$$S(x, y) = T(x, y) + \sum_{j=1}^N \lambda_j R(r_j) \quad (1)$$

where, T is the constant trend, r_j is the distance from point (x, y) to the j th point, R is a weighted function of the distance between the interpolated point and j th data point ($j = 1, 2, 3 \dots N$), N is the number of known point and λ_j is the unknown weight for the measured values at the j th location. For regularized spline interpolation, T and r is defined as:

$$T(x, y) = a_1 + a_2 x + a_3 y \quad (2)$$

$$R(r) = \frac{1}{2\pi} \left\{ \frac{r^2}{4} \left[\ln \left(\frac{2}{2\pi} \right) + c - 1 \right] + \tau^2 \left[K_0 \left(\frac{r}{\tau} \right) + c + \ln \left(\frac{r}{2\pi} \right) \right] \right\} \quad (3)$$

Where, τ is a weight parameter of the third derivatives of the surface in the curvature minimization expression, r is the distance between the point and the sample, K_0 is a modified Bessel function, and c is a constant (0.577). Coefficient a_1, a_2, a_3 are found by the solution of a system of linear equations. The weight parameter was optimized, indicating the smoothness of the interpolant.

Temporal trends analysis in annual precipitation: Temporal trend in annual precipitation was analyzed using a nonparametric Mann-Kendall test.^{32–34} It should be noted that the Mann-Kendall test statistic is non-dimensional, and it does not offer any quantification of the scale of the trend in the units of the time series under study, but is rather a measure of the correlation of a variable with time and, as such, simply offers information as to the direction and a measure of the significance of observed trends. The Mann-Kendall test statistic S is given as follows:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^n \text{sign}(x_i - x_j) \quad (4)$$

Where x_i is the data value at time i , n is the length of the dataset, and $\text{sign}()$ is the sign function which can be computed as:

$$\text{sign}(x_i - x_j) = \begin{cases} 1 & \text{if } (x_i - x_j) > 0 \\ 0 & \text{if } (x_i - x_j) = 0 \\ -1 & \text{if } (x_i - x_j) < 0 \end{cases} \quad (5)$$

For $n > 10$, the test statistic Z approximately follows a standard normal distribution:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (6)$$

Where $\text{Var}(S)$ is the variance of statistic S . A positive value of Z indicates that there is an increasing trend and a negative value indicates a decreasing trend. The null hypothesis, H_0 , that there is no trend in the records is either accepted or rejected depending on whether the computed Z statistics is less than or more than the critical value of Z statistics obtained from the normal distribution table at the 5% significance level.²⁹ If $|Z| > Z_{(1-\alpha/2)}$, the null hypothesis of no autocorrelation and trend in dataset is rejected, in which $Z_{(1-\alpha/2)}$ is corresponding to the normal distribution with α being the significance level.

If the data has a trend, the magnitude of trend can be denoted by trend slope β [35-36]:

$$\beta = \text{Median} \left(\frac{x_i - x_j}{i - j} \right) \text{ Where } i > j \quad (7)$$

Where x_i and x_j are data values at time t_i and t_j ($i > j$), respectively.

Linear regression: Linear regression analysis was applied for analyzing trends in the time series. The main statistical parameter drawn from regression analysis is the slope, which indicates the mean temporal change in the variable under study. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends. The total change during the period under observation was obtained by multiplying the slope by the number of years.³⁴⁻³⁷

Results and discussion

Spatial variation in monthly precipitation across Togo: The spatial variation in mean monthly and annual precipitation across Togo is presented in Figure 2 & Figure 3. While precipitation begins in the Maritime Region (south Togo) with the Kouma-Konda registering the highest amounts, there is progressing precipitation coverage from

the south to northern Togo from January to May. June is the rainiest and wettest month across the country. The Central, Kara, and Savanes regions registered the highest monthly precipitation in July, August, and September averaging 197, 244, and 277mm, respectively, with the highest monthly precipitation registered at Kpewa-Aledjo in the Kara region (Figure 2). During these months, the southern part of Togo experienced a short dry season as shown in Figure 2. Thereafter, precipitation occurred mostly in the Maritime and Plateau regions from September to December, which comprised the second rainy season in the southern Togo. In November, Savanes regions received less than 10 mm of precipitation, while the Central and Kara regions received between 10 to 20mm. On annual basis, Kouma-Konda receiving 1,714mm of precipitation, was revealed the most humid part of the country followed by Kpewa-Aledjo in the eastern part of the Kara Region which received 1,490mm of precipitation (Figure 3). The southern Maritime Region was revealed as the driest part of the country whenever it has two patterns of precipitation (Figure 4). The second growing season [September-November] total precipitation amount in the Maritime Region is decreasing and may disappear upon time with increase in July and August total precipitation as reported by.¹⁶ The results of this study could help crop growers, consultancy agencies, and researchers to adopt planning strategies to match water availability to the choice of crops and or varieties to be grown under rainfed and irrigated conditions. This study is a tremendous addition to the finding of²¹ that delimited the beginning and end of the crop growing season across Togo based on historical climatic data of the 1950-2000 period. Table 1 shows that the greatest variability in precipitation occurred in January (CV=82%), February (CV=65%), and December (CV=76%), while May and June registered the lowest CV of 10 and 15%, respectively. Therefore, May and June had much more consistent precipitation across the country throughout the research period. In fact, June 1st was decreed tree planting day due to the availability of soil water at planting to support plant growth. In addition, the results can help in designing irrigation systems, mostly pumping plants in different agro-ecosystems across the country. The accuracy of the precipitation interpolation across Togo varied among months with correlation coefficients ranging from 0.44 to 0.95. August precipitation was associated with seasonal variability in precipitation and dependence on the location. While the August registered the lowest precipitation in the Maritime Region, the other four regions received almost year peak precipitation. Similar spatial precipitation variation among regions was registered in July and September (Figure 2). Overall, the interpolation was more accurate in the driest period of the year (January, February, and December) with RMSE values less than 6mm; whereas, September had the highest RMSE of 26mm.

Table 1 Descriptive statistics for mean monthly (nationwide) precipitation, and coefficient of determination (R^2), mean error (ME), and root mean square error (RMSE) between observed and predicted monthly precipitation for Radial basis function computed from cross validation of weather stations for all 21 counties across Togo.

	Average	Max	Min	SD	CV%	R^2	Me	Rmse
January	6.15	20.18	0.14	5.07	82	0.7	-0.12	3.26
February	18.09	41.46	2.39	11.69	65	0.81	-0.03	5.86
March	59.87	112.31	17.08	26.42	44	0.86	0.56	10.86
April	102.02	148.37	55.28	24.21	24	0.74	0.57	14.73
May	135.34	159.28	103.25	13.93	10	0.44	0.77	16.19
June	177.72	227.63	142.6	26.16	15	0.69	2.21	17.5

Table Continued....

	Average	Max	Min	SD	CV%	R ²	Me	Rmse
July	178.27	244.71	86.2	51.94	29	0.89	0.14	18.34
August	183.24	279.44	38.3	84.86	46	0.95	-0.72	20.19
September	189.36	264.46	73.93	62.46	33	0.86	0.91	25.81
October	109.94	154.26	68.9	18.77	17	0.44	1.21	20.41
November	22.71	52.01	4.83	13.25	58	0.54	0.58	12.29
December	10	30.31	1.62	7.65	76	0.88	-0.29	2.96

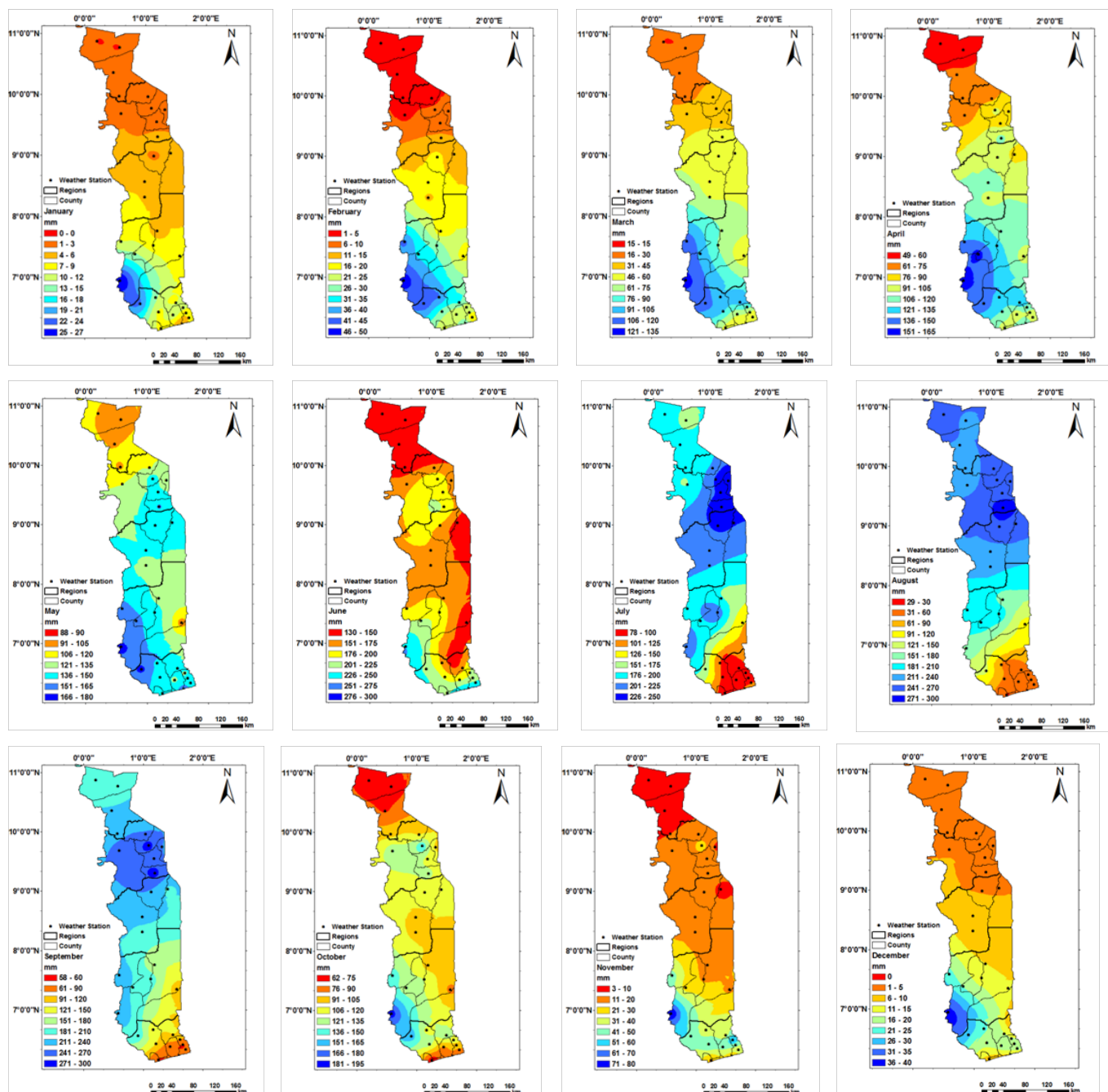


Figure 2 Spatial interpolation of long-term average monthly precipitation (mm) across Togo.

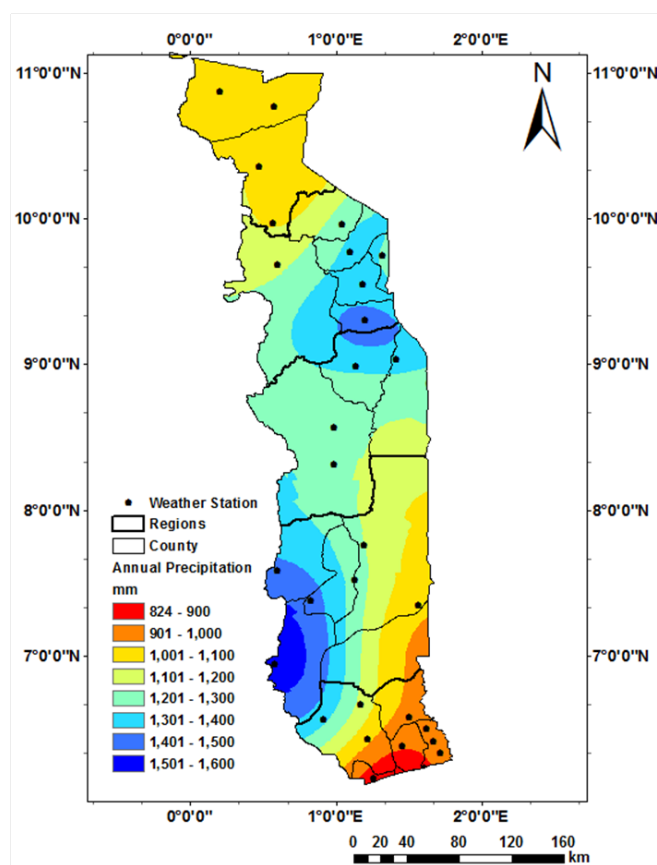


Figure 3 Spatial variation of annual precipitation across Togo.

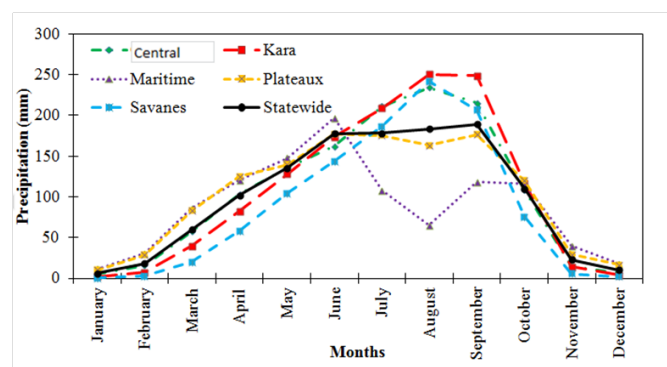


Figure 4 Comparison of monthly precipitation across different regions and country wide across Togo.

Temporal variation in precipitation across Togo: During the 1961–2001 period, annual precipitation decreased at 80% of the weather stations (Table 2). Annual total precipitation only showed an increasing trend at Anie-Mono, Sotouboua, Kara, Ontivou, Kante, and Takpamba. The magnitude of decrease in precipitation varied among regions with the highest decrease in the Maritime region. Precipitation reduction was more pronounced in the eastern part of the Maritime region where the Sen's slope estimates varied between -14.5 and -2.6mm (Table 2). This spatial heterogeneity in the declining rainfall pattern is consistent with earlier studied in West Africa.^{38–41} The decreasing trend in annual precipitation has a direct effect on stream flow, water availability for crop production, household, industries, and

other water users. The highest annual precipitation (2,339mm) was registered in 1989 at Kouma-Konda and the lowest annual precipitation (335mm) was registered in 1967 at Ountivou. On the country average, there were years when below normal annual precipitation was registered, which caused intense drought and consequently, very low crop yield and famine to the most vulnerable families. Most staple food produced in Togo is rainfed, and consequently, crop production heavily declined during the drought years because water is the most critical factor that sustains crop productivity in rainfed agriculture. For example, we can cite the 1977 and 1983 droughts that caused tremendous famine across Africa. At national level, the 1961–2001 period mean precipitation varied from 824 to 1,714mm (Table 2). The western part of the Plateaux region (Kouma-konda, Badou-Tomegebe, Kpalimé-Tove) registered the highest annual average precipitation followed by the eastern part of Kloto County, the southern part of the Amou County, the southern part of Assoli County, and the northern part of the Tchadjo County (Figure 3). The driest part of Togo is the extreme southern area, Vo, Lacs, Golf, Zio, and Yoto counties, which comprise the Maritime Region with average annual precipitation less than 1,000mm where there are two rainy seasons as shown in Figure 5. Precipitation decline is more noticeable in South Togo with shift in the set of the first rainy season and the reduction of precipitation events and magnitude during the second rainy season.³⁴ Some of the consequences are the decreasing trends in precipitation, increase in evapotranspiration, and a shift in the aridity index with environmental impacts, such as soil degradation and loss of biodiversity, loss of forest cover, increase in runoff, agricultural yields decline, reduction in agricultural revenue, and frequent famine caused partly by bad anthropogenic activities such as deforestation, overgrazing, urbanization, and farming close to rivers and water bodies.⁴² The Savanes Region received annual precipitation that ranged between 1,001 and 1,100mm. Regional average precipitation was 1,050; 1,244; 1,269; 1,275; and 1,047mm for the Maritime, Plateaux, Central, Kara, and Savanes regions, respectively (Figure 5). Declining rainfall has been reported throughout West Africa over the past 50 years and may be viewed in the long-term.⁴³ Diagnostic studies provide information concerning the forcing of West Africa rainfall by global sea-surface temperature.^{44,45} Continental surface conditions also play a role in determining the persistence of the drought condition.⁴⁶ The loss of vegetation, with the associated increase in soil albedo and increase in temperature, was proposed as a cause of Sahelian drought by.⁴⁷ Large-scale rainfall deficits have the potential to destroy plant cover, increase evapotranspiration, increase surface albedo, and affect other aspects of the water and energy balance and set in motion a long period of below-normal rainfall.^{48,49} Similar to the results of this study, several studies have shown that West Africa registered notable variability in rainfall regime during the second half of the 20th century.^{6–53} Reported that long-term change in rainfall has occurred in the semi-arid and sub-humid zones of West Africa.⁵⁴ Rainfall during the 30 year period of 1968 to 1997 was on average 15% to 40% lower than the 1931–1960 period. The concept of climate change is mostly demonstrated by drastic decrease in rainfall, which is the principal climatic variable identified for Africa in the literature.^{3–5} Found there are corresponding changes in the atmospheric circulation that is associated with the inter-decadal changes in summer precipitation over Asia and Africa.^{55–60} The decrease in seasonal rainfall induced dramatic consequences on the agricultural production such as severe droughts of years 1970, 1980, 1984, and 2006 in many West African countries. Increasing drought frequency has the potential to affect land-based natural and managed ecosystems, coastal systems, and both

freshwater quality and quantity.^{54–62} Agriculture is inherently sensitive to climate conditions, and is among the most vulnerable sectors to the risks and impacts of global climate change.^{63–64} Found that there is a relation between the rainfall disturbance and the water stress at critical period of maize growth and development in the Togo.⁶⁵ Found that the decrease in seasonal rainfall amount represents a serious threat to maize growth during the second growing season.⁶⁶ Adaptation to climate change and variability necessitates the adjustment of a system to moderate the impacts of climate change, to take advantage of new opportunities, and to cope with the consequences.⁶⁷ A wide variety of adaptation options have been proposed as having the potential to reduce vulnerability of agricultural systems to risks related to climate change. Technology development and farm production practices such as drought resistant crops, adjusting planting dates and plant density, adoption of conservative and sustainable agriculture regarding soil and water management, altering and widening existing crop rotations, government policies, farm financial management and international trade, and agricultural insurance.^{68–70} Human interference is also leading to climate change with changing land use from the impact of agricultural and irrigation practices.⁷¹ In Togo where rainfed agriculture is practiced by more than 90% of crop growers, greater

attention is required when selecting and planting crops to optimize the available water to meet crop water demand as proposed by.²¹ The results of this study will aid crop consultants, food and fiber producers, and researchers to plan and manage rainfed and irrigated agriculture to improve water productivity across the territory of Togo for more sustainable production. Furthermore, the results of this study can be incorporated into the findings of²¹ to make adjustments to crop planting dates using past and current rainfall regimes as well as predicting the onset of the rainy season. Several approaches have been adopted for determining the date of onset of the rainy season.⁵⁶ used the monthly rainfall minimum threshold of 60 and 30mm, respectively, to determine the onset of the rainy season. Defined the onset of growing season as the first ten day period of 20mm of rain without any consideration of occurrence of any dry spell.⁷² Defined the onset of the rains as 20mm in one or more date(s) within the next thirty days.⁷³ Used a simple water balance approach consisting of daily potential ET.⁵⁶ Defined the onset of the wet season as period of five days (pentad) with at least 25mm of rainfall occurring. Crop ET models could also be used to determine the onset dates of the rainy season.⁷⁴

Table 2 Summary of the temporal trends analysis in precipitation at 30 sites in Togo during the 1961–2001 period

Locations	Mean (mm)	Test Z	*Significance	Sen's slope estimate	Intercept (mm)	Change in rain fall	
						(mm)	(%)
Lome-Aeroport	823	-2.24	*	-8.15	997	-334	-40.574
Aneho	969	-2.02	*	-7.43	1083	-297	-30.702
Akoumape	857	-1.81	+	-5.9	961	-236	-27.55
Aklakou	881	-3.34	***	-10.78	1077	-442	-50.174
Attitogon	907	-1.57	n.s	-4.63	1032	-190	-20.958
Afagna	967	-3.52	***	-12.63	1131	-518	-53.546
Tabligbo	1028	-0.73	n.s	-2	1059	-82	-7.996
Tsevie	1039	-0.75	n.s	-2.17	1088	-89	-8.548
Agbelouve	1055	-2.55	*	-7.38	1159	-302	-28.678
Kpalime-Tove	1428	-0.64	n.s	-2.2	1434	-90	-6.312
Kouma-Konda	1714	-1.16	n.s	-5.69	1713	-233	-13.602
Ountivou	854	1.12	n.s	3.52	721	144	16.919
Amou-Oblo	1441	-0.86	n.s	-2.69	1500	-110	-7.652
Badou-Tomegbe	1469	-0.58	n.s	-2.4	1543	-98	-6.685
Atakpame	1335	-0.62	n.s	-2.97	1361	-122	-9.106
Anie-Mono	1129	0.55	n.s	2.18	1064	89	7.924
Blitta	1201	-2.39	*	-9.91	1379	-406	-33.846
Sotouboua	1290	0.02	n.s	0.2	1300	8	0.65
Tchamba	1235	-0.78	n.s	-3.61	1312	-148	-11.987
Sokode	1349	-2.3	*	-6.6	1493	-271	-20.061
Guerin-Kouka	1192	-0.75	n.s	-1.12	1225	-46	-3.859
Kpewa-Aledjo	1490	-1.07	n.s	-3.68	1538	-151	-10.116

Table Continued....

Locations	Mean (mm)	Test Z	*Significance	Sen's slope estimate	Intercept (mm)	Change in rain fall
Kara-St	1321	0.35	n.s	0.81	1244	33
Pagouda	1286	-1.36	n.s	-4.68	1353	-192
Nimtougou	1408	-1.74	+	-4.15	1462	-170
Kante	1221	0.21	n.s	0.28	1212	11
Mango	1069	-1.15	n.s	-2.01	1111	-80
Takpamba	1074	1.15	n.s	3.22	991	132
Borgou	964	-0.45	n.s	-1.49	945	-61
Dapaon-St	1025	-0.24	n.s	-0.64	1029	-26

Significance; n.s, Non significant+, significant at 5% ;, significant at 1% ;***, significant at 0.1%

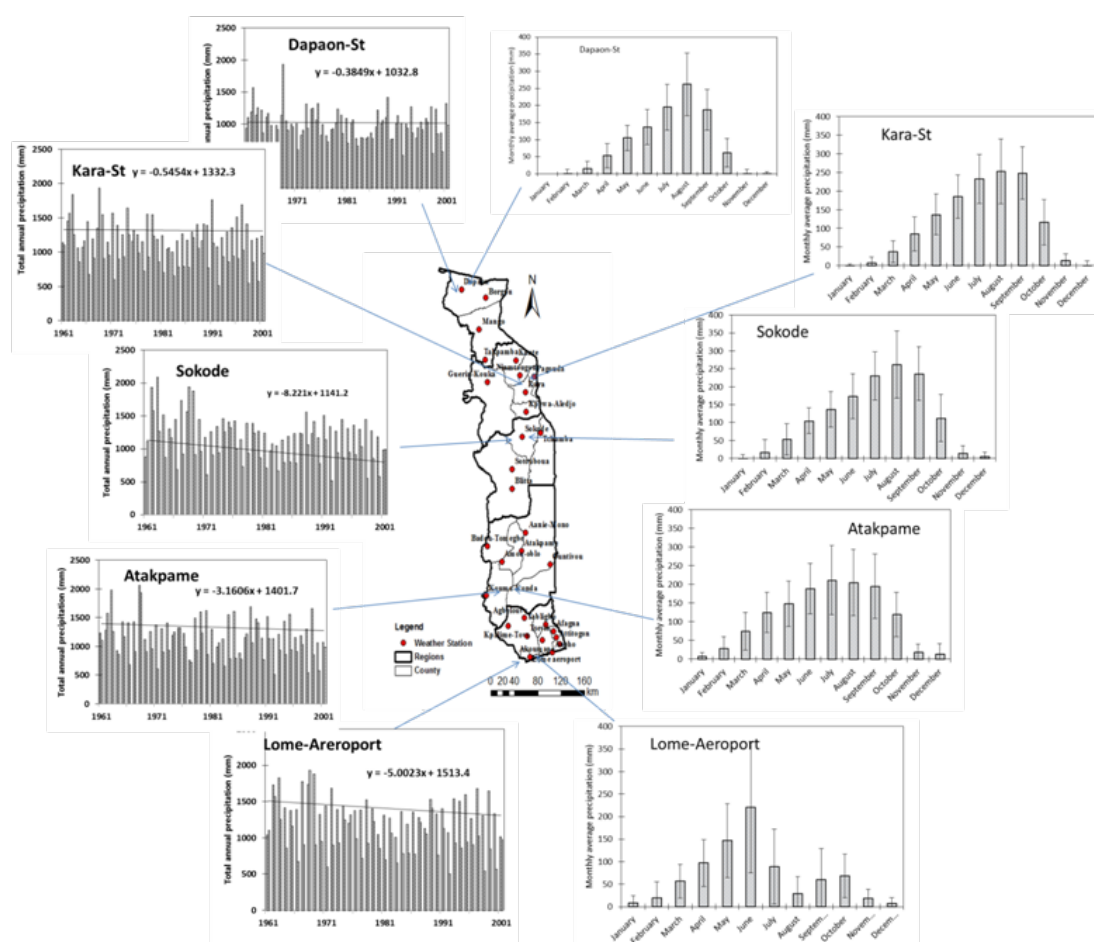


Figure 5 Spatial and temporal variability in monthly and annual regional rainfall in Togo for the 1961–2001 period.

Conclusion

Better understanding of spatio-temporal variability in precipitation across Togo is important and useful for water users and most agricultural activities. The results of this study showed decline in annual total precipitation across almost all agro-ecological zones in Togo. The Maritime Region was revealed the driest and the Plateaux Region, the wettest. The Kouma-Konda site received the greatest 40 year average annual precipitation in the country with 1,714 mm. June was the wettest month across Togo. The greatest coefficient of variation (82%) in monthly precipitation was registered in January

for the study period. The Mann-Kendall test revealed declining trends in annual precipitation at 80% of the weather stations. Therefore most part of the country is experiencing increase in the severity of aridity. The results of this study could be used by water management institutions, universities, and crop consultants for better planning when designing and managing rainfed and irrigated crop production systems in Togo.

Acknowledgment

None.

Conflict of interest

None.

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