Attiogbé *et al.*
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Climate vulnerability of coffee-cocoa agrosystems in the sub-humid mountain ecosystems in south-west Togo (West Africa)

Afi Amen Christèle Attiogbé*, Komla Elikplim Abotsi, Kossi Adjossou, Essi Nadège Parkoo, Kossi Adjonou and Kouami Kokou

Abstract

Changes in climate patterns are the main challenges being faced by the coffee and cocoa production systems, one of the key sources of livelihood for farmers in Togo's humid dense forests zone, also known as "Togo ecological zone IV". The objective of this study was to analyze the climatic vulnerability of coffee-cocoa agroforestry systems (CCAFS) in Togo ecological zone IV both ongoing (last 40 years 1980–2019) and the incoming decades (by 2050) considering climate forecast under AR6 socioeconomic pathways. The Standardized Precipitation Index (SPI) approach with the Mann–Kendall & Sen's tests and the MaxEnt tool were used to assess the drought condition and the potential impacts on CCAFS suitability in the study area. The results show instability in rainfall series with a non-significant progressive trend in the area during the past four decades, while a significant increase in temperature was observed. Beyond 2050, suitable areas for coffee and cocoa species will drift to the pic mountainous part. Thus, respectively 51.91 and 54.50% of currently suitable areas for the two species, will be lost under the future climate scenario SSP3-7.0 and SSP5-8.5. These losses are mainly due to the reduction of precipitation of the driest month (Bio14), precipitation of the driest quarter (Bio17), and precipitation of the coldest quarter (Bio19) of the year. Drought is therefore revealed as the main limiting climatic factor for coffee and cocoa in Togo. The increasing drought intensity in the future is a source of high vulnerability of CCAFS as well as the local farmers' livelihoods.

Keywords: Climate change, Drought, Suitability, Agroforestry, Livelihoods, West Africa

Introduction

The challenge of agriculture in this twenty-first century requires a systemic integration of sustainable development to meet the needs of present generations without sacrificing the livelihoods of future generations. Over the past 30 years, climate change (CC) has been observed at the global level (IPCC 2014). This change is reflected in an increase in global average temperature, higher variability in rainfall, and changes in the occurrence of extreme conditions such as floods, droughts, cyclones, tsunamis, etc. (Amjath-Babu et al. 2016; IPCC 2014). On a global scale, the statistics displayed until the twenty-first century show a warming of the earth at 0.76 °C (Peters et al. 2013). The global warming mapping shows that West Africa is warming over the global average (IPCC 2014). Hence, West African countries will experience, more impacts than other regions (Mbow et al. 2020).

Togo, a West African country, is also concerned by this phenomenon, although it contributes less to global warming as a developing country (MERF 2020). Since the 1990s, Togo has experienced several periods of climate variability, which led to hazards such as droughts, floodings, and high variability in the rain seasonality was observed in 2012s (Badameli & Dubreuil 2015; Badjana et al. 2011; TCN 2015). Furthermore, the fourth

*Correspondence: attiogbeafiamenchristele@gmail.com

Laboratoire de Recherche Forestière, Faculty of Sciences, University of Lomé, Lomé, Togo

communication on climate change in Togo forecasts an increase in the average annual temperature over the entire country from 0.91 to 1.88 °C and an increase in rainfall from 4.73 to 16.3 mm, i.e., an increase of 0.52 to 0.97%, by 2050 (MERF 2020). These phenomena affect several sectors of the economy and the health of the country, including agriculture and forestry. While most of these studies focused on general observations and specify climatic manifestations at the broad scale of the country, it is important to have a particular look at the local scale of coffee-cocoa agroforest systems (CCAFS), which have a potential for adaptation and mitigation to climate change (Gusli et al. 2020; Kandji et al. 2006; Mbow et al. 2014; Nguyen et al. 2013). Indeed, the CCAFS sector makes an important contribution to the Gross Domestic Product (GDP), provides goods for food security, and constitutes a rare sector specific to the sub-humid zone of Togo [called ecological zone IV, located in southwestern Togo (Ern 1979)], where climatic pressures threaten (Abotsi et al. 2020; Koda et al. 2016).

The coffee and cocoa sector occupies about 40,000 farmers who farm, each, an average area of 1.03 ha (DSID 2018b). It also constitutes the main source of livelihood for farmers in the area. In 2019, the coffee and cocoa productions amounted to 21.316 tons and 14.264 tons respectively with a contribution of 1.2% of the agricultural GDP of the country (UTCC 2020). Furthermore, CCAFS provides important environmental benefits such as biodiversity conservation (Adjossou et al. 2019; Jha et al. 2014; Koda et al. 2019); carbon accumulation (Dangbo et al. 2020; Kombate et al. 2019; Van Rikxoort et al. 2014), water storage, and erosion control (Wardle et al. 2012). Getting a good knowledge of the climatic factors to which coffee-cocoa agrosystems are exposed is a preliminary step in managing and planning for the sector in the face of climatic challenges and threats.

Fluctuations in climatic variables such as rainfall and temperature will affect coffee and cocoa plant production, biological diversity, and the geographic distribution of species-friendly habitats (de Sousa et al. 2019; Farrell et al. 2018; Läderach et al. 2013; Schroth et al. 2016; Wang et al. 2016). Changes in the average weather patterns may refer to climate change; the change might be quantitative or qualitative to the system. In response to these weather fluctuations, CCAFS which require longer-lead times may assist in the extinction risk of coffee and cocoa species or their habitats. Ecological zone IV, known as the main coffee and cocoa belt of Togo, has retained researchers' attention due to its valuable resources and potentiality in terms of biodiversity and the outstanding degradation that it is undergoing (Adden 2017; Adjossou et al. 2019; Agbodan et al. 2020; Dangbo et al. 2020; Djiwa et al. 2021; Koda et al. 2019). However, there is still a need for a clear understanding of threats in the context of changes in climate patterns. The current study finds its importance by providing evidence of changes in weather climate that occur in the CCAFS and what is expected to happen under climate scenarios when needed actions are not met.

This study aimed to evaluate the vulnerability of CCAFS of ecological zone IV to climate threats. Specifically, it aims to (i) evaluate the current climatic suitability area for coffee-cocoa cultivation in Togo, and (ii) forecast the suitability area for coffee-cocoa cultivation under the socio-economic greenhouse gas emission scenarios beyond 2050.

Materials and methods

Study area

Togo is a sub-Saharan country located between 6 and 11°N latitude and 0°15'–2° E longitude in the Dahomey corridor which constitutes an interruption of the West African rainforest zone in the Gulf of Guinea (Kokou 2008; Atato et al. 2010). Ecologically, the country is subdivided into five (05) ecological zones. Ecological Zone IV (Fig. 1), the area of the present study, extends between 6°15 and 8°20 N latitude and 0°30 and 1°20 E longitude and covers an area of 6500 Km^2.

The area has a transitional sub-equatorial climate with four seasons: a 'major rainy season from March to July, followed by a 'minor dry season in August, then a 'major dry season from November to February, preceded by a 2 month 'minor rainy season (September to October) (Papadakis 1966). The average annual temperature ranges from 21 to 25 °C and the average annual rainfall is around 1800 mm (Fig. 2).

Ecological Zone IV is characterized by coffee and cocoa-based agroforestry practices. These practices include, in addition to coffee (*Coffea sp.*) and cocoa (*Theobroma cacao*), a large number of forest species such as *Khaya grandifoliola*, *Milicia excelsa*, *Terminalia Superba*, *Alstonia boonei*, *Anthocleista djalonensis*, *Spathodea campanulata*, *Albizia adianthifolia*, *Albizia zygia*, *Ficus mucuso*, *Funtumia africana*, etc.; food crops such as cassava (*Manihot esculenta*), cocoyam (X*anthosoma maffafa*), bananas (*Musa sapientum*), plantains (*Musa paradisiaca*), yams (*Dioscorea* sp), spices of many varieties such as *Monodora myristica* and *Xylopia aethiopica* (Adjossou et al. 2019; Koda et al. 2019).

Data collection

- Climate characterization

  Rainfall and temperature averaged data at monthly and annual time steps over the period of 40 years (1980–2019) were requested from the Amou-Oblo

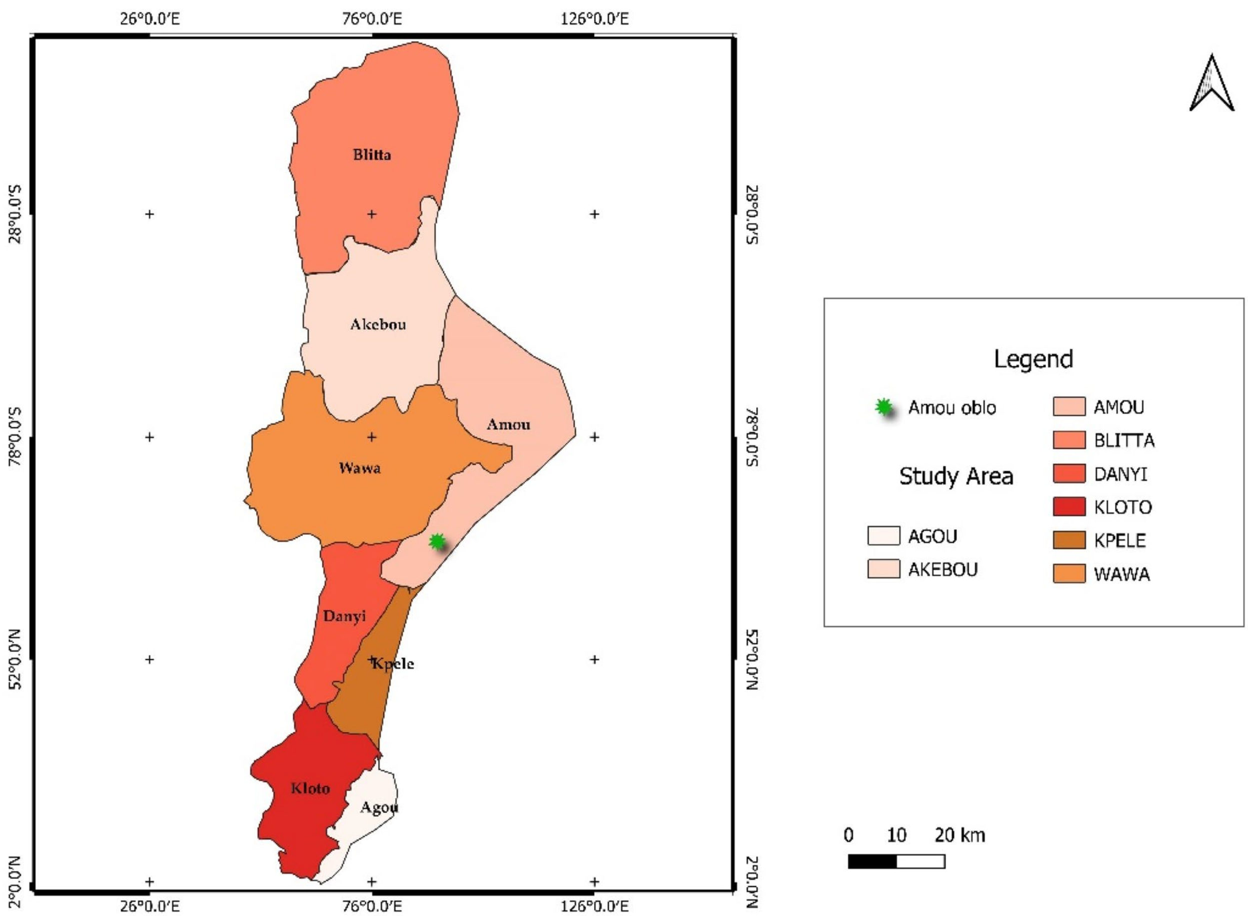

Fig. 1 Location of the study area

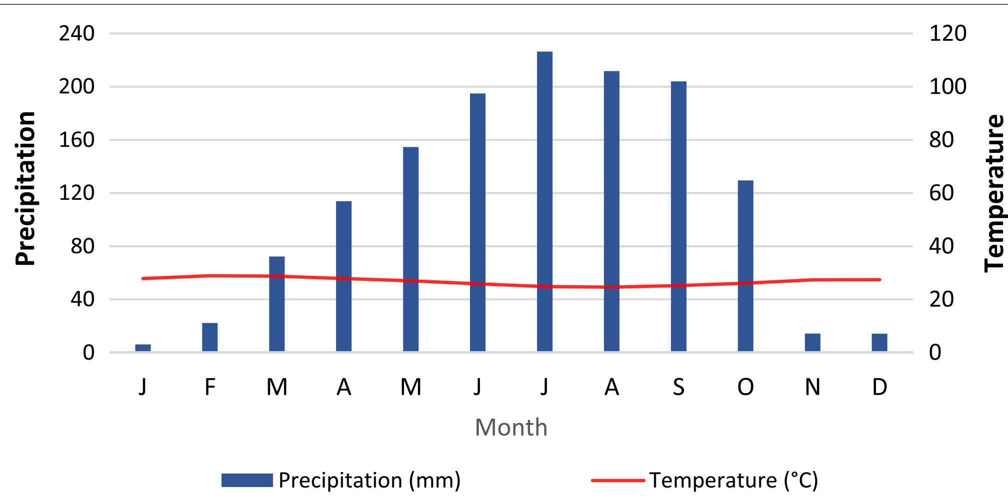

Fig. 2 Ombrothermal curve of Amou-Oblo station

synoptic station at the national meteorological office. The choice of the observed period conforms with the World Meteorological Organization (WMO), specifying a minimum of 30 years for a valid study (WMO 2017).

– Suitability of the coffee-cocoa under current and future climate conditions

The identification of the climatic suitable zone for the development of coffee-cocoa agroforest systems in Togo was done through species distribution modelling (SDM), (Elith* et al. 2006; Guisan & Zimmermann 2000). SDM is a statistical-based method used to determine the environmental niche of a species, system, biome, or genotype, and allows mapping of the distribution both in environmental and geographic space. Environmental variables used in SDM typically include available resources, limiting factors, and, disturbances (Guisan & Zimmermann 2000; Merow et al. 2014; Miller 2010). The present study uses the West African cocoa belt established by Schroth et al. (2016) as a reference site. In total, three (03) models of the improved climate project CMIP6 (Coupled Model Intercomparison Project Phase 6) were used for their high quality and reliability for international climate assessment; (i) BCC-CSM2-MR, Beijing Climate Center-Climate System Model version 2, (ii) CNRM-CM6-1, National Centre for Meteorological Research–Circulation Model version 6 and (iii) CanESM5, Canadian Earth System Model version 5. The MaxEnt version 3.4.1 modelling tool was requested to predict the suitability of coffee and cocoa crops, (Nelson & Phillips 2018). The MaxEnt (Maximum Entropy) software package is one of the most popular tools (machine learning algorithm) for species-distribution modelling that incorporates crop-environment interactions based on the current climatic conditions in the species growing areas. Similar to logistic regression, MaxEnt weighs each environmental variable by a constant. The probability distribution is the sum of each weighted variable divided by a scaling constant to ensure that the probability value ranges from 0(absence) to 1(presence) of the species (Schroth et al. 2017). Our modelling approach compares the distribution of climate zones in which coffee and cocoa is currently produced and their distribution under future climate scenarios. The baseline data were obtained from World Clim version 2 (Booth et al. 2014; Fick & Hijmans 2017). WorldClim, (https://worldclim.org/) is a global weather and climate database that includes bioclimatic variables (Table 1) on a resolution grid referred to as a "1 km" resolution.

Data analysis

Standardized Precipitation Index (SPI), Mann Kendall & Sen's slope statistical tests, and modelling approaches were applied to analyze the distribution of coffee-cocoa species in the CCAFS under the climatic trend. Data were processed using R 4.1.2 software and results were spatialized using QGIS 3.22.

Climatic characteristics in CCAFS

The current climate exposure was assessed based on rainfall and temperature in a series analysis.

Trend in rainfall pattern

To highlight the deficit in annual rainfall variation, SPI was calculated at annual time steps from 1980 to 2019. SPI is a meteorological drought index, worldwide used due to its reliability, and has the advantage to solely based on precipitation data (McKee et al. 1993). SPI compares precipitation with its multiyear average. By transforming the distribution of the precipitation record to a normal distribution, the mean at a yearly scale is then set to zero, and as such, values above zero indicate wet periods compared to periods where values are below zero (Table 2). SPI represents then the difference in rainfall of a year (i) compared to the average of all the years considered, divided by the standard deviation:

Table 1 Bioclimatic variables

ID	Variable
BIO1	Annual mean temperature
BIO2	Mean diurnal range (Mean of monthly (max–min temperature))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature seasonality (standard deviation *100)
BIO5	Maximum temperature of the warmest month
BIO6	Minimum temperature of the coldest month
BIO7	Temperature annual range (Bio5–Bio6)
BIO8	Mean temperature of wettest quarter
BIO9	Mean temperature of driest quarter
BIO10	Mean temperature of warmest quarter
BIO11	Mean temperature of coldest quarter
BIO12	Annual precipitation
BIO13	Precipitation of wettest month
BIO14	Precipitation of driest month
BIO15	Precipitation seasonality (coefficient of variation)
BIO16	Precipitation of wettest quarter
BIO17	Precipitation of driest quarter
BIO18	Precipitation of warmest quarter
BIO19	Precipitation of coldest quarter

Table 2 SPI classification

SPI Classes	Description
SPI > 2	Extremely wet
1 < SPI < 2	Very wet
0 < SPI < 1	Moderately wet
− 1 < SPI < 0	Moderate drought
− 2 < SPI < − 1	Severe drought
SPI < − 2	Extreme drought

Negative annual values indicate drought compared to the selected reference period and positive values indicate wet conditions

$$\mathrm{SPI} = \frac{\mathrm{Xi} - \mathrm{Xm}}{\mathrm{Si}}$$

where: Xi is the cumulative rainfall for a year (i); Xm and Si, are respectively the mean and standard deviation of the annual rainfall observed for the study series; and SPI, Standardized Precipitation Index defines the severity of the drought in different classes (McKee et al. 1993), (Table 2).

Trend in temperature pattern

Apart from rainfall, the temporal evolution of annual average temperatures was analyzed by the linear regressions approach (Badjana et al. 2011). The standard deviation of the temperature dataset was computed for the observed period (1980–2019). This deviation is the difference between the annual average temperature and the normal average for the analysis period. The Mann–Kendall and Sen tests (Kendall 1948; Mann 1945; Sen 1968) were then applied to the climatic variables, to determine the magnitude of the observed trends, if any.

- Mann–kendall test

The Mann–Kendall test is commonly used to detect trends in a time series of environmental, climate, or hydrological data (Pohlert 2018). This test, recommended by the WMO, allows us to appreciate the presence or absence of trends during the study period, (Sirois 1998). One of its advantages is the non-requirement of the dataset to follow a normal distribution. It is also characterized by low sensitivity to abrupt breaks due to heterogeneous time series (Gocic & Trajkovic 2013). Its null hypothesis (H_0) is such that the variables follow a random distribution and there is no trend; and the alternative hypothesis (H_1) is with the trend.

Although the location of this station was not changed during the observed period, we check the consistency of the datasets, by applying the Ljung-Box autocorrelation test was applied at a 95% confidence level (Lazaro et al. 2001). The null hypothesis of this test assumes that the data are independently distributed. The non-significance of our data to this autocorrelation test allows us to conduct the statistical tests as expected (Table 3). However, the months of May and June were found to be auto-correlated at a 95% of confidence level (alpha value = 0.05) but not significant at 90% (alpha value = 0.01).

Table 3 Ljung Box test

Month	1980–2019					
Variables	Rainfall			Temperature		
	x^2	*p*-value	H_0	x^2	*p*-value	H_0
January	16.417	0.08829	Yes	2.9136	0.9834	Yes
February	13.597	0.1922	Yes	8.409	0.589	Yes
March	9.9078	0.4486	Yes	9.3349	0.5006	Yes
April	8.1085	0.6182	Yes	3.7089	0.9595	Yes
May	19.63	0.03296	No	12.196	0.2722	Yes
June	7.211	0.7054	Yes	22.936	0.01099	No
July	17.789	0.05863	Yes	1.7513,	0.9979	Yes
August	6.6311	0.7598	Yes	15.014	0.1316	Yes
September	9.9163	0.447	Yes	50.673	2.007e-07	No
October	16.261	0.0924	Yes	11.904	0.2916	Yes
November	11.232	0.3397	Yes	9.9761	0.4426	Yes
December	14.3	0.1597	Yes	17.751	0.05931	Yes
Total annual	15.825	0.1048	Yes	47.094	9.079e-07	No

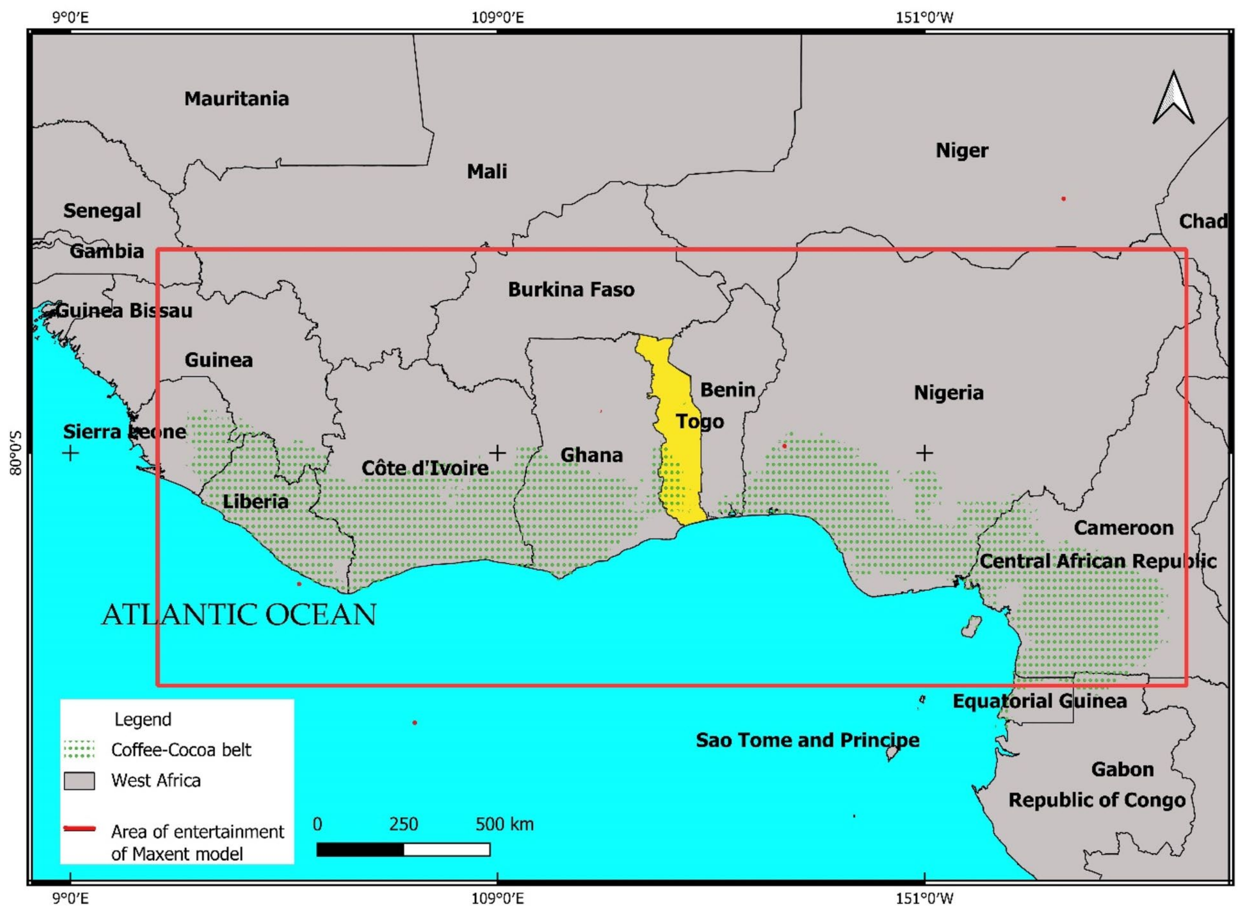

Fig. 3 Production area of coffee-cocoa in West Africa. Adapted from Schroth et al. (2016)

- Theil-sen test

  This approach (Sen 1968; Theil 1950) has been used to estimate the magnitude of the slope of the identified trends (by the Mann–Kendall and Spearman's Rho methods). It is a non-parametric method based on the median slope. Since the latter is less sensitive to outliers than traditional regression methods, it provides a more reliable assessment of the trend (Taibi 2015).

Suitability analysis of coffee-cocoa cultivation area

In the context of this study, the suitability of coffee and cocoa refers to their probability to maintain or shift from their current potential growing area under climatic threats. SDM has recently become very powerful through the introduction of machine-learning algorithms. The coffee and cocoa agroforest occurrence data were extracted from coffee and cocoa production areas in West Africa (Schroth et al. 2016) and digitized using the Quantum GIS version 3.22 software. In total, 822 known presence points were generated in the West African production area at a regular distance of 15 min, from which those in Togo were extracted (Fig. 3). This area was corrected based on ground truth and current knowledge of the production area in Togo. The future climate impact was evaluated by a simulating approach. Three (03) models of the improved climate project CMIP6 (BCC-CSM2-MR, CNRM-CM6-1, and CanESM5) have been used and for each of them, the socio-economic greenhouse gas emission scenarios SSP3-7.0 (medium scenario) and SSP5-8.5 (pessimistic scenario) were acquired at a spatial resolution of 2.5 arc-minutes (i.e. 4.67 km) at the 2050 horizon. The climate data were prepared in the "raster" library of the statistical processing software R version 4.1.2 (R Core Team, 2020). MaxEnt model has been trained at the calibration points of known occurrence and random pseudo absence of coffee and cocoa species with the current (1980–2019) bioclimatic variables acquired further on the WorldClim database and simulate the spatial distribution of relative climatic suitability for cocoa. The quality of the models was assessed through the assessment of values of the area under the curve (AUC)

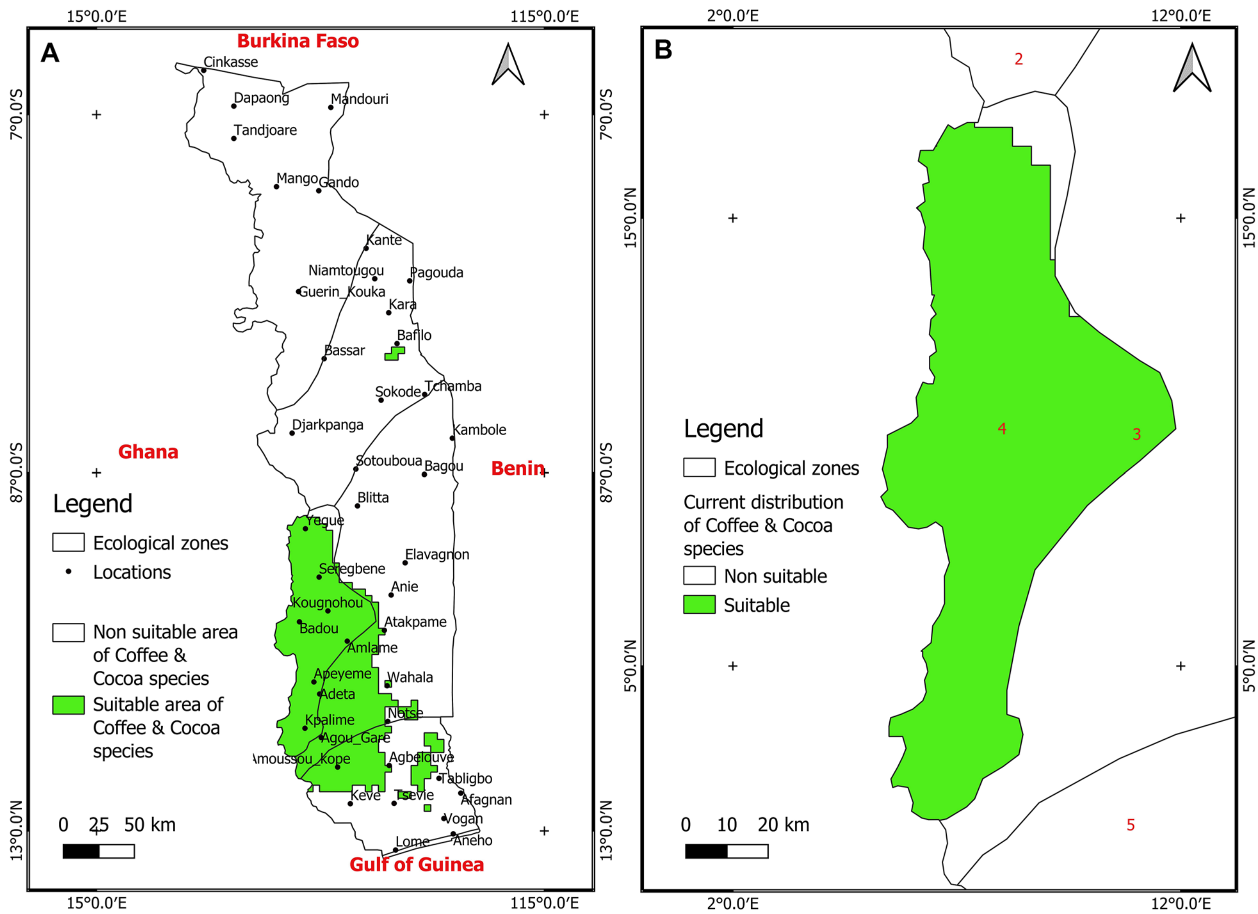

Fig. 4 Potential growing areas of coffee and cocoa (**A**) in Togo, (**B**) zoom on the study area

and the omission rate (Merow et al. 2013). The AUC is the probability that a randomly selected occurrence point is located in a grid with a higher probability of taxon occurrence than a randomly generated point (Phillips et al. 2006) while the model omission rate is the percentage of occurrence points omitted by the model.

The results of the modelling were imported into Quantum GIS 3.22 software to map the current and future geographic distribution of suitable habitats for the coffee and cocoa species under the SSP3-7.0 and SSP5-8.5 scenarios.

Results

Distribution of CCAFS under current climatic conditions

Modelling of the suitable area of the current coffee and cocoa production zone in Togo showed a potentiality of coffee and cocoa crops production in the Ecological Zone IV, but also some significant extent of Ecological Zone III (Notsé), Ecological Zone V (northern part of the prefectures of Avé and Zio (Tovégan, Gapé, Agbélouvé, etc.), and south of Assoli (Bafilo) in Ecological Zone II (Fig. 4). This zone covers an area of 10,504 km^2. The potential coverage that accounts for the ecological zone IV is 5743.70 km^2. The remaining parts may be covered by buildings, forests, other cropland uses due to some socio-economic factors.

The current growing area of coffee and cocoa species underwent a climate characterized by several perturbations or disturbances. Indeed the time series analysis of the annual rainfall showed significant variability, with a slight overall upward trend (Fig. 5). The period is marked by a wide episode of rainfall deficits between 2012 and 2015. The wettest year over the observed period is 2019 (SPI = 1.94) and the driest (SPI = −1.86) results are from 1986. About 60% of the years are characterized by an SPI in the moderate range while 40% carry an SPI in the dry range. This is explained by rainfall amounts that dropped during the first two decades and gradually increased during the last two decades.

In 5 year order, the series analysis distinguishes four wet periods and four dry periods. The average values of the SPI index are globally positive in the years 2005–09 (0.73) and 2015–19 (0.4), while they are negative in all

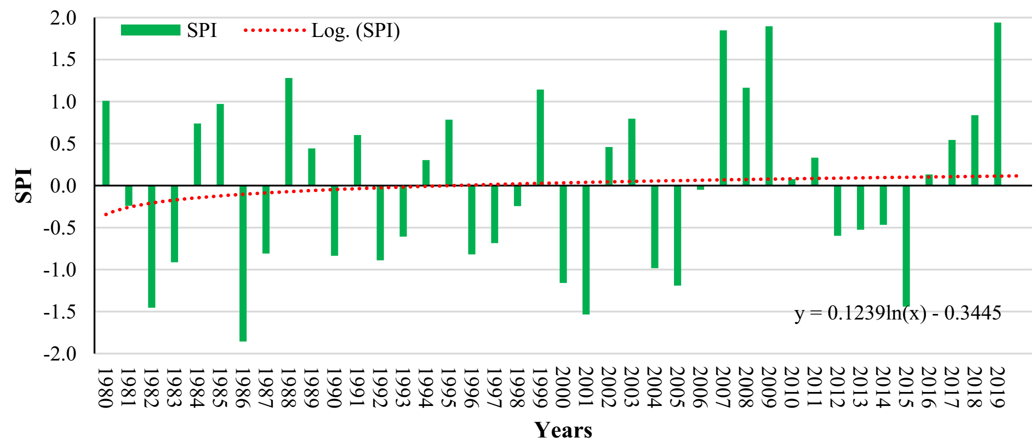

Fig. 5 Evolution of SPI in the study area from 1980 to 2019

Table 4 SPI of 1980–2019

Period	SPI				
	Max	Min	Mean	St. dev	Classes
1980–84	1.01	− 1.45	− 0.17	0.94	MD
1985–89	1.28	1.86	0.01	1.17	MW
1990–94	1.14	− 0.89	− 0.29	0.62	MD
1995–99	1.14	− 0.82	0.04	0.79	MW
2000–04	1.9	− 1.54	− 0.48	0,93	MD
2005–09	1.9	− 1.19	0.73	1.19	MW
2010–14	0.33	− 0.6	− 0.24	0.37	MD
2015–19	1.94	− 1.44	0.4	1.1	MW
1980–2019	1.94	− 1.86	0.01	1	MD

MD moderate drought, MW moderate wet

the dry quinquennia. Moreover, it should be noted that although the periods 1985–86 and 1995–99 appear wet, the magnitude is low since the SPI values, respectively are 0.01, and 0.04. Considering the average of the overall series, SPI = 0.01, the rainfall crisis in the CCAFS has been of moderate order (Table 4).

The Mann–Kendall test confirm the positive trend in all months except April and December, which showed a slight negative trend. However, neither month nor annual rainfall pattern was shown to be statistically significant at the 95% confidence level, p-value < .05 (Table 5). A restrictive analysis of the wet period, corresponding to June, July, August, and September (JJAS), and the meteorologically dry months (November, December, and January) also showed a non-significant positive trend. Although the overall trend in rainfall data analysis is non-significant, it is observed great variability monthly and annual basis of rainfall data over the last four decades (1980–2019).

The analysis of the average temperature over the observed period (1980–2019) reveals an unequivocal increase in temperature. The linear trend observed in the mean temperature indicates an increase with a mean deviation of 0.6 °C and a maximum deviation of 1 °C from normal (Fig. 6). Considering the 10 year averages of this station, there is a remarkable warming in 1998 and a slight cooling in the years 1999, followed by continuous warming over the rest of the period, hence emphasizing the vulnerability of the CCAFS to the climate variability.

Statistically, this upward trend was significant at a 95% confidence level, p-value < .05, (MK = 0.624) with a p-value = 2.22e-16 for all temperature datasets, whether on at monthly or annual basis of the observed period (1980–2019). The trend magnitude of the temperature dataset is an average of S = 0.025, which suggest a slight increase in temperature. The increase in annual temperature observed in the study area is most notable by the increase in the meteorologically dry months of November, December, and January (Table 6).

Distribution of CCAFS under future climate conditions

Future projections based on the median scenario SSP3-7.0 showed a 51.91% (2981.55 Km^2) of reduction in the potential area for coffee-cocoa production in Togo. This is reduced to the sub-mountainous regions of Kpalime, Danyi Apeyeme, Badou, a part of the Akébou plateau (Yégué), and a tiny part of the northern area and account for 48.09% with an area of 2762.15 Km^2 which shows high suitability (Fig. 7a). The result is quite similar under the pessimistic scenario SSP5-8.5 for the distribution of coffee and cocoa, except that there is a greater exclusion of some suitable extent at the northern part. The area loss under this scenario is 3130.32 km^2 which accounts for 54.50% of the total coverage area of the coffee and

Table 5 Result of Mann Kendall and Sens Slope tests for rainfall dataset

Month	1980–2019					
	Z	Tau	*p*-value	Z	S	*p*-value
January	70	0.102	0.39385	0.8526	0	0.394
February	93	0.122	0.28159	1.0768	0.054658	0.281
March	44	0.0564	0.61637	0.51	0.517619	0.616
April	− 78	− 0.1	0.36965	− 0.8971	− 0.7155128	0.37
May	8	0.0103	0.935	0.0815	0.0963768	0.935
June	28	0.0359	0.75308	0.315	0.2645161	0.753
July	134	0.172	0.12124	1.5496	2.337963	0.121
August	− 32	− 0.041	0.71796	− 0.3611	− 0.4750679	0.718
September	45	0.0577	0.60817	0.5126	0.6635714	0.608
October	66	0.0846	0.44886	0.7573	0.59875	0.449
November	50	0.0648	0.56729	0.5720	0.06533	0.567
December	− 57	− 0.0889	0.46721	-0.7270	0	0.467
Total annual	98	0.126	0.25841	1.1302	3.830833	0.258
Wet Period	95	0.122	0.2734	1.0953	0.6644958	0.273
Dry period	63	0.0809	0.46996	0.7225	0.0585784	0.47

cocoa cultivation and the remaining is 2613.38 Km^2 with 45.50%, (Fig. 7b).

In General, under the socio-economic climate scenarios 3–7.0 and 5–8.5, the coffee-cocoa species suitability modelling shows a shift of approximately 50% of the distribution under the current climatic conditions. According to the vulnerability framework of crop suitability proposed by Baca et al. (2014) and Schroth et al. (2016), (1 = high suitability > 50%, 2 = medium suitability 20–50%, 3 = low suitability < 20%), the suitability of the ecological zone IV is in the medium range.

The model of the distribution of coffee and cocoa crops has an excellent predictive quality (AUC = 0.886), Fig. 8. The omission rate was assessed at 10% of the maximum threshold. According to bioclimatic variables considered by the model, Bio14 (precipitation of the driest month), Bio17 (precipitation of the driest quarter), and Bio19 (precipitation of the coldest quarter) had the most

Table 6 Results of Mann–Kendall and Sens Slope of temperature dataset

Month	1980–2019					
	Mann–Kendall (Z)	Mann–Kendall (tau)	2-sided *p*-value	Sens slope (Z)	S	*p*-value
January	213	0.279	0.013198[a]	2.48	0.024	0.01320[a]
February	297	0.389	0.00054252[b]	3.46	0.028	0.00054[b]
March	206	0.269	0.016622[a]	2.40	0.022	0.01662[a]
April	239	0.313	0.0054158[b]	2.78	0.024	0.00542[b]
May	284	0.372	0.00094259[b]	3.31	0.029	0.00094[b]
June	393	0.526	4.1723e-06[b]	4.60	0.025	0.00001[b]
July	372	0.488	1.4544e-05[b]	4.34	0.033	0.00001[b]
August	311	0.41	0.0002867[b]	3.63	0.023	0.00029[b]
September	417	0.55	1.1921e-06[b]	4.87	0.027	0.00001[b]
October	283	0.372	0.00097978[b]	3.30	0.025	0.00098[b]
November	271	0.359	0.0015581[b]	3.16	0.022	0.00156[b]
December	389	0.508	5.8413e-06[b]	4.53	0.046	0.00001[b]
Total annual	469	0.624	2.22e-16[b]	5.49	0.025	0.00001[b]

[a & b] significance level of *p-value;* [a]*statistically significant;*

[b] *statistically highly significant*

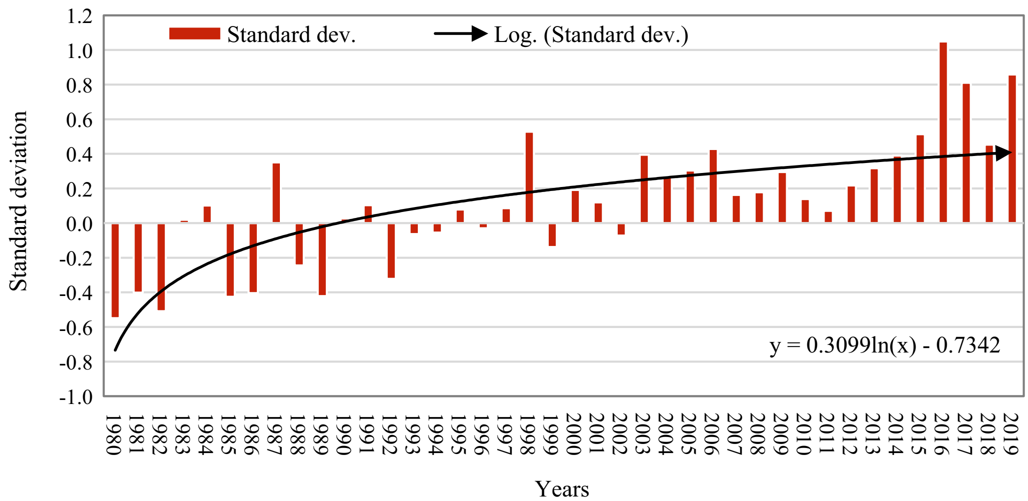

Fig. 6 Trend in observed temperature in 1980–2019

contribution to the distribution of the coffee and cocoa species (Table 7). However, the variable Bio19 explain better the distribution of the species than the others because it decreases the gain the most when it is omitted; therefore Bio19 appears to have the most information that isn't present in the other variables (Table 7). Thus, the precipitation of the driest month (Bio14), and the precipitation of the coldest quarter (Bio 19) constitute the limiting factors of coffee and cocoa species growth.

Discussion

Impact of the historical climate variability on the current distribution of coffee-cocoa species

The climate variability is very serious and is well known as the driver of changes in the agriculture and forestry sectors in Togo (Ali 2018; Emmanuel et al. 2019; Koudahe et al. 2018). Good knowledge of the critical values of the series of various meteorological parameters, such as rainfall, temperature, and some of their derived indices, is useful to both researchers and policymakers in their decision-making, since it plays a dominant role in the decision on the utilization of available moisture for crops production.

Within the observed period, the rainfall and temperature analysis revealed the climatic instability to which CCAFS in Togo are exposed. For instance, the SPI values vary between −1 and 1 ($-1 < SPI < 1$) implying that the rainfall pattern in ecological zone IV is not uniformly distributed. To add, it has fluctuated between moderate and irregular mode. These results are in line with Batebana's findings (2015) which reveals many fluctuations in rainfall across the whole country. High variability found in December, January, February, and March has been confirmed by Djaman (2017). The nonsignificant increase in rainfall has also been affirmed by Nimon's studies in the Southern Togo, (Nimon et al. 2020)**.** Indeed, this result can be explained by the geographical conditions of this mountainous area and the country's objective on reforestation efforts, which favors the conservation of the few forests cover and an increase in tree plantations. In other ways, the observed variability could explain the fact that the potential growing area is not fully covered by coffee and cocoa cultivation, but rather other competing land uses. Concordantly, some studies have revealed that, while global circulation models project rainfall to be increased in some parts of the world and decreased in others, a more widespread projection is that rainfall intensity will increase while annual rainfall will remain largely unchanged (Easterling et al. 2000; Frich et al. 2002). Nevertheless, some studies have found an overall decrease in rainfall across the area, (Djaman 2017; Koudahe et al. 2018). This could be explained by a non-site-specific analysis of these studies. This trend toward shorter rainy seasons was highlighted by Adewi in 2010 in his study on the evolution of rainy seasons, which found, a break in the seasonal cycle and an increase in the variability of the start date of crop seasons (Adewi 2010). Although analysis of the cycle break was not a key to our research objective, we could understand that this factor may affect crop production and determine the harvested products of coffee and cocoa. The driest periods observed in 1990–94 and 2000–04 were also found to be similar in the West African sub-region (Bodian 2014).

The surface temperature was the second climate variable of analysis to understand the variation in time in the growing area of coffee and cocoa in Togo. A maximum

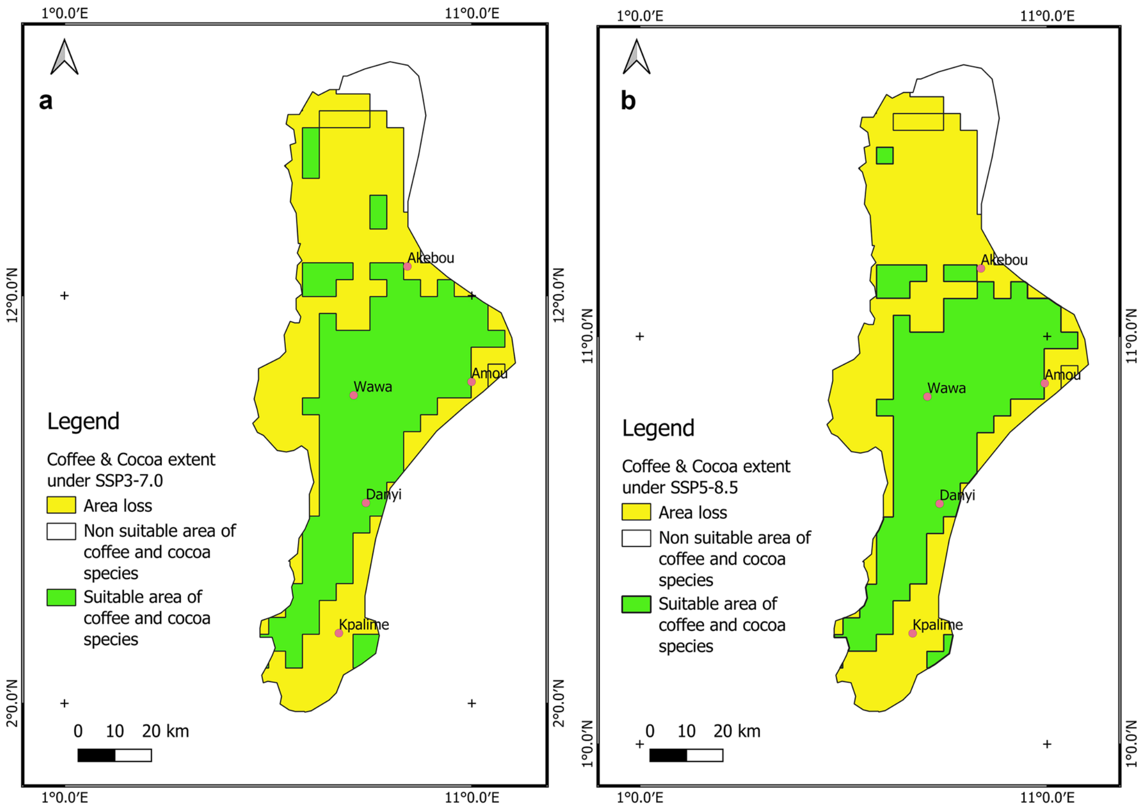

Fig. 7 Coffee-cocoa species distribution in the study area under scenarios SSP3-7.0 (**a**), SSP5-8.5 (**b**) to 2050

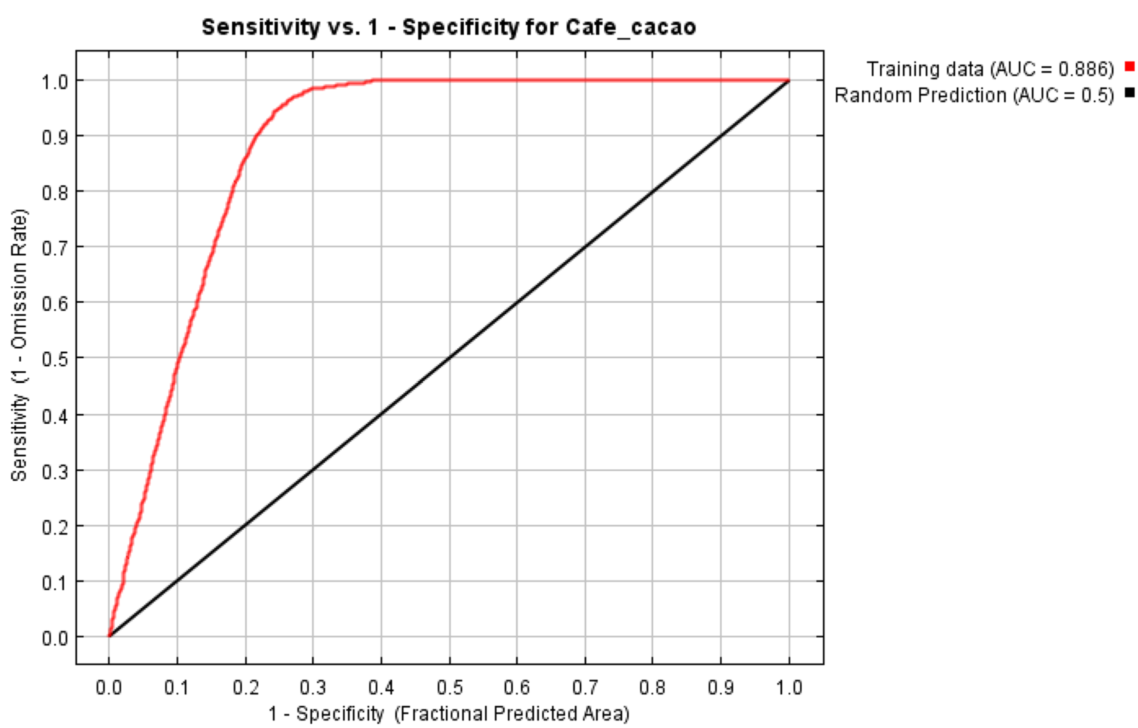

Fig. 8 Predictive quality of the MaxEnt model

Table 7 Environmental variables contribution to the MaxEnt model

Variable	Percentage contribution	Permutation importance
Bio14	66.5	11.5
Bio17	10.1	3.7
Bio19	8.9	15.3
Bio15	3.8	8.9
Bio9	1.8	5.1
Bio2	1.6	5
Bio13	1.3	9.3
Bio11	1.2	2.8
Bio18	1	2.9
Bio7	0.8	4.5
Bio1	0.7	3.5
Bio6	0.6	0.3
Bio16	0.4	6.2
Bio5	0.4	6.1
Bio3	0.3	2.3
Bio8	0.3	2.7
Bio12	0.2	9.5
Bio4	0.2	1.9
Bio10	0	0.3

temperature of 31.60 °C was observed in January and the minimum temperature of 25.4 °C was recorded by August. However, these values are weakly correlated with the correspondent rainfall (R = 0.09), which shows a pic in this August and, the lowest in January. The excessive increase of the temperature observed from the year 2000 until 2019 could be explained by the continuous deforestation activities that have taken place in this area known as the forest zone, and also phenomena of vegetation fires. Sen's slope, however, is not very strong for monthly as well as annual variations, which implies that the magnitude of the increased temperature is slight over the observed period. Results of Koudahe et al. (2017) also confirm this increasing temperature with a rose by minimal temperature by 0.4 °C per decade. Nonetheless, since the result of the Mann–Kendall test and Sen's slope varies one from another, either monthly or annually, over the whole year, it testifies how much variability occurs in the study area. The significant increase in temperature in the Agroforest Systems of the ecological zone IV of Togo is a general observation across the country (Badameli & Dubreuil 2015). Similarly, a study in northern Togo revealed the increase in temperature and its significant impact on the yields of cereals, maize, sorghum, and millet, (Gadedjisso-Tossou 2021). Our results support the vulnerability findings of the fourth national communication by confirming a deterioration of the natural climatic conditions in Togo marked by the increase in the temperature, factor which is influencing the repartition of the coffee and cocoa species.

Impact of future climate conconditions coffee-cocoa species distribution

Climate change has already triggered species distribution shifts in many parts of the world (Carpenter et al. 2014; van Vuuren 2007). Climatic parameters such as rainfall and some of their derived indices are of great importance in detecting variability that has implications for plant growth and is simultaneously related to crop yields (Gadedjisso-Tossou et al. 2019). The modelling for future climatic impacts was revealed through the analysis of the distribution of coffee and cocoa species, which allowed us to improve our knowledge of the climatic factors that are the most determining for the distribution of coffee and cocoa species in its cultivation areas in Togo.

Coffee and cocoa crop cultivation in Togo will experience a shift of approximately 50% under future conditions compare to the current climate conditions' potentiality. The impact of climate change with the warming scenarios will affect the distribution of coffee and cocoa species in the ecological zone IV, particularly by reducing the suitable area. The remaining areas most likely to retain high suitability were found in the very high mountainous part in the proximity of forest reserves and riparian forests where precipitation is most likely to remain sufficiently high (Fig. 7). Similar results have been found by Baca et al. (2014) et Läderach et al. (2013). Climate change is thus likely to cause additional challenges that are already being faced the the coffee and cocoa sector in Togo. Schroth's (2016) study on "Cocoa Vulnerability to Climate Change in West Africa reveals that by 2050 temperature values will no longer be within the tolerable range for cocoa in Togo, Guinea, Liberia, and Nigeria. These trends are said to be of high or very high impact on coffee and cocoa production by changing pests, diseases and weeds, post-harvest risks, soil erosion and to irregular flowering or fruit abortion. The shift in cocoa cultivation area is explained here with only consideration of an increase in temperature variables and the instability in the rainfall pattern, which constitute the exposure aspect (Exposure = 2). Thus, this result could be moderate or exacerbated by other socio-ecological conditions such as farmers' ability to adopt protective measures, shade cover and rehabilitation practices, pest management, irrigation practices, efficiency in soil conservation measures, changes in coffee and cocoa varieties, institution implications in management actions, etc. Soil properties or attributes also have been shown to influence the repartition of cocoa species (Borden 2020; Bunn et al. 2019). Even though the climate scenarios suggest droughts risk conditions in the West Africa belt (Druyan 2011; Rodríguez-Fonseca et al. 2015), the uncertainties in rainfall projections might influence this observation. These results underline the urgency of planning the coffee and cocoa sector production and considering the potential impacts of climate variability in the adaptation strategies. Our result is in line with Läderach et al. (2013) classification, who classify globally the cocoa cultivation area in Togo under Zone 2 of cocoa suitability. According to him, this zone is characterized by medium suitability that can sustain over the coming decades despite increasing environmental pressures with adaptive strategies. Other researches support this claim by arguing that this zone can be improved by a progressive shift to an alternative main crop, and a greater diversity of farming systems within the landscape (Afriyie-Kraft et al. 2020; Schroth et al. 2017). Diversification, especially for crops, is recognized as one key component of an adaptation strategy where decreasing climatic suitability for cocoa implies an increased risk of crop failure during extreme years (Altieri et al. 2015). We argue that the diversification within this area not only implies changes in farming practices but, involves the whole supply chain including the government's institution, the private sector, and the local and international market sector. Substantial difference has been shown between coffee and cocoa species, this is in deference of cocoa which will be more affected by changes in climatic parameters (Abdulai et al. 2018; Läderach et al. 2013; Schroth et al. 2016). As for coffee, the current areas for royalty production will no longer be suitable by 2050, especially in areas of medium-altitude 400–700 m, (de Sousa et al. 2019). This trend is already noticeable on the sites of the low proportion of the cocoa (26,531 ha) crop to coffee (41,405 ha). Production data confirm the downward trend in the area cultivated with cocoa correlated with yield (especially in the prefectures of Kpélé and Amou), (DSID 2018a). Considering rainfall variability, the southwestern part of the CCAFS area will be conducive to coffee and cocoa farming in the upcoming years, only with adaptive strategies. The high vulnerability of agroforestry tree species associated with coffee and cocoa under changing climatic conditions was also highlighted, (de Sousa et al. 2019). Therefore, special attention must necessarily be paid to the management of coffee-cocoa tree species so that agroforestry systems remain the best alternative for climate adaptation of coffee and cocoa fields.

Conclusion

The compelling evidence of global warming and its impact has firmly established that climate change is effective, and its consequences will be severe for coffee-cocoa agroforestry systems in Togo as proved. The purpose of this study was to assess climatic conditions potential impacts on CCAFS distribution in Togo. This study provided a comprehensive understanding of the historical trend of observed rainfall and temperature dataset. The climatic changes felt through a significant variability characterized by a non-significant increase in the rainfall and significant increase in the temperature at annual scale. Looking at the given distribution of the coffee and cocoa species, it is understood that their current occupation has been modelled by fluctuation in the climate and this effect will be exacerbated in the global warming context. These conditions might affect the coffee and cocoa species physiology aspect and thus the yields. The agricultural impacts of these climate variations could be of greatest concern to the country, due to its high dependence on agriculture, subsistence level of operations, low adaptive capacity, and limited institutional support. The consequences of the climate variability might also affect the socio-economic conditions of coffee and cocoa farmers if adaptive measures and mitigation options are not met. However, it is important to mention that though the used MaxEnt distribution model is widely accepted, importance should be given to the global circulation model choice. Other scholars suggest the use of an ensemble model for a better result. Given these findings, we can conclude that our hypothesis that coffee and cocoa agroforestry systems are vulnerable to climate variability and change is verified and confirmed; therefore, adaptation efforts are urgently needed for a better future. In perspective, it is necessary to consider studies of seasonal variations of climatic parameters, factors such as wind, sunshine, soil moisture and their implication on the yields and quality of coffee and cocoa beans to foresee effective adaptation strategies that could better renovate and restore CCAFS in Togo.

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Author contributions

Conceptualization: AACA wrote the manuscript text. The data curation and analysis were performed by AACA, ENP and KEA. The work has been done under the supervision of KA, KA, and KK. The first draft of the manuscript was written by AACA and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate
Not applicable.

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The authors declare that they have no conflict of interest.

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