Heliyon 5 (2019) e02654

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.heliyon.com

Research article

Understanding climate variability and change: analysis of temperature and rainfall across agroecological zones in Ghana

Peter Asare-Nuamah [a,*], Ebo Botchway [b]

[a] Pan African University, P.O. Box 18, Soa, Cameroon
[b] University of Professional Studies, Accra, Ghana

ARTICLE INFO

Keywords:
Environmental science
Climate change
Climate policy
Environmental analysis
Environmental assessment
Sustainable development
Temperature
Rainfall
Ecological zones
Ghana

ABSTRACT

In an agrarian economy like Ghana, the need to understand climate change is as paramount as finding solutions to address the challenges of climate change. While a large body of literature has focused on exploring the impact of climate change, very few studies in Ghana have attempted to expand our knowledge on the extent of climate change across ecological zones in Ghana. This study used Ghana Meteorological Agency's climate data from 1989 to 2015, to assess the characteristics and trends of rainfall and temperature across the six ecological zones in Ghana. With the aid of descriptive statistics, Mann-Kendall test, linear regression, analysis of variance and post-hoc comparison using Tukey HSD test, the study found increasing trend of temperature and decreasing rainfall across ecological zones and provided policy recommendations essential to offset the adverse impact of climate change particularly on agriculture.

1. Introduction

In contemporary global development discourse, climate change is considered a great threat to sustainable development. Indeed, climate change is a matter of life and death due to its grave impact on socio-economic development, particularly in the Global South (FAO et al., 2017; IPCC, 2018). The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change of climate which is attributed directly or indirectly to human activities that alter the composition of the global atmosphere and that is in addition to the natural climate variability observed over comparable time periods" (UNFCC, 2011). Substantial body of literature has demonstrated that climate change is mainly attributed to anthropogenic activities (Anderegg et al., 2010; Doran and Zimmerman, 2009; IPCC, 2013). Manifestation of climate change in the body of literature includes rise in temperature and sea levels, increase in the emission of greenhouse gases (GHGs) and erratic, unpredictable and unreliable rainfall patterns and seasons. In addition, melting of ice and glaciers, floods, droughts and ENSO have dominated literature on climate change (IPCC, 2018, 2013).

In Ghana, about 1 °C increase in temperature occurred between 1960 and 2000 (MESTI, 2013). Future projections indicate that about 1.7 °C–2.04 °C increase in temperature will be observed in Ghana (MESTI, 2013). In addition, about 2.1mm per annum rise in sea level occurred between 1960 and 2000 and it estimated that by 2020, 2050 and 2080 about 5.8 cm, 16.5 cm and 34.5 cm rise in sea level will occur respectively (MESTI, 2013). Moreover, GHGs emission in Ghana increased from 12.2 $MtCO_2e$ to 24 $MtCO_2e$ between 2000 and 2006 (MESTI, 2013). Asante and Amuakwa-Mensah (2015) report that about 107% increase in GHGs emissions occurred in Ghana between 1990 and 2006. In effect, the changing climate has resulted in erratic, unpredictable and unreliable spatial and temporal distribution in rainfall in Ghana (Kabo-Bah et al., 2016; Nyatuame et al., 2014). These changes threaten economic and social development and spell doom for an agrarian economy like Ghana.

Agriculture still plays a dominant role in the livelihoods of households in Ghana, serving as a stimulus for economic growth, providing food security and assisting in poverty reduction (MOFA, 2016). Even though there has been a decline in agricultural sector's performance and its contribution to most socioeconomic indicators, the sector still plays a central role in the Ghanaian economy. For instance, currently the sector contributes about a quarter to the country's GDP but still absorbs the highest proportion of the Ghanaian total employed population, with about 44.7% of the labour force employed in agricultural sector (MOFA, 2016). Notwithstanding, Ghana's agriculture is dominated by smallholder farmers who contribute about 80% of food produced (MOFA,

* Corresponding author.
E-mail address: pasare-nuamah@st.ug.edu.gh (P. Asare-Nuamah).

https://doi.org/10.1016/j.heliyon.2019.e02654
Received 8 September 2019; Received in revised form 4 October 2019; Accepted 10 October 2019

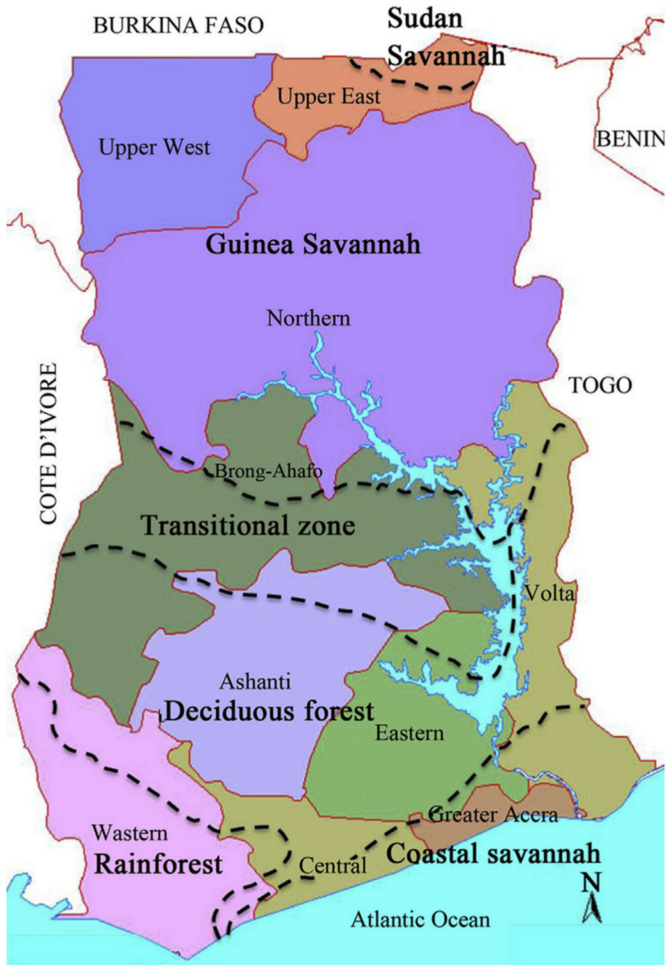

Fig. 1. Ecological zones in Ghana. Source: Kemausuor et al., 2013.

2016). These farmers have limited capacity to adapt effectively to climate change. In addition, agriculture is less mechanized and subsistence in practice, and dominated by the application of physical energy and rudiment tools such as cutlass and hoes. Moreover, only about 3% of arable land in Ghana is under irrigation (MOFA, 2016), which demonstrates the high dependency of Ghana's agriculture on climate particularly rainfall.

The amount of precipitation received determines the availability of water (IPCC, 2013; Nyatuame et al., 2014), for multiple purposes including transportation, hydropower generation, industry and agriculture. Indeed, water is one of the essential natural resources that support both human and animal life. It also serves domestic purposes such as cooking, washing and consumption. One of the most important source of water particularly in developing economies is rain. In Ghana and Sub-Saharan Africa in general, access to water is a great challenge (Sissoko et al., 2011), that hinders social and economic development. This stems from the fact that climate change affects water resources directly through reduction in amount of precipitation and indirectly through high temperature and the corresponding increase in evaporation (IPCC, 2013, 2007). According to Arnell (2004), about 75–250 million Africans are likely to experience water scarcity, due to rising temperature and erratic rainfall.

Nevertheless, few studies have explored rainfall and temperature trends in Ghana (Boansi et al., 2016; Kabo-Bah et al., 2016; Nii Baah, 2018; Nkrumah et al., 2014; Nyatuame et al., 2014). Most of these studies focused on specific areas or regions such as Volta Region (Nyatuame

Table 1
Characteristics of ecological zones in Ghana.

Zone	Rainfall (mm/year)	Proportion of total area (%)	Length of growing season (days)	Major land use systems	Major food crops
Rain forest	2200	3	MJ: 150-160 MN: 100	Forest, plantations	Roots, plantain
Deciduous forest	1500	3	MJ: 150-160 MN: 90	Forest, plantations	Roots, plantain
Transition zone	1300	28	MJ: 200-220 MN: 60	Annual food, cash crops	Maize, roots, plantain
Coastal Savannah	800	2	MJ: 100-110 MN: 50	Annual food crops	Roots, maize
Guinea Savannah	1100	63	180–200	Annual food, cash crops, livestock	Sorghum, maize
Sudan Savannah	1000	1	150–160	Annual food crops, livestock	Millet, sorghum, cowpea

MJ = Major season, MN = Minor season. Source: MOFA, 2016.

Table 2a
Statistical summary of rainfall in deciduous forest.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Total Annual rainfall	756.3	2766.7	3523.0	85391.5	3126.7	226.3	51224.8	-0.039	-1.244	0.07
Average Annual	63.0	230.6	293.6	7116	263.6	18.9	355.7	-0.039	-1.244	0.07
Major season	953.6	1247.5	2183.1	52094	2003.6	171.1	29266.6	-3.621	16.195	0.09
Minor season	818.3	524.3	1342.6	21239.8	816.9	199.8	39910.2	0.568	0.177	0.2
Dry season	453.9	10.5	464.4	5032.1	193.5	115.7	13383.8	0.475	-0.078	0.6
Jan	141.8	2.0	143.8	1265.8	46.9	37.1	1376.6	0.852	0.576	0.8
Feb	184.0	3.0	187.0	2332.6	86.4	60.3	3632.9	0.101	-1.344	0.7
Mar	281.8	135.4	417.2	7389.8	273.7	59	3483.5	0.213	1.011	0.2
Apr	322.0	198.7	520.7	9545.7	353.5	75.9	5766.3	0.494	0.218	0.2
May	366.6	258.6	625.2	12720.4	471.1	100.4	10088.7	-0.553	-0.229	0.2
Jun	284.3	381.8	666.1	14886.5	551.4	72.3	5234.7	-0.446	-0.444	0.1
Jul	392.2	116.9	509.1	9564	354.2	84.6	7158.3	-0.519	1.140	0.2
Aug	353.3	8.1	361.4	4085	151.3	90.9	8254.7	0.533	-0.123	0.6
Sep	668.3	178.7	846.3	10111.8	374.5	133.4	17805.1	1.757	5.051	0.4
Oct	372.3	135.2	525.2	8969.7	332.2	102.9	10588.7	0.098	-0.877	0.4
Nov	303.5	15.4	318.9	2904.4	107.6	95.5	5700.8	0.995	0.727	0.9
Dec	278.9	1.4	280.3	1615.8	59.8	61.8	3851.2	2.293	6.322	1.0

et al., 2014), Central Region (Nii Baah, 2018), Upper East Region (Issahaku et al., 2016) and Kumasi (Campion and Venzke, 2013). Kabo-Bah et al. (2016) took a step further to examine rainfall and temperature across 22 meteorological stations in Ghana but focused on climate change and hydropower generation nexus. While the present study recognizes the growing body of literature, there is a dearth of literature on rainfall and temperature across agro-ecological zones in Ghana. Hence, this study fills the identified gap and contributes to the growing body of literature by assessing changes in rainfall and temperature from 1989 to 2015, across different ecological zones. The remaining sections of the paper present the methods, findings and discussion, conclusion and implications.

2. Materials and methods

2.1. Study setting

The study explored climate change in the six agro-ecological zones in Ghana, which is located in West Africa on Latitude 4° 44′N and 11° 11′N and Longitude 3° 11′ W and 1° 11′E and shares border with Ivory Coast to

Table 2b
Statistical summary of temperature in deciduous forest.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Average Annual	2.2	25.7	28	729.2	27	0.62	0.38	-0.76	0.17	0.02
Jan	3.6	25.1	28.7	733.2	27.1	0.87	0.76	-0.47	-0.01	0.03
Feb	3.8	26.4	30.3	767.4	28.4	1.03	1.06	-0.14	-0.87	0.04
Mar	3.3	27.1	30.4	777.4	28.8	0.81	0.65	-0.25	-0.45	0.03
Apr	2.9	26	28.9	755.4	28	0.71	0.50	-1.02	0.94	0.03
May	2.8	25.8	28.6	742.7	27.5	0.78	0.60	-0.75	0.11	0.03
Jun	3.0	24.7	27.7	717.7	26.6	0.84	0.71	-1.14	0.74	0.03
Jul	2.8	23.8	26.5	691.1	25.6	0.73	0.53	-1.33	1.05	0.03
Aug	2.7	23.5	26.1	683.8	25.3	0.79	0.62	-1.43	1.16	0.03
Sep	2.4	24.2	26.6	697.8	25.8	0.65	0.42	-0.97	0.33	0.03
Oct	2.5	25.2	27.7	719.8	26.7	0.63	0.40	-0.76	0.002	0.02
Nov	2.5	28.4	28.3	735.1	27.2	0.70	0.48	-1.03	0.13	0.03
Dec	3.4	24.8	28.2	729.2	27	0.94	0.88	-0.57	-0.03	0.04

Table 3a
Statistical summary of rainfall in transition zone.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Total Annual rainfall	1963.3	2923.6	4899.9	104110	3855.9	445.2	19200.7	0.153	0.239	0.12
Average Annual	164.7	243.6	408.3	8675.8	321.3	37.1	1376.5	0.153	0.239	0.12
Major season	1351.4	1404.6	2756.0	57479	2128.8	313.9	98523.1	-0.146	-0.005	0.09
Minor season	1065.7	775.6	1841.3	33398	1236.9	265.9	70715.9	0.512	0.359	0.2
Dry season	524.4	66.2	509.6	55046	211.7	138.2	19086.2	1.398	1.788	0.7
Jan	123.7	4.4	128.1	1004.8	37.2	33.1	1094.7	1.439	1.300	0.9
Feb	312.0	26.6	338.6	3097.3	114.7	69.3	4796.9	1.231	2.747	0.6
Mar	485.4	49.6	535.0	6768.2	250.7	104.2	10853.9	0.797	1.653	0.4
Apr	481.7	242.6	724.3	12816	474.7	135.5	18359.3	-0.078	-0.860	0.3
May	532.4	307.6	840.0	13410	496.7	128.6	16548.8	0.781	0.444	0.3
Jun	485.7	274.7	760.4	14829	549.2	139.4	19427.3	-0.235	-0.699	0.3
Jul	763.7	63.8	827.5	96558	357.6	160.0	25602.1	0.830	1.772	0.4
Aug	574.9	22.6	597.5	7452.0	276.0	141.3	19966.0	0.266	-0.266	0.5
Sep	740.3	299.8	1040.1	14732	545.6	156.8	24579.1	1.020	2.324	0.3
Oct	564.1	262.4	826.5	14381	532.6	150.8	22755.5	-0.007	-0.421	0.3
Nov	310.2	16.6	326.8	4284.4	158.7	88.5	7833.2	0.151	-0.930	0.6
Dec	405.2	8.4	413.6	1679.3	62.1	96.3	9282.4	3.020	8.850	1.6

the West, Burkina Faso to the North, Togo to the East and the Atlantic Ocean to the South (MOFA, 2016). The total land surface area of Ghana is 243,438km^2 (MOFA, 2016) and the 2010 population census revealed a total population of 24.5 million but was projected to increase to about 28.31 million by 2016 (Ghana Statisticial Service, 2017). Administratively, Ghana is currently divided into 16 regions with Accra as the national capital. It must be stated that Ghana had 10 regions at the time of data collection. Ghana, a lower middle income country has an agrarian economy (MOFA, 2016). As an agrarian economy, major food crops produced includes cassava, maize, plantain, rice, yam, and cocoyam while cash crops such as cocoa, shea butter and oil palm are also produced. The agriculture system in Ghana is subsistence, with about 90% of farms less than 2 ha (MOFA, 2016). In addition, agriculture is less mechanized, and although parts of Northern Ghana practice bullock farming, only about 3% of arable land is under irrigation in Ghana (MOFA, 2016). The dominance of subsistence and rain fed agriculture demonstrate Ghana's vulnerability to climate change.

Ghana has a sub-tropical warm and humid climate. The mean annual rainfall in Ghana is 1187 mm while mean temperature is 26.1 °C (MOFA, 2016). There are six major ecological zones, defined and characterized by soil, vegetation and climate. The ecological zones include: Rain Forest, Deciduous Forest, Coastal Savanna, Transitional Zone, and Northern Savanna which is further divided into Guinea and Sudan Savanna as shown in Fig. 1. The different ecological zones exhibit different climate characteristics. For instance, Coastal Ghana has 26.1 °C mean annual temperature while the far North has 28.9 °C (MOFA, 2016). Similarly, Guinea Savanna and Sudan Savanna receive a mean annual rainfall of 1100mm and 1000mm respectively while the rain forest receives a mean annual rainfall of about 2200mm (MOFA, 2016). a. For bimodal rainfall zones, the major rainfall season starts from March to July, while the

Table 3b
Statistical summary of temperature in transition zone.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Average Annual	2.2	25.7	28	729.2	27	0.62	0.38	-0.76	0.17	0.02
Jan	3.6	25.1	28.7	733.2	27.1	0.87	0.76	-0.47	-0.01	0.03
Feb	3.8	26.4	30.3	767.4	28.4	1.03	1.06	-0.14	-0.87	0.04
Mar	3.3	27.1	30.4	777.4	28.8	0.81	0.65	-0.25	-0.45	0.03
Apr	2.9	26	28.9	755.4	28	0.71	0.50	-1.02	0.94	0.03
May	2.8	25.8	28.6	742.7	27.5	0.78	0.60	-0.75	0.11	0.03
Jun	3.0	24.7	27.7	717.7	26.6	0.84	0.71	-1.14	0.74	0.03
Jul	2.8	23.8	26.5	691.1	25.6	0.73	0.53	-1.33	1.05	0.03
Aug	2.7	23.5	26.1	683.8	25.3	0.79	0.62	-1.43	1.16	0.03
Sep	2.4	24.2	26.6	697.8	25.8	0.65	0.42	-0.97	0.33	0.03
Oct	2.5	25.2	27.7	719.8	26.7	0.63	0.40	-0.76	0.002	0.02
Nov	2.5	28.4	28.3	735.1	27.2	0.70	0.48	-1.03	0.13	0.03
Dec	3.4	24.8	28.2	729.2	27	0.94	0.88	-0.57	-0.03	0.04

Table 4a
Statistical summary of rainfall in coastal savannah.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Total Annual rainfall	1108.4	850.9	1959.3	38744	1435	303.5	92112.3	-0.171	-0.600	0.2
Average Annual	92.4	70.9	163.3	3228.7	119.6	25.3	639.7	-0.171	-0.600	0.2
Major season	1071.5	435.5	1507	27314	1011.6	241.6	58350.6	-0.275	0.044	0.2
Minor season	544.2	59.2	603.4	7201.1	266.7	147	21612.4	0.281	-0.597	0.6
Dry season	255.7	5.3	262	3247.2	124.9	76.9	5912.1	0.288	-1.054	0.6
Jan	78.6	0.6	79.2	594.6	22.0	18.9	358.2	1.248	1.659	0.9
Feb	202	0	202	1659.2	61.5	56.6	3206.9	0.818	-0.213	0.9
Mar	343.9	2.3	346.2	2884.2	106.8	86.4	7468.7	1.473	1.961	0.8
Apr	305.5	52.7	358.2	4979	184.4	85.3	7278.9	0.345	-1.085	0.5
May	334.1	96.5	430.8	7426.4	275.1	78.6	6170.7	-0.077	0.240	0.3
Jun	653.1	102.7	755.8	8983.3	332.7	161.2	25996.6	0.784	0.373	0.5
Jul	365.4	5.9	371.3	3041.3	112.6	86.1	7407.9	1.390	2.138	0.8
Aug	137.3	0.1	137.4	860	31.9	33.6	1126.5	1.801	3.165	1.1
Sep	264.5	4.6	269.1	2102.4	77.9	75.8	5749.6	1.369	1.172	1.0
Oct	337.1	2.1	339.2	3626.3	134.3	98	9596.8	0.505	-0.692	0.7
Nov	152	14.3	166.3	1472.4	54.5	35	1219.6	1.333	2.538	0.6
Dec	188.6	0.1	188.7	1115.3	41.3	40	1593.9	2.091	6.217	1.0

Table 4b
Statistical summary of temperature in coastal savannah.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Average Annual	1.3	27	28.3	751.1	27.8	0.44	0.197	-0.735	-1.148	0.01
Jan	4.3	26.3	28.4	742.9	27.5	0.98	0.956	-0.608	0.291	0.03
Feb	4.2	28.1	30.2	782.1	29.4	1.10	1.204	0.350	-0.647	0.04
Mar	3.5	28.2	30	790.2	29.1	0.98	0.958	-0.588	-0.839	0.03
Apr	4.1	28.1	30.1	790.9	29.3	1.09	1.193	-0.488	-0.245	0.04
May	4.1	27.2	28.4	770.1	28.2	1.08	1.165	-0.718	-0.352	0.03
Jun	2.8	26.5	27.9	736.1	27.3	0.66	0.435	-0.718	-0.241	0.02
Jul	4.4	24.6	26.8	697.1	25.8	1.46	2.137	-0.471	-1.291	0.06
Aug	4.0	24.1	26.1	678.3	25.1	1.13	1.285	0.019	-1.290	0.04
Sep	5.1	25	27.6	709.6	26.3	1.37	1.889	-0.187	-0.948	0.05
Oct	4.5	26.4	28.7	749.4	27.8	1.29	1.676	-0.535	-1.016	0.04
Nov	2.8	28.1	29.8	783.8	29.2	0.76	0.584	-0.593	-0.474	0.03
Dec	2.9	27.9	28.4	778.3	28.8	0.74	0.545	-0.819	0.268	0.03

minor season is from September to October. In the case of mono-modal rainfall zones, the season starts from July to September (MOFA, 2016). These therefore reinforce the major and minor farming seasons in Ghana. Table 1 provides detailed information on the characteristics of ecological zones in Ghana.

2.2. Data collection

The study sourced secondary climate data from Ghana Meteorological Agency in Accra, in 2016. The collected data comprised daily rainfall and temperature from 1989 to 2015 and covered six regions across the six ecological zones in Ghana. Western, Greater Accra, Ashanti, Brong Ahafo, Northern and Upper East Regions were selected respectively from Rainforest, Coastal Savannah, Semi-Deciduous Rain forest, Forest Savannah Transition, Guinea Savannah and Sudan Savannah ecological zones. Aside the differences in ecological zones, the selected regions also exhibit different rainfall and temperature characteristics.

2.3. Data analysis

The researchers screened the data for missing values and filled missing values through last-observation-carried-forward (LOCF) approach, which has been used in previous studies (Chepkoech et al., 2018). In applying LOCF, missing numerical values are imputed with preceding values (Chepkoech et al., 2018). The imputed and observed values are then analyzed as if there was no missing values in the data

Table 5a
Statistical summary of rainfall in Guinea savannah.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Total Annual rainfall	345.5	883.3	1228.2	29136	1079.1	86.15	7421.5	-0.348	-0.309	0.08
Average Annual	28.8	73.6	102.4	2428	89.9	7.18	51.2	-0.348	-0.308	0.08
Major season	193.5	455.9	651.1	13977	537.6	50.31	2531.3	0.361	-0.172	0.09
Dry season	284.9	369.7	654.6	14048	540.3	72.40	5241.1	-0.653	-0.211	0.1
Jan	32.4	0	32.4	94.1	3.458	7.72	59.63	2.723	7.529	2.2
Feb	25.4	0	25.4	273.8	10.141	9.30	86.47	0.249	-1.529	0.9
Mar	83.3	0	83.3	917.7	33.987	21.94	481.4	0.629	-0.175	0.6
Apr	109.6	38.9	148.5	2666.3	98.753	30.20	9112	-0.036	-0.725	0.3
May	86.2	77.3	163.4	3247.2	120.27	20.28	411.3	-0.317	-0.028	0.2
Jun	122.1	97.4	219.5	4161.4	154.13	28.14	791.6	0.482	0.021	0.2
Jul	158.3	86.8	244.8	4305.4	159.46	31.07	965.5	0.306	1.498	0.2
Aug	179.1	96.2	275.3	4765.6	176.50	42.21	1781.6	0.426	0.303	0.2
Sep	118.4	139	257.4	5430	201.11	32.10	1030.7	-0.186	-0.859	0.2
Oct	194.3	36.9	186.2	2885.4	106.87	35.65	1270.8	0.133	0.206	0.3
Nov	41.2	0	41.2	283.1	10.484	10.28	105.6	1.341	1.835	1.0
Dec	34.8	0	34.8	105.7	3.915	7.40	54.7	3.318	12.282	1.9

Table 5b
Statistical summary of temperature in Guinea savannah.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Average Annual	1.0	27.8	28.8	763.3	28.3	0.28	0.077	0.227	-0.832	0.009
Jan	2.1	26.7	28.8	748.2	27.7	0.55	0.303	0.138	-0.542	0.02
Feb	4.3	27.8	32.1	808.8	30.1	1.07	1.155	0.017	-0.166	0.04
Mar	1.9	30.5	32.4	849.6	31.5	0.51	0.261	0.031	-0.660	0.02
Apr	2.5	29.9	32.4	829.7	30.7	0.60	0.366	1.463	2.622	0.02
May	2.3	27.9	30.2	788.4	29.2	0.55	0.304	-0.396	0.175	0.02
Jun	1.8	26.7	28.5	743.7	27.5	0.43	0.189	0.038	-0.310	0.02
Jul	1.4	26.1	27.5	717.2	26.6	0.32	0.105	1.129	1.390	0.01
Aug	0.9	25.7	26.6	706.9	26.2	0.25	0.064	0.213	-0.832	0.01
Sep	1.2	26	27.2	718.4	26.6	0.33	0.115	0.040	-1.008	0.01
Oct	1.6	26.8	28.4	744.8	27.6	0.41	0.171	0.018	-0.250	0.01
Nov	2.8	26.9	29.7	704.4	28.2	0.61	0.384	-0.127	0.856	0.02
Dec	2.6	26.2	28.8	742.6	27.5	0.63	0.398	-0.023	-0.254	0.02

Table 6a
Statistical summary of rainfall in Sudan savannah.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Total Annual rainfall	998.9	366.4	1365.3	25827	956.55	215.58	46474.5	-0.924	1.698	0.2
Average Annual	83.3	30.5	113.8	2166.8	80.25	18.07	326.7	-0.995	1.715	0.2
Major season	872.2	154	1026.2	15885	588.35	174.54	30462.8	-0.254	1.837	0.3
Dry season	274.1	260.4	534.5	9705.1	373.27	83.14	6912.8	0.751	-0.635	0.2
Jan	12.2	0	12.2	50.2	1.859	2.79	7.80	2.187	6.192	1.5
Feb	26.8	0	26.8	179	6.630	8.48	71.85	1.249	0.096	1.3
Mar	34	0	34	269.9	9.996	10.85	117.71	0.947	-0.290	1.1
Apr	137.8	2.8	176.6	1524	56.44	45.46	2066.7	1.505	1.638	0.8
May	180.9	13.7	194.6	2780.4	102.98	50.10	2509.9	0.081	-0.962	0.5
Jun	190	38.7	228.7	3438.4	127.35	52.45	2751.2	0.295	-0.524	0.5
Jul	221.3	91.3	312.6	4884.6	180.91	63.40	4020	0.440	-0.741	0.4
Aug	432.3	23.2	455.5	7028.8	260.33	104.32	10882.3	-0.130	0.069	0.4
Sep	270.6	27.2	297.8	3972	147.11	65.04	4230.2	0.283	0.086	0.4
Oct	129.4	4.2	133.6	1472.6	54.54	33	1088.9	0.347	-0.458	0.6
Nov	43.4	0	43.4	150.4	6.02	11.29	127.39	2.124	4.337	1.9
Dec	33.6	0	33.6	76.6	2.387	8.74	76.32	3.300	9.940	3.7

(Lachin, 2016). Monthly and annual data were computed. The study used descriptive statistics to understand monthly, annual and seasonal characteristics of rainfall and temperature in ecological zones in Ghana. Descriptive statistics such as mean, standard deviation (SD) and variance were computed. Other computations included range, kurtosis, skewness and coefficient of variation (CV). Coefficient of variation was computed as $\frac{sd}{x}$ and was used with standard deviation to examine variability and predictability of climate (Nyatuame et al., 2014).

To examine rainfall and temperature trends in ecological zones in Ghana, the study employed Mann Kendall test, linear regression and linear plots. These tests have been widely used in previous studies (Chepkoech et al., 2018; Jaiswal et al., 2015; Kabo-Bah et al., 2016; Longobardi and Villani, 2010; Nkrumah et al., 2014; Nyatuame et al., 2014). Mann Kendall is one of the non-parametric tests that has gained dominance in climate trend studies (Jaiswal et al., 2015; Kabo-Bah et al., 2016; Li et al., 2018), as it is flexible to normality and homogeneity and insensitive to sharp breaks in time series data (Jaiswal et al., 2015; Karmeshu, 2015). Thus, it does not require data to be normally distributed and homogenous. In Mann Kendall test, non-detect data are assigned common values and the assigned values are smaller than the smallest value in the data set (Blackwell Publishing, cited in Karmeshu, 2015:15). According to Jaiswal et al. (2015) Mann Kendall test sequentially compares data in the data set to each other. In the process of comparison, Karmeshu (2015) stipulates that Mann Kendall (*S*) statistic is incremented by 1, if the value of a later time period is higher than the value of an earlier time period. Alternatively, a decrement of 1 occurs if the value of a later time period is lower than the value of an earlier time period (Karmeshu, 2015). The test also assumes that data set is randomly ordered and independent. Hence, it tests the null hypothesis that there is no trend (Chepkoech et al., 2018; Jaiswal et al., 2015). The alternative

Table 6b
Statistical summary of temperature in Sudan savannah.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Average Annual	1.3	28.6	29.9	788.5	29.2	0.33	0.11	0.568	0.184	0.01
Jan	4.1	25.5	29.6	750.3	27.8	1.03	1.07	-0.260	-0.560	0.04
Feb	4.4	28.3	32.7	821.7	30.4	1.07	1.15	-0.149	-0555	0.04
Mar	3.3	31	34.4	886	32.8	0.77	0.59	-0.335	0.127	0.02
Apr	2.9	31.4	34.3	884.6	32.8	0.74	0.55	0.014	-0.447	0.02
May	3.9	28.7	32.7	834.6	30.9	1.01	1.02	-0.437	-0.259	0.03
Jun	2.5	27.5	30	775.9	28.7	0.67	0.45	-0.077	-0.561	0.02
Jul	2.1	26.4	28.5	738.2	27.3	0.45	0.20	0.566	0.801	0.02
Aug	1.6	26.2	27.8	722.5	26.8	0.38	0.15	0.860	1.129	0.02
Sep	1.4	26.6	28	734.5	27.2	0.36	0.13	0.606	0.008	0.01
Oct	2.0	27.8	29.7	773.9	28.7	0.60	0.36	0.221	-0.937	0.02
Nov	3.7	27	30.7	783.5	29	0.85	0.72	-0.216	0.399	0.03
Dec	2.4	27	29.4	757	28	0.67	0.44	0.232	-1.019	0.02

Table 7a
Statistical summary of rainfall in Rain forest.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Total Annual rainfall	1117.5	3258.9	4353.4	102579	3799	291	84824	-0.186	-0.183	0.08
Average Annual	93.1	269.7	362.8	8548.2	316.6	24.3	589	-0.186	-0.183	0.08
Major season	789.3	2074.5	2863.8	64548	2391	232	53875	0.834	-0453	0.1
Minor season	796.3	650.5	1446.8	25359	939.2	192	36880	0.824	0.631	0.2
Dry season	574.5	127.1	701.6	7627	293.4	120	14293	1.676	4.290	0.4
Jan	142.8	2.8	145.6	1873.4	69.39	46.7	2179.4	0.173	-1.366	0.7
Feb	183	16.1	199.1	2915.9	108	50	2499	0.002	-0.843	0.5
Mar	249.8	134.8	384.6	7287.9	269.9	68.3	4660	-0.282	-0.622	0.3
Apr	398.5	214.5	613	10083	379.4	103	10696	0.674	-0.139	0.3
May	544.7	237.8	782.5	14806	548.4	137	18662	-0.351	-0.343	0.3
Jun	551.5	559.1	1110.6	22174	821.3	149	22263	0.275	-0.585	0.2
Jul	725.9	28.8	754.7	10197	377.7	171	29280	0.400	-0.138	0.5
Aug	401.9	13.4	415.3	4634.1	171.6	103	10645	0.471	-0.235	0.6
Sep	355.1	79.8	434.9	7192.6	266.4	81.3	6607	-0363	0.720	0.3
Oct	675	183.3	858.3	11295	418.3	159	25348	0.837	0.782	0.4
Nov	283	89	372	6872	254.5	80.8	6531	-0264	-0.787	0.3
Dec	472.2	13.5	485.7	3247.9	120.3	87	7565	3.088	12.093	0.7

Table 7b
Statistical summary of temperature in Rain forest.

Parameter (mm)	Range	Min	Max	Sum	Mean	SD	Variance	Skewness	Kurtosis	CV
Average Annual	1.0	26.9	27.9	738.3	27.3	0.28	0.077	-0.099	1.021	0.01
Jan	2.3	26.2	28.5	738,2	27.3	0.54	0.295	-0.044	-0.112	0.02
Feb	2.5	27.3	29.8	773.3	28.7	0.65	0.424	-0.325	-0.358	0.02
Mar	3.1	27.1	30.2	775.2	28.7	0.60	0.355	-0.150	1.951	0.02
Apr	1.9	27.6	29.5	768.8	28.5	0.50	0.259	0.157	-0.810	0.02
May	1.3	27.4	28.7	754.2	27.9	0.33	0.110	0.558	-0.090	0.01
Jun	1.6	26.2	27.8	727	26.9	0.38	0.143	0.164	-0.297	0.01
Jul	1.5	25.3	26.8	704.9	26.1	0.39	0.150	-0.272	-0.166	0.01
Aug	1.8	24.7	26.4	690.9	25.6	0.42	0.175	0.282	0.039	0.02
Sep	1.2	25.5	26.8	708.4	26.2	0.33	0.108	-0.624	-0.282	0.01
Oct	1.5	26	27.5	728.7	27	0.37	0.137	-0.751	0.265	0.01
Nov	1.7	26.6	28.3	745.4	27.6	0.43	0.188	-0.419	-0.131	0.02
Dec	1.7	26.6	28.3	742.4	27.5	0.46	0.211	-0.161	-0.796	0.02

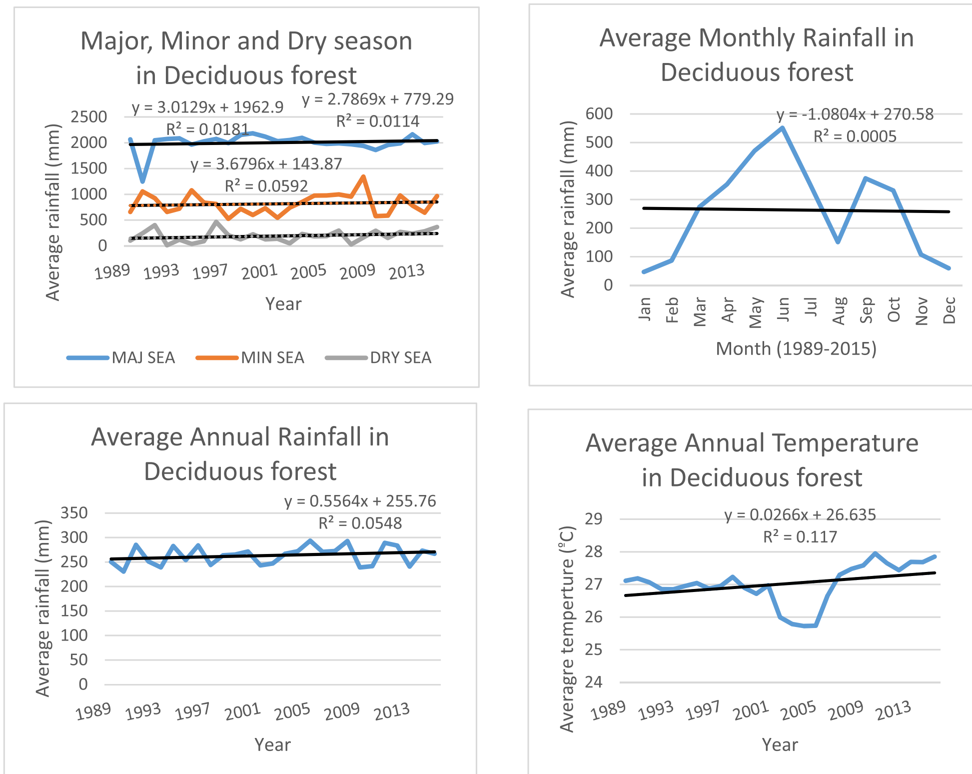

Fig. 2. Trends of rainfall and temperature in deciduous forest. NB. SEA in legend of figures means season.

hypothesis assumes that there is a trend in the data. The use of Mann Kendall helped to explore relationships and patterns of temperature and rainfall in six regions within six ecological zones in Ghana. A positive *S* value indicates an upward trend and vice versa. The study used Addinsoft XLSTAT 2016 software for Mann Kendall test.

Linear regression analysis explored relationships and patterns in temperature and rainfall. Previous studies used linear regression to assess temperature and rainfall trends and relationships (Chepkoech et al., 2018; Jaiswal et al., 2015; Kabo-Bah et al., 2016; Longobardi and Villani, 2010; Nkrumah et al., 2014; Nyatuame et al., 2014). In performing linear regression test, a straight line is fitted to the data. The slope of the fitted line may or may not necessarily differ significantly from zero (Jaiswal et al., 2015; Kabo-Bah et al., 2016; Nkrumah et al., 2014). The dependent variables (Y) were temperature and rainfall and the independent variable (X) was year. In addition, trends lines for each ecological zone was plotted and the coefficient of determination (R^2) (Pallant, 2016) determined the relationship between rainfall/temperature and year. Moreover, the study assessed mean differences in temperature and rainfall in ecological zones. To do this, one-way analysis of variance (ANOVA) test was performed. Where significant mean differences were found, post-hoc comparison with Tukey HDS test examined the differences between the means. The null hypothesis stated that there is no significant differences in mean temperature and rainfall between the ecological zones while the alternative hypothesis assumed that there is a significant differences in mean temperature and rainfall between the ecological zones.

3. Results

3.1. *Descriptive statistics of rainfall and temperature in ecological zones*

The total rainfall in the deciduous forest from 1989 to 2015 was 85391.5mm (*M* = 3126.7mm; *SD* = 226.3mm) while the average annual rainfall was 7116mm (*M* = 263.6mm; *SD* = 18.9mm) as shown in Table 2a. The major raining season had a mean rainfall of 2003.6mm with a standard deviation of 171.1 mm at a range of 953.6mm. The major raining season in the deciduous forest was negatively skewed (-3.621mm) but significantly peaked (16.195mm). The minor raining season had the highest deviation of 199.8mm indicating a high degree of inconsistency and variability of rains in the minor season. Low coefficient

Table 8
Mann Kendall and Linear regression of rainfall and temperature in deciduous forest.

Variables	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	*p*-value
Minor raining season	27.0	0.083	0.571	No trend	Y = 2.787X-4761.15	0.011	0.604
Major raining season	-55.0	-0.17	0.237	No trend	Y = 3.013X-4026.75	0.018	0.512
Dry season rainfall	89.0	0.274	0.053	No trend	Y = 3.680X-7171.23	0.020	0.231
Average annual rainfall	59.0	0.168	0.230	No trend	Y = 0.556X-850.33	0.055	0.240
Average annual temp	99.0	0.28	0.040*	Trend detected	Y = 0.027X-26.526	0.118	0.079

* indicates p<0.05

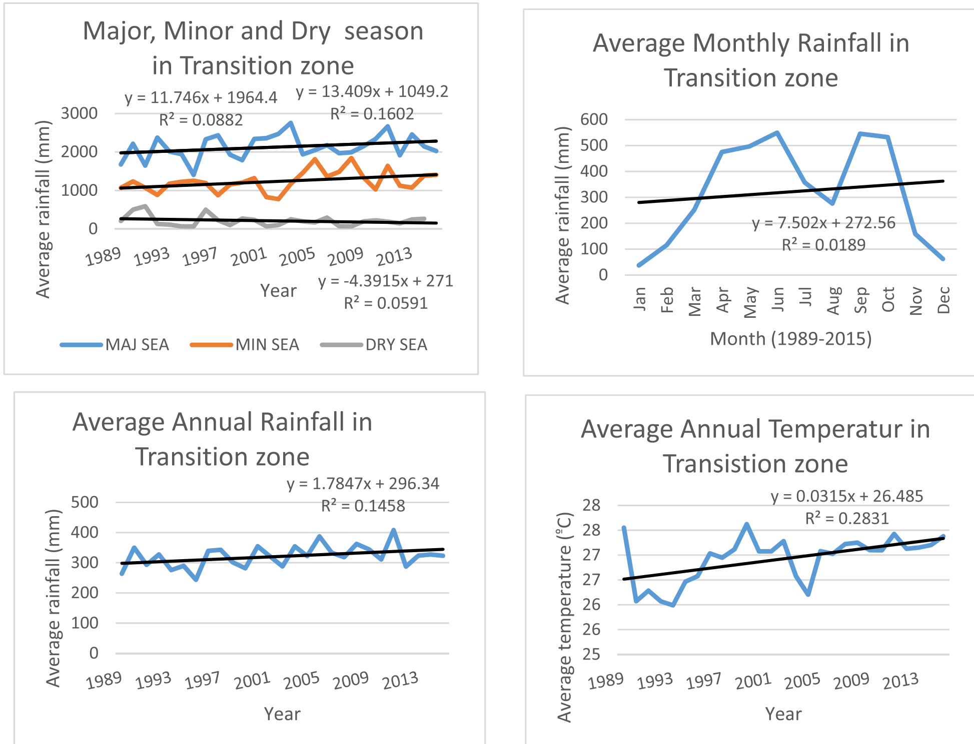

Fig. 3. Trend of rainfall and temperature in transition zone.

of variation associated with total annual, average annual, major and minor rains indicates high reliability and dependability of rainfall particularly for agricultural purpose. The highest mean monthly rainfall in the deciduous forest is June (M = 551.4mm; SD = 72.3mm) which contributes about 17.6% of total annual rainfall. Surprisingly, September received the maximum rainfall of 846.3mm. With the exception of January, February, August, November and December, the monthly rains in the deciduous forest are highly dependable and reliable with coefficient of variation less than 0.5mm. Table 2b presents the temperature statistics in the deciduous forest. The average annual temperature is 27 °C with a low standard deviation of 0.62 °C which indicates less variation or dispersion in temperature. February and March are the hottest months with maximum temperature of 30.3 °C and 30.4 °C respectively while June and July being the coolest temperature months in the deciduous forest.

The transitional zone, as shown in Table 3a has total rainfall of 104110mm (M = 3855.9mm; SD = 445.2mm). The major and minor raining seasons are reliable and dependable with coefficient of variation less than 0.5mm. The major raining season is also variable or inconsistent than the minor raining season, with a high standard deviation of 313.9mm. The wettest month is June, with an average rainfall of 549.2mm. However, September is the month that received the maximum rainfall (1040.1mm). The results also show that rainfall in month of July in the transitional zone is highly variable, with a high standard deviation of 160mm. Unsurprisingly, the month with the lowest mean monthly rainfall was January (37.2mm), followed by December, which recorded an average rainfall of 62.1mm. Rainfall in January, February, November and December are highly unreliable, with high coefficient of variation. In the case of temperature, the average annual temperature in the transitional zone is 27 °C with the hottest temperature recorded in February (30.3 °C) and March (30.4 °C) as shown in Table 3b. July and August are the coolest temperature months with 23.8 °C and 23.5 °C respectively.

Table 4a shows the distribution of rainfall in the coastal savannah. The results show that the average annual rainfall in this ecological zone is 3228.7mm (M = 119.6mm; SD = 25.3), as shown in Table 4a. With the exception of the major season (CV = 0.2), minor and dry seasonal rains are unreliable with 0.6 coefficient of variation each. However, the major season rains are dispersed and inconsistent with high standard deviation of 241.6mm. The month of June is the wettest month with total rainfall of 8983.3mm (M = 332.7mm; SD = 161.2mm). Also, monthly rainfall in the coastal savannah are highly unreliable, with coefficient of variations greater than 0.5mm, with the exception of rainfall in the month of May. The month with the lowest amount of rainfall is January, which recorded a total rainfall of 594.6mm, followed by the month of August (860mm). Rainfall in December is significantly peaked (Kurtosis = 6.217) and skewed to the right (Skewness = 2.091). For temperature in the coastal savannah, the average temperature is 27.8 °C as shown in Table 4b. Temperature is fairly consistent with low coefficient of variations. The

Table 9
Mann Kendall and Linear regression of rainfall and temperature in transition zone.

Variables	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	p-value
Minor raining season	97.0	0.276	0.045*	Trend detected	Y = 13.41X-25607.8	0.160	0.039*
Major raining season	63.0	0.179	0.199	No trend	Y = 11.75X-31286.1	0.088	0.132
Dry season rainfall	-7.00	-0.022	0.896	No trend	Y = -4.39X+9001.3	0.059	0.231
Average annual rainfall	77.0	0.219	0.114	No trend	Y = 1.785X-3251.9	0.146	0.049*
Average annual temp	172.0	0.424	0.001*	Trend detected	Y = 0.032X-36.288	0.285	0.004*

* indicates $p<0.05$

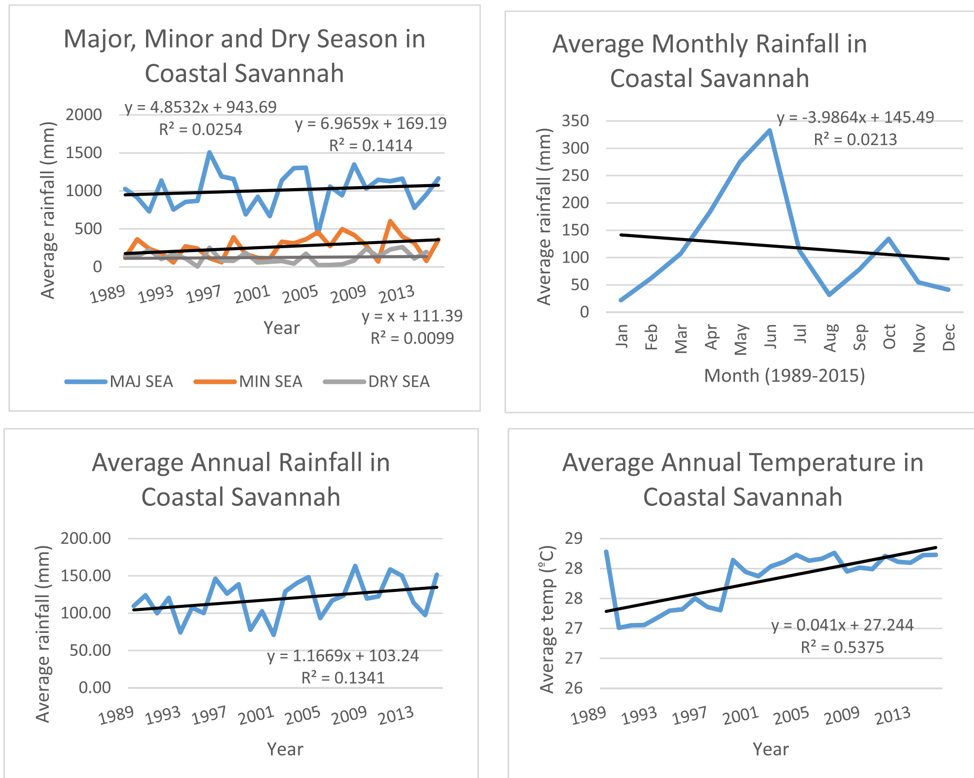

Fig. 4. Trends of rainfall and temperature in coastal savannah.

hottest months are February, March and April with mean temperature of 29.4 °C, 29.1 °C and 29.3 °C respectively.

The Guinea savannah receives a total annual rainfall of 29136mm (*M* = 1079.1mm; *SD* = 86.15mm) as shown in Table 5a. Both major and dry rains are fairly reliable with 0.09mm and 0.1mm coefficient of variations respectively, which peaks at 651.1mm for the major rains and 654.6mm for the dry season rains. It is interesting to note that why the Guinea savannah has just mono-modal rainfall pattern, the observance of a minimum and maximum rainfall of 369.7mm and 654.6mm respectively for the dry season rains indicates a typical change in the rainfall pattern, which may be associated with climate change. Although the raining season in Guinea savannah usually starts in June, the data shows that rainfall picks up from April with a maximum rainfall of 2666.3mm and peaks in September at a maximum rainfall of 5340mm. There is a remarkable increase in the amount of rainfall received in October, which is unusual of the Guinea savannah. Rainfall from April to October is reliable with coefficient of variations less than 0.5. The average annual temperature in the Guinea savannah zone is 28.3 °C as shown in Table 5b. The minimum temperature ranges between 25.7 °C to 30.5 °C while the maximum temperature is between 26.6 °C and 32.4 °C. The hottest months are February, March, April and May with maximum temperature of 32.1 °C, 32.4 °C, 32.4 °C and 30.2 °C respectively. The month of August is the coolest month. In general, temperature has been fairly consistent in this ecological zone with less variation.

The results of rainfall distribution in the Sudan Savannah zone is shown in Table 6a. The results of rainfall and temperature distribution in Sudan savannah is 25827mm (M = 956.6mm; SD = 2.5.6mm), with the main raining season receiving a maximum of 1026.6mm of rainfall as opposed to 534.5mm for the dry season. The month of August is the wettest month with total rainfall of 7028.8mm while January is the driest month with total rainfall of 50.2mm, followed by December, with 76.6mm of rainfall. Rainfall in November and December is positively skewed and highly peaked. Also rainfall in Sudan savannah is highly unreliable in almost all the months, except for July, August and September. In the case of temperature, the Sudan savannah records an annual average temperature of 29.2 °C with February, March, April, May, June and November being the hottest months as shown in Table 6b. There is less variation in temperature in Sudan savannah.

Rainfall and temperature distributions in the rain forest zone are shown in Tables 7a and b respectively. The results indicate that average annual rainfall in the rain forest is 8548.2mm with a mean of 316.6mm and a standard deviation of 24.3mm. Seasonal rainfall is reliable, both in the wet and season. The month of June is the wettest month and contributes about 22% of total annual rainfall. The driest month in this zone is January, with an average rainfall of 69.39mm, followed by February with 108mm average rainfall. Surprisingly, although the months of

Table 10
Mann Kendall and Linear regression of rainfall and temperature in coastal savannah.

Variables	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	*p*-value
Minor raining season	89.0	0.254	0.067	No trend	Y = 6.966X-13678.9	0.41	0.053
Major raining season	57.0	0.162	0.246	No trend	Y = 4.853X-8704.4	0.025	0.427
Dry season rainfall	5.00	0.015	0.931	No trend	Y = 1.000X-1876.6	0.010	0.629
Average annual rainfall	81.0	0.231	0.096	No trend	Y = 1.167X-2216.9	0.134	0.060
Average annual temp	193.0	0.550	0.000*	Trend detected	Y = 0.041X-54.377	0.539	0.000*

* indicates p<0.05

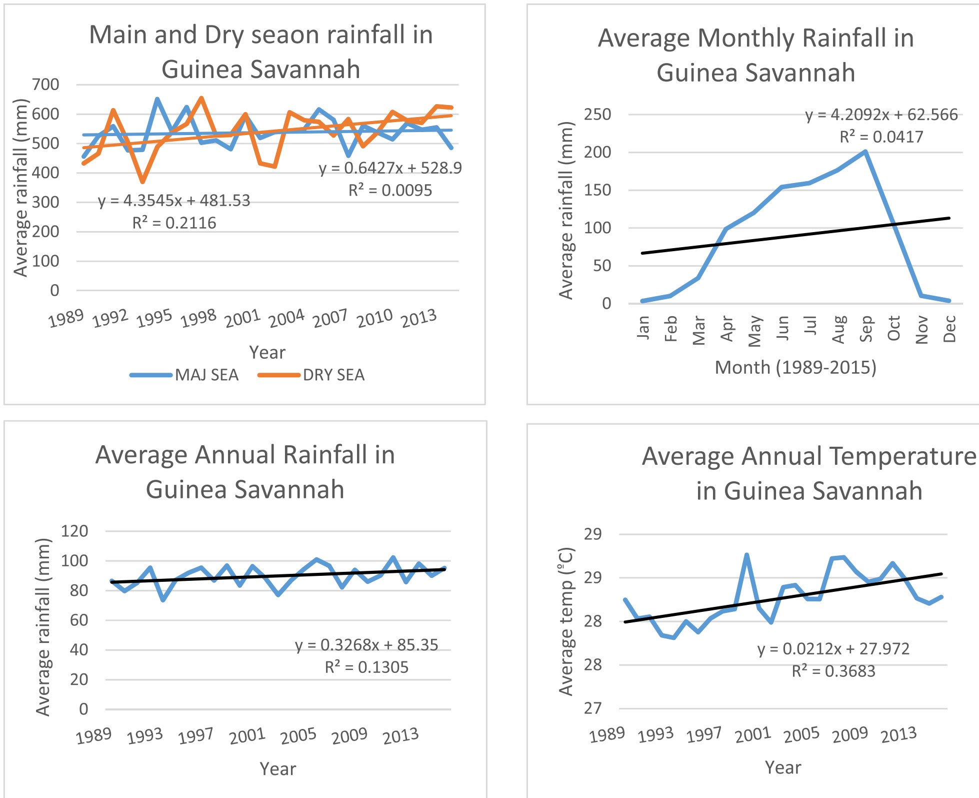

Fig. 5. Trends of rainfall and temperature in Guinea savannah.

November and December are mostly in the dry season in the rain forest zone, rainfall in this zone are fairly good. The results also show that with the exception of rainfall in January, February, July, August and December, monthly rainfall in the rain forest is dependable and reliable particularly for agricultural purpose. In the case of temperature, the results show an average annual temperature of 27.3 °C with a standard deviation of 0.28 °C. Minimum temperature ranges from 24.7 °C to 27.6 °C while maximum ranges from 26.4 °C to 30.2 °C. March is the hottest month while August is the coolest month. There is less variation in temperature in this zone as it is the case in other zones.

3.2. *Trend analysis of rainfall and temperature in ecological zones*

The results for the trend analysis of rainfall and temperature in the deciduous forest ecological zone is shown in Fig. 2, which indicates an increasing trend in rainfall and temperature. However, the monthly rainfall which depicts the bi-modal rainfall pattern in the deciduous forest shows a decreasing trend. Unlike the trend plots, the results of the Mann-Kendall test in Table 8 indicate no significant trend in rainfall except for temperature where an increasing trend is detected. In addition, the linear regression results show an upward trend in rainfall and temperature in the deciduous forest. Except temperature which showed a significant trend ($p < 0.05$), there is no significant trends in seasonal and average rainfall. In addition, there is a weak relationship between rainfall and temperature and year as shown by the R-square statistic.

In the transition zone (see Fig. 3), there is an increasing trend for major, minor, monthly and annual average rainfall and temperature. However, dry season rainfall show a decreasing trend. The Mann-Kendall test results in Table 9 shows a significant positive trend in minor season rainfall ($p = 0.045$) and temperature ($p = 0.001$), and an insignificant downward trend in dry season rainfall. The regression results equally show a downward trend in dry season rains. In addition, the regression results reveal a signigicant upward trends in minor season raifall and temperature and an insignificant upward trend in dry, major and annual rainfall.

The monthly rainfall in the coastal savannah reveals a bi-modal rainfall pattern and a decreasing trend in montly rainfall as shown in Fig. 4. There is, also, an increasing trend in temperature, minor, major and dry season rainfall. However, there is no significant trend in rainfall as shown by the Mann-Kendall test results in Table 10. The regression analysis shows an upward but insignificant weak trends in major and dry season rainfall while a significant trend and moderate relationship is detected in minor and annual rainfall and temperature.

In Fig. 5, we present the monthly rainfall pattern of the Guinea Savannah agroecological zone, which shows a mono-modal rainfall pattern. The trend plots reveal an increasing trend in monthly, major, dry

Table 11
Mann Kendall and Linear regression of rainfall and temperature in Guinea savannah.

Variables	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	*p*-value
Major raining season	45.0	0.138	0.336	No trend	Y = 0.643X-748.7	0.010	0.635
Dry season rainfall	109.0	0.335	0.016*	Trend detected	Y = 4.355–8175.2	0.212	0.018*
Average annual rainfall	81.0	0.231	0.096	No trend	Y = 0.556X-850.33	0.055	0.240
Average annual temp	159.0	0.453	0.001*	Trend detected	Y = 0.327X-564.2	0.131	0.064

* indicates p<0.05

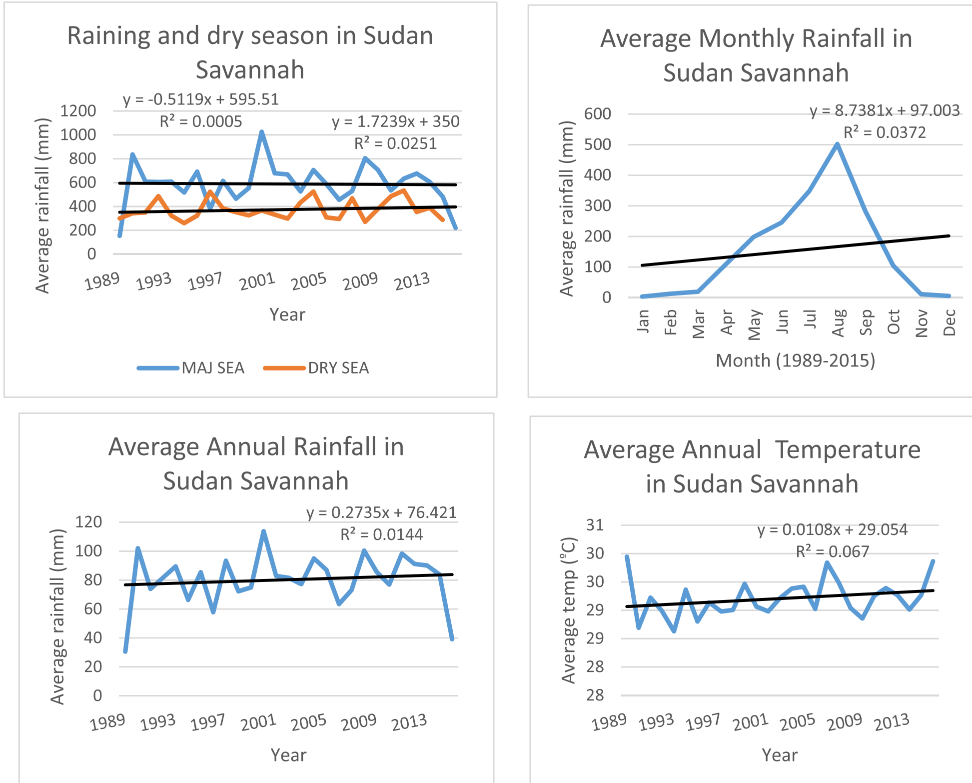

Fig. 6. Trends of rainfall and temperature in Sudan savannah.

and annual rainfall and temperature. In the case of trend analysis in Table 11, Mann-Kendall test detected significant trends in dry season rainfall and temperature, which were also confirmed by the regression analysis. The regression analysis however, showed a weak relationship for major, dry, annual rainfall and temperature as indicated by the weak R-square statistic.

A mono-modal rainfall pattern was also revealed in the Sudan savannah as shown in Fig. 6. The result shows increasing trends for monthly, major, dry and annual rainfall and temperature. While Mann-Kendall test in Table 12 detected no trend in rainfall and temperature, a downward trend (S = -7.00) is observed in major raining season concurred with a similar trend in the regression analysis. The regression results showed no significant trend in rainfall and climate variables while a weak relationship is established between dependent variables (rainfall and temperature) and independent variable (year).

In the case of rain forest, there is a bi-modal rainfall pattern (see Fig. 7). The trend plot reveals a decreasing trend of monthly, major, minor, dry season and annual rainfall. Temperature however, showed an increasing trend. Mann-Kendall test and linear regression results in Table 13 showed an insignificant downward trend in major and average annual rainfall while a downward trend was shown in minor season rains from regression analysis. In addition, Mann-Kendall and linear regression showed significant trend in temperature ($p < 0.05$).

The trends of total annual rainfall in ecological zones in Ghana are presented in Fig. 8. The results reveal an oscillatory trends of rainfall across ecological zones in Ghana. While an increasing trend is detected in deciduous forest, transition zone, rain forest and coastal savannah, a consistent regular trend is found in Sudan and Guinea savannah zones. There is also more variation or oscillation in rainfall in rain forest, deciduous forest, coastal savannah and transition zone than in Guinea and Sudan savannah. This may be explained by the presence of forest, mountains, coastal and river bodies which influence the amount of rainfall received in rain forest, deciduous forest, coastal savannah and transition zone. The Guinea and Sudan savannah have less of the orographic features to influence the amount of rainfall received.

The trend analysis of rainfall in ecological zones is displayed in Table 14. While Mann-Kendall test showed an insignificant upward trend across all ecological zones, there was a downward insignificant trend in rain forest (S = 7.0). The regression analysis also showed an insignificant downward trend in rainfall in the rain forest. The regression analysis showed an insignificantly weak relationship across ecological zones. The results on trend of temperature show an increasing trend in temperature across ecological zones in Ghana, with more variations observed in deciduous forest and transition zone (see Fig. 9). The highest temperature is recorded in Guinea and Sudan savannah, and this is partly due to their proximity to the Sahara desert, in addition to the absence of orographic

Table 12
Mann Kendall and Linear regression of rainfall and temperature in Sudan savannah.

Variables	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	*p*-value
Major raining season	-7.00	-0.020	0.902	No trend	Y = -0.512X+1613.2	0.001	0.908
Dry season rainfall	35.0	0.108	0.458	No trend	Y = 1.724X-3077.0	0.025	0.439
Average annual rainfall	37.0	0.105	0.457	No trend	Y = 0.274X-467.3	0.014	0.551
Average annual temp	87.0	0.248	0.073	No trend	Y = 0.011X+7.584	0.067	0.193

* indicates p<0.05

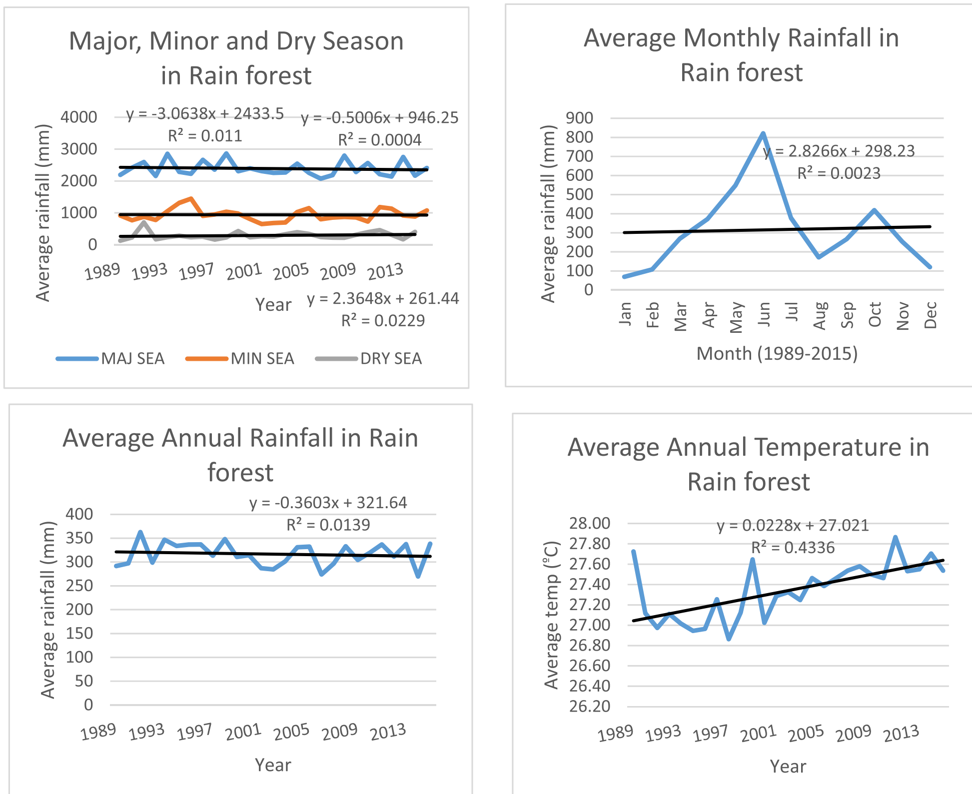

Fig. 7. Trends of rainfall and temperature in rain forest.

Table 13
Mann Kendall and Linear regression of rainfall and temperature in rain forest.

Variables	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	*p*-value
Minor raining season	17.0	0.048	0.741	No trend	Y = -0.501X+1941.5	0.000	0.918
Major raining season	-39.0	-0.111	0.433	No trend	Y = -3.064X+8524.4	0.011	0.603
Dry season rainfall	83.0	0.255	0.071	No trend	Y = 2.365X-4439.8	0.023	0.416
Average annual rainfall	-7.00	-0.020	0.902	No trend	Y = -0.360X+1037.5	0.014	0.559
Average annual temp	181.0	0.516	0.000*	Trend detected	Y = 0.023X-18.640	0.434	0.000*

* indicates $p<0.05$

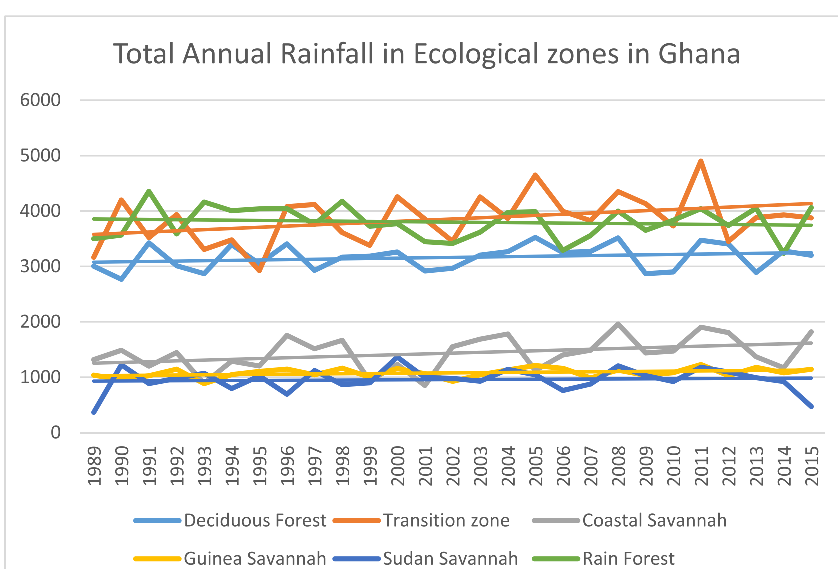

Fig. 8. Trend of rainfall in ecological zones.

Table 14
Mann Kendall and Linear regression of rainfall in ecological zones.

Ecological zones	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	*p*-value
Deciduous forest	59.0	0.17	0.23	No trend	Y = 6.677X-10203.8	0.055	0.240
Transition zone	77.0	0.23	0.12	No trend	Y = 21.417X-39020.8	0.146	0.490
Coastal savannah	81.0	0.23	0.10	No trend	Y = 14.003X-26598.6	0.134	0.060
Guinea Savannah	18.0	0.23	0.10	No trend	Y = 3.922X-6771.9	0.131	0.064
Sudan savannah	18.0	0.05	0.72	No trend	Y = 2.062X-3170.9	0.006	0.707
Rain forest	-7.0	-0.02	0.90	No trend	Y = -4.323X+12454.4	0.014	0.558

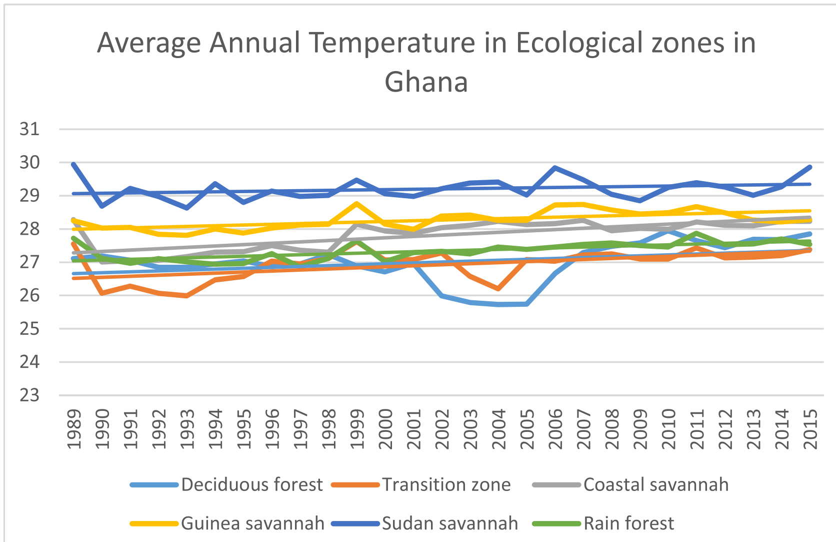

Fig. 9. Trend of temperature in ecological zones.

Table 15
Mann Kendall and Linear regression of temperature in ecological zones.

Ecological zones	MK Statistic (S)	Kendall's tau	Mann-Kendall test		Regression analysis		
			p-value	Test interpretation	Regression equation	R^2	*p*-value
Deciduous forest	99.0	0.29	0.041*	Trend detected	Y = 0.027X-26.527	0.118	0.079
Transition zone	159.0	0.46	0.0001*	Trend detected	Y = 0.032X-36.288	0.285	0.004*
Coastal savannah	190.0	0.55	0.0001*	Trend detected	Y = 0.041X-54.377	0.539	0.000*
Guinea Savannah	160.0	0.46	0.001*	Trend detected	Y = 0.021X-14.423	0.372	0.001*
Sudan savannah	87.0	0.25	0.073	No trend	Y = 0.011X+7.584	0.067	0.193
Rain forest	182.0	0.52	0.000*	Trend detected	Y = 0.023X-18.640	0.434	0.000*

* indicates $p<0.05$

features.

Table 15 in addition, the Mann-Kendall test revealed an increasing trend in temperature in almost all ecological zones, except for the Sudan savannah agroecological zone. The regression analysis also revealed a significant trend in temperature in transition zone, coastal savannah, Guinea savannah and rain forest, and insignificant trends in deciduous forest and Sudan savannah. The strength of the relationship is displayed by the R-square statistic in the regression analysis. A moderate relationship is observed in transition zone, coastal savannah, Guinea savannah and rain forest while a weak relationship is found in deciduous forest and Sudan savannah.

The null hypothesis, which stated that there is no difference in the total annual rainfall in the six ecological zones in Ghana was tested against the alternative hypothesis which stated that there is a significance difference in the total annual rainfall in the six ecological zones in Ghana. The results of the analysis of variance is displayed in Table 16. The results indicate that there is a significant difference in annual rainfall between the ecological zones ($F = 635.277$, $p = 0.000$). The post-hoc comparison with Tukey HSD test in Table 17 indicated that there is a significant mean difference in total annual rainfall between deciduous forest and transition zone, coastal savannah, Guinea savannah, Sudan savannah and rain forest. In addition, the transition zone has a statistically significant mean difference between all ecological zones, except the case of rain forest where there is an insignificant difference (mean diff = 56.707, p = 0.977). The results of the post-hoc analysis also show a statistically

Table 16
Analysis of variance of total rainfall among agroecological zones.

	Sum of square	df	Mean square	F	Sig.
Between groups	254247133.9	5	50849426.78	635.277	0.000*
Within groups	12486695.6	156	80042.921		
Total	266733829.5	161			

NB: df = degree of freedom, F = Fisher test.
* indicates $p<0.05$

Table 17
Post-hoc comparisons of total annual rainfall in ecological zones in Ghana.

(I) Zones	(J) Zones	Mean difference (I-J)	Sig.	95% confidence interval	
				Lower bound	Upper bound
Deciduous forest	Transition zone	-693.259*	0.000	-915.44	-471.08
	Coastal savannah	1727.670*	0.000	1505.49	1949.85
	Guinea savannah	2083.544*	0.000	1861.36	2305.73
	Sudan savannah	2206.096*	0.000	1983.91	2428.28
	Rain forest	-639.552*	0.000	-858.73	-414.37
Transition zone	Deciduous forest	693.259*	0.000	471.08	915.44
	Coastal savannah	2420.930*	0.000	2198.75	2643.11
	Guinea savannah	2776.804*	0.000	2554.62	2998.99
	Sudan savannah	2899.356*	0.000	2677.17	3121.54
	Rain forest	56.707	0.977	-156.48	278.89
Coastal savannah	Deciduous forest	-1727.670*	0.000	-1949.49	-1505.49
	Transition zone	-2420.390*	0.000	-2643.11	-2198.75
	Guinea savannah	355.874*	0.000	133.69	578.06
	Sudan savannah	478.426*	0.000	256.24	700.61
	Rain forest	-2364.222*	0.000	-2586.41	-2142.04
Guinea savannah	Deciduous forest	-2083.554*	0.000	-2305.73	-1861.36
	Transition zone	-2776.806	0.000	-2998.99	-2554.62
	Coastal savannah	-355.874*	0.000	-578.06	-133.69
	Sudan savannah	122.552	0.605	-99.63	344.73
	Rain forest	-2720.096*	0.000	-2942.28	-249791
Sudan savannah	Deciduous forest	-2206.096*	0.000	-2428.28	858.73
	Transition zone	-2899.356*	0.000	-3121.54	165.48
	Coastal savannah	-478.462*	0.000	-700.61	2586.41
	Guinea savannah	-122.552	0.605	-344.73	2942.28
	Rain forest	-2842.648*	0.000	-3064.83	3064.83
Rain forest	Deciduous forest	636.552*	0.000	414.37	858.73
	Transition zone	-56.707	0.977	-278.89	165.48
	Coastal savannah	2364.222*	0.000	2142.04	2586.41
	Guinea savannah	2720.096*	0.000	2497.91	2942.28
	Sudan savannah	2842.648*	0.000	2620.27	3064.83

* indicates p<0.05

Table 18
Analysis of variance of average temperature among agroecological zones.

	Sum of square	df	Mean square	F	Sig.
Between groups	102.316	5	20.463	115.589	0.000*
Within groups	27.617	156	0.177		
Total	129.933	161			

NB: df = degree of freedom, F = Fisher test.
* indicates p<0.05

significant mean difference in annual rainfall between coastal savannah and all other ecological zones. In addition, there is a statistically significant means difference in annual rainfall between Guinea savannah agroecological zone and all ecological zones, except the Sudan savannah agroecological zone, where an insignificant difference is found (mean diff = 122.552, $p = 0.605$).

This study also investigated whether there is a significant difference in temperature across agroecological zones and the results are presented in Table 18. The results indicate a statistically significant mean difference in average temperature among the six ecological zones in Ghana ($F = 115.589$, $p = 0.000$). In view of the statistically significant difference in

Table 19
Post-hoc comparisons of average temperature in ecological zones in Ghana.

(I) Zones	(J) Zones	Mean difference (I-J)	Sig.	95% confidence interval	
				Lower bound	Upper bound
Deciduous forest	Transition zone	0.081	0.980	-0.25	0.41
	Coastal savannah	-0.810*	0.000	-1.14	-0.48
	Guinea savannah	-1.262*	0.000	-1.59	-0.93
	Sudan savannah	-2.198*	0.000	-2.53	-1.87
	Rain forest	-0.333*	0.047	-0.66	0.00
Transition zone	Deciduous forest	-0.081	0.980	-0.41	0.25
	Coastal savannah	-0.892*	0.000	-1.22	-0.56
	Guinea savannah	-1.344*	0.000	-1.67	-1.01
	Sudan savannah	-2.279	0.000	-2.61	-1.95
	Rain forest	-0.415*	0.005	-0.75	-0.08
Coastal savannah	Deciduous forest	0.810*	0.000	0.48	1.14
	Transition zone	0.892*	0.000	0.56	1.22
	Guinea savannah	-0.452*	0.002	-0.78	-0.12
	Sudan savannah	-1.387*	0.000	-1.72	-1.06
	Rain forest	0.477*	0.001	0.15	0.81
Guinea savannah	Deciduous forest	1.262*	0.000	0.93	1.59
	Transition zone	1.344*	0.000	1.01	1.67
	Coastal savannah	0.452*	0.002	0.12	0.78
	Sudan savannah	-0.936*	0.000	-1.27	-0.61
	Rain forest	0.929*	0.000	0.60	1.26
Sudan savannah	Deciduous forest	2.198*	0.000	1.87	2.53
	Transition zone	2.279*	0.000	1.95	2.61
	Coastal savannah	1.387*	0.000	1.06	1.72
	Guinea savannah	0.937*	0.000	0.61	1.27
	Rain forest	1.864*	0.000	1.53	2.19
Rain forest	Deciduous forest	0.333*	0.047	0.00	0.66
	Transition zone	0.415*	0.005	0.08	0.75
	Coastal savannah	-0.477*	0.001	-0.81	-0.15
	Guinea savannah	-0.292*	0.000	-1.26	-0.60
	Sudan savannah	-1.864*	0.000	-2.19	-1.53

* indicates p<0.05

average temperature among ecological zones, Table 19 presents the results of the post-hoc comparison with Tukey HSD test. The results indicate that there is a statistically significant mean difference in average temperature between the deciduous forest and all ecological zones, except the transition zone, where an insignificant mean difference exist (mean diff = 0.081, p = 0.980). Moreover, it is revealed that there is a statistically significant mean difference in average temperature between the coastal savannah and the Guinea savannah, Sudan savannah and rain forest agroecological zones.

4. Discussion and conclusion

Using secondary data on rainfall and temperature, the study has shield light on the extent of climate change across the six agroecological zones in Ghana. In consistent with previous studies which reported rising temperature in different geographic locations in Ghana (Kabo-Bah et al., 2016; Nkrumah et al., 2014), this study also found a rising temperature across agroecological zones in Ghana. The trend in temperature has implication on agricultural activities as Ghana's agriculture is rain fed and subsistence in practice. Rising temperature may increase evapotranspiration, reduce surface and underground water and may lead to drought and water scarcity in the long run, which may cause grave reduction in crop yields due to lack of water for crops (IPCC, 2018). Rising temperature may also affect livestock particularly growth and production patterns, increase heat stress and reduce animal products particularly meat and dairy (Kabubo-Mariara, 2008a, 2008b). There is also the possibility of a reduction in forage and water for livestock (Thornton et al., 2009). Thus, increasing temperature has the potential to retard the contribution of agriculture to poverty reduction, food security, livelihood and pro-poor economic development.

Rainfall across ecological zones in Ghana was found to be decreasing, which is consistent with existing studies (Kabo-Bah et al., 2016; Nkrumah et al., 2014), although Nyatuame et al. (2014) reported oscillatory pattern of rainfall across the Volta region of Ghana. Decreasing rainfall across ecological zones may pose serious threats to agricultural productivity thereby reducing income for smallholder farmers and their households, who depend largely on agriculture, as the main source of livelihood and food security. To offset the impacts of changing rainfall and temperature, particularly on agriculture, there is the need to encourage the use of drought resistant and early maturing crops. Livelihood, crop and livestock diversification can serve as important strategies to reduce climate change impact particularly in rural communities and households (Antwi-Agyei et al., 2014b, 2014a; Roy et al., 2018) Irrigation facilities must be provided particularly in hinterlands and rural areas to improve agricultural productivity. Policy makers must ensure the availability and provision of accurate and reliable early warning signs and information to farmers. This is because available research reveal that smallholder farmers in cocoa growing areas in Ghana have challenges in accessing reliable climate information needed particularly for their agricultural activities (Hirons et al., 2018). Extension and advisory services must also be intensified, particularly, in rural communities to enhance adaptation and adaptive capacity of smallholder farmers. Moreover, social intervention programmes that increase access to economic, social and technological assets to farmers, particularly, in rural communities must be intensified to enhance farmers' adaptive capacity and reduce their vulnerability to climate change.

Declarations

Author contribution statement

Peter Asare-Nuamah: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ebo Botchway: Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Anderegg, W.R.L., Prall, J.W., Harold, J., Schneider, S.H., 2010. Expert credibility in climate change. Proc. Natl. Acad. Sci. 107, 12107–12109.
Antwi-Agyei, P., Dougill, A.J., Stringer, L.C., 2014a. Barriers to climate change adaptation : evidence from northeast Ghana in the context of a systematic literature review. Clim. Dev. 37–41.
Antwi-Agyei, P., Stringer, L.C., Dougill, A.J., 2014b. Livelihood adaptations to climate variability: insights from farming households in Ghana. Reg. Environ. Chang. 14, 1615–1626.
Arnell, N.W., 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. Glob. Environ. Chang. 14, 31–52.
Asante, F.A., Amuakwa-Mensah, F., 2015. Climate change and variability in Ghana: stocktaking. Climate 3, 78–99.
Boansi, D., Tambo, J.A., Müller, M., 2016. Analysis of farmers' adaptation to weather extremes in West African Sudan Savanna. Weather Clim. Extrem. 1–13.
Campion, B.B., Venzke, J.-F., 2013. Rainfall variability , floods and adaptations of the urban poor to flooding in Kumasi, Ghana. Nat. Hazards 65, 1895–1911.
Chepkoech, W., Mungai, N.W., Stöber, S., Bett, H.K., Lotze-campen, H., 2018. Farmers' perspectives: impact of climate change on African indigenous vegetable production in Kenya. Int. J. Clim. Chang. Strateg. Manag. 10, 551–579.
Doran, P.T., Zimmerman, M.K., 2009. Reply to comments on "examining the scientific consensus on climate change. Eos (Washington. DC) 90, 233.
FAO, IFAD, UNICEF, WFP, WHO, 2017. The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security, Rome.
Ghana Statisticial Service, 2017. Provisional 2016 Annual Gross Domestic Product. Accra, Ghana.
Hirons, M., Boyd, E., McDermott, C., Asare, R., Morel, A., Mason, J., Malhi, Y., Norris, K., 2018. Understanding climate resilience in Ghanaian cocoa communities – advancing a biocultural perspective. J. Rural Stud. 63, 120–129.
IPCC, 2018. IPCC Special Report on the Impacts of Global Warming of 1.5 °C - Summary for Policy Makers. Incheon, Korea.
IPCC, 2013. Detection and Attribution of Climate Change: from Global to Regional. Fifth Assessment Report, Working Group I, Chapter 10. Cambridge, United Kingdom and New York, NY, USA.
IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, MA.
Issahaku, A.-R., Campion, B.B., Edziyie, R., 2016. Rainfall and temperature changes and variability in Upper East region of Ghana. Earth Sp. Sci. 3, 284–294.
Jaiswal, R.K., Lohani, A.K., Tiwari, H.L., 2015. Statistical analysis for change detection and trend assessment in climatological parameters. Environ. Process. 2, 729–749.
Kabo-Bah, A., Diji, C., Nokoe, K., Mulugetta, Y., Obeng-Ofori, D., Akpoti, K., 2016. Multiyear rainfall and temperature trends in the Volta river basin and their potential impact on hydropower generation in Ghana. Climate 4, 49.
Kabubo-Mariara, J., 2008a. The economic impact of global warming on livestock husbandry in Kenya; a ricardian analysis. In: African Econ. Conf. Glob. Institutions Econ. Dev. Africa. Tunis, 12-14th Novemb. 2008.
Kabubo-Mariara, J., 2008b. Climate change adaptation and livestock activity choices in Kenya: an economic analysis. Nat. Resour. Forum 32, 131–141.
Karmeshu, N., 2015. Trend detection in annual temperature & precipitation using the Mann Kendall test – a case study to assess climate change on select states in the northeastern United States. Mausam 66, 1–6.
Kemausuor, F., Akowuah, J.O., Ofori, E., et al., 2013. Assessment of feedstock options for biofuels production in Ghana. J. Sustain. Bioenergy Syst. 3, 119–128.
Lachin, J.M., 2016. Fallacies of last observation carried forward analyses. Clin. Trials 13, 161–168.
Li, C., Filho, W.L., Wang, J., Yin, J., Fedoruk, M., Bao, G., Bao, Y., Yin, S., Yu, S., Hu, R., 2018. An assessment of the impacts of climate extremes on the vegetation in Mongolian Plateau: using a scenarios-based analysis to support regional adaptation and mitigation options. Ecol. Indicat. 95, 805–814.
Longobardi, A., Villani, P., 2010. Trend analysis of annual and seasonal rainfall time series in the Mediterranean area. Int. J. Climatol. 30, 1538–1546.
MESTI, 2013. Ghana National Climate Change Policy. Accra, Ghana.
MOFA, 2016. Agriculture in Ghana Facts and Figures (2015). Accra, Ghana.
Nii Baah, D.B., 2018. Changing rainfall patterns in Ghana : implication for small scale farming. J. Geogr. 5, 1–13.

Nkrumah, F., Klutse, N.A.B., Adukpo, D.C., Owusu, K., Quagraine, K.A., Owusu, A., Gutowski, W., 2014. Rainfall variability over Ghana: model versus rain gauge observation. Int. J. Geosci. 5, 673–683.

Nyatuame, M., Owusu-Gyimah, V., Ampiaw, F., 2014. Statistical analysis of rainfall trend for Volta region in Ghana. Int. J. Atmos. Sci. 2014, 1–11.

Pallant, J., 2016. SPSS Survival Manual - A Step by Step Guide to Data Analysis Using SPSS Program, sixth ed. McGraw-Hill Education, London, UK.

Roy, J., Tschakert, P., Waisman, H., Abdul Halim, S., Antwi-agyei, P., Dasgupta, P., Hayward, B., Kanninen, D., Liverman, D., Okereke, C., Pinho, P.F., Riahi, K., Suarez Rodriguez, A.G., 2018. Sustainable development, poverty eradication and reducing inequalities. Global warming of 1.5°C. An IPCC Special Report. In: Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Maycock, T., Connors, S., Matthews, R.B.R., Chen, Y., Zhou, X., Gomis, M.I., S, E.L., Tignor, M., Waterfield, T. (Eds.), Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change. IPCC, pp. 445–538.

Sissoko, K., van Keulen, H., Verhagen, J., Tekken, V., Battaglini, A., 2011. Agriculture, livelihoods and climate change in the West african sahel. Reg. Environ. Chang. 11, 119–125.

Thornton, P.K., van de Steeg, J., Notenbaert, A., Herrero, M., 2009. The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric. Syst. 101, 113–127.

UNFCC, 2011. Fact Sheet: Climate Change Science - the Status of Climate Change Science Today. United Nations Framework Convention on Climate Change.