Original Research Article

Analyses of Climate Variability and Trends in The Oil Palm Belt of Ghana

ABSTRACT

The current production of oil palm in Africa has been severely limited long periods of drought and perennial floods due to the increased rates of climate change. The study was aimed at assessing the climatic variability trends in 7 major Oil Palm growing areas (Benso, Mpohor, Bogoso, Twifo Praso, Kade, Juabeng and Brewaniese) located in the oil palm belt in Ghana spanning the semideciduous and the wet evergreen rainforest zones of Ghana using 30 years of historical weather data (1993-2022). The data was analysed to evaluate the extent of seasonal changes in weather over the 30-year period using the Statistical Package for Social Sciences (SPSS 20.0 version), using descriptive statistics and time series analysis. Trend analysis was conducted using the non-parametric Mann-Kendall (MK) and Sen's slope estimator tests. A seasonal trend in rainfall was observed at all sites with maximum levels observed between May and July as well as a minor rainy season in September to Mid-November. The Mann-Kendall trend analysis showed a generally increasing trend at most stations in rainfall, temperature and solar radiation. A generally increasing trend in annual rainfall was observed from 1993-2022 with significant trends at Mpohor and Juabeng. The trend was higher in the moist evergreen rainforest zone than in the semi-deciduous rainforest zone. An average increase of 6.7 mm/yr in rainfall trend was observed for the period. An increasing trend in monthly maximum, minimum and mean temperatures were also observed. Significant increases in mean temperatures were observed at Bogoso (0.022°C/yr), Benso (0.018°C/yr), Juabeng (0.011°C/yr) and Mpohor (0.017°C/yr). The trend in mean annual solar radiation was generally not significant except in Benso where the mean solar radiation increased at the rate of 0.044 MJ/day. Higher drought levels in the first half year combined with very heavy rains later in the year are features of the ongoing climate change menace.

Key words: Oil palm, Climate, Drought, Solar radiation, Temperature

1. INTRODUCTION

The Oil Palm (*Elaeis guineensis* Jacq.) is known to originate from the West Coast of Africa and currently distributed in three regions of the equatorial tropics namely, Africa, Southeast Asia and Central and South America [1]. Among the oilseeds, it produces the highest average yield of *ca*. 4 to 6 MT/ha of vegetable oil per hectare, which constitutes *ca*. 36% of the global supply of vegetable oils. Between 1970 and 2018, there has been a marked increase in crude palm oil production from 2 million MT to 71 million MT [2]. Countries where oil palm is cultivated include Malaysia, Indonesia, Nigeria, Democratic Republic of the Congo, Ghana, the Ivory Coast, Brazil, Colombia, Costa Rica, and Ecuador with Indonesia being the current highest producer [3].

Oil palm grows best in areas with evenly distributed rainfall of 2000-2,500 mm/yr with no month with less than 100 mm rainfall. Other suitable conditions are maximum and minimum temperatures range of 29-33℃ and 22-24℃, respectively; relative humidity above 85%; minimum solar radiation of 16 or 17 MJ/m^2/d; and a variety of soil conditions, with pH 4-8 ([4], [5]). In Ghana, the forest zone is most suitable for oil palm cultivation due to higher rainfall levels received in such areas. The forest zone consists of the evergreen rainforest and semi-deciduous forest zones ([6], [7]). Key Oil Palm plantations in Ghana include Benso Oil Palm Plantation (BOPP), Plantation Sofinc Ghana (PSG) ltd. and Norpalm Ghana Ltd in Southwestern Ghana, Twifo Oil Palm plantation (TOPP), in the Central region of Ghana and Ghana Oil Palm Development Company (GOPDC), in the Eastern region of Ghana. These plantations are mostly located in areas with water deficits less than 400 mm. Each of these plantations obtain higher fresh fruit bunch (FFB) yields of 20-24 MT/ha annually due to the implementation of best agronomic management practices, whereas relatively lower FFB yields of between 3 and 10 MT/ha are obtained in out grower and small scale farms ([8]. Climate is perhaps the most important physical factor affecting oil palm cultivation. Key climatic parameters that affect oil palm yield include rainfall, solar radiation, and temperature and hence trend analysis of these parameters is highly important in rainfed and irrigated agriculture ([9] [10]). Several studies by Nicholson *et al*., [11], Djomou *et al*.,[12] and Logah *et al*., [13] have analyzed rainfall distribution in West Africa and identified a downward trend for the period 1970-2000. Ghana has been experiencing long-term warming trend since the 1900 with mean annual temperature increases of 1-2°C [14]. Earlier studies by van der Vossen, ([6] ; Gyasi, [7]; Danso *et al*., [5]; Rhebergen *et al.*,[3] have determined and reviewed suitable areas for oil palm cultivation in Ghana.

However, little studies have been carried out on the trends in climatic parameters over time in these oil palm growing areas. The objectives of the current study were, therefore, to assess the trends and extent of variation in rainfall, temperature, and solar radiation in seven (7) major oil palm production areas in Ghana over a 30-year period (1993-2022).

2. MATERIALS AND METHODS

2.1 Experimental sites

The study was carried out in seven (7) locations within the oil palm belt of Ghana across two ecological zones in the Ashanti, Central, Eastern, Oti and Western regions. Secondary data were obtained from the notable oil palm plantations within these locations. Table 1 presents in detail the various locations for the study.

Table 1: Coordinates and rainfall distributions of the experimental centres

Station	GPS Coordinates	Agroclimatic zone	Annual rainfall (mm)			†Sunshine hours	†Humidity (%)	Temperature (°C)			†Windspeed (Km/h)
			Max.	Min.	Mean			Max.	Min.	Mean	
Bogoso	5.5741° N, 2.0126° W	Moist evergreen	2190.5	1252.9	1457.5	10.3	86.8	33.5	24.3	28.9	2.8
Twifo Praso	5.5478° N, 1.5478° W	Semi-deciduous	1988.8	982.8	1480.7	10.2	79.6	33.2	22.1	27.6	2.7
Juabeng	6.8154° N, 1.4138° W	Semi-deciduous	1794.4	1040.9	1324.1	10.7	81.1	33.8	22.3	28.1	2.3
Kade	6.0938° N, 0.8342° W	Semi-deciduous	1927.6	1131.7	1424.0	10.9	80.0	32.1	22.4	27.3	1.7
Benso	5.138° N, 1.923° W	Moist evergreen	2464.0	1331.3	1752.9	7.0	82.5	30.0	24.0	27.0	3.2
Brewaniase	8.0052° N, 0.5565° E	Semi-deciduous	1747.6	808.1	1287.5	11.4	81.0	31.5	18.5	25.0	1.6
Mpohor	4.9280° N, 1.8963° W	Moist evergreen	2375.1	831.2	1702.8	5.9	80.0	29.8	23.9	26.9	2.8

†Mean Annual values

The major rainy season occur between April and July followed by a on dry spell in August and then the minor rainy season from September to mid November. Temperatures are generally high and fairly uniform throughout the year. Oil palm (D x P) variety were planted at all the experimental sites. Bogoso received a maximum average annual rainfall of 2190.5 mm whiles Twifo Praso, Juabeng, Kade, Benso, Brewaniase and Mpohor received maximum levels of 1988.8, 1974.4, 1927.6, 2464.0, 1747.6 and 2375.1 mm, respectively. Highest average rainfall of 1752.9 was observed at Benso. Bogoso receives an average monthly rainfall of 136.3 mm whiles Twifo Praso, Juabeng, Kade, Benso, Brewaniase and Mpohor receives average levels of 88.58, 98.26, 112.69, 144.31, 116.5 and 125 mm, respectively. Highest average monthly rainfall of 144.31 mm was observed at Benso.

Data on other weather parameters are presented in Table 2. Bogoso has an average annual humidity of 86.78% whiles Twifo Praso, Juabeng, Kade, Benso, Brewaniase and Mpohor receives average levels of 79.64, 81.07, 79.97, 82.5, 81 and 80%, respectively. Highest average humidity of 86.78% was observed at Bogoso. Bogoso has a mean temperature of 28.92°C whiles Twifo Praso, Juabeng, Kade, Benso, Brewaniase and Mpohor receives mean temperatures of 27.64, 28.05, 27.26, 27, 25 and 30°C, respectively. Highest mean temperature of 30°C was observed at Mpohor. Lowest minimum temperatures were recorded in Brewaniese which is a known mountainous area.

2.2 Climatic data collection

A period of 30 years weather data was assembled from the meteorological stations within the various locations for the study. Rainfall data was collected using manual rain gauges at the various locations. Daily and monthly datasets including maximum, minimum and mean air temperature (Tmax, Tmin and Tmean), relative humidity (RH), wind speed and atmospheric pressure were obtained from the weather stations in the study sites, as well as the local meteorological stations.

In order to quantify the water stress affecting the palms, monthly and annual soil water deficits were calculated using the IRHO' method [15]:

D = R + P - Pe

Where D = water deficits; R = theoretical soil moisture reserve at the end of the previous month; P = precipitation or rainfall for the month; Pe = potential evapotranspiration for the month.

2.3 Statistical analysis

All data obtained, was subjected to analysis of variance (ANOVA). The analysis of data was done using the Statistical Package for Social Sciences (SPSS 20.0 version) specifically using descriptive statistics and time series analysis. Graphs were produced with Microsoft Excel 2010 to summarise the results. Time series data trend analysis was carried out by a combination of statistical parameters including linear regression, Sen's slope, and Mann-Kendal test of the annual and seasonal weather data. To estimate true slope (change per unit year) within the time series, Sen's nonparametric method ([16] is used where the trend is assumed to be linear. The magnitude of the trend is predicted by the Sen's estimator.

3. RESULTS AND DISCUSSION

3.1 Mean monthly weather at the experimental sites

Records of mean monthly weather parameters in the study areas were collected for the 30-year period (1993-2022). The data for 3 of the centres (with the biggest plantations) i.e., for Benso, Twifo and Kade are presented in Tables 2, 3 and 4, respectively. Mean monthly rainfall received at Benso, Twifo and Kade within the period were 146.1, 123.03 and 116.20 mm, respectively. The observed trend is like the observations in most parts of the country by Antwi-Agyei [17] and Hartley [4] found that a mean minimum rainfall amount of 100 mm with an even distributed within the month as the requirement for oil palm.

Table 2: Monthly meteorological data for Benso during the period of study (1993-2022)

Month	*Rainfall (mm)	‡Temp (ºC)	‡RH_{max} (%)	‡RH_{min} (%)	‡Wind speed (km/h)	‡Atm Pressure (hPa)	‡Solar Radiation ($MJ/m^2/day$)
January	34.4	27.4	95.1	70.5	2.4	1010.9	17.30
February	82.6	28.1	95.0	73.0	3.2	1011.5	18.98
March	126.3	28.3	94.6	74.1	3.5	1009.9	19.59
April	148.7	28.1	94.6	75.2	3.4	1010.3	20.08
May	212.6	27.7	95.1	77.6	2.9	1011.2	19.21
June	295.1	26.5	95.2	81.3	3.2	1012.0	16.10
July	148.7	25.5	95.7	81.8	3.3	1014.1	14.85
August	77.6	25.1	96.3	82.6	3.7	1016.1	13.98
September	145.0	25.6	96.3	82.1	3.9	1013.0	15.71
October	223.3	26.6	95.8	78.4	3.5	1011.9	18.65
November	167.8	27.4	95.3	75.0	2.8	1011.1	19.00
December	90.8	27.6	95.2	73.3	2.5	1010.2	17.20
Sum/Av	**146.1**	**27.0**	**95.3**	**77.1**	**3.2**	**1011.8**	**17.6**

*Total monthly measurement; ‡Mean monthly measurement; RH_{max} = Maximum relative humidity, RH_{min} = Minimum relative humidity

The mean annual minimum (Table 1) levels received in Ghana are, however, very low with uneven distribution. Kouadio *et al*. [18] observed that variations in rainfall distribution in the country were determined by sea surface temperatures.

Table 3: Monthly meteorological data for Twifo Praso during the period of study (1993-2022)

Month	*Rainfall (mm)	‡Temp (°C)	‡RH_{max} (%)	‡RH_{min} (%)	‡Wind speed (km/h)	‡Atm Pressure (hPa)	‡Solar Radiation ($MJ/m^2/day$)
January	40.2	27.1	92.3	47.6	1.6	1012.3	17.2
February	57.3	28.5	92.7	49.4	2.1	1011.7	19.5
March	105.9	28.6	93.1	56.8	2.3	1011.1	19.2
April	149.4	28.3	93.1	62.6	2.3	1011.4	19.8
May	199.5	27.5	93.5	67.2	1.8	1012.7	19.0
June	271.6	26.5	94.0	72.9	1.9	1014.4	16.2
July	139.1	25.7	93.3	72.8	2.4	1015.3	15.1
August	67.6	25.5	93.1	72.6	2.5	1018.1	15.0
September	129.8	26.3	93.1	70.4	2.3	1014.4	16.7
October	186.7	26.7	93.5	68.5	1.9	1013.5	19.1
November	101.6	27.4	93.6	62.2	1.5	1012.7	19.2
December	27.6	27.3	93.2	57.3	1.6	1012.5	18.1
Sum/Av	**123.03**	**27.1**	**93.2**	**63.4**	**2.0**	**1013.3**	**17.8**

*Total monthly measurement; ‡Mean monthly measurement; RH_{max} = Maximum relative humidity, RH_{min} = Minimum relative humidity

Temperatures recorded at the 3 centres ranged between 20.7^{o}C and 34.8^{o}C. Generally, the temperatures were found to be low in December and January, which could most likely be due not to the harmattan winds. The highest mean monthly RH (94.8%) was recorded in Kade. Mean monthly Solar radiation and atmospheric pressure were highest at Twifo (17.8 MJ/d; 1013.3 hPa), whereas the mean monthly wind speed was highest at Benso (3.2 km/h).

Table 4: Monthly meteorological data for Kade during the period of study (1993-2022)

Month	*Rainfall (mm)	‡Temp (ºC)	‡RH_{max} (%)	‡RH_{min} (%)	‡Wind speed (km/h)	‡Atm Pressure (hPa)	‡Solar Radiation ($MJ/m^2/day$)
January	23.1	27.1	94.5	56.6	1.3	1012.0	16.8
February	54.9	28.6	94.0	53.9	1.3	1011.5	18.2
March	114.2	28.6	94.3	58.5	1.4	1010.9	18.6
April	136.0	28.3	94.9	64.6	1.5	1011.1	19.4
May	165.7	27.8	95.3	68.4	1.2	1012.6	18.3
June	210.4	26.6	95.5	72.6	1.2	1014.4	15.5
July	133.4	25.8	94.9	72.8	1.5	1015.3	14.3
August	68.8	25.2	94.3	73.0	1.5	1015.0	14.0
September	127.7	26.0	94.5	70.1	1.4	1014.2	15.8
October	207.0	27.1	95.2	67.3	1.2	1013.2	18.1
November	117.6	27.5	95.2	65.2	1.3	1012.2	18.3
December	35.6	27.3	95.5	63.3	1.0	1012.1	17.2
Sum/Av	**116.2**	**27.2**	**94.8**	**65.5**	**1.3**	**1012.9**	**17.0**

*Total monthly measurement; ‡Mean monthly measurement; RH_{max} = Maximum relative humidity, RH_{min} = Minimum relative humidity

3.2. Seasonal variation in rainfall and water deficit

Generally, annual rainfall in all the study sites have a bimodal pattern with two distinct periods of rain, namely, major and minor rainy seasons. The major rainy periods span from March to July, and a minor rainy season From September to November. A short dry spell is experienced in August. The dry season is usually experienced from mid-November to February. However, observations made in the current study suggest slight modifications to the rainfall pattern. Mean monthly rainfall for the 30-year period (1993-2022) indicates that Mpohor and Benso in the moist evergreen forest zone received the highest rainfall levels in June, compared to other stations. For Brewaniese in the semi- deciduous ecological zone, rainfall levels were slightly higher in September, when less rains hitherto were expected (minor season) than in June, where large amounts of rainfall are received (peak of the major rainy season). A late start in the minor season was, however, observed at Mpohor, while the minor season ended very early in November at Brewaniese. Meanwhile, relatively large amounts of rainfall were received at Benso in December (Figure 1)

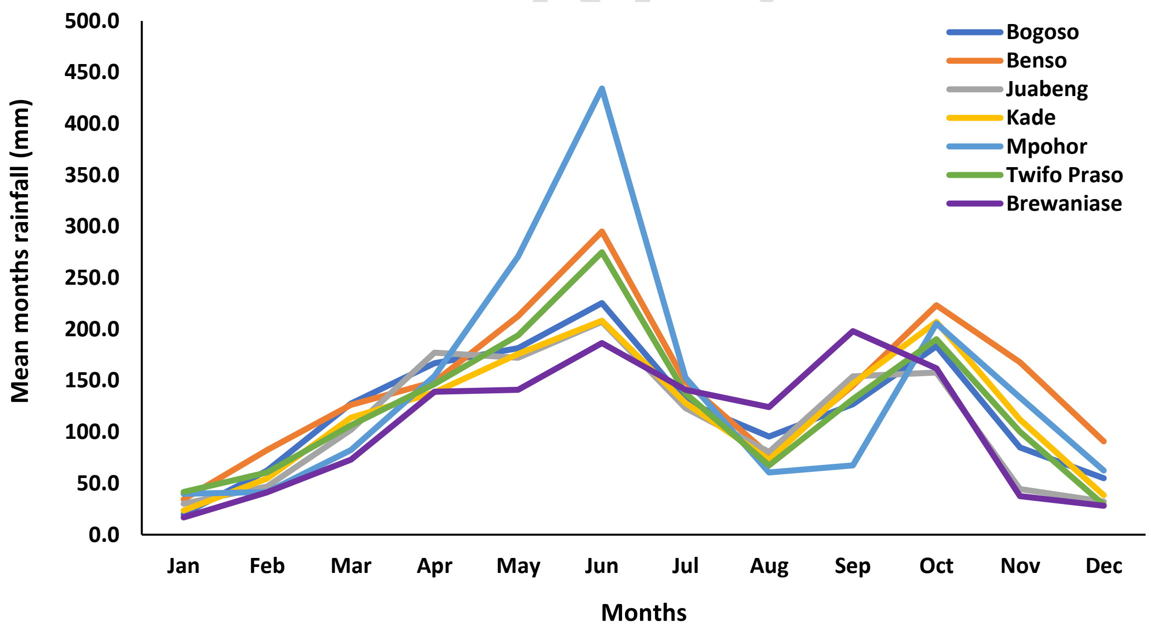

Figure 1: mean monthly rainfall trend at study centres from 1993 to 2022

Mean water deficits followed a similar trend as observed for the rainfall. Over the 30- year experimental period, high water deficits were experienced during the months of dry spell, mainly between December and February, and periodically in August. Though little rainfall is received in August, soil moisture reserves are generally higher than in January mainly due to the residual moisture from previous rains received in the major season. Hence water deficits in August are very low despite the low rainfall received in that month. Water deficit levels observed in the current study compares favourably with the findings of Danso *et al.* [5].

3.3 Trend analysis of weather data (Annual trends)

3.3.1 Trend in Rainfall

Data on descriptive statistics for annual rainfall levels received at the study sites are presented in Table 6. The total rainfall received at Bogoso and Twifo Praso varied between 1252.90 mm and 2190.50 mm, and 982.80 to 1988.80 mm, respectively with mean values of 1457.47 ± 142.86 mm and 1480.66 mm ± 288.14 at decreasing rates (Z = -1.268 and Z = -0.356.) of 4.078 and 1.597 mm/yr, respectively. Regarding Benso and Juabeng, the annual rainfall received ranged from 1331.30 to 2464.00 mm, and 1040.90 to 1794.40 mm with mean values of 1752.94 ± 320 mm and 1324.07 ± 194.54 at increasing rates (Z = +1.748; Z = +2.233) of 13.343 and 7.608 mm/yr, respectively. Similarly, increasing trends (Z = +2.783 and Z= +0.393) were observed at Mpohor and Brewaniase. Annual rainfall received at Mpohor ranged between 831.20 to 2375.10 mm with a mean value of 1702.84 ± 440.18 mm. Rainfall at Brewaniase ranged between 808.10 to 1747.60 mm with a mean value of 1287.47 ± 220.45 for the same period of study. The rate of increase for Mpohor was 28.350 mm/yr whiles Brewaniase increased at a rate of 3.537 mm/yr from 1993 to 2022. Total rainfall at Kade ranged between 1131.71 to 1927.60 mm with a mean value of 1424.00 ± 215.14 mm, with no observable trend.

Table 5: Descriptive statistics and trend analysis of rainfall at study sites

Statistics	Rainfall (mm)						
	Bogoso	**Benso**	**Kade**	**Juabeng**	**Mpohor**	**Brewaniase**	**Twifo Praso**
Minimum	1252.90	1331.30	1131.71	1040.90	831.20	808.10	982.80
Maximum	2190.5	2464.00	1927.60	1794.40	2375.10	1747.60	1988.80
Mean	1457.47	1752.94	1424.00	1324.07	1702.84	1287.47	1480.66
SD	142.86	320.15	215.14	194.54	440.18	220.45	288.14
CV	9.80	18.26	15.11	14.69	25.85	17.12	19.46
N	30	30	30	30	30	30	28
Z test	-1.268	1.748	0.000	2.233	2.783	0.393	-0.356
p-value	0.20	0.08	1.00	0.03	0.01	0.69	0.72
Sen's slope	-4.078	13.343	-0.107	7.608	28.350	3.537	-1.597
Trend	↓	↑	↓	↑	↑	↑	↓
Significance	NS	NS	NS	S	S	NS	NS

↑Increasing trend; ↓Decreasing trend

The increasing trends in the rates of change in rainfall at Juabeng and Mpohor were significant ($p < 0.05$). However, the rates of change at Bogoso, Benso, Kade, Brewaniase and Twifo Praso rainfall were not significant ($p > 0.05$). The rainfall was characterised as moderately variable at both Juabeng (CV = 14.69%) and Mpohor (CV = 25.85%). The current findings compared favorably and, in some cases, differed with the findings of other workers from different ecological zones. Asara-Nuamah & Botcway [19] and Ayamga *et al.* [20], observed generally decreasing trends in annual rainfall levels in the different ecological zones in Ghana. Logah *et al*. [13] conducted a study to determine the variability and distribution of annual and inter decadal rainfall from 1981 to 2010 for 77 stations in Ghana. A general decline in mean annual rainfall was observed for the period 1981-2010 with high rainfalls shifting to the South-western part of Ghana. Decreases in rainfall levels may be attributed to factors like deforestation and urbanization. Increases in inter decadal rainfall levels were however observed, though the rate of increase declined from 8.6% for the decade 1991- 2000 to 2.6% for the decade 2001 to 2010. Issahaku *et al*. [21] observed decreasing rainfall trend in the upper east region whiles Subaar *et al*. [14], observed an increase in decadal rainfall by 4.39mm at Wa from 2019 to 2019. Singh and Sanatan *et al.* [22] observed an insignificant trend in the annual rainfall for some selected centres in India. Ahmed *et al.*

[23] observed a medium to high rainfall variability at the rate of 0.0008 in Malaysia. In the current study an average increase of 6.7 mm/year in rainfall was observed though some trends were observed some stations like Kade and Twifo Praso.

3.3.2 Trends in Sunshine hours and Solar Radiation

The observed mean sunshine hours during the period between 1993 – 2022 are presented in Table 6. The mean Bright sunshine (BSS) hours increased in Bogoso, Benso, Kade, Juabeng, Brewaniase and Twifo Praso at rates of 0.001, 0.040, 0.018, 0.003 and 0.006 h/yr, respectively. On the Other hand, BSS in Mpohor showed a decreasing trend at a rate of 0.008 h/yr. The BSS in Bogoso varied between 4.91 and 6.03 h with an average of 5.39 ± 0.30 h (Z = 0.268 and Sen's slope = 0.001); 5.22 and 7.55 with an average of 5.88 ± 0.54 (Z = 4.103 and Sen's slope = 0.040) in Benso; 4.58 – 6.17 h with an average value of 5.50 ± 0.39 h (Z = 1.720 and Sen's slope = 0.018) in Kade; 4.55 – 5.96 h (Z = 1.249 and Sen's slope = 0.018); and 5.83 – 6.93 h with an average value of 6.44 ± 0.26 h (Z = 0.393 and Sen's slope = 0.003) in Brewaniase; and 5.08 – 6.59 h with an average value of 5.98 ± 0.44 h (Z = 0.553 and Sen's slope = 0.006). The mean bright sunshine hour for Mpohor ranged between 5.47 to 6.44 h with an average value of 5.94 ± 0.25 h (Z = -1.249 and Sen's slope = -0.008).

Table 6: Summary statistics and trends of bright sunshine hours across the study sites

Statistics	Bright Sunshine hours (h)						
	Bogoso	**Benso**	**Kade**	**Juabeng**	**Mpohor**	**Brewaniase**	**Twifo Praso**
Minimum	4.91	5.22	4.58	4.55	5.47	5.83	5.08
Maximum	6.03	7.50	6.17	5.96	6.44	6.93	6.59
Mean	5.39	5.88	5.50	5.31	5.94	6.44	5.98
SD	0.30	0.54	0.39	0.34	0.25	0.26	0.44
CV	5.64	9.13	7.14	6.42	4.22	4.08	7.43
N	30	30	28	30	30	30	28
Z test	0.268	4.103	1.720	1.249	-1.249	0.393	0.553
p-value	0.79	0.00	0.09	0.21	0.21	0.69	0.58
Sen's slope	0.001	0.040	0.018	0.012	-0.008	0.003	0.006
Trend	↑	↑	↑	↑	↓	↑	↑

Significance	NS	S	NS	NS	NS	NS	NS

↑Increasing trend; ↓Decreasing trend

The rate of change of BSS hours in Benso was significant, whereas those observed in Bogoso, Kade, Juabeng, Mpohor, Brewaniase and Twifo Praso were not significant. Meanwhile, the BSS hours in all the study sites had weak variations across the study period in the order of Benso (9.13%) > Twifo Praso (7.43%) > Kade (7.14%) > Juabeng (CV = 6.42%) > Bogoso (CV = 5.64%) > Mpohor (4.22%) > Twifo Praso (CV = 4.08%).

The observed solar radiation during the period between 1993–2022 are presented in Table 7. The total solar radiation (SR) varied between 16.33 and 17.92 kwh/m^2 (17.03 ± 0.45 kwh/m^2) in Bogoso; 14.14 and 18.82 kwh/m^2 (17.55 ± 0.90 kwh/m^2) in Benso; 15.74 – 18.11 kwh/m^2 (17.11 ± 0.58 kwh/m^2) in Kade; 15.80 – 17.90 kwh/m^2 (16.92 ± 0.51 kwh/m^2) in Juabeng; 17.70 – 19.33 kwh/m^2 (18.60 ± 0.39 kwh/m^2) in Brewaniase; 16.53 – 18.81 kwh/m^2 (17.89 ± 0.66 kwh/m^2) in Twifo Praso; and 17.16 – 18.62 kwh/m^2 (17.87 ± 0.38 kwh/m^2) in Mpohor.

Table 7: Summary statistics and trends of solar radiation across the study sites

Statistics	**Solar radiation (kwh/m^2)**						
	Bogoso	**Benso**	**Kade**	**Juabeng**	**Mpohor**	**Brewaniase**	**Twifo Praso**
Minimum	16.33	14.14	15.74	15.80	17.16	17.70	16.53
Maximum	17.92	18.82	18.11	17.90	18.62	19.33	18.81
Mean	17.03	17.55	17.11	16.92	17.87	18.60	17.89
SD	0.45	0.90	0.58	0.51	0.38	0.39	0.66
CV	2.62	5.12	3.41	3.01	2.11	2.10	3.71
N	30	30	28	30	30	30	28
Z test	0.1070	2.855	1.719	1.142	-1.356	0.357	0.533
p-value	0.91	0.004	0.086	0.254	0.175	0.721	0.594
Sen's slope	0.001	0.044	0.026	0.017	-0.011	0.004	0.009
Trend	↑	↑	↑	↑	↓	↑	↑
Significance	NS	S	NS	NS	NS	NS	NS

↑Increasing trend; ↓Decreasing trend

The observed trends in solar radiation (SR) showed increasing rates of 0.001 kwh/m^2/yr (Z = +0.1070), 0.044 kwh/m^2/yr (Z = +2.855), 0.026 kwh/m^2/yr (Z = +1.719), 0.017 kwh/m^2/yr (Z = +1.142), 0.004 kwh/m^2/yr (Z = +0.357) and 0.009 kwh/m^2/yr (Z = +0.533) in Bogoso, Benso, Kade, Juabeng, Brewaniase and Twifo Praso, respectively, and a decreasing trend in Mpohor at a rate of -0.011 kwh/m^2/yr (Z = -1.356). The rate of change in Benso was significant (p = 0.004). The extent of variation in was weak and ranged from 2.10 – 5.12% across the study sites. Little work has been carried on trend analysis of solar radiation recorded over time in Ghana. Xu *et al*. [24] analysed the trends in monthly and annual temperatures, solar radiation and relative humidity in Sudan and observed an increasing trend in solar radiation using the Mann-Kendahl analysis. [Eladawy *et al*. [25], carried out a study of trend and fluctuations of global solar radiation over Egypt in 7 stations. They observed increasing trends in both seasonal and annual solar radiations in three of the stations and decreasing trends in the other four. Padmakumari *et al.* [26] observed a decreasing trend in some parts of India. Solar radiation is an important weather parameter due to its key role in photosynthesis. High solar radiation is playing an important role in fruit ripening. The generally increasing trends in annual solar radiation observed in this study may have a positive impact on yields. However, some setbacks in the seasonal distribution in solar radiation is sometimes encountered in Ghana as solar radiation tends to be low in months with higher rainfall levels like in June and July.

3.3.3 Trend in Temperature

Maximum temperature of Bogoso ranged between 32.22 – 33.20°C with an average value of 32.83 ± 0.27°C (Table 8). The Mann Kendall trend analysis showed that test Z was +2.182 and Sen's slope estimator was +0.014, which indicated that maximum temperature for Bogoso increased at the rate of 0.014°C/yr for the period under study. The rate of increase was significant because it had p-value 0.03. Maximum temperature of Benso varied between 29.62 – 30.83°C with a mean value of 30.31 ± 0.29°C. The trend analysis of maximum temperature of Benso showed that it decreased (Z = -0.054). Maximum temperature of Kade varied between 30.63 to 32.57°C with a mean value of 31.83 ± 0.48°C. Maximum temperature of Kade decreased (Z= -0.410) at the rate -0.004°C/yr as depicted by Sen's slope estimator; the rate of decrease was not significant. Maximum temperature of Juabeng ranged between

30.84 to 32.16°C with an average value of 31.38 ± 0.33°C for the period 1993 to 2022. The Mann-Kendall trend analysis showed that test Z was +2.161 and Sen's slope estimator was +0.017, which indicated that maximum temperature of Juabeng increased at the rate of 0.017°C/yr for the period under study, which was significant because it had $p = 0.031$. Maximum temperature of Mpohor varied between 29.14 to 30.83°C with a mean value of 29.77 ± 0.43°C. Maximum temperature for Mpohor decreased ($Z = -0.393$) at the rate -0.007°C/yr as depicted by Sen's slope estimator, which was not significant. Maximum temperature of Brewaniase varied between 31.75 to 33.66°C with a mean value of 32.58 ± 0.38°C.

Table 8: Summary statistics and trends of temperature (°C) across the study sites

Statistics	Bogoso			Benso			Kade			Juabeng		
	Max. Temp (°C)	Min. Temp (°C)	Mean Temp (°C)	Max. Temp (°C)	Min. Temp (°C)	Mean Temp (°C)	Max. Temp (°C)	Min. Temp (°C)	Mean Temp (°C)	Max. Temp (°C)	Min. Temp (°C)	Mean Temp (°C)
Minimum	32.22	21.66	27.20	29.62	22.78	26.20	30.63	19.16	25.73	30.84	21.73	26.51
Maximum	33.20	23.48	28.29	30.83	24.43	27.57	32.57	23.70	28.13	32.16	22.76	27.42
Mean	32.83	22.51	27.67	30.31	23.70	26.99	31.83	22.46	27.14	31.38	22.22	26.80
SD	0.27	0.45	0.27	0.29	0.43	0.32	0.48	0.79	0.44	0.33	0.25	0.24
CV	0.83	2.02	0.99	0.97	1.81	1.19	1.5	3.53	1.63	1.04	1.12	0.88
N	30	30	30	30	30	30	30	30	30	30	30	30
Z test	2.182	3.573	4.342	-0.054	3.765	2.373	-0.410	1.249	-0.607	2.161	1.127	2.376
p-value	0.03	0.00	0.00	0.957	0.00	0.018	0.682	0.212	0.544	0.031	0.260	0.018
Sen's slope	0.014	0.035	0.022	0.000	0.036	0.018	-0.004	0.019	-0.004	0.017	0.006	0.011
Trend	↑	↑	↑	↑	↑	↑	↓	↑	↓	↑	↑	↑
Significance	S	S	S	NS	S	S	NS	NS	NS	S	NS	S

↑Increasing trend; ↓Decreasing trend

Maximum temperature of Brewaniase decreased (Z = -0.464) at the rate -0.004°C/yr as depicted by Sen's slope estimator, which was not significant. The maximum temperature of Twifo Praso ranged between 26.14 to 32.21°C with an average value of 27.48 ± 1.32°C for the period 1993 to 2022. The Mann-Kendall trend analysis showed that test Z was +2.161 and Sen's slope estimator was +0.005, which indicated that maximum temperature of Twifo Praso increased at the rate of 0.005°C/yr for the period under study, which was not significant. The maximum temperature showed low variations as evidenced by the coefficients of variation at Bogoso (0.83%), Benso (0.97%), Kade (1.50%), Juabeng (1.04%), Mpohor (1.45%), Brewaniase (1.16%), and Twifo Praso (4.81%). However, minimum temperature of Bogoso varied between 21.66 to 23.48°C with a mean value of 22.51 ± 0.45°C.

The trend analysis test showed that the Bogoso minimum temperature increased (Z = 3.573) at the rate of 0.035°C/yr for the period 1993 to 2022, which was significant because it had p = 0.00. The minimum temperature of Benso varied between 22.78 to 24.43°C with a mean value of 23.70 ± 0.43°C, which was significant because it had p-value 0.00. The minimum temperature of Kade varied between 19.16 to 23.70°C with a mean value of 22.46 ± 0.79°C. The minimum temperature of Kade increased (Z = 1.249) at the rate 0.019°C/year as depicted by Sen's slope estimator, which was not significant. Minimum temperature of Juabeng ranged between 21.73 – 22.76°C with an average value of 22.22 ± 0.25°C. It increased (Z +1.127) at the rate of 0.006°C, which was not significant. Minimum temperature of Mpohor varied between 23.08 – 24.83°C with a mean value of 23.89 ± 0.50°C. It decreased (Z = -0.393) at the rate -0.007°C/yr as depicted by Sen's slope estimator (Table 2), which was significant because it had p < 0.0001. Minimum temperature of Brewaniase varied between 22.68 – 23.88°C with a mean value of 23.10 ± 0.28°C. It increased (Z = 0.357) at the rate 0.003°C/yr as depicted by Sen's slope estimator (Table 2), which was not significant. Minimum temperature of Twifo Praso ranged between 20.61 to 23.10°C with an average value of 22.23 ± 0.54°C. Minimum temperature of Twifo Praso increased (Z + 0.428) at the rate of 0.005°C. The minimum temperature showed weak variations across the study sites as evidenced by CV values ranging from 1.21 – 3.53%.

The mean temperature of Bogoso increased (Z = +4.342 the rate 0.022°C/yr whereas mean temperature of Benso increased (Z = +2.373) at the rate 0.018°C/yr (Table 2), both were significant p = 0.00 and 0.018, respectively. However, mean temperature of Kade decreased (Z = -0.607) at the rate

-0.004°C/yr, which was not significant. Mean temperature of Juabeng increased (Z = +2.376) at the rate 0.011°C/yr (Table 2), which was significant because it had $p < 0.018$. Mean temperature of Mpohor increased (Z = +3.087) at the rate 0.017°C/yr (Table 2), which was significant because it had $p < 0.0001$. Mean temperature of Brewaniase increased (Z = +0.054), whereas mean temperature of Twifo Praso increased (Z = +0.856) at the rate 0.013°C/yr (Table 2) and both were not significant. Temperature levels recorded in the current study fell within the acceptable range for oil palm cultivation. Temperature can be a limiting factor for oil palm production Temperatures below 18°C is not suitable for optimum growth and yield of oil palm. Averagely recommended temperature levels range from 27 – 28°C. Maximum recommended temperatures range from 30 – 32°C and a minimum range of 21 – 24°C. Palm activities like flower development, FFB ripening and frond development are favoured by these temperature ranges [4].

Generally, an increasing trend in both maximum and minimum temperatures were observed at most sites, which was significant. This could be due to the effect of climate change. Mean temperatures increased by an average rate of 0.011℃/yr. However, Klutse *et al*. [27] reported an average increase in temperature of 1.0℃ from 1961 – 2000 in Ghana. Accordingly, Läderach [28] predicted an increase by 1.1 – 1.3°C in Southern Ghana and up to 1.4°C in Northern Ghana by 2030Ahmed *et al*. . [23] observed an increase of 5.6℃ at the rate of 0.0357℃/yr with a temperature maximum of 32.01℃ and minimum of 25.45℃. The gradual increase in temperatures may lead to global warming which may have adverse impact on oil palm yields. Sakar [29] observed that increases in temperature by 1 – 4℃ oil palm production may result in a decline in fresh fruit bunch production by 10 – 40%. Frimpong *et al.* [30], also predicted an increase in heat stress related diseases may be observed as a result of global warming. Minia [31] observed that temperature has been increasing more rapidly in the Northern than Southern parts of Ghana. Similarly, Läderach [28], predicted that by 2030, an increase in temperatures by 1.1–1.3°C would be observed in southern Ghana and up to 1.4°C in Northern Ghana.

4. CONCLUSIONS

Generally, an increasing trend in annual rainfall was observed from 1993 – 2022, although there were a few decreasing trends. The rate of increase for Mpohor was 28.35 mm/yr. Rainfall trend at Twifo Praso decreased at the rate of 1.597 mm/yr for the study period. The rate of increases at Juabeng was

7.61 mm/yr. The rates of increases (or decreases) were only significant at Juabeng and Mpohor. Evidently, the moist evergreen forest zone had the highest rates of increase in rainfall amount. Additionally, significantly increasing trends were observed in both maximum and minimum temperatures. Mean temperatures increased by an average of 0.011℃/yr. Significant increases in mean temperatures were observed at Bogoso (0.022°C/yr), Benso (0.018°C/yr), Juabeng (0.011°C/yr) and Mpohor (0.017°C/yr). The trend in mean annual solar radiation was generally not significant except in Benso where the mean solar radiation increased at the rate of 0.044 MJ/day. Studies on climatic water balance at Benso indicate water deficits were high during periods of dry weather from December to March and in August. Water surplus in soil were observed during the rainy periods in May to July and from September to November. The same trend is observed at all sites in the oil palm belt irrespective of the ecological zone. Irrigation of palms during months water deficits would help improve yields.

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