Revisiting The Agro-Climatic Zones Of Ghana: A Re-Classification In Conformity With Climate Change And Variability

Edmund I. Yamba[a,*], Jeffrey N. A. Aryee[a], Emmanuel Quansah[a], Patrick Davies[a], Cosmos S. Wemegah[b], Marian A. Osei[a], Maureen A. Ahiataku[c], Leonard K. Amekudzi[a]

[a]*Department of Meteorology and Climate Science, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana*
[b]*Earth Observation Research and Innovation Center, University of Energy and Natural Resources, Sunyani, Ghana*
[c]*Ghana Meteorological Agency (GMet), Accra, Ghana*

Abstract

Agro-climatic zones are geographical areas delineated based on climate homogeneity and impact on agriculture. Ghana's agro-climatic zones have been in use since the 1960s, with no consideration given to current climate change and variability. The continued use of this age-old classified zones suggest Ghana's climate remains stable despite previous research findings to the contrary. In this study, we reconstructed a more appropriate and dis-aggregated agro-climatic zone map of Ghana that is in tandem with the current climate change and variability. Our findings revealed significant changes in the number of climate zones, their boundary sizes and geographical orientation. The newly proposed agro-climatic zones map consist of five distinctive climate regimes namely Sudan Savannah, Guinea Savannah, Transition, Forest and Coastal zones. The Sudan and Guinea Savannah zones showed a southerly

*Edmund I. Yamba: Email at: eiyamba@knust.edu.gh

expansion. The transition zone shriveled in size as the Guinea Savannah zone took over most of it, notably in the southeast. The forest zone also shrank in size with a northwest shift while the coastal belt grew to encompass the whole coast of Ghana. These changes are strong evidence of climate change and possible food production changes. The findings of this study are useful to agriculture sector in planning their activities, the health sector in predicting specific diseases caused by changes in weather and climate, Ghana Meteorological Agency for weather forecasting purposes, and the National Disaster Management in identifying disaster prone zones.
Keywords: Agro-Climatic, Zones, Ghana, Re-Classification, Climate Change, Variability

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1. Background

Agro-Climatic Zones (ACZs) are geographical areas characterized by homogeneity in meteorological factors or climatic conditions that have a significant impact on crop development and yield [1]. Climate characteristics such as temperature, humidity, amount and type of precipitation, and the passage of seasons within a certain area are commonly used to characterise ACZs [1, 2]. Among these parameters, temperature and precipitation are most commonly used for ACZs delineation [3]. This is because, some locations can have a significant wider minimum and maximum range than others. In the same vein, some locations can have roughly the same amount of rainfall throughout the year, while others may experience very little rainfall for part of the year and a lot of rainfall for the rest of the year. Changes in these climate parameters of an area can have a big impact on plants and animals that live in that area. Information about ACZs can, therefore, help experts track changes that occur within a zone due to climate change or global warming. It can also help identify areas with different crop and animal production potentials according to environmental circumstances [4, 1]. Knowing which plants flourish in particular climates can assist farmers in determining which plants will thrive on their own and which will require assistance. [5, 3].

Ghana's geographical space has been divided into four ACZs by the Ghana Meteorological Agency (GMet), namely the North, Transition, Forest, and Coastal zones. This classification was carried out for purposes of weather forecasting and application of agricultural information. The zonation has been in use since the 1960s without reference to contemporary climate change and variability. The continued usage of this age-old classification indicates that Ghana's climate is stable. However, there are mounting evidence from previous research [6, 7] suggesting that climate variables such as temperature and rainfall have changed with time in Ghana. Amekudzi et al. [8] used rain gauge data to analyze the variations in the onset, cessation and length of the rainy season across Ghana's agro-ecological zones and found evidence of significant heterogeneity in the rainfall onset and cessation dates across the country. Baidu et al. [9] employed wavelet analysis to assess the long-term spatio-temporal rainfall variability over Ghana and discovered a significant declining trend in seasonal rainfall, implying a major effect from both climate change and anthropogenic activities. Increased temperatures, late commencement and early termination of the rainfall season, and certain severe mid-season droughts have also been corroborated in research studies

[10, 11, 12, 13, 14, 15] addressing farmers' observations of climate change and variability in Ghana. Given that climate change and variability can have a substantial impact on ACZs, evidence of climatic changes in Ghana, in combination with population expansion and increased human activity [16], necessitates a revision of Ghana's current ACZs to reflect the current climate. Continuing to use ACZ classifications that are out of step with contemporary climate change and variability is a disservice to the public.

To our knowledge, no previous study has evaluated the extent to which climate change has affected Ghana's ACZs and reclassified the zones to reflect contemporary climate and variability. Aryee et al. [17] defined the ACZs of Ghana using annual mean rainfall data and a k-means clustering technique. This climate map, on the other hand, was an attempt to evaluate a high spatial resolution rainfall data that the authors generated for Ghana. However, using annual mean rainfall for ACZ categorization, as was the case of GMet, has the disadvantage of not accounting for seasonal rainfall contrast and dry spells. Furthermore, using annual mean total rainfall can mask large areas together as having similar features without taking into account local variability.

Our study, therefore, addressed this knowledge gap on ACZs by taking a cue from the previous classifications. We reconstructed a more appropriate and dis-aggregated ACZ map of Ghana in tandem with the current climate change and variability. To define the climate regime of an area, at least 30 years of rainfall and temperature data is required [18]. Using monthly rainfall and temperature data spanning 30 years, we quantified the contrast in their seasonal amount across the country, characterized their distribution and classified Ghana's climate. Our findings are intended to give information useful for agricultural practices, weather forecasting, disease control, water resource management, socio-economic activities and food security in Ghana.

2. Materials and methods

2.1. Study area

Ghana, the study area, is a West African country with geographical boundaries between latitudes 4.5°N and 11.5°N and longitude 3.5°W and 1.5°E (see Figure 1). It is bordered on the north by Burkina Faso, on the east by Togo, on the west by Côte d'Ivoire, and on the south by the Gulf of Guinea. The country has a tropical monsoon climate with agricultural land accounting for about 65 percent of the overall land area [19, 16]. Rainfall in Ghana is governed by the West African Monsoon (WAM), a pressure system driven by the energy and temperature gradient between the Gulf of Guinea and the Sahara [8]. This pressure system is modulated by the Inter-Tropical Discontinuity (ITD) [20, 21]. The ITD oscillates between the north and south of Ghana, resulting in a bi-modal and uni-modal rainfall distribution [17]. The northern Ghana is characterized by uni-modal rainfall distribution which starts from April through mid-October with peak rainfall in August or September. The south of Ghana has a bi-modal rainfall distribution. The first season runs from March to July, with peak in June, while the second season runs from September to mid-November, with peak in October. Other factors influencing the country's rainfall pattern include local convective activity, sea surface temperature, and atmospheric dynamic sta-

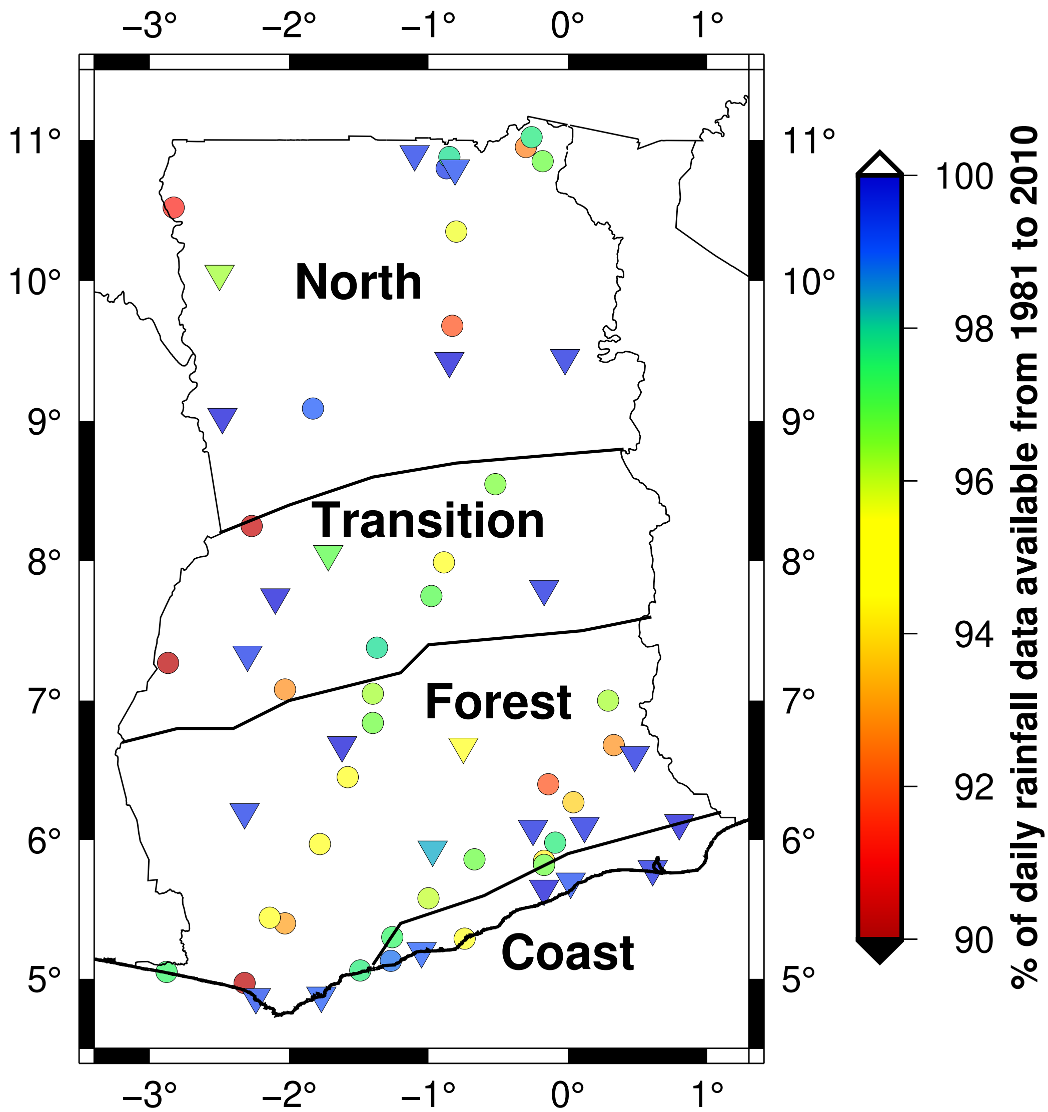

Figure 1: A map of Ghana showing the GMet synoptic weather stations (inverted triangles), and other ground-based weather stations (circles). The color gradient reflects the percentage of daily rainfall data available. It also shows the existing ACZs demarcations adapted from Amekudzi et al. [8] which include North, Transition, Forest and Coastal zones

bility [9]. Between December and February, the harmattan, a north-easterly desert wind, dominates the country. The harmattan winds are more prevalent in the north, lowering humidity and resulting in hotter days and cooler nights in this area of the country.

2.2. Meteorological data

In this study, monthly rainfall and temperature data were used. The rainfall data was obtained from the Global Precipitation Climatology Centre (GPCC) data [22]. GPCC data is a gridded gauge-analysis products and available globally from 1891 to 2016 at a high spatial resolution of 0.25^o by 0.25^o. The GPCC data was chosen because it offers data for the time period covered in this study (1921-2010). Besides, it is a rain gauge-analysis product obtained from quality-controlled rainfall data from ground-based weather stations. Furthermore, GPCC data has been demonstrated to be reliable and consistent with ground-based weather observations in earlier validation investigations [20, 23].

Rainfall data from ground-based weather stations across Ghana were also obtained from the Ghana Meteorological Agency (GMet). These station data were available daily and covered the years 1981-2010. Stations with at least 90% of the data available over the period, totaling 61, were selected. Fig 1 depicts the geographic locations of each selected station as well as the percentage of data that is available. For stations with missing data, daily rainfall data from the Climate Hazards Group Infra-Red Precipitation (CHIRPs) [24] was used to patch up those gaps. CHIRPS is a gridded satellite-gauge product with a high spatial resolution of 0.25^o by 0.25^o and available globally on a daily time scale from 1981 to the present. CHIRPs was used because, previous validation studies [23] found that it correlated well with ground-based observations over Ghana. Besides, CHIRPS was built utilizing a combination of satellite and ground-based observations [24].

Temperature data covering the years 1981-2010 were gathered from 24 GMet synoptic weather stations (see inverted triangles in Fig 1) and were available on a daily time scale. The proportion of daily minimum and maximum temperature data available for the period are shown in Table 1. Stations with gaps in the temperature data were filled with daily data from the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis, 5th generation (ERA5) [25]. ERA5 is a gridded re-analysis product with a high spatial resolution of 0.25^o by 0.25^o and available globally on an hourly time scale from 1979 to the present. ERA5 is a widely recommended dataset for meteorological research. For the purposes of this study, all daily rainfall and temperature data were converted to monthly values.

2.3. Data analysis

We applied a simple rainfall Seasonality Index (SI) developed by Walsh and Lawler [26] to the monthly rainfall data (from GPCC and ground-based weather stations) and quantified the contrast in seasonal rainfall amount year by year for different climate windows: 1921-1950, 1951-1980 and 1981-2010 using Equation 1. The climatological mean of SI_i, $\overline{SI}$, for each climate period was then computed using Equation 2.

$$SI_i = \frac{1}{R_i} \sum_{n=1}^{n=12} |X_{in} - \frac{R_i}{12}| \quad (1)$$

Table 1: GMet Stations and the percentage of data available over the period 1981-2010.

Station	Longitude	Latitude	% of data available		
			Rainfall	Max Temperature	Min Temperature
Navrongo	-1.10	10.90	99.45	99.99	100.00
Wa	-2.50	10.05	98.07	99.73	99.73
Tamale	-0.85	9.43	100.00	96.16	97.48
Yendi	-0.02	9.45	100.00	99.36	83.22
Bole	-2.48	9.03	99.97	99.11	99.72
Kete_Krachi	-0.17	7.80	99.98	99.61	99.73
Sunyani	-2.30	7.33	99.43	99.72	99.72
Wenchi	-2.10	7.74	99.98	90.34	89.90
Ho	0.48	6.61	99.74	98.84	98.90
Kumasi	-1.62	6.68	99.99	99.67	99.69
Akim_Oda	-0.97	5.93	100.00	99.44	99.44
Abetifi	-0.75	6.67	93.61	99.47	99.19
Sefwi_Bekwai	-2.32	6.20	100.00	99.46	99.72
Koforidua	-0.25	6.08	100.00	94.13	99.55
Akatsi	0.80	6.12	94.71	99.89	99.92
Akuse	0.12	6.10	99.72	93.15	97.13
Ada	0.61	5.79	99.97	99.73	99.61
Accra	-0.17	5.65	100.00	100.00	100.00
Tema	0.02	5.70	99.43	92.79	93.07
Takoradi	-1.77	4.88	99.74	97.63	97.55
Saltpond	-1.05	5.20	98.88	97.15	97.22
Axim	-2.24	4.87	99.46	92.78	92.78
Kintampo	-1.72	8.05	98.58	43.35	42.79
Zuarungu	-0.81	10.80	99.16	61.26	61.00

where R_i is the total annual rainfall for a particular year i and X_{in} is the actual monthly rainfall for month n of the respective year i.

$$\overline{SI} = \frac{1}{N} \sum_{n=i}^{n=j} SI_{ij} \tag{2}$$

where N is the number of years for each climate window, at least 30 years, and corresponded with the World Meteorological Organization's (WMO) base years for climate analysis. Higher values of $\overline{SI}$ indicate a great overall departure from an equal distribution of rainfall throughout the year and near zero values suggest that there is little or no seasonal variation in precipitation [26]. The class limits of $\overline{SI}$ and their representative rainfall regimes are shown in Table 2. Locations with similar $\overline{SI}$ estimates were then mapped out as areas with similar rainfall regimes. The SI is key in this case because it classifies the type of climate in relation to water availability. The higher the SI values of a region, the greater the water resources variability and scarcity in time and the more vulnerable the area is to desertification [27, 18].

Temperature regimes were only computed for the 1981-2010 climate window

Table 2: Seasonality Index (SI) class limits and the associated rainfall regimes. Adapted from Walsh and Lawler [26].

SI Class Limit	**Defined Rainfall Regime**
≤ 0.19	Rainfall spread throughout the year
0.20 - 0.39	Rainfall spread throughout the year but with a definite wetter season
0.40 - 0.59	Rainfall is seasonal with a short dry season
0.60 - 0.79	Rainfall is seasonal
0.8 - 0.99	Rainfall is markedly seasonal with a long drier season
≥ 1.00	Most rainfall in 3 months or less

since temperature data for the other climate eras (1921-1950 and 1951-1980) were not available. Using both the observed and ERA5 temperature data, the study calculated the annual mean temperature climatology for the 1981-2010 climate window and mapped out areas with similar patterns. Given that the ground-based temperature observations were point data, ERA5 was used to complement the spatial temperature distributions over the country.

The study also computed the length of the growing season for each climate regime for the 1981-2010 climate window. The Standardized Rainfall Anomaly Index (SRAI) was applied to the monthly rainfall data from the GMet synoptic stations and determined the wet and dry months of station within each climate regime. The wet and dry months were determined because they are critical for defining the length of the growing season. SRAI was originally developed as a drought index [28] and has since been widely used to monitor and assess drought in many research works [29, 30, 31]. The SRAI was calculated using Equation 3 as follows:

$$SRAI_n = \frac{(X_n - \mu)}{\sigma} \tag{3}$$

where, X is the climatological monthly rainfall total for month n, μ is the climatological mean monthly rainfall and σ is the standard deviation of the monthly rainfall over the period of observation. Using the SRAI, positive anomalous months were deemed wet, whereas negative anomalous months were considered dry. The number of positive anomalous months was used to determine the length of the growing season for each regime. The first and last positive anomalous month for each regime were classified as the onset and cessation months of the growing season respectively. The corresponding monthly temperature observations (minimum and maximum) for each synoptic station were plotted along with with the monthly anomalies to observe monthly temperature fluctuations.

3. Results

3.1. Rainfall regimes

Figure 2 shows the rainfall SI map of Ghana statistically estimated from Equation 2 using the rainfall data for the different climate periods: 1921-1950, 1951-1980 and 1981-2010. The observed 1981-2010 map (lower right corner) is a replication of the GPCC 1981-2010 (lower left corner) map using rainfall data from the ground-based weather stations as validation. In this SI map, the contrast in SI is shown. Areas with similar SI values and their geographical extent are delineated for each climate window. The SI ranges clearly reflects changes in seasonal rainfall concentration, as indicated in Table 2. The contrast in rainfall seasonality which defines the different rainfall regimes is closely related to the latitudinal variation over the country. The highest SI values are observed over the northern fringes of the country (mostly at latitudes above 10 °C) decreasing to lower values over the forest areas (below latitude 8 °C) with coastal areas mimicking that of the Guinea Savannah. It is also observed from the maps that the SI values generally increased from one climate period to the other. That is, SI values for each distinct region were generally low in 1921-1950 period compared to the 1981-2010 period. Besides the increase in the SI values, an expansion in the geographical extent of areas with similar SI values has also been observed. The 1981-2010 period has witnessed the highest spatial expansion of

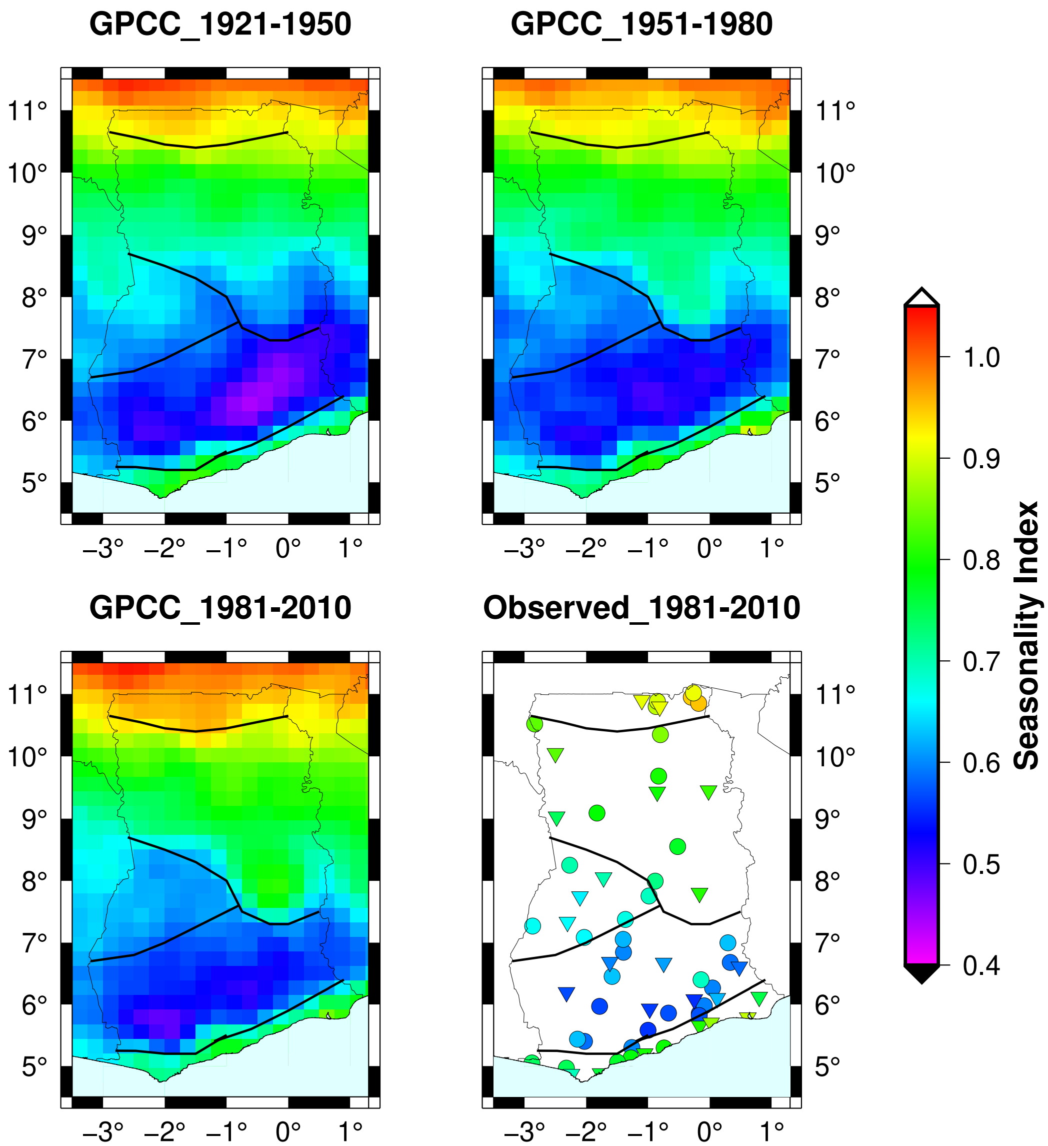

Figure 2: Rainfall SI map of Ghana and their geographical extent. The black solid lines shows the geographical boundaries of areas with similar SI.

the regimes compared to other periods.

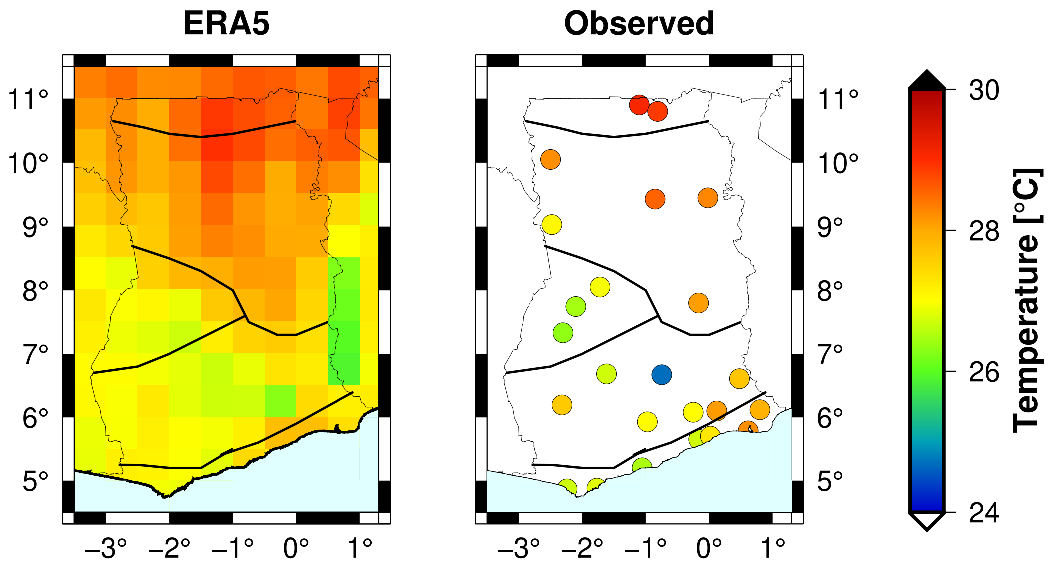

Figure 3: The map of Ghana showing mean temperature patterns. The map was produced from mean temperature climatology computed from ERA5 and ground-based weather station temperature data for the period 1981-2010

3.2. Temperature regimes

Figure 3 shows the temperature regimes of Ghana for the 1981-2010 climate window. In this figure also, areas with similar temperature patterns are delineated. It is observed that the temperature contrast over Ghana mirrors similar patterns seen in the rainfall regime map (see Figure 2). High temperature records are observed over the northern fringes of the country, then falls to lower values over the forest areas. Furthermore, a strong southerly temperature trajectory, particularly in the south-east, is observed from the northern fringes of the country. Coastal temperatures are similar to those in the transition zone and slightly higher than those in the forest areas.

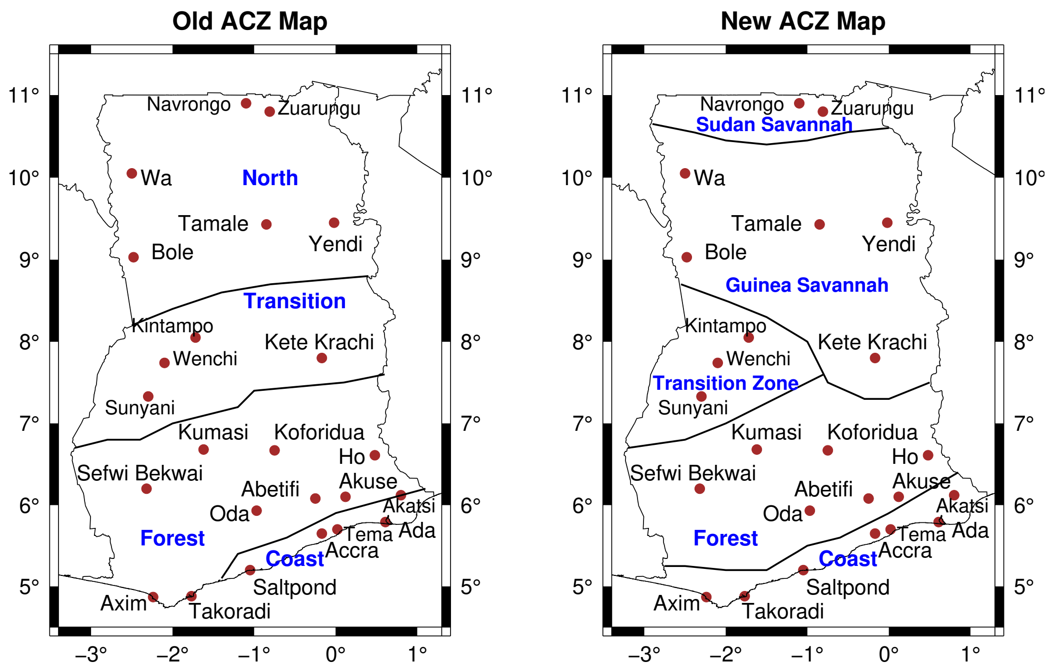

Figure 4: A comparison of Ghana's old (left) and newly proposed (right) ACZ maps. The brown circular dots indicate the locations of GMet Synoptic stations whose data were used to calculate the growing season length.

3.3. Proposed new ACZ map of Ghana and length of growing season

In Figure 4, a new ACZ map of Ghana (on the right) is proposed and contrasted with the existing old map (on the left). The proposed new ACZ map uses the well reflected geographical distinctions in rainfall and temperature contrast over the country (see Figure 2 and Figure 3). Unlike the old ACZ map, five zones were observed in the new map and named as Sudan Savannah, Guinea Savannah, Transition, Forest and the Coastal zones. The Sudan Savannah zone showed highest SI values and covered the northern fringes of the country. In this zone, rainfall is markedly seasonal with longer drier season. As shown in Figure 5, the zone has a single wet period of about 4-5 months (May to September), with the rest of the year remaining dry (October to April). Seasonal temperature distribution ranges between a minimum of 20 °C during the harmattan season to a high of about 40 °C during the pre-monsoon season. The zone also records the lowest annual rainfall total of about 900 mm and highest annual mean temperature about 29 °C.

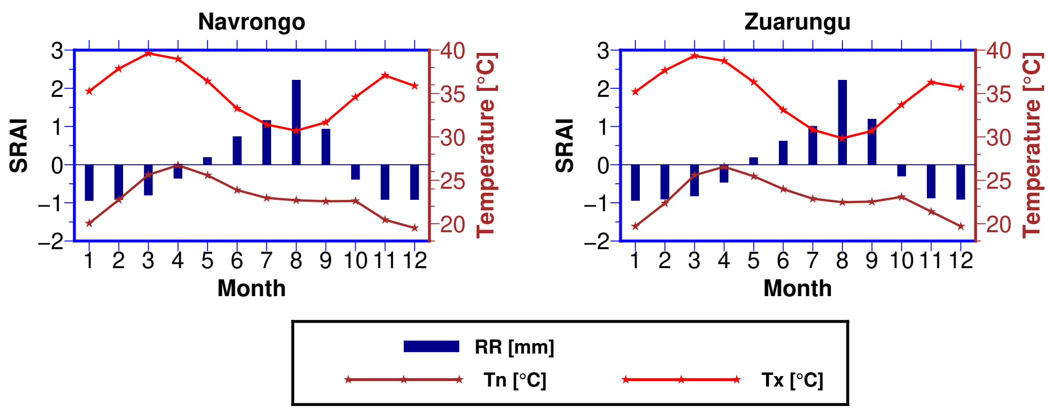

Figure 5: The wet and dry months and their temperature distribution for synoptic stations within the Sudan Savannah zone

The Guinea Savanna showed the next highest SI values after Sudan Savannah. This region lies between latitudes 8 °N and 10°N. Seasonal rainfall in this zone, as shown in Figure 6, is uni-modal with wet period ranging between 5-6 months in the northern parts of the zone (Wa, Tamale and Yendi) to about 6-7months in the south (Bole and Kete-Krachi). Mean seasonal temperatures are lower than that of the Sudan Savannah and ranges between 20 °C and 35 °C. Mean annual rainfall ranges between 1100 and 1200 mm with mean annual temperature range of about 28 °C to 29 °C.
The Forest zone showed the lowest SI ranges and covers the areas between

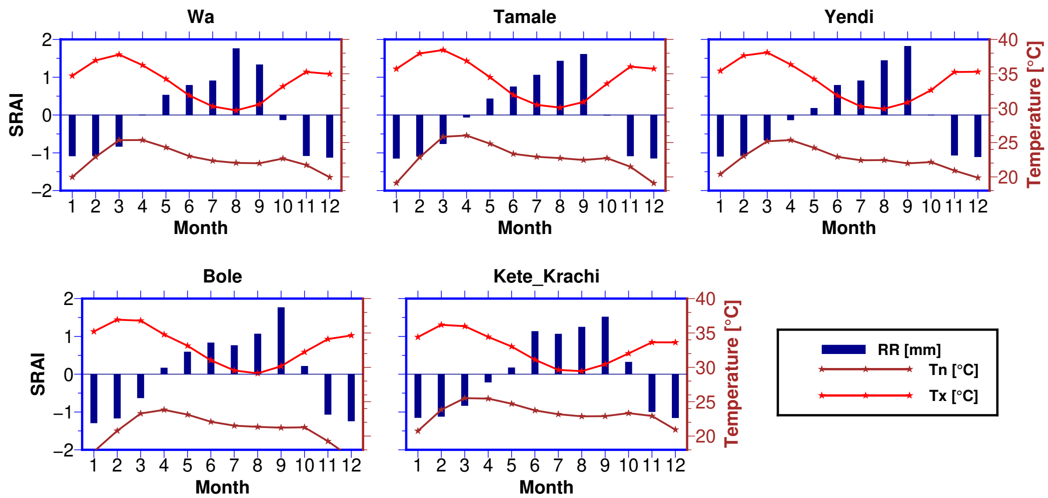

Figure 6: The wet and dry months and their temperature distribution for synoptic stations within the Guinea Savannah zone

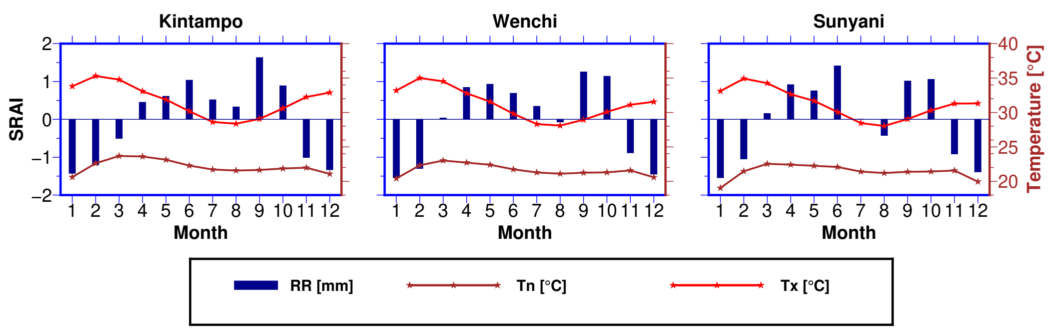

Figure 7: The wet and dry months and their temperature distribution for synoptic stations within the Transition zone

5 °N and 8 °N. Figure 8 shows that rainfall in this zone is seasonal but with a shorter dry season compared to the Guinea Savannah zone. It also shows a bi-modal rainfall season with two wet seasons, a major and minor season. The first rainy season (major season) starts from March to July with a dip in August followed by a minor rainy season from September to October. This zone also shows the lowest temperature records from as low as 18 °C to a

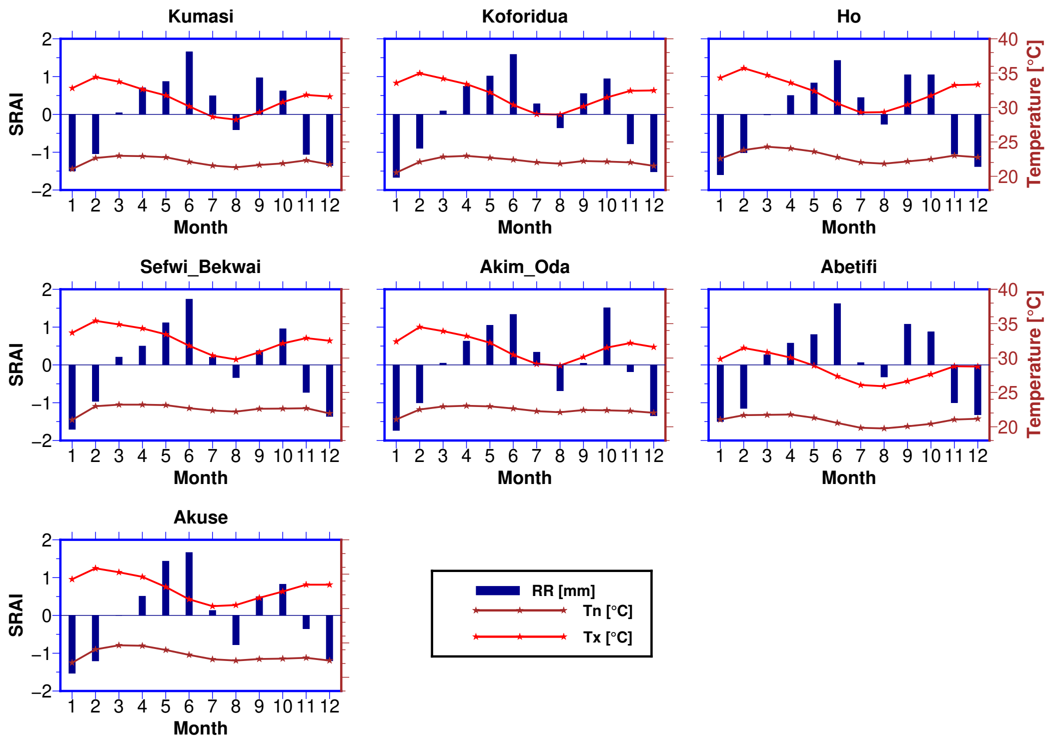

Figure 8: The wet and dry months and their temperature distribution for synoptic stations within the Forest zone

maximum below 35 °C. The zone records the highest annual rainfall total of about 1300–1800 mm and with mean annual temperature of about 26.5 °C. In Figure 7, the seasonal rainfall and temperature characteristics of the Transition zone are shown. It is observed that the transition zone exhibits similar seasonal characteristics as that of the forest zone. The difference is that mean annual rainfall total for the transition zone is lower compared with that of the forest areas.

The Coastal zone has similar seasonal rainfall and temperature characteristics as the Guinea Savannah zone. Unlike the Guinea Savannah zone, the coastal zone has a bi-modal rainfall season (see Figure 9) as observed in the

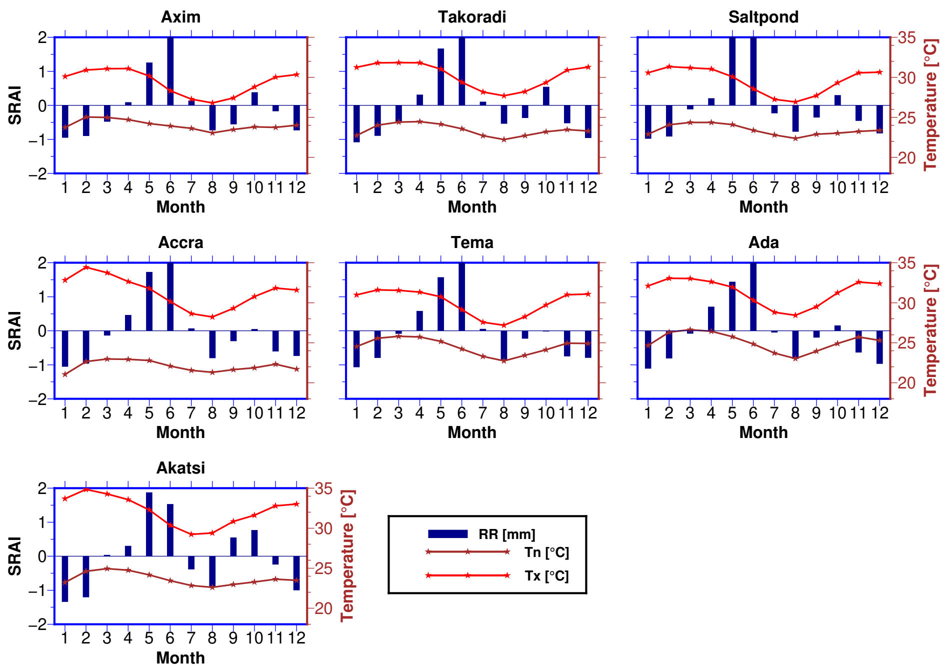

Figure 9: **The wet and dry months and their temperature distribution for synoptic stations within the Coastal zone**

Forest zone. However, the major monsoon season of the Coastal zone is shorter in duration compared with the forest zone. In addition, the minor season is not as distinctive as observed in the forest zone.

In general, Ghana experiences a tropical climate. As shown in Figure 10, the annual mean total rainfall varies from as low as 800–900 mm in the Sudan Savannah and Coastal zones to as high as 1900 mm in the Forest zone. Most of the high annual total mean rainfall are observed in major parts of the Forest zones, southeastern fringes of the Guinea Savannah and Transition zones. The highest annual total rainfall of about 1900 mm is observed in the extreme South-Western part of the country. Major parts of the Guinea

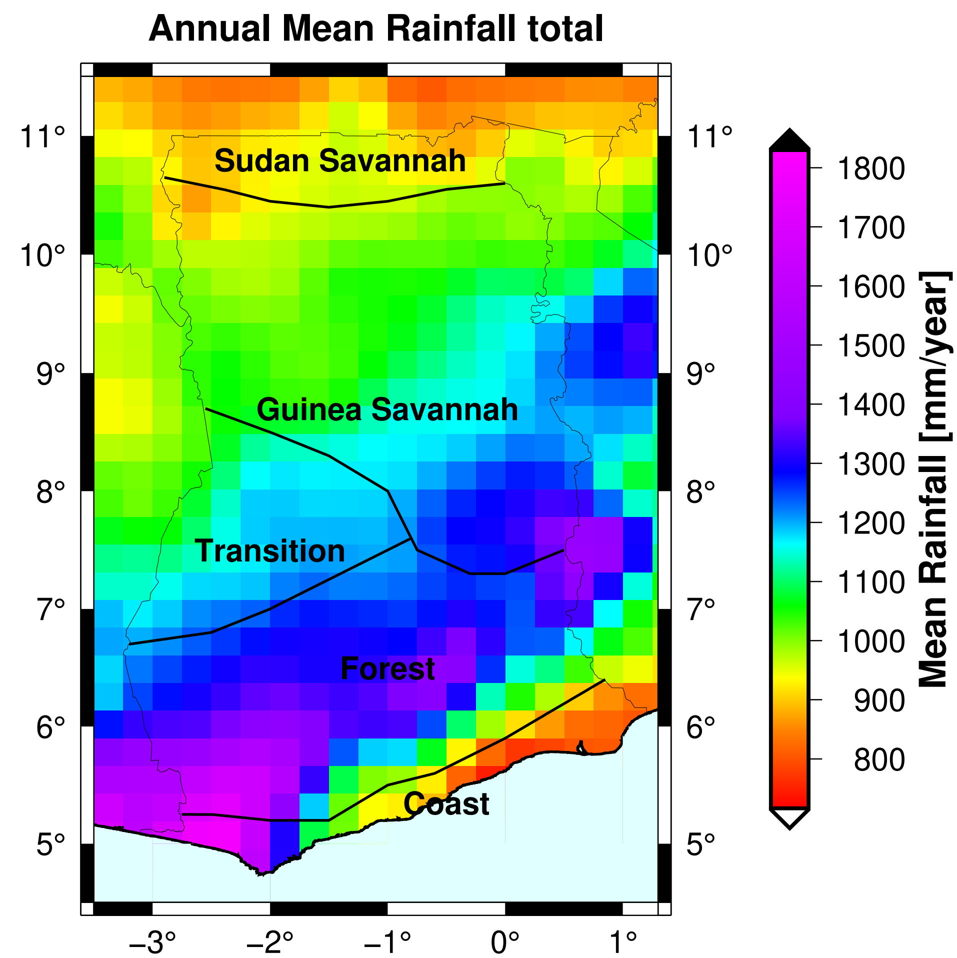

Figure 10: **A map of Ghana showing patterns in mean annual total rainfall. This map was produced from annual total rainfall climatology computed from GPCC data for the period 1981-2010.**

Savannah zone has annual total mean rainfall of about 1100 mm. There is a wide spatial and temporal variations in both the seasonal and annual rainfall. The reliability in seasonal and annual rainfall over the country increases with decreasing latitudes from North to South. The mean annual temperature is observed to vary from about 25.5°C around the south-Western coastal areas to about 30°C in the northern parts of the country.

4. Discussions

Ghana's existing ACZs were examined and reclassified to reflect current climate change and variability. We quantified the contrast in rainfall and temperature amounts in Ghana over a 30-year period and mapped out places with comparable patterns. Our work re-defined the geographical space of Ghana into five ACZs namely Sudan Savannah, Guinea Savannah, Transition, Forest, and Coastal zones. The previously designated Northern belt (old map) was reclassified into the Sudan Savannah and Guinea Savannah zones. The Guinea Savannah zone showed a southerly expansion, engulfing much of the transition zone as well as extending slightly into the forest zone. The Coastal Zone has also been expanded to encompass all places along Ghana's coast.

The contrast in rainfall and temperature amount observed among climate zones can be linked to the movement of the Inter-Tropical Convergence Zone (ITCZ) north and south of the country. The ITCZ modulates the West African Monsoon pressure systems, resulting in the country's rainy and dry seasons [8, 16]. In the Sudan Savannah, Guinea Savannah, and Transition zones, the ITCZ oscillation provides a unimodal rainfall distribution, but in Ghana's Forest and Coastal areas, it creates a bimodal rainfall distribution. In all the five identified zones, the rainy seasons doubles as the growing seasons and the number of rainy months determines the length of the growing season. The rainy season in the Sudan Savannah zone lasts from

May to September, with August seeing the most precipitation. It rains from April/May through October in Guinea Savannah, with September being the wettest month. Two rainy seasons are experienced in Ghana's south, which includes the Forest and Coastal belts. The first season runs from March to July, with June being the wettest month, while the second (minor) season runs from September to mid-November, with October being the wettest month. Other mechanisms such as local convective activities, sea surface temperature and atmospheric dynamic stability also influence the rainfall pattern in the country [9]. For instance, the more months of rainfall in the forest zone is attributed to the influence of the Togo-Akwapim mountain ranges, which stretch from Togo through to the central part of the forest zone of Ghana. These ranges are known to enhance the convective activities of the forest zone, and areas in the windward side of the mountains are strongly affected [8]. The coastal zone showing indexes of similar magnitudes to that of the Guinea Savannah zone is attributed to the low moisture content in the area due to the flat physical nature of the land and the monsoon winds blowing parallel to the coastal land. The harmattan, which is a dry desert wind from north-east dominates the country from December to February. The presence of the harmattan winds is predominant in the North, lowering the humidity and causing hotter days and cooler nights in this part of the country. Mean maximum temperature are low during the harmattan months and highest during the months of March to April especially in the North.

As previously mentioned [14, 13, 6], the shifting limits of the ACZs and the decline in seasonal rainfall are strong indications of climate change and variability. The Sudan Savannah zone has expanded into the Guinea Savannah zone, while the Guinea Savannah zone has expanded into the Transition and Forest zones. In these instances, a spread of arid conditions from the previous zone to the next is observed. The spread of arid conditions is another evident evidence of climate change and variation. As a result, scheduling the ideal period for crop cultivation becomes more complex, making ACZs less useful as a planning tool for successful and sustainable agricultural production. The Sudan and Guinea Savannah zones are important for cereal crops like maize, soya beans, peanuts, and tubers like yam, all of which contribute significantly to Ghana's economy [32]. The growth of arid conditions in these zones indicates a reduction in the appropriateness of certain crops for cultivation. This has major consequences for food security, necessitating the adoption of climate change and variability mitigation techniques by farmers.

Other studies [33, 34, 35] have applied the length of growing season as an additional criterion for ACZs classification. The growing season defines the period of the year when both moisture and temperature conditions are suitable for crop production [34]. The growing period concept is essential because it provides a way of including seasonality in land resource appraisal [33]. The SRAI was used as our approach to determining the length of the growing season. This index was chosen because it can accommodate dry spells in the middle of the season as well as specify wet and dry month of the season. It can also display the borders and number of zonal shifts in rainfall regimes over an area, as well as the period of rainfall concentration within a year.

5. Conclusions

Given the environmental dynamism and taking the advantage of observed meteorological data and technology, a review of the existing ACZs of Ghana was carried out to keep them updated and abreast with the present climate situation. The study used a simple and explicit approach to produce a more accurate and predictive pattern of the ACZs of Ghana. It quantified the seasonal contrast in rainfall and temperature amount within a year over a period of 30 years and described the distinctive climate regimes over the country. Unlike the previous attempt that provided the old ACZ map for the country, the current work considered the classification at a micro-scale level by using highly resolved grid-spaced rainfall and temperature data.

Our study revealed changes in the existing ACZs in terms of the number and boundary sizes of the zones. Based on the revelations of our study, a new ACZ map of Ghana was proposed with distinctive climate regimes as Sudan Savannah, Guinea Savannah, Transition, Forest and Coastal zones. Compared with old ACZ map, the new map clearly shows the changes in the number of zones, the boundary sizes and geographical orientations. Our results also highlight specific areas within each zone where farmers may face challenges related to adverse climate conditions as well as ever changing environment. These changes clearly point to the influence of climate change and variability.

The newly proposed ACZ map will allow for area-specific land use planning, enable research and extension activities as well as for agro-technology transfer between related zones [33, 34]. It will assist farmers in developing and implementing climate resilient management plans to improve water retention and food security in drought-prone regions such as the Sudan and Guinea Savannah zones. It will also help GMet create seasonal forecast that are in tandem with climatic variability and associated atmospheric dynamics within the climate zones. The new map can also help health officials forecast the prevalence and spread of climate-related diseases like malaria and meningitis.

Author Contribution

The work presented here was carried out collaboratively among the authors. Edmund I. Yamba co-designed the project, prepared the database, conducted the analysis for some figures and drafted the manuscript. Jeffrey N. A. Aryee and Emmanuel Quansah co-designed the project and co-authored the paper. Patrick Davies and Cosmos S. Wemegah conducted the analysis for some figures and reviewed the manuscript. Marian A. Osei and Maureen A. Ahiataku contributed to results and reviewed the manuscript. The project was supervised by Leonard K. Amekudzi, who also co-authored the paper. The manuscript was proofread by all authors.

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Conflict of interest

The authors declare no conflict of interest.

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