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WATER BUDGET CHARACTERISTICS, AVAILABILITY OF WATER PERIODS AND CROP PRODUCTION IN GHANA

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Abstract

This paper examines the water budget characteristics and their effect on some crop production in Ghana. Cocheme and Franguin's method (1967) has been employed to assess the nature of water budget and availability of water periods. Thornthwaite and Mather's moisture index (1955) has been employed to divide Ghana into moisture (climatic) regions and shifts of these climatic types during some drought periods have been underlined. The viability of crops such as maize, rice and cotton in these moisture regions has been examined.The study reveals that the southwest and central part of the country have water surplus while the rests of the country has water deficit. The largest deficits occur in the extreme northeast followed by the southeast coastal plains. The country can be divided into five moisture regions and the moisture boundaries fluctuate towards drier regions in times of drought. Crops such as maize, rice and cotton can be grown in all the moisture regions as their growth cycles fit into the availability of water periods. However, since the length of humid period is shorter in the dry southeast coastal plains and the northeast, it is suggested that to obtain good yields, irrigation should be practised.

Introduction

The term water budget has several meanings but with regard to the present enquiry, water budget has been used to express moisture relationships i.e. water surplus, water deficit etc. A comparison monthly mean potential evapotranspiration (PE) and average rainfall amounts gives some information on such relationships. For instance, a knowledge of the moisture deficit is basis to any understanding of the economic feasibility of irrigation for it gives information on the total amount of water needed by crops at any time. It also gives a final measure of drought. It results in information that permit water surplus and deficit to be compared and with water need provide climatic indices that can be used in classification. A comparison of these quantities provides indices for humidity and aridity (Thornthwaite and Mather, 1955). It is against this background that this paper examines water budget characteristics such as water surplus, water deficit and availability of water periods in relation to some crop production.

Methods

The computation of mean water budgets for selected stations in Ghana was based on Cocheme and Fraquin's method (1967). The calculation of the potential evapotranspiration (PE) was based on Thornthwaite and Mather's Methods (1955). The PE values were computed for 27 stations using 10 years mean monthly temperature. The following water budget parameters were obtained. Water surplus (WS), which is the excess rainfall over PE; water deficit (WD) which is the excess of potential evapotranspiration over rainfall; ground storage (GS) the amount stored

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up to the assumed maximum. Storage capacity or water holding capacity are other names referring to ground storage. It should be realised that the water holding capacity varies with the texture and structure of the soil.

In computing the water budget over a large number of geographical zones encompassed by the country, it was not possible to take into account all of the different water holding capacities of the soil which might occur in different areas, because such data were not available. It was therefore, deemed necessary to assume one constant value of water holding capacity over the whole country (Thornthwaite and Mather, 1955). It was assumed that the water holding capacity of the soil within the root zone was 200 mm. When the soil was at its field capacity and if water deficit occurred in the subsequent months, the amount of each monthly deficit was subtracted from GS. Ground charge (GC) is the amount of water entering the soil to be stored. The GC was subtracted from GS. Evaporation loss (EL) is the amount of rain falling early in the season or relatively dry soil which is evaporated without being used by crops. Run-off (RO) is the surplus left after full ground charge. This includes deep drainage for which no assumption was made. Run-off was obtained when water surplus exceeded G.C. Effective rainfall (ER) is the amount available for crop production, that is excluding both evaporation loss and run-off. During the rainy season, effective rainfall is equal to PE. Before rainy season, rainfall is practically used up by a fast developing and well tended crop. After season, effective rainfall would be equal to rainfall plus the amount stored in the ground.

The ten years monthly mean PE estimates were compared with 30 years mean rainfall (1931) - 1960) to obtain the mean water budget and the availability of water periods. Using graphical interpolation of the monthly mean PE and the monthly rainfall (P) together with lines for the values PE/2 and PE/10, the number of days during which rainfall exceeded or equalled PE, PE/2 and PE/10 were determined. The availability of water periods were designated as followed: humid (H) when rainfall exceeded PE. The two P=PE points limit the humid period. The point P = PE/10 to PE/2 is defined as the farming or preparatory period (pre). Intermediate period was the first P = PE/2 and the first P = PE points also known as the prehumid (PR). The second intermediate period extended from the end of the humid period (second P = PE) to the second P = PE/2 (Fig. 1). The second intermediate period was known as posthumid (PO). Reserve (R) is the period of soil moisture utilisation and is evident in areas with two rainy seasons. The first and second intermediate and humid periods together formed the moist period (M) which was considered without storage (Reserve, R)(Fig.1).

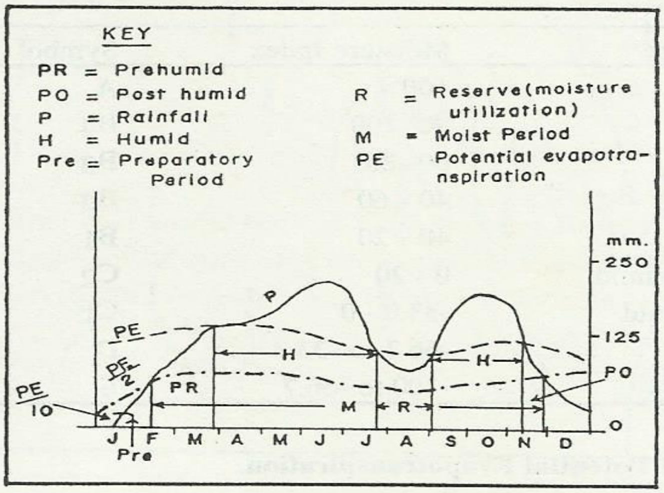

Figure 1 Mean availability of water periods

Ghana was divided into climatic types on the basis of Thornwaite and Mather's moisture index which combines humidity and aridity indices. The humidity index was defined as:

$$Ih = \frac{100S}{PE}$$

Where Ih = humidity index, S was the water surplus and PE was the potential evapotranspiration.

The aridity index was defined as:

$$Ia = \frac{100}{PE}$$

Where D was the water deficit. The difference between Ih and Ia was the moisture index:

$$Im = Ih - Ia = \frac{100S - 100D}{PE}$$

Where Im was the moisture index.

Table 1 shows Thornthwaite's climatic types according to the 1955 moisture index.

Table 1 Moisture Index by Thornthwaite

Climatic Type	Moisture Index	Symbol
Perhumid	100	A
Humid	80 -100	B_4
Humid	60- 80	B_3
"	40 - 60	B_2
"	40 - 20	B_1
Moist Sub-humid	0 - 20	C_2
Dry Sub-humid	-33.0 - 0	C_1
Semi-arid	-66.7 to -33.3	D
Arid	-100 to -66.7	E

Distribution of Potential Evapotranspiration.

Figure.2 shows the distribution of mean annual potential evapotranspiration (PE) over Ghana. Lowest PE values are found in the central part which lies in the forest region. PE values range from 1200 mm in the forest areas to 2300 mm in the northeast. Abetifi has the lowest PE in the country (1234 mm) while Zuarungu in the northeast has the highest values (2300 mm). The low value at Abetifi can be explained in terms of its altitude where humidity with height tends to increase cloud cover as the condensation level draws nearer. This decreases potential evapotranspiration with height. The PE values in the Southwestern part are fairly low compared with those in the northern part.

In respect of monthly PE, values are much higher in the dry season than in the rainy season and reach their maximum at the beginning of the rainy season. The Stations in the north and northeast have their maximum PE in April while the rest of the country have theirs in March. The low PE in the rainy season is attributed to **high humidity and cloud cover which** reduce the amount of insolation reaching the **earth's surface.**

Annual and Monthly Mean Water budget characteristics

Figure 3 shows the distribution of mean annual water deficit and surplus. The southwestern and central parts of the country have mean annual water surplus while the rest of the country have mean deficit. With the exception of Abetifi area, the amount of water surplus decreases from southwest to northeast. Mean water surplus varies from 671 mm at Aim in the Southwest to 17 mm at Mampong

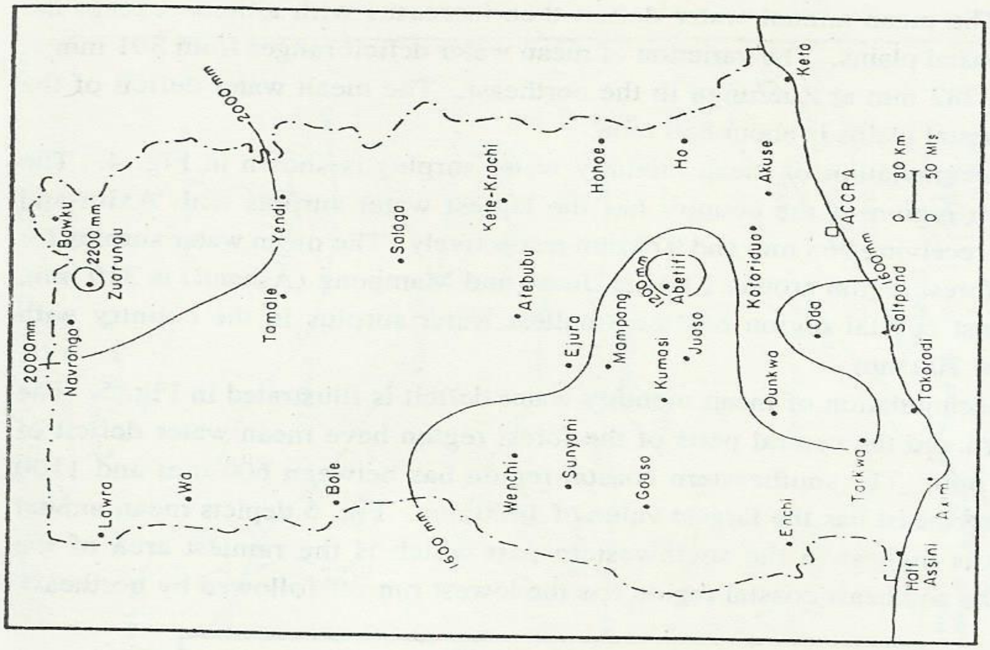

Figure 2 Potential evapotranspiration (mm) Thornwaite's method.

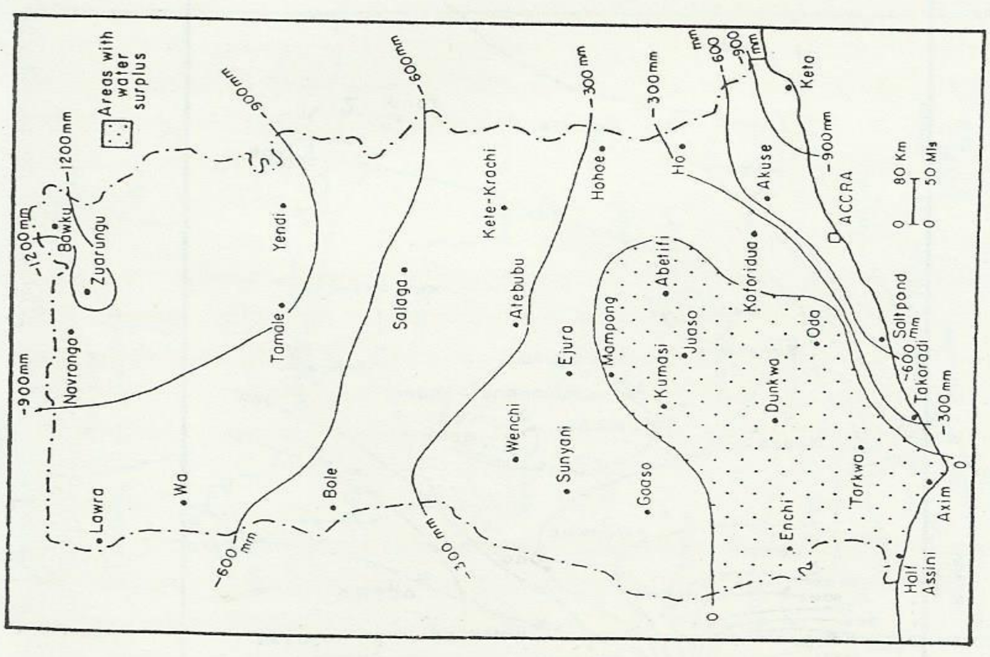

Figure 3 Annual mean water surplus and deficit.

Ashanti). The mean annual water deficit then increases with altitude except the southeast coastal plains. The variation of mean water deficit ranges from 301 mm at Takoradi to 282 mm at Zuarungu in the northeast. The mean water deficit of the southeast coastal plains is about 850 mm.

The accumulation of mean monthly water surplus is shown in Fig. 4. The southwestern region of the country has the largest water surplus with Axim and Half-Assini receiving 968 mm and 970 mm respectively. The mean water surplus for the central forest region around Kumasi, Juaso and Mampong (Ashanti) is 310 mm. The southeast coastal region has the smallest water surplus in the country with values below 200 mm.

The accumulation of mean monthly water deficit is illustrated in Fig. 5. The southwestern and the central parts of the forest region have mean water deficit of below 300 mm. The southeastern coastal region has between 600 mm and 1100 mm. The northeast has the largest value of 1400 mm. Fig. 6 depicts mean annual run-off. It is highest in the southwestern part which is the rainiest area of the country. The southeast coastal region has the lowest run-off followed by northeast.

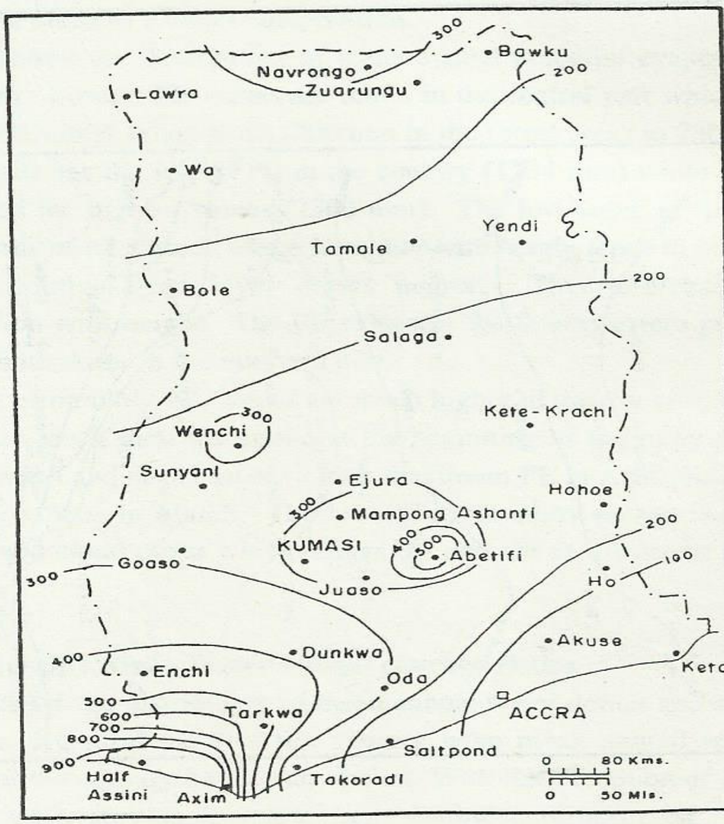

Figure 4 Accumulation of mean monthly water surplus (mm)

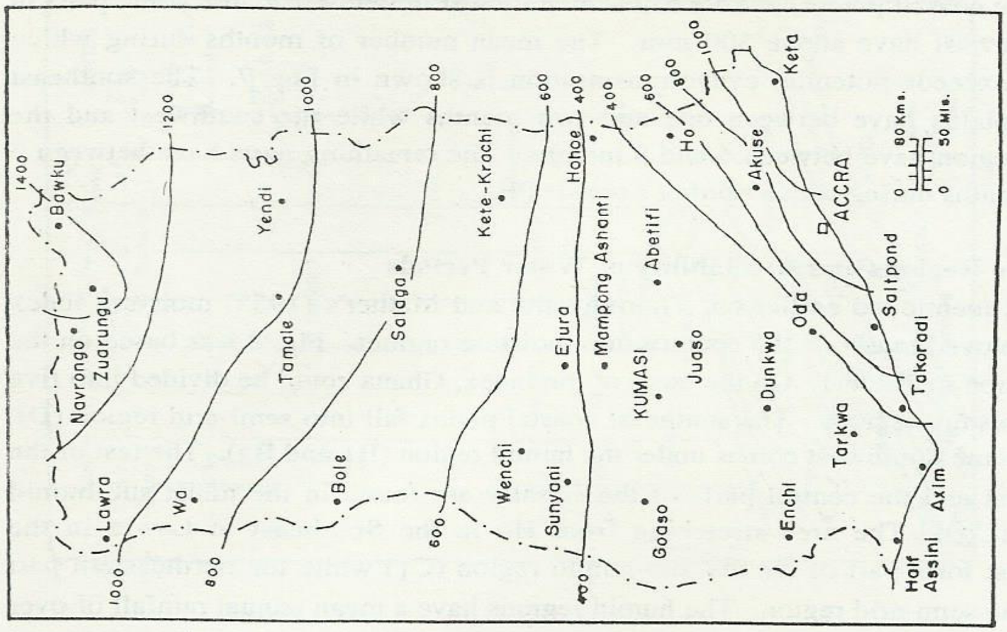

Figure 5 Accumulation of mean monthly water deficit (mm).

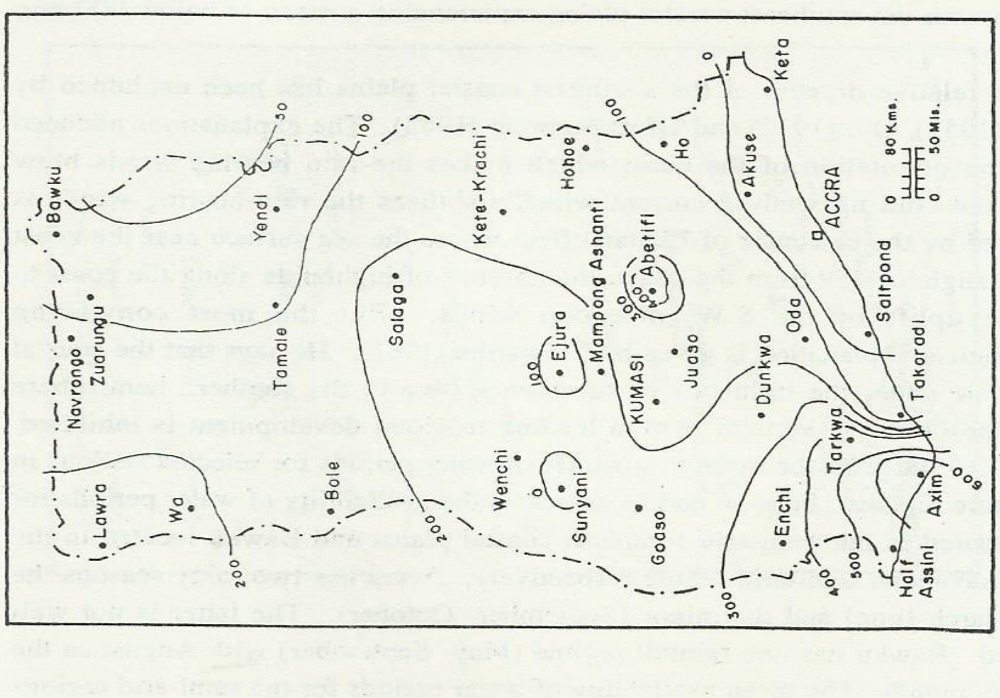

Figure 6 Accumulation of mean monthly run - off (mm).

The coastal plains have a mean annual run-off of below 100 mm while parts in the southwest have above 500 mm. The mean number of months during which rainfall exceeds potential evapotranspiration is shown in Fig. 7. The southeast coastal plains have between one and two months while the southwest and the central region have between 6 and 8 months. The remaining parts have between 3 and 5 months during which rainfall exceeds PE.

Moisture Regions and Availability of Water Periods

As mentioned earlier on, Thornthwaite and Mather's (1955) moisture index was employed to divide the country into moisture regions. Fig. 8 was based on the information in Table 1. On the basis of the index, Ghana could be divided into five main moisture regions. The southeast coastal plains fall into semi-arid region (D). The extreme Southwest comes under the humid region (B_1 and B_2). The rest of the southwest and the central part of the country are found in the moist sub-humid region (C_2). The area stretching from Ho in the Southeast to Lawra in the northwest form part of the dry sub-humid region (C_1) while the northeastern part lies in the semi-arid region. The humid regions have a mean annual rainfall of over 1700 mm; the moist sub-humid has between 1700 and 1400 mm; the dry sub-humid receives between 1400 mm and 1100 mm while the semi-arid regions receive below 1100 mm with the southeast coastal plains experiencing a mean of below 900 mm (Fig. 9).

The relative dryness of the southeast coastal plains has been explained by Walker, (1957), Ojo (1977) and Ofori-Sarpong (1983). The explanations adduced include the orientation of the coast which makes the rain bearing winds blow parallel; the cold up welling current which stabilises the rain-bearing winds is engendered by the existence of Ekman effect where the sea surface near the coast forms an angle of 45^o from the coast; the absence of highlands along the coast to force the uplift of the S.W. monsoon winds. But the most convincing meteorological explanation is given by Trewartha (1961). He says that the coastal plains come under the influence of subsidence (due to the southern hemisphere anticyclone) and any vertical motion leading to cloud development is inhibited. Figs. 10 - 15 illustrate the mean availability of water periods for selected stations in the moisture regions. Figs. 10 and 11 represent the availability of water periods for Accra situated in the semi-arid southeast coastal plains and Bawku located in the northern savannah semi-arid region respectively. Accra has two rainy seasons the major (March-June) and the minor (September- October). The latter is not well developed. Bawku has one rainfall regime (May- September) with August as the peak rainy month. The mean availability of water periods for the semi-arid regions show that the latter have 1½ -3 months of humid condition.

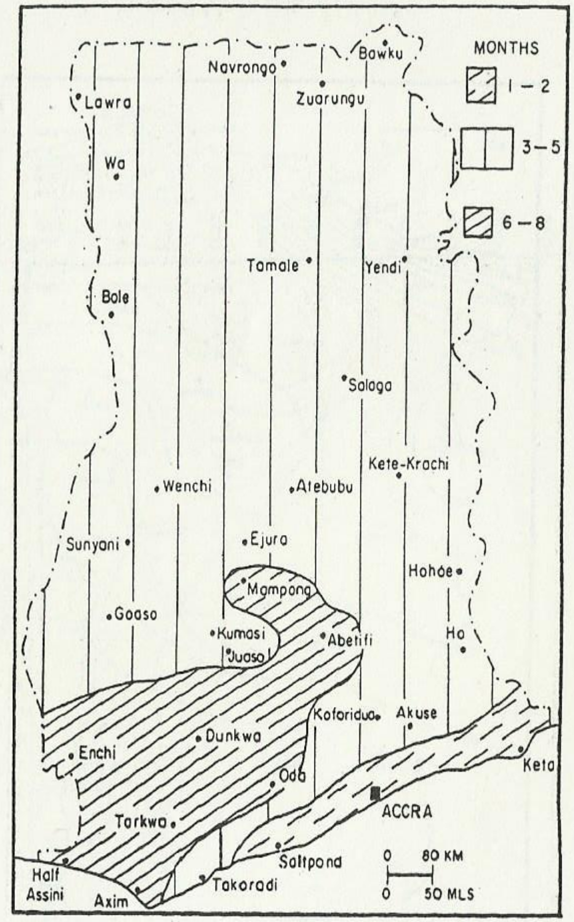

Figure 7 Mean number of months during which rainfall exceeds potential evaporation.

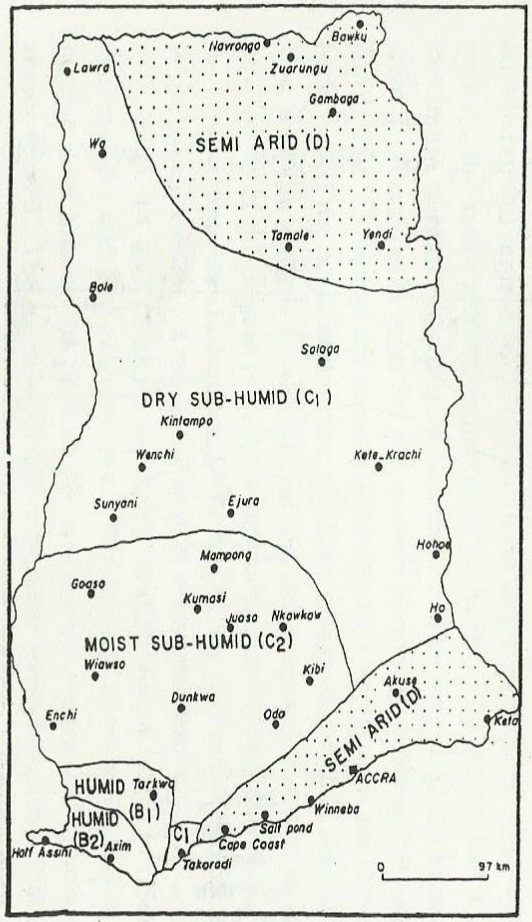

Figure 8 Climatic regions.

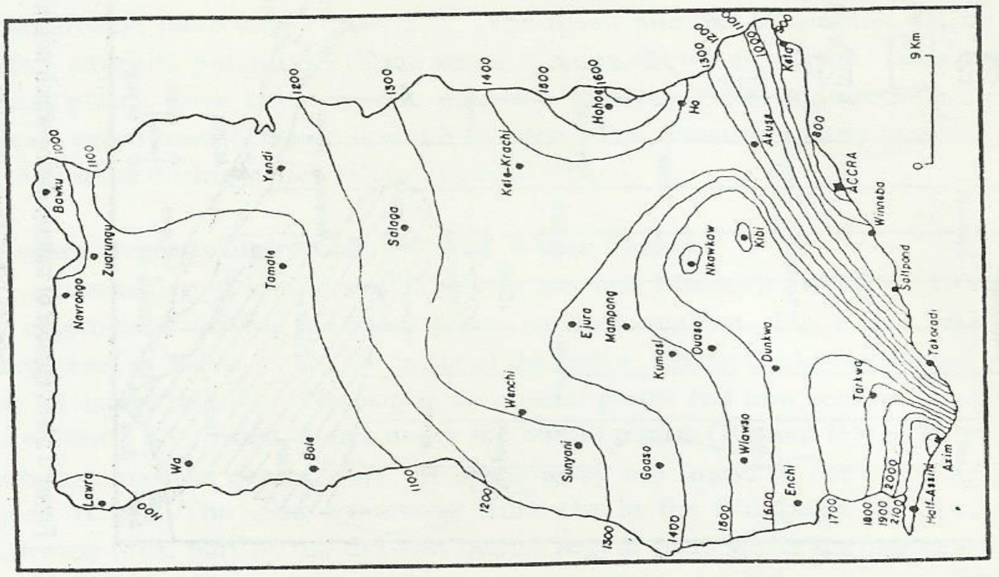

Figure 9 Mean annual rainfall.

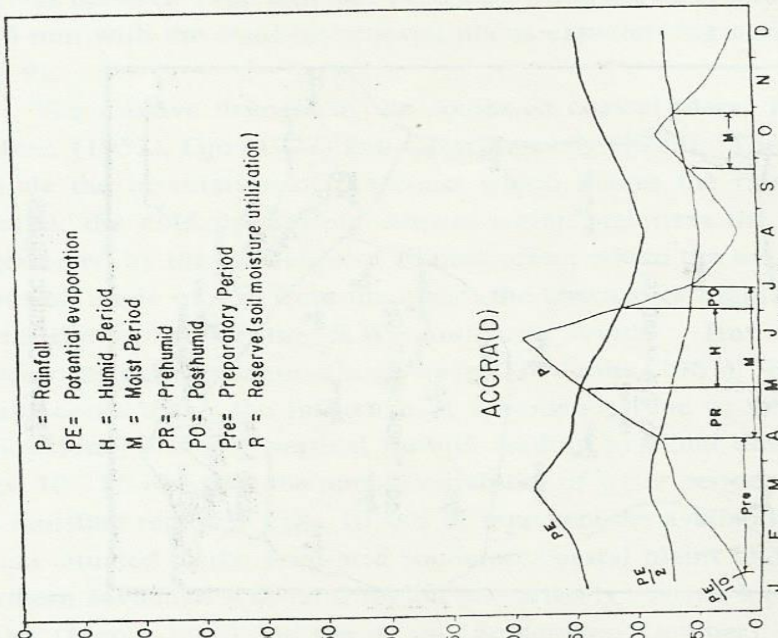

Figure 10 Mean availability of water periods for Accra in the semi - arid region.

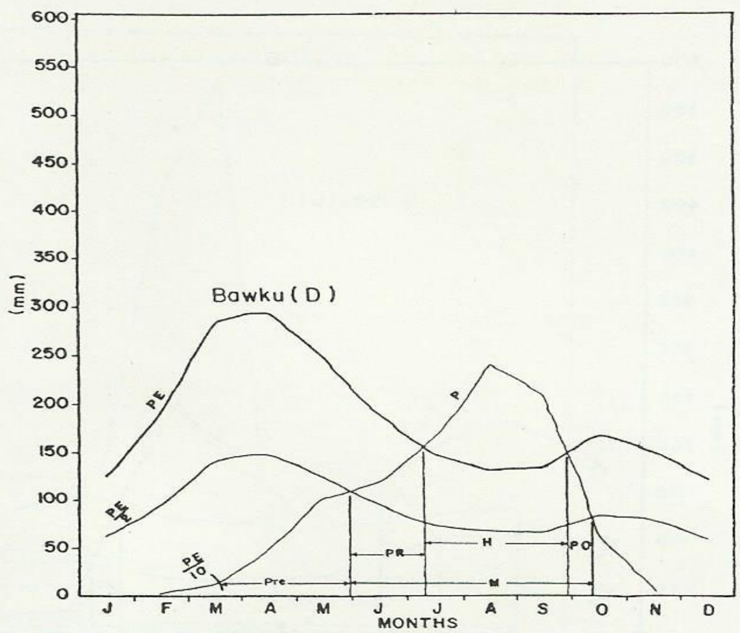

Figure 11 Mean availability of water periods for Bawku in the semi - arid region

The mean availability of water periods for the dry sub-humid region is represented by Salaga (Fig.12). The areas which are found below latitude 8^{O}N have doublé rainfall regime while those exhibit single regime. In areas with single rainfall regime, the rainy season commences in April up to the end of October with the maximum rainfall occurring in September. The length of the humid period ranges from 2 - 4$^{1}/_{2}$ months with the preparatory period for farming between February and April. Fig. 13 depicts the mean availability of water periods for the moist sub-humid region. All the areas within this moisture region experience double rainfall regime. The average length of the humid period ranges from 4$^{1}/_{2}$ to 6 months. The vegetation of this region is moist semi-deciduous forest. The preparatory period fŏr farming commences in January. June has the maximum rainfall for the major season while the maximum for the minor season occurs in October.

Figs. 14 and 15 show the mean availability of water periods for the humid regions (B_2 and B_1) respectively. The regions have well marked double rainfall regime with June as the peak of the major rainy season and October the peak of the minor season. The mean availability of water periods indicate that the length of the humid period is generally between 6 and 8 months. Preparation for farming starts from January. The two humid regions are characterised by tropical rain forest.

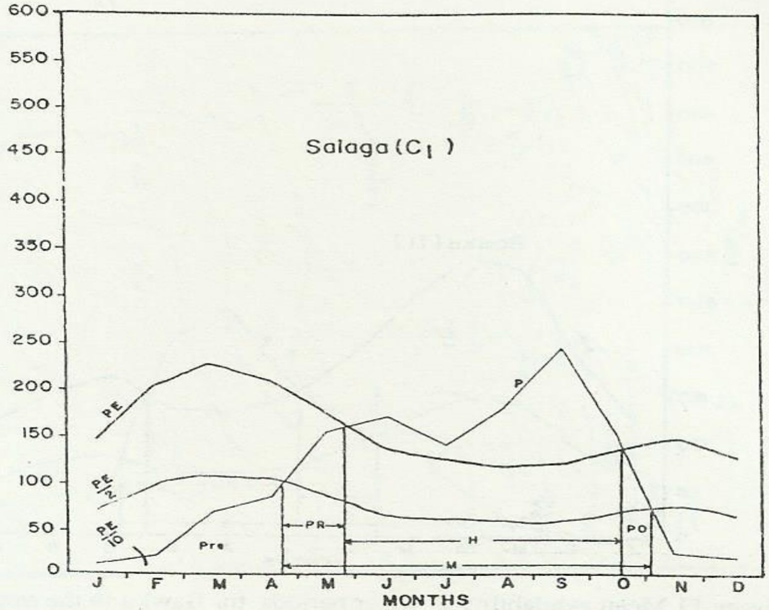

Figure 12 Mean availability of water periods for Salaga in dry subhumid region.

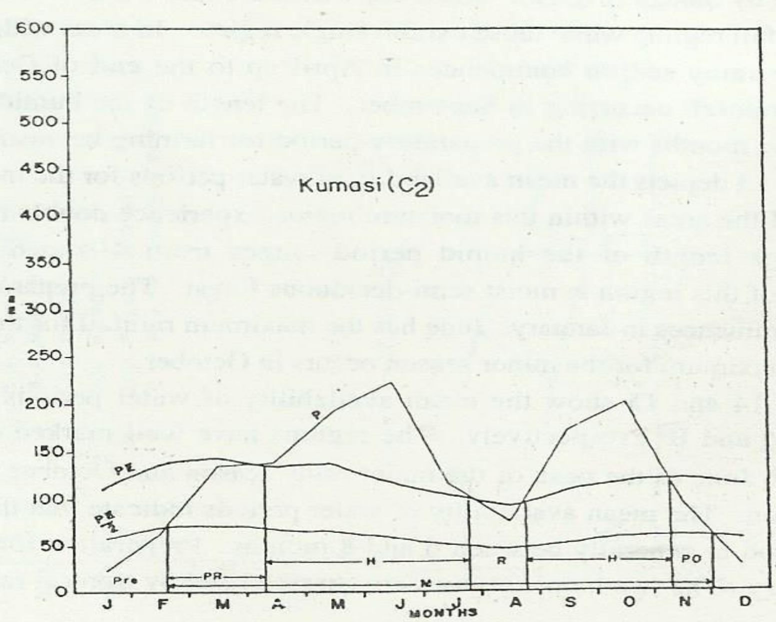

Figure 13 Mean availability of water periods for Kumasi in moist subhumid region.

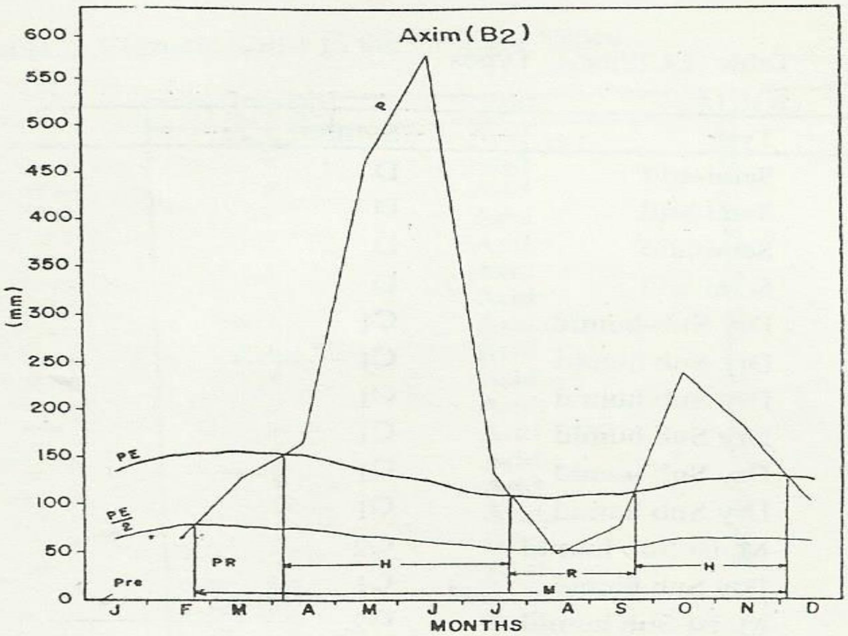

Figure 14 Availability of water periods for Axim in the humid region.

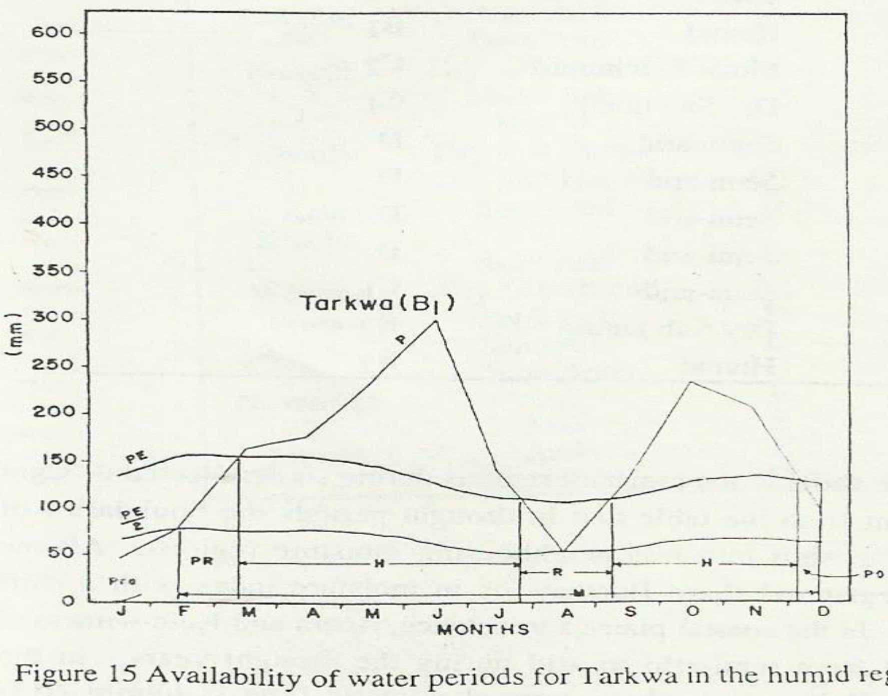

Figure 15 Availability of water periods for Tarkwa in the humid region.

Table 2 Climatic Types

Station	Type	Symbol
Bawku	Semi-arid	D
Zuarungu	Semi-arid	D
Navrongo	Semi-arid	D
Tamale	Semi-arid	D
Dole	Dry Sub-humid	C_1
Salaga	Dry Sub humid	C_1
Ujura	Dry Sub humid	C_1
Wenchi	Dry Sub humid	C_1
Wa	Dry Sub humid	C_1
Kete-Krachi	Dry Sub humid	C_1
Goaso	Moist Sub humid	C_2
Sunyuni	Dry Sub humid	C_1
Kumasi	Moist Sub humid	C_2
Asante (Mampong)	Moist Sub humid	C_2
Oda	Moist Sub humid	C_2
Abetifi	Humid	B_2
Tarkwa	Humid	B_1
Enchi	Moist Sub humid	C_2
Ho	Dry Sub humid	C_1
Akuse	Semi- arid	D
Keta	Semi-arid	D
Acera	Semi-arid	D
Saltpond	Semi-arid	D
Takoradi	Semi-arid	C_1
Axim	Dry Sub humid	B_2
Half-Assini	Humid	B_2

Climate Shifts

Table 3 illustrates the shifts in the moisture regions during some selected drought years. It is self-evident from the table that in drought periods the boundaries of moisture regions tend to shift into less neighbouring moisture regions. All the stations in the table registered sharp fluctuations in moisture index with a shift towards drier climates. In the coastal plains for instance, Accra and Keta witnessed moisture displacement from semi-arid to arid during the drought years. In the southwest, Axim and Half-Assini whose normal climatic type is humid (B_2) experienced displacement towards moist sub-humid (C_2) and dr

Table 3 Climatic Shifts in the Drought Years

STATION	TYPE	SYMBOL	YEAR
Accra	Arid	E	1903
"	Arid	E	1906
"	Arid	E	1912
"	Arid	E	1919
"	Arid	E	1920
"	Arid	E	1923
"	Arid	E	1926
"	Arid	E	1977
Keta	Arid	E	1923
"	Arid	E	1914
"	Arid	E	1918
"	Arid	E	1919
"	Arid	E	1920
"	Arid	E	1923
"	Arid	E	1926
"	Arid	E	1972
"	Arid	E	1977
Saltpond	Semi Arid	D	1924
"	Arid	E	1927
"	Semi Arid	D	1930
"	Arid	E	1932
"	Semi Arid	D	1945
"	Semi Arid	D	1977
Sunyani	Semi Arid	D	1967
"	Semi Arid	D	1977
Kumasi	Dry Sub Humid	C_1	1967
"	Moist Sub Humid	C_2	1977
Abetifi	Dry Sub Humid	C_1	1955
"	Dry Sub Humid	C_1	1977
Kete-Krachi	Semi Arid	D	1956
"	Semi Arid	D	1961
Wenchi	Dry Sub Humid	C_1	1961
Ejura	Semi Arid	D	1964
Salaga	Semi Arid	D	1958
"	Semi Arid	D	1977
Navrongo	Arid	E	1947
"	Arid	E	1977
Tamale	Arid	E	1950
"	Semi Arid	D	1918

Continued Table 2

Wa	Semi Arid	D	1970
Bole	Semi Arid	D	1950
Dunkwa	Dry Sub Humid	C_1	1954
Bawku	Arid	E	1954
"	Arid	E	1961
Takoradi	Semi Arid	D	1936
"	Semi Arid	D	1937
"	Semi Arid	D	1945
"	Semi Arid	D	1958
"	Semi Arid	D	1972
"	Semi Arid	D	1977
Axim	Dry Sub Humid	C_1	1918
"	Dry Sub Humid	C_1	1919
"	Moist Sub Humid	C_2	1922
"	Moist Sub Humid	C_2	1924
"	Moist Sub Humid	C_2	1936
"	Dry Sub Humid	C_1	1977
Half-Assini	Moist Sub Humid	C_2	1925
"	Moist Sub Humid	C_2	1936
"	Moist Sub Humid	C_2	1937
"	Humid	B_1	1977
Enchi	Moist Sub Humid	C_2	1948
"	Dry Sub Humid	C_1	1958
"	Dry Sub Humid	C_1	1977
Akuse	Semi Arid	D	1925
"	Arid	E	1977
Ho	Semi Arid	D	1937
"	Semi Arid	D	1977
Zuarungu	Semi Arid	D	1948
"	Arid	E	1977
Tarkwa	Dry Sub Humid	C_1	1964
Oda	Dry Sub Humid	C_1	1915
"	Dry Sub Humid	C_1	1977

Sub-humid (C_1) in some drought years. In 1918, 1919 and 1977, Axim had dry sub-humid climate while in 1922, 1924 and 1936, it had moist sub-humid. Half-Assini had moist sub-humid climate in 1925 and 1937 while in 1977 it experienced humid (B_1) climate.

Crop Production

On the basis of moisture (climatic) regions as well as mean availability of water periods, one can consider the general production of crops such as maize, rice and cotton, assuming that these three crops would depend entirely on rainfall for moisture.

The mean availability of water periods discussed above show that a crop such as maize can be grown throughout the country since maize requires a growth cycle of 4 months (120 days) and produces best with a range of 600-900 mm of rainfall (Purseglove, 1972). In the semi-arid areas of the country, a sufficient amount of rainfall should occur for a single crop of maize to be grown each year. Classen and Shaw (1970) state that water deficiency at different stages of growth has different effects on yield of maize. According to Salter and Goode (1967), soil moisture during flowering and early grain formation seems particularly critical in determining yield. Robins and Domingo 1953) indicate that maize has a high requirement for moisture during the tasselling stage. They suggest that soil moisture deficit which causes wilting at this stage for one or two days reduces yield by 22 per cent. Wrigley (1969) states that water stress in the early growth delays flowering.

The benefits of early planting of maize have been shown by Gwynne (1964), Turner (1965) and Gray (1970). Turner (1965) in Tanzania found that late planted maize received much less rainfall from the tasselling stage to harvest than early planted maize. In Ghana, Koli (1970) found that Kumasi and Ejura in the forest and forest-savannah mosaic zones respectively, gave highest maize yields when planted in the March rains around the middle of the month. Results in the forest zone of Volta Region (eastern part of the country) showed that the optimum planting date occurred in the third week of April. In the coastal plains, Koli (1970) found that the optimum planting date occurred within the second week of April when P = PE/2. But in the north which lies in the Guinea and Sudan savannah zones, the optimum date occurred between late May and the third week of June.

Evidence has shown that in Ghana low yields of late planted maize result from both limited water and inadequate supplies of nutrients. Koli (1970) has shown that too early or too late planting leads to a considerable loss in maize yield. In the Guinea savannah zone in the north, late April to early May planting led to 32 - 47 per cent loss in yield as this period forms part of the preparatory period when PE/2 is higher than rainfall (P). In the southeast coastal plains and Volta region between 41 and 44 per cent loss occurred when planted in March instead of Mid-April. Furthermore, in the forest and forest-savannah mosaic zones, a delay into late April could cause between 46 and 55 per cent loss in maize yield.

These optimum dates for planting however, are usually thrown out of gear in the event of drought. This was evident in those drought years when rainfall during the major rainy season was either insufficient or the minor rains absolutely failed thus creating large water deficits during the humid and moist periods. Cereals grown in 1977 were badly affected by unavailability of water. Consequently, maize production dropped sharply from 485,700 tonnes in 1974 to 274,000 tonnes in 1977 (Ofori-Sarpong, 1980). Fig. 16 - 18 illustrate the availability of water periods for Tamale and Akuse in the northern and coastal semi-arid regions respectively during the drought of 1977. Rainfall was very low and consequently the humid periods were non-existent in most parts of the country.

Rice is another crop which can be gown in several parts of the country since the length of the growing cycle is 5 months. It can be successfully grown in the moisture regions (climatic types (B_2, B_1, C_2 and C_1) without irrigation. However, in the marginal areas (D) such as the southeast coastal plains and the northeast of the country where the length of the humid period is short ($1^1/_2$- 3 months), irrigation is an essential prerequisite. Rice is highly sensitive to moisture deficiency at heading and flowering (Salter land Goode, 1967). This is the stage of maximum water use and a deficiency can have an adverse effect on yield.

Cotton is another crop which has very good prospects of doing well in the moist sub-humid, dry sub-humid, and semi-arid regions. Because of its great economic significance in various parts of the world, the effects of water on cotton yields have received considerable attention, particularly in terms of irrigation. Cotton has 4 months growing cycle and can be grown in the semi-arid region of the country. The moisture requirements differ according to variety (Ochse et al, 1961; Wrigley, 1969). Experiments to determine moisture sensitive stages indicate that adequate water is needed before flowering to ensure good growth (Marani and Horwitz, 1963). Mcdowell (1937) however, suggests that the critical periods of moisture requirement for cotton are the planting time when adequate amount of moisture must be present in the soil for germination; the early stages of growth when the plant needs ample supply of moisture and the period just between flowering. According to Mante and Khan (1968) while irrigation facilities are desirable for cotton production in the Akuse area of the southeast coastal plains in years of average rainfall, good yields of cotton can be obtained without irrigation. Since cotton thrives under hot, sunny conditions, water is often a limiting factor for yield and quality, and therefore, irrigation is often of great importance when grown particularly in the semi-arid regions of the country.The availability of water periods in the semi-arid areas are so critical that without irrigation, only hardy crops such as millet and sorghum (guinea corn) can thrive best. These two cereals are the most drought resistant particularly millet and are also the most staple food of the people in Northern Ghana. In areas where the availability of moisture is not conducive to maize production, millet and sorghum are the best substitutes since their growth cycle fits into the pattern of water availability.

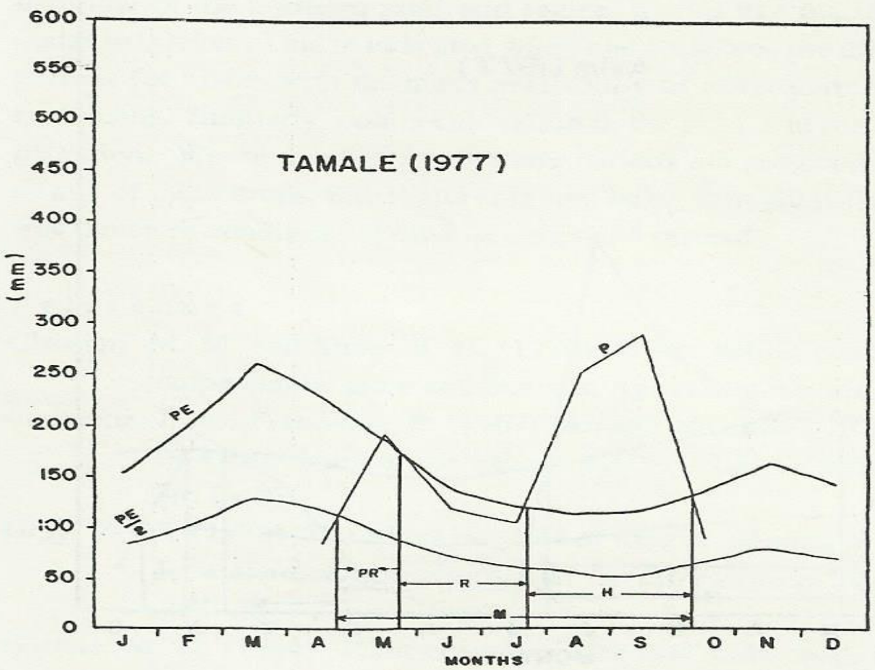

Figure 16 Distribution of rainfall.

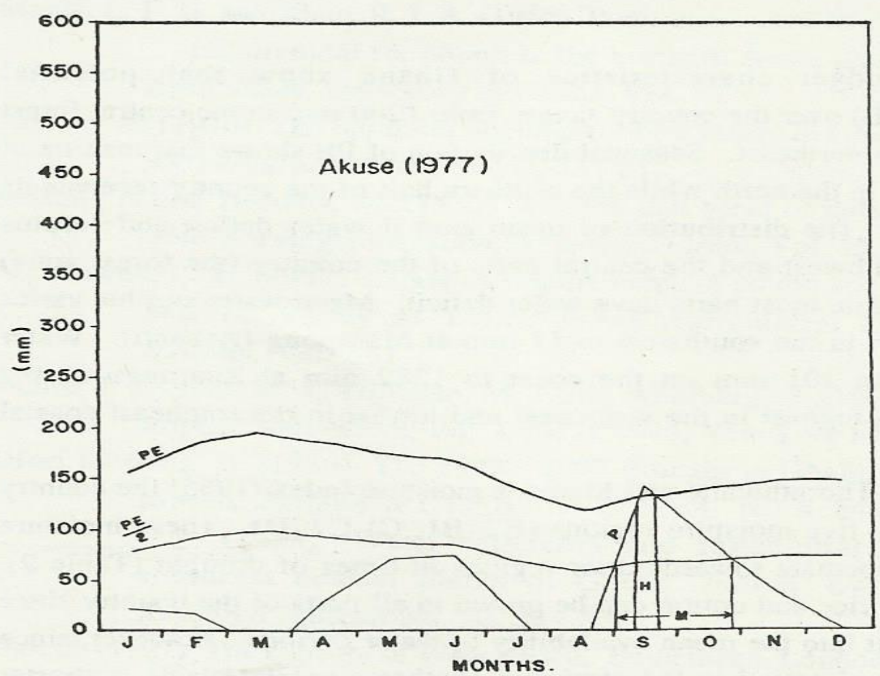

Figure 17 Distribution of rainfall.

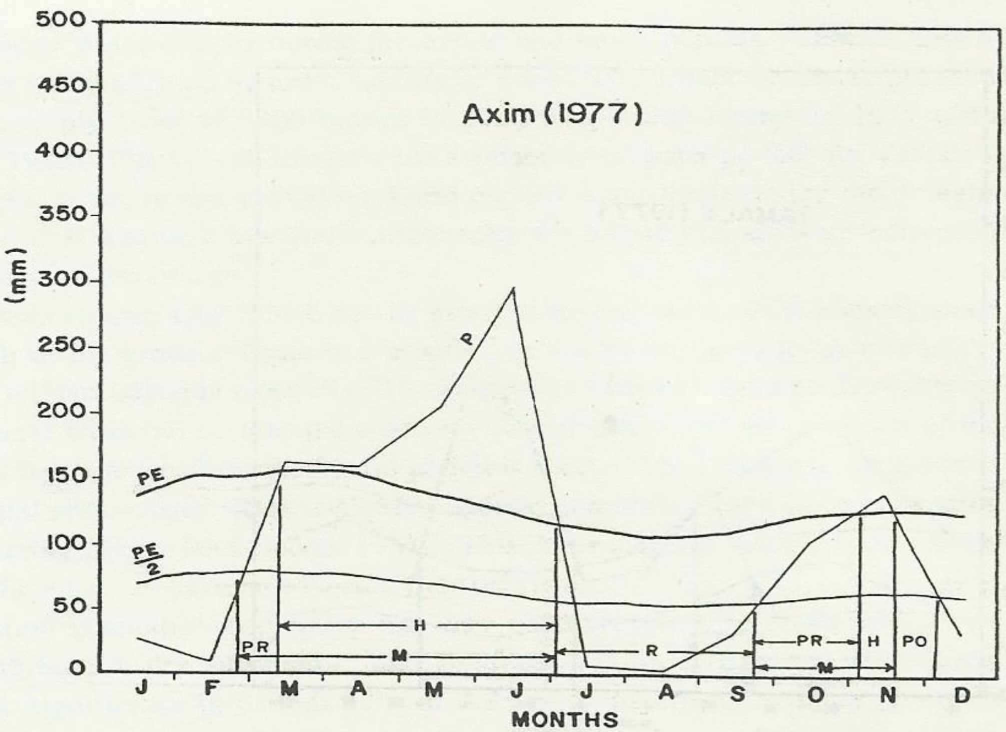

Figure 18 Distribution of rainfall.

Conclusion

The water budget characteristics of Ghana show that potential evapotranspiration (PE) over the country ranges from 1200 mm in the central forest belt to 230 mm in the northeast. Seasonal distribution of PE shows that maximum values occur in April in the north while the southern half of the country receives its maximum in March. The distribution of mean annual water deficit and surplus indicates that the southwest and the central parts of the country (the forest zone) have water surplus while most parts have water deficit. Mean water surplus varies from 671 mm at Aim in the southwest to 17 mm at Mampong (Ashanti). Water deficit increases from 301 mm on the coast to 1282 mm at Zuarungu in the northeast. Run-off is highest in the southwest and lowest in the southeast coastal plains.

On the basis of Thornthwaite and Mather's moisture index (1955) the country could be divided into five moisture regions (B2, B1, C1.C2, D). These moisture boundaries tend to fluctuate towards drier regions in times of drought (Table 2). Crops such as maize, rice and cotton can be grown in all parts of the country since their growth cycles fit into the mean availability of water periods. However, since the length of the humid period in the semi-arid southeast coastal plains is shorter than that of the northern semi-arid region, a crop like maize can prove better here under irrigation. This is indicated when one compares the critical moisture sensitive periods for maize with the mean availability of water periods for the coastal semi-arid plains. Similarly, cotton cultivation in the semi-arid region can be enhanced by irrigation. Where availability of water periods are not conducive to the cultivation of any of these crops, millet and sorghum being drought resistant and which require less moisture conditions should be cultivated instead.

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