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Determination of Supplementary Water Requirements of Selected Food Crops per Growth Stage Using Climatic Indices

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Abstract The present study examines the possibility of determining supplementary water requirements of selected food Crops per growth stage using the climatic indices alone. Rainfall and temperature datasets on high-resolution (0.5x0.5 degree) grids resolution were assembled from the Climatic Research Unit CRU TS 3.21 of the University of East Anglia, Norwich, United Kingdom for the period 1943-2012. To ascertain the suitability of the datasets for use in the study area the Pearson Product moment correlation was undertaken with measured rainfall data from Yelwa synoptic station, Nigerian Meteorological Agency. Melon, Beans, Millet, Sorghum, Soybean and Cucumber were used for estimating seasonal supplementary irrigation water needs in the Sokoto Rima, River Basin. The observed seasonal patterns of rainfall and PET shows that soil moisture surplus in the basin sets in from June – August while April to May is the soil water recharge periods. From October, water is withdrawn from the basin, paving way for moisture deficit which last from November-March. The study shows that even during the rainy months, supplementary irrigation is needed to compensate for deficit due to increased rate of evapo-transpiration. It is also possible to carry out an all year round cultivation in the basin. For an all-year-round cultivation of crops with greater yields, full scale irrigation is needed for a second cultivation season (from October to February) when the soil moisture storage of the basin is below the basin field capacity. In absence of spatial dataset, the use of CRU proves to be an alternative in climatic response and modelling studies.

Keywords: *potential evapotranspiration, rainfall, crop water requirement, supplementary irrigation*

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1. Introduction

Availability of adequate water is one of the most important inputs in successful crop production as temporal water deficit is fatal to crop development especially during the vegetative and flowering stages of the crops. At present, the Sokoto-Rima River basin (SRRB) which lies between the Sahel eco-climatic zone in the extreme north and Sudano-Sahelian belt in the south is facing two main environmental pressures namely increasing population and water shortage due increasing municipal and industrial demands and in recent time climatic variability and change. As a result, less water is available for agricultural production. In fact it has been reported that parts of the basin now faces the threat of desert encroachment at a very fast rate per year occasioned by fast reduction in the amount of surface water, flora and fauna resources on land [1,2]. There is also evidence of tragic crop failures which reduced agricultural productivity, increased hunger, poverty, malnutrition and diseases [1,3]. Under the present environmental scenario a fundamental step toward water resources management for improved agricultural yield will be to develop a clear understanding of the actual amount of water that evaporates and transpires (AET), and the amount of water that would evaporate and transpire if water were always readily available (PET). This is more so because in the tropic the water potential of a region cannot be adequately assessed from precipitation alone due to the seasonal character of rainfall and even more so owing to the changing climate scenario. The concept of crop water requirement has assumed a focus of discussion among scholars in recent time mainly due the seemly sensitivity of crops to climatic change as well as the fact that it is an important practical consideration for improved water-use efficiency [4]. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement [5,6] and Arora [7] also defined it as the quantity of water needed by a crop for normal growth regardless of its supply source for a given period of time under field condition. Crop water requirements vary during the growing period, mainly due to variation in crop canopy and climatic conditions, and are governed by crop evapotranspiration (ETc) [4].

In addition, investigating seasonal Cu values are useful in scheduling irrigation, and may be obtained for cropped field throughout an entire planting season. Again peak period Cu is particularly useful for irrigation system design, as ET, Kc and Cu are also affected by crop type, plant growth stage and weather conditions. The irrigation water requirement on the other hand represents the difference between the crop water requirement and effective precipitation [8]. If the rainfall is sufficient to cover the water needs of the crops, irrigation is not required. If there is no rainfall, all the water that the crops need has to be supplied by irrigation [9]. If there is some rainfall, but not enough to cover the water needs of the crops, irrigation water has to supplement the rain water in such a way that the rain water and the irrigation water together cover the water needs of the crop. This is called supplemental irrigation scheduling. Irrigation scheduling is one of the most effective tools to preserve water [10]. Furthermore, it allows the increase of crop yield, water economy for a better adjustment to the crop requirements during the growth season and energy savings by avoiding excessive water application [11]. Thus for any realistic policy planning for crop suitability needs a comprehensive understanding of the climate, particularly rainfall, demand for evaporation and the interaction between rainfall being input variable and evapotranspiration. The present study is aimed to determine the supplementary irrigation water needs as well as design irrigation schedule for selected food crops in the Sokoto-Rima River basin, northwest of Nigeria.

2. Materials and Methods

2.1. Study Area

The study area is located in the northwestern Nigeria and lies largely in the far north Sudano- Sahel of West Africa in zone of Savanna-type vegetation belt generally classified as semi-arid [12]. It lies between latitudes 12° and 14° N and longitudes 5° and 7°E. The Sokoto River joins the Niger about 75 km downstream of the border and extends upstream with a broad floodplain for about 387km [13]. There are an estimated 470,000 ha of seasonal floodplains on the Niger/Sokoto system [14]. The Sokoto River has its source near Funtua in the south of Katsina State, some 275 km in straight line from Sokoto. It flows north-west passing Gusau in Zamfara State, where the Gusau Dam forms a reservoir that supplies major towns with water (Figure 1). Further downstream the river enters Sokoto State where it passes by Sokoto and is joined by the Rima River, then turning south and flowing through Birnin Kebbi in Kebbi State. Flood ponds are common within the flood basins of most of the major rivers and are usually cut off from the main river channels during periods of low water.

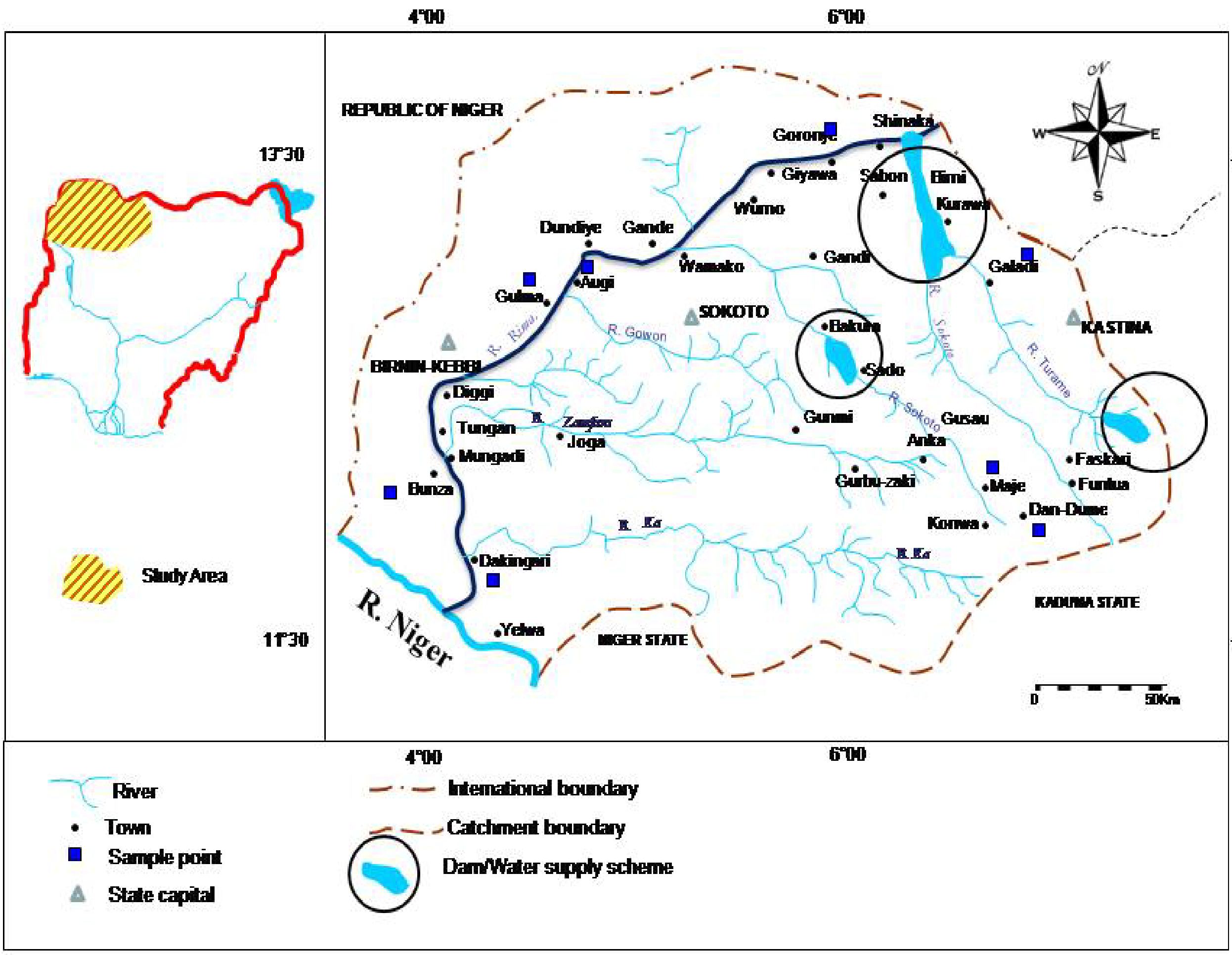

Figure 1. SOKOTO RIVER BASIN (source: Adopted from [13])

The Basin is underlain by a sequence of inter-bedded semi-consolidated gravels, sands, clays and some limestone and ironstone of Cretaceous to Quartenary age resting on pre-Cambrain Basement Complex rocks which outcrop extensively to the East and South of Zamfara State as well as to the South of Kebbi State [12]. The sedimentary sequences are sub-divided from bottom to top into the late Jurassic to early Cretaceous Illo and Gundumi formations, the Maestrichtian Rima Group, the late Paleocene Sokoto Group and the Eocene-Miocene Gwandu Formation. Thick sediments of both marine and continental origins constitute the series of aquifers in the basin with the oldest being the Gundumi formation that uncomformably overlies the basement complex. The Sokoto Basin is a semi-arid region marked by distinct weather conditions-the wet and dry seasons. Rainfall is highly seasonal and controlled by the movement of the Inter Tropical continuity (ITD). Rainy season usually starts from May or June of each year and lasts till September or early October depending on the rainfall pattern for that year. There is a marked seasonal variation in temperature and diurnal range of temperature. Daily maximum temperature of the basin is between 36°C-40°C. During the harmmattan season, daily minimum temperature may fall below 18°C. Between February and April which is the peak of heat, temperature reaches the highest of 44°C. In the extreme north, the shrubby and thorny vegetation of the Sahel zone is dominant vegetation type.

2.2. Data Collection and Analysis

Precipitation and Temperature datasets which is available on high-resolution (0.5x0.5 degree) grids resolution from the Climatic Research Unit CRU TS 3.21 of the University of East Anglia, Norwich, United Kingdom [15,16] were used in this study and is on http://www.cru.uea.ac.uk/. Data were collected for a period of 70 years for Bunza and Dakindari, Southwest of the basin, Gulma and Augi, North West, Goronyo and Galadi, North East and Maje and Dan-Dume South East for the period 1943-2012. Quality control of CRU datasets is discussed in detail by [15]. In addition the suitability of CRU datasets were verified by correlating rainfall data from this source with measured rainfall data from Yelwa synoptic station, Nigerian Meteorological Agency for the period 1950-2012. Of the Fifty-eight (58), data points from the CRU, only points that yielded positive relation were used in the study (Table 1& Table 2).

Table 1. Result of correlation of Rainfall data from CRU data set with measured data from NIMET (Yelwa Station)

Data Point	Multiple R	R Square	Adjusted R Square	Standard Error
Bunza	0.97	0.94	0.93	14.8
Dakingari	0.96	0.92	0.91	17.2
Gulma	0.97	0.95	0.95	13.5
Augi	0.98	0.96	0.96	12.1
Goronyo	0.95	0.90	0.89	29.7
Galadi	0.96	0.92	0.92	26.1
Maje	0.97	0.95	0.94	16.7
Dan-dume	0.97	0.94	0.93	18.8

Correlation was performed on monthly basis.

Table 2. Result of Correlation of Temperature (°C) data from CRU data set with measured data from NIMET

Data Point	Multiple R	R Square	Adjusted R Square	Standard Error
Bunza	0.96	0.92	0.91	0.6
Dakingari	0.98	0.96	0.96	0.42
Gulma	0.93	0.87	0.85	0.83
Augi	0.92	0.86	0.85	0.8
Goronye	0.82	0.67	0.64	1.32
Galadi	0.86	0.74	0.72	1.17
Maje	0.97	0.95	0.94	0.50
Dan-dume	0.88	0.77	0.75	1.66

Correlation was performed on monthly basis.

2.3. Data Analysis

Analysis of data was achieved using the excel analysis toolPak. The Thornthwaite water balance computer software version 1.10 which was developed by the United States Geological Survey department was use for computing components of water balance. Water balance components investigated in the study include rainfall and potential evapotranspiration (PET).

Monthly *PET* was estimated from mean monthly temperature (*T*). In this study, *PET* was calculated by using the Hamon equation [17]:

$$PET_{Hamon} = 13.97 \times d \times D2 \times Wt$$

Where PET_{Hamon} is *PET* in millimeters per month, *d* is the number of days in a month, *D* is the mean monthly hours of daylight in units of 12 hrs, and *Wt* is a saturated water vapor density term, in grams per cubic meter, calculated by:

$$W_t = \frac{4.95 \times e^{0.062 \times T}}{100}$$

Where *T* is the mean monthly temperature in degrees Celsius [17].

2.3.1. Determination of Supplementary Water Requirements Per Crop Growth Stage

Supplementary water need of crops per growth stage was determined by relating values of reference evapotranspiration (ETo) with crop coefficient (Kc) at different growth stages. This is expressed mathematically as;

$$ETo^{month} xKc.$$

In this study, only K_c values of the initial stage, average K_c value of development/mid-season stage (i.e mean value of Kc during crop development stage and mid-season stage) and late season stage were considered. This re-grouping/consideration is in line with three stages of crop growth according to [18] classification i.e vegetative, flowering and harvesting stages. According to the author, about 40- 60% of water consumed by a crop is during the flowering stage while the remaining percentage is shared between the vegetative and harvesting stages. In this study, the development and mid-season stages have been bridged together as flowering stage, while initial and late season stage is considered as vegetative and harvesting stages respectively.

K_c is crop coefficient dimensionless. It is the ratio of the crop ET_c to the reference ETo, and it represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These are Crop height, Albedo, Canopy resistance and evaporation from soil, especially exposed soil [19]. Due to the sparseness of data on crop coefficient in developing countries, empirical estimates are usually employed and the most common is the FAO estimates [9] see Table 3. The Kc values are estimated under a standard climatic condition. This condition has been defined as crops grown in large fields under non-limiting agronomic and soil water conditions [20].

Table 3. Estimated values crop factor (Kc) for various crops under a standard climatic condition and growth stages

Crop	Total growing period (days)	Initial stage Kc	Crop dev. Stage Kc	Mid-season stage Kc	Late season stage Kc
Maize (grain)	125-180	0.40	0.80	1.15	0.70
Groundnut	130-140	0.45	0.75	1.05	0.70
Tomato	135-180	0.45	0.75	1.15	0.80
Cabbage	120-140	0.45	0.75	1.05	0.90
Carrot	100-150	0.45	0.75	1.05	0.90
Green Bean	75-90	0.35	0.70	1.10	0.30
Onion (dry)	150-210	0.50	0.75	1.05	0.85
Melon	120-160	0.45	0.75	1.00	0.75
Millet	105-140	0.35	0.70	1.10	0.65
Sorghum	120-130	0.35	0.75	1.10	0.65
Soybean	135-150	0.35	0.75	1.10	0.60
Cucumber	105-130	0.45	0.70	0.90	0.75
Pepper	120-210	0.35	0.70	1.05	0.90
Bean (dry)	95-110	0.35	0.70	1.10	0.30
Potato	105-145	0.45	0.75	1.15	0.85

Source: FAO Irrigation and Drainage Paper, No. 24 [9].

The total growing period was divided into 4 growth stages following, [9] and [20].

1. **The Initial Stage:** this is the period from sowing or transplanting until the crop covers about 10% of the ground.
2. **The Crop Development Stage:** this period starts at the end of the initial stage and lasts until the full ground cover has been reached (ground cover 70-80%); it does not necessarily mean that the crop is at its maximum height.
3. The **Mid - Season Stage:** this period starts at the end of the crop development stage and lasts until maturity; it includes flowering and grain-setting.
4. The **Late Season Stage:** this period starts at the end of the mid-season stage and lasts until the last day of the harvest; it includes ripening.

2.3.2. Estimation of Effective Precipitation

Effective precipitation (P_e) is refers to the fraction of the total amount of rainwater useful for meeting the water need of the crops after provisions have been made for runoff, evaporation and deep percolation. In the absence of data on effective rainfall for climatic stations in the study area, values of effective precipitation ($P_{e)}$ were empirically determined using the procedure described by [5]. The FAO manual for irrigation water needs provided estimate values of Pe for different rainfall events. [8]

2.3.3. Selected Crop

Six (6) food crops were selected to estimate for the design of supplementary water needs per crop growth stage. These include Melon, Beans, Millet, Sorghum, Soybean and Cucumber. The choice of these crops is based on the fact that they are the major sources of food and income for the teaming population of the semi-arid regions of Nigeria [22,23]. Besides the sensitivity of these crops to water stress are considered to range from medium to high [9].

3. Results

In Figure 2 – Figure 4 the seasonal distribution of rainfall and Potential evapotranspiration are presented. Northwest of the Sokoto-Rima River Basin, PET was very high throughout the year, reaching a peak in May which usually marks the onset of rainfall in the basin. Similarly PET was seen to vary greatly with the lowest values in January and December. Rainfall on the other hand was generally lowest between December and January. Highest amount was recorded in August before a sign of recession in September. In the southwestern part of the basin rainfall was highest in August with a total rainfall value of 228.6mm as against 219.5mm recorded in August northwest of the basin. Similar to pattern observed in the northwest of the basin, PET was very high through the year with highest amount in May, followed by April. Lowest PET was recorded in the part of the basin in January (93.1mm). Northeast of the Sokoto-Rima Rima Basin, seasonal rainfall amounts were generally low compared to amounts in northwest, southwest and southeast of the basin. Unlike with other parts of the basin the month of May recorded the lowest rainfall amount of 27mm compared to 61mm 48.9mm and 81mm recorded in southwest, northwest and southeast respectively. In addition, there are only 5 months of rainfall with only June-August as the active rainy months. This is unlike other parts of the basin where there are 6 months of rainfall with five months of active rainfall. Incidentally most of the water resources projects in the basin are located in the northeast part of the basin such as the Goronye dam and the Bakolari irrigation project. Southeast of the basin, seasonal PET values were seen to be low in comparison with distributions in other parts of the basin. Highest PET was recorded in May (148.9mm) followed April (147.86mm). Lowest value was recorded in December. August rainfall which usually marks the peak of rain in the study area was highest with a rainfall value of 258.4mm. The above distribution also have implications for water resources projects in the basin as the months of June-September represent surplus, while April – May is the recharge period. Between November-March the basin experiences water deficit.

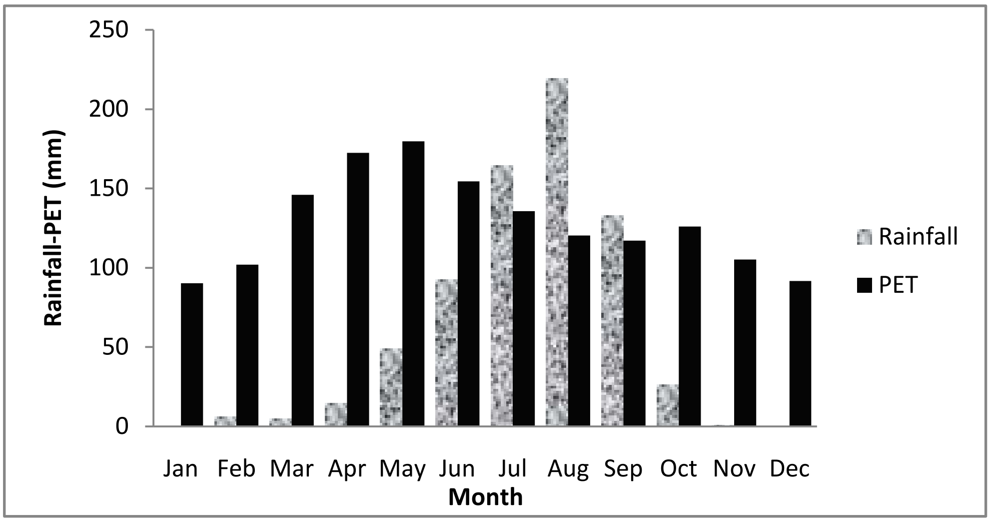

Figure 2. Seasonal distribution of Rainfall-PET, northwest of SRRB

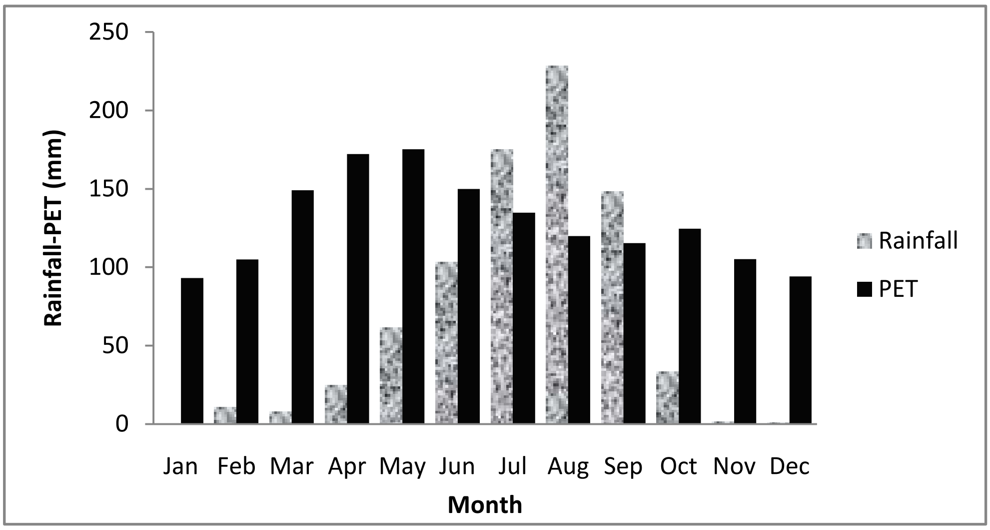

Figure 3. Seasonal distribution of Rainfall-PET, southwest of SRRB

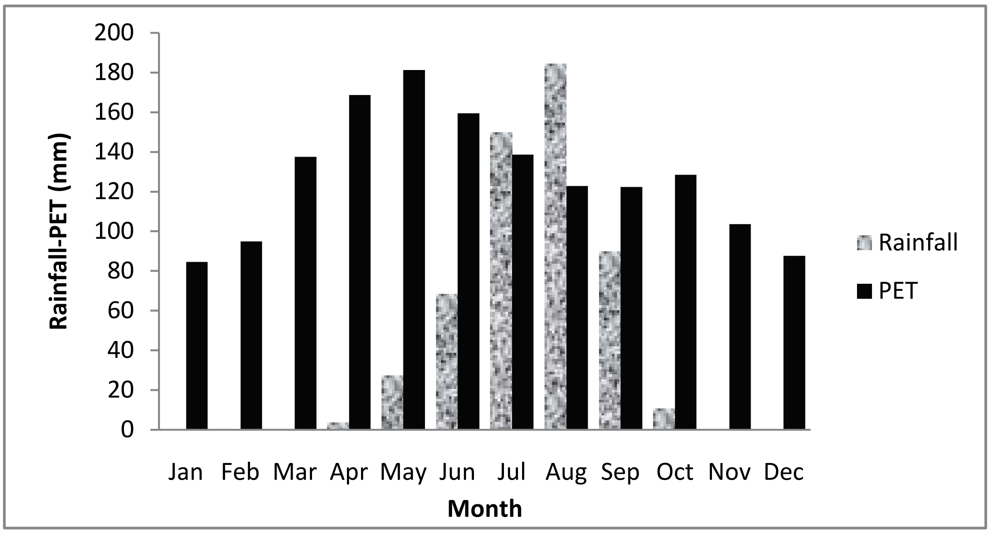

Figure 4. Seasonal distribution of Rainfall-PET, Northeast of SRRB

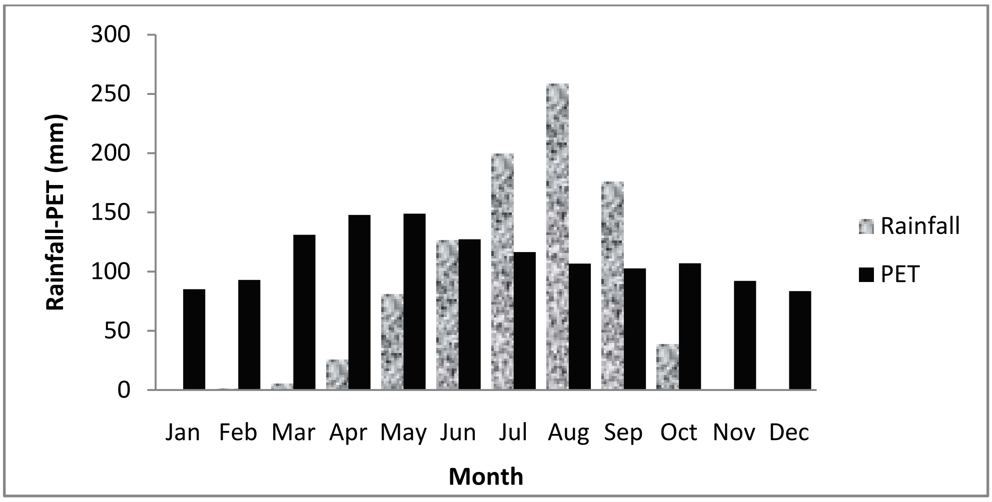

Figure 5. Seasonal distribution of Rainfall-PET, Southeast of SRRB

The results of computed monthly water needs of selected food crops, northwest of the Sokoto-Rima river basin are presented in Tables 4-9. In the initial stage of melon cultivation, a total of 83.8mm water is needed. During the flowering and late season stages water needs of melon were 388.7mm and 78.08mm respectively. A total of 550.58mm is required during the various stages of melon cultivation (Table 4). Bean (dry) requires a total of 259.51mm throughout the stages of cultivation, out of which 65.2mm is needed in the initial stage, 165.53mm in the development/mid-season stage and 30.78mm during the late season stage (Table 5). Millet recorded a consumptive water use of 65.2mm in the initial stage of cultivation. Between June and August, which represents crop development/mid stage consumptive water need of 270.09 mm was estimated. In the late season stage, millet requires 80.99mm water. Total water need throughout the stages of cultivation was 416.28mm (Table 6). In the case of sorghum with total consumptive water need throughout the stages of cultivation of 539.45mm, specific water need in the initial stage was 65.2mm, 396.83mm during the flowering stage and 77.42 mm in the late season stage (Table 7). In the initial stage of soybean cultivation, a total of 65.2 mm water is needed. During the flowering and late season stages water needs of soybean were 413.7mm and 60.66mm respectively. A total of 539.4mm is required during the various stages of soybean cultivation (Table 8). Cucumber requires a total of 418.7mm throughout the stages of cultivation, out of which 83.88mm is needed in the initial stage, 260.88mm in the development/mid-season stage and 73.95mm during the late season stage (Table 9).

Table 4. Consumptive water need per stage of growth for Melon in mm, northwest, Sokoto-Rima river Basin

Melon	Average Growing Period : 140 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season stage	Late season stage	
Consumptive use per stage (mm)	83.8	388.7	78.08	550.58

Table 5. Consumptive water need per stage of growth for Bean (dry) in mm, northwest, Sokoto-Rima river Basin

Bean (dry)	Average Growing Period : 83 days			
Months	May	June-July	July	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season stage	Late season stage	
Consumptive use per stage (mm)	65.2	163.53	30.78	259.51

Table 6. Consumptive water need per stage of growth for Millet in mm, northwest, Sokoto-Rima river Basin

Millet	Average Growing Period : 123 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	65.2	270.09	80.99	416.28

Table 7. Consumptive water need per stage of growth for Sorghum in mm, northwest, Sokoto-Rima river Basin

Sorghum	Average Growing Period : 125 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	65.2	396.83	77.42	539.45

Table 8. Consumptive water need per stage of growth for Soybean in mm, northwest, Sokoto-Rima river Basin

Soybean	Average Growing Period : 143 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	65.2	413.57	60.66	539.43

Table 9. Consumptive water need per stage of growth for Cucumber in mm, northwest, Sokoto-Rima Riv er Basin

Cucumber	Average Growing Period : 118 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	83.88	260.88	73.95	418.71

In Table 10 -Table 15, results of computed water needs of selected food crops south-west of the Sokoto-Rima River Basin are presented. In the initial stage of melon cultivation, a total of 78.53mm water is needed. During the flowering and late season stages water needs of melon were 371.36mm and 74.55mm respectively. A total of 524.44mm is required during the various stages of cultivation of melon (Table 10). Bean (dry) requires a total of 248.4mm throughout the stages of cultivation, out of which 61.08mm is needed in the initial stage, 153.5mm in the development/mid-season stage and 33.78mm during the late season stage (Table 11).

Millet recorded a consumptive water use of 61.0mm in the initial stage of cultivation. Between June and August, which represent crop development/mid stage consumptive water need of 133.74mm was estimated. In the late season stage, millet requires 78.91mm water. Total water need throughout the stages of cultivation was 272.73mm (Table 12). In the case of sorghum with total consumptive water need throughout the stages of cultivation of 513.95mm, specific water need in the initial stage was 61.08mm, 395.25mm during the flowering stage and 57.84 mm in the late season stage (Table 13). In the initial stage of soybean cultivation, a total of 61.08 mm water is needed. During the flowering and late season stages water needs of soybean were 395.25mm and 57.84mm respectively. A total of 514.17mm is required during the various stages of soybean cultivation (Table 14). Cucumber requires a total of 397.76mm throughout the stages of cultivation, out of which 78.53mm is needed in the initial stage, 247.68mm in the development/mid-season stage and 71.55mm during the late season stage. It was observed that supplementary water needs of these crops in the southwest part of the basin were lower than water needs of the same crops in the northwest part of the basin (Table 15).

Table 10. Consumptive water need per stage of growth for Melon in mm, southwest, Sokoto-Rima river Basin

Melon	Average Growing Period : 140 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season stage	Late season stage	
Consumptive use per stage (mm)	78.53	371.36	74.55	524.44

Table 11. Consumptive water need per stage of growth for Bean (dry) in mm, southwest, Sokoto-Rima river Basin

Bean (dry)	Average Growing Period : 83 days			
Months	May	June-July	July	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season stage	Late season stage	
Consumptive use per stage (mm)	61.08	153.54	33.78	248.4

Table 12. Consumptive water need per stage of growth for Millet in mm southwest, Sokoto-Rima river Basin

Millet	Average Growing Period : 123 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	61.08	133.74	78.91	273.73

Table 13. Consumptive water need per stage of growth for Sorghum in mm, southwest, Sokoto-Rima river Basin

Sorghum	Average Growing Period : 125 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	61.08	378.51	74.36	513.95

Table 14. Consumptive water need per stage of growth for Soybean in mm, southwest, Sokoto-Rima river Basin

Soybean	Average Growing Period : 143 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	61.08	395.25	57.84	514.17

Table 15. Consumptive water need per stage of growth for Cucumber in mm, southwest, Sokoto-Rima river Basin

Cucumber	Average Growing Period : 118 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	78.53	247.68	71.55	397.76

The results of computed monthly water needs of selected food crops, northeast of the Sokoto-Rima river basin are presented in Table 16 - Table 21. In the initial stage of melon cultivation, a total of 80.07mm water is needed. During the flowering and late season stages water needs of melon were 376.31mm and 75.65mm respectively. A total of 532.03mm is required during the various stages of cultivation of melon (Table 16). Bean (dry) requires a total of 255.13mm throughout the stages of cultivation, out of which 62.28mm is needed in the initial stage, 158.99mm in the development/mid-season stage and 33.86 mm during the late season stage (Table 17).

Millet recorded a consumptive water use of 62.28mm in the initial stage of cultivation. Between June and August, which represent crop development/mid stage consumptive water need of 260.58mm was estimated. In the late season stage, millet requires 78.71mm water. Total water need throughout the stages of cultivation of millet was 401.57mm (Table 18). In the case of sorghum with total consumptive water need throughout the stages of cultivation of 521.34mm, specific water need in the initial stage was 62.28mm, 383.74mm during the flowering stage and 75.32 mm in the late season stage (Table 19). In the initial stage of soybean cultivation, a total of 62.28 mm water is needed. During the flowering and late season stages water needs of soybean were 400.48mm and 58.72mm respectively. A total of 521.48mm is required during the various stages of soybean cultivation (Table 20). Cucumber requires a total of 403.81mm throughout the stages of cultivation, out of which 80.07mm is needed in the initial stage, 252.42mm in the development/mid-season stage and 71.32mm during the late season stage (Table 21).

Table 16. Consumptive water need per stage of growth for Melon in mm, northeast, Sokoto-Rima river Basin

Melon	Average Growing Period : 140 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	80.07	376.31	75.65	532.03

Table 17. Consumptive water need per stage of growth for Bean (dry) in mm, northeast, Sokoto-Rima river Basin

Bean (dry)	Average Growing Period : 83 days			
Months	May	June-July	July	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	62.28	158.99	33.86	255.13

Table 18. Consumptive water need per stage of growth for Millet in mm, northeast, Sokoto-Rima river Basin

Millet	Average Growing Period : 123 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	62.28	260.58	78.71	401.57

Table 19. Consumptive water need per stage of growth for Sorghum in mm, northeast, Sokoto-Rima river Basin

Sorghum	Average Growing Period : 125 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	62.28	383.74	75.32	521.34

Table 20. Consumptive water need per stage of growth for Soybean in mm, northeast, Sokoto-Rima river Basin

Soybean	Average Growing Period : 143 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	62.28	400.48	58.72	521.48

Table 21. Consumptive water need per stage of growth for Cucumber in mm, northeast, Sokoto-Rima river Basin

Cucumber	Average Growing Period : 118 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	80.07	252.42	71.32	403.81

In Table 22 – Table 27, results of computed water needs of selected food crops south-east of the Sokoto-Rima River Basin are presented. In the initial stage of melon cultivation, a total of 68.09mm water is needed. During the flowering and late season stages water needs of melon were 328.3mm and 65.18mm respectively. A total of 461.57mm is required during the various stages of cultivation of melon (Table 22). Bean (dry) requires a total of 219.41mm throughout the stages of cultivation, out of which 53.96mm is needed in the initial stage, 136.71mm in the development/mid-season stage and 28.74 mm during the late season stage (Table 23).

Table 22. Consumptive water need per stage of growth for Melon in mm, southeast, Sokoto-Rima river Basin

Melon	Average Growing Period : 140 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	68.09	328.3	65.18	461.57

Table 23. Consumptive water need per stage of growth for Bean (dry) in mm, southeast, Sokoto-Rima river Basin

Bean (dry)	Average Growing Period : 83 days			
Months	May	June-July	July	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	53.96	136.71	28.74	219.41

Table 24. Consumptive water need per stage of growth for Millet in mm, southeast, Sokoto-Rima river Basin

Millet	Average Growing Period : 123 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	52.96	222.9	70.46	346.32

Table 25. Consumptive water need per stage of growth for Sorghum in mm, southeast, Sokoto-Rima river Basin

Sorghum	Average Growing Period : 125 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	52.96	429.66	66.24	548.86

Table 26. Consumptive water need per stage of growth for Soybean in mm, southeast, Sokoto-Rima river Basin

Soybean	Average Growing Period : 143 days			
Months	May	June-August	September	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	52.96	349.77	50.34	453.07

Table 27. Consumptive water need per stage of growth for Cucumber in mm, southeast, Sokoto-Rima river Basin

Cucumber	Average Growing Period : 118 days			
Months	May	June-July	August	Total water need
Growing stage	Initial stage	Crop Dev. Stage -Mid season state	Late season stage	
Consumptive use per stage (mm)	68.09	218.96	61.8	348.85

Millet recorded a consumptive water use of 52.96mm in the initial stage of cultivation. Between June and August, which represent crop development/mid stage consumptive water need of 222.9mm was estimated. In the late season stage, millet requires 70.46mm water. Total water need throughout the stages of cultivation of millet was 346.32mm (Table 24). In the case of sorghum with total consumptive water need throughout the stages of cultivation of 548.86mm, specific water need in the initial stage was 52.96mm, 429.66mm during the flowering stage and 66.24 mm in the late season stage (Table 25). In the initial stage of soybean cultivation, a total of 52.96 mm water is needed. During the flowering and late season stages water needs of soybean were 349.77mm and 50.34mm respectively. A total of 453.07mm is required during the various stages of soybean cultivation (Table 26). Cucumber requires a total of 348.85mm throughout the stages of cultivation, out of which 68.09mm is needed in the initial stage, 218.96mm in the development/mid-season stage and 61.8mm during the late season stage (Table 27).

4. Discussion

From the observed seasonal rainfall and PET distributions, water surplus in the basin sets in from June – August while April to May is the soil water recharge periods. From October, water is withdrawn from the basin, paving way for moisture deficit which last from November-March. The spatial pattern of rainfall distribution can be explained in the light of movement of The Inter-tropical Discontinuity (ITD which is most popularly accepted medium that influence rainfall distribution in Nigeria [24,25]. Studies have shown that to the southern part of ITD, varying degrees of convective activity and precipitation takes place, whereas, little or no cloud development or precipitation occur to the northern most part. In other words, rain falls mostly when an area is over-lain by the Tropical maritime (mT) air mass and ceases when the area is over-lain by the Continental Tropical (cT) air mass. This makes the position of ITD a great determinant of most rainfall attributes in the region. Prominent among these attributes are the length of the rainy season [26]. It, thus, appears as if the ITD is a rain-producing phenomenon in itself, but in reality, weather zones occur in a latitudinal spatial relationship to it [27]. The study also shows that May and August are the months with considerable soil moisture storage to support adequate crop yields. Furthermore, because rainfall is observed to begin in the basin from May, crops planted before this month may suffer water stress during the vegetative stage due to the pattern of soil moisture shortage. Even during the rainy months in the study area, our investigation showed that supplementary irrigation is needed to compensate for the occasionally deficit due to increased rate of evapo-transpiration over the basin. In the same vein, it is possible under a scientific irrigation scheme to carry out an all year round cultivation. For an all-year-round cultivation of crops with greater yields, full scale irrigation is needed for a second cultivation season (from October to February) when the soil moisture storage of the basin is below the basin field capacity. Variation however may exist in the amount needed per growing season due to variations in locations, methods and efficiency of irrigation. It is important to note that scarcity of climatic data especially on a wider coverage is a major limitation modeling climatic changes in Nigeria. One of the ways to address this which this study adopted is the use of CRU dataset. As with other studies where the CRU dataset have been used a Pearson product moment correlation was carried to ascertain the suitability of the dataset for use in the study area. As temperature is expected to rise due to global warming, this may result in increased evapotranspiration rate over the study area leading to greater soil moisture deficit and crop water stress. There is dare need for stakeholders in the basin to plan for future agricultural operations especially under the increasing weather variability. This study can be a guide in this direction.

5. Conclusion

The Sokoto-Rima River Basin (SRRB) is located in the semi-arid region of Nigeria, a region which is characterized by occasional extreme climatic variability and in recent time climate change. In addition, 70% of population in this region relies on rainfed agriculture as their major source of livelihood. As climate change and variability intensifies, with attendant implications for food supply, the need to examine ways to improve on agricultural outputs hence meeting the food demands of the teaming population of the study area becomes imperative. The objective of this study is to evaluate the character of climatic indices in the SRRB, northern Nigeria as well as design a supplementary irrigation water requirement scheme for selected food/cash crops. The aim is to scientifically, quantify the amount of water that is required to meet the crop water needs at various stages of growths. Findings from this study revealed the study area is already under water stress as supplementary irrigation is required for optimum crop development even during rainy months (i.e onset and departures of rains). With such information as time of moisture recharge, surplus, deficit and amount of water required to compensate for losses due to increased evapotranspiration as illustrated in this study famers can now practice sustainable agricultural development as well as water conservation in the study area.

Poor training of famers on the other will limit the extent to which this approach can be applied in the region as many of the famers are illiterate. There is therefore need for agricultural training programmes for famers on scientific application of water conservation method as illustrated in the present study. This will not only ensure optimum yield production without water wastage, but a right step toward climate change adaptation. Secondly, most of the famer in the region are yet to appreciate how climate change and variabilities is impacting no their activities. There is urgent need to increase awareness programmes for rural famers on the cause, impacts and adaptation measures to climate change and extreme conditions in the region.

References

[1] Obioha E (2008). “Climate Change, population drift and violent conflict over land resources in North Eastern Nigeria” *J. Hum. Ecol*., 23(4): 311-324.

[2] Hanafi, A. and Jauffret, S.A. (2008). “Long-term vegetation dynamics useful in monitoring and assessing desertification processes in the arid steppe, southern Tunisia”, *Journal of Arid Environments*, vol. 72 (4), 557-572.

[3] Zoellick S and Robert BA (2009). *Climate Smart Future. The Nation Newspapers*. Vintage Press Limited, Lagos, Nigeria, pp 18.

[4] Benli, B., Kodal, S., Ilbeyi, A., Ustun, H., (2006). Determination of evapotranspiration and basal crop coefficient of alfalfa with a weighing lysimeter. *Agric. Water Manage*., 81, 358-370.

[5] Allen, R.G., (1996). Assessing integrity of weather data for use in reference evapotranspiration estimation. *J. Irrigat. Drainage Eng*. ASCE 122 (2), 97-106.

[6] Verplancke, H. (1985). The process of evaporation. Colloquium on energy-flux; The soil atmosphere interface, at College on soil Physics; ICTP, Trieste, Italy. 6-10 May.

[7] Arora K.R (2004). *Irrigation, Water power and Water Resources Engineering*, Standard publishers, Delhi.

[8] FAO. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. By: Richard Allen, Luis Pereira, Dirk Raes and Martin Smith. FAO Irrigation and Drainage Paper 56. Rome, Italy.

[9] Food and Agriculture Organization of the United Nations FAO (1986). *Irrigation Management, Training Manual*, no 3. Via delle Terme di Caracalla, 00100 Rome, Italy.

[10] Fereres, E. (1996). *Irrigation scheduling and its impacton the 21st century*. p 547-553. In. C. Camp, E.Sadler, R. Yoder (eds.). Evapotranspiration and Irrigation Scheduling. A.S.A.E. San Antonio, Texas. USA.

[11] Katerji N, Rana G (2008*). Crop evapotranspiration measurement and estimation in the Mediterranean region*, ISBN 978 8 89015 2412. INRA-CRA, Bari.

[12] Sombroek, W. G., and Zonneveld, I. S. (1971). *Ancient Dunes Fields and Fluviatile Deposits in the Rima Sokoto River Basin, Soil Survey Paper* No.5, Netherland Soil Survey Institute, Wageningen, pp109.

[13] Hughes, R.H. and J.S. Hughes, (1991). *A directory of African wetlands*, IUCN, Gland, Switzerland.

[14] Ita E.O (1993). *Inland Fishery Resources of Nigeria CIFA Occasional Paper* No 20. Rome, FAO. 1993. 120p.

[15] New, M., Hulme M., and. Jones, P.D (2000). Representing twentiethcentury space–time climate variability. Part 2: Development of 1901-96 monthly grids of terrestrial surface climate. *J. Climate*, 13, 2217-2238.

[16] Mitchell T. D and. Jones P.D (2005). An Improved method of constructing a database of monthly climate observations and associated high-resolution grids *Int. J. Climatol*. 25: 693-712.

[17] Hamon, W.R., (1961). Estimating potential evapotranspiration: *Journal of the Hydraulics*. 87, p. 107-120.

[18] Israelsen O.W, Hansen V.E. (1962). *Irrigation Principles and Practices*, John Wiley and Sons. Inc, New York.

[19] Allen, R.G., Smith, M., Perrier, A., and Pereira, L.S. (1994). An update for the definition of reference evapotranspiration. *ICID Bulletin*. 43(2). 1-34.

[20] FAO (2002). Crop *Water Requirements and Irrigation Scheduling.* In A. P. Savva and K. Frenken (eds.) FAO Irrigation Manual Module 4 Rome, Italy.

[21] Tekwa I. J. and Bwade E. K. (2011). Estimation of Irrigation Water Requirement of Maize (Zea-mays) using Pan Evaporation Method in Maiduguri, Northeastern Nigeria. *The CIGR Journal*. Vol.13 (1).

[22] Yugunda B. S (1976). Assessment of food crops produced in north-eastern Nigeria. *Agric Bul* 5, 8-16.

[23] Ahmed H. A (1978). The pattern of farming systems and crops production in Borno State, Nigeria. *Journal of Agricultural Science*, 2(1): 9-16.

[24] Adejuwon J.O, Balogun E.E, Adejuwon S.A (1990). On the Annual and Seasonal Pattern of Rainfall Fluctuations in Sub-Saharan West Africa. *International Journal of Climatology*, 10: 810-848.

[25] Lamb P.J (1983). Sub-Saharan Rainfall Update for 1982 Continious Drought. Journal of Climatology, 3: 419-422.

[26] Omogbai B.E (2010). An Empirical Prediction of Seasonal Rainfall in Nigeria *J Hum Ecol*, 32(1): 23-27.

[27] Ilesanmi, O. (1981). Aspect of the Precipitation Climatology of the July-August Rainfall Minimum of Southern Nigeria. Urban and Regional Planning Problems in Nigeria. University of Ile-Ife, Nigeria. Geographical Associations Regional Planning Committee. Seminar on Urban and Regional Problems in Nigeria University of Ile-Ife 13th–14th March, 1981.