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Rainfall Intensity and Evapotranspiration Patterns Nexus over Nigeria in Different Solar Cycles

O. O. Ajileye[1*], J. O. Otu[1], Najib Yusuf[1] and O. O Akinola[1]

[1]*Centre for Atmospheric Research, National Space Research and Development Agency, Kogi State University Campus, Anyigba, Kogi State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all the authors. Authors OOA and NY designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JOO and OOA managed the analyses of the study and restructure the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The study employed Mass – Transfer Model (MTM) to estimate evapotranspiration (ET) from 12 selected locations spread across three climatic zones over Nigeria at intervals of 30 years (1988 and 2018) depicted by different solar cycles. Based on this finding the impacts of rainfall intensity on evapotranspiration patterns over Nigeria were investigated. Daily averaged values of wind speed at 2 m from soil, air temperature and relative humidity for 12 selected stations across Nigeria were employed for 1988 and 2018. The actual vapour pressure and saturated vapour pressure were estimated. A correlation between evapotranspiration with rainfall intensity was established to determine impacts of rainfall intensity on evapotranspiration patterns over Nigeria in solar maxima and minima scenarios. The results showed that ET was higher in 2018 than 1988 in 3 out of 4 stations in tropical monsoon; in tropical savannah and only Ibadan and Akure had a reduction in these values when 1988 was compared with 2018. Lowest values of ET was observed between August and October corresponding to the peak of rainy season. 7 stations out of 12 were influenced by solar minima phenomenon namely Port Harcourt, Owerri, Enugu, Ibadan, Minna, Borno and Gusau. The lowest values of ET were recorded at Calabar and Port Harcourt for both 1988 and

**Corresponding author: E-mail: ajileyeseun@rocketmail.com;*

2018 while the highest values were observed at Borno for 1988 and Sokoto for 2018. Rainfall intensity had greater impacts on ET values in tropical monsoon than any other climatic zone in Nigeria.

Keywords: Evapotranspiration (ET); solar minima; solar maxima; rainfall intensity; mass-transfer model; climatic zones.

1. INTRODUCTION

Terrestrial evaporation, or evapotranspiration, is the transfer of water from soil and vegetation into the atmosphere. It is a critical component of the global water cycle and, in recent years, it has gained increased attention due to its role in global warming and water cycle intensification. Land surface evapotranspiration, ET, plays an important role in the climate of semiarid areas of sub-Saharan Africa, such as Nigeria, where a few intense rainfall events may generate much or sometimes most of the season's runoff [1]. Rainfall is the primary source of water and a major component of the water cycle for most human activities in the world. The effect of rainfall on surface evaporation is very important in understanding water resource availability in a region.

Rainfall dynamics have been used as representative in the study of climate change and variability [2], particularly in sub-Sahara Africa. Rainfall is considered as the reverse of surface evaporation, therefore evaporation rate is strongly controlled by the availability of water from previous rainfall. The global climate has been reported to change rapidly with the global mean temperature increasing by 0.7^0C within the last century with an erratic increase or decrease in rainfall. However, the rates of change are significantly different among regions [3]. The total evaporation calculated by the surface scheme and locally observed rainfall in Sahelian Africa compared reasonably well with observations at the same site [4].

In previous studies, rainfall and evaporation data analysis in southeastern Nigeria (Nsukka) showed that rainfall exhibited unimodal distribution with a peak in September and minimum values in January and December, with a mean annual value of 1533 mm. At Nsukka evaporation has a maximum value in January corresponding to the peak of harmattan period while the minimum value occurred in September corresponding to the period of maximum rainfall; the mean annual evaporation at Nsukka is 1601.20 mm [5]. Two statistical models were used to establish a periodic function relating the deficits and surpluses to a time series, the comparison of the model for Nsukka showed that the logistic model predicted better deficits while the Gompertz predicted better surpluses [5].

In a study carried out by [6], ET for Kano (Lat. 12.00N, Long. 8.30E at an altitude of 472.45m above sea level) using the Food and Agriculture Organization (FAO) Penman-Monteith Method, for effective irrigation planning and management at Kano, within the semi-arid Sudan savannah zone, was evaluated. The climatic data used were obtained from International Institute for Tropical Agriculture in Ibadan (1977-2010). The results showed that the lowest ET (60.41 mm/day), was obtained in the rainy season (August) due to the high humidity of the air and the presence of clouds, while the highest ET (125.08 mm/day) was obtained in dry season (February) as a result of hot dry weather due to the dryness of the air and the amount of energy available. It was observed that solar radiation had the highest effect on ET as it provided the energy needed for evapotranspiration to take place.

In another study conducted by [7] correlation of ET with climatic parameters for Ibadan, Sokoto and Kano were evaluated since the rate of ET depends on the available climatic parameters. The ET was estimated using the FAO-56 Penman-Monteith Method. The results showed that solar radiation, sunshine hour, air temperature, wind speed and clearness index were positively correlated with ET while relative humidity and cloudiness were negatively correlated. The correlation coefficients obtained ranged from 0.538 – 0.871, 0.164 – 0.953 and 0.031 – 0.994 for Ibadan, Sokoto and Kano respectively. The result also showed that the correlation of each parameters with ET depended on the prevailing climatic conditions of the location, rainfall was completely left out of the various analysis.

Several studies had been carried out on evaluation of evapotranspiration and its correlation with climatic parameter. However, there is a gap in the analyses in terms of what specific climatic parameter was correlated and the models used for the estimation. This research addressed the missing gap using Mass – Transfer Model (MTM) to estimate evapotranspiration from 12 selected locations spread across three climatic zones over Nigeria for two years separated by 30 years interval (1988 and 2018); and depicted by different solar cycles. A correlation of evapotranspiration with monthly rainfall intensity was established to determine the impacts of different rainfall regimes on evapotranspiration patterns over Nigeria in solar maxima and minima scenarios.

2. THEORETICAL BACKGROUND

The energy budget methods (including the Penman combination methods) are reliable in theory and suitable for research purposes only in small areas, because of their requirements for detailed meteorological data, such as net radiation, sensible heat flux, etc. The practical utility of the models for larger study areas is limited. Although [8] presented tables for rapid computation of evaporation by the Penman method, Schulz [9] presented a graphical procedure for using this model, and [10] presented a simplified generalized model, it still requires an evaluation of the net radiation which is not so easily obtainable for many applied engineering problems.

The mass-transfer (aerodynamic) based methods utilize the concept of eddy motion transfer of water vapour from an evaporating surface to the atmosphere. All such methods are based on Dalton's law. The mass-transfer methods give satisfactory results in many cases [11] and normally use easily measurable variables and have simple model form. However, wind speed and air temperature have been measured at inconsistent heights, resulting in a large number of equations with similar or identical structure. The wide-ranging inconsistency in meteorological data collection procedures and standards has given rise to over 100 evaporation formulae and has made it impossible for a comparative study [12].

Clearly, evaporation depends on the supply of heat energy and vapour pressure gradient, which, in turn, depend on meteorological factors such as temperature, wind speed, atmospheric pressure, solar radiation, quality of water and the nature and shape of the evaporating surface [13]. These factors also depend on other factors, such as geological locations, seasons, etc. Thus, the process of evaporation is rather complicated. A complete physical model may be too difficult to develop since there exist many factors that are not controllable and measurable.

The mass-transfer method is one of the oldest methods [14,15,16] and is still an attractive method for estimating free water surface evaporation because of its simplicity and reasonable accuracy. The mass-transfer methods are based on the Dalton equation, which for free water surface can be written as:

$$\mathrm{ET} = 0.35(1 + 0.24\mathrm{U_2})(\mathrm{e_s} - \mathrm{e_a}) \quad (1)$$

$$\mathrm{e_a} = \frac{\mathrm{e_s RH}}{100} \quad (2)$$

$$\mathrm{e_s} = \frac{5854}{\mathrm{T^5}} \times 10^{\left(20-\left(\frac{2950}{\mathrm{T}}\right)\right)} \quad (3)$$

ET is evapotranspiration (mm/day)
U_2 is wind speed (m/s) at 2 m from ground
e_s is saturated water vapour pressure (mb)
e_a is actual water vapour pressure (mb)
RH is relative humidity (%)
T is surface air temperature (K)

A close consideration of the above mass-transfer-based equations reveals that the three major meteorological factors considered to affect evapotranspiration, vapour pressure gradient, wind speed and temperature, are adequately captured. The air pressure, fluid density and water surface elevation for a given location may not greatly affect the rate of evaporation. Evapotranspiration is proportional to vapour pressure gradient and also proportional to wind speed, but the relationship between evaporation and temperature is not explicitly included in most of MTM equations except that of equation 1.0.

3. METHODOLOGY

3.1 Study Area

The study area comprise of 12 selected stations in Nigeria between latitude 4.17°N and 13.67°N longitude 2.83°E and 14.65°E. It is bounded in the North by Sahel and Sahara Desert and by the Atlantic Ocean in the South. Nigeria is located in the tropics, where the climate is seasonally damp and very humid. Nigeria is affected by four climate types; these climate types are distinguishable, as one moves from the southern part of Nigeria to the northern part of Nigeria through Nigeria's middle belt. The seasonal northward and southward oscillatory movement of the Inter-Tropical Discontinuity (ITD) largely dictates the weather pattern of Nigeria. The moist southwesterly winds from the South Atlantic Ocean, which is the source of moisture needed for rainfall and thunderstorms to occur, prevail over the country during the rainy season (April – October).

In reverse, northeasterly winds which raise and transport dust particles from the Sahara Desert prevail all over the country during the Harmattan period (November – March). The overall changes in temperature, rainfall and other meteorological parameters determine the changes in climate in the country each year. The selected stations in Nigeria for this study include Calabar, Port Harcourt, Owerri, Enugu, Akure, Ibadan, Lafia, Minna, Bauchi, Borno, Gusau and Sokoto. The climatic features of the stations are shown in Table 1. Three stations were selected from tropical monsoon; five stations were selected from tropical savannah and four stations from warm semi-arid climatic zone as shown in Fig. 1.

The tropical monsoon climate experiences abundant rainfall like that of the tropical rain forest climate, but it is concentrated in the high-sun season. Being located near the equator, the tropical monsoon climate experiences warm temperatures throughout the year. The tropical savanna climate has alternating dry and wet seasons, hence its name [2]. It shares some similar characteristics with the tropical monsoon climate, but it receives less annual rainfall as compared to the tropical monsoon climate. Hot semi-arid climates characterize the tropics and sub-tropics often located near the tropical savanna climate or on the fringe of the sub-tropical desert climate. Warm semi-desert climate is known for hot summer and cool winter, with relatively low precipitation. The selection was done with a view to deduce evapotranspiration patterns at different climatic zones over Nigeria.

3.2 Data Collection

With Goddard Earth Observing System, GEOS-5, a renewed effort was put forth to make a broadly disseminated reanalysis dataset to support many of NASA's strategic elements. This reanalysis dataset was called the Modern Era Retrospective analysis for Research and Applications, or MERRA [17]. MERRA included a number of output variables unique among reanalysis, for example, complete vertically integrated budgets and 50m winds (for wind power generation). MERRA data have been widely used in the community; high-quality reanalysis datasets are always in great demand.

Meteorological dataset including air temperature, wind speed and relative humidity were obtained from MERRA for the study. MERRA was processed in three separate streams, each spun-up in two stages: a two-year analysis at 2° × 2.5° and then a one-year analysis on the MERRA grid. Unfortunately, some system changes were made between spin-up and production; these included small changes to the model that should have had little impact on the analysis [18]. Since the spin-up was primarily aimed at the root-zone soil moisture, it was felt that these changes would not impede spin-up. However, Streams 1 and 2 were each extended to overlap the next stream so that the overlaps could be used to examine the adequacy of the spin-up procedure and to quantify the uncertainty in individual fields.

Table 1. Climatic features of the selected stations in Nigeria

Stations in Nigeria	Latitude (degrees)	Longitude (degrees)	Altitude (m)	Mean rainfall (mm/mth)	Climatic zone
Calabar	4.96^0N	8.35^0E	47.20	229.16	
Port Harcourt	4.85^0N	7.01^0E	23.10	225.66	Tropical Monsoon
Owerri	5.48^0N	7.03^0E	73.40	184.92	
Enugu	6.46^0N	7.56^0E	160.50	144.17	Tropical Savannah
Akure	7.36^0N	3.98^0E	355.60	121.25	
Ibadan	7.10^0N	4.83^0E	181.05	109.25	
Lafia	8.48^0N	8.52^0E	290.01	109.67	
Minna	9.62^0N	6.55^0E	243.03	102.42	
Bauchi	10.31^0N	9.84^0E	628.76	84.08	
Borno	11.83^0N	13.15^0E	352.11	51.08	Warm Semi-Arid
Gusau	12.16^0N	6.66^0E	451.34	74.00	
Sokoto	13.06^0N	5.24^0E	296.67	52.42	

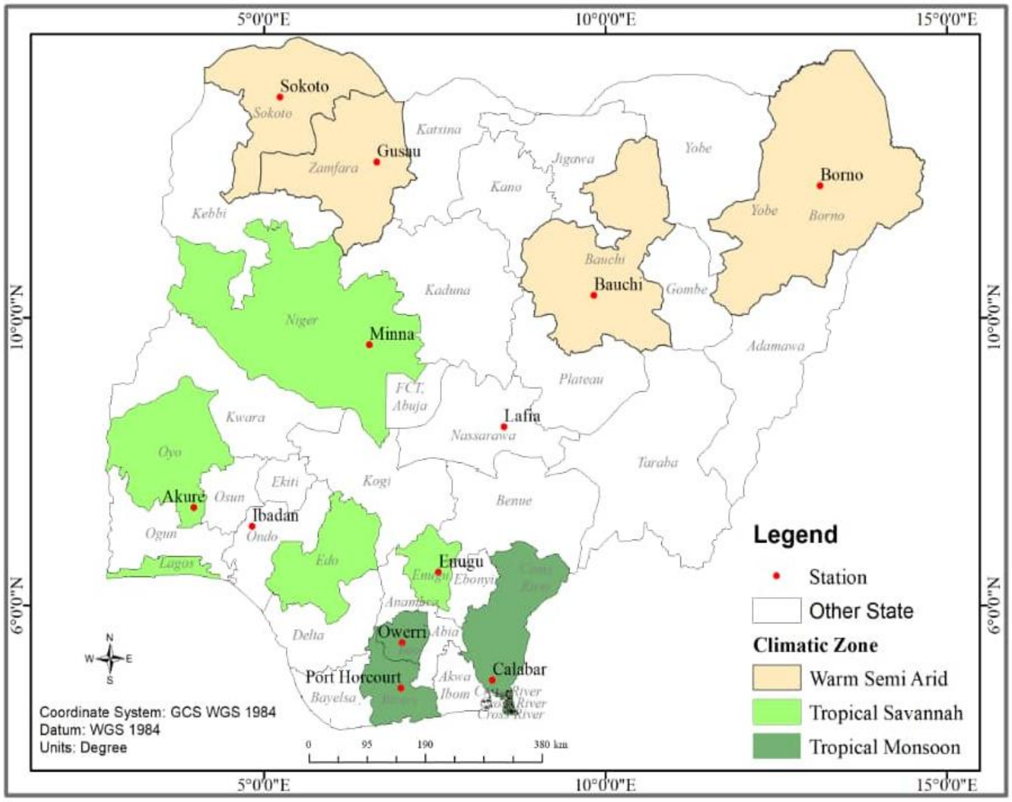

Fig. 1. Twelve Selected Stations over Nigeria

The final MERRA distribution is from Stream 1 for 1 January 1979 to 31 December 1992, followed by Stream 2 for 1 January 1993 to 31 December 2000, and then continues with Stream 3 for 1 January 2001 to the present [19]. Hence, the distributed product segments from Streams 1, 2 and 3 have been spun up for zero, four and three years, respectively, at MERRA resolution with the precise MERRA system configuration. With the overlaps complete, and Stream 3 now at “the present”, data production is being continued as a near-real-time climate analysis from Stream 3 alone.

The MERRA site provides access to world coverage of climate and hydrology average and time-series data. Each indicator/dataset can either be downloaded, plotted or reviewed in a metadata format. Daily averages of relevant meteorological parameters were therefore downloaded covering the 12 selected stations for 1988 (solar maxima scenario) and 2018 (solar minima scenario). Solar minima and maxima are the two extremes of the Sun's 11-year activity cycle. At a maximum, the Sun is peppered with sunspots, solar flares erupt, and the sun hurls billion-ton clouds of electrified gas into space [17]. At a solar minimum, there are fewer sunspots and solar flares subside. Sometimes, days or weeks go by without a spot.

The year 1988 was within the solar cycle 22 which lasted 9.9 years, beginning in September 1986 and ending in August 1996. The maximum smoothed sunspot number observed during the solar cycle was 212.5 (November 1989), and the starting minimum was 13.5. For 2018, the average temperature across global land and ocean surfaces was 0.79°C above the 20th century average. This was the fourth-highest among all years in the 1880–2018 record, behind 2016 (highest), 2015 (second highest), and 2017 (third highest). As of 2018, the sun showed signs of a reverse magnetic polarity sunspot appearing and beginning this solar cycle which is typical during the transition from one cycle to the next to experience a period where sunspots of both polarities exist (during the solar minimum) [20].

3.3 Method of Analysis

There are many equations available for calculating evaporation. The wide range of data type and the expertise needed to use the various equations correctly makes it difficult for many hydrologists to select the most suitable equation to use for a given study. Estimates of evaporation can be made based on water budget methods, temperature methods, humidity methods, radiation methods, mass transfer (or aerodynamic) methods or combination (energy budget and aerodynamic) methods. The accuracy of the water budget methods depends on the accuracy with which the budget terms are evaluated. The most difficult and unreliable term to measure or estimate is the seepage rate term, especially at short time-scales, and therefore this method was not used in the study.

The energy budget-based methods account for incoming and outgoing energy balanced by the amount of energy stored in the system. The accuracy of the evaporation estimate is highly dependent on the reliability and precision of a number of measurements involved in radiation measurements. Because of the detailed requirements for meteorological data this method was not used in the study either. Based on the foregoing discussion and the availability of meteorological data, a mass transfer method was selected for the investigation and the equations 1 – 3 were applied. Daily averaged values of wind speed at 2 m of the ground, air temperature and relative humidity for 12 selected station stations across Nigeria were downloaded for 1988 and 2018. The actual vapour pressure and saturated vapour pressure were estimated using equations 2 and 3 above. The evapotranspiration were calculated using equation 1. Monthly averages of ET was estimated for 1988 and 2018. Monthly ET patterns during solar maxima (1988) was compared with monthly ET patterns during solar minima (2018). Impacts of monthly rainfall intensity on ET patterns were deduced and correlation of ET with rainfall was established.

4. RESULTS AND DISCUSSION

4.1 Evapotranspiration (ET) Patterns at Intervals of 30 Years over Nigeria

In Figs. 2 – 4, the results of monthly ET patterns at intervals of 30 years in different solar cycles over Nigeria were presented. Generally, ET was higher in 2018 (248.96 mm) than 1988 in tropical monsoon except at Port Harcourt due to annual increase in rainfall intensity by 349.99 mm; in tropical savannah, Ibadan and Akure had lower ET values in 2018 than 1988. The remaining 3 stations namely Lafia, Minna and Bauchi had an increase of 12%, 23% and 64% in 2018 over 1988. In hot semi-arid, 2 stations out of the 3 had an increase in ET in 2018. Fig. 2 showed the monthly patterns at Calabar, Port Harcourt, Owerri and Enugu. At Calabar, the value of ET on monthly average increased by 4.02 mm/month from 1988 to 2018. The ET had monthly average of 73.71 mm/month in 1988 and 77.23 mm/month in 2018. In 1988 and 2018, at Calabar, ET had its lowest value of 53.07 mm and 60.35 mm in October, corresponding to the peak of the rainy season in the region. The peak ET values were 109.69 mm in February 1988 and 114.51 mm in January 2018. At Port Harcourt, ET on monthly average reduced by 1.13 mm/month, which is the lowest value in tropical monsoon for 1988 and 2018. On monthly average, Port Harcourt had 65.57 mm/month in 1988 and 64.44 mm/month in 2018. Port Harcourt had least ET value of 47.51 mm in October 1988 and 47.73 mm in September 2018. The highest values of ET were 92.60 mm in February 1988 and 99.06 mm in January 2018. The lowest values of ET lagged behind by a month in 2018 influenced by solar minima cycle. On the overall, seasonal influence had a strong impact on ET in addition to the solar cycles. High solar activity period results in high solar intensity, as such the incoming radiant energy tends to have a stronger impact on water bodies, thus, the likely reason for high ET during dry season in some climatic regions.

At Owerri, monthly average of ET increased by 5.15 mm/month from 1988 to 2018, the second-highest value in the climatic zone due to an increase in surface temperature along the latitudes. In 1988, ET had monthly average of 76.24 mm/month and in 2018, the monthly average was 81.39 mm/month. The lowest and peak occurrence of ET at Owerri followed the patterns in Port Harcourt. At Owerri, lowest ET of 53.77 mm in October 1988 and 56.98 mm in September 2018 were observed. The peak value of 113.29 mm was observed in February 1988 while 137.99 mm was observed in January 2018. It was expected that solar maxima in 1988 and minima in 2018 would influence high and low values of ET respectively. At Enugu, monthly average of ET increased significantly by 13.21 mm/month which was the highest value in tropical savannah climate over Nigeria, for 1988 and 2018. Monthly average of 89.65 mm/month was observed in 1988 while 102.86 mm/month was observed in 2018. Lowest values of 57.40 mm and 65.16 mm were observed in October 1988 and 2018 respectively. Peak values of 139.13 mm in February 1988 and 199.77mm in

January 2018 were observed at Enugu. Results from the 3 stations in tropical monsoon showed that solar cycle activities only had a slight influence at Port Harcourt while Calabar, Owerri and Enugu were influenced by an increase in surface temperature along the latitudes.

Fig. 3 captured results from four stations out of five in tropical savannah namely Ibadan, Akure, Lafia and Minna. Ibadan and Akure followed similar ET trends and had the closest patterns obviously due to station proximity and very close weather features. The two stations recorded a reduction in monthly average of ET by 2.53 mm/month for 1988 and 1.38 mm/month for 2018 at Ibadan and Akure respectively. At Ibadan, monthly average of 81.60 mm/month in 1988 and 79.07 mm/month in 2018 were observed. At Akure, monthly average of 76.45 mm/month in 1988 and 75.07 mm/month in 2018 were observed. Lowest ET values were observed in September, 65.07 mm for 1988 and 52.88 mm for 2018 at Ibadan; 50.56 mm for 1988 and 46.64 mm for 2018 at Akure respectively. The peak values were 127.30 mm in February 1988 and 127.07 mm in January 2018 at Ibadan. At Akure, peak values were 124.74 mm in February 1988 and 131.43 mm in January 2018.

ET trends at Lafia was extremely significant. The station recorded highest value of ET in all the estimations at tropical savannah climatic zone. The monthly average increased significantly from 1988 to 2018 by 102.15 mm/month, the highest increment over Nigeria. The monthly average of 158.94 mm/month was obtained for 1988 while 261.09 mm/month was obtained for 2018. The monthly variation in lowest and highest ET continued to lag behind corresponding to the peak of rainy season and dry season at the location. Least value of 72.02 mm was obtained in August 1988 while 79.26 mm was obtained in September 2018. ET increased to the peak values of 298.10 mm in February for 1988 and 566.46 mm in January 2018. An unusual increase was observed at Lafia compared with the remaining stations. Minna was second highest in ET at tropical savannah with an increment of 32.35 mm/month in 2018 over 1988. Monthly average of 135.44 mm/month was obtained in 1988 while 167.79 mm/month was obtained in 2018. Least ET of 61.90 mm was obtained in September 1988 and 68.47 mm was obtained in August 2018. Peak values of 252.84 mm were observed in February 1988 and 327.98 mm in January 2018.

Fig. 4 showed the results from Bauchi, Borno, Gusau and Sokoto. The results clearly depicted a change in climatic zone from tropical savannah to warm semi-arid climate, surface temperature in the region is continuously rising. The ET values were extremely high, in multiples of five, compared with the tropical monsoon. Bauchi was the border station from tropical savannah to hot semi-arid with increased monthly average ET of 31.51 mm/month from 1988 to 2018. Bauchi had monthly average of 255.21 mm/month in 1988 and 286.72 mm/month in 2018. Least values of 67.58 mm were obtained in August 1988 and 79.73 mm in August 2018. Peak values of 511.79 mm in February 1988 were observed while 511.57 mm was obtained in March 2018. The peak of dry season as depicted by least ET had shifted forward by a month while the peak of rainy season had shifted backward by a month corresponding to a reduced rainy period obtainable at semi-arid climate compared with tropical monsoon. At Borno, ET increased in monthly average by 53.92 mm/month, the highest in semi-arid climate. ET monthly average was 388.81 mm/month in 1988 and 442.73 mm/month in 2018. The least value of 106.54 mm was obtained in August 1988 and 124.72 mm was obtained in September 2018. Peak value of 788.23 mm was obtained March 1988 and 771.30 mm was obtained in March 2018. ET increased from 1988 to 2018 in rainy season while ET reduced from 1988 to 2018 in dry season.

At Gusau, ET on monthly average increased by 16.28 mm/month from 1988 to 2018. Monthly average was 313.88 mm/month in 1988 and 330.16 mm/month in 2018. Least values were 86.52 mm in September 1988 and 89.62 mm in September 2018. Peak values were 626.49 mm in March 1988 and 574.91 mm in March 2018. At Sokoto, monthly average of ET reduced by 48.02 mm/month from 1988 to 2018. Monthly average of 429.22 mm/month was obtained in 1988 while 381.20 mm/month was obtained in 2018. Least value of 112.85 mm was obtained in August 1988 while 96.07 mm was obtained in September 2018. Peak value of 788.95 mm was obtained in March 1988 and 663.17 mm was obtained in March 2018. The station experienced reduction in ET from 1988 to 2018 depicting a shift from solar maxima to solar minima.

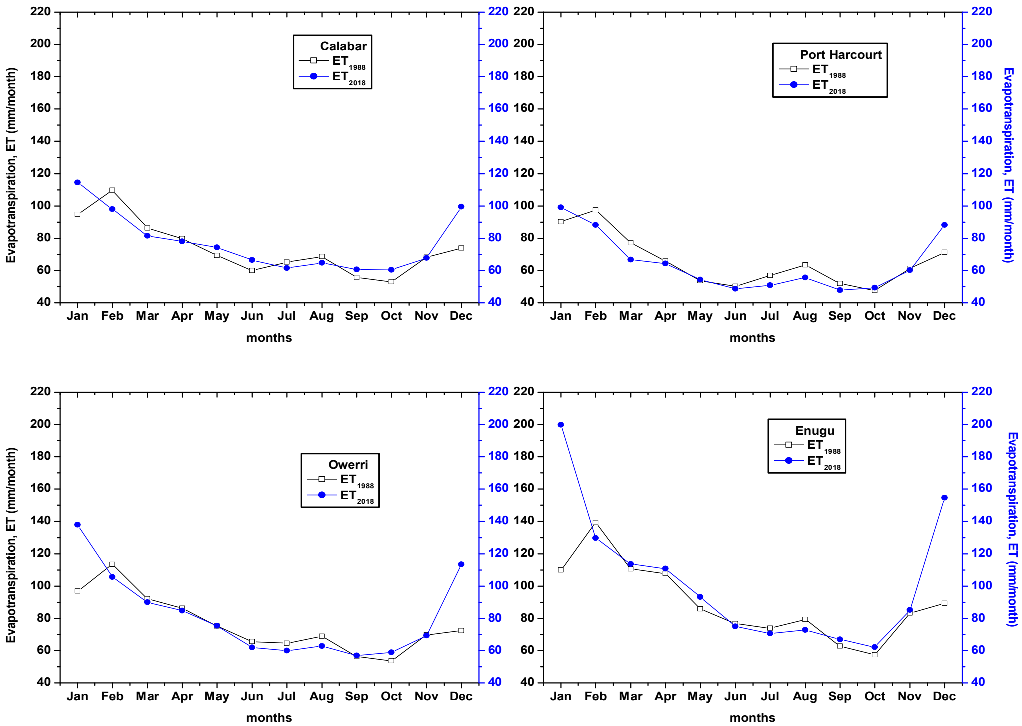

Fig. 2. Monthly ET patterns at Calabar, Port Harcourt, Owerri and Enugu

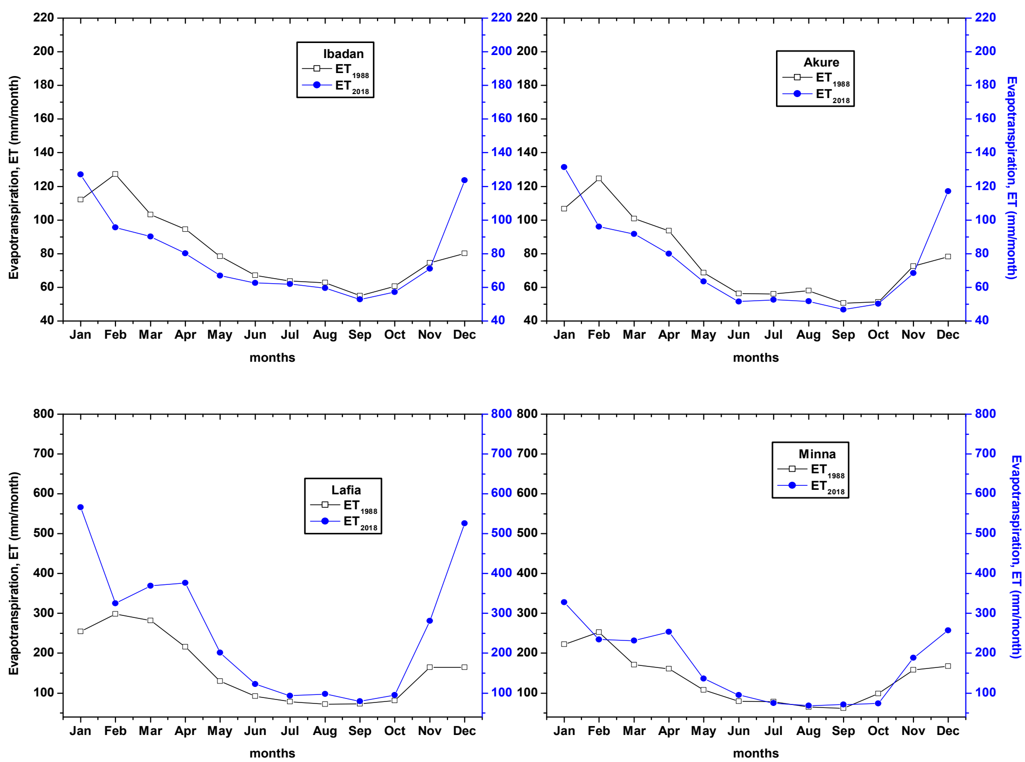

Fig. 3. Monthly ET patterns at Ibadan, Akure, Lafia and Minna

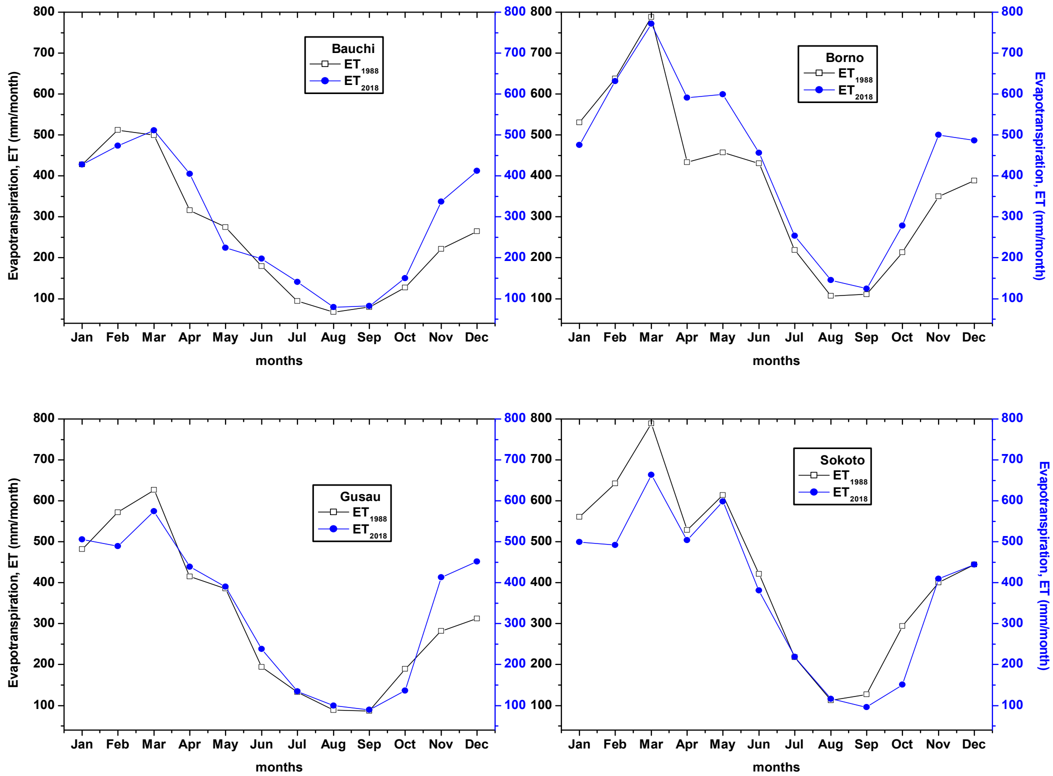

Fig. 4. Monthly ET patterns at Bauchi, Borno, Gusau and Sokoto

4.2 Variation of Rainfall Intensity with Et over Nigeria

Figs. 5 – 10 showed the monthly variation of rainfall intensity with ET over Nigeria for 1988 and 2018. The results showed, on monthly average, that ET reduced/increased as rainfall intensity increased/reduced at 5 stations namely Calabar, Akure, Lafia, Bauchi and Sokoto. Points of highest rainfall intensity almost corresponded to points of lowest ET. Peak of ET were mostly found between January and March corresponding to peak of dry season with little or no rainfall while lowest ET were found between August and October corresponding to peak of rainy season across Nigeria. 7 stations out of 12 were influenced by solar minima phenomenon and year 2018 being the fourth hottest year in the century. The station were Port Harcourt, Owerri, Enugu, Ibadan, Minna, Borno and Gusau. At the 7 stations, increase in rainfall intensity in 2018 compared with 1988 had no reduction on monthly average of ET.

In Fig. 5, the results from Calabar showed that monthly average of rainfall intensity was lower in 2018 than 1988 and the impact was seen in the ET values. Rainfall intensity was 365.53 mm/month and ET was 73.71 mm/month for 1988. Rainfall intensity was 354.95 mm/month and ET was 77.23 mm/month. Rainfall intensity reduced by 10.58 mm/month while ET increased by 3.52 mm/month. The results from Port Harcourt showed that the reduction in rainfall intensity for 2018 when compared with that of 1988 did not correspond to increase in ET which may be as a result of solar minima phenomenon. Rainfall intensity was 251.34 mm/month and ET was 65.57 mm/month for 1988. Rainfall intensity was 226.03 mm/month and ET was 64.44 mm/month. Rainfall intensity reduced by 25.31 mm/month and ET also reduced by 1.13 mm/month which was unusual.

In Fig. 6, results from Owerri and Enugu were shown. At Owerri, monthly average of rainfall intensity was 228.70 mm/month for 1988 with estimated ET monthly average of 76.24 mm/month. Rainfall intensity on monthly average was 249.58 mm/month with ET estimates of 81.39 mm/month for 2018. Rainfall intensity was higher in 2018 than 1988 by 20.88 mm/month while ET was higher in 2018 than 1988 by 5.15 mm/month. Increment in rainfall intensity on the average should have resulted in reduced ET for 2018 but this was not the pattern at Owerri due to impact of solar minima phenomenon. At Enugu, rainfall intensity was 179.18 mm/month on the average with ET estimates of 89.65 mm/month for 1988. Rainfall intensity was 223.35 mm/month with ET estimates of 102.86 mm/month for 2018. Influence of solar minima phenomenon was felt at Enugu as rainfall intensity increased on monthly average by 44.17 mm/month in 2018 with increase of 13.21 mm/month in ET estimates.

In Fig. 7, the results from Ibadan and Akure was plotted, at Ibadan, rainfall intensity was 170.43 mm/month with average ET estimates of 81.60 mm/month for 1988. Rainfall intensity was 165.78 mm/month with ET estimates of 79.09 mm/month. Rainfall intensity on monthly average was lower in 2018 than 1988 by 4.65 mm/month while ET was lower by 1.53. Lower rainfall intensity in 2018 should have led to increased ET in 2018, on the contrary, it was also affected by solar minima phenomenon. The situation at Akure was different from that of Port Harcourt, Owerri, Enugu and Ibadan. Rainfall intensity on monthly average was 163.88 mm/month with ET estimates of 76.45 mm/month for 1988. Rainfall intensity was 174.77 mm/month with ET estimates of 75.07 mm/month for 2018. Rainfall intensity increased by 10.89 mm/month from 1988 to 2018 while ET reduced by 1.38 mm/month for same period. ET trends at Akure was majorly influenced by rainfall intensity over solar cycle phenomenon.

In Fig. 8, results from Lafia and Minna were shown; at Lafia, ET patterns were influenced by rainfall intensity on monthly totals and averages. Rainfall intensity on monthly average was 112.44 mm/month with ET estimates of 158.94 mm/month for 1988. Rainfall intensity on monthly average was 107.34 mm/month while ET estimates was 261.90 mm/month for 2018. Rainfall intensity on monthly average was lower in 1988 on compared with 2018 by 5.10 mm/month while ET was higher in 2018 by 102.96 mm/month compared with 1988. At Minna, rainfall intensity on monthly average was 134.29 mm/month with ET estimates of 135.44 mm/month for 1988. Rainfall intensity on monthly average was 138.64 mm/month with ET estimates of 167.79 mm/month for 2018. Rainfall intensity was lower in 1988 by 4.35 mm/month compared with 2018 while ET was lower in 1988 by 32.35 mm/month compared with 2018.

In Fig. 9, results from Bauchi and Borno were presented; at Bauchi, monthly average of rainfall intensity was 87.55 mm/month with ET estimates of 255.21 mm/month for 1988. Monthly average of rainfall intensity was 54.66 mm/month with ET estimates of 286.72 mm/month. Rainfall intensity in 2018 was lower by 32.69 mm/month while ET in 2018 was higher by 31.51 mm/month. At Borno, monthly average of rainfall intensity was 36.48 mm/month with ET estimates of 388.81 mm/month for 1988. Monthly average of rainfall was 43.20 mm/month with ET estimates of 442.73 mm/month. Rainfall intensity on monthly average was higher in 2018 by 6.72 mm/month while ET was higher by 54.92 mm/month.

In Fig. 10, results from Gusau and Sokoto were presented. At Gusau, monthly average of rainfall intensity was 58.63 mm/month with ET estimates of 313.88 mm/month for 1988. Monthly average of rainfall intensity was 95.02 mm/month with ET estimates of 330.16 mm/month for 2018. Rainfall intensity on monthly average was higher in 2018 by 36.39 mm/month while ET was also higher in 2018 by 16.28 mm/month. At Sokoto, monthly average of rainfall intensity was 43.33 mm/month with ET estimates of 429.22 mm/month for 1988. Monthly average of rainfall intensity was 34.52 mm/month with ET estimates of 381.20 mm/month for 2018. Rainfall intensity on monthly average was lower in 2018 by 8.81 mm/month while ET estimate was lower in 2018 by 48.02 mm/month.

4.3 Correlation Coefficient of Rainfall Intensity with ET over Nigeria for 1988 and 2018

Table 2 presented the Pearson correlation coefficient of rainfall intensity with ET for 1988 and 2018 in 12 selected stations. The table showed the intercept for each station; intercept corresponds to the value of ET when rainfall in zero. A correlation coefficient equal to 1.0 is perfect correlation; 0.90 – 0.99 is very high; 0.70 – 0.89 is high; 0.50 – 0.69 is moderate; 0.30 – 0.49 is low; 0.10 – 0.20 is very low and 0 – 0.09 is negligible. Negative correlation and slope showed that rainfall intensity is inversely proportional to ET. Slope in the table corresponds to increment in value of ET per unit increase in rainfall intensity. This is the basis of the discussion of the results.

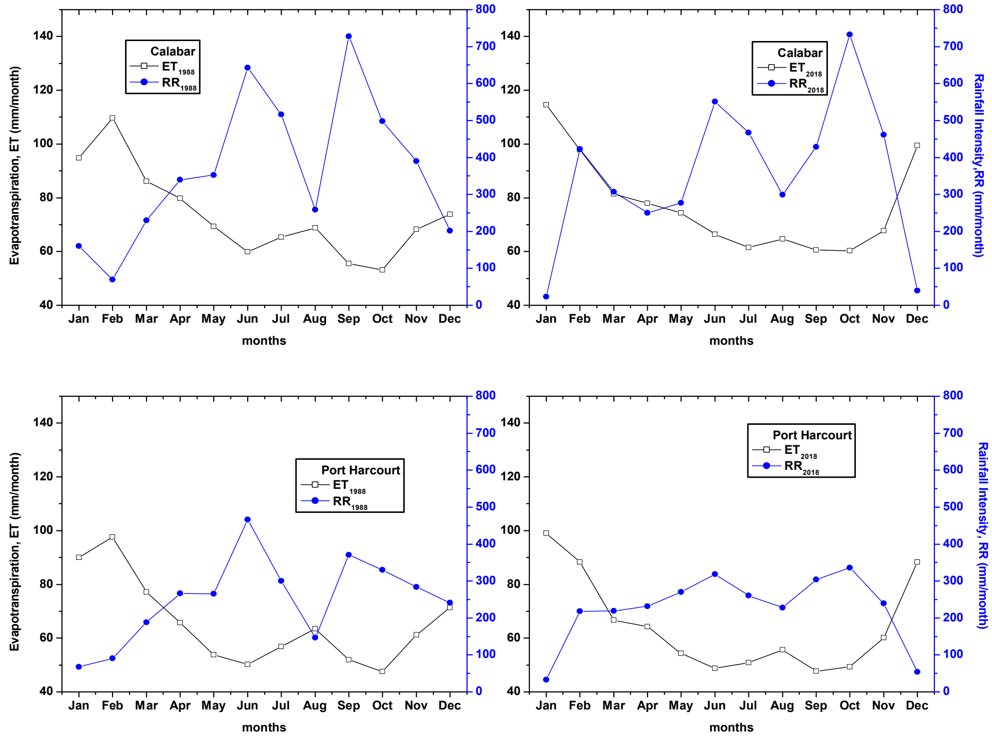

Fig. 5. Impacts of rainfall intensity on ET at Calabar and Port Harcourt

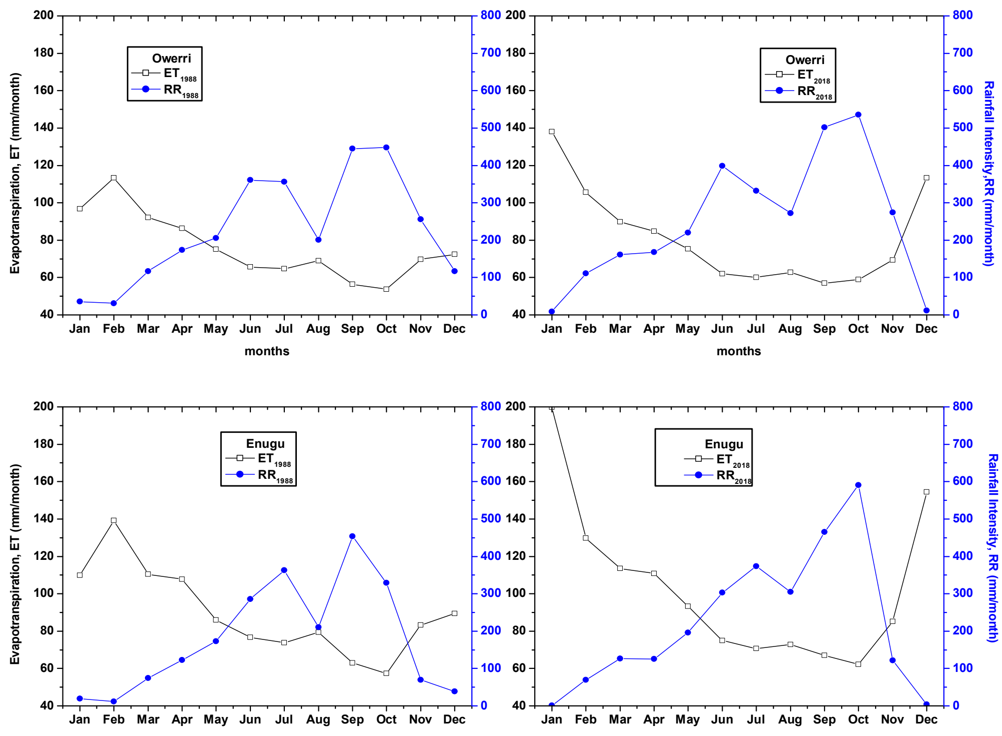

Fig. 6. Impacts of rainfall intensity on ET at Owerri and Enugu

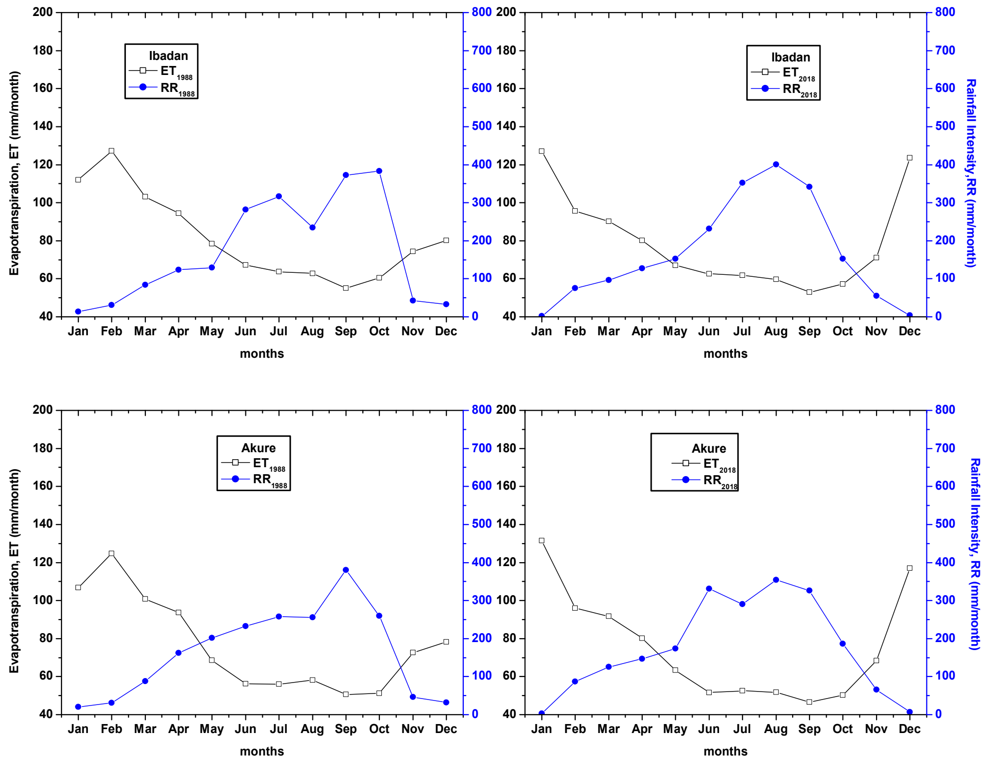

Fig. 7. Impacts of rainfall intensity on ET at Ibadan and Akure

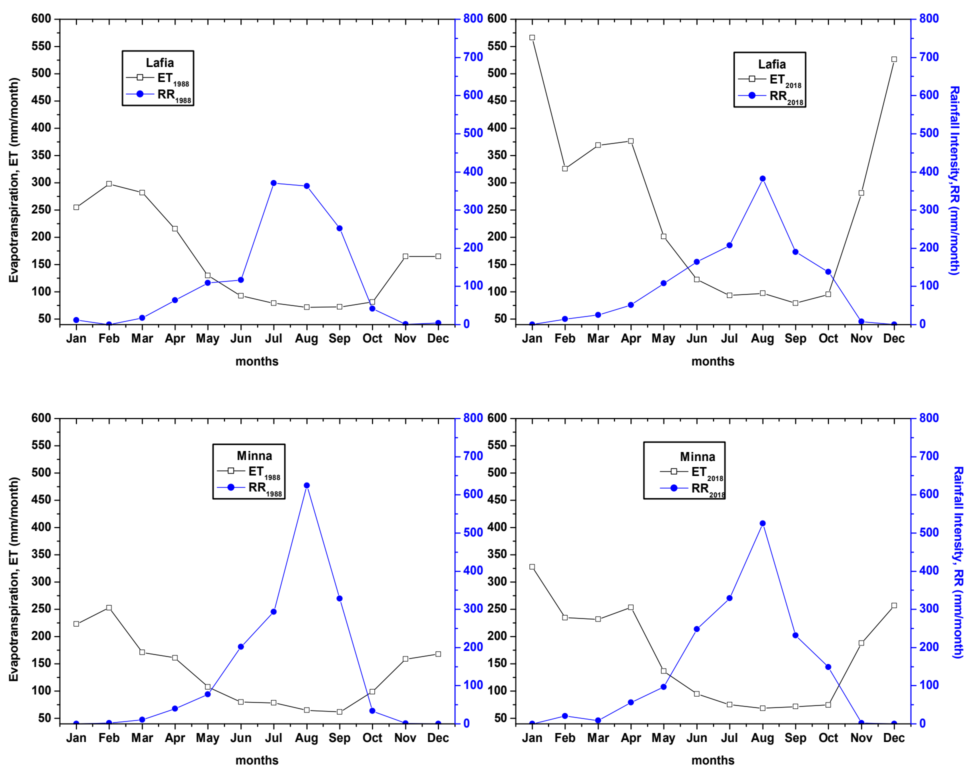

Fig. 8. Impacts of rainfall intensity on ET at Lafia and Minna

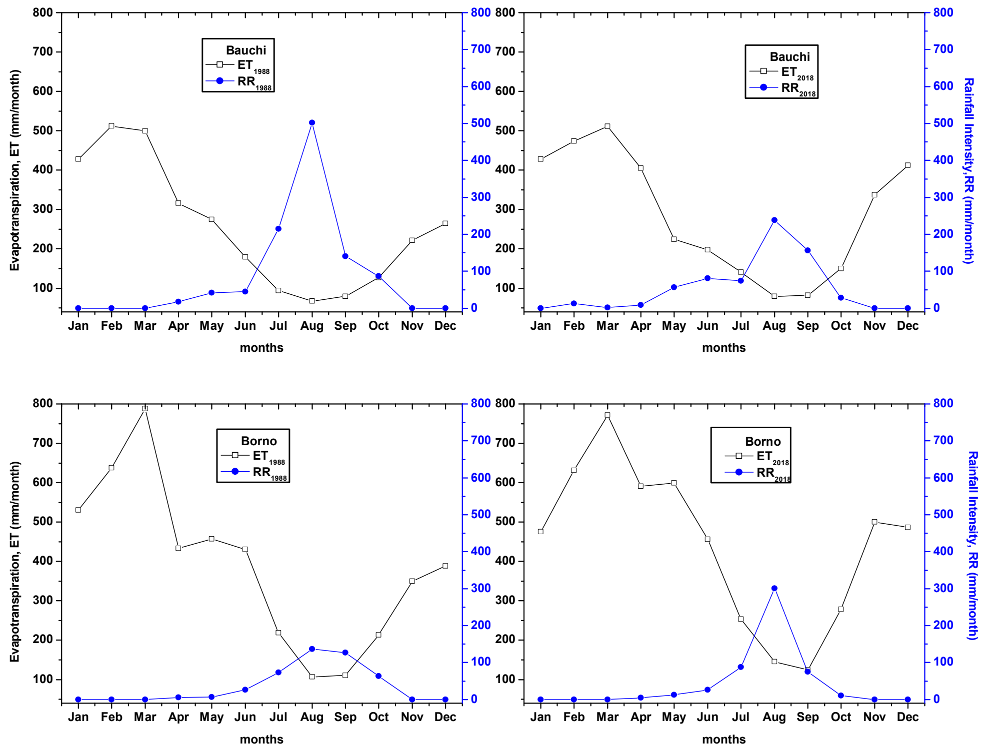

Fig. 9. Impacts of rainfall intensity on ET at Bauchi and Borno

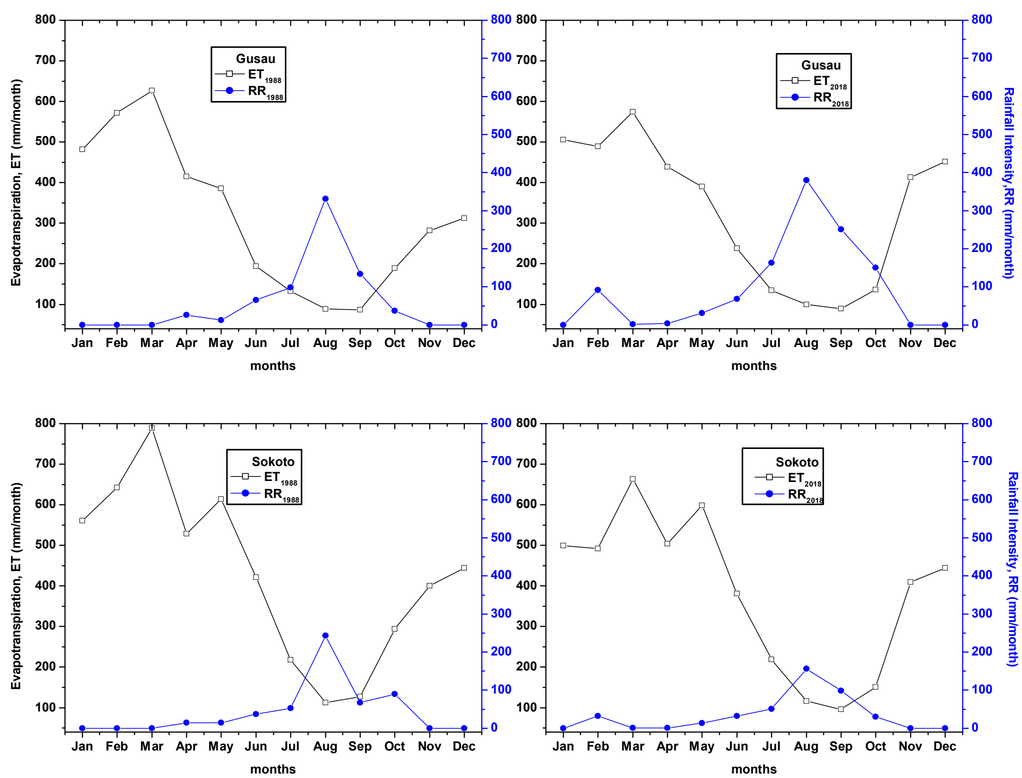

Fig. 10. Impacts of rainfall intensity on ET at Gusau and Sokoto

Table 2. Correlation Coefficient Parameters of Rainfall Intensity with ET for 1988 and 2018

Stations in Nigeria	1988			2018		
	Intercept	R-Square	Slope	Intercept	R-Square	Slope
Calabar	1116.47	-0.72	-10.19	1010.49	-0.57	-8.49
Port Harcourt	659.17	-0.74	-6.22	529.67	-0.80	-4.71
Owerri	793.43	-0.80	-7.41	729.13	-0.79	-5.89
Enugu	645.60	-0.65	-5.17	601.05	-0.67	-3.67
Ibadan	562.94	-0.62	-4.81	498.52	-0.61	-4.21
Akure	458.18	-0.64	-3.85	460.67	-0.74	-3.81
Lafia	292.36	-0.48	-1.13	244.82	-0.62	-0.53
Minna	436.84	-0.52	-2.23	379.43	-0.63	-1.44
Bauchi	241.61	-0.42	-0.60	162.32	-0.63	-0.38
Borno	115.67	-0.68	-0.20	170.12	-0.45	-0.29
Gusau	169.08	-0.45	-0.35	282.33	-0.69	-0.57
Sokoto	145.39	-0.52	-0.23	108.22	-0.59	-0.19

When rainfall intensity equals to zero, the value of ET shown by the intercept was lower in 2018 than 1988 at 9 stations namely Calabar, Port Harcourt, Owerri, Enugu, Ibadan, Lafia, Minna, Bauchi and Sokoto. This was attributable to the solar maxima phenomenon in 1988 and solar minima phenomenon in 2018. There were 3 stations with exception; at zero rainfall intensity, ET was marginally higher in 2018 by 2.51 mm at Akure, 54.45 mm at Borno and 113.25 mm at Gusau. At zero rainfall intensity, highest of ET would be expected at Calabar while the least intensity of ET would be expected at Borno and Sokoto.

Table 2 showed the correlation coefficient for all the 12 stations selected across Nigeria. In 1988, ET at Calabar, Port Harcourt and Owerri had high negative correlations with rainfall intensity as a result of intense warming due to oil exploration going on in the region. Moderate negative correlations were observed at Enugu, Ibadan, Akure, Minna, Borno, and Sokoto for 1988. Low negative correlations was observed at Lafia, Bauchi and Gusau. In 2018, Port Harcourt, Owerri and Akure had high negative correlations. Moderate negative correlations were observed at Calabar, Enugu, Ibadan, Lafia, Minna, Bauchi, Gusau and Sokoto. Low negative correlation was observed at Borno. Rainfall intensity had greater impacts on ET values in tropical monsoon (due to the cold wind from the ocean) effect than any other climatic zone in Nigeria.

5. CONCLUSION

Evapotranspiration (ET) patterns at 12 selected stations across Nigeria during solar maxima (1988) and solar minima (2018) phenomena were investigated in the study. Correlations of rainfall intensity with ET for 1988 and 2018 were also established and explained. ET was higher in 2018 than 1988 in 3 out of 4 stations in tropical monsoon; in tropical savannah, only Ibadan and Akure had reduction in ET values in 2018 compared with 1988. The remaining 3 stations namely Lafia, Minna and Bauchi almost had increase of 12%, 23% and 64% in ET in 2018 on compared with 1988. In hot semi-arid, 2 stations out of the 3 had increase in ET in 2018. Monthly average of ET reduced as rainfall intensity increased at 5 stations namely Calabar, Akure, Lafia, Bauchi and Sokoto. Points of highest rainfall intensity almost corresponded to points of lowest ET. Peak of ET were mostly found between January and March corresponding to peak of dry season with little or no rainfall while lowest ET were found between August and October corresponding to peak of rainy season across Nigeria. 10 stations out of 12 were influenced by solar cycle phenomenon except Borno and Gusau. The lowest value of ET was recorded at southern Calabar for 1988 and 2018 while the highest value of ET was observed at northern Borno for 1988 and Sokoto for 2018. This was influenced by cloud cover and rainfall intensities. Rainfall intensity and intense warming due to oil exploration had greater impacts on ET values in tropical monsoon than any other climatic zone in Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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