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Full Length Research Paper

Regional trend analysis of pan evaporation in Nigeria (1970 to 2000)

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The trends pan evaporation (PE) in 4 different climatic regions (Sahel, Midland, Guinea Savannah and Coastal/Tropical Rainforest) covering about 21 tropical stations in Nigeria (during the period 1970 to 2000) were investigated. The influence of meteorological variables, which have significant impact on the spatial and temporal trends of pan evaporation for three consecutive decades across the different regions in Nigeria was tested. Mann-kendal statistical test was carried out to investigate the trend. A decade to decade trend analysis was carried out for 3 consecutive decades over all the regions. A general decrease trend was observed in all the regions except Sahel region in the first decade under consideration. The decade (1970 to1979) coincided with the period when there was a global solar dimming. However, the rest decades witness an increase trend in pan evaporation for all the climatic regions across Nigeria. The general trend analysis of PE for Nigeria shows that about 80% of stations involved in the study experience increase trend (development of arid condition) out of which, only 50% were significant. The rest 20% exhibited decrease trend (creation of humid condition) with none significant. Further trend analysis was carried out on the various seasons and this revealed that all the wet season (April to October) exhibits downward trend for all the regions while similar trend regime was established for dry season months (December to March) in Sahel and Guinea Savannah and upward trend for midland and the coastal or tropical rainforest. Evidence of pan evaporation paradox was also established for certain period in Nigeria.

Key words: Pan evaporation, trend, potential evaporation, meteorological variables.

INTRODUCTION

In the last decades, both the local and global climate had undergone tremendous changes. This is not unconnected with the increased human activities on the environment ranging from deforestations to air pollution resulting from the fast growing industrial activities. In view of this all climate variables have equally undergone commensurate modification. The cumulative effect of the above is responsible for the increased concentration of greenhouse gases released into the atmosphere which is impacting the environment. Douville et al. (2001) observed that the mean average global temperature has increased by 0.6°C over that of the twentieth century. This was also supported by a study carried out by Loaiciga et al. (1996) that the global temperature will experience an upward trend staggering between 1 and 5°C by the middle of the twenty-first century. The global hydrological cycle is not left out in the global climatic changes because it had already been predicted (Loaiciga et al., 1996; Trenberth, 1998; Douvile et al., 2001) that there would be an intensified hydrological cycle in response to increasing trend in temperature. Evaporation is an important component of the hydrological cycle and has great effect on the water balance of the earth surface. Higher evaporation rate creates more arid environment while downward trend of evaporation results in a more humid environment. Pan evaporation (PE) is important because it gives useful clues to the direction of the change in actual evaporation.

This study aimed at the temporal and spatial characteristic trends of pan evaporation variations across the different climatic regions in Nigeria and further investigated the response of PE to weather meteorological variables. This is because of the global concern of climate change on the security of water supplies which have attracted a renewed interest in evaporation processes. Studies of evaporation trends from the many regions have been conducted and the conclusions vary. Increasing pan evaporation trends have been documented in Bet Dagan, Israel by Cohen et al. (2002), Balling and Brazel (1987) in Phoenix, Arizona and

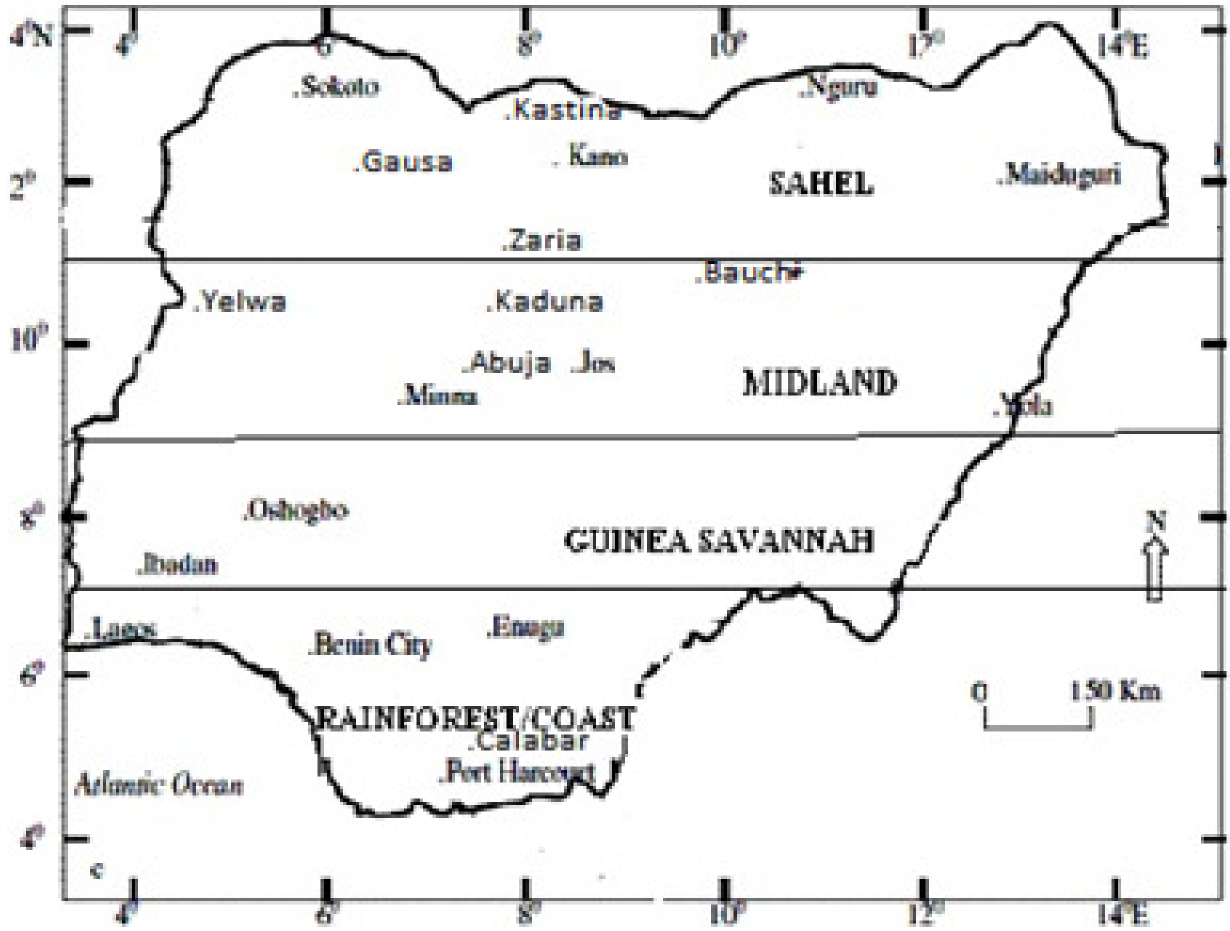

Figure 1. Map of Nigeria showing all the locations used in the study.

in northeast Brazil by da Silva (2003), also in West Africa by Oguntunde et al. (2006) and in Iran by Tabari and Marofi (2011).

However, decreasing trends of PE were reported by Roderick and Farquhar (2004) in Australia, Peterson et al. (1995) in the United States, the former Soviet Union, Europe and Siberia, by Chattopadhyay and Hulme (1996) in India.

SITE DESCRIPTION, DATA AND METHODS

Nigeria lies in the tropics, which is in the Northern Hemisphere within the latitudinal range from 4°N (the Coastal Region) to 13°N (Sahel) (Figure 1). The country can be divided into four climatic zones (in this study), namely: Coastal/Tropical Rainforest, Guinea Savannah, Midland and Sahel/Arid (Olaniran and Sumner, 1989). The coastal zone is dominated by tropical maritime (mT) round the year. The vegetation is characterized by tropical forest. The zone is found along the coast up to 100 to 150 km inland. The annual temperature ranges between 27 and 30°C. The relative humidity in the region is as high as 80% and characterized with over 300 cm of annual rainfall having double peaks of rainfall. They also have a long wet season typically 7 to10 months. The coastal zone is followed by Guinea Savannah zone which experiences the dominance of mT air for about seven months and tropical continental (cT) air for the remaining five months annually. The stations within this zone are found further inland after the coastal zone. The zone experiences longer temperature range, lower annual rainfall and shorter wet season of about 6 to 8 months than the coastal region and well marked dry season of 4 to 6 months. The region has a widespread of vegetation belt characterized by tall grasses and tall trees and has an annual rainfall of 100 to 200 cm having an annual relative humidity of 60%. The midland zone is dominated by a tropical continental air mass and is predominantly highlands and having a vegetation characterised by short grasses and scattered drought-resistant tree. Effectively, the topography is usually responsible for the usual long period of humid condition due to localized convection. Sahelian zone, a region where cT air mass predominates and the mT air mass invades for between 2 and 3 months at most because of its distance from the coastal environment. This zone embraces all stations in the north-eastern extremity of Nigeria. This type of climatic environment has a highly accentuated continentality with a wide annual and diurnal range of about 15 to 20°C. Dry season is excessively long, up to 8 to 10 months and desert-like conditions prevail. The mean monthly characteristic as it varies from region to region is shown in Table 1.

The climatic variables, such as air temperature, evaporation, windspeed and solar radiation exhibits decreasing tendency from the Sahel zone through the rest zones toward the coastal zones.

Table 1. Summary of site description and regional climatic characteristics.

Region/Stations	Latitude (north)	Longitude (east)	Regional mean monthly weather characteristics					
			Evaporation (ml/day)	Temperature (°C)	Wind speed (m/s)	Relative humidity (%)	Solar radiation (MJ/m^2/day)	Rainfall (mm)
Sahel								
Sokoto	13.00	5.25						
Katsina	13.00	7.67						
Kano	12.07	8.43	6.9	34.0	6.0	44.7	17.8	61.9
Zaria	11.13	7.63						
Maiduguri	11.91	13.17						
Nguru	12.91	5.30						
Gusau	12.00	6.65						
Midland								
Minna	9.62	6.53						
Abuja	9.17	7.17						
Jos	9.87	8.52						
Yola	9.23	12.47	6.5	33.6	4.7	50.6	16.8	79.7
Yelwa	10.88	4.75						
Kaduna	10.60	7.45						
Bauchi	10.32	9.18						
Guinea savannah								
Ibadan	7.43	3.90	5.6	32.6	4.5	62.7	15.1	98.4
Osogbo	7.73	4.48						
Coastal								
PortHarcourt	4.85	7.02						
Calabar	4.97	8.35						
Enugu	6.47	7.55	3.4	31.5	4.2	79.0	12.5	148.0
Benin	6.32	5.60						
Lagos (Ikeja)	6.58	3.33						

However, other variables such as rainfall and relative humidity diminish as the country is transversed from the coastal region towards the Sahel zone.

Altogether, 21 stations fairly distributed into all the zones (except guinea savannah) were involved. These stations were selected based on the availability of sufficient data of the required meteorological variables for this study (Table 1). The meteorology variables used for the investigation include: pan evaporation from class A, relative humidity, air temperature (average of the minimum and maximum temperature), windspeed and rainfall. Daily data of the above-named weather variables were collected from the archives of the Nigerian Meteorological Agency (NIMET) whose headquarter is based in Oshodi, Nigeria. The data collected were processed into monthly and annual mean values for all the stations. The integrity of the data was determined by collating the data from each of the data source and checking for inconsistencies and gaps. Gaps in the records were filled with monthly mean values computed for each station and for each variable.

The trend analysis was carried out using Mann-Kendal statistics. This statistical trend test had been used by other researchers or scientists in various similar investigations (Hirsch et al., 1982; Gan and Kwong, 1992; Olaniran and Sumner, 1989; Ogolo and Adeyemi, 2009) and had been found to be an effective tool for spotting or recognising trends in hydrological and other allied variables. According to Michael T. (2001), Mann-Kendall statistics is given by Equation (1):

$$S = \sum_{k=1}^{n=1} \sum_{j-k+1}^{n} sgn(x_j - x_k) \qquad (1)$$

Where n is the length of the time series xi...xn, and sign (.) is the sign function.

The second term in Equation 1 above represents an adjustment for tied or censored data. Mann-Kendall test statistic is non-dimensional, which is to say that it does not offer any quantification of the scale of the trend in the units of the time series under study, but is rather a measure of the correlation of *xi* with time and, as such, simply offers information as to the direction and a measure of the significance of observed trends.

RESULTS AND DISCUSSION

The long-term variations and trends in annual mean of pan evaporation and the associated weather parameters are shown in the time series plots for each region and the results of the statistical tests which were applied to both the regional and the individual station (Figures 2, 3 and 4).

Figure 2 is the plot for the mean monthly variation of the major meteorological variables for the four climatic regions. Bimodal of air temperature was observed for the regions. The first peak occurred between March and April (the peak of dry season and the transition period from dry season into wet season in Nigeria) while the second peak was in November (the early onset of dry season and transition into the harmattan period). The variation is higher in the Sahel region than the rest regions. It was also observed from Figure 2b that the variation of relative humidity reflects unimodal which occurred in August with the highest variation in the coastal and rainforest region. Figure 2c is the seasonal variation of solar radiation. Here, the trend of variation is similar to air temperature in terms of numbers of peaks and time of occurrence. Again, the highest variation as observed from the figure occurred in Sahel region with the least occurrence in the coastal and rainforest. This trend follows the condition of the sky which is predominantly clear in the Sahel region and cloudy in the rainforest and coastal. The regime of the seasonal variation of windspeed for all the regions is shown in Figure 2d. The peak values of windspeed for all except Sahel occurred between March and April while the peak for Sahel was in June and it exceeds the rest regions.

The monthly variation of pan evaporation is shown in Figure 3. The variation of PE exhibits one peak for all the 4 regions, which occurred in February. The variation is large for Sahel and least for the coastal environment.

The Sahel, midland, Guinea Savannah and the coastal to tropical rainforest regions respectively. The PE trend across the 4 regions under consideration exhibits an increasing trend. This is further corroborated by the results of trend comparison given in Table 2. The observed increasing trend as seen on the table was found to be significant at 90% confidence level in Sahel and Midland regions including the cumulative trend for Nigeria (see Table 2) while the trend in the rest regions (that is, Guinea Savannah and the Coastal/Tropical Rainforest regions) are not quite significant. The implication of this observation suggests the increase in aridity in substantial part of the country particularly in the Sahel and the Midland regions where the PE trend exhibits significant increase. In addition, the result shows that the annual trend of pan evaporation is larger in Sahel than the rest region. It has the highest percentage annual increase of 19.3% (Table 2). This may due to the largest receipt of solar irradiance in the Sahel because of its closeness to the desert and the prevalent clear-sky condition compared with the rest regions under consideration. In addition, the highest windspeed is also obtainable in this region which is another factor that promotes rate of evaporation.

Data from twenty one evaporation pans positioned at different climatic stations covering all the regions across Nigeria were utilised for this study. Results of the analysis of trend (Table 2), show that, out of the 21 stations, only 20% of them exhibits a non-significant decreasing trend while 80% stations were characterized with increasing trend, of which 50% of them were significant between 90% and 95% level of confidence. The implication of this result is that there is widespread of aridity in Nigeria. However, the above result does not agree with the decreasing trend widely reported in literatures (Golubev et al., 2001; Huntington, 2006; Liu et al., 2004; Roderick and Farquahar, 2005).

Table 3 is the result of the Mann-Kendall non-parametric test for regional trend analysis of PE across Nigeria (Mann, 1945; Kendall, 1975). Here, the test had been applied to investigate the regional trend of PE and allied meteorological variables for three consecutive decades, namely: 1970 to 1979, 1980 to 1989 and 1990 to 2002. From the table, the decennial trend analysis of pan evaporation (PE) in all the regions with the exception of the Sahel exhibit decreasing trend and the decrease is significant in midland and Guinea Savannah region at 95% level of confidence but not in the coastal to rainforest. This result is consistent with literatures which confirmed global decline in the evolution of pan evaporation

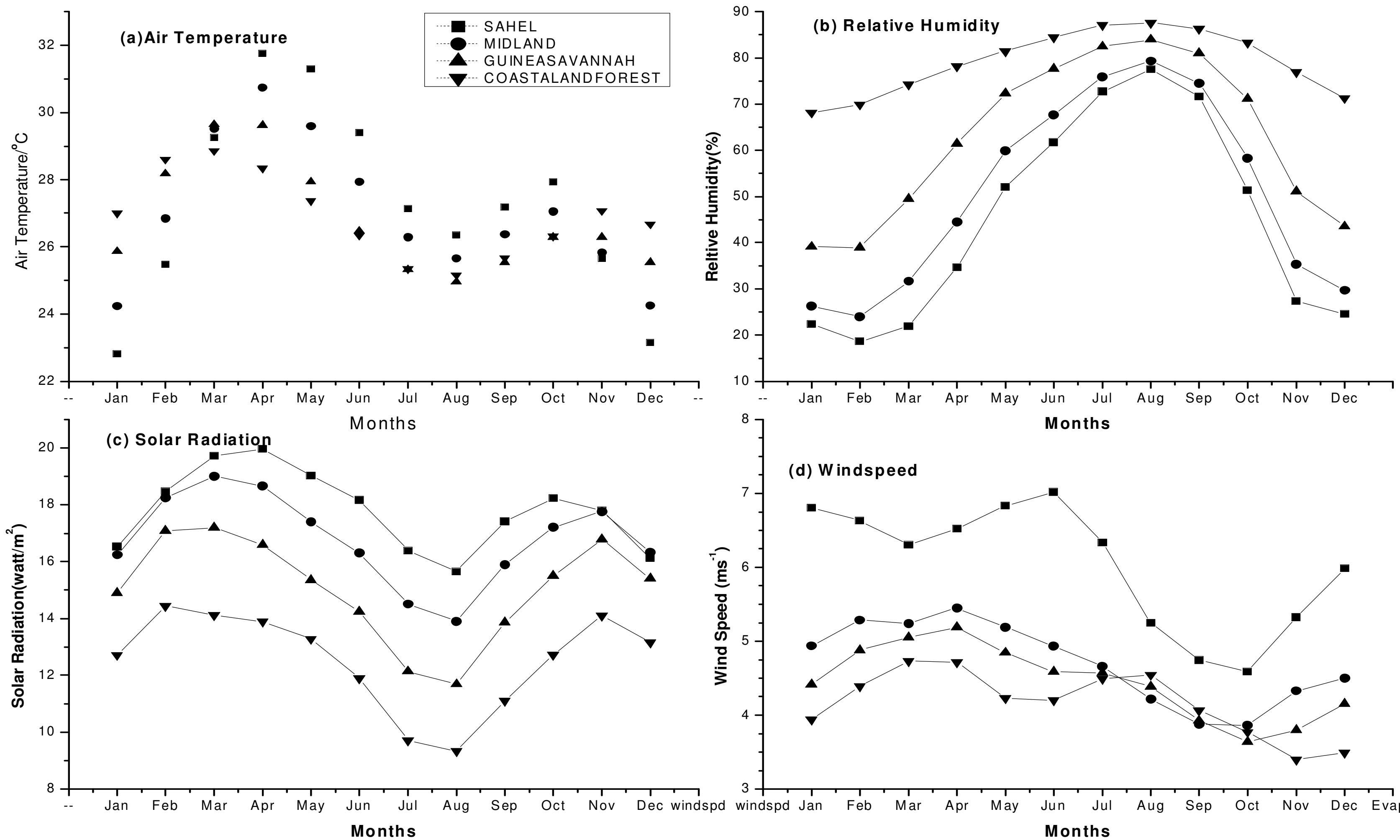

Figure 2. Mean monthly variations of the major meteorological variables (a) air temperature (b) relative humility (c) solar radiation and (d) windspeed.

within the period under consideration (1970 to 1979). The observed decrease may be attributed to decrease in solar radiation (Liepert et al., 2004) or changes in wind speed (Rayner, 2007). In addition, the results on Table 3 shows that only air temperature and solar radiation exhibit similar trend with PE indicating that the rest allied meteorological variables may not have any significant contribution to the PE downward trend which was observed between 1970 and 1979. During the period of 1970s to the mid 1980s, global dimming was widely reported particularly in the Northern

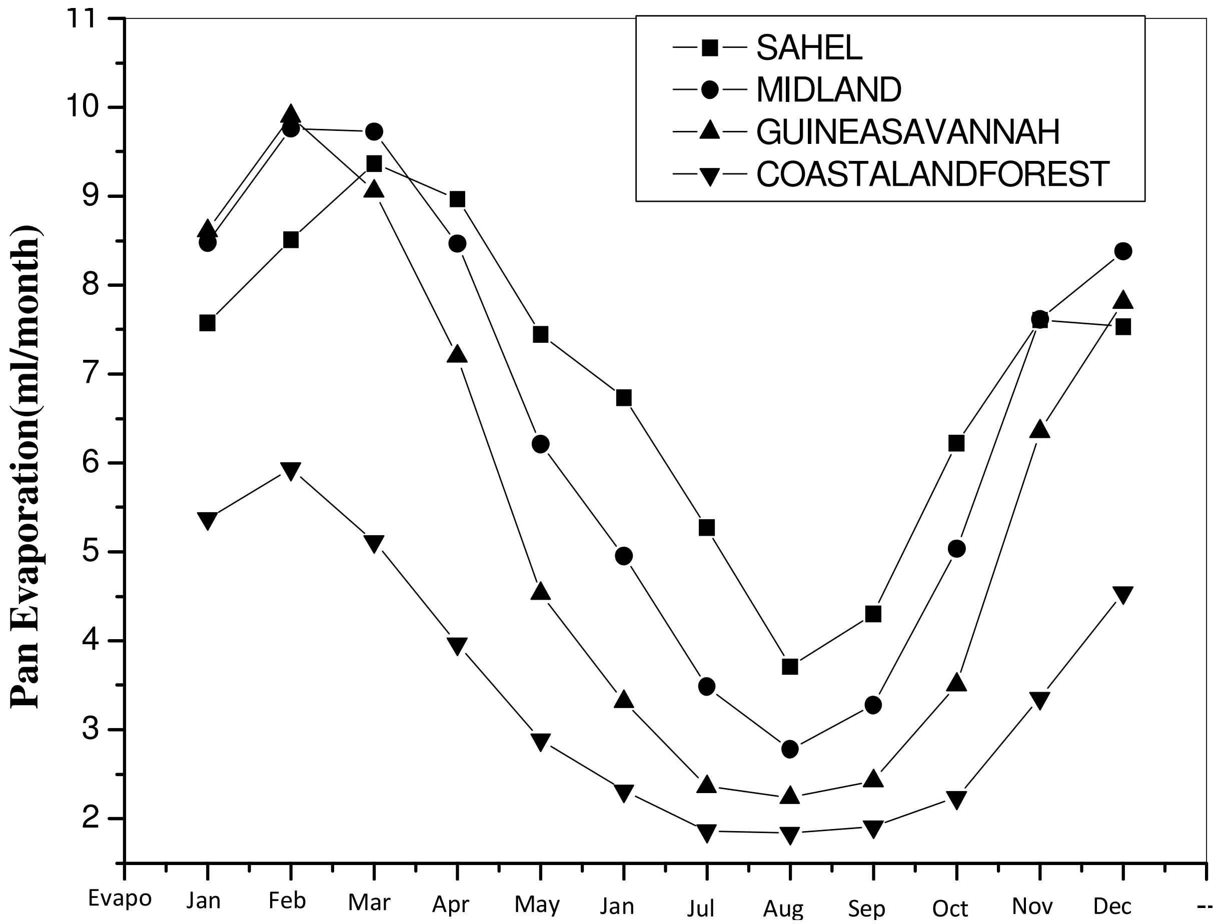

Figure 3. Variation of pan evaporation for all the four zones in Nigeria.

Hemisphere which was later followed by a period of solar brightening from the mid 1980s. Possible explanation was partly due to the observed increase in the cloud cover (decrease in the sunshine hours) which may result to more scattering and reflection of incoming solar radiation (Johnson and Sharm, 2007).

However, Norris and Wild (2007) objected to the above assumption and suggested that the changes in the concentrations of anthropogenic aerosols may be responsible for the observed 'global solar dimming' which was assumed to be strongly responsible for the global downward trend in PE during the decade under consideration.

However, the regional trend of PE reverses to upward trend in the next decade (1980 to 1989), though not significant in all the regions. Contrary to the previous decade (discussed above), an increasing trend was observed also for solar radiation for all the regions and only significant at 95% confidence level in midland and guinea savannah. In the same manner, the windspeed exhibits an increasing tendency and only significant in the Sahel region. Generally, there was a downward trend in the relative humidity, though not significant in any of the regions during the period under consideration. Changes in humidity and solar radiation regime was observed by Roderick and Farquhar (2004) had been found to have a strong influence on the rate of pan evaporation and this explains the reasons for the upward trend of PE observed during this period. The increase in the solar radiation played a positive effect on the observed upward regional trend in pan evaporation and the effect is quite significant in Guinea Savannah and coastal or tropical rainforest.

Also, the increasing trend of windspeed have a positive effect on the PE increase in only two regions (Table 3) and the impact is significantly stronger in the Sahel while the effect is negative on PE increase in the rest regions(Midland and Guinea Savannah) as the windspeed decreases. The downward trend in RH favoured the increase in the upward trend in PE in all the regions but not significant.

The upward trend of PE continues into the third decade, that is, 1990 to 2000 (Figure 4 and Table 3), though the observed trend is not significant in any of the region. Also, similar increasing trend was observed for air temperature, windspeed, relative humidity and a downward trend in solar radiation. The decreasing trend in the

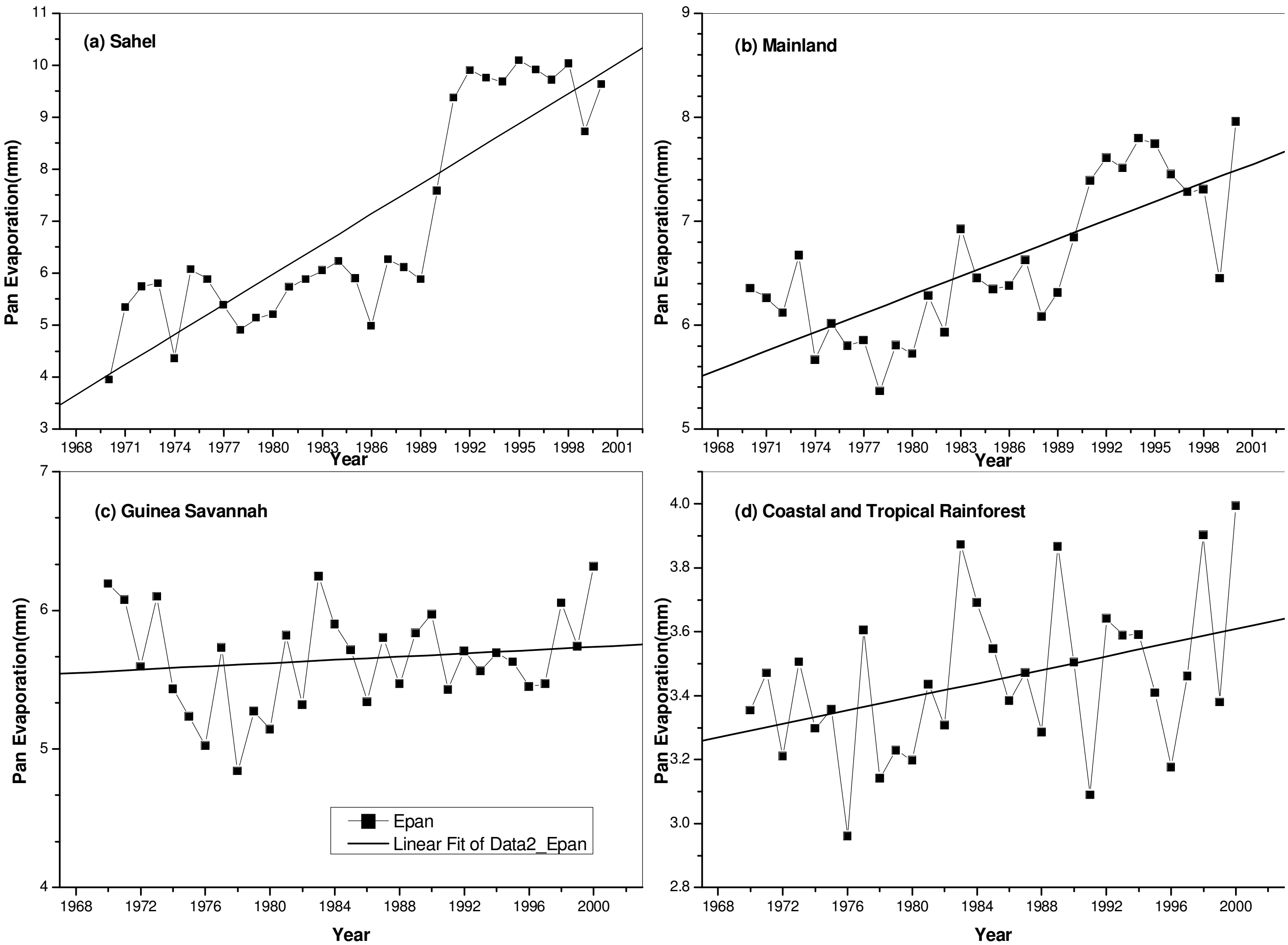

Figure 4. Trends of mean annual of pan evaporation for three decades in (a) Sahel (b) midland (c) guinea savannah and (4) coastal and tropical rainforest in Nigeria.

solar radiation played a negative effect on the PE increase in all the regions except Sahel. While RH increase has a positive effect on the increasing trend in PE in all the regions but have more significant effect in the midland. In addition, the observed increasing trend in the air temperature in all the regions (except Sahel Region) was also found to have a non-significant positive effect on the PE increase. On the contrary, this trend in the air temperature produces a negative effect on PE increase in Sahel.

The effects of greenhouse warming is obvious with the aforementioned trend regime of the meteorological variables, which increased greenhouse gases and enhance the heat trapping capacity of the atmosphere that contributed partly to the observed earth rising air temperature and the revolution in global cycle observed in the last hundred years. Hall and Manabe (2000) suggested that the intensity of global hydrological cycle is enhanced when water vapour anomalies are allowed to affect the longwave radiation calculation. This is because the observed increase in relative humidity (evidence of large water vapour in the atmosphere) and some other related greenhouse gases act as a cap for lower atmospheric boundary layer; this prevents the escape of the longwave radiation and which consequently increased the air temperature of the lower atmosphere in spite of the significant decrease in solar radiation.

The regime of trend of pan evaporation across Nigeria in the three decades is also shown in Table 3. In the first decade, there was a simultaneous decreasing trend in pan evaporation and solar radiation including air temperature with decrease in RH. On the contrary, the whole country witnessed an upward trend both in solar radiation and PE in the second decade under consideration with a decrease in RH and windspeed. This trend extends into the third decade except that solar radiation

Table 2. Trend comparisons of all the meteorological parameters and the pan evaporation for all stations, regions and Nigeria as a whole using linear trend analysis.

Meteorological parameter	Evaporation trend (ml/yr)	Relative humidity trend (%/yr)	Air temperature trend (°C/Year)	Solar radiation trend (Mjm^2/yr)	Wind speed trend (ms^{-1}/yr)
Sahel	0.19314±0.021**	0.04793±0.042	0.00537±0.007	0.00363±0.024	0.03415±0.00892*
Midland	0.05985±0.010**	0.15747±0.038*	0.01156±0.006	-0.0078±0.023	-0.0173±0.00488**
Guinea Savannah	0.00592±0.008	0.04304±0.034	0.00743±0.006	-0.02003±0.031	0.0009±0.00557
Coastal and tropical rain forest	0.01059±0.005	-0.05814±0.028	0.01627±0.005*	-0.1254±0.037**	0.00198±0.00455
Overall	0.06730.0081**	0.04757 0.03083	0.01016 0.00566	-0.0374 0.02242	0.00447 0.0034
Yelwa	0.35647±0.047**	0.126±0.029**	0.02734±0.010	None	-0.04505±0.01362*
Sokoto	0.19452±0.027**	-0.00695±0.071	0.01051±0.010	0.03299±0.015	-0.00677±0.02227
Gussau	0.40411±0.066**	0.3583±0.044**	-0.00181±0.010	None	0.03046±0.01569
Kaduna	0.18633±0.040**	0.193±0.025**	0.03662±0.010**	None	-0.0126±0.00978
Katsina	0.21632±0.054*	0.3961±0.062**	0.01378±0.011	None	0.10387±0.03888
Kano	0.0658±0.025	0.191±0.037**	0.00657±0.0123	-0.0026±0.016	0.1493±0.02638**
Nguru	0.07775±0.025*	0.230±0.049**	0.00507±0.014	-0.00175±0.035	-0.03774±0.0262
Maiduguri	0.06519±0.023	0.0567±0.023(ns)	-0.00165±0.010	0.01507±0.057	-0.03184±0.017
Bauchi	-0.0218±0.022	0.0879±0.023**	0.01348±0.012	None	None
Bida	-0.06865±0.028	0.068±0.022*	-0.03431±0.021	None	0.11271±0.019**
Minna	-0.05007±0.019	-.0180±0.021(ns)	0.02476±0.008*	0.02912±0.015	-0.02438±0.008*
Abuja	0.00651±0.013	-0.049±0.028(ns)	None	None	0.15356±0.018**
Jos	-0.01294±0.009	-0.045±0.018(ns)	0.01569±0.010	0.13961±0.017**	-0.10088±0.050
Yola	0.00711±0.008	0.0118±0.013(ns)	0.00884±0.012	0.10057±0.017**	0.08684±0.015**
Ibadan	0.03098±0.006**	-.0057±0.008(ns)	0.03657±0.010*	0.05725±0.017**	-0.1704±0.0228**
Osogbo	0.01203±0.006	0.00866±0.007	0.01325±0.009	0.05725±0.0175	-0.01894±0.016
Ikeja	0.00749±0.005	0.03357±0.006*	0.01917±0.008	0.05093±0.022	0.02545±0.007**
Benin	0.00223±0.010	0.01707±0.006*	0.02691±0.008**	0.18404±0.043**	-0.02195±0.014
PH	0.02108±0.004**	0.00906±0.004	0.02432±0.008*	0.15242±0.033**	-0.04467±0.0143**
Enugu	0.00337±0.009	0.00337±0.009	0.01207±0.007	-0.01894±0.0100	0.00618±0.015
Calabar	0.01976±0.004	0.01976±0.004	0.02422±0.007**	None	0.07439±0.014**

and windspeed exhibit a decreasing trend.

Table 4 depicts the comparative study of trend analysis of PE for each month for different regions in Nigeria. Two major seasons are identified in Nigeria namely: dry and wet seasons. The dry season spans from November to March (five months) while the wet seasons occurred in the months of April to October (seven months) annually. The occurrences of dry and wet seasons for any given location to region in such monsoon controlled climate follow the oscillatory movement of the international convergence zone (ITCZ), which is the imaginary boundary region between the SW moisture laden trade wind from the ocean and the NE dust laden trade wind from the Sahara (Ogolo and Adeyemi, 2009). From the table, it is observed that all the regions experienced a decreasing trend in PE from January to May. This is terminated in June by the onset of high precipitation during the wet season and continued till August for almost all the regions. At the onset

Table 3. Decennial trends analysis of PE and meteorological variables in Nigeria for three decades.

Regions/duration	PE trend (ml)	Air temperature (°C)	Rainfall (mm)	RH (%)	Shortwave radiation (watt/m²)	Windspeed (m/s)
1970 to1979						
Sahel	+ve	+ve	+ve	+ve	+ve (*)	-ve
Midland	-ve(*)	-ve	+ve	+ve	+ve	+ve
Guinea Savannah	-ve(*)	-ve	+ve	+ve	-ve	+ve
Coastal and tropical rainforest	-ve	-ve	+ve	+ve	-ve	+ve
Overall	-ve	-ve	+ve	+ve	-ve	+ve
1980 to 1989						
Sahel	+ve	+ve	-ve	-ve	+ve	-ve
Midland	+ve	+ve	+ve	-ve	+ve(**)	-ve
Guinea Savannah	+ve	+ve	-ve	-ve	+ve(**)	+ve
Coastal and tropical rainforest	+ve	+ve	-ve	-ve	+ve(**)	+ve
Overall	+ve	+ve	-ve	-ve	+ve	-ve
1990 to 2000						
Sahel	-ve	+ve	+ve	+ve	-ve(*)	-ve
Midland	+ve	+ve	+ve(*)	+ve(**)	-ve(*)	+ve
Guinea Savannah	+ve	+ve	+ve	+ve	-ve	+ve
Coastal and tropical rainforest	+ve	+ve	-ve	+ve	-ve	+ve(*)
Overall	+ve	+ve	+ve	-ve	-ve	+ve

+ve represents increasing trend, –ve stand for decreasing trend, (*) and (**), respectively denote 95 and 90% significant level of confidence.

Table 4. Results of mann-kendall statistical test of the seasonal trend of PE across regions in Nigeria.

Months	Sahel	Midland	Guinea savannah	Coastal and tropical rainforest	Overall
January	+ve(**)	+ve(**)	+ve	+ve	+ve(**)
February	+ve(**)	+ve(**)	+ve	+ve (**)	+ve(**)
March	+ve(**)	+ve (**)	+ve	+ve	+ve(*)
April	+ve(**)	+ve (**)	+ve	+ve	+ve(*)
May	+ve	-ve	-ve	+ve	+ve
June	-ve	-ve	-ve	+ve	-ve
July	-ve	-ve	-ve	-ve	-ve
August	-ve	-ve(**)	-ve	-ve	-ve
September	+ve	+via(*)	+ve	+ve	+ve
October	+ve	+ve	+ve(*)	+ve(*)	+ve(*)
November	+ve (*)	+ve(*)	+ve	+ve	+ve(*)
December	+ve (**)	+ve (*)	+ve	+ve (*)	+ve(*)

+ve represents increasing trend, –ve stand for decreasing trend, (*) and (**) respectively denote 95% and 90% significant level of confidence.

of dry season, an increasing trend of PE which was earlier observed continued from September to December. For Sahel and midland, the trend was significant at 90% level of confidence in January-April and significant at 95% level of confidence in November to December. The coastal region which experienced rainfall throughout the year also had significant increase in October to December.

Generally, it is observed that all the regions experienced increasing trend in PE during the dry season and decreasing trend during the wet season periods. This is because the environmental conditions depicted by the

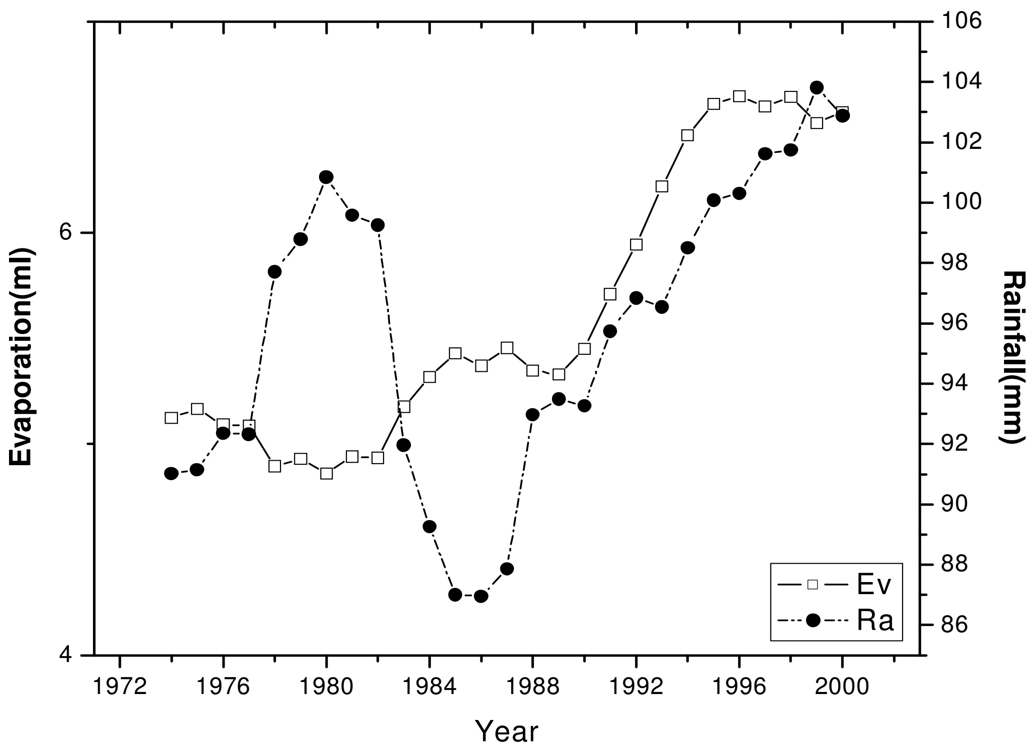

Figure 5. Overall time distribution of a 5 year moving average of pan evaporation and rainfall in Nigeria (1970 to 2002).

seasonal variation of insolation, windspeed and relative humidity strongly agree with the observed seasonal trends analysis of PE for the regions. For instance, the condition of high insolation, strong windspeed, low vapour pressure deficit (VPD) and high ambient temperature during the dry season provide good condition for high PE. On the contrary, during the wet season, low PE is prevalent in a condition of low solar irradiance, low windspeed, high VPD and low temperature. The above trend analysis is also observed for Nigeria as a whole (Table 4), irrespective of the different climates.

Figure 5 depicts the year to year variability of PE and rainfall for Nigeria, spanning three decades. During the period intervals 1973 to 1982 and 1983 to 1988, there was a sharp contrast between the observed and the expected in the trend of pan evaporation and rainfall including other meteorological variables. This contrast that posed a question on 'how can evaporative demand decline if the average air temperature is increasing' was strange and scientists named it 'pan evaporation paradox'. The concept of pan evaporation paradox was not accepted by scientists (Brutsaert and Parlange, 1998; Roderick and Farquhar, 2002) as there was no any scientific fact to explain this unusual occurrence.

Graham et al. (2004) argued that pan evaporation is not directly sensitive to changes in average air temperature. The physics of evaporation shows that the evaporative demand of the atmosphere is directly dependent on the net radiation (which is dependent on solar radiation), vapour pressure deficit (VPD) and windspeed. This concept of evaporation paradox makes it pretty difficult to explain the trend of hydrological cycle. The first interval named above was characterised with upward trend in rainfall, temperature, relative humidity and a downward trend in pan evaporation and solar radiation, respectively. The decrease in pan evaporation could be explained by the downward trend in solar radiation (called global solar dimming which characterised the period of investigation). The upward trend in relative humidity is another potent factor that can produce positive impact on the observed trend. This is because the increase in the relative humidity is an indication of the presence of water in the atmosphere and consequently, the tendency for more water to escape into the atmosphere through evaporation becomes slim. The implication of this observation is that the volume of water that enters the ground is greater than what goes back into the atmosphere.

In addition, large concentration of water in the atmosphere is a further indication of strong possibility of rainfall; hence the upward trend in rainfall during the period. The inverse trend observed between PE and rainfall was an indication of occurrence of flood during the period under investigation. Coincidentally, the largest city in Africa (Ibadan) was among other places that experienced flood in 1980. A major river called 'Ogunpa' in the city overflowed its bank and resulted to flood that destroyed lives and properties. The second time segment during the period under investigation gave a reversal trend between pan evaporation and rainfall including the allied meteorological variables. In this case, there was a synchronised upward trend between pan evaporation and solar radiation. This period too, is an indication of drought-cum- overall reduction in aridity because the regime of the trend between rainfall and pan evaporation shows that more volumes of water escaped (through evaporation) from the earth surface than it is being replenished (through rainfall) from the atmosphere.

Conclusion

A study was carried out on the trend of pan evaporation in 4 different climatic regions covering about 21 tropical stations in Nigeria. The influence of the change in some meteorological variables on the observed trend in PE was also investigated. An upward trend of PE was established for all the regions. This trend was found to be significant at both the Sahel and the midland regions.

About 80% of all the tropical stations involved in the study exhibited upward trend out of which 50% were significant. The rest 20% experienced downward trend with none significant. This shows that there is an increase of aridity experienced in larger part of Nigeria.

Decennial trend analysis for three decades (1970 to 2002) for all the regions was carried out. There was a general downward trend observed for all the regions in the first decade (1970-1979). This occurrence was coincidental with the widely reported global solar dimming. However, an upward trend of PE was observed for the rest two respective decades for all the regions including the average trends for Nigeria.

On the seasonal trend analysis, all the wet season months including the analysis for the whole country, experienced a downward trend which suggest the prevalence of humid condition in the region under consideration during the wet season. For the dry season period, Sahel, Guinea Savannah and the whole country also exhibit similar trend except midland and the coastal or tropical rainforest which experience arid condition.

Finally, 'pan evaporation paradox' was found from the average trend analysis for Nigeria between 1973 to 1983.

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