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ABSTRACT: The importance of adequate analysis of climatological data cannot be overemphasized as it helps in making vital decision relevant to agricultural practices. Thus, this study gave an overview on nonparametric trend technique for determination of the onset and cessation of rainfall changes over agroecological zones. The rainfall analysis technique reviewed in this study is useful for making decisions at the farm and regional levels and for establishing agroclimatic maps and models for any nation. The study helped to provide baseline information needed for accurate agroclimatic (rainfall) data analysis to enhance agriculture and therefore help farmers in proper planning before and during the growing seasons.

KEYWORDS: Onset, cessation, rainfall, techniques, growing seasons

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Introduction

Weather and climate change

Weather is the day-to-day state of the atmosphere and is a chaotic nonlinear dynamic system. The average state of weather is fairly stable and predictable. Climate includes the average temperature, the amount of precipitation, day of sunlight, and other variables that might be measured at any given site. This makes it possible to predict futuristically. However, if this climate changes and the changes occur with humans uninformed, it creates a huge problem in decision making and affects agricultural production. This includes any long-term significant change in the average weather that a given region experiences. Average weather may include average temperature, precipitation, and wind patterns. It involves changes in the variability or average state of the temperature over durations ranging from decades to millions of years. These changes can be caused by dynamic processes on earth, external forces including variations in sunlight intensity, and more recently by human activities. The Intergovernmental Panel on Climate Change (IPCC) defines extreme weather event as an event that is rare within its statistical reference distribution at a particular place.[1] The IPCC predicts that the temperatures are probably going to increase by 1.8°C to 4°C (3.2°F-7.2°F) by the end of the century. It is also projected that sea levels are most likely to rise by 28 to 43°cm, and this is likely to influence the intensity of tropical rainfall.

Definition of onset and cessation of rainfall

The onset of rainfall can be described as the possible start of rainfall in a year, whereas the cessation is a period that is characterized by the end of rainfall in a year, this also means the scanty few days of rainfall which may occasionally occur. A number of researchers have defined the onset of rainy season. For example, according to Stern et al (1981)[2], the start of rains is the first occurrence of any specified rainfall amount (20 mm) in 1 or 2 consecutive days with no dry spell of 10 days or more within the next 30 days. Faheun (1983)[3], in modeling daily rainfall sequence for farm operations planning in Ibadan (Nigeria), defined the start of rains as the first 10-day period with a minimum cumulative rainfall of 20 mm followed by a dry spell of less than 10 days. In this definition, a day was considered rainy if the rainfall amount was 2 mm or more. Omotosho et al (2000)[4] modified the definition for the onset of rainy season. This is the beginning of the first 10-day period with cumulative rainfall of 20 mm, above one of which is 10 mm, or above, followed by another two 10-day period each with 50% or more of the minimum decadal crop water requirement. The minimum decadal crop water requirements for Nigerian southern region (coast to 8°N), the middle belt (8°N to 11°N), and the northernmost (11°N to the northern border) are 3, 4 to 5, and 6 mm, respectively. Nnoli (1996)[5] defined the cessation of rainy season as any day (after 1 September) that was the last day of rain or any day after which there existed a dry spell of 20 days or more. Omotosho et al (2000)[4] defined cessation of rainfall as any day from 1 September after which there are 21 or more consecutive days of rainfall less than 50% of the decadal crop requirement.

Onset, cessation, and length of growing season

The method proposed by the AGRHYMET[6] was used to calculate the onset of rainy season (date) over the city. This was defined as the first decade in which at least 25 mm of rainfall was followed by 2 decades, which is a total of at least

20 mm of rain. The cessation of rainy season was defined by Sivarkumar (1988)[7] as the date after 1 September following which no rain occurs over a period of 20 days, whereas the length of rainfall can be defined as the number of days between the onset date and cessation date (cessation date minus onset date). A dry spell, on the other hand, is defined as a sequence of consecutive dry days with precipitation equal to or less than 1 mm. Dry spell begins and ends the day after and day before a daily rainfall amount greater than 1 mm, respectively.[8] The dry spell day can reveal significant changes in the structure of drought. Besides, the probable number of duration of dry spells can be used in timing the application and dosage of fertilizers and fungicides; herbicides are easily washed off if there is rainfall for 2 days after spraying.[9] Analysis of dry spell could be done employing differences in rainfall threshold distribution value for a dry day such as greater than or equal to 0.1 and 10 mm.[10] Meanwhile, the dry spell can be divided into smaller subperiods to provide a more suitable and reasonable distribution.

Factors affecting onset, cessation, and number of wet days

Factors affecting onset and cessation are meteorological and surface factors are rate limiting. The meteorological factors may in turn be subdivided into energy and aerodynamics variables, such as wind speed at the surface and vapor pressure difference between the surface and lower atmosphere, to control the rate of transfer of condensed vapor into the atmosphere for the formation of rain.[11] It is useful to distinguish between those stations where free water is present on the surface and those where it is not. Factors of importance include the amount and state of the water and those surface characteristics that affect the transfer process through the air or through the water surface. Factors influencing evaporation are the direction and velocity of wind, the temperature differences between water surface and the surrounding surface, which directly affect evaporation. Others are vapor pressure difference in the atmosphere, atmospheric pressure that increases or reduces the rate of formation of vapor and vegetation, and slope of the area under consideration.[11]

Rainfall

Rainfall is the most important single meteorological parameter that conditions agriculture as it provides the water necessary for the functioning of the soil-plant-atmosphere-system.[12,13] Rainfall regulates the flow of sap through the plant and the elaboration of the dry matter, which can be harvested as products. In addition to a general characterization of agroecological zone, based on average rainfall, potential evapotranspiration, and water balance, the variability of rainfall is extremely important, as it is mainly responsible for wide fluctuations in agricultural production.[12] This is particularly of a serious concern in developing nations which do not yet have the mechanism to obviate serious food crisis. Regular rainfall measurement is also an essential requirement in many aspects of agriculture, forestry, industry, education, and other activities. Rainfall is rarely uniform in intensity or duration across a wide area, so continuous data on local conditions are of particular importance to farmers and those concerns with irrigation, scientists researching into crop performance and soil erosion and to water and river authorities in respect of reservoir supplies and ground water feeding into rivers. Accurate measurement is also essential for calculating evaporation. There are other more recent developments in the rainfall measurement such as radar and satellite as these allow rainfall measurement over a large area.[14] Rainfall at any one place against time is expressed in terms of the depth to which it would cover the surface locally, assuming that there was no loss by evaporation or runoff and measured with a gauge in conjunction with other instruments for a full picture of local climatic conditions.

Estimation of onset and cessation of rainfall

The precise onset and cessation dates as well as the amount and the distribution of rainfall each year are usually some of the needs of agriculturists to ensure that they realize a bumper harvest of crops. The information is strongly dependent on the unique characteristics of high seasonal, monthly, and daily variability in its moisture content and the vertical depth. Therefore, the onset, cessation dates, and length of rainy/growing season as well as the amount and the distribution of rainfall each year could show high variability in subsequent years. Omotosho et al (2013)[15] found that the variation of onset dates of rainy season at any station could be up to 70 days from one year to another. The exercise of mapping out of the mean onset and cessation dates of rainy season is conducted by some researchers.[3,5,16,17,18,19,20,21] To give corresponding onset,[16] grouped rainfall amounts into pentads as he used 12.7 mm rainfall as a threshold of 25.4 mm/cessation dates of heavy rains. This approach of grouping into pentads and decades, however, tends to smooth out valuable information inherent in the raw data. The work performed on the variability of the onset and cessation dates of rainy season in some stations around Kainji Dam in Nigeria by Adebayo et al (1994)[21], when compared with the abovementioned work, revealed that there was a general late onset and cessation of rainy season. In Eastern Europe, estimation of extreme wet weather condition based on averaging of daily precipitation which allows determining periods of the precipitation regime more than 50 years was done.[22] The wet days were selected from the calculation results of the precipitation moving average in the estimation, as a day was considered as extremely wet when the moving average of daily precipitation was at least 10 mm on successive days until the exact day. It was concluded that the interannual variability of the average number of wet days in Estonia has remarkably grown in 1957-2006.The increase in annual total number of extreme wet days was found to be obvious. Stephens et al (1995)[23] investigated trend in arid and semi-arid regions of Iran using 79 climatologically stations with 36 years of data record. Monthly and annual precipitation data were studied from homogeneity and randomness point of view. A number of homogeneity tests were applied and discontinuities were adjusted in no-homogeneous stations. Annual precipitation time series from 1965-2000 were checked for climate variability and for possible trend using nonparametric Mann-Kendall statistics test. The result showed that there is no evidence of climate change in the study area. Although many stations showed negative trends indicating the decrease in precipitation, this trend was not statistically significant at 95% significant level. A study by Sivakumar et al (1993) used the concept of the seasonal average quantity of rainfall, which gives the idea of a given type of crop, in particular, the knowledge of the 70% probability of rainfall, which is sometimes called dependable rainfall in Niger from which the agricultural map for Niger was produced. Findings from some researchers at the International Institute of Tropical Agriculture (IITA)[24], Ibadan concluded that there was a general decline of rainfall in Nigeria over both time and space depending on topography and location.

Kenya and North Eastern Tanzania daily rainfall data for 30 years (1958-1987) analyze the aim to characterize the interannual variability of the onset and cessation of eastern Africa long rains (Spring et al, 1990). The leading principal component (PCI) depicts consistent rainfall variation over much of the region. Cumulative PCI score for each year serves to identify onset and cessation dates. The robustness of the dates derived from this method was demonstrated with an independent sample of stations. Their spatial representative was assessed by daily rainfall. The interannual variability of the onset (SD 11.5 days) is larger than that of the withdrawal (10.3 days), but the onset is also spatially much more consistent. Oladipo and Kwaghsaa (1994) analyzed trend of onset and cessation of rain in Senegal over the 43-year period using rainfall data from 34 stations. The use of principal component analysis based on rainfall only indexes the onset and cessation of rains. The minimum and maximum values of the cumulative scores of principal components for each year locate the onset and cessation dates, respectively; very distinct spatial rainfall patterns are found before and after onset/cessation mean dates when compared favorably with those based on other definitions. The time series analysis for the cessation shows a significant trend toward earlier dates with an abrupt shift occurring in the early years. However, the interannual variability of onset is greater than that of the cessation duration, and total rainfall amounts are generally significant, but not as high as expected.[13] Good illustration with nearly identical rainfall amounts of an onset delayed by 1.5 months. The sequence amount and occurrence of rainfall have been given attention over the past few years for their need to predict flood and their subsequent use in the design of irrigation and drainage requirement.[25] Rainfall analysis could come in the form of hourly, daily, weekly, monthly, or seasonal rainfall, but analysis proposed by Sivakumar et al (1993) and Oladipo and Kwaghsaa (1994) for rainfall on daily basis is the most useful especially for agricultural purposes. Rainfall analysis including amount, intensity, and spatial coherence is relevant to agriculture; the dependency of wet sequence or days has become an interesting starting point for agronomically relevant analysis.[13] Investigation of weather and climate is not new and various researchers' models fit into the characteristic dependence of daily rainfall. In 1998, to know the variation of onset and cessation of rains and the impact this will have on rain-fed crops in the 2 stations, it was discovered that normal onset of rains and its cessation came in the months of March and October, respectively, in Ibadan.

Nonparametric trend test for estimation of onset and cessation of rainfall

The Mann-Kendall test, a nonparametric test recommended by the World Meteorological Organization (WMO) to explore trends in hydro-climatological time series,[26–29] was used in this study to test for the present trends in this study. This test is applicable in cases when the data values X of a time series were assumed to obey the model:

$$\chi = f(t) + ei \tag{1}$$

where $f(t)$ is a continuous monotonic increasing or decreasing function of time and the residual e_i can be assumed to be from the same distribution with zero-mean Mann-Kendall test statistic S, which is given by Salami et al,[26] as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{2}$$

where n is the length of the time series $X_j \ldots X_n$, and Sgn ( ) is a sign function, X_j and X_k are values in years j and k, respectively. The expected value of S equals 0 for series without trend and the variance is computed as follows:

$$\sigma^2(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] \tag{3}$$

Here, q is the number of tied groups and t_p is the number of data values in pth group. The test statistic Z is then given as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\sigma^2(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{\sigma^2(S)}} & if \quad S < 0 \end{cases} \tag{4}$$

As a nonparametric test, no assumptions as to the underlying distribution of the data are necessary. The Z statistic can then be used to test the null hypothesis, H_o, that the data are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. A positive (negative) value of Z indicates an upward (downward) monotonic trend. H_o is rejected at a particular level of significance if the absolute value of Z is greater than $Z_{1-}\alpha/2$, where $Z_{1-}\alpha/2$ is obtained from the standard normal cumulative distribution tables.

It should be noted that the Mann-Kendall test is nondimensional and does not quantify the scale or the magnitude of the trend in the units of the time series under study but is rather a measure of the correlation of x_i with time and, as such, simply offers information as to the direction and a measure of the significance of the observed trends. Hobbins et al (2001) noted that Mann-Kendall test is nondimensional and does not quantify the scale or the magnitude of trend but the direction of trend. Sen's nonparametric method will be used to estimate the slope of an existing trend. This method is good as it tends to bring out the true slope of any existing trend, and researchers often use it.[26]

Sen's method can be used in cases where the trend can be assumed linear. This means that $f(t)$ in equation (2) equals to

$$f(t) = Qt \pm B \tag{5}$$

where Q is the slope and B is a constant. To get the slope estimate Q in equation (6), we first calculated the slopes of all data value pairs as follows:

$$Q_i = \frac{\chi_j - \chi_k}{j - k} \tag{6}$$

where $j > k$. If there are n values x_j in the time series, we get as many as $N = n(n-1)/2$ slope estimates Q_i. Sen's estimator of slope is the median of these N values of Q_i. Both trend and slope test can be computed using MAKESENS 1.0. software.[28]

Conclusions

The importance of adequate analysis of climatological data cannot be overemphasized. It helps in making vital decision relevant to agricultural practices. The study by Akinseye et al[30] established the most reliable and suitable method for determining the onset of growing season as well as the length of growing season (LGS) in the various Malian agroecological zones (and crops). The methods tested showed a strong relationship between the onset and LGS across the selected stations which is consistent with previous studies. The study gave an overview of nonparametric trend test method for the estimation of onset and cessation of rainfall. This methodology is not only useful for making decision at the farm and regional levels but it can also be used for establishing agroclimatic atlas for a nation. This work recommends that the methodology can be adopted for all ecological zones for crop zonation and land use planning because for agricultural purpose, the date of the onset of rain is more important than the cessation date and the major problem farmers are facing is when to start tilling and planting as early maturing crops are needed.

Author Contributions

OIO prepared and developed the paper with inputs from MFI who also vetted the paper for publication.

REFERENCES

1. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2001: Synthesis Report. In: *A Contribution of Working Group I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Watson, R.T., (Ed.), Cambridge, UK: Cambridge University Press, 2001, pp. 239–397.
2. Stern RD, Dennett MD, Garbutt DJ. *The start of the rains in West Africa. J Climatol.* 1981;1:59–68.
3. Fasheun A. Modeling of daily rainfall sequence for farm operations planning in Ibadan. *Nigerian Meteorological Journal*. 1983;1:102–109.
4. Omotosho JB, Balogun AA, Ogunjobi K. Predicting monthly and seasonal rainfall, onset and cessation of the rainy season in West Africa using only surface data. *Int J Climatol*. 2000:20;865–880.
5. Nnoli NO. Mean onset and cessation dates of rainy season in Nigeria. In: *Proceedings of the 11th Nigerian Meteorological society conference on climate change and its impact on Agriculture*, Ibadan, Nigeria, 24–25 October 1996. IFTA.
6. AGRHYMET. Méthodologie de suivi des zones à risque. *AGRHYMET FLASH, Bulletin de Suivi de la Campagne Agricole au Sahel 0/96*, Vol. 2., no. 2, 1996, [Available from Centre Regional AGRHYMET, B.P. 11011, Niamey, Niger.]
7. Sivakumar MVK. Predicting rainy season potential from the onset of rains in the southern Sahelian and Sudanic climatic zones of West Africa. *Agric For Meteor.* 1988;42:295–305.
8. Maheras P. Changes in precipitation conditions in the Western Mediterranean over the last century. *J Climatol*. 1988;8:179–189.
9. Kutiel H, Maheras P. Circulation and extreme rainfall conditions in the eastern Mediterranean during the last century. *Int J Climatol*. 1992;16:73–92.
10. Kutiel H. The multimodality of the rainfall course in Israel, as reflected by the distribution of dry spells. *Arch Meteor Geophys Bioclimatol Ser B*. 1985;36:15–27.
11. Omotosho JB. Synoptic meteorology: pathway to seasonal rainfall prediction for sustainable agriculture and effective water resource management in West Africa But Nigeria in particular. *J Niger Meteor Soc*. 2002;3(2):81–86.
12. Food and Agricultural Organization (FAO). Early agrometeorological crop yield assessment. *Plant Production and Protection*. Paper 73. FAO, Rome, 1986, pp. 114–123.
13. Oladipo EO, Kwaghsa EA. Dependence of wet and dry days at three stations in the Savanna areas of Nigeria: Samaru. *J Agric Res*. 1994;11:49–62.
14. Munro DS. A surface energy exchange model of glacier melt and net mass balance. *Int J Climatol*. 1991;11(6):689–700.
15. Omotosho JB, Agele SO, Balogun IA, Adefisan EA. Climate variability, crop-climate modeling and water ecophysiology research: implications for plant's capacities for stress acclimation, yield production and food security. 2013.
16. Oshodi FR. 1971. A study of pentade normal of rainsfall in Nigeria. Nigerian Meteorological Service. *Quart Meteor Mag*. 1971;1:4.
17. Ilesanmi OO. An empirical formulation of the onset, advance and retreat of rainfall in Nigeria. *J Tropical Geography* 34: 17–24
18. Obasi GOP, Adefolalu DO. *Maps of Mean Onset and Cessation Dates of Rainfall in Nigeria*. Lagos: Nigerian Meteorological Research, 1977.
19. Stern RD. Computing a probability distribution for the start of the rains from a Markov chain model for precipitation. *J Appl Meteorol*. 1982;21:420–423.
20. Omotosho JB. Onset of thunderstorms and precipitation over northern Nigeria. *Int J Climatol*. 1990;10:849–860.
21. Adebayo AA. The Effect of Climate on the growth of cotton at Ngurore, Adamawa State. Paper presented at N.G.A. Conference, College of Education, Ikere, Ekiti State, 1994.
22. Estonian Meteorological and Hydrological Institute (EMHI). *Estonian environment monitoring 2004–2006*. Information about environment, Information and Technological Centre of Environmental Ministry, pp. 8–9 (in Estonian), 2007.
23. Stephens W, Hess TM, Maryah UM. Rainfall trends in the North East and Zone of Nigeria Agric. *For Meteorol*. 1995;74:87–97.
24. International Institute of Tropical Agriculture (IITA). *Rainfall Changes Call for Shift in Cropping Practices the Case of Nigeria Annual Report*. Ibadan, Nigeria: IITA; 1992.
25. Ekwue EI, Stone RJ, Smith R. Statistical analysis of Caribbean rainfall data: Formulating linear models relating dependable rainfall to mean monthly rainfall. *West Ind J Eng*. 1997;19(2):49–58.
26. Salami T, Maatta A, Anttila P, Ruoho-Airola T, Amnell T. Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates—the excel template application MAKESENS. Helsinki: Finnish Meteorological Institute; 2002. Publications on Air Quality, No. 31.
27. Tosic I, Unkasevic M. Analysis of precipitation series for Belgrade. *Thor Appl Climatol*. 2005; 80:67–77.
28. Oguntunde PG, Friesen J, Van de Giesen N, Savenije HHG. Hydroclimatology of the Volta River Basin in West Africa: trends and variability from 1901 to 2002. *Phys Chem Earth*. 2006;31:1180–1188.
29. Dinpashoh Y, Jhajharia D, Fakheri-Fard A, Singh VP, Kahya E. Trends in reference crop evapotranspiration over Iran. *J Hydrol*. 2011; 339:422–433.
30. Akinseye FM, Agele SO, Traore PCS, Adam M, Whitbread AM. Evaluation of the onset and length of growing season to define planting date—"a case study for Mali (West Africa)". *Theor Appl Climatol*. 2015;124:973–983. doi:10.1007/s00704-015.