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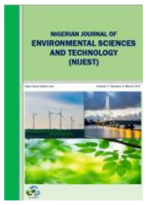

Preliminary Analysis of Daily Rainfall Data from Kano State using Statistical Techniques

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ABSTRACT

A 35-year annual rainfall was collected from NIMET to determine the Standard Precipitation Index (SPI) and also to study the trend of rainfall parameter in the Kano State, Northern Nigeria. The paper captures the average rainfall (normal rainfall) data for thirty-five years period which implies a rainfall of about 1081.56mm. The positive values (above zero) signify rainfalls that were higher than normal (wet); while the negative values (below zero) imply rainfalls that were lower than normal (dry). From the rainfall anomaly, 18 years (52.9%) recorded wet due to the fact that rainfall occurred in those years were greater than the normal rainfall of 1081.56; while 16 years (47.1%) recorded dry because the rainfalls that occurred in those years were below normal rainfall. In the study, Weilbul method was used to determine the return period in order to predict the year of occurrence of maximum rainfall. In addition, Standard Precipitation Index was used to determine periods of dry, normal or wet temperatures. September 1991 recorded the minimum SPI value of -0.86 (moderately dry), while October 2011 recorded the maximum SPI value of 1.88 (moderately wet). This study is carried out because of the importance of agriculture in the region and to Nigeria at large. Kano state is well known to support food production in the country. Also, the presence of dams further buttresses this study. Dams have many purposes; one is agriculture during dry and wet season. It is observed that the rainfall in the basin has no definite pattern.

Keywords: Standard Precipitation Index (SPI), Statistical Analysis, Rainfall, Anomaly, Return period.

1.0. Introduction

Water is imperative for any life process. It is used for transportation, source of power, domestic consumption, industrial and agricultural purposes. Rain is the main important source of water in any area with a great effect on agriculture. Statistical analysis helps to predict the probability of occurrence of rainfall from past records of hydrological data. Probability distribution or frequency help to reconcile the magnitude of extreme events such as severe storms, floods, and drought with their number of occurrences over time, these data can be used to predict future occurrence (Arvind *et al*., 2017).

There is no doubt that the availability of quality and sustainable freshwater has become a limiting factor for development worldwide (Gat, 2004). Therefore, it is important to understand rainfall variability in order to optimally manage the scarce water resources that are under perpetual stress as a result of increasing water demands due to population growth and economic development. (Herath and Ratnayake, 2004).

To further elaborate, studies have shown that the incidence of unusual weather patterns as they affect the wet and dry seasons have been observed in the West African sub-region, including Nigeria. Sometimes, heavier rainfall than usual may occur for a prolonged period of time extending into the dry season (Nnaji, 2009). Rainfall varies in amount from month to month, year to year or season to season and may show a downward or upward trend over a given period (Fidelis, 2021). An increasee in precipitation can lead to flood as well as increased erosion and deterioration of groundwater quality causing different forms of water pollution (Okorie, 2016). Water pollution occurs due to sedimentation, dissolved organic matter, pathogens, nutrients, pesticides, heavy metals and salts; these pollutants are likely to infiltrate many aquifers quickly (Okeke and Okorie, 2009). According to Okorie (2020), rainfall variability can affect agricultural productivity leading to decrease outputs, which would adversely affect the socioeconomic wellbeing of the people.

Rain has some special characteristics that have practical implications. Some of these characteristics include amount, duration, and intensity of rain. It also includes seasonal and diurnal distribution, frequency of rainy days, and variability. The amount of water (soil water) available to plants depends on the start, length, and end of rainfall. These affect the success or failure of the harvest season (Ntat *et al*., 2018). Notably, humans cannot control the occurrence, distribution, and amount of rainfall (Stroosnyder, 2008). However, the knowledge of frequency of rain for different durations is necessary for efficient crop production (Nunez *et al*., 2011).

Rainfall is an essential part of an area's water cycle. Part of the rain that fall in an area infiltrate to replenish soil moisture and aquifers, while others escape joining streams and rivers. A significant amount of water is lost in the process of evapotranspiration. The place of rainfall in the water cycle cannot be underestimated. Other water sources such as surface water and underground water rely on rainfall for replenishment. The understanding of temporal and spatial dynamics of rainfall is very crucial to achieve a sustainable water resource management. Water resource management implies the activity of planning, distributing and managing the optimum use of water resources. Water management is aimed at achieving one or more of the following: domestic water supply, industrial water use, irrigation farming, flood control, water quality control, among others. Rainfall trends have been observed to have a significant impact on the water cycle and thus on both the quality and quantity of water resources (Ogunbode and Ifabiyi, 2019). Therefore, this study aims to achieve the seasonal variability of rainfall in the study area, investigate the overall trend (increase/decrease) of rainfall, and provide information to farmers with respect to planting time and hydraulic structure design in the basin.

2.0. Methodology

2.1. Description of Study Area

The study location is situated in the Sahelian geographic region, south of the Sahara covering total area of 20,131m^2 with the latest official estimate population of 9,383,682 (2006 Estimate). Kano is located between Latitude 12^0 0' 0.0000" N and Longitude 8^0 31' 0.0012" (Google Earth, 2021). Figure 1 depicts the study area.

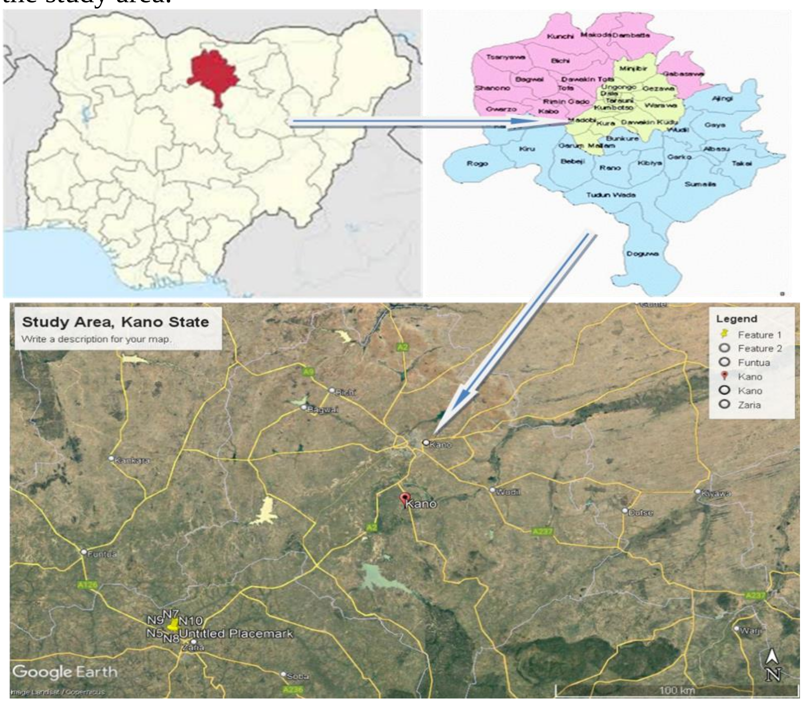

Figure 1: The Study area. (Top left: Map of Nigeria; Top right: Map of Kano state; Bottom: Study area) (Google Earth, 2021).

2.2. Data Collection

The rainfall data used in this study were obtained from the Nigerian Meteorological Agency (NiMet). NiMet station is a standard weather station that gives most climatic data. The rainfall data analyzed in this paper is from a period of 35 years. The duration is used in order to provide sufficient data to establish a long-term climatological basis. The database is maintained in a spreadsheet format with access to MS Excel for ease of analysis and editing. The database was created and statistical analysis was carried out in different time resolutions.

2.3. Statistical Analysis of Annual and Seasonal Rainfall

Monthly and annual data were computed by summing the daily rainfall data. Annual and seasonal rainfall data from hydrological years 1983 to 2017 was analyzed.

2.3.1. Determination of return period of rainfall using Weilbul method:

$$\text{Tr} = \frac{M}{N+1}$$

Where M is the rank and N is the number of years under observation.

2.3.2. Standard Precipitation Index (SPI):

SPI is a drought index used for estimating wet or dry condition based on precipitation variables. SPI is expressed as standard deviations that the observed precipitation would deviate from long-term mean for a normal distribution and fitted probability distribution (Mckee et al, 1993).

The SPI probability density function fitted to a gamma probability function to a time series of precipitation is defined as:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}$$

Where $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ is the gamma function, which is defined as:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy$$

Using Thom (1958) approximation, α and β can be estimated as

$$\alpha = \frac{1}{4A} \text{ X } (1 + \sqrt{1 + \frac{4A}{3}}) \quad , \quad \beta = \frac{x}{\alpha} \quad , \quad \text{and} \quad A = \ln x - \frac{\sum \ln(x)}{n}$$

Where n is the number of observations.

Integrating the probability density function with respect to x yields the expression G(x) for cumulative probability:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} \; e^{-x/\beta} dx$$

Substituting $t = \frac{x}{\beta}$

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} \; e^{-1} dt$$

Since the gamma distribution is undefined for x = 0

The cumulative probability function for gamma distribution is then modified as follows:

$$H(x) = q + (1 - q)\, G(x)$$

Where q is probability of zero precipitation

$$z = \text{SPI} = - \left(t - \frac{co + c1t + c2t^2}{1 + d1t + d2t^2 + d3t^3} \right) \quad , \quad t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)}$$

for $0 < H(x) < 0.5$

$$z = \text{SPI} = + \left(t - \frac{co + c1t + c2t^2}{1 + d1t + d2t^2 + d3t^3} \right) \quad , \quad t = \sqrt{\ln\left(\frac{1}{1.0 - (H(x))^2}\right)}$$

for $0.5 < H(x) < 1.0$

where,

c0 = 2.515517, c1 = 0.802853, c2 = 0.010328, d1 = 1.432788, d2 = 0.189269, d3 = 0.001308

Table 1: Classification of SPI

SPI	Cumulative Probability	Interpretation
-3.0	0.0014	extremely dry
-2.5	0.0062	extremely dry
-2.0	0.0228	extremely dry (SPI < -2.0)
-1.5	0.0668	severely dry (-2.0 < SPI < -1.5)
-1.0	0.1587	moderately dry (-1.5 < SPI < -1.0)
-0.5	0.3085	near normal
0.0	0.5000	near normal
0.5	0.6915	near normal
1.0	0.8413	moderately wet (1.0 < SPI < 1.5)
1.5	0.9332	very wet (1.5 < SPI < 2.0)
2.0	0.9772	extremely wet (2.0 < SPI)
2.5	0.9938	extremely wet
3.0	0.9986	extremely wet

3.0. Results and Discussion

3.1. Rainfall Trend

Figure 2 depicts the annual variations in the rainfall during the thirty-five years period. It was discovered that year 2001 recorded the highest annual rainfall value of 1789.4 mm followed by 2012 with annual rainfall value of 1689.5mm. On the other hand, 1984 recorded the lowest annual rainfall value of 473.7 mm. Figure 3 depicts the maximum rainfall during the thirty-five years. It is apparent that 2009 recorded the highest rainfall of 241mm followed by 2008 with rainfall of 240mm. The Figures below reveals a significant level of fluctuation during the thirty-five years because some years recorded higher rainfall than others.

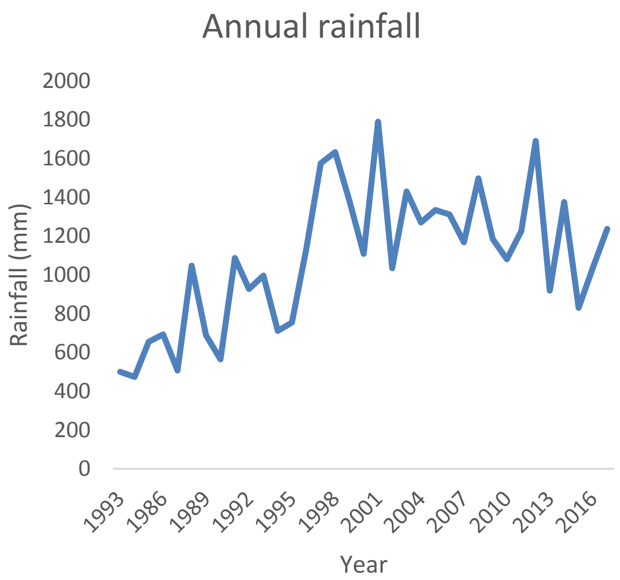

Figure 2: Total annual rainfall trend (1983–2017)

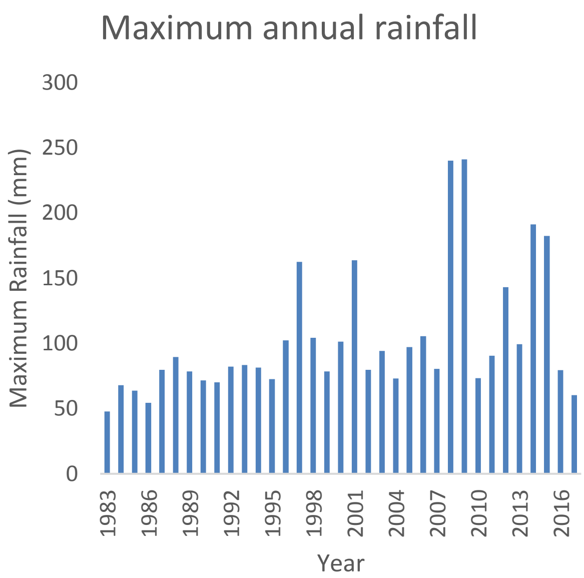

Figure 3: Max rainfall in mm (1983 – 2017)

3.2 Annual Anomaly of the Rainfall

The rainfall anomaly during the thirty-five years (1983-2017) was computed to show the deviation in the rainfall pattern from the established normal rainfall. The established normal rainfall is 1081.56mm (average rainfall). The deviation from this rainfall normal signifies rainfall variability.

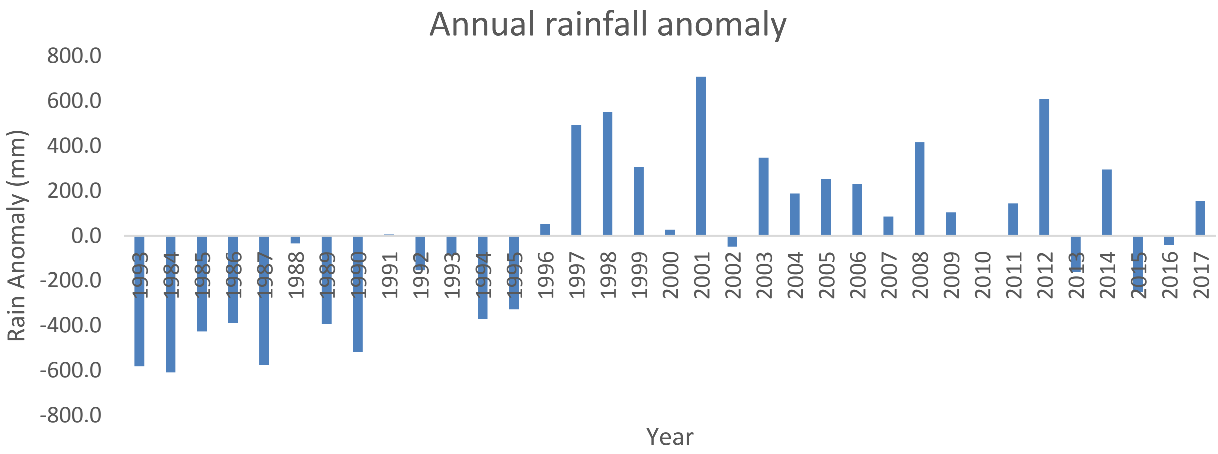

Figure 4: Annual rainfall anomaly

Figure 4 depicts the rainfall anomaly during the thirty-five years (1983-2017). The observed baseline from the figure is the corresponding zero line, and it is the average rainfall record for thirty-five years which also implies the normal rainfall (1081.56mm). The positive values (above zero) signify rainfalls that were higher than normal (wet); while the negative values (below zero) imply rainfalls that were lower than normal (dry). From the rainfall anomaly, 18 years (52.9%) recorded wet due to the fact that the rainfall in those years were greater than the normal rainfall; while 16 years (47.1%) recorded dry because the rainfall in those years were below normal rainfall.

The greatest wet of 707.8mm occurred in 2001, followed by 2012, 1998, 1997, 2008, 2003, 1999 and 2014 having precipitation of 607.9mm, 551.3mm, 493.2mm, 416.1mm, 347.9mm, 304.1mm, and 294.4mm respectively and the least wet of 5.8mm occurred in 1991. However, the greatest dry of 607.9mm happened in 1984 while the least dry of 1.1mm occurred in 2010. It is apparent from the plot that the first thirteen years (1983-1995) were dry. Wet period from 1996 to 2001, and from 2002 to 2012. It can be said that the wet that occurred from 1983-2017 in the area ranged from 5.8mm – 707.8mm while the dry ranged from 1.1mm – 607.9mm. The occurrences of wet or dry during the thirty-five years had no definite pattern.

3.3. Recurrence Interval

3.4.1. *Determination of Recurrence Interval from Probability Plot*

Figure 5 depicts the graph of maximum rainfall plotted against return period. From the graph it can clearly be observed that rainfall of 200mm will have a return period of 15years, rainfall of 175mm will have a return period of 10years, rainfall of 150mm will have return period of 6years, rainfall of 100mm will have return period of 2.5years, rainfall of 75mm will have return period of 1.5years which means such rainfall has tendency to occur frequently.

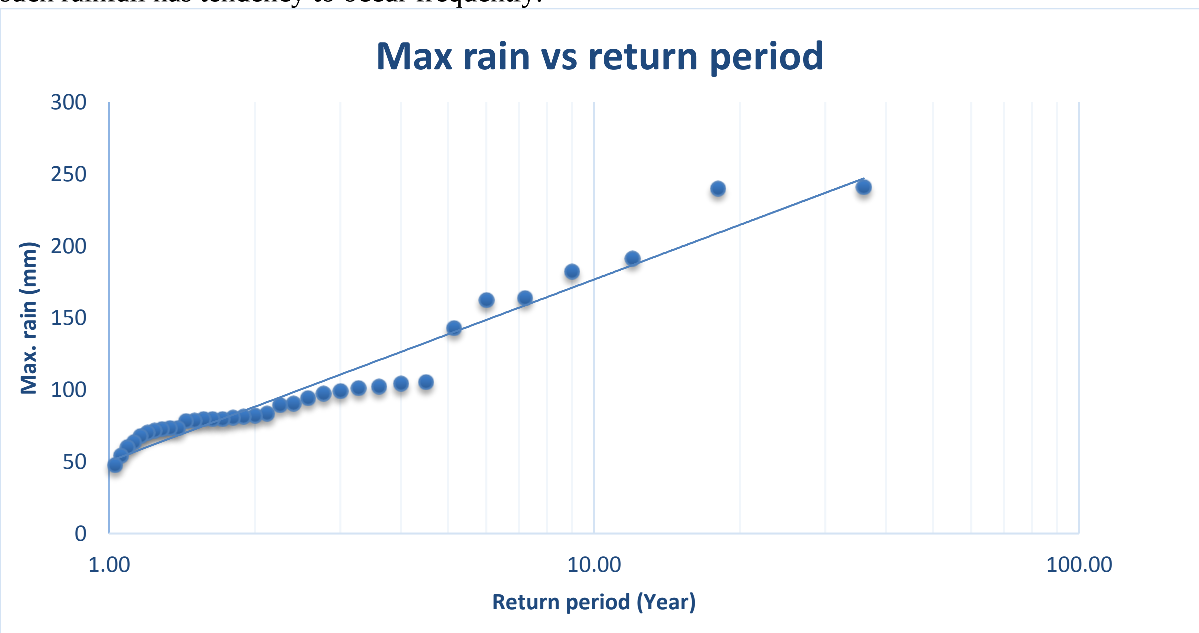

Figure 5: Probability plot recurrence interval

Table 2: Standard Precipitation Index (SPI)

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual SPI
1983	-0.22	-0.53	-0.58	-0.56	0.05	-0.34	-0.72	-0.41
1984	-0.16	-0.16	-0.19	-0.18	-1.06	0.07	0.30	-0.20
1985	-0.22	0.45	0.42	-0.12	-0.32	0.01	-0.72	-0.07
1986	0.00	0.27	0.25	0.23	-0.27	-0.02	-0.29	0.03
1987	-0.22	-0.28	-0.32	-0.15	-0.57	-0.35	0.21	-0.24
1988	1.00	0.35	0.33	0.06	0.60	0.28	-0.72	0.27
1989	-0.22	-0.69	-0.76	-0.26	0.33	-0.19	1.00	-0.11
1990	-0.22	-0.38	-0.42	0.10	-0.37	-0.15	-0.72	-0.31
1991	1.54	0.35	0.33	0.33	0.53	-0.86	-0.72	0.21
1992	1.09	-0.56	-0.61	-0.03	0.22	0.53	-0.72	-0.01
1993	-0.22	1.06	1.04	-0.18	0.42	-0.11	-0.60	0.20
1994	-0.22	-0.48	-0.53	-0.22	0.18	0.29	0.79	-0.03
1995	0.28	0.39	0.37	-0.04	-0.40	0.38	-0.33	0.09
1996	-0.22	0.31	0.29	0.16	0.42	0.76	1.03	0.39
1997	0.96	0.44	0.42	0.21	0.52	0.73	0.91	0.60
1998	0.52	0.50	0.47	1.06	0.74	0.58	0.57	0.63
1999	-0.22	-0.09	-0.12	0.97	0.55	0.68	0.31	0.30
2000	-0.22	0.13	0.10	0.53	0.24	0.38	0.75	0.27
2001	1.17	0.80	0.78	1.13	0.66	0.53	-0.72	0.62
2002	0.05	0.19	0.16	0.29	0.35	0.51	1.16	0.39
2003	0.38	0.88	0.86	0.64	0.55	0.65	0.14	0.59
2004	-0.22	0.59	0.57	0.55	0.19	0.64	-0.72	0.23
2005	-0.01	0.69	0.67	0.61	0.40	0.39	1.35	0.59
2006	-0.22	0.12	0.09	0.59	0.21	1.07	-0.39	0.21
2007	1.19	1.22	1.21	-0.04	0.52	-0.63	-0.72	0.39
2008	-0.22	0.19	0.16	0.81	1.05	0.24	-0.07	0.31
2009	-0.22	0.04	0.01	0.59	0.61	0.43	-0.44	0.15
2010	1.59	0.16	0.14	0.26	0.09	0.72	1.22	0.60
2011	0.47	0.35	0.33	0.17	0.35	0.63	1.88	0.60
2012	-0.22	1.59	1.58	0.70	0.86	0.10	0.34	0.71
2013	1.24	-0.20	-0.23	-0.18	0.43	0.40	0.03	0.21
2014	0.60	-0.09	-0.12	0.86	0.64	0.44	0.29	0.38
2015	-0.22	-0.28	-0.32	-0.21	0.59	0.05	-0.03	-0.06
2016	-0.04	-0.09	-0.12	0.28	-0.16	1.12	0.64	0.23
2017	1.24	0.79	0.77	0.06	0.41	-0.09	-0.31	0.41

4.0. Conclusion

The analysis performed in this paper focused on various important descriptive statistical measurements of daily, monthly, seasonal, and annual precipitation. The time series of precipitation of data was examined and the annual trends were reported. Daily precipitation data was analyzed in terms of frequency of precipitation during the study period. The general conclusions are summarized as follows:

(i) Figures 2 and 3, clearly show the trend of annual rainfall and maximum rainfall in Kano with no definite pattern.

(ii) Figure 2 and 3 show a significant fluctuation in the rainfall. This may depict great economic impact on agricultural activities and water supply since most of the people depend on rain fed agricultural practices to earn a living.

(iii) Figure 4 shows the normal rainfall as 1081.56mm, therefore, any deviations from this normal signify rainfall variability.

(iv) Out of the thirty-five years, 18 years (51.4%) recorded wet due to higher rainfall occurrence during the period, which are more than the normal rainfall; while 17 years (48.6%) recorded dry because the rainfalls that occurred in those years were below normal rainfall.

(v) Years with low rainfall (dry) can lead to low productivity of crops, livestock and scarcity of water supply. On the other hand, years with high rainfall (wet) above normal can lead to the destruction of crops and high availability of water supply.

(vi) Table 2 shows the standard precipitation index. September 1991 recorded the minimum SPI value of -0.86 (moderately dry), while October 2011 recorded the maximum SPI value of 1.88 (moderately wet)

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