



Climate Change and Rainfall Variability: A Case Study of Gwagwalada, Federal Capital Territory, Abuja, Nigeria

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Abstract

Climate change significantly alters rainfall patterns globally, with far-reaching implications for ecosystems, agriculture, and human settlements. Nigeria, particularly the rapidly urbanizing area of Gwagwalada, remains highly vulnerable to climate-related hazards. This study assesses changes in rainfall patterns in Gwagwalada by examining trends, variability, and extremes using historical climate data and statistical analysis. Results revealed that the highest monthly rainfall amount during the study period was 469.4 mm, recorded in August 2007, while the lowest monthly rainfall amount (≥ 1 rainy day) was 2.2 mm, observed in November 2008, and again in February and November 2017. The number of rainy months per year ranged between seven and ten. In 2010, a total of 1333.1 mm of rainfall was received over seven months, whereas in 2018, 1131.1 mm was recorded across ten months. This indicates that rainfall amount is not necessarily dependent on the duration of the rainy season. These findings highlight the variability and unpredictability of rainfall in the study area and provide valuable insights for policymakers, urban planners, and stakeholders. Ultimately, the objective of this research is to enhance understanding of rainfall dynamics in Gwagwalada in order to support the development of climate-resilient strategies for sustainable agriculture, ecosystem management, and urban development.

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Introduction

Rainfall is a vital component of the Earth's hydrological cycle, playing a crucial role in shaping the environment, supporting agriculture, and sustaining human life (Olumuyiwa *et al.*, 2017). The dynamics of rainfall patterns are complex and influenced by various factors, including climate change, topography, and atmospheric circulation. In recent years, changes in rainfall patterns have been observed globally, with significant implications for ecosystems, agriculture, and human settlements (M. H. González *et al.* 2015). Climate change has become a pressing global concern, with far-reaching implications for environmental sustainability, food security, and human settlements (Olumuyiwa *et al.*, 2017). According to (Ali, 2011; Olumuyiwa *et al.*, 2017) Climate change tends to affect all natural and human systems and may be a threat to human development and survival socially, politically and economically (Ali, 2011). One of the most significant manifestations of climate change is the alteration of rainfall patterns, which can have devastating

consequences on ecosystems, agriculture, and urban planning (IPCC, 2007; Olumuyiwa *et al.*., 2017). Nigeria, like many other countries in West Africa, is highly vulnerable to climate-related hazards, including changes in rainfall patterns (Abdulkadir *et al.*, 2017). Gwagwalada, a rapidly urbanising area in the Federal Capital Territory of Nigeria, is no exception. The region's rainfall pattern plays a crucial role in shaping its ecosystem, agriculture, and water resources. However, there is growing concern that changes in rainfall patterns may be occurring in Gwagwalada, with potential implications for the region's socio-economic development.

This study aims to assess changes in rainfall patterns in Gwagwalada, using a combination of historical climate data and statistical analysis. By examining trends, variability, and extremes in rainfall patterns, this research seeks to contribute to a deeper understanding of the impacts of climate change on local ecosystems and communities. The findings of this study will enhance the understanding of rainfall dynamics in Gwagwalada in order to support the

development of climate-resilient strategies for sustainable agriculture, ecosystem management, and urban development.

Study Area

The research area is Gwagwalada city. It's one of the biggest satellite cities in Abuja [NPC, 91]. It is also one of the most heavily inhabited districts in the Federal Capital Territory (FCT) and the headquarters of one of the oldest councils in the Federal Capital Territory, Abuja [Ejaro,2013]. It lies amid latitude 08°55' and 09°00' North and longitude 07°00' and 07°05Est [Balogun 2001]. Gwagwalada also experiences outstanding development and improved

land conversion speed, leading to temperature increase over time (Agu et.al. 2021). The vegetation in Gwagwalada is not uniform in nature, with shrub savannah vegetation type dominating the northern part of the FCT, while riparian vegetation is common on the flood plains of River Gurara and Usuma (Adakayi, 2000). The continuing loss of vegetal cover for construction, as well as consequent buildings and urbanisation, normally led to a temperature rise in Gwagwalada urban with time [Ejaro,2013]. Gwagwalada settlement is situated about 55 kilometres from the Federal Capital City (FCC) inside the Federal Capital Territory.

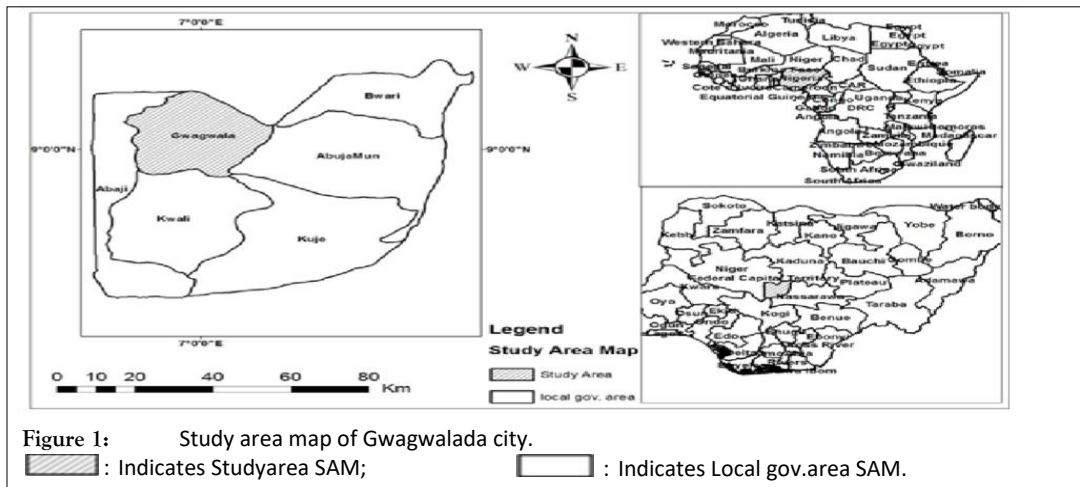


Fig 1: Map of the study area (Source: Agu, C.C. et al., 2021)

Materials and Methods

Rainfall records of the Gwagwalada Station, as obtained from the Abuja Agricultural Development Project (ADP), a subsidiary parastatal under the Federal Ministry of Agriculture and Water Resources, are used for this study. The data cover a period of sixteen years (2005 to 2020). The data collected are subjected to certain analytical techniques ranging from the simple arithmetic mean to the deviation from the mean technique. The mean here is the regional mean of 1200mm (Adakayi, 2000); the region is the FCT within which Gwagwalada is located.

Data analysis

The Statistical techniques used in this study include: the simple statistical measures of arithmetic mean, sample standard deviation and the coefficient of variation (C.V) of rainfall totals on a monthly and yearly basis. The “Deviation from the mean” technique is also used.

The Arithmetic Mean

The formula below was employed in calculating the mean monthly and mean annual rainfall in Gwagwalada for the study period, where the arithmetic mean is denoted by (x). If for instance, the set of observations x_1, x_2, \dots, x_n not necessarily all distinct, represents a finite population size n, then the population mean is given by.

$$x = \frac{\sum x}{n}$$

Where,

- x = Arithmetic mean
- \sum = Sigma (summation)
- x = the variable (observation)
- n = Total number of variables

The Sample Standard Deviation

The Sample Standard Deviation, being a basic measure of variability, is used to collate information on the monthly and annual variation of rainfall in Gwagwalada. Calculated by obtaining the arithmetic

mean and then measuring how each value differs from the arithmetic mean. It is given as:

$$S = \sqrt{\frac{\sum(x - \bar{x})^2}{n}}$$

Where,

S	=	Sample Standard Deviation
\sum	=	Sigma (Summation)
$(x - \bar{x})^2$	=	The square of all deviations from the arithmetic mean
n	=	Total number of variables.

Co-efficient of Variation

This statistical tool was employed to show rainfall totals in terms of their coefficient of variation, on a monthly and yearly basis in Gwagwalada. The coefficient of variation is an expression of variability obtained by converting the standard deviation to a percentage of the mean of rainfall total in a given month of the mean of annual rainfall total over a specified number of years in a given rainfall gauging station. It is defined as;

$$C.V = \frac{S}{\bar{X}} \times 100\%$$

Where,

C.V.	=	Coefficient of variation
S	=	Sample Standard deviation
x	=	Mean of the monthly or annual rainfall total.

Deviation from the 'Mean'

Obasi *et al* (1977) studied annual rainfall fluctuations for 29 long-period recording stations and noted 9 rainy years and 8 dry years within the study period 1906 –

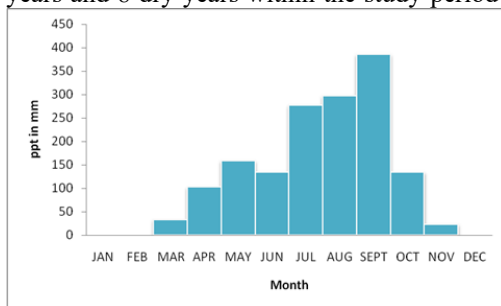


Fig 2: Total monthly rainfall for 2005 (mm)

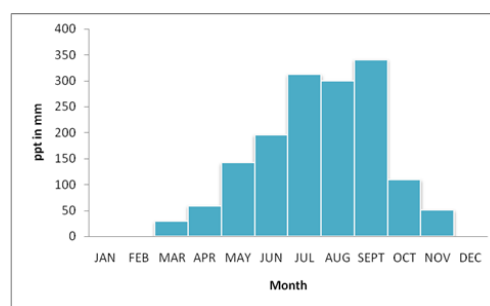


Fig 3: Total monthly rainfall for 2006 (mm)

1977. The reference mean here is the FCT's regional mean, which, according to Adakayi (2000), is put at 1200mm. In order to make the work relevant within the existing literature, the results of the deviation from the mean are shown graphically.

Results and Discussion

Rainfall data that was emphatically described above are collated, analysed and presented as a summary in tables, graphs and charts. The results obtained are then interpreted in consonance with the aim and objectives of the study. Below in the table are the data obtained with the mean (in mm), standard deviation and coefficient of variation of rainfall in Gwagwalada from 2005 to 2020 on both a monthly and annual basis. Rainfall total (in mm) monthly is shown in Fig. 2 – Fig. 17. Fig. 18 depicts total annual rainfall (in mm). Figure 4.17 shows, with the aid of a chart, how annual rainfall total deviates from the regional mean (of 1200mm).

Monthly Pattern of Rainfall in Gwagwalada

The histograms (Fig. 2 – Fig. 17) below clearly show the pattern of monthly rainfall of Gwagwalada from 2005 to 2020, tentatively a coverage period of about sixteen years. A close look at the histogram reveals that monthly rainfall received during the study period is dominated by a single maximum, which either occurs in July, August or September, except for 2020, which occurred in June.

Double maxima were experienced five times within the sixteen-year study period. These include: 2006 in July and September; 2008 in June and August; 2010 in June and September; 2016 in June and September; and finally 2017 July and September.

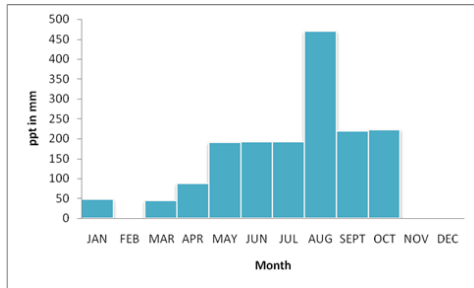


Fig 4: Total monthly rainfall for 2007(mm)

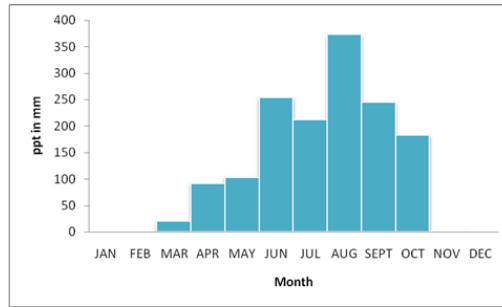


Fig 5: Total monthly rainfall for 2008(mm)

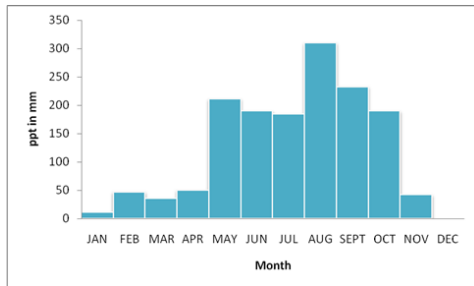


Fig 6: Total monthly rainfall for 2009(mm)

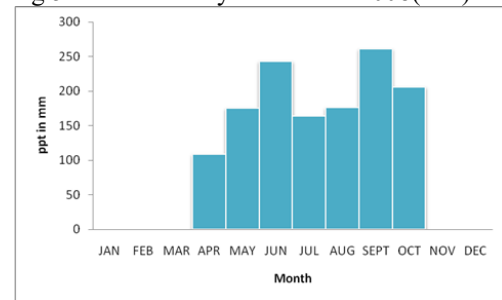


Fig 7: Total monthly rainfall for 2010(mm)

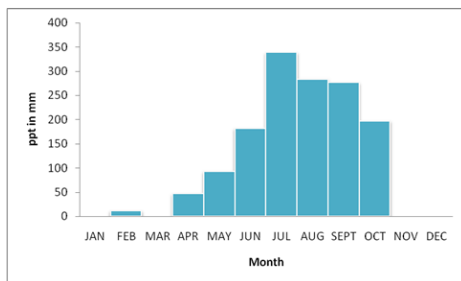


Fig 8: Total monthly rainfall for 2011(mm)

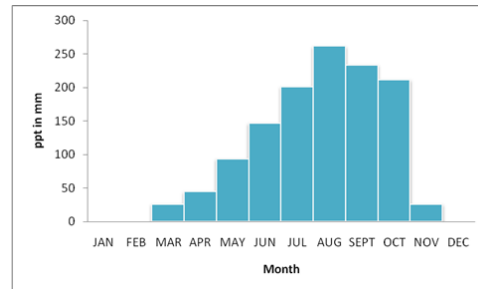


Fig 9: Total monthly rainfall for 2012(mm)

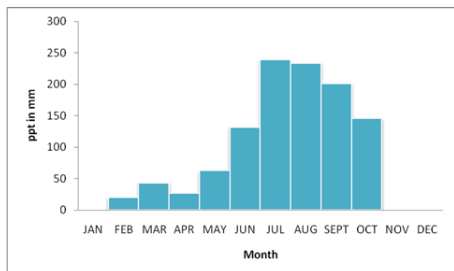


Fig 10: Total monthly rainfall for 2013(mm)

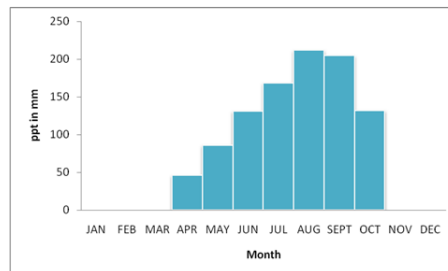


Fig 11: Total monthly rainfall for 2014(mm)

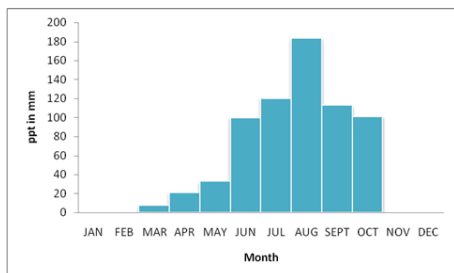


Fig 12: Total monthly rainfall for 2015(mm)

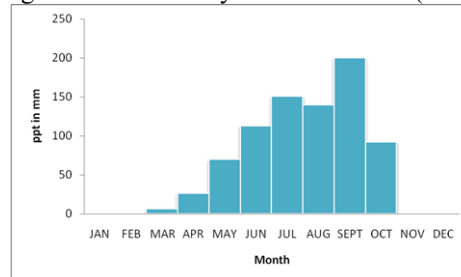


Fig 13: Total monthly rainfall for 2016(mm)

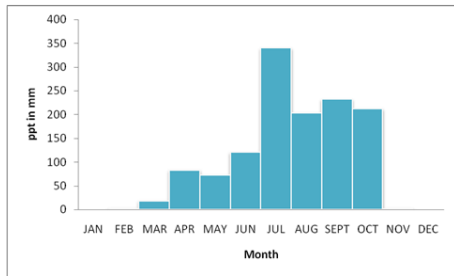


Fig 14: Total monthly rainfall for 2017(mm)

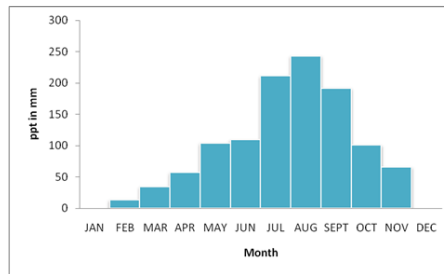


Fig 15: Total monthly rainfall for 2018(mm)

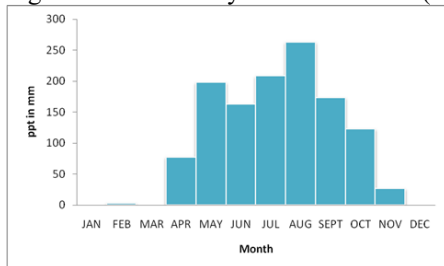


Fig 16: Total monthly rainfall for 2019(mm)

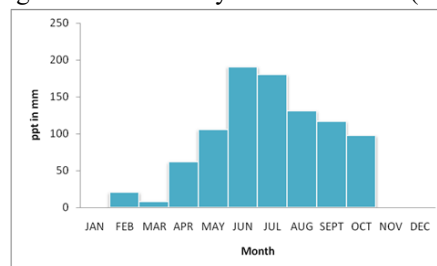


Fig 17: Total monthly rainfall for 2020(mm)

As shown below in Table 1, the highest monthly rainfall amount recorded during the study period is 469.4mm, attained in August 2007. On the other hand, the lowest rainfall amount recorded in a month during the study period at least one rainy day, is 2.2mm, which in fact occurred more than once, in November 2008, February and November 2017. The number of rainy months within the study period ranged between

seven months and ten months. In 2010, the total amount of rainfall received was 1333.1mm, over seven months. Whereas in 2018, for instance, the total amount of rainfall received over a period of ten months is 1131.1mm. This scenario proves that rainfall amount is not necessarily influenced by duration.

	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	TL	ME AN	S.D	C.V
J	0	0	47	0	11.5	0	0	0	0	0	0	0	0	0	0	0	58.5	3.7	11.5	311
F	0	0	0	0	47	0	11.5	0	19.6	0	0	0	2.2	13.3	2.5	20.5	116.6	7.3	12.5	171
M	33.1	28.6	43.7	20.6	35.3	0	0	26.1	43	0	7.5	6.6	18	34.5	0	7.8	304.8	19.1	15.6	82
A	102.3	58.8	87	91.5	50.3	108.8	46.7	44.6	26.7	45.9	20.7	26	83	57	77.4	61.6	988.3	61.8	26.5	43
M	158.4	141.8	190	103.3	211.3	175.1	92.6	93.6	62.6	85.9	33	70	72.3	103.9	197.9	105.7	1897.7	118.6	52	44
J	134.7	195.9	192.5	254.2	189.6	243	181.6	146.8	131.6	130.8	100	113	120.2	109.4	162.6	190.8	2596.7	162.3	45.2	28
J	277.4	312.3	191.3	212.2	184.7	163.4	338.6	201.4	238.6	168.4	120.3	150.8	339.8	211.3	208.2	180	3498.7	218.7	64	29
A	297.5	299.7	469.4	372.8	310.2	175.9	283.5	261.6	233.5	211.7	183.2	139.5	203.4	243.3	263	131	4079.2	255.0	84	33
S	385.4	340.7	219.8	244.8	232.7	260.9	276.3	233.7	200.6	204.5	112.8	200.1	232	191.8	173.1	116.7	3625.9	226.6	67.2	30
O	134.2	109.1	222.6	183.2	189.5	206	196.9	211.5	145.5	131.8	100.8	92.3	212	100.8	122.8	97.6	2456.6	153.5	46.5	30
N	23	51	0	2.2	41.9	0	0	26	0	0	0	0	2.2	65.8	26.5	0	238.6	14.9	21	140
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
TL	1546	1537.9	1663.3	1484.8	1504	1333.1	1427.7	1245.6	1103.7	979	678.3	798.3	1285.1	1131.1	1234	911.7	1986.4	1655.3	1490.1	90
ME AN	128.8	128.2	138.6	123.7	125.3	111.1	119	103.8	92	81.6	56.2	66.5	107.1	94.3	102.8	76	124.5			
S.D	125.2	102.7	132	121.7	100.2	100.7	123.9	97	89.4	81.2	60.7	68.4	109.9	79.5	92.6	67.9	280			
C.V %	97	80	95	98	80	91	104	93	97	100	108	103	103	84	90	89	23			

Table 1: Rainfall amount (in MM), Mean (in MM), Standard deviation and coefficient of variation for Gwagwalada from 2005 to 2020 on both monthly and annual bases. (Source: Agricultural Development Project and Author's Computation.)

Annual Pattern of Rainfall in Gwagwalada

From Fig. 18 below, it is clear, as depicted by the aggregation of the bars constituting the histogram, that the annual rainfall amount in Gwagwalada is seen to have more or less decreased from 2005 to 2015. But in 2016 and 2017, there was a progressive increase, only to be visited by yet another decrease in 2018 by approximately 12% over the previous year. There was still a rise in 2019, but it was immediately followed by a decline of about 26% in 2020. Therefore, the trend of annual rainfall quantity as seen from the chart shows an undulating nature between 2016 and 2020. In terms of the year with the highest amount of rainfall, it is the year 2007 that recorded the total amount of 1663.3mm, as illustrated in the histogram below in Fig. 18, with its bar rising above others. The year with the lowest rainfall amounts is 2015, with a value of 678.3mm. The range of the annual rainfall amount for the sixteen-year study period is 984mm.

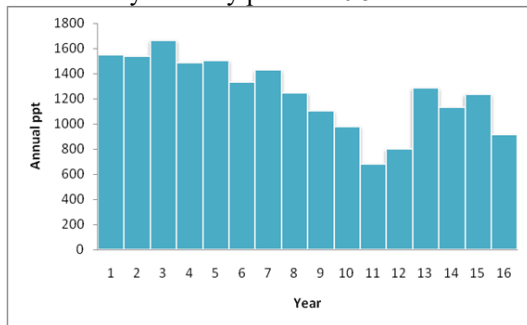


Fig 18: Total Annual rainfall from 2005 - 2020 in mm

Monthly Variation of Rainfall in Gwagwalada

The month of January has the highest coefficient of variation value in Gwagwalada, as shown in Table 1, with a numeric value of 311%. This, therefore, implies that rainfall is highly unreliable during this month. Next in terms of a high coefficient of variation is February with 171%. The month of December recorded no rainfall through the study period, consequently recording a numerical value of zero (0) for both the arithmetic mean and standard deviation – this situation makes it practically impossible to work out the numeric value of the coefficient of variation for December. The months of March and April have a coefficient of variation value of 82% and 43% respectively.

In May, the coefficient of variation value is 44%, in June it was 28%, it was 29% in July, August 33%, in September 30%, in October 30% and in November 140%. June has the lowest numeric value of the coefficient of variation, thus this connotes that the reliability of rainfall is highest in June within Gwagwalada.

On a final note, December recorded the lowest amount of rainfall, but January statistically has the highest rainfall unreliability. Whereas June has the highest rainfall reliability, but in August, especially over the sixteen years (2005 to 2020), it recorded the highest rainfall amount in Gwagwalada.

Annual Variation of Rainfall in Gwagwalada

The annual pattern of rainfall variation in Gwagwalada illustrates the following: the highest annual variation occurred in 2015 with a coefficient of variation value of 108%; the lowest variation of 80% occurred twice, in 2006 and 2009. Table 1 shows a summary of the annual rainfall, arithmetic mean, standard deviation and coefficient of variation for the sixteen-year study period. The table further reveals that rainfall is highly variable from year to year. The coefficient of variation during the sixteen years, as worked out below, is 23% indicating a relatively good reliability of rainfall in the study area.

To obtain the coefficient of variation from the cumulative of the 16 years

Study period:

Mean (X) = 1241.5

$\sum(X - X)^2 = 1254096.5$

n = 16

Standard deviation(S) = $\sqrt{\frac{\sum(X - X)^2}{n}}$

= $\sqrt{\frac{1254096.5}{16}}$

= $\sqrt{78381.03}$

= 280

Coefficient of variation = $\frac{S}{X} \times 100$

= $\frac{280}{124.5} \times 100$

= 23% (approximately).

Deviation From the ‘Mean’

From 2005 to 2012, it was consistently rainy as adjudged by the annual quantity recorded. 2013 through to 2016 were consistently dry years, as the rainfall amounts recorded during these years were less than 1200mm. There was a marked fluctuation in the rainfall deviations recorded between 2017 and 2020. The deviation in 2017 was positive, but negative in the preceding year, 2018. In 2019, it went back positive but went down negative in 2020 (as seen above in Fig 18). Generally, the rainfall deviation is seen to move from the positive side (excess above 1200mm) in 2005 downward to negative toward 2020 (though not consistently), indicating an initiation in the change in weather characteristics in the study area. Merely because within the sixteen-year study period, the

deviation from the regional 'mean' shows ten rainy years and six dry years, one may say rainfall reliability is relatively high. But one interesting aspect here is that consistently between 2005 and 2012, it was rainy (above 1200mm), and between 2013 through to 2016, it was dry (below 1200mm). But from 2017 to 2020, there was a fluctuation in the deviation from the 'mean'. One can therefore infer from this that the rainfall amount between 2005 and 2016 has been declining, but more recently, between 2017 and 2020, there has been a marked fluctuation in the rainfall amount relative to the regional mean.

Conclusion

This study focused on assessing changes in rainfall patterns in Gwagwalada, bringing about the conclusion of certain facts below:

One very significant observation made upon which a conclusion can be drawn with respect to the study aim and objectives is that of the rainfall trend. Observably from the graph of rainfall deviation from the 'mean' and the trend of annual rainfall amount, two things can be discovered. The first is that the trend of rainfall amount is found to decline from 2005 to 2015. Secondly, it will be observed that from 2015 to 2020, the trend line is seen to oscillate. Therefore, since the rainfall trend within the study period involved an initial decline and a subsequent oscillation, it will only be appropriate to study the rainfall trend for some more time beyond the study period to ascertain the actual direction of the trend.

A weather forecast specifically for rainfall should be carried out, perhaps for ten years beyond the present. This will show what to expect, especially in the future, with regard to rainfall output.

The fluctuation in rainfall amount witnessed in the more recent part of the study period calls to some extent for investigative research about the trend of some other key weather elements, such as temperature.

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