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Rainfall Variability over Northern Zambia

Libanda Brigadier[1,2*], Nkolola Barbara[3] and Musonda Bathsheba[4]

[1]School of Atmospheric Sciences, Department of Applied Meteorology, Nanjing University of Information Science and Technology, 219 Ningliu Road, Nanjing, China.
[2]Meteorological Department, Box 80015, Kabwe, Zambia.
[3]Department of Environmental Science and Engineering, School of Engineering, Nanjing University of Information Science and Technology, 219 Ningliu Road, China.
[4]Meteorological Department, Headquarters, Box 30200, Lusaka, Zambia.

Authors' contributions

This work was carried out in collaboration between all authors. Author LB designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. Authors NB and MB managed the analyses for the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The main aimwas to establish, if any, a trend in the amount and distribution of annual rainfall climatologyover Zambia.
Study Design: Diverse statistical methods representing approaches in long term rainfall climatology analysis were employed.
Place and Duration of Study: Zambia Meteorological Department, Kabwe, Zambia and School of Atmospheric Sciences, Nanjing University of Information, Science and Technology, Nanjing, China, between September 2014 and December 2014.
Methodology: In this paper, the amount and seasonal distribution of rainfall from 1960 to 2010 over Northern Zambia as observed by 7 Provincial Meteorological Stations scattered across the study area was studied. A relationship between the rainfall patterns and the El Nino Southern Oscillation (ENSO) was explored and found. Composite analysis was also employed.

**Corresponding author: Email: brigadierlibanda@rocketmail.com;*

Results: The results showed that during the peak of the rainy season (October – April), the northwestern parts of the study area particularly Ndola, experiences more rainfall than any other area over Northern Zambia while during rainy season off peaks (May – September) Isoka receives more rainfall. During warm (cool) ENSO events, dry (wet) conditions generally occur over much of the summer rainfall.

Conclusion: For agricultural tactical purposes, the start of the rain season has been identified as November with October being a transitional month while the end of the season is March and April being a month of transition. The strong link between ENSO and rainfall over Northern Zambia suggests that there is a practical usability in forecasting whenever it is established that an ENSO episode is in progress.

Keywords: Rainfall variability; climatology; ITCZ; ENSO; Northern Zambia.

1. INTRODUCTION

In Southern Africa Development Community (SADC) region, Zambia is particularly highly vulnerable to climate change impacts [1,2]. Zambia has high intra-seasonal and inter-annual rainfall variability, with extreme events such as droughts and floods occurring frequently [3]. Social-economic sectors such as water management, agriculture and infrastructure development are affected by the average amount and the temporal distribution of precipitation, as both excessive precipitation and lack of precipitation have adverse effects [4,5,6]. Therefore, evaluating a long range that accurately reflects precipitation variability is critical for water resource applications. Understanding the distributions of precipitation makes it possible to estimate the likelihood of rainfall being within a specified range. In order to better prepare for future extreme events, understanding the trend of past climate variability is therefore, paramount. The amount and seasonal distribution of rainfall are the most important factors to consider when looking at rainfall across Zambia.

In this paper, the amount and seasonal distribution of rainfall from 1960 to 2010 over Northern Zambia as observed by 7 Provincial Meteorological Stations (Fig. 1) scattered across Northern Zambia was studied. The Zambia Meteorological Department (ZMD) is a government technical department in charge of weather and climate monitoring in Zambia. It runs a network of 22 meteorological stations widely spread over Northern Zambia. 7 carefully chosen Provincial Meteorological Stations with quality-controlled data have been used in this study. These stations have the most complete and continuous data records and are distributed widely compared to other stations in Northern Zambia. The majority of the rainfall occurs in the summer half of the year (October to April). The rainy season reaches a peak between December and February when most of Southern Africa receives 80% of its annual rainfall, with some parts receiving as much as 90% [7].

2. METHODOLOGY

2.1 Composite Analysis

In this study, in order to establish the spatial rainfall distribution, composite analysis was employed. Composite analysis involves identifying and averaging one or more categories of fields of a variable selected according to their association with key conditions. Results of the composites are then used to generate hypotheses for patterns which may be associated with the individual scenarios [8]. A number of authors, including [9,10] have used composite methods in their analyses over the African continent.

2.2 Rain Season Definition

The rainy season is defined at each station on the basis of daily precipitation following the approach suggested by Liebmann and Marengo [11]. As a way to view the seasonality of precipitation they defined the rainfall accumulation quantity A for a given calendar day as:

$$A(day) = \sum_{n=1}^{day} R(n) - \bar{R} \times day \quad (1)$$

Where R(n) is the climatological daily precipitation as a function of the day of the year and R is the climatological annual mean daily precipitation. If the rainy season at a given stations is considered as the period, during which climatological daily precipitation exceeds its

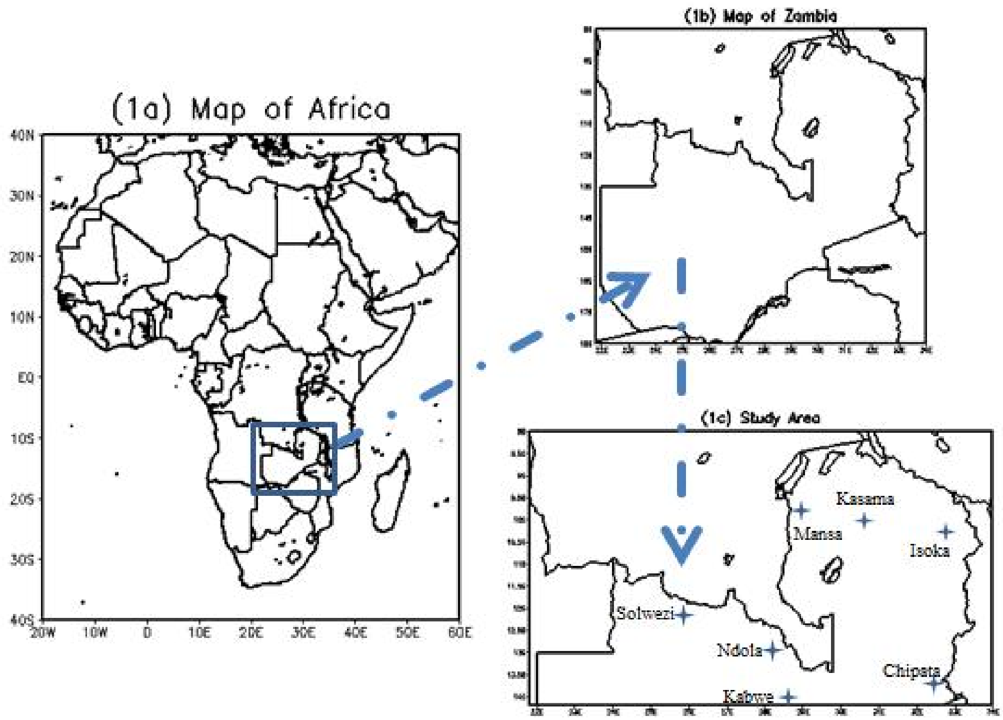


Fig. 1. Study area

annual average, then a positive slope of the accumulation quantity indicates the onset of the rainy season, while a negative slope indicates the end. Here, the rainfall accumulation quantity has been derived from 5-day running mean values of the climatological daily precipitation at a given station in order to reduce the effect of the internal noise on the estimates to the extent possible. It is important to note that the definition of the rainy season used here is local, as it is based on the climatology of daily precipitation at a given station.

3. RESULTS AND DISCUSSION

3.1 Study Location

In this chapter the results obtained from the methods used to address the aims of the present study are presented and discussed.

Table 1 presents the latitudes and longitudes for the meteorological stations used to gather rainfall data from 1960 – 2010. These stations are chosen because they have the most complete data records in Northern Zambia.

Table 1. Locations of the stations used

Name	Latitude (°S)	Longitude (◦E)
Mansa	10.173	28.942
Kasama	10.224	31.14
Isoka	10.272	32.68
Solwezi	12.171	26.367
Ndola	12.994	28.659
Chipata	13.564	32.589
Kabwe main	14.448	28.302

Recently, several gridded data sets of daily precipitation based on satellite products have become available for the entire African continent. In most of these data sets the satellite products have actually been merged with information based on rain gauge data. These gridded data sets, however, provide quite different representations of daily precipitation behavior [12], giving rise to a substantial degree of uncertainty. Hence, the value of such data sets for the quantitative evaluation of various characteristics of precipitation beyond the basic ones is limited. Moreover, these data sets extend only back to few years in history. For these reasons, we have mainly used rain-gauge measurement data in this study. Fig. 1 shows the geographical location of Zambia on the map of

Africa (1a), the Map of Zambia (1b) extracted from the map of Africa and Northern Zambia (1c) with the meteorological stations used in the study as extracted from the map of Zambia. The network of rain-gauges shown in this map, including those in surrounding areas, are sufficient to study the relationship between rainfall and synoptic meteorological conditions.

3.2 Spatial Characteristics of 1960 - 2010 Rainfall

Fig. 2 displays the average seasonal rainfall over the study area. From the figure, it can be seen that the north and northwestern regions such as Solwezi and Kasama tend to receive more rainfall compared to other regions of the study area. The south most region of Kabwe receives the least annual rainfall in the study area.

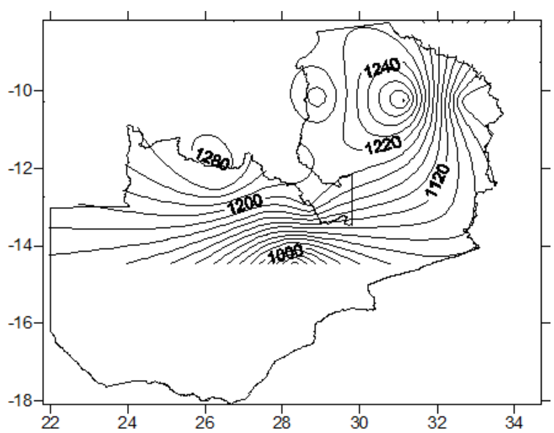


Fig. 2. Mean seasonal rainfall (mm) distribution over Northern Zambia

Northern Zambia receives much of its rain from October to April with December and January as the peak of the rain season. As can be seen from the composite above (Fig. 3) during October – April, Ndola received the heaviest rainfall while Isoka received the least amount. The results also suggest December / January as the months when significant amounts of rainfall are received over the study area. From 1960 – 2010, all areas received less than 50 mm of rainfall during the month of October. While October and April are both transitional months, the study area receives more rains in April than in October.

During 1960 – 2010, as can be seen from Table 2, all stations recorded high amounts of rainfall during December and January and a decline in March. This trend confirms the life cycle of the Inter Tropical Convergence Zone (I.T.C.Z.). The I.T.C.Z is a zone of convergence between the Northeast and the Southeast trade winds [13,14]. It is formed over the area of maximum heating inland where an equatorial low pressure is formed [15]. It is known as the Inter Tropical Front (I.T.F.) in West Africa; it is the northern edge of the Western African Monsoon [16]. It's movement north and south of the equator is a consequence of the earth's rotation around the sun [17]. The I.T.C.Z is the dominant rain producing mechanism over Southern Africa. Over Zambia it remains ill-defined and inactive until early or mid-December, reaches it's peak in January giving Northern Zambia it's main rains before it traverses southwards.

During the rainy season off peak (Fig. 4), Isoka, which is geographically located further north of the study area receives more rainfall than any other station. This trend can be explained as the remnants of the influence of the I.T.C.Z as it traverses northwards. Kabwe, which is south of the study area receives the least amounts of rainfall during this period.

Individual station rainfall climatology during the period of study is shown in Figs. 5 – 11. The figures show the standard deviation, maximum rainfall recorded and the lowest rainfall recorded. The highest monthly rainfall received on record for Mansa during the study period was 497.1mm in 2002 in the month of January (Table 3). Kabwe recorded the highest monthly rainfall in December 1969 which amounted to 459.5 mm. The highest monthly rainfall reported in Kasama was 509.5 mm in the month of December 1961. 750.8 mm is the highest monthly rainfall received during the 1960 – 2010 period in Chipata in December 2008. Isoka received the maximum monthly rainfall in December 1997 which amounted to 452.3 mm. Solwezi reported 637.9mm in December 1997 during the period of study. In December 1977 Ndola received 560.7 mm as it's maximum monthly rainfall during the study period.

From these results, it can further be clearly seen that apart from Kabwe which is south of the study area, all stations experience a decrease in precipitation during March / Aprilcoinciding with the period when the I.T.C.Z traverses southwards giving Kabwe, Central and Southern parts of Zambia their main rains.

Table 2. Mean monthly rainfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mansa	255.5	221.3	203.5	51.7	5.6	0.1	0	0.1	3.7	31.6	137.4	255.1
Kasama	280.4	254.1	244.9	80.2	8.1	0.2	0.1	0.1	3.1	32.6	143.1	277.8
Isoka	227.6	233.4	178	76	11.1	0.2	0.1	0.1	0.2	9.6	84.9	207.7
Solwezi	274	227.4	233	59.9	4.6	0.3	0	0.7	3.6	44.5	168.8	278.7
Ndola	296	242.7	172.7	35.7	3.4	0.4	0.2	0.3	2.4	27.3	122.1	298.6
Chipata	266.7	242.6	172.9	45.7	3.4	0.6	0.2	0.1	0.9	11.3	84.3	258.7
Kabwe Main	228.9	184.9	108.6	24.3	3.7	0.1	0.7	0.1	1.1	15.1	104.7	236.7

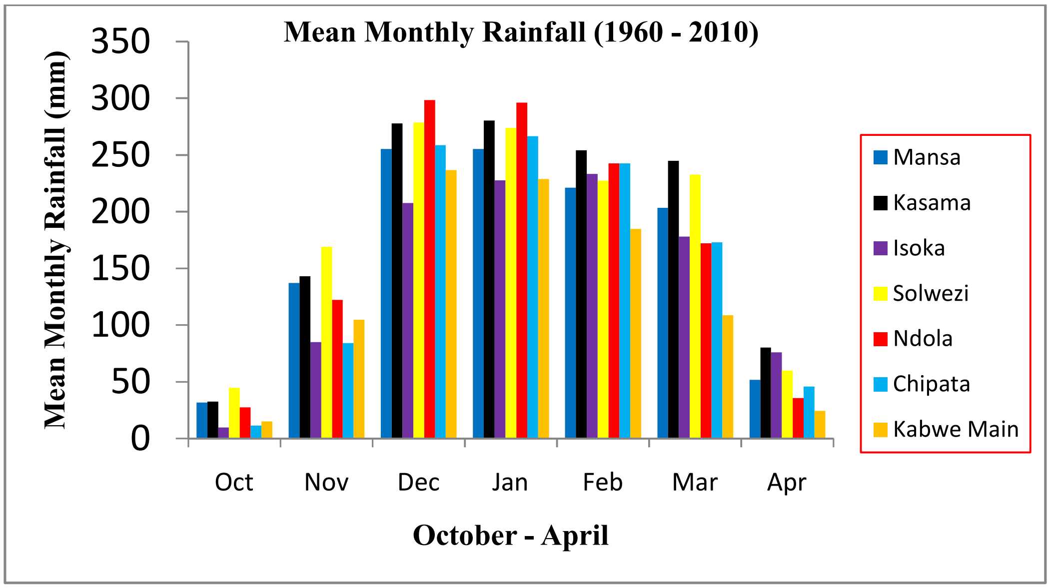


Fig. 3. Mean monthly rainfall (October- April)

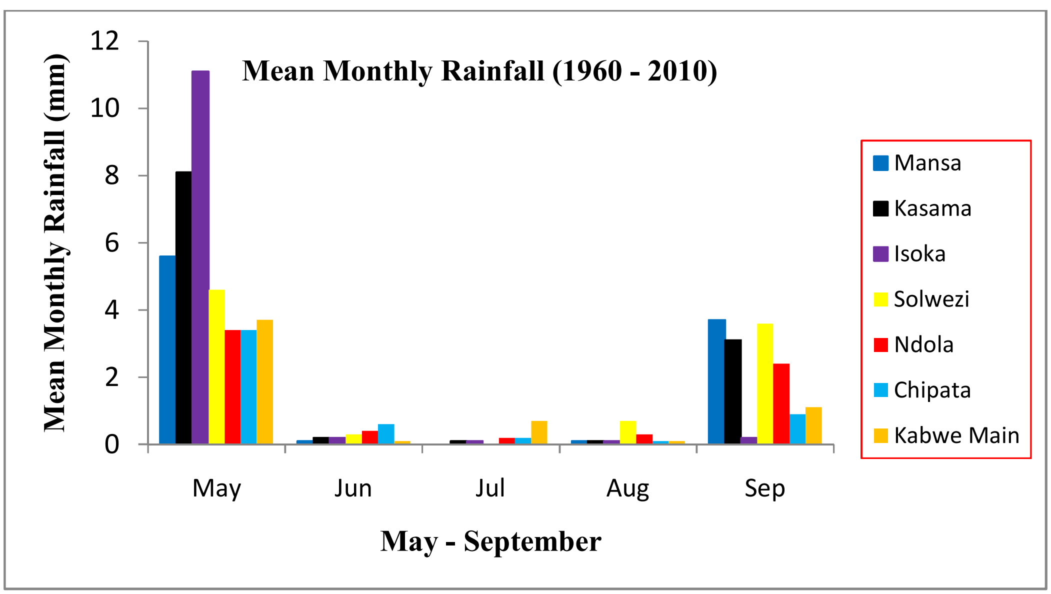
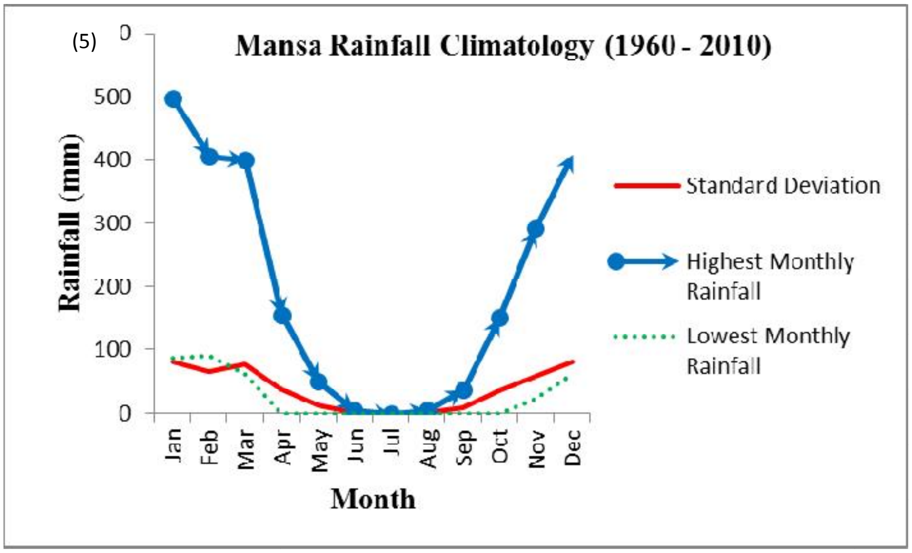
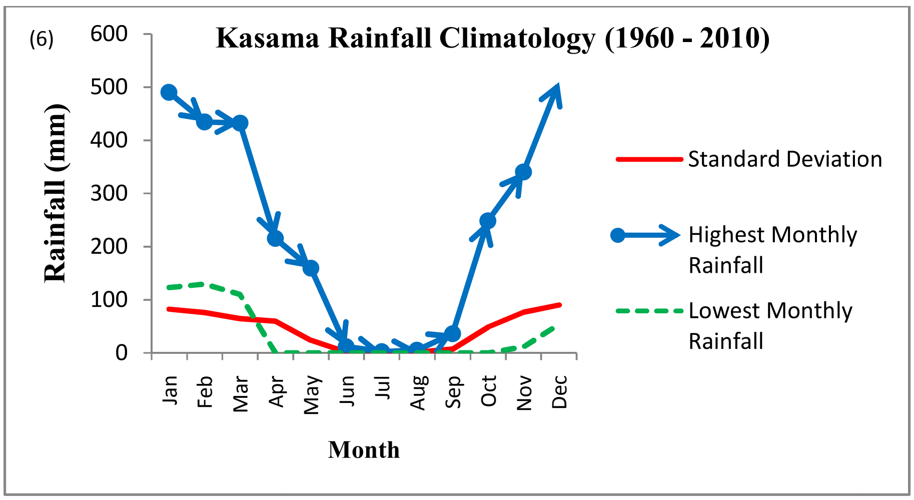
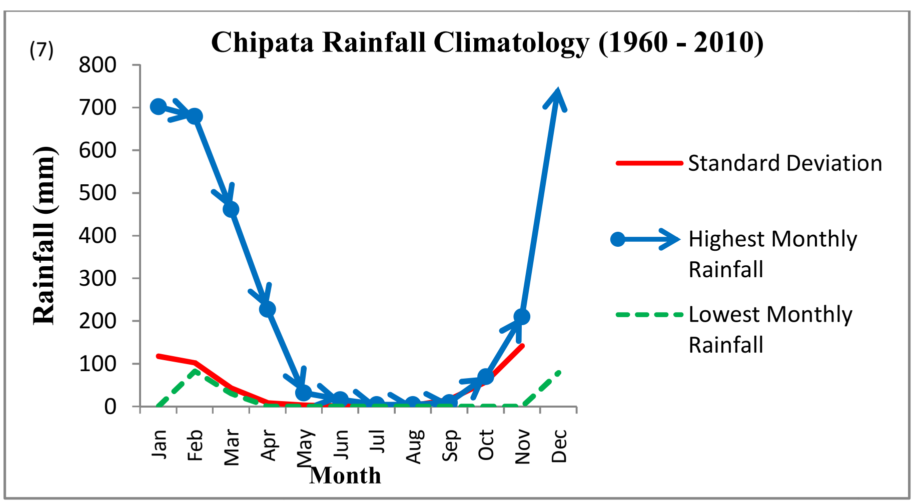
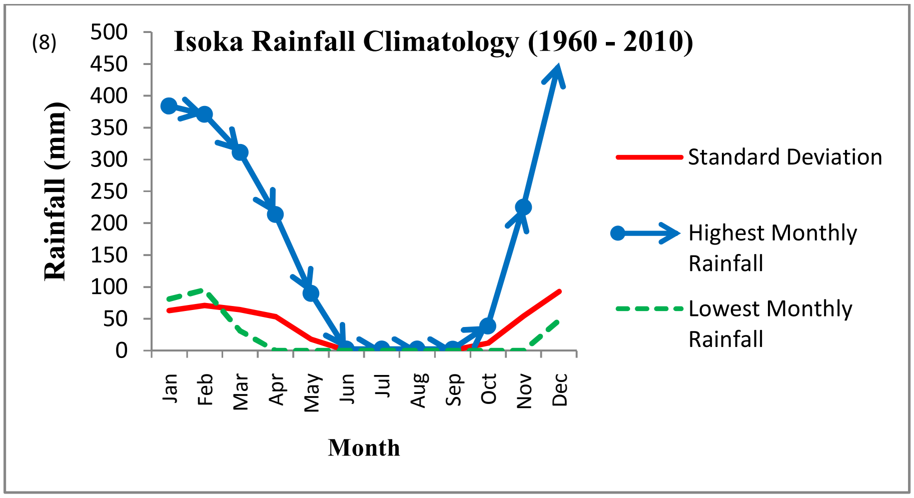


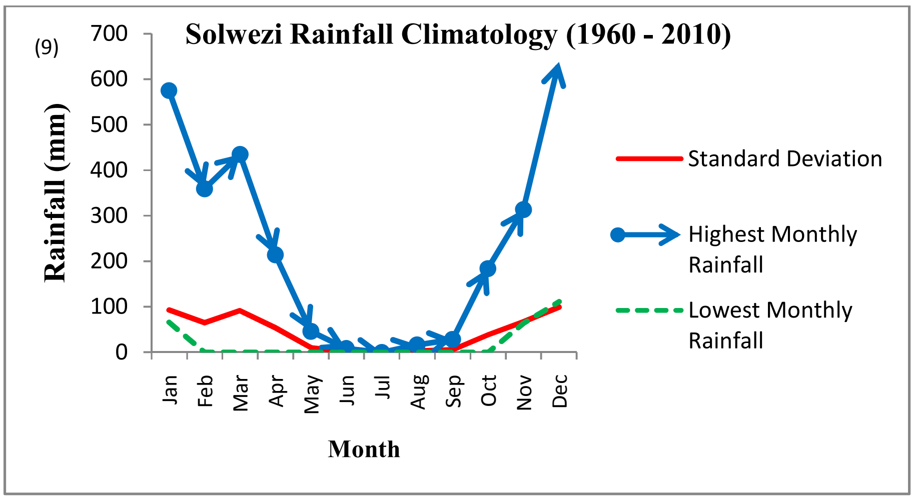
Fig. 4. Mean monthly rainfall (May– September)

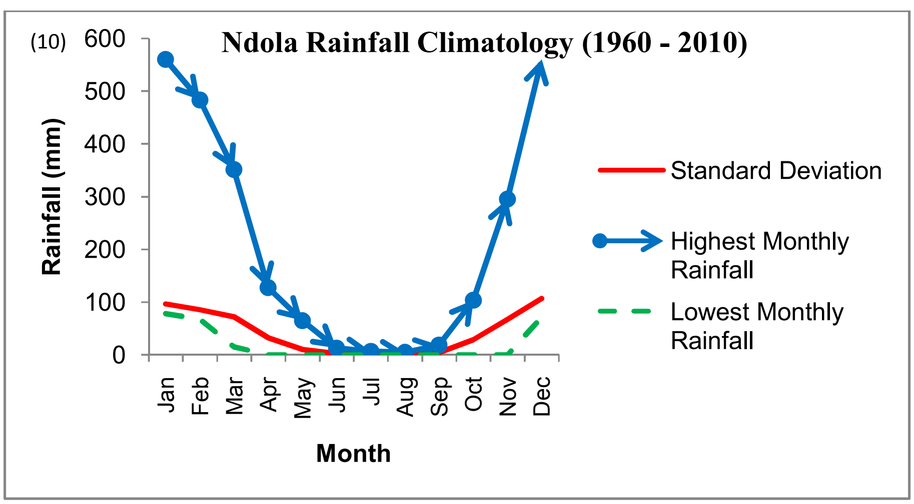

(5)
Mansa Rainfall Climatology (1960 - 2010)
Rainfall (mm)
0
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Standard Deviation
Highest Monthly Rainfall
Lowest Monthly Rainfall


(6)
Kasama Rainfall Climatology (1960 - 2010)
Rainfall (mm)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Standard Deviation
Highest Monthly Rainfall
Lowest Monthly Rainfall


(7)
Chipata Rainfall Climatology (1960 - 2010)
Rainfall (mm)
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Standard Deviation
Highest Monthly Rainfall
Lowest Monthly Rainfall


(8)
Isoka Rainfall Climatology (1960 - 2010)
Rainfall (mm)
500
450
400
350
300
250
200
150
100
50
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Standard Deviation
Highest Monthly Rainfall
Lowest Monthly Rainfall


(9)
Solwezi Rainfall Climatology (1960 - 2010)
Rainfall (mm)
700
600
500
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Standard Deviation
Highest Monthly Rainfall
Lowest Monthly Rainfall


(10)
Ndola Rainfall Climatology (1960 - 2010)
Rainfall (mm)
600
500
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
Standard Deviation
Highest Monthly Rainfall
Lowest Monthly Rainfall

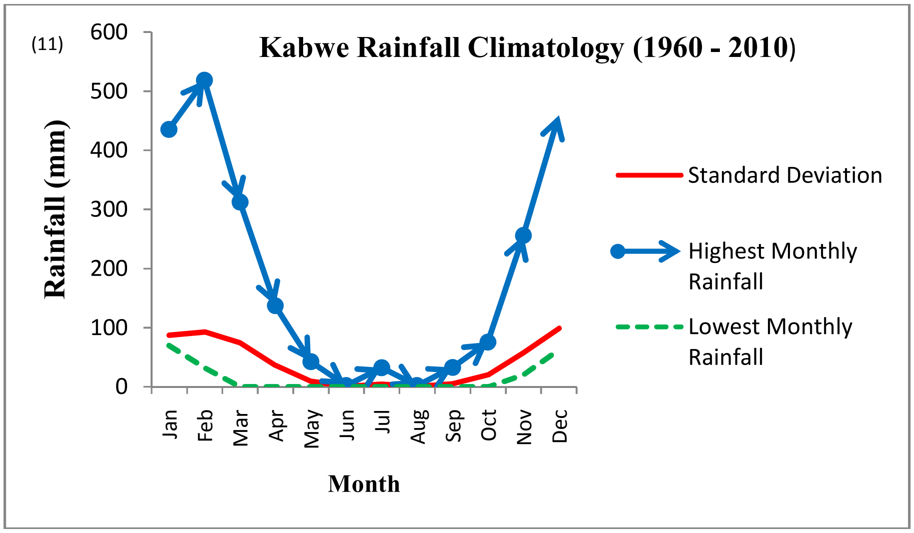


Fig. 5-11. Rainfall variability at individual stations

Table 3. Highest station rainfall received during study period

Station	Rainfall (mm)	Year	Month
Mansa	497.1	2002	January
Kasama	509.5	1961	December
Chipata	750.8	2008	December
Isoka	452.3	1997	December
Solwezi	637.9	1997	December
Ndola	560.7	1977	December
Kabwe	459.5	1969	December

3.3 Relationship with El Nino Southern Oscillation (ENSO)

ENSO episodes based on a threshold of +/- 0.5ºC for the Oceanic Niño Index (ONI) in the Niño 3.4 region [18] showed that during *El Niño,* warm episode, Zambia has a high risk of severe drought while during the cold episode, *La Niña*, most parts of Zambia experience above average rainfall [19]. The study found that *El Niño* conditions (warm phase) bring drier than average conditions in the wet summer months (DJF) in the southern half of the country, whilst the north of the country simultaneously experiences significantly wetter-than average conditions. The reverse pattern occurs with *La Niña* (cold phase) episodes, with dry conditions in the north and wet conditions in the south. Zambia was one of the countries in Africa most severely affected by the 1997/1998 *El Niño* event, suffering flooding due to abnormally persistent and heavy rainfall in the north, as well as near-drought conditions in the south [20].

4. CONCLUSION

Northern Zambia receives much of its rain from October to April with December and January as the peak of the rain season. May – September is the off peak of the rain season in Northern Zambia; during this period, Isoka receives more rainfall. The north and northwestern regions such as Solwezi and Kasama tend to receive more rainfall compared to other regions of the study area. Northern Zambia is particularly affected by the movement of the I.T.C.Z which brings rains when it enters Zambia from the North in December and January as it traverses to the south of the country. During warm (cool) ENSO events, dry (wet) conditions generally occur over much of the summer rainfall.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Barnston Ag, Smith Tm. Specification and prediction of global surface temperature and precipitation from global SST using CCA. J. Climate. 1996;9:2660-2697.
2. Hellmuth ME, Moorhead A, Thomson MC, Williams J (Eds). Climate risk management in Africa: Learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, USA; 1997.
3. Jury MR, Pathack BMR. Composite climatic patterns associated with extreme modes of summer rainfall over southern Africa: 1975–1984. Theoretical and Applied Climatology. 1993;47(3):137-145.
4. Allan Robert J, Chambers Don, Drosdowsky Wasyl, Hendon Harry, Latif Mojib, Nicholls Neville, Smith Ian, Stone Roger C, Tourre Yves. Is there an Indian Ocean dipole and is it independent of the El Niño-Southern Oscillation. CLIVAR Exchanges. 2001;6(3):18-22. ISSN 1026 – 0471.
5. Mason SJ, Jury MR. Climatic variability and change over southern Africa: A reflection on underlying processes. Progress in Physical Geography. 1997;1 (21):23-50.
6. Sadiq N, Qureshi MS. Estimating a recurrence intervals of extreme rainfall through a probabilistic modeling approach for different urban cities of Pakistan. Arabian Journal for Science and Engineering. 2014;39(1):191-198.
7. Hobbs JE, Lindesay JA, Bridgman HA. Climates of the Southern Continents. Present, Past and Future. Wiley and Sons, Chichester; 1998.
8. Folland CK. Regional-scale interannual variability of climate. A north-west European perspective. Meteorological Magazine. 1983;12:163 -187.
9. Okoola RE. A diagnostic study of the East African monsoon circulation during the northern hemisphere spring season. Int J Climatol. 1999;19:143-169.
10. Ininda JM. Numerical simulation of the influence of sea surface temperature anomalies on the East African seasonal rainfall. PhD Thesis, University of Nairobi, Kenya; 1995.
11. Liebmann B, Marengo JA. Interannual variability of the rainy season and rainfall in the Brazilian Amazon basin. J Clim. 2001; 14:4308-4318.
12. Sylla MB, Giorgi F, Coppola E, Mariotti L. Uncertainties in daily rainfall over Africa: assessment of gridded observation products and evaluation of a regional climate model simulation. Int J Climatol. 2012;21. 10.1002/joc.3551.
13. Barry Roger Graham, Chorley Richard J. Atmosphere, weather, and climate. London: Routledge; 1992. ISBN 978-0-415-07760-6. OCLC 249331900.
14. Djurić D. Weather Analysis. Prentice Hall; 1994. ISBN 0-13-501149-3.
15. Bernard Cros, Robert Delmas, Dominique Nganga, Bernard Clairac, Jacques Fontan. Seasonal trends of ozone in equatorial Africa: Experimental evidence of photochemical formation. Journal of Geophysical Research: Atmospheres. 1988;3(9):8355–8366.
16. Serge Janicot. Spatiotemporal Variability of West African Rainfall. Part II: Associated Surface and Airmass Characteristics. J. Climate. 1992;5:499–511.
    Available:http://dx.doi.org/10.1175/1520-0442(1992)005<0499:SVOWAR>2.0.CO;2
17. Sharon E. Nicholson. Rainfall and Atmospheric Circulation during Drought Periods and Wetter Years in West Africa. Mon. Wea. Rev. 1981;109:2191–2208.

Available: http://dx.doi.org/10.1175/1520-0493(1981)109<2191:RAACDD>2.0.CO;2

18. NOAA, Historical El Nino/ La Nina episodes (1950-present). 2014, accessed 26th December 2014.

    Available:http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

19. Nicholson SE. On the characteristics of warm episodes in the tropical Atlantic and Indian Oceans. Int. J. Climatol; 1997.

20. Ropelewski CF. The biennial component of ENSO variability. J. Mar. System. 1990; 71–90.

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