Inter annual-Fluctuation of Rainfall Time Series in Malawi; An Analysis of Selected Areas

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1. Introduction

One of the most important aspects of climate change that requires thorough investigation is the time distribution of rainfall and its historical changes. An understanding of temporal and spatial characteristics of rainfall is central to water resources planning, agricultural planning and climate change impacts. Malawi has an agro-based economy where crop production and the choice of the crops that can be grown are largely determined by climatic and soil factors. Therefore, a detailed knowledge of precipitation regime is an important prerequisite for agricultural planning and country's economic development. This paper analyses the fluctuation in space and time of rainfall time series at 9 stations of Malawi which was carried out over a 30 year period.

2. Materials and methods

2.1 Study area

Malawi is located in eastern southern Africa. Malawi has a sub-tropical climate, which is relatively dry and strongly seasonal. The warm-wet season stretches from November to April, during which 95% of the annual precipitation occurs. Annual average rainfall varies from 725mm to 2,500mm. Wet season rainfalls depend on the position of the Inter-Tropical Convergence Zone (ITCZ). Topographical influences also cause local variations to the rainfall with the highest altitude regions receiving the highest rainfalls.Inter-annual variability in the wet-season rainfall in Malawi is also strongly influenced by Indian Ocean sea surface temperatures. A cool, dry winter season is evident from May to August and a hot, dry season lasts from September to October with average temperatures varying between 25 and 37 degrees Celsius.

Fig. 1 Map showing study areas

2.2 Methodology

a. Seasonal index

The Seasonal Index (*SI*) designed by Walsh and Lawler (1981) was used to assess the aspect of rainfall seasonality in this study. The Seasonal Index is given as:

$$SI = \frac{1}{R}\sum_{n=1}^{12}\left|X_n - \frac{R}{12}\right| \quad \text{……………………………………………} (1)$$

Where; X_n, is rainfall of month *n* and *R* is annual rainfall.

b. Precipitation concentration index

The seasonality and heterogeneity of rainfall amounts were evaluated by using the *PCI*;

$$PCI = \frac{\left(\sum_{i=1}^{12} Pi^2\right)}{\left(\sum_{i=1}^{12} Pi\right)^2} * 100 \quad \text{……………………………………………} (2)$$

Where; p_i is the rainfall amount of the month *i*.

c. Power spectral analysis

The spectral analysis used the Maximum Entropy Method (MEM).

$$r(t) = a_0 + \sum_{i=1}^{n}\left[a_i \cos 2\pi f_i t + b_i \sin 2\pi f_i t\right] \text{……………………………………………} (3)$$

Where; *a*, *b*: the Fourier coefficient, t: period, n: number of terms.

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3. Results and discussion

3.1 Seasonal index

Table 1 outlines the results of the seasonal index. The results show that Nkhatabay with an annual seasonal index of 0.74 was the only station with seasonal rainfall. Nkhatabay receives both convectional and topographical rainfall and has even rainfall distribution throughout the year. The rest of the stations had seasonal index values ranging from 1.03 to 1.15 which means that they receive most rain in 3 months or less. The decadal seasonal index did not show any significant changes in the pattern of rainfall for all the station.

Table1 Seasonal index

Station	Nkhatabay	Ngabu	Karonga	Makoka	Mangochi	Dedza	Bolero	Kasungu	Salima
Annual *SI*	0.74	0.87	1.03	1.03	1.04	1.06	1.08	1.13	1.15
Remark	seasonal	markedly seasonal	most rain in 3 months or less						

3.2 Precipitation concentration index

Table 2 shows the results of the *PCI* analysis. The analysis of the *PCI* showed that seasonal precipitation concentration index varied from 14 to 21. Only Nkhatabay with a *PCI* value of 14 had ‘moderately seasonal’ rainfall concentration. Ngabu, Makoka, Mangochi and Karonga with *PCI* values ranging from 17 to 19 had ‘seasonal’ rainfall concentration. The rest of the stations had *PCI* values greater than 20 which mean they have highly seasonal rainfall concentration. The temporal *PCI* was calculated from the rainfall data set of individual years and later averaged over 31years. The temporal *PCI* showed the intra-annual variability in rainfall concentration of the stations.

Table 2 Precipitation concentration index

Station	Nkhatabay	Ngabu	Karonga	Makoka	Mangochi	Dedza	Bolero	Kasungu	Salima
PCI	14	17	18	19	19	20	21	21	21
Remark	moderately seasonal	seasonal					highly seasonal		
Temporal *PCI*	18	21	23	23	24	23	24	25	27
	seasonal	highly seasonal							

3.3 Power spectrum

The results of the analysis are tabulated in **Table 3**. Spectral analysis of the rainfall index revealed cycles at 2.4, 3.8 years and 11.1 years, suggesting links with El Nino Southern Oscillation (ENSO), the Quasi-Biennial Oscillation (QBO) and the solar cycle respectively. The influence of sun spot number was apparent. There were similarities between the periodicities of Karonga and Bolero (*T*=9.1 years); Nkhatabay, Dedza, Salima and Mangochi had similar periodicities, *T* equal to 10.5 and 10.6 respectively. This can be explained by the locality of the stations for example in the same regions.

Table 3 Detected frequencies

Station	Detected Frequencies										
					Bolero						
Frequency(cycle/year)	0.34	0.31	0.24	0.21	0.17	0.14					0.11
Time (year)	2.9	3.2	4.1	4.9	5.9	7.2					9.1
					Salima						
Frequency(cycle/year)	0.39	0.38	0.37	0.33	0.29	0.24	0.23	0.19	0.16	0.10	0.09
Time (year)	2.5	2.6	2.7	3	3.4	4.2	4.3	5.1	6.3	9.8	10.6
					Mangochi						
Frequency(cycle/year)	0.42	0.41	0.37	0.31	0.28	0.25	0.23	0.18	0.16	0.13	0.09
Time (year)	2.4	2.5	2.7	3.2	3.5	4.1	4.4	5.4	6.4	7.9	10.5

4. Conclusion

There was a high spatial variability of rainfall both annually and monthly. The rainfall pattern in Malawi suggests that local factors like topography and location affect the spatial distribution of rainfall. Annual rainfall had a property of periodical fluctuation where a wet year was followed by a dry year. *SI* analysis showed that only one station Nkhatabay had a seasonal rainfall pattern and the rest of the stations receive rainfall in 3 months or less. The *PCI* showed that Nkhatabay had moderately seasonal rainfall with the rest of the stations showing seasonal to highly seasonal rainfall concentration. Spectrum analysis of the rainfall time series revealed cycles at 2.1, 2.4 3.8, and 11.1 years, suggesting links with QBO, ENSO and the solar cycle and in some cases double solar cycle respectively. The influence of sun spot number and Southern Oscillation Index was apparent.