Journal of Climate Change, Vol. 5, No. 2 (2019), pp. 23-34.
DOI 10.3233/JCC190010

Long-term Rainfall Analysis towards Detection of Meteorological Drought over Kozhikode District of Kerala

U. Surendran[1]*, B. Anagha[1], Girish Gopinath[2] and E.J. Joseph[1]

[1] Water Management (Agriculture) Division, Centre for Water Resources Development and Management, Kozhikode, Kerala – 673571, India

[2]Geomatics Division, Centre for Water Resources Development and Management Kozhikode, Kerala – 673571, India

✉ u.surendran@gmail.com

Received January 3, 2019; revised and accepted June 30, 2019

Abstract: This study was carried out with the objective of identifying the trends in season, annual rainfall and occurrence of drought events using different statistical methods for the period of 110 years for Kozhikode district of Kerala, India. The results showed that the average annual rainfall of Kozhikode is 3177 mm with the standard deviation of 551.7 mm. The coefficient of variation confirmed that annual rainfall has very low inter annual variability, but the seasonal variability is high. Trend analysis results revealed that the rainfall is decreasing in Southwest Monsoon, Northeast Monsoon and Winter Season while increasing trend was observed in Summer Season. To understand the variation due to climate change, the time scales were divided into two (viz., 1902-1956 and 1957-2012), and trend analysis were carried out. The results showed that the Southwest Monsoon indicated a decreasing trend in both time scales; however substantial decreasing trend was observed for the recent decade i.e. 1957-2012 indicating the climatic variability. Precipitation Concentration Index (PCI) analysis showed that, among the 110 years, 57 years are coming under the classification of strong irregularity in the rainfall (PCI > 20) and the remaining years falls under the class of irregular precipitation with the PCI value 15-20. Drought indices were characterized using Rainfall Anomaly Index, Departure Analysis of Rainfall, Deciles, and Standardized Precipitation Index and the occurrence of drought events were identified. The wavelet analysis clearly showed noticeable change in the rainfall pattern after 1950 and indicating the impact of climate change. Findings from such studies are useful tools for policy makers to devise strategic management plans to overcome droughts and mitigate their effects on the activities in different sectors of the Kerala State.

Keywords: Rainfall; Trend analysis; Drought; DrinC; Wavelet analysis; Climate change.

Introduction

Climate change and unpredictability of these variations will affect hydrological regimes and have repercussions on water resources management. Water stress is severe in many countries and water for agriculture is becoming scarce day by day, particularly in India. Timely availability of water and a favourable climate are the vital determining factors for food (agriculture and allied sectors) and energy security of India. The primary source of water in any area is rain and it decides the development of that region. Global climate changes may manipulate long-term rainfall patterns and influences the water availability, along with the

*Corresponding Author

risk of increasing occurrences of droughts and floods. Rainfall information is indispensable for understanding the hydrological balance and complex interactions among the components within the hydrological cycle on any scale (global, regional, macro/micro watershed etc). Evapotranspiration (ET) and rainfall eventually determine the water balance, crop water and irrigation requirements of different crops of the region (Surendran et al., 2014; Surendran et al., 2016; Surendran et al., 2017a). Studies of such climatic parameters are thus helpful in defining the risk levels in arable agriculture.

Past studies related to changes in rainfall for country (India) as a whole have concluded that there is no clear trend in average annual rainfall, but region-wise analysis pointed out different results of either increasing or decreasing trends (Dash et al., 2007; Krishnakumar et al., 2008). Studies of temporal variation in rainfall over Kerala for 1871–2005 by Krishnakumar et al. (2009) revealed significant decrease in SW monsoon rainfall, and an increase in post-monsoon season rainfall.

Kerala is a primary producer of many of the commercial agricultural commodities in India and it experiences a humid tropical climate, which is characterized by the presence of heavy rainfall, high relative humidity, sunshine and ambient temperature. The yield of most of the crops remain static or less when compared to national average. Even though the mean annual rainfall in the State is 3000 mm, its temporal distribution is highly uneven, resulting in a periodical long dry spell of about 5 to 6 months. The rainfall variability is very high in Kerala and the state is experiencing more drought during the last two to three decades, which is contributing to the decline in agricultural production (Guhathakurta and Rajeevan, 2008; Pal and Al-Tabbaa, 2009).

As a result of the large inter-annual rainfall variability which often results in climatic hazards, there is dire need to study the rainfall characteristics of even a smaller region to understand the pattern of rainfall and also to plan for future water management scenarios. Understanding rainfall variability is essential to deal with the scarce water resources optimally that are under continuous stress due to increasing water demands, increase in population, and the economic development. With this as a background the present study was carried out with the objective of analyzing the trends in rainfall and also to understand the occurrence of drought for a long term period of Kozhikode district in a detailed manner for humid tropical region of Kerala.

Methodology

Study Area

The selected study area of Kozhikode district falls under humid tropical region of Kerala State, India, which is abundant with an annual average rainfall of above 3000 mm, and it is three times higher than the Indian national average. It lies between North latitudes 11° 08′ to 11° 50′ and East longitudes 75° 30′ to 76° 8′. It is falling in parts of Survey of India Toposheets 58 A and 49 M. Kozhikode district is bounded on the north by Kannur district, on the east by Wayanad district, on the south by Malapuram district and on the west by Arabian Sea.

Data and Climatic Description

Rainfall data in mm for Kozhikode district, Kerala for the period of 1902-2012 (110 years) was collected from Indian Meteorological Department (IMD), Pune. Season-wise analysis has been carried out based on IMD classification as Southwest monsoon (June–September), Post-monsoon/northeast monsoon (October–December), winter (January–February) and Pre-monsoon/summer (March–May). Descriptive statistics such as mean, standard deviation (SD), skewness, kurtosis and coefficient of variation (CV) were derived for the monthly, annual and seasonal-rainfall. Besides, percentage contribution towards annual rainfall for monthly and seasonal was also calculated.

Trend Analysis

Linear Regression

Identification of trend was done using the statistical analysis of linear regression (parametric) and Mann Kendall test (non-parametric). Linear regression is used to calculate the trend of data in time series and the equation is as follows.

$$Y = a + bX \tag{1}$$

where X is the independent variable (year/time) and Y is the dependent variable (rainfall). The P value from the analysis is the test for the significant level $\alpha = 0.05$.

Mann Kendall Trend Test

The Mann Kendall trend test (Mann, 1945; Kendall, 1975) is a non-parametric test and is based on the correlation between the ranks of a time series and their time order. The equation is given below

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i) \tag{2}$$

where S is the Mann Kendall statistics.

$$\text{Variance} = \sigma^2 = \frac{1}{18} n(n-1)(2n+5) \tag{3}$$

n = no of years

If tied values are present then the equation for variance will change into

$$\sigma^2 = \frac{1}{18} n(n-1)(2n+5) + \frac{1}{18} t_p(t_p+1)(2t_p+5) \tag{4}$$

where t_p = No of tied values

$$Z = \begin{cases} \frac{S-1}{\sigma}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sigma}, & S < 0 \end{cases} \tag{5}$$

Trend in Mann Kendall is predicted by using Mann Kendall test statistics (Z), a positive (negative) value Z signifies the upward (downward) trend.

Rainfall Concentration and Seasonality Analysis

The Precipitation Concentration Index (PCI; Oliver, 1980) shows the rainfall concentration (de Luis et al., 2000, 2011). PCI is calculated on an annual scale by using the equation (6)

$$\text{PCI}_{\text{Annual}} = \frac{\sum_{I-1}^{12} P_i^2}{\left(\sum_{I-1}^{12} P_i\right)^2} \times 100 \tag{6}$$

where P_i is the monthly rainfall for month i.

PCI values are classified into four no's based on the monthly distribution of rainfall and the lowest value of PCI is 8.3, leading to a perfect uniformity in rainfall distribution (de Luis et al., 2011).

Seasonality Index

Seasonality Index (SI) is an index which calculates the degree of variability in monthly rainfall through the year (Walsh and Lawer, 1981; Guhathakurta and Saji, 2013). It is calculated using the following formula given in equation (7)

$$\text{SI} = \frac{1}{N} \sum_{n=1}^{12} \left| X_n - \frac{\overline{R}}{12} \right| \tag{7}$$

where X_n is the mean rainfall of month n and $\overline{R}$ is the mean annual rainfall.

Theoretically, the SI can vary from zero (if all the months have equal rainfall) to 1.83 (if all the rainfall occurs in one month) (Kanellopoulou, 2002).

Drought Analysis

The focus of drought analysis is based on the rainfall related drought. Departure Analysis of Rainfall (DAR), Rainfall Anomaly Index (RAI), and Standardized Precipitation Index (SPI) are the rainfall related drought indices. Out of these three indices, two (DAR, RAI) of them were calculated using formula mentioned below and the SPI was calculated using a Drought Indices software named DrinC.

Rainfall Anomaly Index (RAI)

Rainfall Anomaly Index is a ranking procedure to assign magnitudes to positive and negative precipitation anomalies, which is calculated as Equation (8).

$$\text{RAI} = \pm 3 \frac{P - \overline{P}}{\overline{E} - \overline{P}} \tag{8}$$

where RAI is Rainfall Anomaly Index, $\overline{P}$ is measured precipitation, $\overline{E}$ is mean precipitation, and P is average of 10 extrema. Here extrema is meant by highest and lowest rainfall years during the study period. According to the magnitude, RAI is classified into nine classes which is varying from extremely wet to extremely dry ranges.

Departure Analysis Rainfall (DAR)

Percentage departure in annual rainfall is calculated for understanding the drought year by using the formula in equation (9) based on the value of departure. DAR is classified into five categories; this classification is ranging from excess (<20%) rain to no rain condition (–100%)

$$D\% = \frac{X_i - X_m}{X_m} \times 100 \tag{9}$$

where X_m is the mean annual rainfall from the annual rainfall series (X_i)

Drought Characterization Using DrinC

Standardized Precipitation Index (SPI): DrinC (Drought Indices Calculator) is a software package which can be used for calculating drought indices by providing a simple, though adaptable interface by considering all the factors. Details about the structure and calculation steps can be referred from Tigkas et al. (2014). Certain long term meteorological data are used as input to obtain various indices such as deciles, Standard Precipitation Index (SPI) and RDI, based on which the drought severity can be analyzed and the trend of occurrence of drought can be predicted. The Standardized Precipitation Index (SPI) is widely used as drought meteorological index, to identify the duration and/or severity of a drought. Based on the severity, drought is classified into eight classes, which is ranging from extremely wet (SPI>2) to extremely dry (<–2) (Tsakiris and Vangelis, 2004). Gamma method and Log normal method are the two commonly used methods to calculate SPI. This index is also calculated by using software DrinC.

Wavelet Analysis

Wavelet analysis is the common tool for analyzing localized variation of power within a power series and is also used to determine the frequency or period of a signal. The wavelet transform can be used to analyze time series using the following equation

$$W(\omega, \tau, x(t)) = \omega^{1/2} \int x(t)\psi(\omega(t-\tau))dt \qquad (10)$$

where ω is the scale factor (frequency), τ is time shift, t is time, $x(t)$ is the time series, each value is separated in time by a constant time interval dt and Ψ is the complex conjugate of the wavelet function. The wavelet transform is just the inner product (or convolution) of the wavelet function with our original time series. Wavelet analysis was carried out on the basis of both annual rainfall and monthly rainfall series for visualization of occurrence of events in a broad time scale by using available online tool http://paos.colorado.edu/research/wavelets/ in Kozhikode district (Morlet et al., 1982).

Results

Rainfall Characteristics

Data with respect to average, % Contribution to annual rainfall, Standard Deviation, Coefficient of Variation-CV (%), Skewness and Kurtosis are presented in Table 1. The average annual rainfall of Kozhikode in Kerala for 110 years is 3177 mm with the standard deviation of 551.7 with maximum rainfall of 4962 mm (observed in 1961) and minimum of 2162 mm (observed in 1976). The rainfall range confirms the difference between the maximum and minimum annual rainfall. The standard deviation and the range indicate the variability of annual rainfall and we can understand the reliability of the rainfall in terms of its persistence as constant. However considering the average annual rainfall of 3177 mm, standard deviation seems to be low which indicates that fluctuations are lower.

The coefficient variation of annual rainfall is low

Table 1: Monthly and seasonal means of rainfall (mm) in Kozhikode for 110 years (1902-2012)

	Average (μ)	*% contribution to annual rainfall*	*Standard deviation (σ)*	*CV (%)*	*Skewness*	*Kurtosis*
Month-wise analysis						
January	6.54	0.21	16.55	252.9	4.15	21.28
February	5.65	0.18	18.48	327.1	5.59	31.13
March	19.62	0.62	38.22	194.8	3.72	18.15
April	86.81	2.73	74.64	85.9	1.06	1.28
May	267.89	8.43	228.09	85.1	1.30	1.22
June	829.30	26.11	239.29	28.8	-0.20	-0.01
July	832.65	26.21	315.21	37.8	0.71	0.48
August	438.54	13.81	203.13	46.3	1.48	3.18
September	241.42	7.60	166.24	68.8	0.93	0.29
October	275.01	8.66	146.29	53.1	1.07	2.03
November	144.28	4.54	105.56	73.1	0.98	0.73
December	28.95	0.91	40.18	138.8	1.85	3.24
Season-wise analysis						
Winter	12.19	0.38	24.10	197.74	3.27	12.80
Summer	374.31	11.78	236.87	63.28	1.15	1.08
SW monsoon	2341.92	73.72	510.82	21.81	0.63	0.46
NE monsoon	448.23	14.11	175.71	39.20	0.44	0.17
Annual	3176.65	100	551.67	17.37	0.64	0.38

(17%) which implies that inter annual variability of annual rainfall is very low. The maximum share of annual rainfall is from the months of June (26.1%) and July (26.2%), which together contribute more than 50% to the annual rainfall, followed by August (13.8%) and October (8.6%). January, February and March receive negligible rainfall and these three months together contribute only less than 1% to the annual rainfall. Coefficient of variation is maximum (>100%) in the months of December to March, thereby indicating a higher variability in the rainfall, whereas it is minimum in the months of June to August (<50%) indicating less variability in the rainfall pattern. The low coefficient of variability recorded for the aforementioned months is an indication of highly dependable rainfall.

Major share of annual rainfall (74%) is contributed by Southwest monsoon. Pre monsoon and Post monsoon seasons receives rainfall of 374 mm (11.7%) and 448 mm (14.1%) of rainfall respectively. Compared to annual rainfall, seasonal rainfall shows more variability. Out of the four seasons winter shows more variability (CV=198%) which shows that winter rainfall is less dependable compared to other seasons, whereas SW monsoon is highly dependable (CV=21.8%). The reason is that this region is dominated by the south-west (SW) monsoon and the winds are southwesterly (meaning from the south-west) to westerly during these months resulting in high rainfall and it is dependable.

Rainfall Trend in Annual and Seasonal Scales

The Mann Kendall test during the period of 1902-2012 IMD data suggests that annual, SW monsoon, post monsoon (NE monsoon) and winter showed a declining trend. There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second the test has low sensitivity to abrupt breaks due to inhomogeneous time series. Only pre monsoon (summer) season showed an increasing trend in Mann Kendall test for the time scale of 1902-2012 (Table 2). This is in contrast to the earlier findings of Krishnakumar et al., 2009, in which post monsoon also showed an increasing trend.

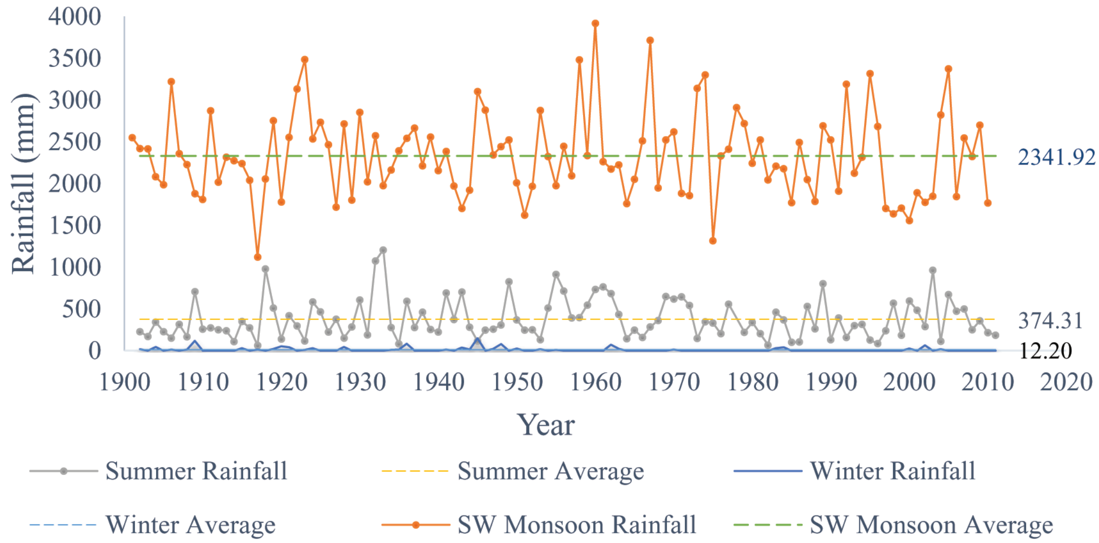
To understand the difference, the data were split into two time scales viz., 1902-1956 and 1957-2012; each consists of 55 years. When this data were subjected to the trend analysis the trend showed different pattern. The first 55 years showed an increasing trend in the annual rainfall, whereas the next 55 years showed a declining trend. The main reason is that the amount of increase in the initial 55 years is less compared to the declining trend in the later 55 years; therefore the overall trend showed a declining trend. Similarly, in both the two time scales post monsoon (NE monsoon) showed an increasing trend. This indicated that Mann Kendall trend analysis relates the value on the correlation between the ranks of a time series and their time order.

Linear regression equation for annual and seasonal scale was calculated and presented in Table 2 and Figures 1a and b. Annual, southwest monsoon and winter showed a declining trend, whereas northeast monsoon and summer exhibited an increasing trend for the 110 year period. This is similar to the earlier findings of Krishnakumar et al., 2009; Archana et al., 2014 and Thomas and Prasannakumar. 2016. With respect to two different time scales (viz., 1902-1956 and 1957-2012), some interesting things could be established. Even though the southwest monsoon decreased in both the time scales, the quantum of declining is higher in the recent decade i.e 1957-2012. This is evident from the slope of SW monsoon for the time scale of 1957-2012 is -7.01 but the same for the previous time scale –0.356, which implies that the reduction in SW monsoon is huge during 1957-2012 time scale, when compared

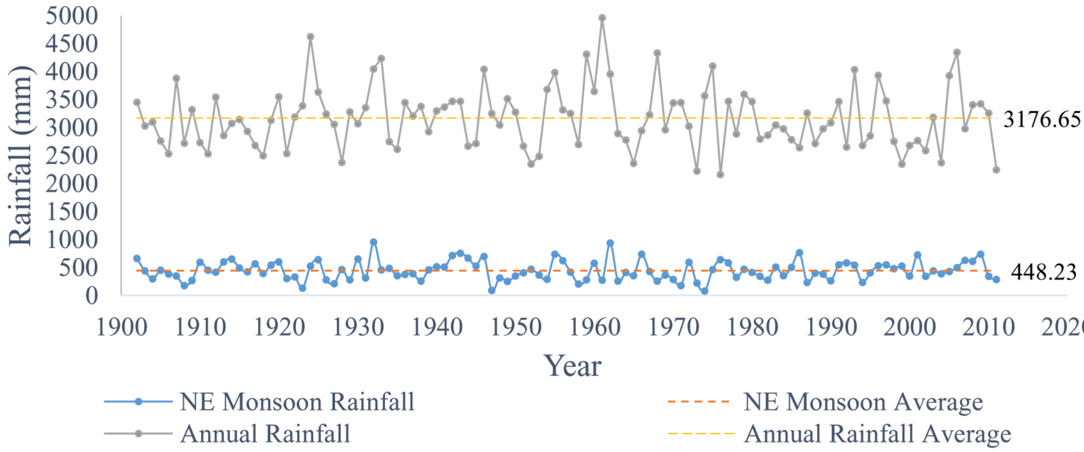
Table 2: Mann Kendall and Linear regression equations result for time scale 1902-2012, 1902-1956 and 1957-2012

		1902-2012	*1902-1956*	*1957-2012*
Annual	Mann Kendall	–	+	–
	Linear	y = –0.221x + 3597.9	y = 4.8159x – 6123.9	y = –7.0341x + 17128
SW Monsoon	Mann Kendall	–	–	–
	Linear	y = –0.4577x + 3232.8	y = –0.3562x + 3007	y = –7.0186x + 16284
NE Monsoon	Mann Kendall	–	+	+
	Linear	y = 0.0896x + 269.22	y = 0.6872x – 871.83	y = 1.9472x – 3429
Winter	Mann Kendall	–	–	+
	Linear	y = –0.1527x + 310.9	y = 0.0343x – 48.452	y = –0.027x + 60.004
Summer	Mann Kendall	+	+	–
	Linear	y = 0.1136x + 152.61	y = 3.8742x – 7094.4	y = –2.0366x + 4417.1

+ Increasing trend; – Decreasing trend



(a) SW monsoon, summer and winter rainfall



(b) NE monsoon and annual rainfall

Figure 1(a and b): Rainfall trend analysis of different seasons and annual for 110 (1901-2012) years.

with the earlier time scale. In other words the decrease in rainfall quantity is higher in the recent decades, if we take it numerically.

However this trend is different with respect to post monsoon (northeast monsoon), the slope is more positive (1.94) during the 1957-2012 time period than in the former (0.687) time period. The first 55 years showed an increasing trend in the annual rainfall, whereas the next 55 years showed a declining trend. In 1957-2012 time period, even though the north east monsoon is increasing, all other seasonal rainfall showed decreasing trend and that might have been reflected for the trend in annual rainfall. But in the former time scale of 55 years (1901-1956) all seasonal rainfalls other than south west monsoon season showed increasing trend and hence the overall trend also was increasing.

However as indicated earlier, for the whole 110 years the annual rainfall showed a declining trend. The main reason is that the amount of increase in the initial 55 years is less compared to the declining trend in the later 55 years; therefore the overall trend showed a declining trend. There is significant decrease in southwest monsoon rainfall while increase in post monsoon season was observed in the study area.

The reduction/decreasing trend in rainfall during southwest monsoon contributes to short-term meteorological droughts, which is having strong negative implications on the yield of plantation/perennial crops and also the entire water resources of Kerala, while the increasing rainfall during other seasons helps to reduce the drought severity. This reduction in rainfall during southwest monsoon rainfall for the region of Kerala is evinced by earlier studies (Guhathakurta and Rajeevan, 2008; Rajeevan et al., 2008; Krishnakumar et al., 2009; Thomas and Prasannakumar, 2016). When the reasons were analyzed, a strong decreasing trend was observed in depression frequency over last 100 years and this depression frequency is nearly less than 50% of the frequency of depressions observed at the start of the twentieth century (Joseph and Xavier, 1999). Besides, in some of the other studies the authors have found that southwest monsoon current from surface to 1.5 km altitude between 10 and 12 N latitude had showed significant decreasing trend and also the strength of Tropical Easterly Jet Stream was decreasing in recent 5 decades (Rao et al., 2004; Joseph and Simon, 2005; Sathiyamoorthy, 2005). These all factors might have contributed for the decreasing trend/reduction in southwest monsoon rainfall in the study area also. Apart from this there is extreme change in land use and land cover pattern in the study area (i.e. declining of paddy area, many anthropogenic interventions), which might have also affected the rainfall processes which occurred between the Land-Ocean-atmosphere interaction and influenced the frequency and quantity of local rainfall during this season.

With respect to north east monsoon season an increasing trend was observed for the study area. Usually the occurrence of cyclones is higher during this period in the southernmost part of India and which has a characteristic climate due to the influence of Bay of Bengal (Krishnakumar et al., 2009). Earlier studies confirmed that frequency of cyclones during the northeast monsoon season is increasing and it might be one of the possible reasons for the increasing rainfall observed in the study area. There has been a two-fold increase in the tropical cyclones frequency over Bay of Bengal during November in past 122 years (Singh et al., 2001).

Precipitation Concentration Index (PCI)

PCI for 110 years were calculated and are presented in Table 3. The PCI value in annual scale calculated for the study area varies from 15-30. According to Oliver's (1980) classification, PCI ≤ 10 represents low precipitation concentration (uniform monthly rainfall distribution over the year), whereas PCI values from 11 to 15 denote a moderate precipitation concentration (seasonality in rainfall distribution) and values from 16 to 20 denote irregular rainfall distribution. However, PCI > 20 represents a strong irregularity/monthly variability in rainfall distribution (i.e., high precipitation concentration) (de Luis et al., 2000; Thomas and Prasannakumar, 2016). Among the 110 years, 57 years come under the classification of strong irregularity in the rainfall (PCI>20) and the balance 53 years come under next lower classification of irregular precipitation with the PCI value 15-20. The average of PCI is 20.59 which indicated that the annual rainfall is concentrated roughly in less than half of the year. This confirms the fact that the southwest monsoon contributes significant amount of rainfall (73.71%) towards the annual rainfall in just four months and hence this PCI value is higher than 20. The years which showed the PCI as irregular precipitation might be due to the relatively less contribution from south west monsoon (68.8% value) and indicated comparatively more distribution through the other seasons also.

Seasonality Index

The rainfall distribution can also be expressed by SI values, and consequently SI values were computed for 110 years and are presented in Table 3. In general, the lower the value of SI, better the distribution of monthly rainfall during the year, and higher value implies more irregularity of rainfall concentration in the year. The decreasing trend shown by rainfall concentration (i.e.,

Table 3: Classification of Precipitation Concentration Index (PCI) and Seasonality Index (SI) with implications on rainfall regime for 110 years and for two different time periods

PCI	*Classification*	*No. of years*	*SI*	*Rainfall regime*	*No. of years*
<10	Low precipitation	0	<0.19	Very equable	0
			0.20-0.39	Equable but with a definite wetter season	0
10-15	Moderate precipitation	0	0.40-0.59	Rather seasonal with a short drier season	0
			0.60-0.79	Seasonal	2
15-20	Irregular precipitation	53	0.80-0.99	Markedly seasonal with a long drier season	69
			1.00-1.99	Most rain in 3 months or less	37
>20	Strongly irregular precipitation	57	>1.20	Extreme, almost all rain in 1–2 months	2

PCI) is also supported by the decreasing trend in SI. Among the 110, 69 years come under category markedly seasonal with long drier season, 37 years under the category of most rain in three months, two years under seasonal (1930, 1960) and balance two years (1923, 1991) come under the category of almost rain in one or two months. The average value of seasonality index for 110 years is 0.96. This indicates that, in general, the study area falls under the category of rainfall of markedly seasonal with a long drier season, which is similar to PCI data.

Drought Analysis

Rainfall Anomaly Index (RAI)

RAI for 110 years were calculated and classified in Table 4. Among the 110 years, 39 years are under wet condition, out of these 39 years, five years are in extremely wet condition (1924, 1959, 1961, 1968, and 2007). 38 years falls under slightly/moderately dry condition. Kozhikode district experiences eight very dry years within 110 years. So the returning period of very dry condition in Kozhikode district is approximately 14 years.

While dividing into two time scales (1902-1956 and 1957-2012), the scenario is entirely different. Extremely dry events, which could not be observed for the whole of 110 years are there in these two time scales. The sum of very dry and extremely dry events is more in 1st 50 years (11) compared to next 50 years (6). This indicated that the frequency of drought in 1902-1956 period is one in five years, while the same in 1957-2012 is one in nine years. This is in contrast to the most of the studies, which showed that the extreme drought occurrences are higher under recent years. However, if we take all the dry categories together, former time scale shows less no of years (21) compared to recent 55 years (27 years).

The trend is contradictory in the case of wet conditions. The sum of extremely wet and very wet events is seven in numbers in 1902-1956 while that is nine in next time scale of 1957-2012, indicating the frequency of occurrence of wet years more in the recent 55 years. However if we take all wet years (extremely wet to slightly wet), then the conditions are different, i.e. 22 years falls under the first time scale and only 20 wet years are observed in the second time scale. This shows that there is lot of climatic variability occurring in humid tropical region.

Departure Analysis of Rainfall (DAR)

According to drought classification of Departure Analysis of Rainfall by IMD (Table 5) for 110 years, 12 years in Kozhikode district are under drought condition. This indicates that the drought has the return period of 9.1 years. No scanty and no rain condition were experienced in Kozhikode during the period of 110 years and most of the years (83) falls under near normal condition and 15 years experienced excess rainfall. While dividing this 110 years into two time scales it is noticed that six drought years are coming under both time scales but the excess condition of rainfall is higher in second time scale 1957-2012.

Table 4: Standard ranges of Rainfall Anomaly Index (RAI) and Standard Precipitation Index (SPI) along with the classification for 110 years and for two different time periods

RAI	*Classification*	*No. of years (1902-2012)*	*No. of years (1902-1956)*	*No. of years (1957-2012)*	*SPI*	*Classification*	*No. of years (1902-2012)*	*No. of years (1902-1956)*	*No. of years (1957-2012)*
≥3.0	Extremely wet	5	5	4	≥2.00	Extremely wet	4	2	1
2.0 to 2.99	Very wet	9	2	5	1.50 to 1.99	Very wet	6	3	4
1.0 to 1.99	Moderately wet	8	8	3	1.00 to 1.49	Moderately wet	5	2	4
0.5 to .99	Slightly wet	17	7	8	–0.99 to .99	Near normal	80	37	40
–0.49 to 0.49	Near normal	25	12	8	–1.00 to –1.49	Moderately dry	7	9	3
–0.99 to –0.50	Slightly dry	12	3	9	–1.50 to 1.99	Severely dry	7	2	3
–1.99 to –1.0	Moderately dry	26	7	12	≤–2	Extremely dry	1	0	0
–2.99 to –2.0	Very dry	8	9	5					
≤–3.0	Extremely dry	0	2	1					

Table 5: Departure Analysis of Rainfall and the classification for 110 years and for two different time periods

DAR	*Classification*	*No. of years (1902-2012)*	*No. of years (1902-1956)*	*No. of years (1957-2012)*
≥20	Excess	15	6	9
19 to –19	Normal	83	43	40
–20 to –59	Deficit	12	6	6
–60 to –99	Scanty	0	0	0
≥100	No rain	0	0	0

Drought Index by DrinC

Standardized Precipitation Index: SPI for the time scale of 1902-2012 is calculated by using software DrinC and tabulated in Table 4. SPI indicates the severity of dryness compared to DAR; hence it is a better option for the analysis of drought. By SPI the most affected years by drought in Kozhikode district (extremely dry and severely dry) are eight in numbers (1928, 1952, 1965, 1973, 1976, 2000, 2005, 2012). Hence, the frequency of occurrence of extremely dry and severely dry year is 1 in 14 years. The probability of occurrence of near-normal condition is 72.7% and years to become in extremely wet condition have a probability of 3.6%. The lead author of the paper characterized drought using DrinC (Drought indices calculator) for a semi arid region of India and found that these approaches will help to develop plan to combat the consequences of drought even for humid tropical regions of India (Surendran et al., 2017b).

Wavelet Analysis

The wavelet spectrum for annual (Figure 2a) scale shows the power (absolute value squared) of the wavelet transform for the annual rainfall of the selected data. This gives information on the relative power at a certain scale and a certain time, that means period where it oscillates with the corresponding frequency. In the case of the annual rainfall series, most of the high power (red colour) can be found concentrated within a band of 2-8 years or in other words the annual spectrum has a periodicity of 2-8 years. Due to edge effects of wavelet processing, the cone of influence which represents the periods with uninterpretable is also shown in Figure 2a (hatched areas) and consequently they have been ignored in all analyses.

Wavelet spectrum in annual scale also shows some higher powers in higher values of periodicity that is 8-32 years. In the initial decades, the spectrum shows a periodicity nearly two years, but it has lesser value of power. But in 1920-1930, it lies in between 8 and 16 years. During the period 1950-1980, good periodicity is observed in the range 4-8 years, but it also shows some periodicity in 2-4 years and 8-16 years with lesser intensity. While in 1990-2010, high intensity periodicity in the range of 16-32 years is observed. Along with this low periodicity (2-4 years) with high intensity is also observed. The wavelet analysis clearly shows a noticeable change in the rainfall pattern after 1950. That means periodic component are responsible for producing increasing trend in the annual rainfall series and change in rainfall pattern after 1950. This fact might be due to climate change as larger anthropogenic trends are recorded during the period of 1950-2000.

While in case of rainfall spectrum in monthly scale (Figure 2b), most of the higher power of the spectrum is lying in 2-4 years. And some periodicity with lesser intensity is observed in higher periods also. During the initial decades, some decades don't show any periodicity. This is happening in 1910-1950 and 1990-2010. In the first decades 1900-1910, in addition to the 2-4 years of periodicity it also shows some periodicity in the higher range also. That is in 8-16 years. But the intensity or the power is lower than that in the former. In 1980-2010, considerable periodicity with high intensity is absent.

Conclusions

To summarize, the study is conducted with the objective to have a better understanding of rainfall variability using different statistical methods and trend analysis during the last 110 years for Kozhikode region of Kerala. The average annual rainfall of Kozhikode is 3177 mm with the standard deviation of 551.7 mm. The coefficient variation of annual rainfall showed that inter annual variability is very low; however seasonal variability is higher. Mann Kendall rank statistics analysis revealed decreasing rainfall in southwest, northeast monsoon

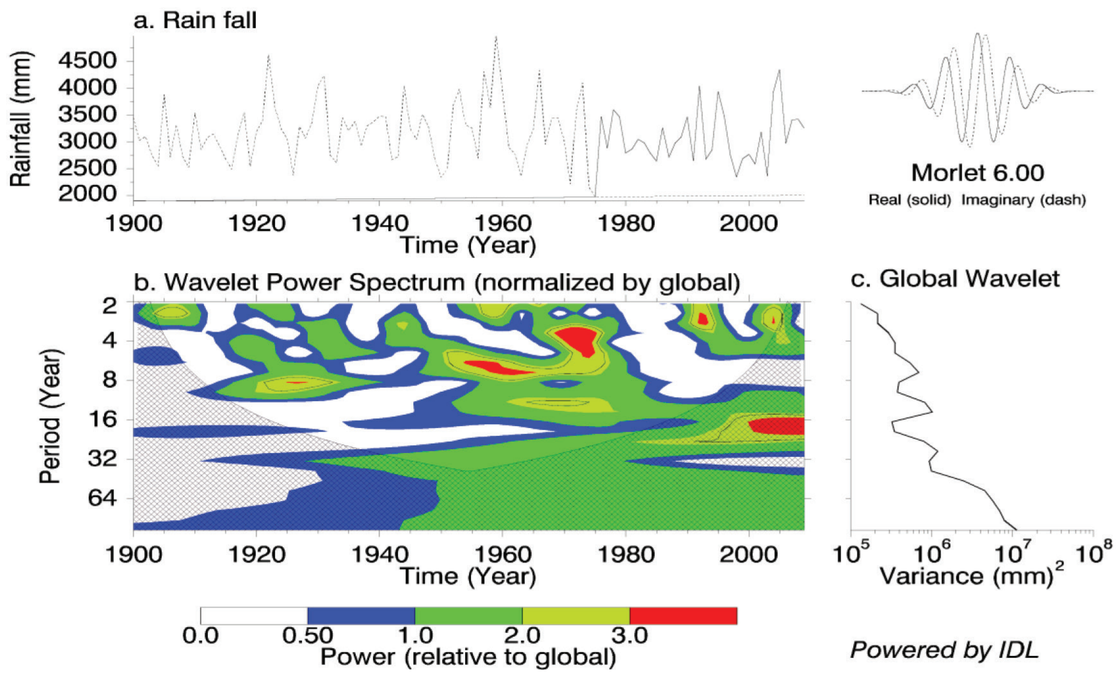


Figure 2a. Wavelet spectrum analysis of annual rainfall data.

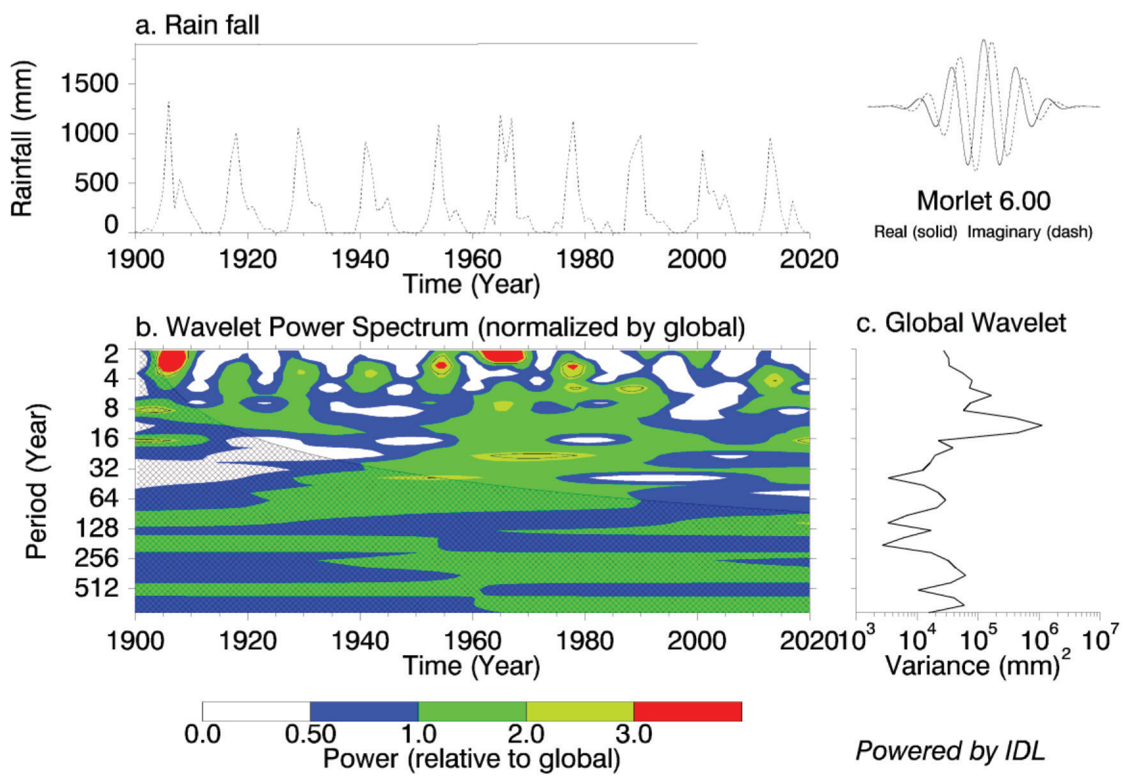


Figure 2b: Wavelet spectrum analysis of monthly rainfall data.

and winter season, while increase in summer season. Besides, analysis were carried out at two different time scale (viz., 1902-1956 and 1957-2012), and it showed that the southwest monsoon decreased in both the time scales; however the quantum of declining is higher in the recent period i.e. 1957-2012 and showed an increasing trend in the northeast monsoon recent period i.e. 1957-2012. Seasonality index for 110 years is 0.96 and this indicated that, the study area falls under the category of rainfall of markedly seasonal with a long drier season. Drought indices were characterized using Rainfall Anomaly Index, Departure Analysis of Rainfall, Deciles and Standardized Precipitation Index and the occurrence of drought events were identified. Eight to 12 drought years were observed during the study period depending on the indices in the category of severely dry to extremely dry years. The wavelet analysis clearly shows a noticeable change in the rainfall pattern after 1950. That means periodic components are responsible for producing increasing trend in the annual rainfall series and change in rainfall pattern after 1950. This fact might be due to climate change as larger anthropogenic trends are recorded during the period of 1957-2012. Findings from such studies need to be used by policy makers/planners and all stakeholders to devise proper drought adaptation plans to overcome the same and mitigate their effects on the activities in different sectors of the Kerala State.

Acknowledgements

The authors are thankful to the Executive Director of the Centre for providing the necessary support and encouragement for smooth completion of this study. Research funding support from the Plan fund of CWRDM is gratefully acknowledged.

References

Dash, S.K. and Hunt, J.C.R., 2007. Variability of climate change in India. *Current Science*, **93(6):** 782-788.

de Luis, M., Gonzalez-Hidalgo, J.C., Brunetti, M. and Longares, L.A., 2011. Precipitation concentration changes in Spain 1946–2005. *Natural Hazards and Earth System Sciences*, **11(5):** 1259-1265. http://dx.doi.org/10.5194/nhess-11-1259-2011.

de Luis, M., Raventos, J., Gonzalez-Hidalgo, J.C., Sanchez, J.R. and Cortina, J., 2000. Spatial analysis of rainfall trends in the region of Valencia (east Spain). *International Journal of Climatology*, **20(12):** 1451-1469. http://dx.doi.org/10.1002/1097-0088(200010)20:12<1451::AID-JOC547>3.0.CO;2-0.

Goswami, B.N., Venugopal, V., Sengupta, D. and Madhusoodhanan, M.S., 2006. Increasing trend of extreme rain events over India in a warming environment. *Science*, **314(5804):** 1442-1445.

Guhathakurta, P. and Rajeevan, M., 2008. Trends in the rainfall pattern over India. *International Journal of Climatology*, **28(11):** 1453-1469. http://dx.doi.org/10.1002/joc.1640.

Guhathakurta, P. and Saji, E., 2013. Detecting changes in rainfall pattern and seasonality index vis a vis increasing water scarcity in Maharashtra. *Journal of Earth System Sciences*, **122(3):** 639-649.

Joseph, E.J., Anitha, A.B., Jayakumar, P., Sushanth, C.M. and Jayakumar, K.V., 2011. Climate Change and Sustainable Water Resources Management in Kerala. Centre for Water Resources Development and Management Kunnamangalam – 673571, Kozhikode, Kerala, India.

Joseph, P.V. and Xavier, P.K., 1999. Monsoon rainfall and frequencies of monsoon depressions and tropical cyclones of recent 100 years and an outlook for the first decades of 21st century, Meteorology beyond 2000. International Proceedings of India Meteorological Society, TROPMET-99. pp. 364-371.

Joseph, P.V. and Simon, A., 2005. Weakening trend of the southwest monsoon current through peninsular India from 1980 to the present. *Current Science*, **89(4):** 687-694.

Kanellopoulou, E.A., 2002. Spatial distribution of rainfall seasonality in Greece. *Weather*, **57:** 215-219.

Kendall, M.G. (1975). Rank Correlation Methods, Fourth Edition. Charles Griffin, London, U.K.

Krishnakumar, K.N., Rao, G.S.L.H.V.P. and Gopakumar, C.S., 2009. Rainfall trends in twentieth century over Kerala, India. *Atmospheric Environment*, **43:** 1940-1944.

Krishnakumar, K.N., Rao, G.S.L.H.V.P. and Gopakumar, C.S., 2008. Climate change at selected locations in the humid tropics. *Journal of Agrometerology*, **10(1):** 59-64.

Mann, H.B., 1945. Nonparametric tests against trend. *Econometrica*, **13(3):** 245-259. http://dx.doi.org/10.2307/1907187.

Morlet, J., Arens, G., Fourfeau, E. and Giard, D., 1982. Wave propagation and sampling theory 1: Complex signal and scattering in multi-layered media. *Geophysics*, **47(2):** 203-221. http://dx.doi.org/10.1190/1.1441328.

Oliver, J.E., 1980. Monthly precipitation distribution: A comparative index. *The Professional Geographer*, **32(3):** 300-309. http://dx.doi.org/10.1111/j.0033-0124.1980.00300.x.

Pal, I. and Al-Tabbaa, A., 2009. Trends in seasonal precipitation extremes – An indicator of climate change in Kerala, India. *Journal of Hydrology*, **367:** 62-69.

Raj, N.P.P. and Azeez, P.A., 2012. Trend analysis of rainfall in Bharathapuzha River basin, Kerala, India. *International Journal of Climatology*, **32(4):** 533-539. http://dx.doi.org/10.1002/joc.2283.

Rajeevan, M., Bhate, J. and Jaswal, A.K., 2008. Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. *Geophysical Research Letters*, **35:** L18707. http://dx.doi.org/10.1029/2008GL035143.

Rao, G.S.L.H.V.P. and Krishnakumar, K.N., 2005. Monsoon onset over Kerala (India): 1870-2004. *Journal of Agrometerology*, **7(2):** 161-167.

Rao, B.R.S., Rao, D.V.B. and Rao, V.B., 2004. Decreasing trend in the strength of Tropical Easterly Jet during the

Asian summer monsoon and the number of tropical cyclonic system over Bay of Bengal. *Geophysical Research Letters*, **31:** L14103. http://dx.doi.org/10.1029/2004GL019817.

Sathiyamoorthy, V., 2005. Large scale reduction in the size of the Tropical Easterly Jet. *Geophysical Research Letters*, **32:** L14802. http://dx.doi.org/10.1029/2005GL022956.

Simon, A. and Mohankumar, K., 2004. Spatial variability and rainfall characteristics of Kerala. *Earth and Planetary Science*, **113:** 211-221.

Singh, O.P., Ali Khan, Tariq Masood and Rehaman, Sazedur, 2001. Has the frequency of intense tropical cyclones increased in the north Indian ocean? *Current Science*, **80(475):** 575-580.

Soman, N.K., Krishnakumar, K. and Nityanand Singh, 1988. Decreasing trend in the rainfall of Kerala. *Current Science*, **57(1):** 7-12.

Surendran, U., Sushanth, C.M., George Mammen and Joseph, E.J., 2017a. FAO-CROPWAT model-based estimation of crop water need and appraisal of water resources for sustainable water resource management: Pilot study for Kollam district – Humid tropical region of Kerala, India. *Current Science*, **112:** 76-86.

Surendran, U., Kumar, V., Ramasubramoniam, S. and Raja, P., 2017b. Development of drought indices for semi arid region using drought indices calculator (DrinC) – A case study from Madurai District, a semiarid region in India. *Water Resources Management*, **112:** 76-86.

Surendran, U., Sandeep, O. and Joseph, E.J., 2016. The impacts of magnetic treatment of irrigation water on plant, water and soil characteristics. *Agricultural Water Management*, **178:** 21-29.

Surendran, U., Sushanth, C.M., George Mammen and Joseph, E.J., 2014. Modeling the impacts of increase in temperature on irrigation water requirements in Palakkad district – A case study in humid tropical Kerala. *Journal of Water and Climate Change*, **5(3):** 471-487.

Thomas, J. and Prasannakumar, V.T., 2016. Temporal analysis of rainfall (1871-2012) and drought characteristics over a tropical monsoon-dominated state (Kerala) of India. *Journal of Hydrology*, http://dx.doi.org/10.1016/j.jhydrol.2016.01.013.

Tigkas, D., Vangelis, H. and Tsakiris, G., 2014. DrinC: A software for drought analysis based on drought indices. *Earth Science Informatics,* doi: 10.1007/s12145-014-0178-y.

Tsakiris, G., Nalbantis, I., Vangelis, H., Verbeiren, B., Huysmans, M., Tychon, B., Jacquemin, I., Canters, F., Vanderhaegen, S., Engelen, G., Poelmans, L., De Becker, P. and Batelaan, O., 2013. A system-based paradigm of drought analysis for operational management. *Water Resources Management*, **27:** 5281-5297.

Tsakiris, G. and Vangelis, H., 2004. Towards a drought watch system based on spatial SPI. *Water Resources Management*, **18(1):** 1-12.

Walsh, R.P.D. and Lawer, D.M., 1981. Rainfall seasonality: Description, spatial patterns and change through time. *Weather*, **36:** 201-208.