A Regional Scale EOF Analysis of Rainfall over Kerala

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Abstract
The state of Kerala in India has been facing climate related issues over past 3-4 years. Here, recent changes over the state have been examined using a 0.25° × 0.25°gridded rainfall data procured from India Meteorological department (IMD). The result suggests that, some significant changes are happening over the state especially over Kasargod, Idukki and Wayanad districts. The feature analysis using Empirical Orthogonal Functions also reveals the same story of change in climate. The EOF1 and EOF2 show distinct features and the principal component loadings indicate the high correlation of PC1 with the observed rainfall. The high correlation of PC1 indicates its efficacy to predict the Kerala rainfall.

1. INTRODUCTION

The average change in weather conditions is known as climate change. Since a few years ago, the effects of global climate change have been exceptional, manifesting as severe flooding, heat waves, landslides, thunderstorms, depressions, cyclones (Seneviratne et al., 2012). There is a direct or indirect effect of this climate change on a common man. Not only human beings but other species are also affected by it. Unstable weather patterns, rise in sea level and increase in greenhouse gas emissions are exacerbating from past few years (Mimura, 2013; Watkiss et al., 2005, Hunt and Watkiss 2011).
India is one of the more geographically exposed nations to the effects of climate change. According to a special report by Victor, 2015, risks from drought, precipitation deficiencies, and extreme weather are expected to rise by 2°C in some locations.. The monsoon pattern may occasionally vary as a result of climate change, resulting in the monsoon season arriving later and the rainy seasons having longer gaps. (Kumar and Jain, 2011; Parthasarthy and Dhar, 1975; Joshi and Rajeevan, 2006) affecting the agriculture in India. Studies on climate modelling imply that the weaker and later start of the monsoon and the day-by-day increase in temperature are to blame for the loss in agriculture in South Asia. Consequently, the topic covers global climate change concerns, the effects of which may be felt across a small state. In India, Kerala The Lakshadweep Sea and the Western Ghats border Kerala, a state. Being tucked between the northern latitudes of 8°18' and 12°48' and the eastern longitudes of 74°52' and 77°22', Kerala has a humid tropical rainforest environment with occasional cyclones. The state's breadth ranges between 11 and 121 kilometres, while its coastline measures 590 kilometres (370 mi) (7 and 75 mi).Geographically speaking, Kerala is a tropical region with a monsoon climate, and its far eastern edges have a tropical wet and dry climate. The south-west monsoon (June – September) and the north-east monsoon (October – November) season are the principal rain-giving seasons in Kerala. Other than the main rainy seasons, the other months are distinguished by the state's highest level of thunderstorm activity and the lowest levels of cloud cover and

precipitation. Although there are not significant interannual fluctuations in the state's overall seasonal rainfall total, there are significant regional differences in the rainfall distribution.
From past few years, Kerala is experiencing major climate shift in forms of extreme floods. One of the climatological variables that has been extensively studied for a long time is rainfall. In the current article, an effort has been made to collect data on rainfall characteristics as it helps with policy choices about agricultural patterns, sowing dates, road development, and supplying drinking water to rural and urban regions, among other things. As a result, the study focuses on analysing changes over Kerala, which would reveal any climatic disparities in the areas (Dirk, 2013). Only a few number of research (Hunt et al., 2020; Nair et al., 2014; Indrani and Al-Tabba, 2009; Krishnakumar et al., 2009) have attempted to investigate these variations across Kerala. The order of the full document is as follows: Data and methods are covered in Section 2, research findings are explained in Section 3, and concluding remarks are included in Section 4..

2. DATA AND METHODOLOGY

2.1 Study Area:

Kerala is regarded as the Gateway of monsoon. Located at the southwestern tip of India peninsula, There are 14 districts in Kerala, and the Malabar area includes Kasaragod, Kannur, Wayanad, Kozhikode, Palakkad, and Malappuram, Ernakulam and Thrissur to central region and Alappuzha, Kollam, Trivandrum, Pathanamthitta , Kottayam, Idukki to Travancore region (Figure 1).

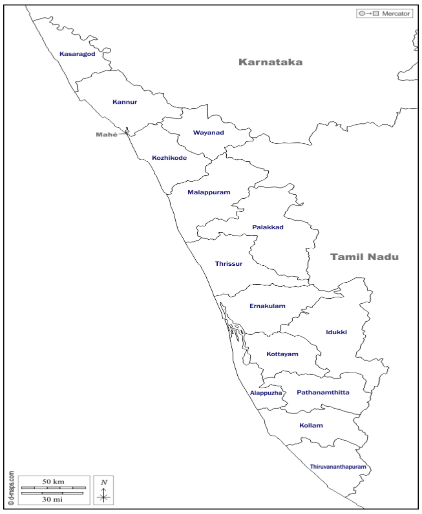

Figure 1: Image of Kerala

2.2 Datasets

Daily rainfall data of Kerala for the year 1901-2000 (0.25° × 0.25°) has been collected from Indian Meteorological Department (IMD) and they are averaged to get monthly values. Here, we estimate average rainfall patterns of Kerala and changes in Kerala rainfall. The collected data has been analysed and interpreted through MATLAB. Following methods are adopted to study the climate change:

2.3 Methodology

(i) Mean

The mean of the data is found by averaging the rainfall over each gridpoints in the study area, which is known as climatology of rainfall.

$$\bar{R} = \sum \frac{X_{ij}}{n}$$

where x_{ij} is the rainfall at the i-j th grid point and *n* is the number of years.

(ii) Standard Deviation

$$\sigma = \sqrt{\frac{\sum x_i^2}{n} - \left(\frac{\sum x_i}{n}\right)^2}$$

where x_i is the rainfall at the ith grid point.

(iii) Coefficient of Variation

$$CV = \frac{\sigma}{\bar{R}}$$

(iv) T- test for Statistical Difference

T- test is used to determine if there is a significant difference between the means of the groups .

The formula for two sample t-test (also known as student's t- test) :-

$$t = \frac{\overline{x1} - \overline{x2}}{\sqrt{(s^2(\frac{1}{n_1} + \frac{1}{n_2}))}}$$

Where t is the *t* value , $x_1$and x_2 are means of two groups being compared , s^2pooled standard error of the two groups and n_1 and n_2 are the number of observations in each of groups

(v) T – test for Correlation

To determine whether the correlation coefficient is statistically significant or not we can perform a t – test which involves calculating a **t-score** and a corresponding **p –value**
Formula for t-score :-

$$t = r\sqrt{(n-2)(1-r^2)}$$

where *r* is the correlation coefficient and *n* the sample size . The p-value is calculated as the corresponding two sided p value for t- distribution with *n-2* degrees of freedom .

(vi) Emprical Orthogonal Functions (EOF)

An Empirical Orthogonal function (EOF) analysis has been carried out to elucidate the variation in rainfall and to find the possible patterns of climate variability. An EOF analysis aims at finding the set of variables which has most observed variance from the original set and this is through the linear combination of original variables.

The Anomaly field is defined at (t, s) and is given by

$$x'_{ts} = x_{ts} - \bar{x}_{.s}$$

$$\mathrm{X}' = \mathrm{X} - \mathbf{1}\bar{x} = (I - \tfrac{1}{n}\mathbf{1}\mathbf{1}^{\mathrm{T}})\mathrm{X} \quad \text{----------- (1)}$$

which is the matrix form where $\mathbf{1} = (1, \ldots, 1)^T$ is the (column) vector containing n ones, and $\mathbf{I}$ is the $n \times n$ identity matrix.
The Covariance matrix is given by

$$\Sigma = \frac{1}{n-1} X'^{T} X' \qquad \text{-------------(2)}$$

which contains the covariance between any pair of grid points. The aim of EOF/PCA is to find the linear combination of all the variables, i.e. grid points, that explains maximum variance. That is to find a direction $a = (a_1, \ldots, a_p)^T$ such that $X'a$ has maximum variability.
Now the variance of the time series $X'a$ is

$$\text{Var}(X'a) = \frac{1}{n-1}\|X'a\|^2$$
$$= \frac{1}{n-1}(X'a)^T(X'a)$$
$$= a^T\Sigma a$$

To make the problem bounded, we need to make a unitary matrix. Hence it yields :

$$\max_{a} (aT\Sigma a), \text{ such that } a^Ta = 1 \qquad \text{-------------(3)}$$

The solution to (3) is a simple eigen value problem (EVP):

$$\Sigma a = \lambda a \qquad \text{--------------(4) where}$$

Σ is symmetrical and therefore diagonalisable
The k'th EOF is simply the k'th eigenvector a_k of Σ after the eigenvalues, and the corresponding eigenvectors, have been sorted in decreasing order. The covariance matrix is semi-definite, hence all its eigenvalues are positive.
The eigenvalue λ_k corresponding to the k'th EOF gives a measure of the explained variance by a_k, where $k = 1, \ldots p$.
The explained variance in percentage is given by :

$$\frac{100\lambda_k}{\sum_{k=1}^{p}\lambda_k}\ \%$$

The projection of the anomaly field X' onto the k'th EOF a_k, i.e $c_k = X'a_k$ is the k'th principal component (PC)

$$c_k(t) = \sum_{s=1}^{p} x'(t,s)a_k(s) \qquad \text{-------------((5)}$$

3. Result and Discussion

In order to study the changes in the rainfall pattern of Kerala, the basic statistical properties namely mean, standard deviation and coefficient of variation has been studied to learn the changes in the present years. Empirical Orthogonal Function (EOF) analysis is carried out to study the dominant features in the rainfall. In the rest of the subsections, we will be discussing about these properties.

(a) Climatology of rainfall

The spatial changes in rainfall over 0.25° × 0.25° of Kerala is shown in Figure 2 for two different periods. The figure also depicts the difference between the two periods (1959-2020 and 1901-1958). It is clear from the figure that the southern part of Kerala receives less rainfall than the northern part. Above 30mm/day of rainfall variation is seen in the district Kannur, Kasaragod. The rainfall ranges from 20-30 mm/day in districts Malappuram, Kozhikode, Kannur, Kasaragod, and Wayanad. Over Pathanamthitta, Ernakulam, Thrissur, Alappuzha, Idukki, Kottayam, Malappuram, Kozhikode 15-20 mm/day rainfall variation is seen. 10-15 mm/day rainfall variation is found in districts such as Kollam, Alappuzha, Pathamathitta, Idukki, Palakkad, Wayanad, Kannur. Least rainfall of order 0-10 mm/day is noticed in the districts Thiruvananthapuram, pathanamthitta , Idukki, Palakkad, Wayanad, Palakkad and Idukki.

The Figure 2(b) (1959-2020) shows the mean rainfall of the state for the southwest monsoon season. The north part of the Kerala receives highest average rainfall when taken as whole. Southern part of Kerala receives lowest average rainfall. Above 30 mm rainfall variation in Kasaragod above, 15-20 mm over southern part (Pathanamtitta , Idukki, Alappuzha), central part (Thrissur and Ernakulam) and Northern part (Kozhikode, Wayanad, Malappuram) can be seen. 10 – 15 mm/day rainfall variation is found in districts Kollam, Alappuzha, Idukki, Palakkad, Thrissur. (5-10) mm rainfall variation is found in districts Thiruvananthapuram, Idukki, Wayanad and Palakkad. Over southern part of Kerala 0-5 mm of rainfall is noticed.

Figure 2c depicts the difference in mean rainfall between the two periods. The region with significant difference has been marked. The difference in average is least in Kozhikode, Wayanad, Malappuram and the difference in average is high in Kasaragod, Idukki, and Wayanad. Thiruvananthapuram, Ernakulam, Kannur are the districts which does not have much difference in their climatology. Hence, it is clear that changes have occurred in some districts.

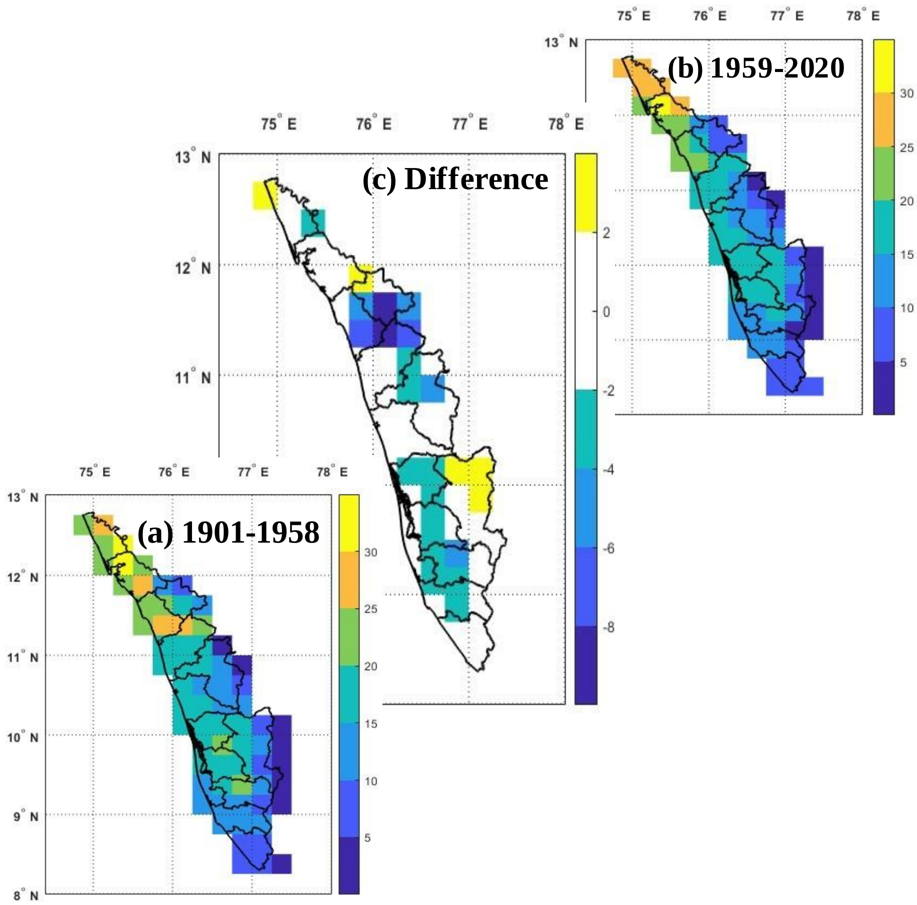

Figure 2: The spatial distribution of mean climatology for two different time periods (mm/day) (a) 1901-1958 (c) 1959-2000 (b) the difference of mean climatology (c)-(a), significant differences are shaded.

(b) Standard Deviation

Low standard deviation indicates that the values tend to be close to the mean of the set, while a high standard deviation indicates that the values are spread out over a wider range. The standard deviation for the period 1901-1958 is depicted in Figure 3(a). Very high deviation of the order of 12mm/day can be seen over Northern Kerala. The deviation decreases from North to South. From the central Kerala to south Kerala, the deviation decreases from 7mm/day to 4mm/day. Over the eastern Kerala, the deviation is less as compared to eastern Kerala. Similar to the 1901-1958 period, the deviations are more over northern Kerala, while it decreases southwards. Also, the deviation increases eastwards similar to the first period.

The differences (Figure 3c) between the two periods show statistical increasing deviation over eastern parts of Trivandrum and Idukki which is very much evident from the rainfall changes also. Since, changes in rainfall are more over these regions, hence the deviation is also large. Some positive deviations are also seen over Kannur-Wayanad border. Negative deviations are seen over southern part of Wayanad and Kasargod-Kannur border.

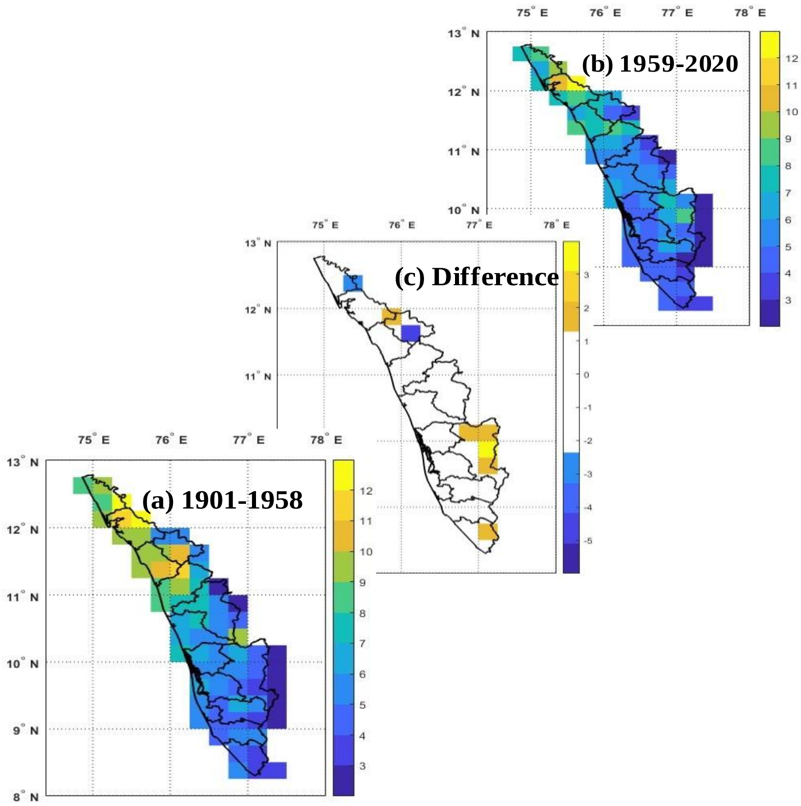

Figure 3: Same as in Figure 1 but for standard deviation

(c) Coefficient of variation (CV)

In both the periods, the variations are found more over eastern parts of Kerala as compared to western side (Figure 4). The variation also increases from north to south. This implies that major changes are seen over Idukki district where a change of 100 to 150% of the mean has been found. The differences in CV as shown in Figure 4(c), is the least in small parts of Palakkad. Higher difference in coefficient of variation is seen in some parts of Wayanad, Malappuram, Palakkad, and some parts of Idukki, Kottayam, Pathanamthitta , Kollam, Thiruvananthapuram, whereas less difference is seen in almost every small part of northern and central districts of Kerala. Districts of Kannur, Thrissur, Kozhikode, Alappuzha, Kottayam, Kollam, Palakkad are the districts which does not have much difference in their coefficient of variation.

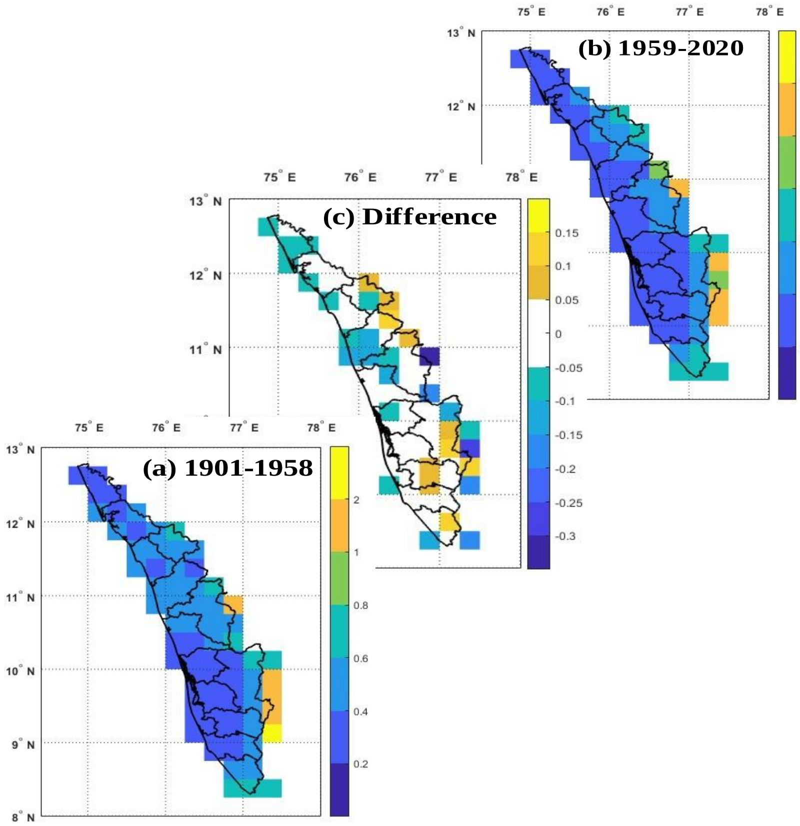

Figure 4: Same as in Figure 1 but for coefficient of variation

The results discussed above show that some significant changes are happening over Kerala and the changes are notable over Idukki and Malappuram districts of Kerala.

(d) Dominant patterns of rainfall -Empirical Orthogonal Function Analysis

The variability in terms of orthogonal vector is shown in Figure 5. The first EOF (EOF1) is plotted on the upper panel while EOF2 is plotted on the bottom panel. EOF1 explains 75% of the total variability while merely 15% is depicted by EOF2. The variation in terms of EOF for the 1901 – 1958 period shows high positive loadings over Kozhikode, Malappuram, Thrissur, parts of Palakkad and Ernakulam. The high positive loadings become less prominent over eastern and extreme parts of Kerala. In the 1959 – 2020 period, area of high positive loadings is found diminished whereas the area covered by low loadings are increased. Moreover, the EOF1 depicts the similarity with average rainfall over Kerala. The second EOF on the other hand shows negative as well as positive loadings, the negative loadings are mainly seen on the southern part of Kerala where high negative loadings are seen in Pathanamthitta and Kollam districts. In EOF2 also high loadings are visualised over eastern part of Kerala. Some positive loadings are also seen over northern and western parts of Kerala. The EOF1 and EOF2 loadings show distinct behaviour which indicates the effect of climate change.

The two principal components (PC1 and PC2) alongwith the observed rainfall are shown in Figure 6. It is observed from figure 6(a) that the magnitude of both the principal components is higher than the observation. The PC1 shows a significant correlation coefficient of 0.85 with observation while PC2 shows a correlation 0f of 0.1 only. In the second period from 1959-2020, PC1 again shows the similar fluctuation as observation with a correlation coefficient of 0.9 and PC2 with 0.12. This implies that the PC1 structure that shows the dominant structure in rainfall is relatively more dependent on observed rainfall. The high correlation coefficient of PC1 with observation shows that the PC1 can contribute to the prediction of Kerala rainfall.

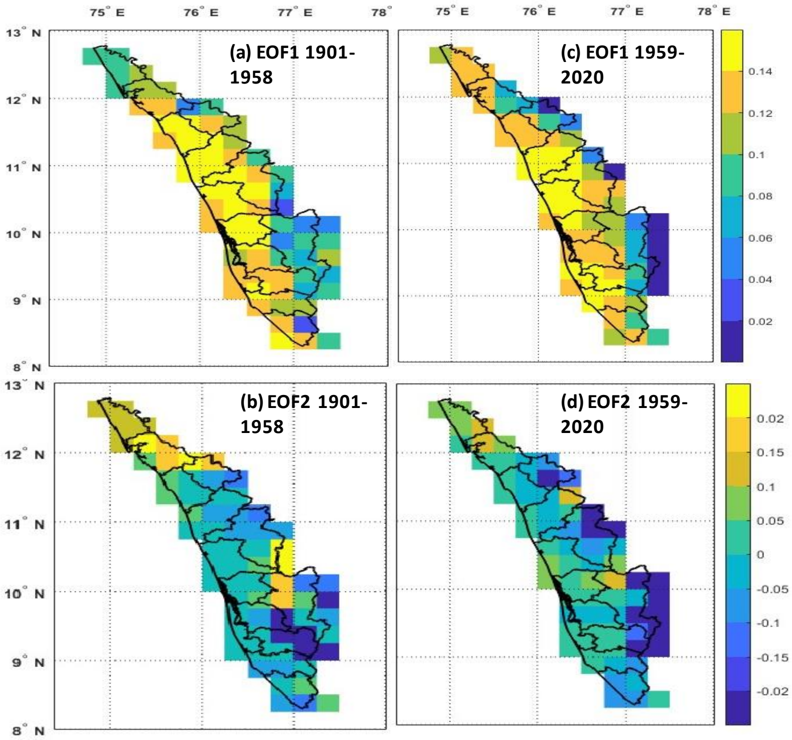

Figure 5: The first and second empirical orthogonal functions for different time periods

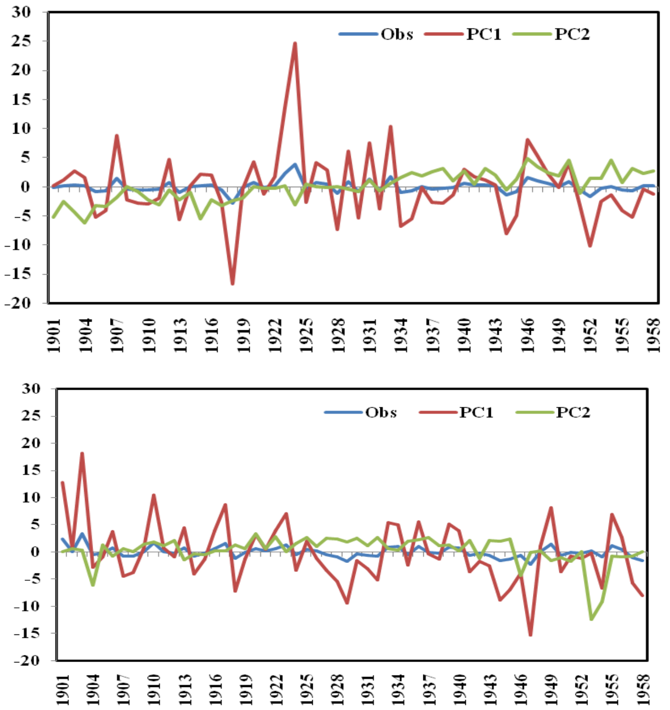

Figure 6: The first and second principal component for the two time periods

4. Conclusions

From past few years, Kerala is witnessing climate aberrations in the form of extreme rainfall, temperature changes, storm etc. To access the quantity of changes (0.25x0.25) India Meteorological department data has been extracted and analysed over Kerala. The results suggest significant changes over kerala. Major changes happened over Northern kerala especially over Kasaragod, Idukki, and Wayanad whereas districts such as Thiruvananthapuram, Ernakulam, Kannur doesn't show much effect of changes in climate. The dominant patterns as seen through the Empirical orthogonal Function Analysis show positive prominent features of change overKozhikode, Malappuram, Thrissur, parts of Palakkad and Ernakulam showing the footprints of climate change. The principal component loadings show high degree of variability with PC1 showing 85% coherence with the observation. This implies that principal components can be employed for predicting the Kerala rainfall.

References:

1. Dirk, R. A. E. S. (2013). Frequency analysis of rainfall data. College on Soil Physics—30th Anniversary (1983-2013),The Abdus Salam International Centre for Theoretical Physics, 244-10.
2. Hunt, A., & Watkiss, P. (2011). Climate change impacts and adaptation in cities: a review of the literature. Climatic change, 104(1), 13-49.
3. Singh, S. . (2022). Unconditionally G ?odel Degeneracy for Quasi-Meager, Smooth Moduli. International Journal on Recent Trends in Life Science and Mathematics, 9(1), 28–36. https://doi.org/10.17762/ijlsm.v9i1.139
4. Hunt, Kieran MR, and Arathy Menon (2020).The2018 Kerala floods: a climate change perspective. Climate Dynamics 54.3,2433-2446.
5. Joshi UR, Rajeevan M (2006) Trends in precipitation extremes over India. National Climate Center Research Report 3, October 2006, India Meteorological Department, Pune.
6. V. N. Patil and D. R. Ingle, "A Novel Approach for ABO Blood Group Prediction using Fingerprint through Optimized Convolutional Neural Network", Int J Intell Syst Appl Eng, vol. 10, no. 1, pp. 60–68, Mar. 2022.
7. Krishnakumar, K. N., GSLHV Prasada Rao, and C. S. Gopakumar (2009). Rainfall trends in twentieth century over Kerala, India. Atmospheric environment 43.11: 1940-1944.
8. Kumar, V., & Jain, S. K. (2011). Trends in rainfall amount and number of rainy days in river basins of India (1951–2004). Hydrology Research, 42(4), 290-306.
9. Mimura, N. (2013). Sea-level rise caused by climate change and its implications for society. Proceedings of the Japan Academy, Series B, 89(7), 281-301.
10. Nair, A., Joseph, K. A., & Nair, K.S. (2014). Spatio-temporal analysis of rainfall trends over a maritime state (Kerala) of India during the last 100 years. Atmospheric Environment, 88, 123-132
11. Gupta, D. J. . (2022). A Study on Various Cloud Computing Technologies, Implementation Process, Categories and Application Use in Organisation. International Journal on Future Revolution in Computer Science &Amp; Communication Engineering, 8(1), 09–12. https://doi.org/10.17762/ijfrcsce.v8i1.2064

12. Pal, Indrani, and Abir Al-Tabbaa (2009). Trends in seasonal precipitation extremes–An indicatorof ‘climate change’in Kerala, India. Journal of Hydrology 367.1-2 : 62-69.10.
13. Parthasarathy, B., and O. N. Dhar (1975). Trend analysis of annual Indian rainfall. Hydrol. Sci. Bull 20.2 , 257-260. 11.
14. Seneviratne, S., Nicholls, N., Easterling, D., Goodess, C., Kanae, S., Kossin, J., ... & Zwiers, F. W. (2012). Changes in climate extremes and their impacts on the natural physical environment.
15. Kadhim, R. R., and M. Y. Kamil. “Evaluation of Machine Learning Models for Breast Cancer Diagnosis Via Histogram of Oriented Gradients Method and Histopathology Images”. International Journal on Recent and Innovation Trends in Computing and Communication, vol. 10, no. 4, Apr. 2022, pp. 36-42, doi:10.17762/ijritcc.v10i4.5532.
16. Pawan Kumar Tiwari, Mukesh Kumar Yadav, R. K. G. A. . (2022). Design Simulation and Review of Solar PV Power Forecasting Using Computing Techniques. International Journal on Recent Technologies in Mechanical and Electrical Engineering, 9(5), 18–27. https://doi.org/10.17762/ijrmee.v9i5.370
17. Watkiss, P., Downing, T., Handley, C., & Butterfield, R. (2005). The impacts and costs of climate change. Brussels, European Commission DG Environment Victor, D. (2015). Climate change: Embed the social sciences in climate policy. Nature News, 520(7545), 27