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Temporal behavior of north east monsoon rainfall during extreme NEMR years over Peninsular India

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Strong, weak and normal Northeast Monsoon Rainfall (NEMR) are defined depending on the strength of the Northeast Monsoon (NEM) rainfall compared to the long period average (LPA) using monthly rainfall data of Peninsular India (PI). Behavior of NEM monthly (October, November and December) rainfall and contribution of monthly rainfall towards NEM seasonal rainfall is examined during extreme (strong and weak) NEMR years. Strength of association between PI monthly and PI NEM seasonal rainfall is computed and the Wilcoxon Mann-Whitney rank sum test is used to evaluate the differences in the rainfall of NEM months between strong and weak NEM years. It is observed that October/November months contribute maximum rainfall to the NEMR and December contributes the least irrespective of the strength of NEMR and that during strong NEMR years rainfall contribution in October – December months is significantly more than the rainfall in the corresponding months during weak NEMR years. Composite analysis shows that rainfall in each of the NEM months is more than the LPA of the corresponding months during strong NEMR years and less than the LPA of the corresponding months during weak NEMR years. Correlation analysis between PI NEMR and PI monthly rainfall shows that November rainfall has the highest linear correlation whereas December rainfall has the least. The percentage contribution of rainfall is largest in October and least in December and the annual variability is highest for November and least for December.

[**Keywords**: Northeast monsoon rainfall, Peninsular India, Temporal variability, Wilcoxon Mann-Whitney rank sum test]

Introduction

The peninsular India (PI) consisting of the Indian meteorological sub-divisions *viz*., coastal Andhra Pradesh, Rayalseema, south interior Karnataka, coastal Karnataka, Tamil Nadu, and Kerala[1] receives about 29.3 % of its annual rainfall during the NEM season. This season is also known by other names like, retreating south west monsoon, winter monsoon[2] and post-monsoon season[3].

It is observed by Raj[4] that NEM is very critical for the southeast peninsular India, especially for Tamil Nadu where the percentage contribution of NEM rainfall is 47.4 % of its annual rainfall. NEM rainfall is very important for the agricultural development of southeast PI and it is established by Rao Krishna & Jagannathan[5] that the agricultural production of southeastern parts of PI depends on the NEM.

Various characteristic features of the NEM have been widely studied and investigated. Sreekala *et al*.[6] has studied the variability of NEMR over PI and attribute to ENSO, IOD, and EQUINOO and the studies of Kripalani and Kumar[7] and of Aditya *et al*.[8] shows that the NEMR variability is directly related to IODM. Yadav[9] has related the inter-annual variability of NEMR to the ENSO influence.

In this study, we try to examine how the NEM monthly rainfall behaves during strong, weak and normal NEMR years. This study is specifically indented to undertake a systematic analysis of the monthly rainfall data received from Indian Institute of Tropical Meteorology (IITM) to objectively examine the variability of NEM monthly and seasonal rainfall during contrasting NEMR years.

The paper is sequentially structured in standard sections and sub sections. The rainfall data and the various methods used in this study are given in detail in data and methodology. Important findings and results are presented in results and discussion. Next sub section describes the monthly rainfall distribution of PI during extreme years of NEMR – four extreme weak and four extreme strong NEMR years along with composites of weak NEMR years, strong NEMR years and normal NEMR years. Changes of NEM monthly rainfall during the extreme NEMR years in

comparison to the rainfall during composites of weak and strong NEM periods are described in the next sub section. Further, we try to find the strength of association between PI NEMR and the PI monthly rainfall and is discussed in detail. Then we proceed with an objective statistical significance test, the Wilcoxon Mann-Whitney rank sum test, for testing the differences in monthly rainfall over PI between years of strong and weak NEMR. Next, annual variabilities of Peninsular India monthly rainfall in comparison to the corresponding long period averages during NEM season is studied and presented. Finally, we conclude by summarizing the findings in summary and discussion.

Data and Methodology

Peninsular India which consists of the six India meteorological sub-divisions, coastal Andhra Pradesh, Rayalseema, south interior Karnataka, coastal Karnataka, Tamil Nadu, and Kerala[1] spread across the four southern states Kerala, Tamil Nadu, Karnataka and Andhra Pradesh is selected for the present study.

The monthly rainfall data of IITM (Indian Institute of Tropical Meteorology) for the period 1871-2016 for PI is used in this study. The monthly rainfall for October, November & December (OND) and the seasonal rainfall for peninsular India is extracted from this dataset. The dataset in text tabular format is read into R software and the required months and seasons are extracted. The methodology used by Zheng *et al.*[10] is adopted in the present study.

Results and Discussion

In order to understand the temporal variability of North East Monsoon Rainfall (NEMR) over peninsular India, we define strong, weak and normal NEMR year depending on the strength of the NEM Rainfall compared to the long period average NEMR as defined by Parthasarathy *et al.*[11] and Simon *et al.*[12]. Figure 1 illustrates the distribution of the peninsular India OND rainfall for the years 1871-2016. Strong, weak and normal NEMR years are marked blue, red and grey according to the defined criteria and there are 25 strong, 21 weak and 100 normal NEMR years during 1871-2016(ref. 12).

Distribution of monthly rainfall during extreme years along with composites

The statistical features of the monthly rainfall of NEM are given in Table 1. October has the highest mean rainfall, followed by November and then December, with the lowest mean rainfall. Other statistical parameters are also given in Table 1.

The monthly rainfall pattern of NEM season is studied during the extreme years - four strongest (1946, 2010, 1930 and 1993) and four weakest (1876, 2016, 1988 and 1938) NEMR years in order to find out the variation in contribution of monthly rainfall towards the NEM season (Fig. 2).

It is observed that the contribution of either November or October rainfall is the highest and that of December is lowest towards NEM seasonal rainfall during the strongest NEMR years. But during the weakest NEMR years, October contributes the highest in all the four years, November contributes the next except in 2016 and December contributes the lowest (except for 2016). During 2016, December

Table 1 — General statistical parameters of monthly rainfall of peninsular India during the period 1871-2016

Month	Mean (mm)	Min (mm)	Max (mm)	SD (mm)
Oct	180.5	47.0	351.6	59.3
Nov	121.3	10.3	278.5	65.8
Dec	41.5	0.3	153.4	31.9

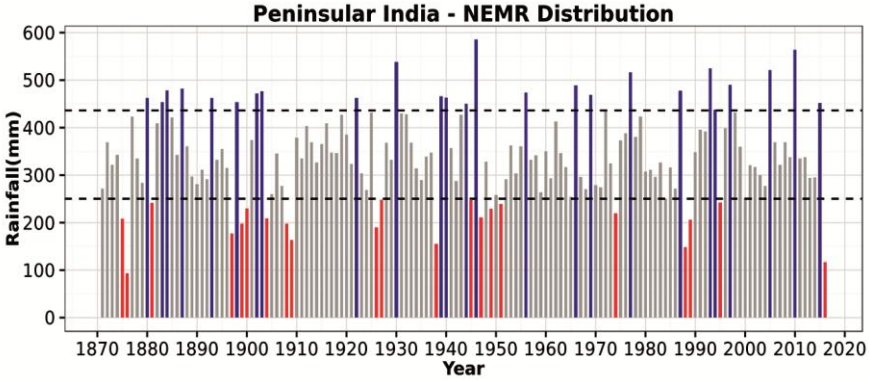

Fig. 1 — Distribution of Peninsular India NE Monsoon Rainfall for the period 1871-2016. Strong NEMR (blue), weak NEMR (red) and normal (grey). Upper dashed line indicates Mean+1SD and Lower dashed line indicates Mean-1SD (Courtesy: Simon *et al.*[12])

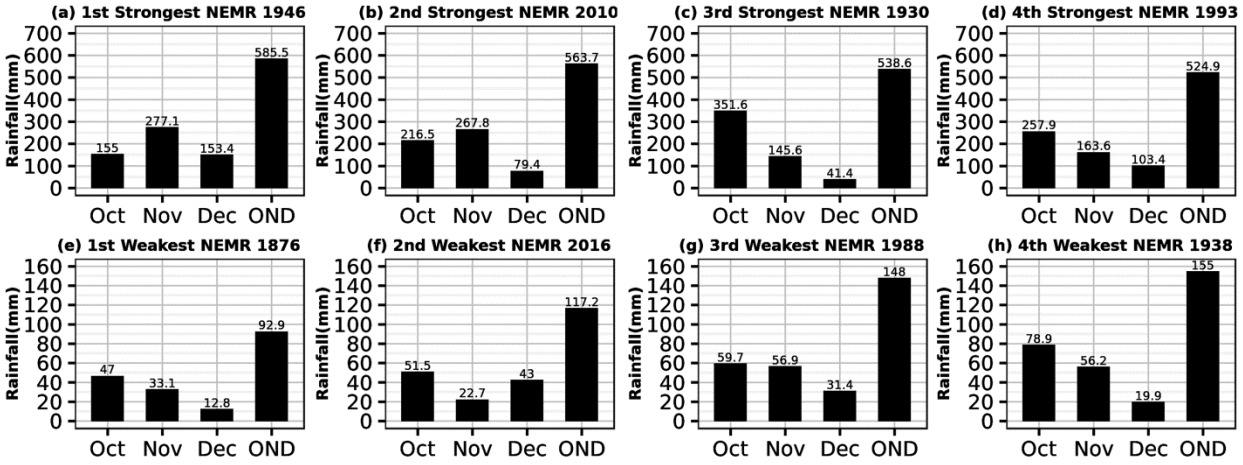

Fig. 2 — Monthly rainfall distribution during the four strongest NEMR years (a) – (d), and the four weakest years (e) – (f)

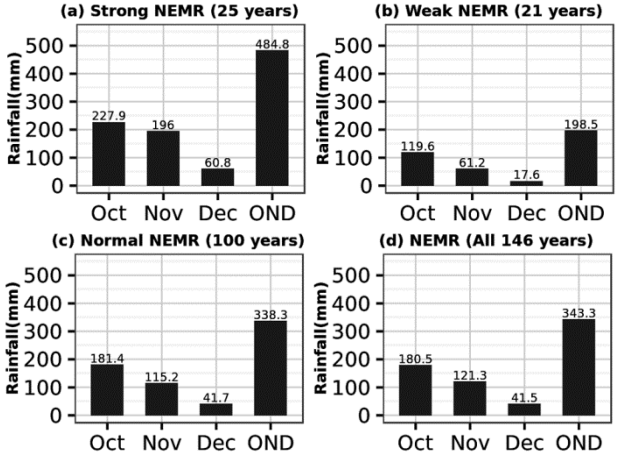

Fig. 3 — Composites of monthly rainfall distribution based on (a) 25 strong years, (b) 21 weak years, (c) 100 normal years and (d) full NEMR period 146 years

contributes second highest and November, the lowest. It can also be noted that NEM monthly rainfall is greater during the strongest NEMR years than the corresponding monthly rainfall during the weakest NEMR years.

The composite graph of 25 years of strong NEMR, 21 years of weak NEMR and 100 years of normal NEMR in Figure 3 gives a true view of the distribution pattern of the monthly rainfall. The long period average of 146 years of monthly and OND rainfall shows that October has the highest rainfall, then November and December the lowest (Fig. 3d). The distribution pattern of the monthly rainfall is similar during strong, weak and normal years (Figs. 3a – c). It is also observed that the monthly rainfall composite of NEM season during strong NEMR years is always greater than the monthly rainfall composite during the weak NEMR years and monthly rainfall composite during normal NEMR years is very similar to the long period average rainfall (146 years). Table 2 shows the difference of monthly rainfall composites between strong NEMR years and weak NEMR years. It is highest for November (134.76 mm) and lowest for December (43.24 mm).

Changes in PI monthly rainfall during extreme years

In this section, we investigate the changes in rainfall in the three months of the NEM season over PI during strong and weak NEMR years. PI monthly rainfall changes are computed as the ratios of NEM monthly rainfall to the LPA of the rainfall of the corresponding NEM months and is expressed as percentage [Monthly Rainfall Ratio = (monthly Rainfall/ LPA rainfall)*100]. The composites of strong, weak and normal NEMR are computed and presented. These graphs depict the change of rainfall in percentage relative to the corresponding LPA during the extreme and normal years. An increase in OND rainfall is observed in the composites (averaged over 25 strong, 21 weak and 100 normal years) during strong NEMR years and an overall decrease in OND rainfall is also noted during the weak NEMR years. Rainfall during the normal years is very similar to the average of 146 years (Fig. 4).

Figure 5 shows the deviation of monthly NEM rainfall from the respective monthly LPA for 25 strong, 21 weak and 100 normal years. The graph shows that there is an increase in rainfall from 19.3 mm in December to 74.7 mm in November during strong NEMR years, the highest being in November and the lowest in December. During the weak

Table 2 — Mean monthly and OND rainfall of peninsular India during strong, weak and normal NEMR. Column 6 gives the difference of monthly rainfall between strong and weak NEMR years.

Month	Strong NEMR (25 Yrs) (mm)	Weak NEMR (21 Yrs) (mm)	Normal NEMR (100 Yrs) (mm)	All NEMR (146 Yrs) (mm)	(Strong – Weak) (mm)
Oct	227.92	119.62	181.42	180.49	108.30
Nov	196.01	61.25	115.25	121.31	134.76
Dec	60.83	17.59	41.66	41.48	43.24
OND	484.75	198.46	338.33	343.28	286.29

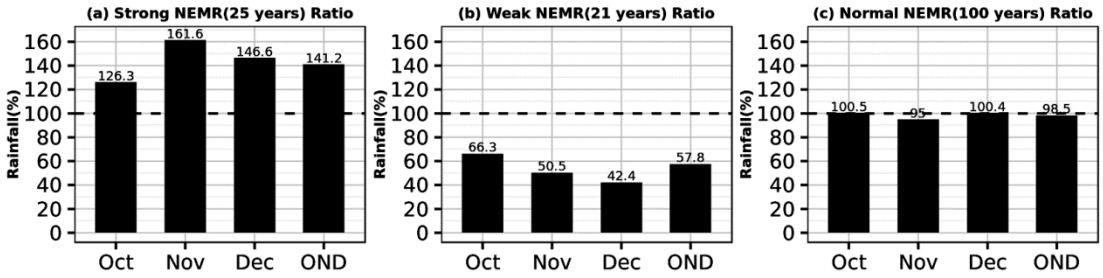

Fig. 4 — Ratios in % of OND monthly rainfall based on (a) 25 strong years, (b) 21 weak years, (c) 100 normal NEMR years to the corresponding monthly long period average. The horizontal dashed line represents the value of 100 %.

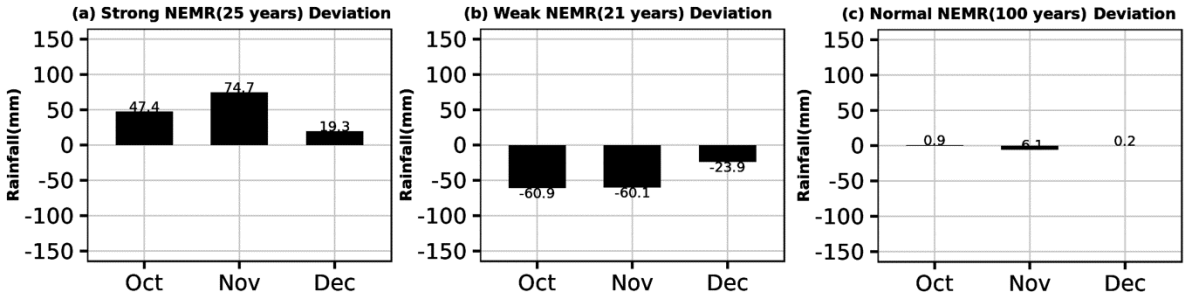

Fig. 5 — OND monthly rainfall deviation in mm from the corresponding monthly long period average for (a) 25 strong NEMR years, (b) 21 weak NEMR years, (c) 100 normal NEMR years

NEMR years, the rainfall decrease has a lower range (23.9 mm – 60.9 mm). Month of October shows the highest reduction (60.9 mm) and December shows a much lower reduction (23.9 mm). The difference of monthly/OND rainfall percentage between strong and weak NEMR years (Table 3) showed that the difference is highest (111.1 %) for November and lowest (60.0 %) for December.

To summarize, there is an increase of rainfall from 26.3 % (Oct) to 61.6 % (Nov) during strong NEMR years and a decrease of 33.7 % (Oct) to 57.6 % during weak NEMR years. This is in confirmation with actual deviation of composite monthly rainfall. The deviation of actual rainfall in Figure 5 shows a positive deviation of 19 mm in December to 75 mm in November during strong NEMR years and a negative deviation of 24 mm in December to 61 mm in October.

Relationship between monthly rainfall and NEM rainfall over PI

In this section, we probe into the relationship between monthly rainfall and the Peninsular India NEMR. Figure 6 presents the scatter plot of monthly rainfall against the PI NEMR over the period 1871-2016. The linear correlation coefficient is computed for each month and is displayed on the graph. A regression line is drawn and its slope is computed and is also displayed on the graph.

The scatter plot shows that there is moderate correlation (0.68; Fig. 6b) for November rainfall, then October (0.58; Fig. 6a) and least for December (0.43; Fig. 6c). The highest correlation is observed for November among the three NEM months. The plot indicates that the tightness of the linear relationship is highest between November rainfall and NEMR rainfall (Table 4). December rainfall has least linear

relationship with NEMR rainfall. Strength of October relationship is in between November and December. The steepness of the linear relationship is indicated by the slope which is highest for November and least for December in concordance with the correlation coefficient.

Testing the differences in monthly rainfall over PI between strong and weak NEMR years

First, we try to find out how much variation in rainfall occurs in the months (October, November and December) during strong and weak NEMR years. The box plot in Figure 7 shows that the rainfall distribution is very much different in all the three months between weak and strong NEMR years.

Further, we test whether the differences observed in the monthly rainfall features of Peninsular India during NEM between weak and strong NEMR are statistically significant. For this significance test, we make use of Wilcoxon Mann-Whitney rank sum test[13], a non parametric test, to test the two sets of rainfall data – rainfall for strong as well as weak NEMR years. This method does not make any assumption about the rainfall data distribution.

The null hypothesis in the hypothesis testing is that the two distributions of monthly rainfall - one during strong NEMR years and the other during weak NEMR years are similar and the alternate hypothesis is that the monthly rainfall occurred during strong NEMR years are significantly greater than that received during weak NEMR years at specified confidence/significance level.

Table 3 — Ratios (in %) of peninsular India monthly rainfall to the corresponding LPA computed over the period 1871-2016 for 25 strong, 21 weak and 100 normal NEMRs

Month	Strong NEMR (25 Yrs) %	Weak NEMR (21 Yrs) %	Normal NEMR (100 Yrs) %	(Strong – Weak) %
Oct	126.3	66.3	100.5	60.0
Nov	161.6	50.5	95.0	111.1
Dec	146.6	42.4	100.4	104.2
OND	141.2	57.8	98.5	83.4

For the hypothesis testing we make use of R function named 'wilcox.test'. Table 5 shows the results of the test at 95 % and 99 % confidence level. The p values generated from the test shows that monthly Peninsular India rainfall (of months October, November and December) of 25 strong NEMR years are greater than the corresponding months of 21 weak NEMR years and the difference is statistically significant.

Annual variability of PI monthly rainfall during NEM season

The yearly variation of Peninsular India NEM rainfall is examined in this section. For this, the ratio of PI NEMR monthly rainfall (October, November and December) to the LPA of NEM rainfall (NEM

Table 4 — Correlation coefficient and regression slope of monthly rainfall to the seasonal OND rainfall of peninsular India over the period 1871-2016.

Month	Correlation Coefficient	Regression Slope
Oct	0.58	0.37
Nov	0.68	0.48
Dec	0.43	0.15

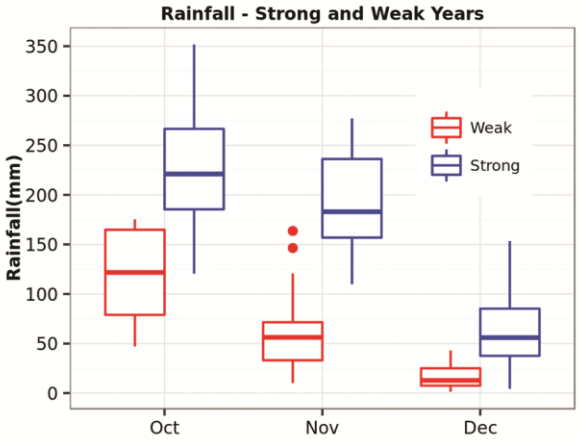

Fig. 7 — Boxplot of rainfall in the months (Oct, Nov, Dec) during strong and weak NEMR years. Red box indicates weak NEMR and blue indicates strong NEMR.

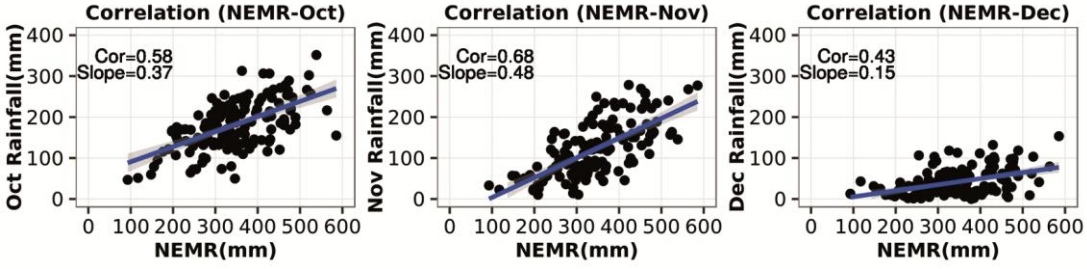

Fig. 6 — Scatter plot and best fit line of (a) October rainfall, (b) November rainfall, (c) December rainfall vs NEMR for the period 1871-2016 of PI. The correlation coefficient and slope of the best fit line is printed in the left top part of each graph.

Climatology) is computed and graphs are presented (Fig. 8). It is evident from Figure 8 that the percentage in October is largest among the three months, November comes next and December has the lowest percentages. The standard deviation gives a clear measure of the extent of variability of the monthly rainfall time series about its mean value. The annual variability of rainfall during the three months is 17.28 %, 19.16 % and 9.30 %, respectively with highest variability in November and lowest variability in December.

Table 5 — The Wilcoxon-Mann-Whitney rank sum test regarding whether monthly PI rainfall during 25 strong NEMRs are significantly greater than those during 21 weak NEMRs at 95 % & 99 % confidence level.

Month	P-value	Significant at 95%?	Significant at 99%?
Oct	7.88E-008	pval < .05, yes	pval < .01, yes
Nov	5.11E-008	pval < .05, yes	pval < .01, yes
Dec	2.79E-005	pval < .05, yes	pval < .01, yes

Summary and Conclusion

In this paper, the temporal variability of monthly rainfall in the PI during the NEM season is investigated utilising the IITM monthly mean rainfall data for the PI for the period 1871-2016.

Irrespective of whether it is a weak or strong NEMR, the analysis of NEMR monthly time series shows that the first two months of NEM (October/ November) contributes the maximum rainfall to the total NEMR.

The withdrawal month of NEM (December) contributes the least towards the total NEMR in spite of a weak or strong NEMR. The rainfall received during each of the NEM months is generally larger during strong NEMR years, compared to the

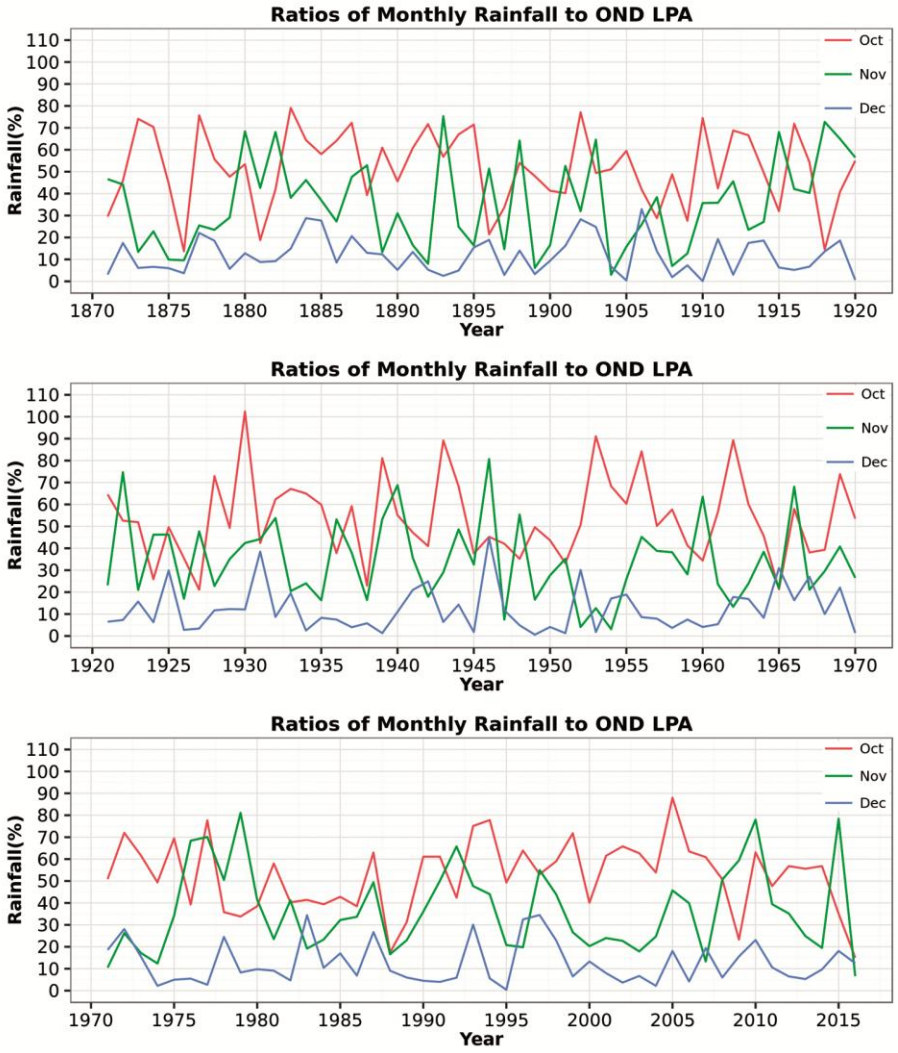

Fig. 8 — Time series of ratios in percentage of NE Monsoon OND monthly rainfall to the corresponding long period average

corresponding months of weak NEMR years and the difference is statistically significant (Table 5) at 99 % confidence level.

Analysis of average rainfall for weak and strong NEMR years shows that during strong NEMR years, average rainfall in each month of NEM is bigger than the LPA of respective months (up to 61.1 % increase) and during weak NEMR years, it is smaller than the LPA of the corresponding months (up to 57.6 % decrease; Fig. 4). Composite analysis of actual rainfall shows that the change of rainfall has a wider range of about 19 mm – 75 mm between months of strong NEMR years and the rainfall has a narrower range of about 24 mm – 64 mm between months of weak NEMR years.

Correlation analysis, which displays the strength of association between PI NEMR and the PI monthly rainfall, indicates that the November rainfall has the highest linear correlation and December rainfall has the least. The steepness of the linear relationship indicated by its regression slope is also highest for November and lowest for December.

Monthly rainfall in October – December demonstrates inter-annual variability (Fig. 8). The percentage contribution of rainfall in October is largest among the three months, November comes next and December has the lowest percentage. The annual variability of monthly rainfall is highest for November and lowest for December.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

EKS, RS & BM: Conceptualization and design of the work; EKS: Data collection, analysis and interpretation, Software and Writing - original draft; RS & BM: Supervision; RS & BM: Writing - review, editing and final approval.

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