Changing Trends of Monsoon in Himachal Pradesh

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Introduction:

In ancient India, it was believed that the sun causes rainfall (Adityat Jayate Vrishti) and that good rainfall in the rainy season is the key to bountiful agriculture and food for the people. Kautilya's Arthashastra contains records of scientific measurements of rainfall and its application to the country's revenue and relief work. Kalidasa in his epic, 'Meghdootam' has written around the seventh century, and even mentioned the date of onset of the monsoon over central India and traces the path of the monsoon clouds. Indian Classical music system celebrates monsoon with several ragas.

Agriculture and related sectors, food security, and energy security of India are crucially dependent on the timely availability of adequate amount of water and a conducive climate. The rainfall received in an area is an important factor in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply and for hydroelectric power generation. Global climate changes may influence long-term rainfall patterns impacting the availability of water, along with the danger of increasing occurrences of droughts and floods. The southwest (SW) monsoon, which brings about 80% of the total precipitation over the country, is critical for the availability of freshwater for drinking and irrigation. Changes in climate over the Indian region, particularly the SW monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the country. The heavy concentration of rainfall in the monsoon months (June–September) results in scarcity of water in many parts of the country during the non-monsoon periods. Therefore, a proper trend analysis of ISMR is required for social and economic planning to assess the impacts of global warming.

Parthasarathy *et al*. (1994) have found that the monsoon rainfall is without any trend and mainly random in nature over a long period of time, particularly on the all India time scale (Mooley and Parthasarathy, 1984). But on the spatial scale, existence of trends was noticed by Parthasarathy (1984) and Rupa Kumar et al. (1992). Though south-west monsoon is the major rain producing season over the country, other seasons have also significant contribution in some specific areas. The rainfall during the winter and pre-monsoon seasons are mostly predominant by western disturbances and convective activities whereas during northeast monsoon is predominant over southern states during the October-December period. Therefore, trends analysis was also carried out on sub-divisional rainfall series for the winter season (January – February), pre-monsoon season (March-May), post-monsoon season (October-December) and also for the annual rainfall.

Many studies have attempted to determine the trend in rainfall on both country and regional scales. Most of these deal with the analysis of annual and seasonal series of rainfall for some individual stations or groups of stations. Some past studies related to changes in rainfall over India have concluded that there is no clear trend in average annual rainfall over the country (Kumar *et.al.*,2010). Though the monsoon rainfall in India exhibited no significant trend over a long period of time, particularly in the all-India scale, pockets of significant long-term rainfall changes were identified in some studies (Kumar and Jain, 2010). The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy events is offset by decreasing moderate events (Goswami *et.al.*, 2006).

Data source and Methodology:

The 112 years accumulation data on precipitation was obtained for twelve districts of Himachal Pradesh from Indian Meteorological Department (IMD), Pune. The data used for this study is for the time period: 1901-2012 and was measured in millimetre (mm).

Trend analysis of a time series consists of the magnitude of trend and its statistical significance. Rainfall data for all twelve districts were analysed for studying trend using 112 years' rainfall data. The analysis was carried out by using non parametric Mann-Kendall (MK) and Sen's slope estimator tests describing trend at all stations and entire Himachal Pradesh (Yu *et.al.*1993, Singh *et. al.*, 2003). The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

The software used for performing the statistical Mann-Kendall test is XLSTAT 2014. The null hypothesis is tested at 95% confidence level for precipitation data for the twelve districts. In addition, to compare the results obtained from the Mann-Kendall test, linear trend line is plotted for each district using Microsoft Excel 2007.

Results & Conclusion:

The trend analysis of monsoon in Himachal Pradesh has been done with 112 years of precipitation from the year 1901 to 2012. Himachal Pradesh was divided into twelve districts. Mann-Kendall and Sen's Slope Estimator has been used for the determination of the trend. The trend analysis is carried out for all the districts by using average rainfall data divided into four seasons i.e. Winter rains (January- February), Pre monsoon rains (March- May), Monsoon rains (June-September) and Post monsoon rain (October- December). The MK trend analysis test showed an increasing trend during winter rains and summer rains in entire

Himachal Pradesh while no significant trend has been noticed in monsoon and post monsoon rainfall. At district level increasing or decreasing trends have been observed during different seasons.

Winter rains (*January- February*): An increasing trend has been noticed in Kangra and Kullu while no statistical significant trends have been observed in rest of the districts (Table:1).

Pre monsoon rains (*March- May*): The significant increasing trend was observed in all the districts except Bilaspur where no significant trend has been noticed (Table:1).

Monsoon rains (*June-September*): The significant increasing trend has been noticed in Hamirpur, Kangra, Sirmour, Solan and Una while significant decreasing trend was observed in Kinnaur and Lahaul& Spiti. There was no statistical significant trend noticed in Bilaspur, Chamba, Kullu, Mandi and Shimla (Table:1).

Post monsoon rains (*October- December*): No statistical significant trends were observed in all the districts (Table:1).

On running the Mann-Kendall test on precipitation data, the following results in Table 1 were obtained for the twelve districts of Himachal Pradesh during winter rains, pre monsoon, monsoon and post monsoon. If the p value is less than the significance level α (alpha) = 0.05, H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant.

Table1: Results of the Mann-Kendall test for precipitation data for twelve districts of Himachal Pradesh

WINTER RAINS									
District	**Mean**	**S.D**	**Mann-Kendall Statistic (S)**	**Kendall's tau**	**Var(S)**	**p-value (Two-tailed)**	**alpha**	**Sen's slope**	**Test Interpretation**
Bilaspur	54.239	21.785	-38.000	-0.166	1254.667	0.296	0.05	-1.125	Accept H_0
Chamba	41.973	25.556	765.000	0.123	158161.667	0.055	0.05	0.126	Accept H_0
Hamirpur	33.155	19.517	712.000	0.115	158162.667	0.074	0.05	0.098	Accept H_0
Kangra	36.060	20.315	980.000	0.158	158162.667	0.014	0.05	0.137	Reject H_0
Kinnaur	42.680	24.717	297.000	0.048	158161.667	0.457	0.05	0.05	Accept H_0
Kullu	45.505	27.590	1114.000	0.179	158162.667	0.005	0.05	0.206	Reject H_0
Lahaul & Spiti	40.970	19.546	526.000	0.085	158162.667	0.187	0.05	0.075	Accept H_0

Mandi	35.647	18.632	660.000	0.106	158162.667	0.098	0.05	0.087	Accept H_0
Shimla	36.835	18.899	558.000	0.090	158162.667	0.161	0.05	0.079	Accept H_0
Sirmour	29.062	16.281	116.000	0.019	158162.667	0.772	0.05	0.012	Accept H_0
Solan	28.311	15.896	498.000	0.080	158162.667	0.211	0.05	0.052	Accept H_0
Una	28.614	18.399	580.000	0.093	158162.667	0.145	0.05	0.069	Accept H_0

PRE MONSOON RAINS

District	Mean	S.D	Mann-Kendall Statistic (S)	Kendall's tau	Var(S)	p-value (Two-tailed)	alpha	Sen's slope	Test Interpretation
Bilaspur	40.874	20.945	-25.000	-0.108	0.000	0.504	0.05	-0.365	Accept H_0
Chamba	32.869	16.537	1450.000	0.233	158162.667	0.000	0.05	0.155	Reject H_0
Hamirpur	22.661	12.853	1390.000	0.224	158162.667	0.000	0.05	0.107	Reject H_0
Kangra	25.935	13.108	1520.000	0.245	158162.667	0.000	0.05	0.121	Reject H_0
Kinnaur	37.291	18.120	922.000	0.148	158162.667	0.021	0.05	0.098	Reject H_0
Kullu	36.020	20.601	1526.000	0.245	158162.667	0.000	0.05	0.198	Reject H_0
Lahaul & Spiti	36.794	17.519	822.000	0.132	158162.667	0.039	0.05	0.102	Reject H_0
Mandi	25.537	13.857	1498.000	0.241	158160.667	0.000	0.05	0.126	Reject H_0
Shimla	27.726	13.468	1440.000	0.232	158162.667	0.000	0.05	0.122	Reject H_0
Sirmour	19.212	11.178	1384.000	0.223	158162.667	0.001	0.05	0.088	Reject H_0
Solan	18.405	10.130	1399.000	0.225	158161.667	0.000	0.05	0.085	Reject H_0
Una	19.384	10.031	1262.000	0.203	158162.667	0.002	0.05	0.083	Reject H_0

MONSOON RAINS

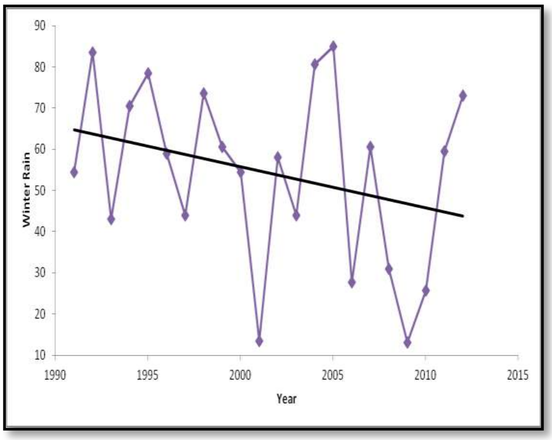
District	Mean	S.D	Mann-Kendall Statistic (S)	Kendall's tau	Var(S)	p-value (Two-tailed)	alpha	Sen's slope	Test Interpretation
Bilaspur	231.130	44.520	-49.000	-0.194	0.000	0.208	0.05	-2.475	Accept H_0
Chamba	158.273	52.216	-230.000	-0.037	158162.667	0.565	0.05	-0.078	Accept H_0
Hamirpur	169.857	55.424	1082.000	0.174	158162.667	0.007	0.05	0.481	Reject H_0
Kangra	176.650	71.027	1148.000	0.185	158162.667	0.004	0.05	0.563	Reject H_0
Kinnaur	172.170	61.198	-1334.000	-0.215	158162.667	0.001	0.05	-0.637	Reject H_0
Kullu	180.779	55.368	-528.000	-0.085	158162.667	0.185	0.05	-0.193	Accept H_0

Lahaul & Spiti	124.721	48.378	-1150.000	-0.185	158162.667	0.004	0.05	-0.417	Reject H_0
Mandi	180.440	53.210	776.000	0.125	158162.667	0.051	0.05	0.342	Accept H_0
Shimla	186.857	49.177	-432.000	-0.069	158162.667	0.278	0.05	-0.156	Accept H_0
Sirmour	178.084	56.679	1010.000	0.162	158162.667	0.011	0.05	0.385	Reject H_0
Solan	156.757	45.130	866.000	0.139	158162.667	0.030	0.05	0.275	Reject H_0
Una	151.919	53.687	1300.000	0.209	158162.667	0.001	0.05	0.506	Reject H_0

POST MONSOON RAINS

District	Mean	S.D	Mann-Kendall Statistic (S)	Kendall's tau	Var(S)	p-value (Two-tailed)	alpha	Sen's slope	Test Interpretation
Bilaspur	16.243	21.469	25.000	0.099	1431.667	0.526	0.05	0.178	Accept H_0
Chamba	13.326	8.717	378.000	0.061	158160.667	0.343	0.05	0.025	Accept H_0
Hamirpur	10.416	7.902	173.000	0.028	158161.667	0.665	0.05	0.008	Accept H_0
Kangra	11.500	8.079	455.000	0.073	158161.667	0.254	0.05	0.026	Accept H_0
Kinnaur	15.954	9.598	-15.000	-0.002	158161.667	0.972	0.05	-0.002	Accept H_0
Kullu	15.176	10.802	579.000	0.093	158161.667	0.146	0.05	0.043	Accept H_0
Lahaul & Spiti	14.817	9.105	8.000	0.001	158160.667	0.986	0.05	6.068E-4	Accept H_0
Mandi	11.499	7.420	61.000	0.010	158161.667	0.880	0.05	0.004	Accept H_0
Shimla	12.899	7.820	69.000	0.011	158161.667	0.864	0.05	0.004	Accept H_0
Sirmour	10.065	6.660	-49.000	-0.008	158159.000	0.904	0.05	-0.003	Accept H_0
Solan	8.952	6.075	17.000	0.003	158161.667	0.968	0.05	6.124E-4	Accept H_0
Una	9.214	7.307	359.000	0.058	158161.667	0.368	0.05	0.016	Accept H_0

BILASPUR



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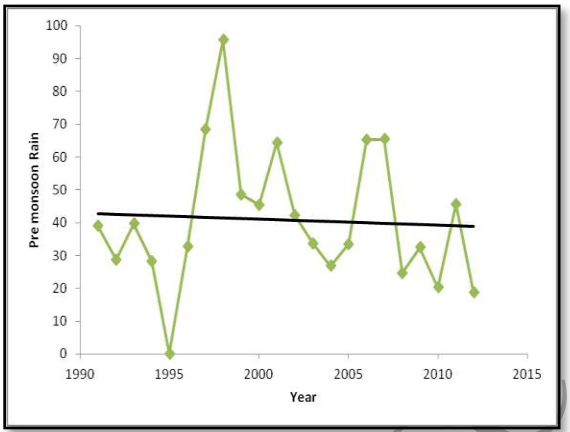

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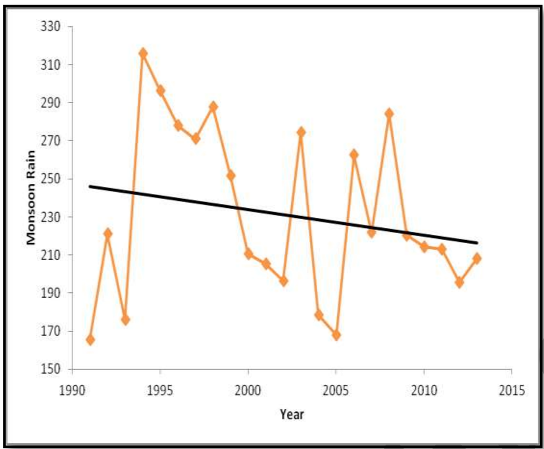

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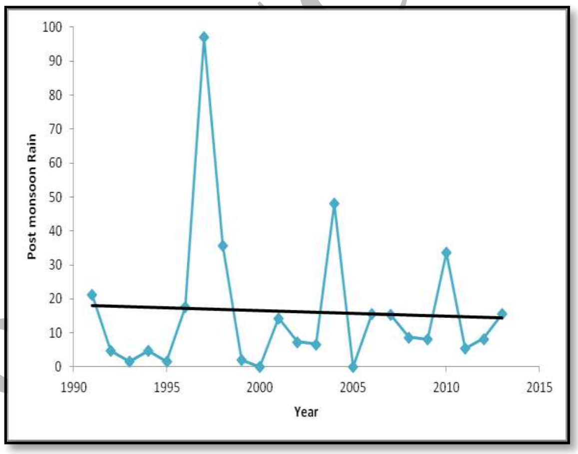

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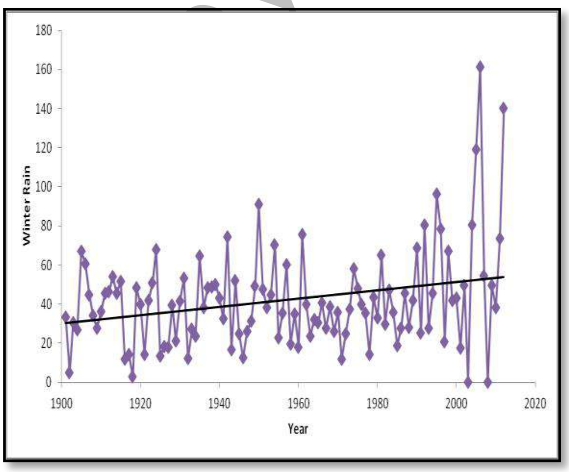

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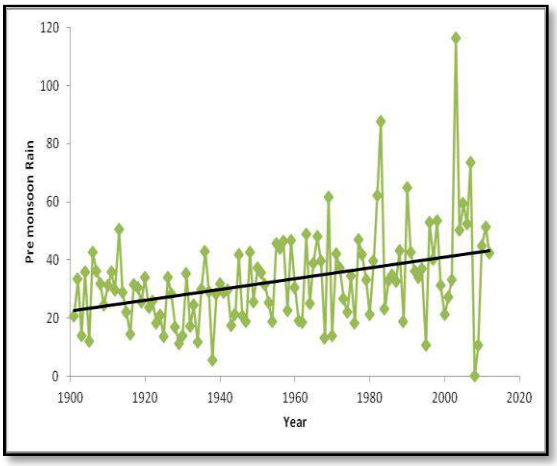

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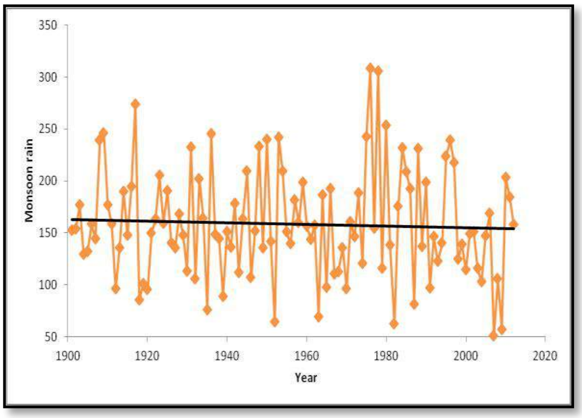

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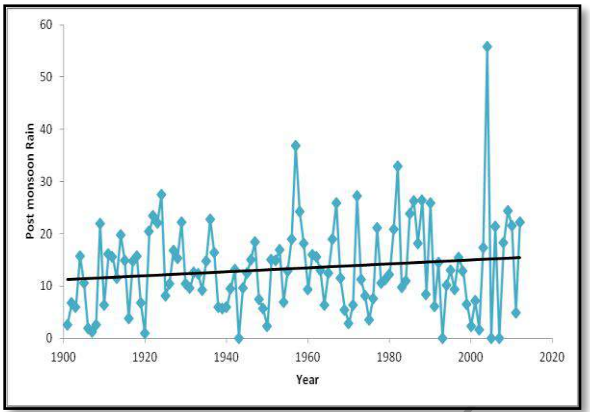

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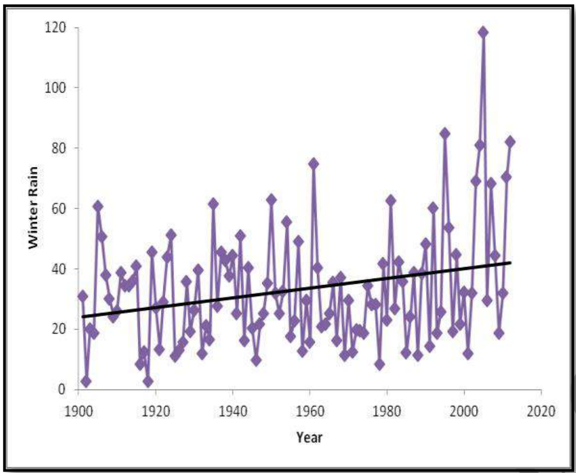

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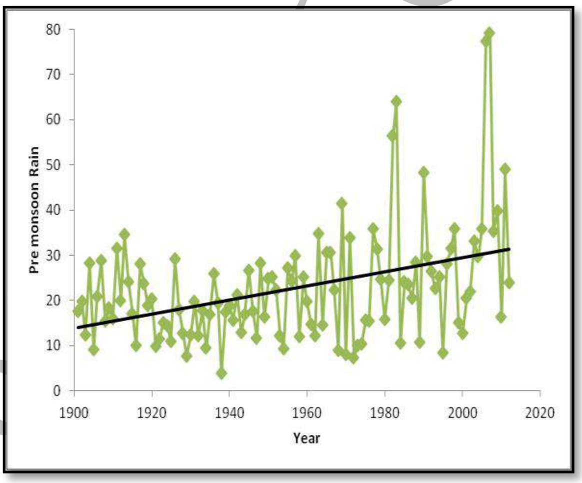

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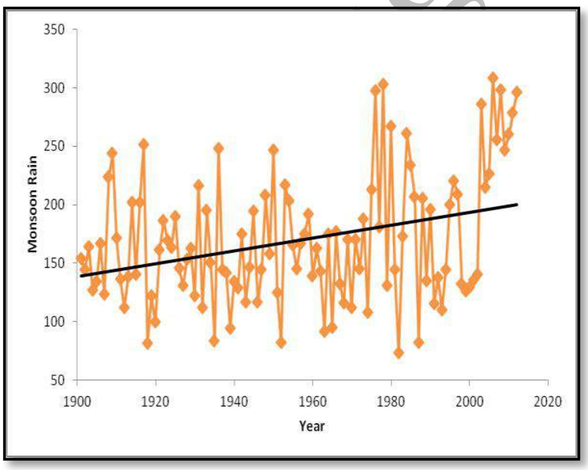

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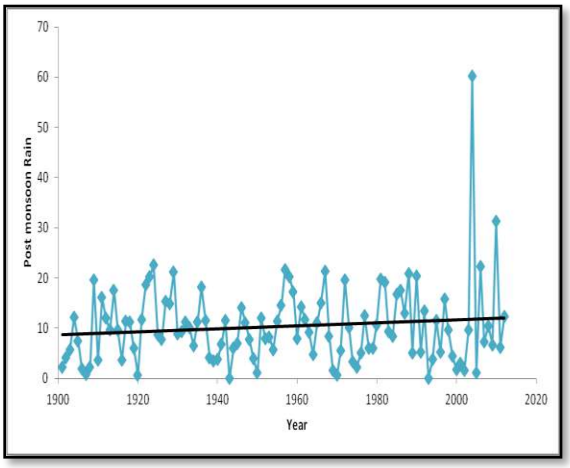

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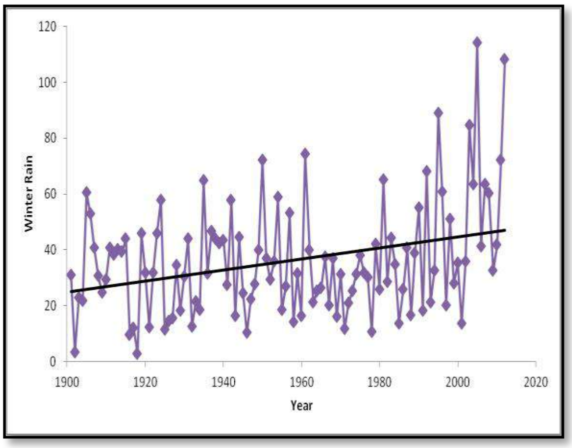

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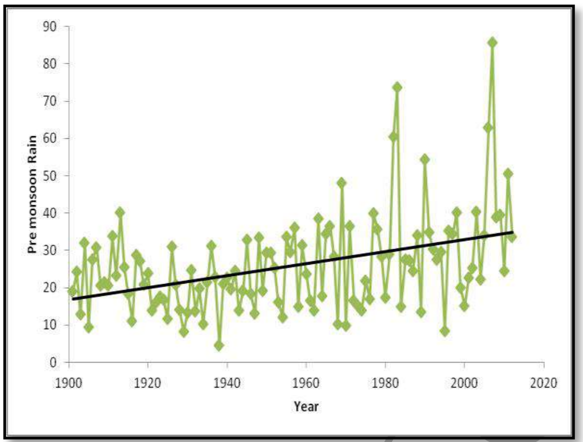

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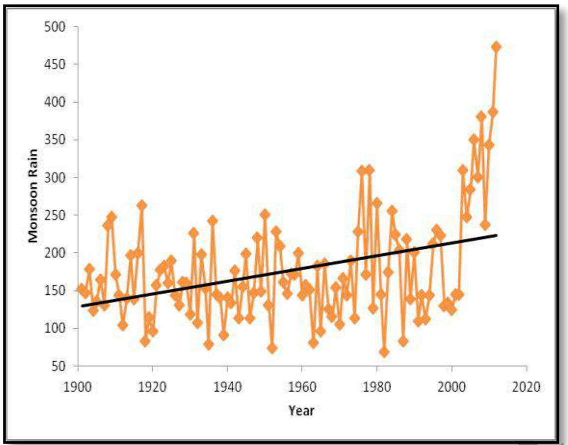

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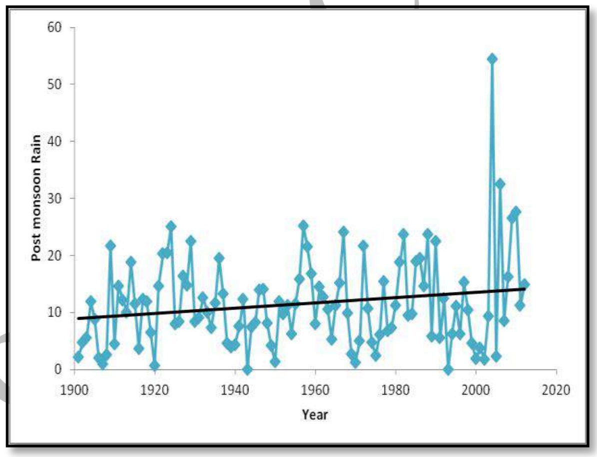

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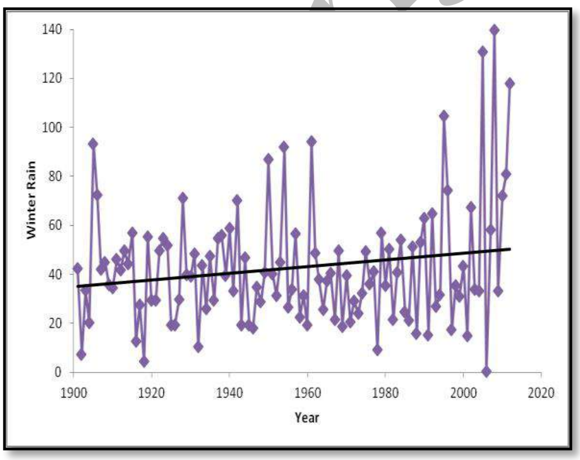

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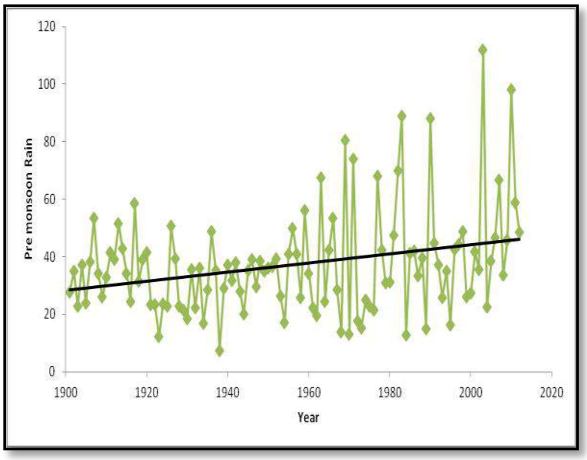

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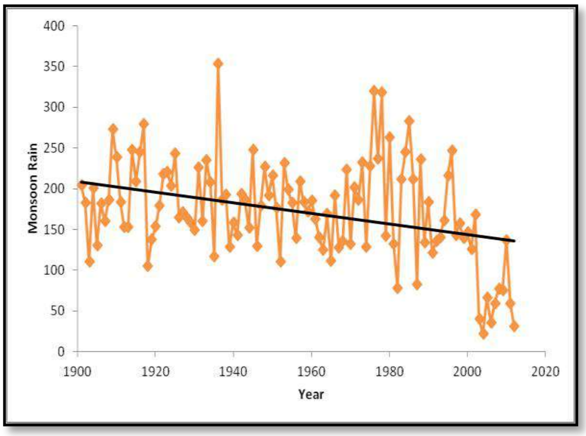

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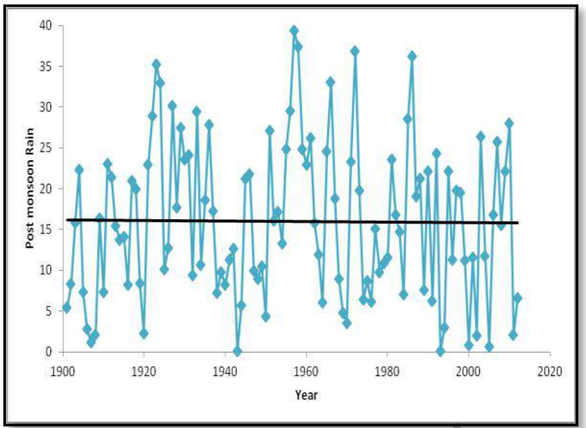

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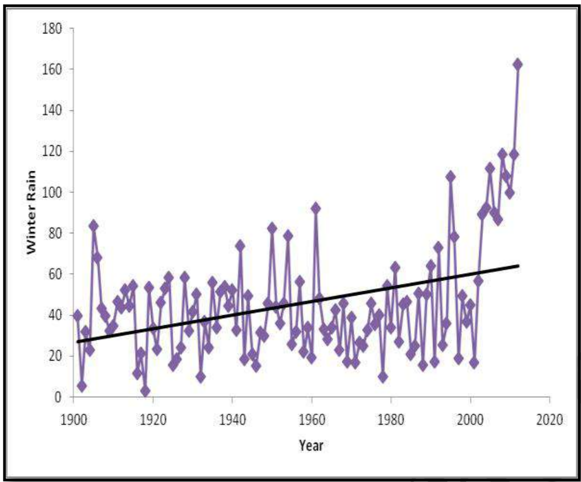

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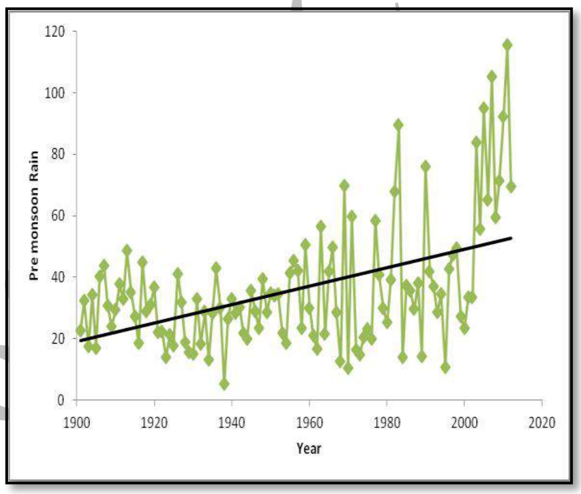

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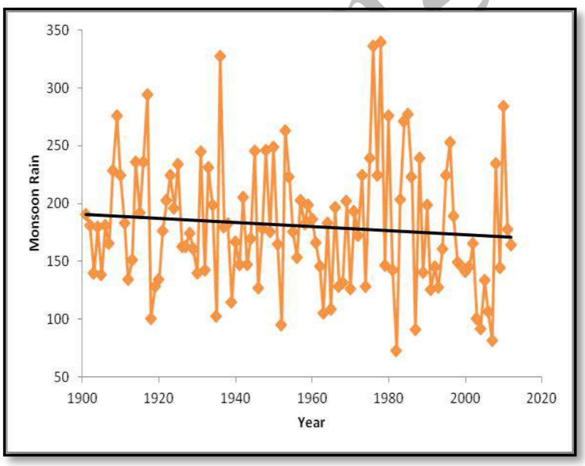

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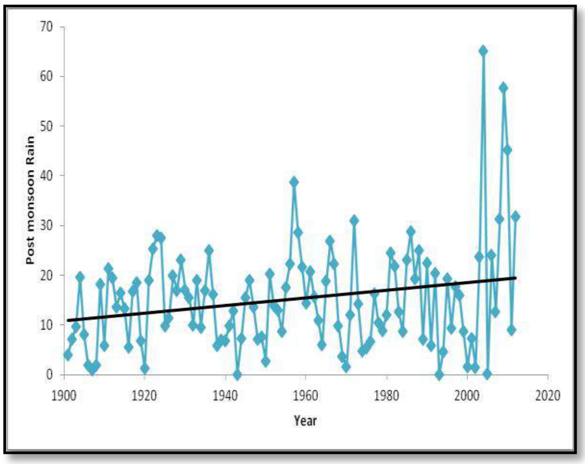

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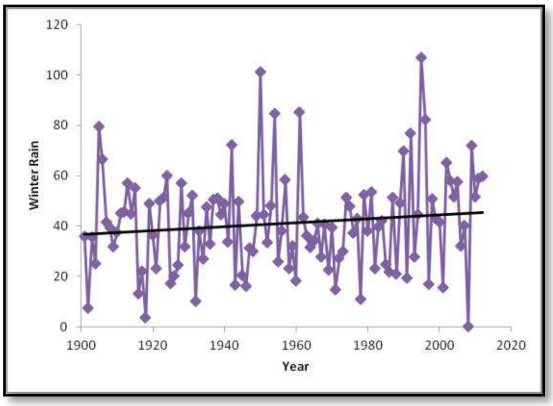
LAHAUL & SPITI



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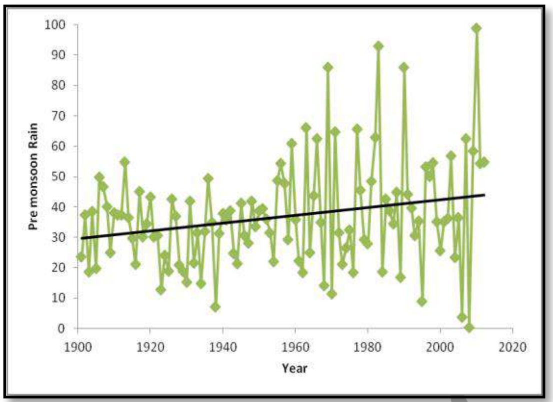

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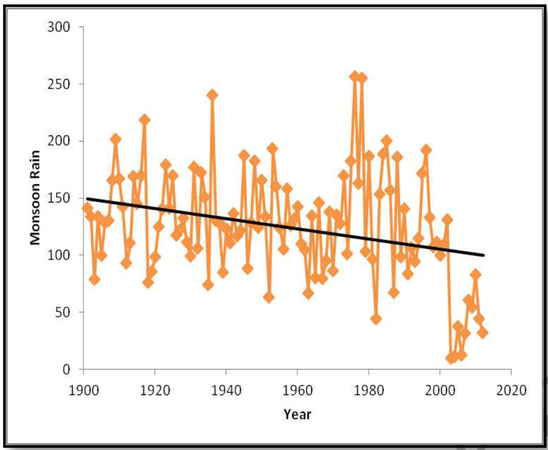

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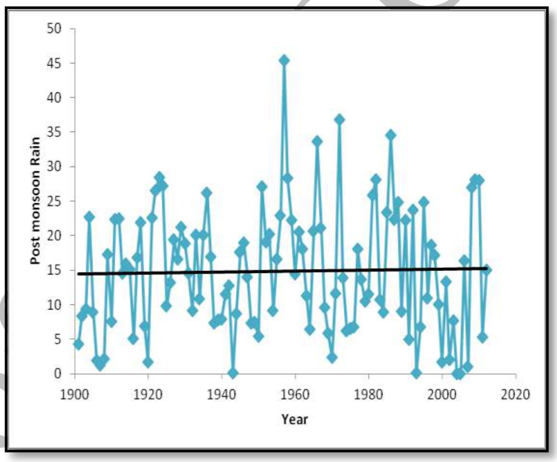

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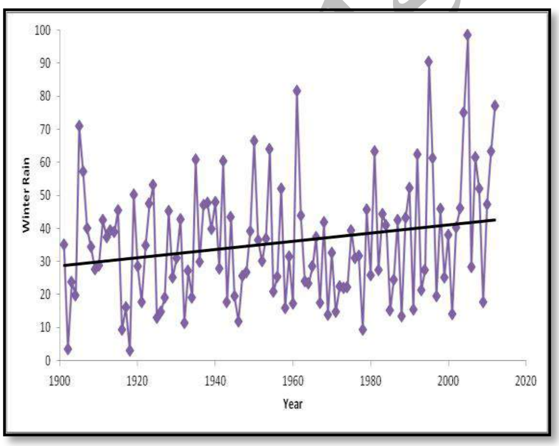

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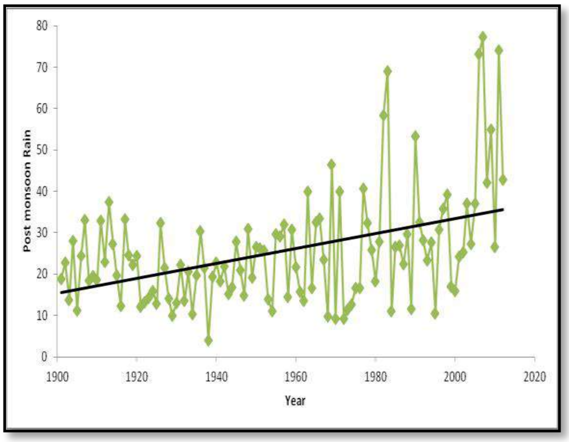

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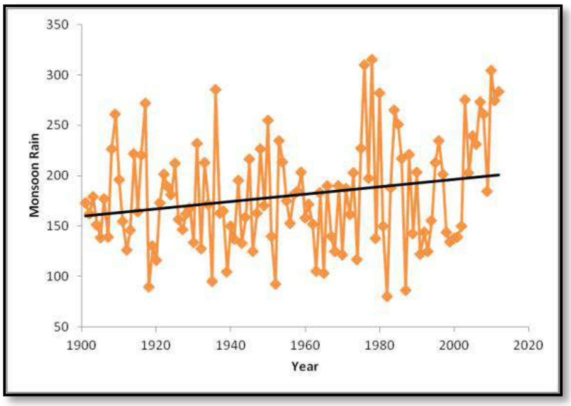

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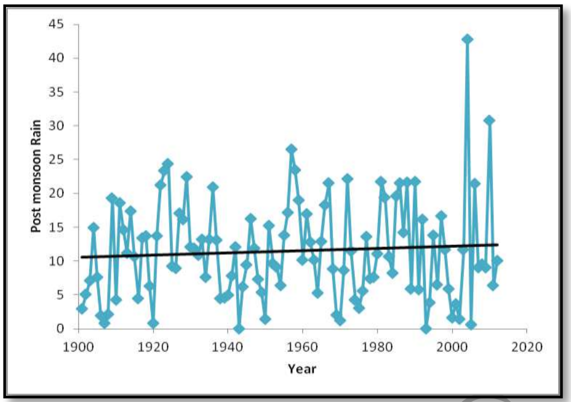

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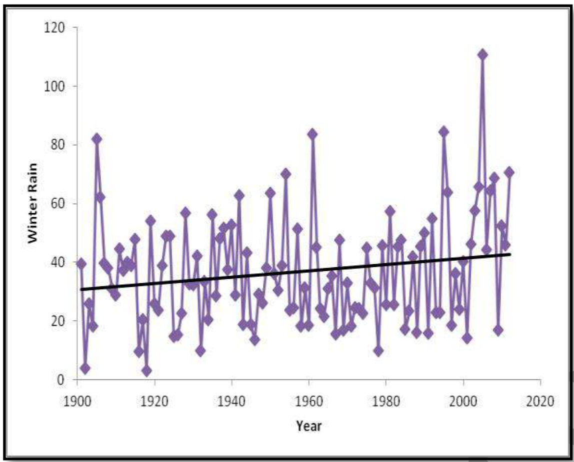

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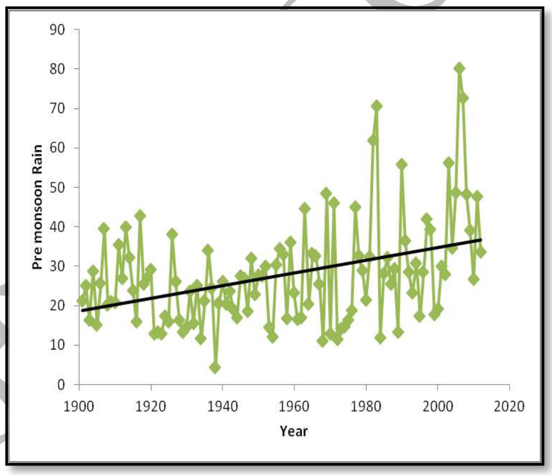

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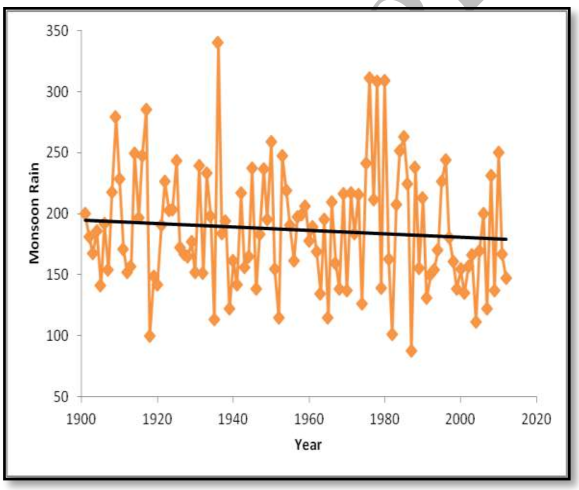

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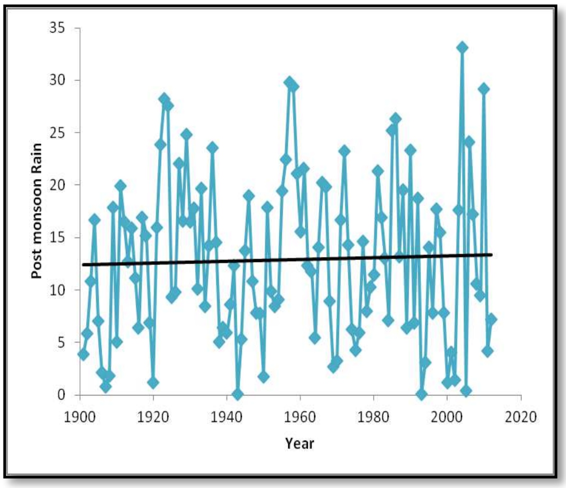

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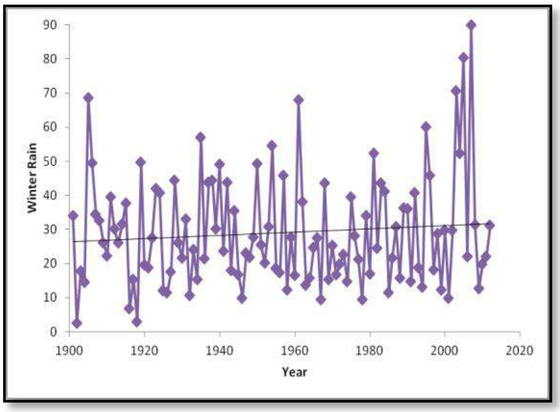
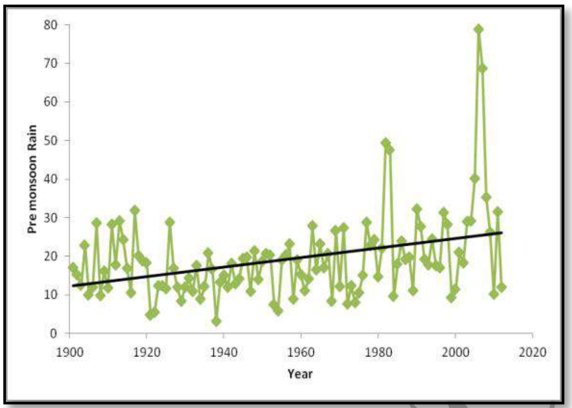


WINTER RAIN



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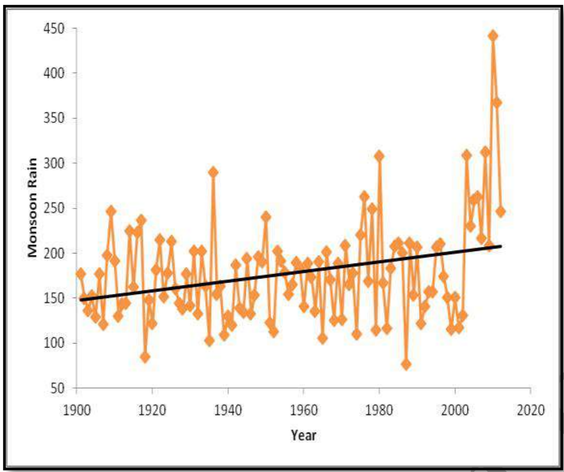

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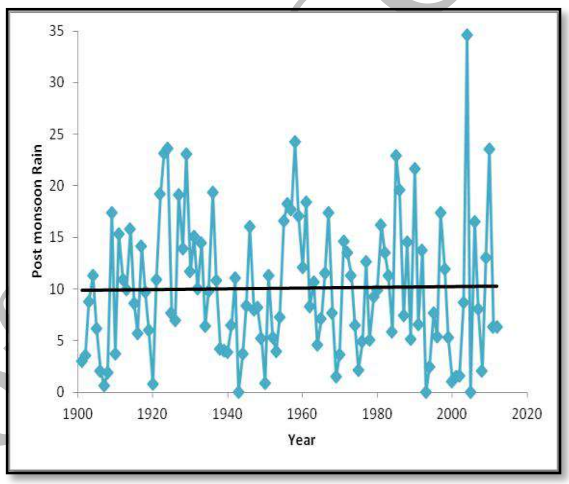

POST MONSOON RAIN

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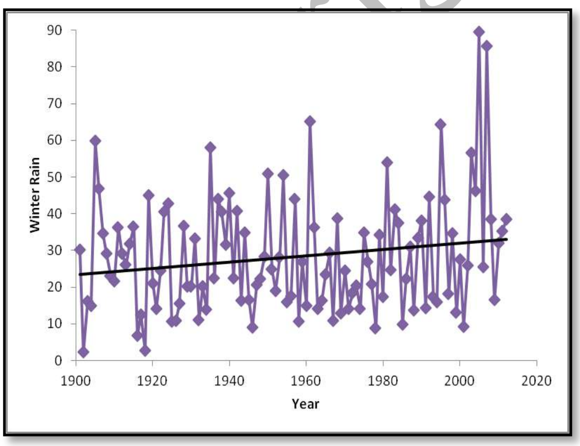

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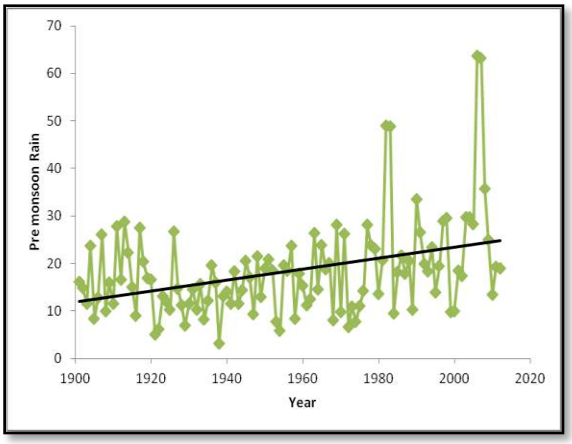

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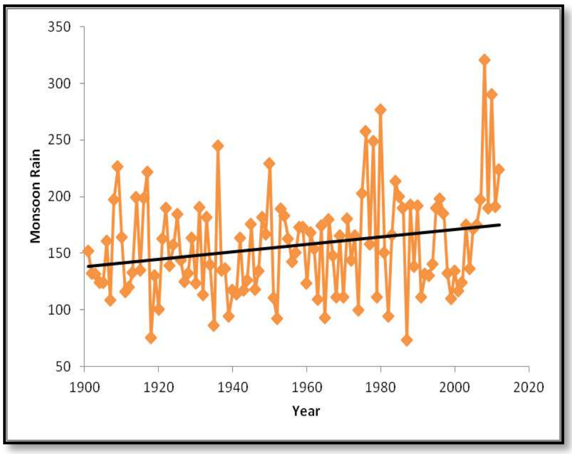

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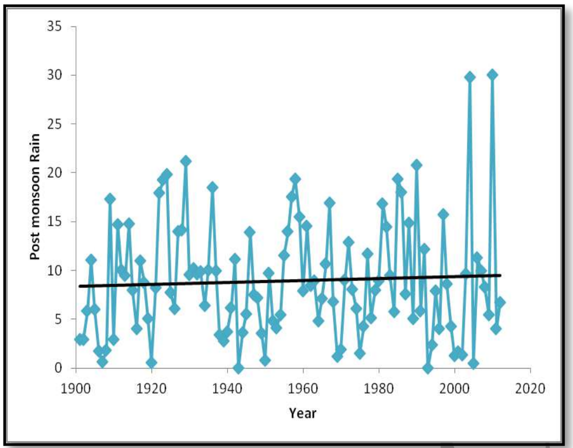
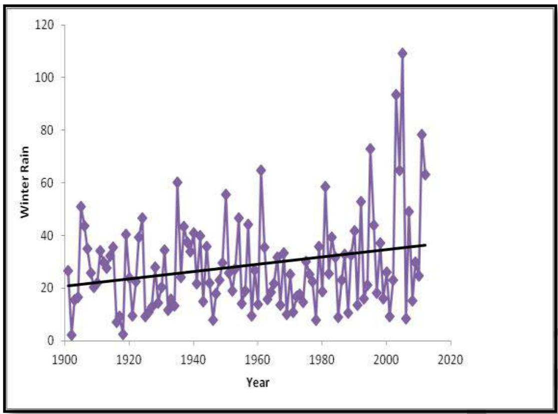


POST MONSOON RAIN

UNA



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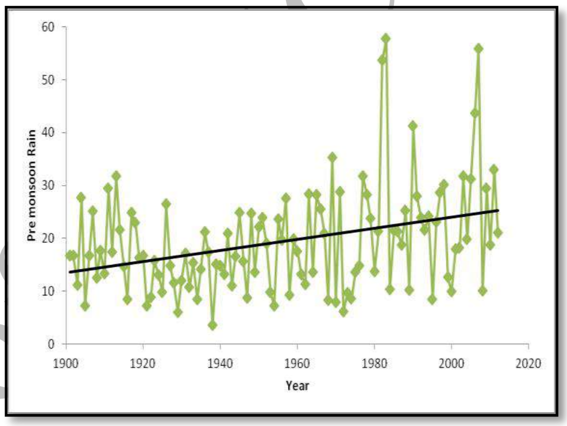

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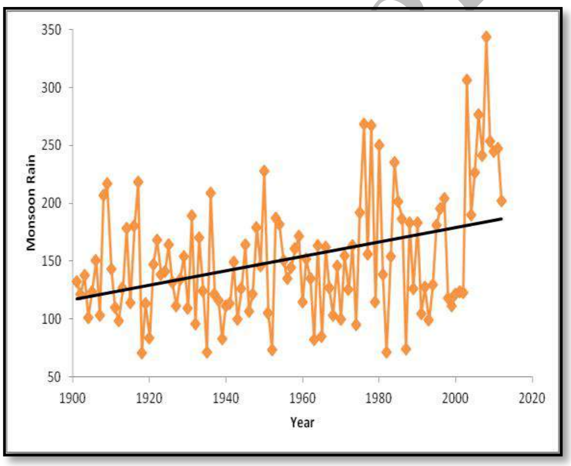

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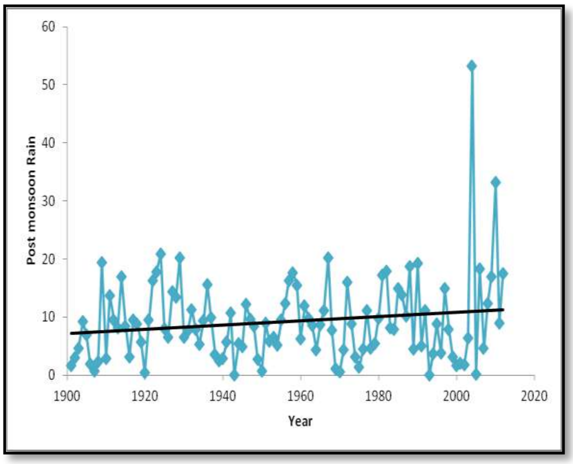

POST MONSOON RAIN

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