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Research Article

Entropy induced Rainfall Variability Assessment for Regions of Himachal Pradesh located in Outer Himalayas

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Abstract

Global climate change can cause shift in rainfall pattern. Shift in rainfall pattern can impact agricultural practices and water management both in rural and urban societies. Information theory can be used to study the shift in rainfall pattern. In the present study, marginal entropy has been used to understand the randomness in rainfall data of Shivalik hills or outer Himalayan regions of Himachal Pradesh of India. Bilaspur, Sirmaur and Solan are the districts of Himachal Pradesh which are located in Outer Himalayas. In this study, rainfall variability assessment of these regions has been done using marginal entropy approach. Marginal entropy quantifies the uncertainty or randomness associated with a single variable. In this study, the single variable was rainfall. Rainfall time series data from 1980 to 2021 has been used for both the study locations. The results suggested that in these districts of Himachal Pradesh, marginal entropy (ME) of at least 50% of the total number of study period, exceeded average ME. The average ME was 0.117, 0.118 and 0.127 for Sirmaur, Solan and Bilaspur respectively. It indicated that shifts in rainfall behavior were taking place, possibly due to climatic or anthropogenic influences in the region.

Keywords: Marginal entropy, rainfall variability, Bilaspur, Sirmaur, Solan

Introduction

Hydrological cycle is one of the significant phenomena responsible for maintaining balance in the nature and sustaining life on earth. Rainfall is one of the primary components of this hydrological cycle. Due to the excelled advancement in technology, race of improving living standards, global warming, deforestation and other human induced activities, rainfall variability is increasing swiftly which results in the unpredicted natural disasters such as floods and droughts (Mehta and Yadav, 2021;

Alahacoon et. al., 2021). In 2016, almost 23.5 million people were dislocated because of natural disasters related to extreme meteorological events—mainly storms and floods in the Asia-Pacific region (Li and Nguyen, 2021). The rainfall causing storms and floods have become more common in the last decade and needs to be addressed as it is impacting the agriculture and water management sector significantly (Saharia et. al., 2021; Wang et. al., 2023). The variation in the pattern of rainfall of the driving reason for these unpredictable floods and this variation need to be understood quickly. Marginal entropy can be a helpful tool in the assessment of rainfall variability (Singh et. al., 2023; Mohammed et. al., 2022). There have been a number of researchers who have used this marginal entropy technique for the assessment of variability in the rainfall and have given positive response for the method such as Montesarchio et. al., 2011 studied the rainfall variability in Mignone river basin in Central Italy using the threshold value of rainfall calculated with the help of information entropy concept. This study helped particularly in the issue of safety alarms and warnings against flash floods in the regions in the real time basis. Wang et. al., 2018 carried out a study for the optimization of rainfall network using the information entropy theory in Shanghai (in Yangtze River basin) and Xi'an (in Yellow River basin) of China, with respect to temporal variability analysis. This study opted an algorithm known as Maximum Information Minimum Redundancy (MIMR) for optimizing rainfall networks, which showed the difference in entropy values for wet and dry season, particularly pitching the value of entropy in wet season. Another study by Choobeh et. al., 2023 was carried out to assess the rainfall variability in Iran. In this study, 50 stations in Iran were selected and their precipitation data was observed from 1980-2020. Marginal entropy concept was used to analyze the variability in monthly, seasonal and annual precipitation. The apportionment entropy (AE) was applied to the time series to investigate the intra-annual and decadal distribution of monthly and annual precipitation values. The study also utilized the Mann–Kendall test to examine the marginal and relative entropy trends of the study stations. The results of the study revealed that the entropy was highest in September and lowest in January. The results also highlighted that the variability in rainfall was more in summer and spring season than in winter and fall seasons. Mishra et. al., 2005 carried out a study of rainfall variability assessment in Texas, USA by assessing the monthly, seasonal and annual precipitation data from 1925 to 2005 using the marginal entropy approach. The apportionment and intensity entropy were used for the inter-annual and decadal variability analysis of time series. The Kann Kendall test and hurst exponent were also employed to assess the trend of variability in [precipitation. The results of the study revealed that there were high variability disorders in the Texas state of USA and this variability increases from east to west of Texas. A study by da Silva et. al., 2016 was about the assessment of spatio-temporal variability assessment of rainfall in Brazil using Shannon entropy. The study analyzed the 10 years precipitation data of 189 stations of Brazil and prepared entropy maps by calculating the marginal entropy values. The result of this study showed the high entropy value indicating the high variability in the rainfall resulting in unpredicted rainfall events. Singh et. al., 2021 carried out a study in Almora, Nainital and Pauri districts of Uttarakhand to asses the variability in rainfall using the marginal entropy approach. The precipitation data from 1901 to 2016 had been collected from Indian Meteorological Department and Disaster Index and Mean Marginal Disaster Index were calculated for all the three districts and the mean marginal disaster index was observed high (i.e. 0.351) for the post– monsoon season at Nainital station, followed by Pauri, and Almora stations. Guntu et. al., 2020 used Standard Variability Index using the entropy approach to investigate the spatio-temporal variability at different timescales within the Indian subcontinent. The result of this study revealed that the intra-annual variability and the number of rainy days increased over the Indian subcontinent. The result also revealed that variability of the rainfall increased from east to west of India. Singh and Kumar, 2024 studied the variability of rainfall in all districts of Haryana from 1951-2020. The study used various entropy approaches to observe the intra-variability in precipitation at different time scales. The results od the study showed that intra-variability in both rainfall amounts and rainy days increased with an increase in the time scale for all districts in Haryana, and inconsistency on rainy days was more pronounced than rainfall amounts, which further means that the distribution of rainfall intensity was highly inconsistent in the study region. The present study gives a detailed insight about the marginal entropy concept with reference to the rainfall variability assessment and objects to assess the variability of Rainfall in Bilaspur, Sirmaur and Solan district of Himachal Pradesh

Study Area

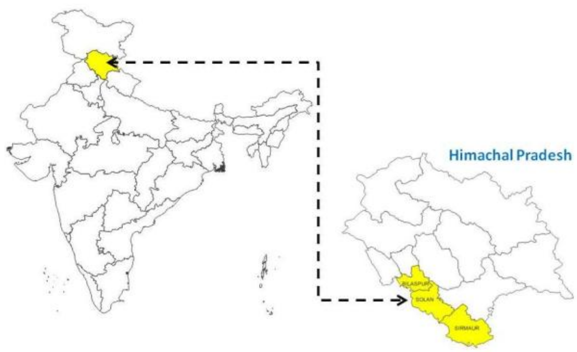
Himanchal Pradesh is the northern Indian state. The climate varies from hot and sub-humid tropical (450–900 meters) in the southern low tracts, warm and temperate (900–1800 meters), cool and temperate (1900–2400 meters) and cold glacial and alpine (2400–4800 meters) in the northern and eastern high elevated mountain ranges. Fig.1 shows the geographical location of study area. In the present study, Bilaspur, Sirmaur and Solan districts of Himachal Pradesh has been selected.

Bilaspur, located in the outer foothills of the Himalayan Mountain range as shown in Fig. 1, is a district in Himachal Pradesh spanning an area of 1167 km^2. The area is basically a mountain prone region with very little flat areas. There are seven hill ranges found in the area namely Bahadurpur, Bandla, Jhanjiar, Kot, Naina Devi, Ratanpur and Tiun. The district is a part of Shivalik ranges and the major river contributing to satisfy the water demand of the district id Sutlej River which passes through the center of the district dividing it into two equal halves.

Sirmaur, a district of Himachal Pradesh, is situated in the Shivalik ranges shown in Fig. 1. It is known for its diverse geographical features. The district is located at an elevation of 300-3000 m above mean sea level. The topography of the region primarily constitutes of hills and mountains along with deep intermountain valleys. The major rivers found in the region are Giri and Tons and the Giri river merges with Yamuna River in this area.

Solan district of Himachal Pradesh, shown in Fig. 1, is situated in the Shivalik ranges at an elevation of 300-3000 meter above mean sea level. The area is bounded by Shimla in the North, Ambala district of Haryana and Ropar district of Punjab in the south, Sirmaur district in the east and Bilaspur district in the west. the district is blessed with the drainage basins of Yamuna, Sutlej, and Ghaggar rivers. The topography of the district is rich in rocks and mountains including the Choordhar and Karol mountains.

For the present study, precipitation data from 1980-2021 and time series data for the three districts has been utilized. The precipitation data has been taken from WRIS and the time series data has been divided into four seasons namely the Winter Season (WS) lasting from January to February, Pre-Monsoon season (Pre-M) beginning from March and ending in June, Monsoon season i.e., from July to September and Posr-Monsoon season (Post-M) staying from October to December. Also, in this study QGIS has been used to georeferenced the average Marginal Entropy of the three districts i.e., Bilaspur, Sirmaur and Solan from 1980-2021.



Entropy Theory

Entropy is a thermodynamic property associated with measuring the degree of randomness or disorder of a system. It is associated with the second law of thermodynamics. Higher the entropy, higher will be the degree of randomness in the system (Bien, 2006; Wherl, 1978). In present study, for the assessment of rainfall variability, marginal entropy has been used. Marginal entropy, with reference to rainfall variability, refers to the variability or randomness in the rainfall pattern of the area with respect to the time series, that may be monthly, quarterly, half yearly or annual. For the study, the higher the marginal entropy, higher will be the variability of rainfall in the study area (Wang et. al., 2018; Twaróg, 2025; Prajapati et. al., 2024). The mathematical expression for evaluating ME is given by:

$$ME = -\sum_{i}^{n} \frac{r_i}{R} log_2[\frac{r_i}{R}] \quad (1)$$

where r_i denotes the rainfall amount for the i^{th} year and R denotes the total rainfall for the period taken, here 1980-2021.

Marginal entropy provides insights into the variability or randomness of a variable, without considering any relationships or dependencies with other variables. In hydrology and climate studies, marginal entropy is particularly useful for assessing the variability of environmental factors such as rainfall or temperature at a specific location or time. This measure aids in identifying periods or regions with high climatic uncertainty, which is crucial for water resource planning, drought risk management, and agricultural decision-making.

Result and Discussion

This section delves into the result of entropy assessment of Bilaspur, Sirmaur and Solan districts of Himachal Pradesh to characterize the variability of rainfall in these three districts and showcases them in the statistical and tabular forms.

Entropy Assessment of Bilaspur

Marginal entropy values indicate the degree of uncertainty or variability associated with a single variable, such as rainfall or streamflow, without considering the influence of other variables. Higher marginal entropy values suggest greater unpredictability or randomness in the variable's distribution, while lower values imply more regularity or predictability.

From Table 1, it is clear that out of 41 years of the study period (1980-2021) for Bilaspur district of Himachal Pradesh, maximum value for the years exceeding the value of average marginal entropy was in the Winter and Pre-Monsoon season. In winter season, the value of marginal entropy excelled in 22 years with the range of marginal entropy to be 0.033-0.236. The median and standard deviation values were 0.127 and 0.048 respectively. In Pre-Monsoon season also, there were 22 years in which the value of average marginal entropy exceeded. The range of marginal entropy was 0.049-0.225 and the median and standard deviation values for the Bilaspur district of Himachal Pradesh for the study period were 0.132 and 0.033 respectively. There were 17 years in the Monsoon period in Bilaspur district when the value of average marginal entropy hiked and the range of marginal entropy for the season was 0.078-0.180. The values of median and standard deviation for the winter season in Bilaspur district from 1980 to 2021 were 0.126 and 0.023 respectively. For the Post-Monsoon season the median and standard deviation values for the study period in Bilaspur district were 0.108 and 0.079 respectively with the marginal entropy range of 0.004-0.350. The number of years in which the value of average marginal entropy exceeded was 22.

In Fig.2, there are four graphs showing the seasonal change in the marginal entropy of Bilaspur district of Himachal Pradesh from 1980 to 2021. The four graphs are for Jan-Feb i.e, the Winter season, Mar-Jun which is the Pre-Monsoon season, the Monsoon season i.e., from Jul-Sep, and the Post-Monsoon season which is Oct-Dec.

Entropy Assessment of Sirmaur

Further, for Sirmaur district, it is evident from Table 2 that in the winter season there were 20 years from 1980-2021 when the value of average marginal entropy exceeded. The range of the marginal entropy within the study period was 0.025-0.268 with the median and standard deviation values as 0.117 and 0.051 respectively. In the Pre-Monsoon season, there were again 20 years which had excelled average marginal entropy value and the range of marginal entropy was 0.054-0.203. The median and standard deviation values for Pre-Monsoon season of Sirmaur district were 0.123 and 0.039 respectively. In the Monsoon season, there were 20 years within the study period in which the value of average maximum entropy increased the threshold value. The range for the marginal entropy in the Monsoon season for Sirmaur district was 0.078-0.191 and the median and standard deviation values for the same were 0.127 and 0.027 respectively. The median and standard deviation values for Post-Monsoon season for the Sirmaur district were 0.088 and 0.085 respectively, and the range for marginal entropy was 0.006-0.337. Out of 41 years of the study period, there were only 20 years in the Post-Monsoon season in which value of average marginal entropy excelled for Sirmaur district.

Entropy Assessment of Solan

From Table 3 it is clearly evident that in the winter season, the range of marginal entropy was 0.052-0.223 with 19 years within the study period which had average maximum entropy value more than the threshold value and the values for median and standard deviation were 0.118 and 0.047 respectively for the Solan district of Himachal Pradesh. In the Pre-Monsoon season of the Solan district, from 1980-2021, the values of median and standard deviation along with the range of maximum entropy were 0.120, 0.035 and 0.049-0.205 respectively. There were 21 years out of the 41 years of the study area wherein the value of average marginal entropy value was found excelled in Pre-Monsoon season. The range of maximum entropy was 0.076-0.215 with the median and standard deviation as 0.125 and 0.26 respectively in the Monsoon season. During the study period, 19 years were there whose value exceeded the average marginal entropy value in Solan district during Monsoon season. For the Post-Monsoon season, the range of maximum entropy was 0.003-310 during the study period. The values of median and standard deviation for this season in Solan district were observed as 0.106 and 0.079 respectively.

In Fig. 4, four graphs representing the variation of maximum entropy in Solan district of Himachal Pradesh in four seasons i.e., Winter (Jan-Feb), Pre-Monsoon (Mar-Jun), Monsoon (Jul-Sep) and Post-Monsoon (Oct-Dec) for the study period i.e., from 1980 to 2021 have been shown.

Conclusion

Entropy is the measure of randomness of an event. Marginal entropy provides the degree of variability involved in a process. In present study, marginal entropy is used to investigate the variability of rainfall in Bilaspur, Sirmaur and Solan districts of Himachal Pradesh. All the three districts are mountain regions and are apple of tourists' eye. Due to this increased tourism and resulting global warming, the natural climate of the area is affecting substantially and the most affected phenomenon is precipitation. From the study it can be concluded that there is high variability in the rainfall of the three districts since 1980-2021.

Table 1 Statistical performance of marginal entropy for Bilaspur district

	Year	1980-2000	2001-2021	1980-2021
WS	No. of years exceeding average ME	13	9	22
	Median	0.129	0.113	0.127
	Standard Deviation	0.041	0.054	0.048
	Range	0.066-0.117	0.033-0.236	0.033-0.236
Pre-M	No. of years exceeding average ME	11	11	22
	Median	0.130	0.137	0.132
	Standard Deviation	0.033	0.033	0.033
	Range	0.095-0.225	0.049-0.171	0.049-0.225
Monsoon	No. of years exceeding average ME	10	7	17
	Median	0.124	0.126	0.126
	Standard Deviation	0.026	0.021	0.023
	Range	0.078-0.176	0.092-0.180	0.078-0.180
Post-M	No. of years exceeding average ME	13	7	20
	Median	0.133	0.088	0.108
	Standard Deviation	0.094	0.057	0.079
	Range	0.005-0.350	0.004-0.208	0.004-0.350

Table 2 Statistical performance of marginal entropy for Sirmaur district

	Year	1980-2000	2001-2021	1980-2021
WS	No. of years exceeding average ME	10	10	20
	Median	0.017	0.117	0.117
	Standard Deviation	0.038	0.062	0.051
	Range	0.065-0.198	0.025-0.268	0.025-0.268
Pre-M	No. of years exceeding average ME	11	9	20
	Median	0.129	0.120	0.123
	Standard Deviation	0.038	0.042	0.039
	Range	0.054-0.196	0.055-0.203	0.054-0.203
Monsoon	No. of years exceeding average ME	13	7	20
	Median	0.138	0.120	0.127
	Standard Deviation	0.028	0.025	0.027
	Range	0.082-0.189	0.078-0.191	0.078-0.191
	No. of years exceeding average ME	11	7	18

Post-M	Median	0.145	0.079	0.088
	Standard Deviation	0.103	0.050	0.085
	Range	0.006-0.337	0.023-0.183	0.006-0.337

Table 3 Statistical performance of marginal entropy for Solan district

	Year	1980-2000	2001-2021	1980-2021
WS	No. of years exceeding average ME	11	8	19
	Median	0.127	0.102	0.118
	Standard Deviation	0.041	0.053	0.047
	Range	0.062-0.214	0.052-0.223	0.052-0.223
Pre-M	No. of years exceeding average ME	9	12	21
	Median	0.118	0.137	0.120
	Standard Deviation	0.033	0.037	0.035
	Range	0.072-0.205	0.049-0.173	0.049-0.205
Monsoon	No. of years exceeding average ME	10	8	18
	Median	0.122	0.125	0.125
	Standard Deviation	0.030	0.022	0.026
	Range	0.076-0.215	0.091-0.173	0.076-0.215
Post-M	No. of years exceeding average ME	12	8	20
	Median	0.163	0.097	0.106
	Standard Deviation	0.093	0.059	0.079
	Range	0.006-0.310	0.003-0.214	0.003-0.310

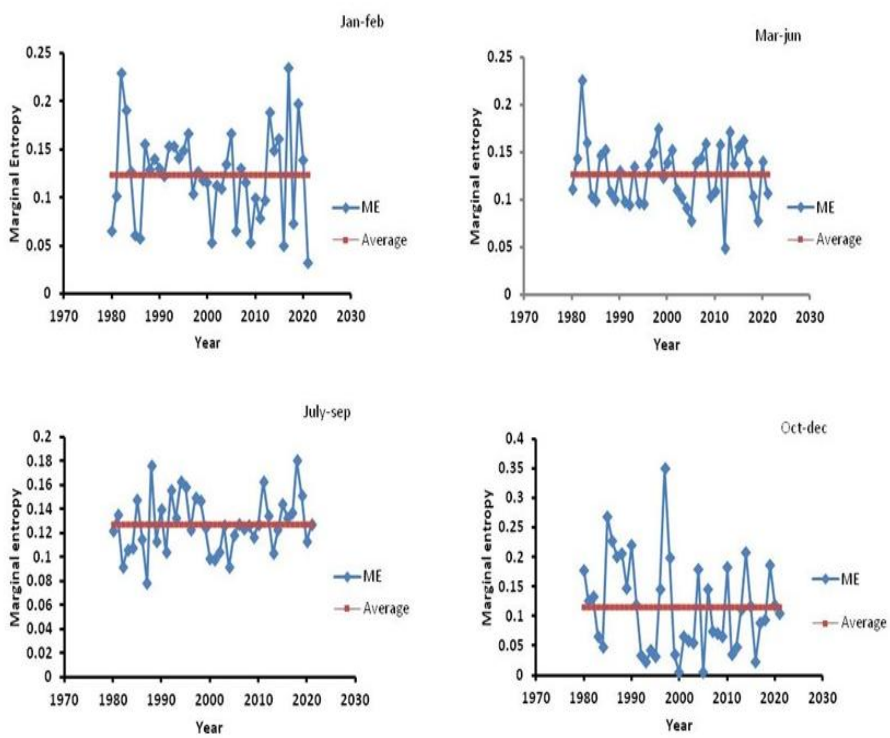


Fig. 2 Marginal entropy of Bilaspur district of HP

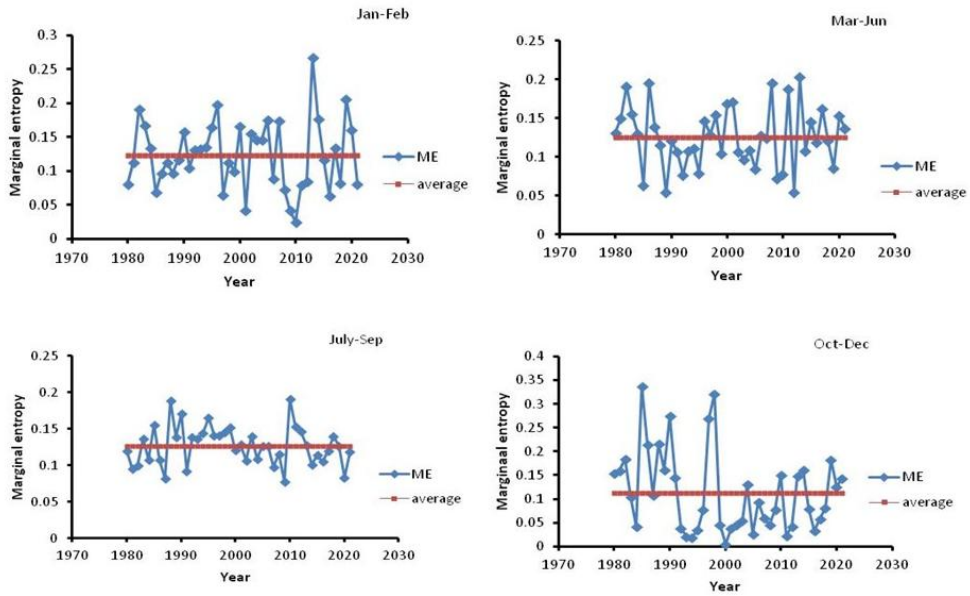


Fig. 3 Marginal entropy of Sirmaur district of HP

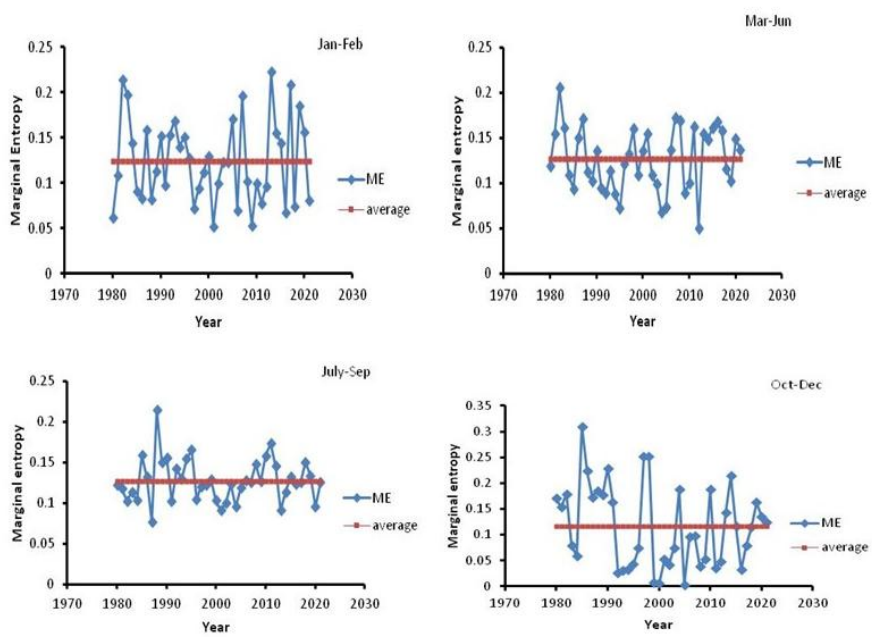


Fig. 4 Marginal entropy of Solan district of HP

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