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Analysis of Precipitation and Drought (1951-2002) for Rajasthan State, India

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Abstract Over the past few centuries, India has been adversely affected by droughts which have a negative impact on the growth of the country. In this study draught analysis of 32 districts of Rajasthan state is carried out for the time period 1951-2002. Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are used to detect Meteorological Drought in the study area using Precipitation and potential evapotranspiration. For trend analysis, the well-known statistical method known as the "Mann Kendal Test" is used. The result of most of the districts shows a negative trend while a very less number of districts shows a positive trend in drought. Baran district is showing a maximum increasing trend while the Hanumangarh district has a maximum decreasing trend.

Keywords: *drought analysis, standardized precipitation index, standardized precipitation evapotranspiration index, rainfall*

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1. Introduction

Drought is a natural hazard that results from lower levels of precipitation than what is considered normal. When this phenomenon extends over a season or a longer period of time, precipitation is insufficient to meet the demands of human activities and the environment. It is a recurrent extreme climate event with tremendous hazards for every specter of the natural environment and human lives. There are many different methodologies for monitoring drought. Droughts are regional in extent and each region has specific climatic characteristics. Drought analysis usually involves characterizing drought severity, duration, and intensity [8,9].

There is no universal definition of drought, in the most general sense, drought can be defined with different disciplinary perspectives, namely, meteorological drought, agricultural drought, hydrological drought, and socioeconomic drought (National Drought Mitigation Center). While instead of being independent of each other, different types of droughts are closely related and interact with each other. As Dingman [2] indicated, drought originates from a deficiency of precipitation over a prolonged time period, often but not always, accompanied by unusually high temperature, high winds, low humidity, and high solar radiation which result in increased evapotranspiration, known as meteorological drought. These situations would produce extended periods of abnormal low soil moisture, and then affect agriculture and natural plant growth, known as agricultural drought. The deficit of precipitation might result in streamflow, lake, wetland, reservoir levels, and water-table elevations declining to unusually low levels, which then is defined as hydrological drought [10]. Low streamflow could cause reduced hydroelectric power generation, which would lead to socioeconomic drought [11].

The National Commission on Agriculture in India defines three types of droughts, namely, Meteorological, Agricultural and Hydrological droughts. Meteorological drought is defined as a situation when there is a significant decrease from normal precipitation over an area (i.e. more than 25%) [12]. Agricultural drought occurs when soil moisture and rainfall are inadequate during the growing season to support healthy crop growth to maturity and cause crop stress and wilting [13]. Hydrological drought may be a result of long-term meteorological droughts which result in the drying up of reservoirs, lakes, streams, and rivers, and fall in groundwater level [10].

2. Study Area and Data Collection

Rajasthan state is situated between 23º 30' – 30º 11' N and 69º 29'- 78º 17' E in the north-western region of India.

Rajasthan is the largest State of India with an area of 342,000 km^2 (10.4% of the country total) and a population of 68.6 million (5% of the country total) of which 76.6% is rural. Administratively, the State is divided into 33 districts.

For historical and geographical reasons, the State remains socially and economically backward. Recurrent drought a poor resource base for economic development, the highest cost of development per capita due to aridity and very low density of population, low level of literacy (particularly among women), a very high rate of population growth, and scarcity of water make the task of socio-economic development a challenge compared to many other States in the country. The climate of Rajasthan State varies from arid to sub-humid.

Three main physiographic regions can be delineated in the State. To the west of the Aravalli hills range, there are 11 districts covering approximately 50 % of the area. The climate here is characterized by low and erratic rainfall, extremes of diurnal and annual temperatures, low humidity, and high wind velocity [15]. To the east of Aravalli, the climate is semi-arid to sub-humid. The 12 districts in this region are characterized by more or less the same extremes in temperatures, relatively lower wind velocity, and high humidity with better rainfall. The remaining area falls within the Aravalli range with high rainfall, hilly topography, and forest cover and is classified as a tribal area [14].

The southwest monsoon, which begins in the last week of June in the eastern parts, may last till mid-September. Pre-monsoon showers begin towards the middle of June and post-monsoon rains occasionally occur in October. In the winter season also, there is sometimes little rainfall associated with the passing western distribution over the region. In most places, the highest normal monthly rainfall is during July and August [15]. The number of rainy days during this period varies from 10 in Jaisalmer to 40 in Jhalawar and to 48 in Mount Abu. The number of rainfall days during the rest of the year in different parts of Rajasthan ranges from 2 to 7 [3].

For the detection of Meteorological Drought, Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are calculated which needs Precipitation and potential evapotranspiration data that is obtained from Indian Meteorological Department (IMD) site India water portal(http://www.indiawaterportal.org/metdata) during the period 1951-2002 that for 32 districts of Rajasthan. For the analysis purpose, the well-known statistical method known as “Mann Kendal Test” has been carried out and Sen's slope estimator test was used to detect monotonic trend direction and magnitude of change.

Figure 1. Location of Rajasthan in India and Districts of Rajasthan

3. Methodology

Different tests are used to analyse the drought conditions in Rajasthan. Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are used to determine the Meteorological Drought [16,17,18]. For trend detection of long-term time series of meteorological and hydrological records. For the detection of significant trends in time series of meteorological drought different statistical tests are used. These tests can be classified as parametric and non-parametric methods. Parametric trend tests require data to be independent and normally distributed, while non-parametric trend tests require only that the data be independent. In this study, non-parametric methods are used to detect the trend, its magnitude, and shift. Following indices and non-parametric tests are mostly used for drought analysis.

- Standardized Precipitation Index (SPI)
- Standardized Precipitation Evapotranspiration Index (SPEI)
- Mann-Kendall trend test
- Sen's slope method
- Mann-Whitney Pettit test

3.1. Standardized Precipitation Index (SPI)

The SPI was developed to quantify the precipitation deficit for multiple time scales [4]. These timescales reflect the impact of drought on the availability of the different water resources. The SPI has also been used by the National Drought Mitigation Center (NDMC) to monitor moisture supply conditions. The key advantage of SPI is that it can be calculated for different time scales. The SPI for 3-month, 6-month,12 months, and 24-month rainfall total can be obtained with only monthly precipitation input relatively long-time records of 30 years data are recommended [23,24,25].

3.1.1. One Month Standardized Precipitation Index

One month SPI compares the one-month precipitation total for January in that particular year with the January precipitation totals of all the years on record. Because the one-month SPI reflects short-term conditions, its application can be related closely to meteorological types of droughts along with short-term soil moisture and crop stress, especially during the growing season. Interpretation of the one-month SPI may be misleading unless climatology is understood. In regions where rainfall is normally low during a month, large negative or positive SPIs may result even though the departure from the mean is relatively small. The one-month SPI can also be misleading with precipitation values less than the normal in regions with a small normal precipitation total for a month.

3.1.2. Three Month Standardized Precipitation Index

The three-month SPI provides a comparison of the precipitation over a specific three-month period with the precipitation totals from the same three-month period for all the years included in the historical record. In other words, a three-month SPI at the end of February compares the December–January–February precipitation total in that particular year with the December–February precipitation totals of all the years on record for that location. Each year data is added, another year is added to the period of record. As with the one-month SPI, the three-month SPI may be misleading in regions where it is normally dry during any given three-month period. Large negative or positive SPIs may be associated with precipitation totals not very different from the mean.

3.1.3. Six Month Standardized Precipitation Index

The six-month SPI compares the precipitation for that period with the same 6-month period over the historical record. For example, a six-month SPI at the end of September compares the precipitation total for the April–September period with all the past totals for that same period. The six-month SPI indicates seasonal to medium-term trends in precipitation and is still considered to be more sensitive to conditions at this scale than the Palmer Index. A 6-month SPI can be very effective in showing the precipitation over distinct seasons. For example, a six-month SPI at the end of March would give a very good indication of the amount of precipitation that has fallen during the very important wet season period from October through March for certain Mediterranean locales. Information from a six-month SPI may also begin to be associated with anomalous stream flows and reservoir levels, depending on the region and time of year.

3.1.4. Nine Month Standardized Precipitation Index

The nine-month SPI provides an indication of inter-seasonal precipitation patterns over a medium timescale duration. Droughts usually take a season or more to develop. SPI values below -1.5 for these timescales are usually a good indication that dryness is having a significant impact on agriculture and may be affecting other sectors as well. Some regions may find that the pattern displayed by the map of the Palmer Index is closely related to the nine-month SPI maps. For other areas, the Palmer Index is more closely related to the twelve months SPI. This time period begins to bridge a short-term seasonal drought to those longer-term droughts that may become hydrological, or multi-year, in nature.

3.1.5. Twelve Month Standardized Precipitation Index

The SPI at these timescales reflects long-term precipitation patterns. A twelve-month SPI is a comparison of the precipitation for twelve consecutive months with that recorded in the same twelve consecutive months in all previous years of available data. Because these timescales are the cumulative result of shorter periods that may be above or below normal, the longer SPIs tend to gravitate toward zero unless a distinctive wet or dry trend is taking place. SPIs of these timescales are usually tied to stream flows, reservoir levels, and even groundwater levels at longer timescales. In some locations, the twelve-month SPI is most closely related to the Palmer Index, and the two indices can reflect similar conditions.

For this study, SPI is calculated for the 6-month time scale. Standardized precipitation index (SPI) is the simplest drought index based on precipitation data, to measure precipitation deficit for multiple time scales.

According to the normal distribution, it can be calculated by taking the difference of the precipitation from the mean for a particular time scale then dividing by the standard deviation.

$$SPI = \frac{(X - X_m)}{\sigma}$$

Where, X is precipitation for the station, X_m is mean precipitation and σ is standardized deviation.

Table 1. Standard Precipitation Index Conditions

SPI	Condition
≥ 2.0	Extreme wet
1.5 to2.0	Very wet
1.0 to 1.49	Moderate wet
0.99 to -0.99	Near normal
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤ -2.0	Extreme drought

3.2. Standardized Precipitation Evapotranspiration Index (SPEI)

The Standardized Precipitation-Evapotranspiration Index (SPEI) was introduced in 2010 [1]. It is an extension of the SPI, i.e., it uses a similar normalization approach, but it takes into account both precipitation and potential evapotranspiration. Therefore, it accounts for losses due to the increase of temperature in the evaluation of atmospheric water demand. The SPEI is based on an atmospheric water balance, which is calculated as a difference between precipitation and potential evapotranspiration.

The SPEI is based on precipitation and potential evapotranspiration data, and it has the advantage of combining multi-scalar character with the capacity to include the effects of potential evapotranspiration variability on drought assessment [1,22,25]. The procedure to calculate the index is detailed and involves a climatic water balance, the accumulation of deficit/surplus at different time scales, and adjustment to a log-logistic probability distribution. Mathematically, the SPEI is similar to the standardized precipitation index (SPI), but it includes the role of potential evapotranspiration.

The main criticism of the SPI is that its calculation is based only on precipitation data. The index does not consider other variables that can influence droughts, such as temperature, evapotranspiration, wind speed, and soil water holding capacity. Low data requirements and simplicity explain the wide use of precipitation-based indices, such as the SPI, for drought monitoring and analysis. Precipitation-based drought indices, including the SPI, rely on two assumptions: 1) the variability of precipitation is much higher than that of other variables, such as temperature and potential evapotranspiration (PET), and 2) the other variables are stationary (i.e., they have no temporal trend). In this scenario the importance of these other variables is negligible, and droughts are controlled by the temporal variability in precipitation. However, some authors have warned against systematically neglecting the importance of the effect of temperature on drought conditions. For example, Hu and Wilson assessed the role of precipitation and temperature in the PDSI and found that the index responded equally to changes of similar magnitude in both variables [5]. Only where the temperature fluctuation was smaller than that of precipitation was variability in the PDSI controlled by precipitation.

3.3. Mann-Kendall (MK) Test

Mann-Kendall test is the rank-based nonparametric test and recently used by several researchers to detect trends in temperature data [19]. It is based on the test statistic S defined as:

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

Where, x_1, x_2, x_3 …………… x_n represent n data points where x_j represents the data point at time j.

A very high positive value of S is an indicator of an increasing trend, and very low negative value indicates a decreasing trend.

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 \ldots\ldots if\ (x_j - x_i) > 0 \\ 0 \ldots\ldots if\ (x_j - x_i) = 0 \\ -1 \ldots\ldots if\ (x_j - x_i) < 0 \end{cases}$$

It has been documented that when n ≥ 10 the statistic S is approximately normally distributed with the mean

$$E(S) = 0$$

And its variance is

$$\mathrm{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)}{18}$$

Where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and t is the number of data points in the i^{th} group.

The standard test statistic Z is computed by as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S > 0 \end{cases}$$

Positive values of Z indicate increasing trends while negative Z values show decreasing trends. The null hypothesis, H_0, is meaning that no significant trend is present, is accepted if the test statistic Z is not statistically significant, i.e. $-Z_{\alpha/2} < Z < Z_{\alpha/2}$, where $Z_{\alpha/2}$ is the standard normal deviate. Testing trends is done at the specific α significance level.

The Mann-Kendall test is essentially limited to testing the null hypothesis that the data are independent and identically distributed. Our time series data may diverge from this assumption in two ways. First there may be autocorrelation and second may be a seasonal component. To eliminate these factors we can use annual data but this has the effect of reducing the power [21]. For strong positive autocorrelation in the series, the effect of using annual totals will reduce the effect of this autocorrelation substantially and the loss of power is, perhaps, not expected to be too much.

3.4. Theil - Sen's Estimator

If a linear trend is present, the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen [7]. The slope of n pairs of data points was estimated using the Theil-Sen's estimator [6,7] which is given by the following relation:

$$\beta = median\left(\frac{x_j - x_i}{j-i}\right) For\ all\ i < j$$

In which 1 < j < I < n and β | is the robust estimate of the trend magnitude. A positive value of β indicates an “upward trend”, a negative value of β indicates a “downward trend”.

3.5. Mann-Whitney-Pettitt Method (MWP)

The Pettitt's test is a nonparametric test that requires no assumption about the distribution of data. The Pettitt's test is an adaptation of the rank-based Mann-Whitney test that allows identifying the time at which the shift occurs [20].

Consider a time series $\{x_1, x_2, \ldots \ldots x_n\}$ with a length n. let t be the time of the most likely change point. Two samples, $\{x_1, x_2, \ldots \ldots x_t\}$ and $\{x_1, x_2, \ldots \ldots x_n\}$, can then be derived by dividing the time series at time t. An index, U_t is derived by:

$$U_t = \sum_{i+1}^{t} \sum_{j=i+1}^{t} \operatorname{sgn}\left(x_j - x_i\right)$$

Where,

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} 1 \ldots\ldots if\left(x_j - x_i\right) > 0 \\ 0 \ldots\ldots if\left(x_j - x_i\right) = 0 \\ -1 \ldots\ldots if\left(x_j - x_i\right) < 0 \end{cases}$$

A plot of U_t against t for a time series with no change point would results in a continually increasing value of $|U_t|$. However, if there is a change point (even a local change point) then $|U_t|$ would increase up to the change point and then begin to decrease. The most significant change point t can be identified as the point where the value of $|U_t|$ is maximum.

$$K_t = \max_{1 \le t \epsilon T} |U_t|$$

The approximated significance probability P (t) for a change point is given by:

$$P = 1 - \exp\left[\frac{-6K_t^2}{n^3 + n^2}\right]$$

The change point is statistically significant at time t with a significance level of α when probability P (t) exceeds (1-α).

4. Result and Conclusion

4.1. Evaluation of Drought Indices

The SPI and SPEI may be evaluated at different accumulation periods, from 1-month onwards. In this study, a 6-month accumulation period was used, allowing for the integration over the half-year cycle. The indices differ in their description of drought. As mentioned in previous sections, SPI is based solely on precipitation while SPEI uses precipitation and potential evapotranspiration as input variables. The SPI and SPEI both describe meteorological drought. A comparison of temporal patterns of SPI-6 and SPEI-6 indices under specific drought conditions gives an indication of how well those indices represent historical drought and also informs on their ability to illustrate the transformation of meteorological drought. For detecting the trend direction and magnitude of change over time Mann–Kendall test and Sen's slope estimator test were used. Pettitt-Mann–Whitney test was applied to detect possible change points in the time period of 1951 to 2002. The SPI-6 and SPEI-6 were tested by comparison of temporal patterns for all 32 districts of Rajasthan.

Table 2. Results of all statistical tests applied for SPI (six months)

S. N.		Results for SPI			
	Variable	Mann-Kendal Test		Sen's slope Test	Shift Detection Test
		Z	P		T
1	Ajmer	-1.0743	0.28265	-0.00024	1983
2	Alwar	-0.3782	0.70526	-0.00009	1974
3	Banswara	-2.2188	0.0265	-0.00054	1983
4	Baran	-4.3613	0.00001	-0.00102	1983
5	Barmer	-0.1513	0.87968	-0.00003	1974
6	Bharatpur	-2.2440	0.02483	-0.00052	1967
7	Bhilwara	-1.8425	0.0654	-0.00042	1983
8	Bikaner	0.80782	0.41919	0.00018	1969
9	Bundi	-2.6931	0.00708	-0.00063	1983
10	Chittaurgarh	-2.1561	0.03107	-0.00052	1983
11	Churu	1.18216	0.23714	0.00026	1973
12	Dausa	-1.4938	0.13521	-0.00034	1986
13	Dhaulpur	-4.0531	0.00005	-0.00094	1971
14	Dungarpur	-1.9942	0.04612	-0.00048	1963
15	Ganganagar	1.35941	0.17402	0.00031	1973
16	Hanumangarh	1.73900	0.08203	0.00038	1975
17	Jaipur	-0.2190	0.82659	-0.00005	1974
18	Jaisalmer	0.61092	0.54125	0.00014	1975
19	Jalor	1.11329	0.26558	0.00025	1974
20	Jhalawar	-3.1853	0.00145	-0.00076	1983
21	Jhunjhunun	1.54405	0.12257	0.00035	1974
22	Jodhpur	-0.2525	0.80062	-0.00007	1983
23	Karauli	-3.0639	0.00218	-0.00071	1967
24	Kota	-3.2986	0.00097	-0.00076	1983
25	Nagaur	0.35293	0.72413	0.00008	1972
26	Pali	-0.4957	0.62007	-0.00011	1983
27	Rajsamand	-1.6958	0.08992	-0.00039	1983
28	Sikar	1.27477	0.20239	0.00029	1973
29	Sirohi	1.45455	0.14579	0.00034	1974
30	S.Madhopur	-2.5306	0.01138	-0.00058	1983
31	Tonk	-1.9693	0.04891	-0.00045	1983
32	Udaipur	-1.7316	0.08334	-0.0004	1983

Table 2 and Table 3 represents the results of all statistical tests applied for SPI-6 & SPEI-6 evaluated using observations from the period 1951–2002 for all 32 districts of Rajasthan.

Table 3. Results of all statistical tests applied for SPEI (six months)

S. N.		Results for SPEI			
	Variable	Mann-Kendal Test		Sen's slope Test	Shift Detection Test
		Z	P		T
1	Ajmer	-1.0868	0.27711	-0.00026	1983
2	Alwar	-0.4136	0.67914	-0.0001	1974
3	Banswara	-2.2834	0.02241	-0.00056	1983
4	Baran	-4.3263	0.00002	-0.00105	1983
5	Barmer	-0.1692	0.86558	-0.00004	1974
6	Bharatpur	-2.1937	0.02826	-0.00052	1967
7	Bhilwara	-1.8292	0.06736	-0.00044	1983
8	Bikaner	0.81716	0.41383	0.00019	1969
9	Bundi	-2.6958	0.00702	-0.00065	1983
10	Chittaurgarh	-2.2915	0.02193	-0.00056	1983
11	Churu	1.19500	0.23208	0.00027	1973
12	Dausa	-1.43393	0.15159	-0.00034	1986
13	Dhaulpur	-4.02201	0.00006	-0.00096	1970
14	Dungarpur	-1.9977	0.04574	-0.00048	1963
15	Ganganagar	1.35260	0.17618	0.00032	1973
16	Hanumangarh	1.74309	0.08132	0.00041	1975
17	Jaipur	-0.1747	0.8613	-0.00004	1974
18	Jaisalmer	0.59283	0.55329	0.00014	1975
19	Jalor	1.14364	0.25277	0.00026	1974
20	Jhalawar	-3.2048	0.00135	-0.00079	1983
21	Jhunjhunun	1.54133	0.12324	0.00038	1974
22	Jodhpur	-0.3004	0.76387	-0.00008	1983
23	Karauli	-3.0402	0.00236	-0.00072	1967
24	Kota	-3.3025	0.00096	-0.0008	1983
25	Nagaur	0.39768	0.69086	0.00009	1972
26	Pali	-0.5245	0.5999	-0.00012	1983
27	Rajsamand	-1.6954	0.08999	-0.0004	1983
28	Sikar	1.34443	0.17881	0.00032	1973
29	Sirohi	1.46428	0.14312	0.00034	1974
30	S.Madhopur	-2.4931	0.01266	-0.0006	1967
31	Tonk	-1.9732	0.04847	-0.00046	1983
32	Udaipur	-1.7771	0.07554	-0.00042	1983

4.2. Comparison results of SPI and SPEI

4.2.1. Ajmer

As the values of Sen’s slope estimator test are -0.00024 & -0.00026 for SPI and SPEI respectively which shows that trend of SPEI is more downward. The maximum and minimum values of SPI are 2.635 and -3.495 respectively and of SPEI are 2.39 and -2.64 respectively. The possible change point year for SPI and SPEI both is 1983 after that drought duration is decreasing and the drought severity is increases.

4.2.2. Alwar

The values of Sen’s slope estimator test are -0.00009 & -0.0001 for SPI & SPEI respectively. The maximum and minimum values of SPI are 2.843 and -3.659 respectively and of SPEI are 2.313 and -3.257 respectively. The possible change point year for SPI and SPEI both is 1974, after that drought duration is decreasing and the drought severity increases.

4.2.3. Banswara

As the values of Sen’s slope estimator test are -0.00054 & -0.00056 for SPI & SPEI respectively which shows that trend of SPEI is more downward. The maximum and minimum values of SPI are 2.35 and -2.84 respectively and of SPEI are 2.24 and -2.26 respectively. The possible change point year for SPI and SPEI both is 1983 after that both drought duration and the drought severity are increasing.

4.2.4. Baran

As the values of Sen’s slope estimator test are -0.00102 & -0.00105 for SPI & SPEI respectively which shows that trend of SPEI is more downward than SPI. The maximum and minimum values of SPI are 2.52 and -3.53 respectively and of SPEI are 2.47 and -2.35 respectively. The possible change point year for SPI and SPEI both is 1983 after that drought duration, drought events, and the drought severity all are increasing.

4.2.5. Barmer

The values of Sen’s slope estimator test are -0.00003 & -0.00004 for SPI & SPEI respectively. The maximum and minimum values of SPI are 2.36 and -2.47 respectively and of SPEI are 2.22 and -1.98 respectively. The possible change point year for SPI and SPEI both is 1974 after that there is negligible change in drought duration and the drought severity.

4.2.6. Bharatpur

The values of Sen’s slope estimator test are almost equal for SPI & SPEI that is -0.00052 which shows that SPI and SPEI both are following the same trend. The maximum and minimum values of SPI are 2.41 and -3.31 respectively and of SPEI are 2.31 and -2.37 respectively. The possible change point year for SPI and SPEI both is 1967 after that drought duration and the drought severity both are increasing.

4.2.7. Bhilwara

As the values of Sen’s slope estimator test are -0.00042 & -0.00044 for SPI & SPEI respectively which shows that trend of SPEI is a little more downward than SPI. The maximum and minimum values of SPI are 2.69 and -3.45 respectively and of SPEI are 2.27 and -3.48 respectively. The possible change point year for SPI and SPEI both is 1983 after that drought duration and the drought severity both are increasing.

4.2.8. Bikaner

The values of Sen’s slope estimator test are 0.00018 & 0.00019 for SPI & SPEI respectively. The maximum and minimum values of SPI are 2.60 and -3.11 respectively and of SPEI are 2.45 and -2.2 respectively. The possible change point year for SPI and SPEI both is 1969 after that drought duration and drought events are decreasing and the drought severity is approximately constant.

4.2.9. Bundi

As the values of Sen’s slope estimator test are -0.00063 & -0.00065 for SPI & SPEI respectively which shows that trend of SPEI is a little more downward than SPI. The maximum and minimum values of SPI are 2.66 and -3.61 respectively and of SPEI are 2.38 and -2.80 respectively. The possible change point year for SPI and SPEI both is

1983 after that drought duration and the drought severity both are increasing.

4.2.10. Chittaurgarh

As the values of Sen’s slope estimator test are -0.00052 & -0.00056 for SPI & SPEI respectively which shows that trend of SPEI is a little more downward than SPI. The maximum and minimum values of SPI are 2.87 and -3.13 respectively and of SPEI are 2.33 and -2.79 respectively. The possible change point year for SPI and SPEI both is 1983 after that drought duration, drought events, and the drought severity all are increasing.

4.2.11. Churu

The values of Sen’s slope estimator test are 0.00026 & 0.00027 for SPI & SPEI respectively which shows that trends of SPI & SPEI both are upward. The maximum and minimum values of SPI are 3.03 and -3.29 respectively and of SPEI are 2.49 and -2.48 respectively. The possible change point year for SPI and SPEI both is 1973 after that drought duration and drought events are decreasing while the drought severity is increasing.

4.2.12. Dausa

As the values of Sen’s slope estimator test are -0.00034 & -0.00034 for SPI & SPEI respectively which shows that trends of SPI & SPEI both are downward. The maximum and minimum values of SPI are 2.43 and -3.73 respectively and of SPEI are 2.35 and -2.60 respectively. The possible change point year for SPI and SPEI both is 1986 after that drought duration is decreasing while the drought events and drought severity are increasing.

4.2.13. Dhaulpur

As the values of Sen’s slope estimator test are -0.00094; -0.00096 for SPI; SPEI respectively which shows that trend of SPEI is a little downward than SPI. The maximum and minimum values of SPI are 2.45 and -2.91 respectively and of SPEI are 2.36 and - 2.18 respectively. The possible change point year for SPI and SPEI are 1971 and 1970 respectively after that drought duration, drought events and the drought severity all are increasing.

4.2.14. Dungarpur

As the values of Sen’s slope estimator test are equal for both SPI & SPEI that is -0.00048 which shows that trends of both SPI and SPEI are downward. The maximum and minimum values of SPI are 2.69 and -2.42 respectively and of SPEI are 2.39 and -2.2 respectively. The possible change point year for both SPI and SPEI is 1963 after that drought duration, drought events, and the drought severity all are increasing.

4.2.15. Ganganagar

The values of Sen’s slope estimator test are 0.00031 & 0.00032 for SPI & SPEI respectively which shows that both trends are almost same and upward. The maximum and minimum values of SPI are 2.85 and -2.53 respectively and of SPEI are 2.43 and -2.17 respectively. The possible change point year for both SPI and SPEI is 1973 after that drought duration and drought events are decreasing while the intensity, duration, and events of wetness all are increasing.

4.2.16. Hanumangarh

The values of Sen’s slope estimator test are 0.00038 & 0.00041 for SPI & SPEI respectively which shows that both trends are almost same and upward. The maximum and minimum values of SPI are 3.19 and -2.77 respectively and of SPEI are 2.43 and -2.18 respectively. The possible change point year for both SPI and SPEI is 1975 after that drought duration and drought events are decreasing while the intensity and duration of wetness are increasing.

4.2.17. Jaipur

As the values of Sen’s slope estimator test are -0.00005 & -0.00004 for SPI and SPEI respectively which shows that trend of SPI is more downward. The maximum and minimum values of SPI are 2.88 and -3.73 respectively and of SPEI are 2.41 and -2.81 respectively. The possible change point year for SPI and SPEI both is 1974, after that drought duration is decreasing and the drought severity increases.

4.2.18. Jaisalmer

As the values of Sen’s slope estimator test are 0.00014 for both SPI & SPEI which shows that trends of SPI and SPEI are the same and upward. The maximum and minimum values of SPI are 2.38 and -2.55respectively and of SPEI are 2.16 and -1.97 respectively. The possible change point year for SPI and SPEI both is 1975 after that drought duration is decreasing and the drought severity is approximate constant and the duration of wetness is also increasing.

4.2.19. Jalor

As the values of Sen’s slope estimator test are 0.00024 and 0.00025 for SPI & SPEI respectively which shows that trends of SPI and SPEI are approximate same and upward. The maximum and minimum values of SPI are 2.25 and -2.87 respectively and of SPEI are 2.14 and -2.21 respectively. The possible change point year for SPI and SPEI both is 1974 after that drought duration and the drought severity both are decreasing.

4.2.20. Jhalawar

As the values of Sen’s slope estimator test are -0.00076 & -0.00079 for SPI & SPEI respectively which shows that trend of SPEI is a little downward than SPI. The maximum and minimum values of SPI are 2.55 and -3.44 respectively and of SPEI are 2.29 and -2.18 respectively. The possible change point year for both SPI and SPEI is 1973 after that drought duration and the drought severity both are increasing.

4.2.21. Jhunjhunun

The values of Sen’s slope estimator test are 0.00035 & 0.00038 for SPI & SPEI respectively which shows that both trends are almost same and upward. The maximum and minimum values of SPI are 3.20 and -3.52 respectively and of SPEI are 2.56 and -2.46 respectively. The possible change point year for both SPI and SPEI is

1974, after that drought duration is decreasing while the duration of wetness is increasing.

4.2.22. Jodhpur

As the values of Sen's slope estimator test are -0.00007 & -0.00008 for SPI & SPEI respectively which shows that trend of SPEI is a little downward than SPI. The maximum and minimum values of SPI are 2.42 and -3.35 respectively and of SPEI are 2.24 and -2.09 respectively. The possible change point year for both SPI and SPEI is 1983 after that drought duration is decreasing while the drought events and the drought severity both are increasing.

4.2.23. Karuli

As the values of Sen's slope estimator test are -0.00071 & -0.00072 for SPI & SPEI respectively which shows that trend of SPEI is a little downward than SPI. The maximum and minimum values of SPI are 2.45 and -3.45 respectively and of SPEI are 2.45 and -2.37 respectively. The possible change point year for both SPI and SPEI is 1967 after that drought duration and the drought severity both are increasing.

4.2.24. Kota

As the values of Sen's slope estimator test are -0.00076 & -0.0008 for SPI & SPEI respectively which shows that trend of SPEI is a little downward than SPI. The maximum and minimum values of SPI are 2.47 and -3.74 respectively and of SPEI are 2.38 and -2.48 respectively. The possible change point year for both SPI and SPEI is 1983 after that drought duration and the drought severity both are increasing.

4.2.25. Nagaur

The values of Sen's slope estimator test are -0.00008 & -0.00009 for SPI & SPEI respectively which shows an almost similar downward trend. The maximum and minimum values of SPI are 2.82 and -3.58 respectively and of SPEI are 2.43 and -2.52 respectively. The possible change point year for SPI and SPEI both is 1972 after that drought duration is decreasing and the drought severity is increasing.

4.2.26. Pali

The values of Sen's slope estimator test are -0.00011 & -0.00012 for SPI & SPEI respectively which shows an almost similar downward trend. The maximum and minimum values of SPI are 2.41 and -3.36 respectively and of SPEI are 2.35 and -2.60 respectively. The possible change point year for SPI and SPEI both is 1983 after that drought events and the drought severity both are increasing.

4.2.27. Rajsamand

The values of Sen's slope estimator test are -0.00039 & -0.00040 for SPI & SPEI respectively which shows an almost similar downward trend. The maximum and minimum values of SPI are 2.53and -3.25 respectively and of SPEI are 2.21 and -2.86 respectively. The possible change point year for SPI and SPEI both is 1983 after that draught event and the draught severity both are increasing.

4.2.28. Sikar

The values of Sen's slope estimator test are 0.00029 & 0.00032 for SPI & SPEI respectively which shows that both trends are almost same and upward. The maximum and minimum values of SPI are 3.08 and -3.66 respectively and of SPEI are 2.48 and -2.50 respectively. The possible change point year for both SPI and SPEI is 1973, after that drought duration is decreasing while the severity of the drought is increasing.

4.2.29. Sirohi

As the values of Sen's slope estimator test is 0.00034 for both SPI & SPEI respectively which shows that both trends are same and upward. The maximum and minimum values of SPI are 3.28 and -2.99 respectively and of SPEI are 2.10 and -2.41 respectively. The possible change point year for both SPI and SPEI is 1974 after that drought duration and drought events both are decreasing.

4.2.30. Sawai Madhopur

The values of Sen's slope estimator test are -0.00058 & -0.0006 for SPI & SPEI respectively which shows an almost similar downward trend. The maximum and minimum values of SPI are 2.43 and -3.69 respectively and of SPEI are 2.39 and -2.52 respectively. The possible change point year for SPI is 1983 and for SPEI is 1967 after that drought events and the drought severity both are increasing.

4.2.31. Tonk

The values of Sen's slope estimator test are -0.00045 & -0.00046 for SPI & SPEI respectively which shows an almost similar downward trend. The maximum and minimum values of SPI are 2.65 and -3.71 respectively and of SPEI are 2.42 and -3.02 respectively. The possible change point year for SPI and SPEI both 1983 after that drought events and the drought severity both are increasing.

4.2.32. Udaipur

The values of Sen's slope estimator test are -0.0004 & -0.00042 for SPI & SPEI respectively which shows an almost similar downward trend. The maximum and minimum values of SPI are 2.38 and -2.84 respectively and of SPEI are 2.18 and -2.37 respectively. The possible change point year for SPI and SPEI both 1983 after that drought duration, drought events and the drought severity all are increasing.

5. Conclusion

In the present study, Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are calculated for the 32 districts of Rajasthan State. The trends in the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are calculated for the 32 districts of Rajasthan State. This was carried out using the Mann–Kendall (MK) test. The Sen's slope is also estimated over the study period (1951-2002). Both positive and negative trends were observed in SPI and

SPEI. The conclusions drawn from the study are as follows:

1. Twelve districts were found significant changes.
2. The most significant trends were found negative.
3. In most of the districts the trend is found negative for Rajasthan.
4. In almost all the districts the drought duration is decreasing and the drought severity and drought events are increasing. In a few districts the duration and intensity of wetness is increasing.
5. The maximum negative trend is found in Baran district while maximum positive trend is found in Hanumangarh district.

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