A spatio-temporal analysis of changing trends in rainfall patter: A case study of Kutch District

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Abstract: Changing trends captivate millions of analytical minds. It grabs much when the impact on human lives and properties is involved. The utmost concern is changing weather patterns, which led to a worse impact on the amount and distribution of the precipitation. Essentially, the challenge in several nations is to reach the whole population with adequate water per day. Even a country like India, which has thousands of rivers, streams, lakes, ponds, etc. unable to reach the whole population, as it depends on the uneven event, the Monsoon for its >80% annual rain during monsoon months (June-September). The Nation's westernmost district, Kutch, which holds the title for the largest area-wise district in India, has been bearing from changing trends in rainfall for a long time. The rainfall distribution within the district is uneven and has experienced contrasting extreme events like drought and flood within consecutive years. The present study attempts to analyse the Spatio-temporal rainfall pattern for 58 years from 1961 to 2018 for the Kutch district using the IMD4 long-term daily gridded (High Spatial Resolution, 0.25° x 0.25°) rainfall dataset. In addition, the Mann-Kendall (MK) test and Sen's slope method were performed to detect the trends and the magnitude of change over the studied period, respectively. The results indicate high rainfall variability during monsoon months in the north and northwest, while relatively moderate and low in the south and west parts of the district, respectively, and show an upward trend in monsoon rainfall at a 5% significance level in all the Taluka of the Kutch district.

Keywords: Rainfall Variability, Trend, Mann-Kendall, Sen's Slope, IMD

1. Introduction

Studies to detect climate change and its impact on the various sectors deserve urgent attention in light of the impact of climate change on agriculture, increased risk of hunger (Solomon, S. et al., 2007), water scarcity, rapid melting of glaciers, and decreased river flows (Jain et al., 2013). Climate may vary in different ways over different time scales and geographical scales (Mehta & Yadav, 2021; Zarch et al., 2011). Many researchers have been focusing on rainfall and temperature trend and forecasting future values and changes in climate all over the world to understand the effects of climate change (Deoli & Rana, 2019). Climate variability in the arid parts of India poses a great risk to the people and resources of these regions (Attri & Tyagi, 2010; Narayanan et al., 2013) as the smallest fluctuations of weather parameters like precipitation, not only damage the agriculture and economy of the region but disturb the overall water cycle (Krishna Kumar et al., 2004; Narayanan et al., 2013; Zhang et al., 2011).

Although climate change is a broad area of research, the changing pattern of precipitation deserves urgent and systematic attention as it will affect the availability of food supply (Jain et al., 2013). Rainfall contributes significantly to the hydrological cycle, and the Spatio-temporal rainfall variability is crucial from both a scientific and a socioeconomic standpoint (Mehta & Yadav, 2021; Ramkar & Yadav, 2019). Precipitation changes used to have a substantial impact on society, and thus it's necessary to have up-to-date data to predict where precipitation is occurring and how much it varies (Gajbhiye et al., 2016; Yaduvanshi et al., 2015). Floods and droughts would occur due to the precipitation trend's abrupt change (Edossa et al., 2010; Gajbhiye et al., 2016). Long-term rainfall pattern detection is required to understand the problems associated with flooding, droughts, and various uses of water (Mehta & Yadav, 2021). It will improve the outcome of future climatic scenarios (Edossa et al., 2010). Therefore, regular precipitation monitoring is necessary for better analysis and forecasting (Mehta & Yadav, 2021).

Understanding and quantifying long-term rainfall variability at the regional scale is crucial for a country like India, where economic growth is much dependent on agricultural production, which is linked closely to rainfall distribution (Mohapatra et al., 2021). In the past, several attempts have been made to identify national and regional rainfall trends in India (Gajbhiye et al., 2016). The ability to predict potential future changes using trend analysis has shown to be a beneficial tool (Islam et al., 2014; Yue & Hashino, 2003). Even before the 17th century, researchers in India began to study the rainy season, and since then, scientific research has advanced due to improved knowledge and forecasting tools. India's economy is heavily dependent on agriculture. Hence research into the space-time variability of rainfall assumes enormous significance (Davey & Pielke, 2005). As per estimates, India experiences large spatial variations in annual precipitation, with a lower value of 35% in Tamilnadu and Pondicherry, while in contrast, Gujarat experiences maximum variations (95%). Therefore, studying rainfall variability in Gujarat is of the utmost. The findings may be applicable at the micro-level only because rainfall in the State varies from less than 500 mm in the arid Kutch regions to more than 2500 mm in the South Gujarat region (Priyan, 2015).

The present study attempts to understand the Spatio-temporal variability of monsoon rainfall from 1961 to 2018 in the Kutch district of Gujarat. In addition, the study involves a monotonic trend analysis of rainfall data for the Kutch district. Although the trend assessment can be done using several methods, The Mann-Kendall (MK) test and the Sen's slope estimator have been used in the present study and are the most widely employed methods for hydrological trend analysis. The handling of missing data, the requirement for a few assumptions, the independence of the data distribution (Ali et al., 2019; Dabanlı et al., 2016), and searching for a trend in a time series without specifying whether the trend is linear or non-linear are one of the few benefits of these non-parametric methods and are known to be more resistant to outliers than other analysis techniques (Luo et al., 2020).

2. Materials and methods

2.1 Study area

Being the largest and westernmost district of the Nation, Kutch (Kachchh) has covered about 45,674 sq. km. of area. The district lies between latitudes 22°44'11 to 24°42'25 and longitudes 68°09'46 to 71°55'47. The district is bounded on the north and northwest by Pakistan, northeast by the state of Rajasthan, east by districts of Banaskantha and Patan, South-east by Surendranagar and Morbi districts, South by the Gulf of Kutch, and South-west by the Arabian Sea (https://kachchh.nic.in/about-district/). The district has 10 Taluka viz. Abdasa, Anjar, Bhachau, Bhuj, Gandhidham, Lakhpat, Mandvi, Mundra, Nakhatrana, and Rapar (https://www.census2011.co.in/data/district/182-kachchh-gujarat.html).

2.2 Data source

The India Meteorological Department (IMD) maintains weather observatories in India; they calibrate all instruments and check the quality of all observed data (Dave & James, 2017). Long-term daily gridded (High spatial Resolution, 0.25 x 0.25) rainfall data over India for the year 1961-2018 has been collected from the Indian Meteorological Department Library. The unit of rainfall is in millimetres (mm). The yearly data file consists of 365/366 records corresponding to non-leap/ leap years (Pai et al., 2014). For operational convenience, the Indian land area is divided into 36 meteorological subdivisions by the IMD. Primarily, such a classification is meant for generating weather forecasts over political boundaries like states (Mohapatra et al., 2021; Saikranthi et al., 2013).

The present study is based on a newly developed high spatial resolution IMD4 dataset that was interpolated at fixed spatial grid points of 0.25° x 0.25° resolution nationwide (Pai et al., 2014) for the Kutch district (Figure 1). The distribution of 60 grid points containing the rainfall data over the Kutch district is shown in Table 1.

Table 1. Distribution of grid points Taluka-wise.

Taluka	Grid points
Abdasa	3
Anjar	1
Bhachau	3
Bhuj	8
Gandhidham	2
Lakhpat	4
Mandvi	2
Mundra	1
Nakhatrana	3
Rapar	4
Rann*	29

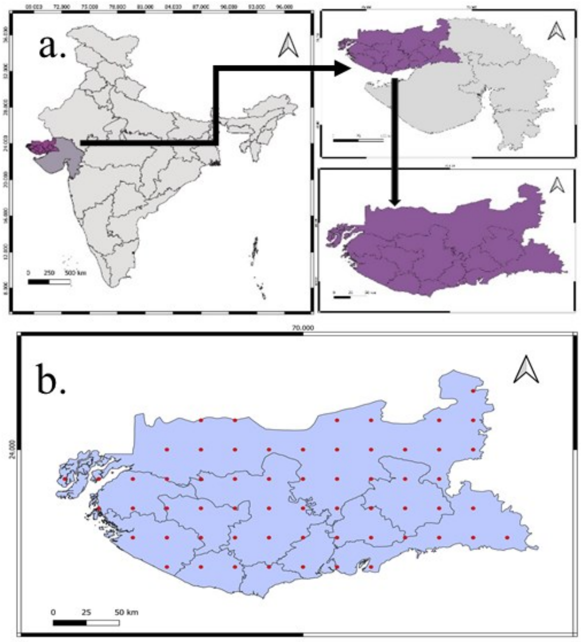

Figure 1. a: Location of Kutch in Gujarat and India, 1b: Distribution of grid points over the Kutch district.

Stations are separated as per IMD criteria:
1. Winter season (January- February),
2. Pre-monsoon season (March-May),
3. Monsoon season (June-September),
4. Post-monsoon season (October- December).

2.3 Methods

The flowchart in Figure 2 illustrates the methods used in the study. At first, the Python console (plugin to QGIS) has used to collect grid points containing the rainfall data for the Kutch district from IMD Library.

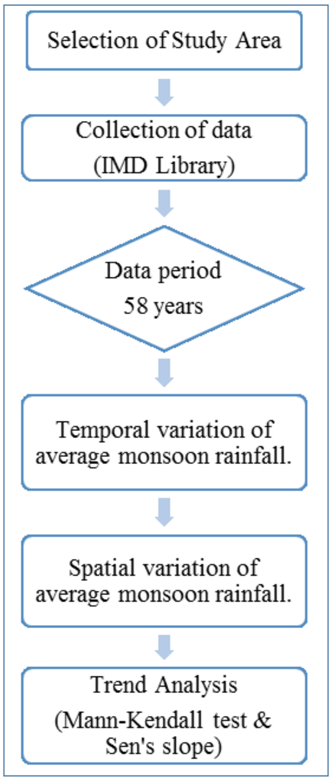

Figure 2. Flowchart of the methodology adopted

Later, an intersection algorithm has performed to extract the overlapping portions of features in the input data (Study area) and overlay layers (grid points). The intersection algorithm is applied separately for each taluka of the Kutch district to extract the overlapping grid points. Basic statistical parameters, including mean, standard deviation (SD), and coefficient of variation, have been determined as part of the analysis's initial stage using rainfall data for each Taluka in the Kutch district.

2.3.1 Spatio-temporal Rainfall Variability

Rainfall variability and probability trends were determined using IMD4 daily gridded rainfall data. The coefficient of variation (CV), derived from the mean and standard deviation (Sample), has been calculated as follows:

$$\text{Coefficient of variation} = \frac{\text{Standard deviation}}{\text{Mean}} \text{ x } 100 \quad (1)$$

The CV is a standardization of the standard deviation, allowing for comparison of variability estimates regardless of the magnitude of analyte concentration, at least for the majority of the assay's working range (Reed et al., 2002). Whereas, Standard deviation is calculated by

$$\text{SD} = \frac{\sqrt{1}}{\text{n}-1} \sum (\text{xi} - \ddot{\text{x}})^2 \quad (2)$$

Here, ẍ is the Arithmetic mean of the observations, and SD is the Sample standard deviation.

A 5-years moving average was applied to smoothen out the variability in the monsoon rainfall over 58 years (1961-2018) at 10 Taluka of the Kutch district.

2.3.2 Trend Analysis

Mann-Kendall Test

A rank-based non-parametric Mann-Kendall (MK) test has been used in this study and is considered the most popular test used for trend analysis of hydro meteorological data (Yue & Hashino, 2003). (Mann, 1945) primarily used this test, and (Kendall, 1975) subsequently derived the test statistic distribution. The Mann-Kendall test performs well with skewed variables, can manage missing values, and is resistant to the impact of extremes (Deni et al., 2010; Mishra et al., 2009). Furthermore, other researchers have primarily employed this approach to detect rainfall trends in their studies and got reliable results (Basistha et al., 2009; CHEN et al., 2007; Dufek & Ambrizzi, 2008; Goswami et al., 2006; Patra et al., 2012; Río et al., 2011; Rose, 2009)

For a series $X_1, X_2, . . , X_n$ (Sharma & Singh, 2017), S statistics can be given by:

$$\text{S} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}\left(X_j - X_i\right) \quad (3)$$

where X_i is ranked from i = 1, 2,.., n − 1 and X_j is ranked from j = i + 1 and n is the length of the data set.

$$sgn(\theta) = \begin{cases} 1 \ldots if\ \theta > 0 \\ 0 \ldots if\ \theta = 0 \\ -1 \ldots if\ \theta < 0 \end{cases} \quad (4)$$

The test statistics S's positive/ negative signs imply an upward/ downward trend in the data. The Mann-Kendall statistics' variance for a sample size of n = 8 is given by (Patra et al., 2012; Sharma & Singh, 2017):

$$Var(S) = \frac{[n(n-1)(2n+1) - \sum_t t(t-1)(2t+5)]}{18} \quad (5)$$

where t_i is the number of ties present up to sample i (Sharma & Saha, 2017).

The following formula has been used to estimate the standardised MK test statistics (Z) (Sharma & Singh, 2017):

$$Z = \begin{cases} \frac{s-1}{\sqrt{V(s)}}\ if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{s+1}{\sqrt{V(s)}}\ if\ S < 0 \end{cases} \quad (6)$$

The Z follows a standard normal distribution with zero mean and unit variance, where the positive value indicates an upward trend while a negative value indicates a downward trend. If the value of Z is greater than $Z_{\alpha/2}$, then it is considered a significant trend (where α is the significance level) (Sharma & Singh, 2017; Yao et al., 2018). In this study, significance level α = 0.05 has used.

Sen's slope

Theil-Sen's estimator calculates the magnitude of the rainfall trend (Sen, 1968; Theil, 1950). Sen's nonparametric approach have used to calculate the true slope of an existing trend (as a change annually) and is also used in cases where the trend is linear (Thenmozhi & Kottiswaran, 2016). The slope estimates of N pairs of data are primarily calculated by

$$\beta = \left[\frac{(X_i - X_j)}{i-j}\right] for\ i = 1, n \quad (7)$$

Here X_i and X_j are data values at the time i and k, respectively, where (i > j). The median of the N values of β is Sen's estimator slope (Narayanan et al., 2013), which is calculated as

$$N = (n(n-1))/2 \quad (8)$$

The practical significance of a trend was assessed using Theil and Sen's median slope and evaluating the percentage change over the mean for the relevant period because statistically significant trends might not have practical significance and vice versa (Narayanan et al., 2013). The monotonic trend is measured using β (Kundu et al., 2015; Xu et al., 2003). When $\beta > 0$, the time series indicates an upward trend; otherwise, a downward trend prevails (Luo et al., 2020).

3. Results and discussion

Monsoon Months (June-September) receive about 94% of annual rain in the Kutch district. The uneven phenomenon, Monsoon generally arrives at the end of June over the Kachchh district, while it withdraws to mid-September. Figure 3. indicates a high variation in monsoon rainfall in the Kutch district, which has experienced deficit, and surplus rain years often and within consecutive years and showed a long-term increasing trend in monsoon rainfall, while an insignificant decline trend was found between 2009 to 2018 for monsoon rain showed in Figure 4.

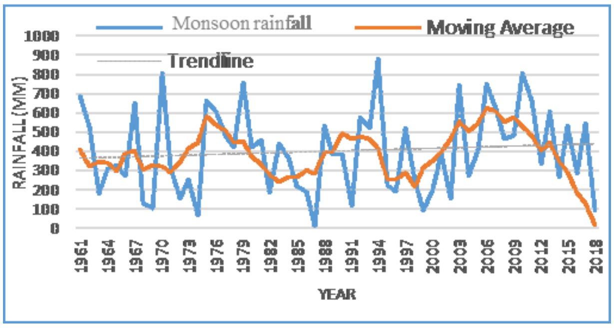

Figure 3. Monsoon rainfall for the Kutch district (1961-2018) with a 5-years Moving average.

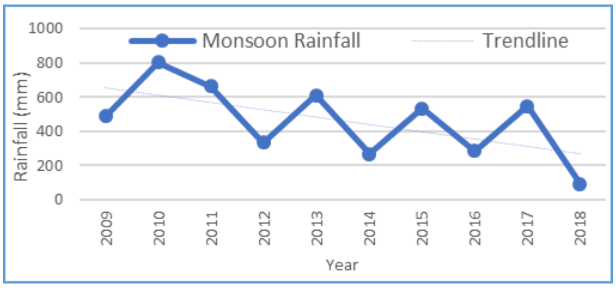

Figure 4. Variation in monsoon rainfall of the Kutch district, 2009-2018.

Criteria analysis

The annual rainfall during the studied period has been classified (Table 2.) as a deficit, below normal, normal, above average, and surplus based on Central Arid Zone Research Institute report, which has prepared by R. S. Singh (Lakhia, 2016).

Table 2. Criteria to classify the annual rain years.

Type	Definition
Deficit years	A year receiving the rainfall less than 50% to the normal annual rainfall.
Below Normal years	A year receiving the rainfall between 50 to 75% of the normal annual rainfall.
Normal Years	A year receiving the rainfall between 75 to 125% of the normal annual rainfall
Above Normal years	A year receiving rainfall between 125% to 150% of the normal annual rainfall.
Surplus years	A year receiving a rainfall of 150 % or more to the normal annual rainfall.

According to the analysis (Table 3), Kutch has experienced 11 (18.96%) deficit years, 10 (17.24%) years with below-normal rainfall, 19 (32.75%) years with normal rainfall, 8 (13.79%) years with above-average rainfall, and 10 (17.24%) years with surplus rainfall over the studied period of 58 years.

Table 3. Distribution of Rainfall for the Kutch District.

Deficit years <215mm	**Below Normal years 215-324mm**	**Normal years 324-540mm**		**Above Normal years 540-646mm**	**Surplus years >646mm**
1968	1963	1962	1998	1976	1961
1969	1964	1965	1999	1980	1967
1972	1966	1977	2001	1981	1970
1974	1971	1978	2005	1992	1975
1986	1973	1983	2008	2007	1979
1987	1982	1984	2009	2013	1994
1991	1985	1988	2012	2015	2003
1996	1995	1989	2016	2017	2006
2000	2004	1990			2010
2002	2014	1993			2011
2018		1997			
Total 11 years	**Total 10 years**	**Total 19 years**		**Total 8 years**	**Total 10 years**

Seasonal distribution

Kutch receives its maximum rain during the monsoon months between June to September, followed by Post-monsoon, Pre-monsoon, and least rain during the winters. Non-Monsoon months contribute nearly 6% to the average annual rainfall. Post-monsoon months (October-December) contribute maximum rain among the non-monsoon months, i.e., $\leq$4% of annual rainfall, while October receives the highest rain during the Post-monsoon months. One of the vital causes of heavy rainfall during the Post-monsoon months is the occurrence of a cyclone or late withdrawal of monsoon. Whereas, Pre-monsoon and winter seasons contribute less precipitation and receive rain due to the occurrence of local events and western disturbances. While examining the trend of rainfall in the Kutch district, monsoon rain has been considered and taken into account. The temporal variation of the monsoon rainfall at 10 Taluka was examined individually from 1961 to 2018 (Figure 5).

The mean monsoon rainfall for the Kutch district is 402.28 mm over the studied period of 58 years (Table 4). The Coefficient of variation and probability of monsoon rainfall is 54.34% and 45.65%, respectively. Table 5. highlights the mean, CV, and monsoon rainfall probability for all the Taluka of the Kutch district, including Rann.

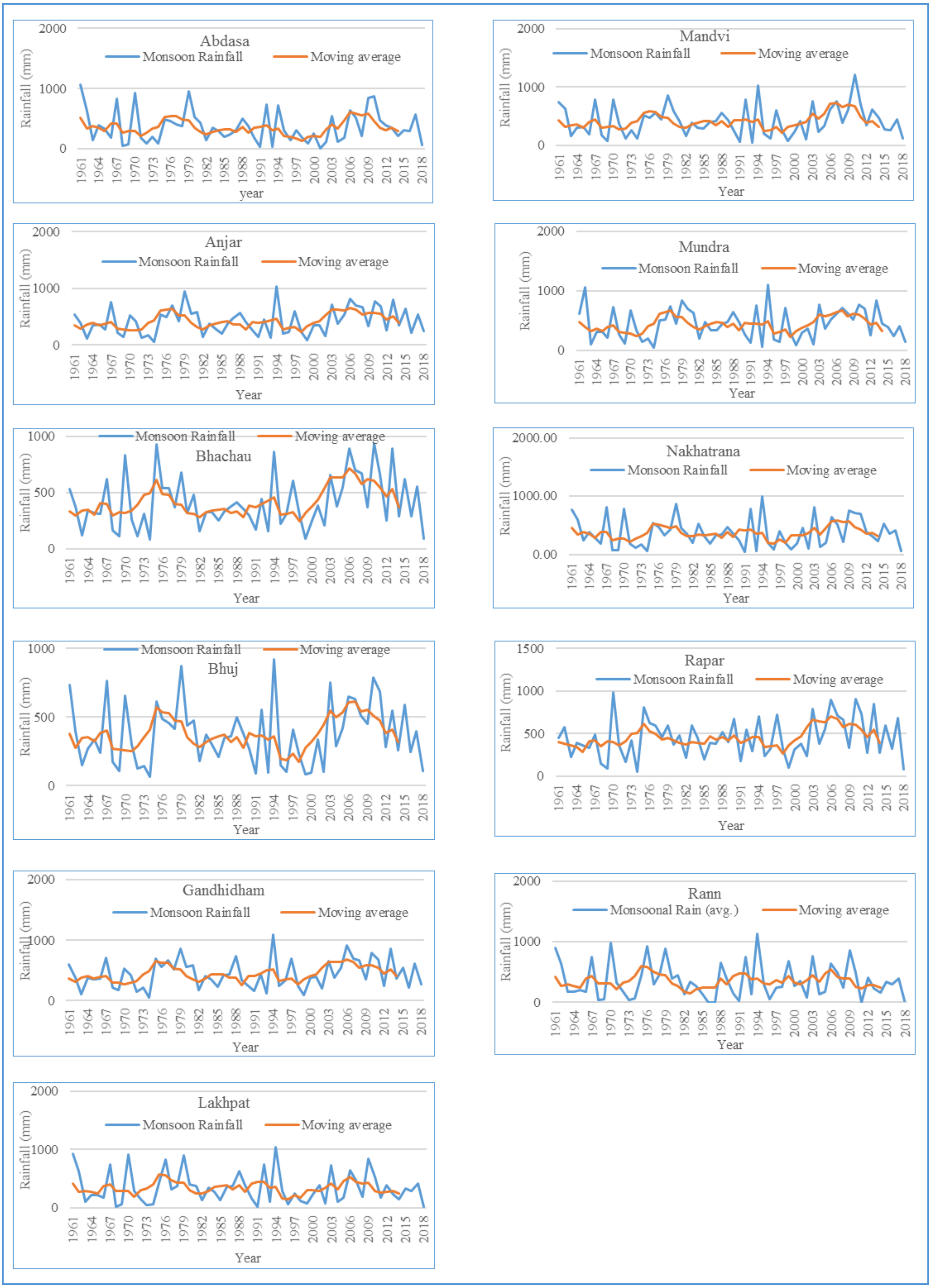

Figure 5. Temporal variations of average monsoon rainfall for the Taluka of Kutch district (1961-2018) with a 5 years moving average.

Table 4. Monsoon Rainfall Statistics for the Kutch district.

Monsoon Rainfall Statistics

District	Mean (mm)	Standard deviation (mm)	Coefficient of Variation (%)	Rainfall Probability (%)
Kutch	402.28	218.62	54.34	45.65

Table 5. Monsoon Rainfall Statistics for the Taluka of Kutch district. *Not included as Taluka.

Taluka	Mean (mm)	Standard deviation (mm)	Coefficient of Variation (%)	Rainfall Probability (%)
Abdasa	394.72	271.74	68.84	31.16
Anjar	441.24	243.50	55.18	44.82
Bhachau	427.55	262.67	61.43	38.57
Bhuj	388.56	244.21	62.85	37.15
Gandhidham	465.39	254.11	54.60	45.40
Lakhpat	367.00	275.78	75.14	24.86
Mandvi	439.50	271.72	61.82	38.18
Mundra	452.84	272.82	60.24	39.76
Nakhatrana	389.74	258.80	66.40	33.6
Rapar	499.91	237.68	47.54	52.46
Rann*	353.50	288.47	81.60	18.40

According to (Arnhold & Milani, 2011) criteria to classify the Coefficient of variation depends on the mean and standard deviation of CVs. The calculated mean and standard deviation of CV is 63.24 and 9.59, respectively.

The CVs were ranked as low [CV ≤ (m - 1 SD)], moderate [(m - 1 SD) < CV ≤ (m + 1 SD)], high [(m + 1 SD) < CV ≤ (m + 2 SD)] and very high [CV ≥ (m + 2 SD)], whereas, m is the mean of the CV, while SD is standard deviation (Arnhold & Milani, 2011).

Accordingly, values of CV ≤ 53.64% are low, 53.64% < CV < 72.83% are moderate, 72.83% < CV < 82.42% are high, and CV ≥ 82.42% are very high. Table 6 shows the maximum number of Taluka fallen in moderate CV class (i.e., 8 Taluka), followed by high (2, including Rann) and low (1). Rapar has the least CV among all the Taluka, while Rann, followed by Lakhpat, has the highest CV (Figure 6).

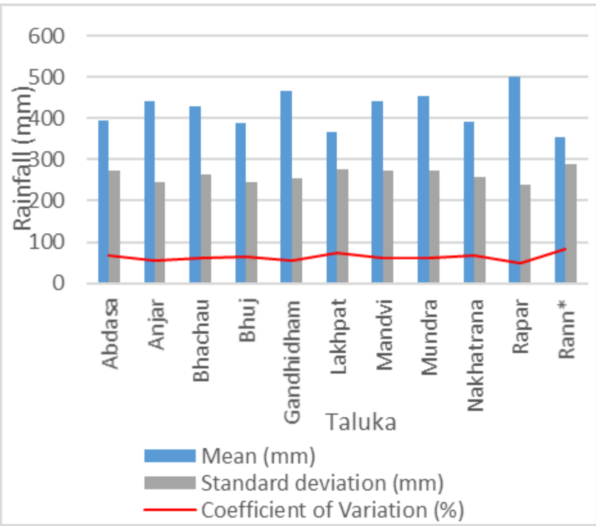

Figure 6. Taluka-wise monsoon rainfall statistics.

Table 6. Classification of Coefficient of variation.

Range	Value	Number of Taluka (Incl. Rann)
≤53.64	Low	1
53.64-72.83	Moderate	8
72.83-82.42	High	2
≥82.42	very high	-

The probability of monsoon rain is high in Rapar (52.46%), followed by Gandhidham and Anjar (45.40% and 44.82%, respectively). While in contrast, a low probability of monsoon rain has been found in Rann (18.40%), followed by Lakhpat (24.86%) (Figure 7).

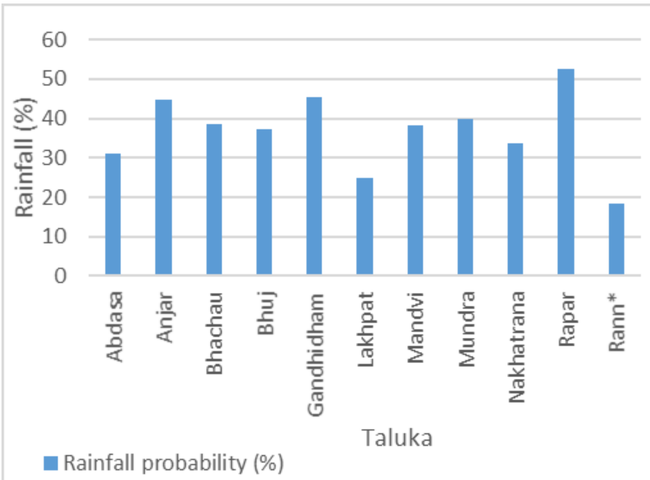

Figure 7. Taluka-wise monsoon rainfall probability.

The north and northwest part of the district has high monsoon rain variability which indicates a higher probability of extreme events occurring, while the south and south-central parts have relatively moderate rainfall variability, followed by the west having the lowest rainfall variability among all (Figure 8).

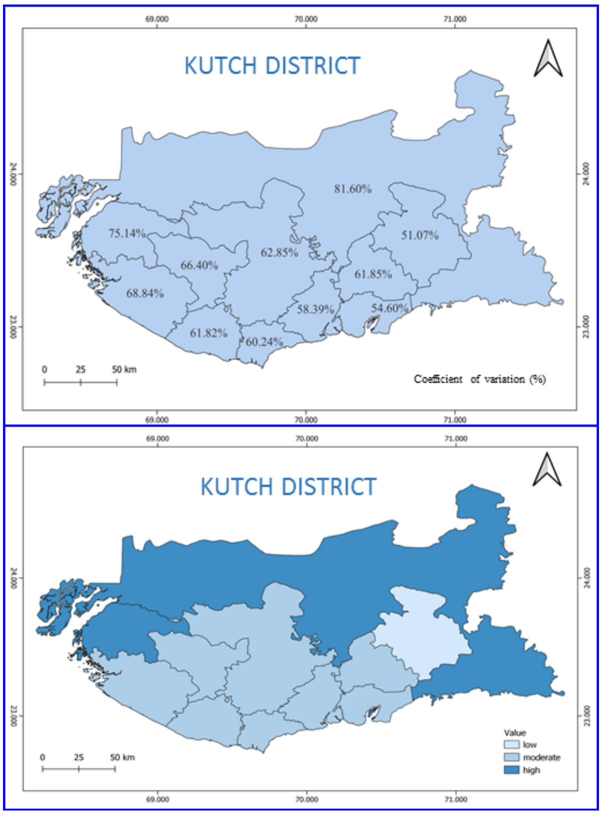

Figure 8. Rainfall Variability for the Kutch district, 1961-2018.

Although, the present study demands criteria that classify the Coefficient of variation with its mean and SD i.e., (Arnhold & Milani, 2011), otherwise, the CV above 40% assumes high (Asif et al., 2015), and indicates the higher risk of extreme events occurring.

Trend analysis

Table 7. shows a monotonic upward trend in monsoon rainfall for the Kutch district as $Z > 0$, i.e., 2.50. at a 5% significance level. The value of β is 2.578, i.e., $\beta > 0$. The positive value of β shows an upward trend in Figure 10.

Table 7. MK and Sen's slope statistics for the Kutch district.

	p-value	Sen's slope (β)	Alpha (α)	S	Z
Kutch	0.012	2.578	0.05	33700	2.50

The positive β value ($\beta > 0$) indicates an upward trend in monsoon rainfall over the studied period of 58 years (Figure 9).

The β value for all the Taluka of the Kutch district, including Rann, is > 0 at a 5% significance level. This indicates an upward trend in monsoon rain at all the Taluka (Table 8).

The upward trend has been found ($Z > 0$) in all the Taluka (Figure 10) and Rann of the Kutch district at a 5% significance level (Table 9).

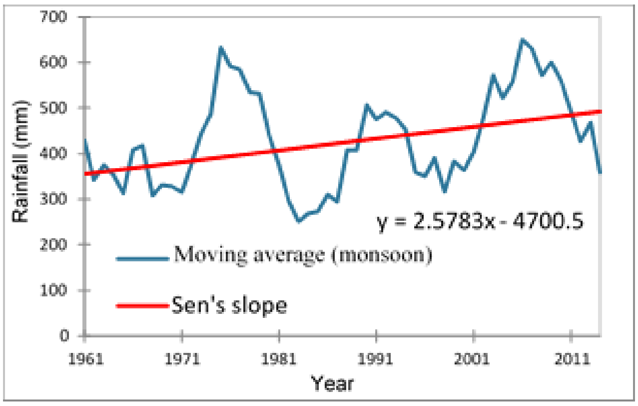

Figure 9. Trend of Monsoon rainfall for the Kutch district.

Table 8. MK and Sen's slope statistics for the Taluka of Kutch district.

Taluka	p-value	Sen's slope (β)	Alpha (α)	S	p-value < 0.05
Abdasa	0.238	1.270	0.05	158.00	False
Anjar	0.004	3.220	0.05	388.00	True
Bhachau	0.004	4.100	0.05	381.00	True
Bhuj	0.041	2.200	0.05	274.00	True
Gandhidham	0.001	3.754	0.05	432.00	True
Lakhpat	0.704	0.376	0.05	051.00	False
Mandvi	0.033	2.425	0.05	286.00	True
Mundra	0.029	2.514	0.05	293.00	True
Nakhatrana	0.063	2.111	0.05	249.00	False
Rapar	0.010	2.304	0.05	347.00	True
Rann*	0.041	2.200	0.05	274.00	True

Table 9. Z Statistics and trend for the Taluka of Kutch district.

Taluka	Z	Trend
Abdasa	1.17	Upward
Anjar	2.88	Upward
Bhachau	2.83	Upward
Bhuj	2.03	Upward
Gandhidham	3.21	Upward
Lakhpat	0.37	Upward
Mandvi	2.12	Upward
Mundra	2.17	Upward
Nakhatrana	1.85	Upward
Rapar	2.58	Upward
Rann*	2.03	Upward

Figure 10. Trend of Monsoon Rainfall for each Taluka of the Kutch district, 1961-2018

4. Conclusions

The present study involves the observation of rainfall trends using 60 grid points (IMD4 rainfall dataset, 0.25° x 0.25°) having the daily gridded rain data over the Kutch district from 1961 to 2018 for 58 years. The observed high rainfall variability in monsoon months during the studied period indicates a higher probability of extreme events occurring in the north and northwest part of the district, while relatively moderate in the south and central Kutch and least among all in Rapar (west). There have been 11 (18.96%) deficit years, 10 (17.24%) years with below-normal rainfall, 19 (32.75%) years with normal rainfall, 8 (13.79%) years with above-average rainfall, and 10 (17.24%) years with surplus rainfall over the studied period of 58 years. The non-parametric Mann-Kendall (MK) test have used to quantify the significance of the rainfall trend, which shows an upward trend for all the Taluka of Kutch district ($Z > 0$) at a significance level of 5%. The Sen's slope shows the trend's magnitude, which results in an upward trend ($\beta > 0$). This study would help us to forecast future rainfall, which is beneficial to prevent extreme events and their consequences.

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