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Spatio-temporal Trend Detection of Rainfall for Climate Change Assessment in Ahmedabad-Gandhinagar District of Gujarat State, India

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Abstract: The present research aims to assess the historical change in rainfall patterns with the changing climate in the Ahmedabad-Gandhinagar district in the state of Gujarat in India. The Mann-Kendall (MK) test along with Sen's slope estimator have been used for detecting the trend of rainfall data series. The trend of annual rainfall is carried out for – (1) six rain gauge stations established by the State Water Data Center (SWDC) and (2) 11 grid data available from the National Center for Environmental Prediction-Climate Forecast System Reanalysis (NCEP-CFSR) for 35 years starting from 1979 to 2013. Results obtained from these two data sets for the trend detection were found consistent. Furthermore, the analyses of annual and monthly rainfall using MK test and Sen's slope estimator at six rain gauge stations are carried out in three time periods i.e. 1974-1987, 1988-2001 and 2002-2016. The inverse distance weighted (IDW) method of interpolation is used for the results obtained from the spatial distribution of the temporal rainfall trend for interpolating the station value over the study area. Annual rainfall for data length of 1979 to 2013 shows an increasing trend. The trend of annual and monthly rainfall for July and September shows a positive trend for the span 2002-2016. This study would be useful to the water resource department and policymakers for climate change adaptation in the study area.

Keywords: Mann-Kendall test; Sen's slope estimator; Spatio-temporal distribution; Ahmedabad-Gandhinagar district.

Introduction

Climate change is one of the significant threats to society. Change in the hydrological cycle is significantly impacted by global warming (Chattopadhyay and Jha, 2016) and adversely affecting the Earth's ecosystem (Giupponi and Gain, 2017). In the recent decade, climate change influence precipitation properties which has drawn considerable attention throughout the world (Purcz et al., 2018; Yang et al., 2016). Investigation of variation in regional impact is required for understanding and identifying the impact of climate change on the hydrological cycle, eco-environment and agriculture (Biniyam and Kemal, 2017).

Rainfall is a main source of water and one of the key components of the hydrological cycle. India is an agricultural country in which all the agricultural activities are dependent on rainfall and through the withdrawal of groundwater and adding back to the agricultural fields by artificial supply. Uneven and untimely distribution of rainfall may unfavourably affect the agricultural activities (Jain and Kumar, 2012).

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Therefore, it is essential to detect variation in the trend of precipitation at different spatial and temporal scales at a regional scale. Many research has been carried out to investigate the spatial and temporal inconsistency in the rainfall trend nationwide (Radhakrishnan et al., 2017; Parthasarathy et al., 1994; Ay and Özyildirim, 2017; Amirabadizadeh et al., 2015) as well as regional wide (Cui et al., 2017; Krishnakumar et al., 2009; Issahaku et al., 2016).

Statistical assessment of rainfall in Ken River basin situated in Central India reveals annual as well as seasonal decrease in rainfall for the span 1901–2010 (Meshram et al., 2017). Non-parametric Mann-Kendall and Sen's methods applied to rainfall data series on station situated at the command area of the eastern Ganga canal show a reducing trend for annual rainfall (48.11 to 42.17 mm/decade) and monsoon rainfall (79.78 to 49.67 mm/decade) (Krishan et al., 2018). Temporal variation in annual, monthly and seasonal rainfall over Kerala (1871-2005) analysed by MK test reveals that rainfall in the months of June and July significantly decreases while for the months of winter and summer, it insignificantly increases (Krishnakumar et al., 2009). The reducing trend in the rainy season for rainfall is observed in the North-Eastern state of India using the MK test (Oza and Kishtawal, 2014). The seasonal rainfall of India for the span of 1901 to 2003 shows an increasing trend for pre-monsoon and post-monsoon rainfall with 0.4 cm and 1 cm, respectively (Dash et al., 2009).

In this study, the annual rainfall trend is analysed using two datasets. One is station data provided by SWDC and another is NCEP-CFSR. The National Weather Service provides Climate Forecast System Reanalysis (CFSR) dataset. CFSR dataset consists of hourly weather data which include fore cast data and predicted data. The precipitation is updated in near-real-time data every 6 hours (Fuka et al., 2013). The CFSR weather data is produced using cutting-edge data assimilation techniques as well as highly advanced atmospheric and surface modelling components at ~38 km resolution after various spatial and temporal interpolation (Dile and Srinivasan, 2014).

Most of the studies on rainfall trend/analysis are only limited to seasonal rainfall and annual rainfall, while in this study, the contribution of each major rain-producing month (i.e. June, July, August, and September) is analysed along with the annual rainfall trend. The significance of the trend in a climatological time series is assessed with the Mann-Kendall test. The magnitude of the trend in the data series has been determined using Sen's estimator. The Mann-Kendall test statistic depends on the sign of differences, not on the values of the random variable (Hirsch et al., 1991). Using the Mann- Kendall test (MK test), the trend track (positive or negative) and the significance of the trend (5% or 10% etc.) has been determined. The MK test and Sen's slope estimation at six rain gauge stations are carried out in three time periods i.e. 1974-1987, 1988-2001 and 2002-2016. The spatial distribution of precipitation trends is modelled in ArcGIS using geostatistical analysis by the IDW method.

The objective of this study for Ahmedabad and Ganhinagar districts is to – (1) compare the results of trend analysis of annual rainfall using weather data from CFSR and SWDC and (2) identify the trend of annual and monthly rainfall of monsoon season in a three-time period i.e. 1974-1987, 1988-2001 and 2002-2016. The study also compares the results of the trend for annual rainfall and monthly rainfall in this time series.

Study Area and Data Collection

In this study, Ahmedabad and Gandhinagar are considered for analysing the historical changes in rainfall patterns. Ahmedabad district is situated in the central part of the state of Gujarat, India. Ahmedabad district covers a geographic area of 8087 Sq. km. between 21°58" and 23°30" north latitudes and 71°35" and 73°02" east longitudes having 11 taluka (sub-regions) and 512 villages (Verma, 2014a) with population of 72.1 lakhs as per 2011 Census. A major portion of the district falls under the Sabarmati river basin. The mean rainfall of the basin is 827 mm. Gandhinagar city is the capital of the Gujarat state and is located on the left bank of the Sabarmati river. This district covers a geographic area of 2137.62 Sq. km. between 22°56" and 23°36" north latitudes and 72°23" and 73°05" east longitudes consisting four taluka (sub-regions) and 252 villages (Verma, 2014b) with population 13.9 lakhs as per 2011 Census. Figure 1 shows the Index map of India along with the district map of the Gujarat state.

There are six rain gauge stations maintained by State Water Data Centre (SWDC) located in the study area, which provides the available rainfall data collected over a time period ranging from 1974 to 2016 (48 years). Another set of gridded available data have been collected from the National Centers for Environmental Prediction-Climate Forecast System Reanalysis (NCEP-CFSR) for 35 years starting from 1979 up to 2013. Figure 2 shows the geographic location of the rain gauge station (SWDC) and grid point (NCEP-CFSR) in the

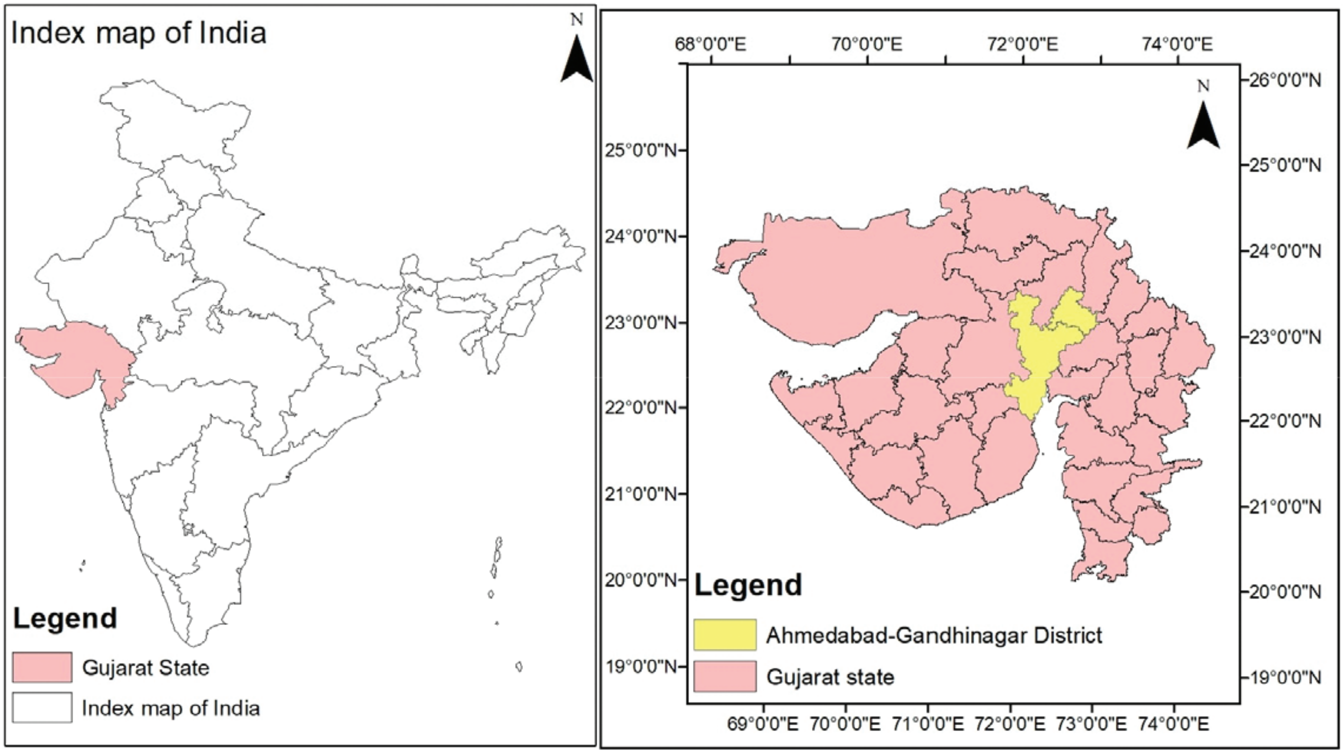

Figure 1: Index map of India along with the district map of Gujarat state and study area (Ahmedabad-Gandhinagar district).

Ahmedabad-Gandhinagar district. The socio-economic system in the basin demands water for irrigation, urban sectors, and industries because the Sabarmati river basin, which passes through these two districts is one of the most water-stressed river basins in India.

Methodology

To analyse the trend in the hydro-meteorological data series, the Mann Kendall test and Sen's slope methods are widely used (Najibi and Devineni, 2018). The non-parametric statistical Mann-Kendall method has been used for trend detection and to identify the significance of the trend, while Sen's slope estimator method been has used for the trend evaluation. These tests have been used recently by many researchers to assess trends in hydro-meteorological parameters in India (Jain and Kumar, 2012; Radhakrishnan et al., 2017; Meshram et al., 2017, Joshi and Makhasana, 2020; Chandole et al., 2019).

In this study, the annual and monthly data have been collected to prepare monthly and annual rainfall series for the stations located in Ahmedabad-Gandhinagar districts. The nature of the trend in time series is determined by statistical non-parametric tests, Mann-Kendall (MK) test and Sen's slope estimator test. The step-by-step technique adopted in the current study is described in Figure 3.

The results for trend analysis i.e. Sen's slope and significance of trend for annual rainfall have been obtained for both SWDC station and grid points of NCEP-CFSR grid data sets for the data span 1979 to 2013 in Ahmedabad and Gandhinagar districts. The spatial distribution of trend of annual rainfall obtained from both data sets by IDW method in Arc – GIS 10.3 have been compared.

Moreover, the monthly and annual rainfall trends at SWDC stations for annual and monthly rainfall of each monsoon month have been analysed for three-time series 1974 to 1987, 1988 to 2001 and 2002 to 2016. The spatial distribution of annual and monthly rainfall trends has been developed and results are compared.

Mann-Kendall Trend Test

The Mann-Kendall test statistic S is considered as (Mann, 1945; Kendall, 1975)

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

The application of trend test apply to a time series x_i ($i = 1, 2, \ldots n - 1$) and x_j ($j = i + 1, 2, \ldots n$).

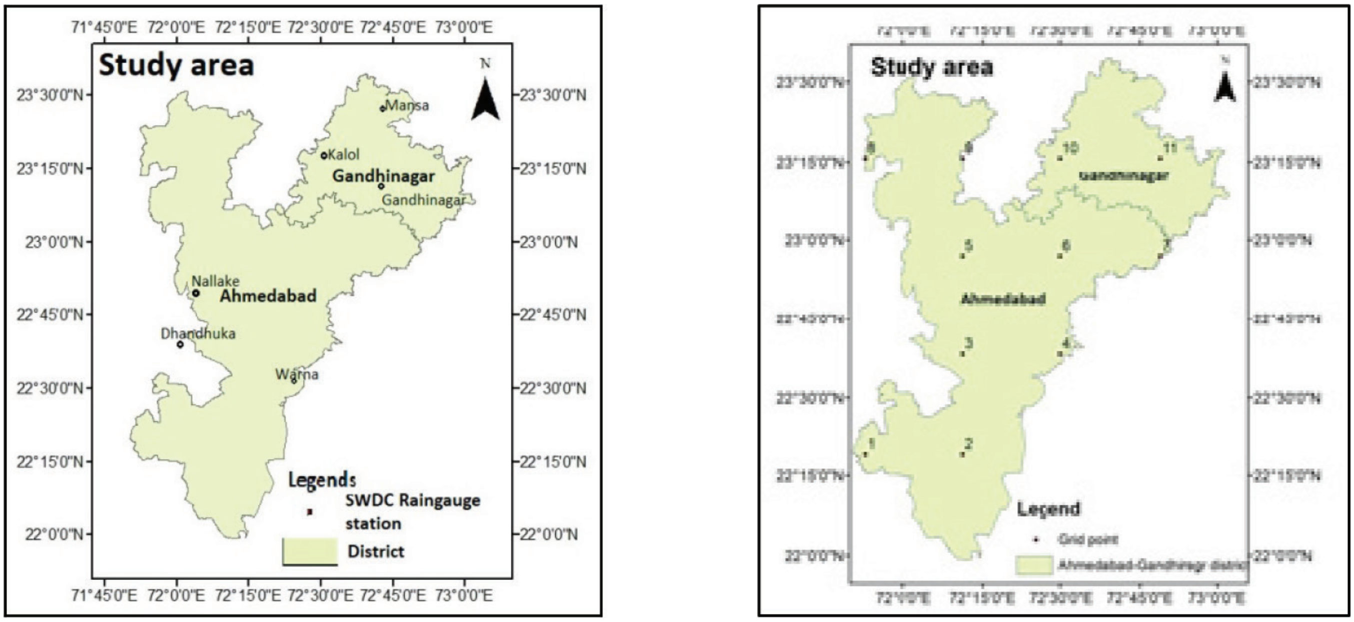

Figure 2: Geographic location of the rain gauge station and grid point in Ahmedabad-Gandhinagar district.

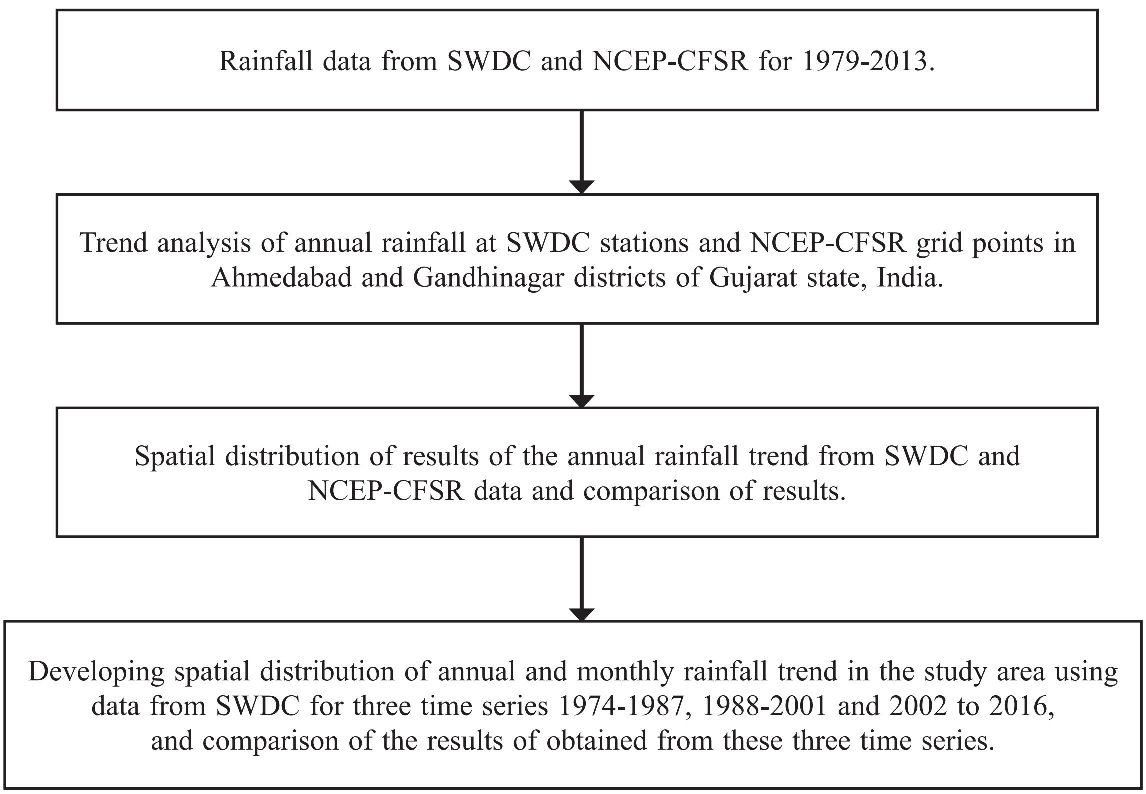

Figure 3: Step by step procedure for Spatio-temporal trend analysis followed in the current study.

Each of the data points x_i is taken as a reference point which is compared with the rest of the data point x_j so that,

$$\text{sgm}(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, < (x_j - x_i) \end{cases} \quad (2)$$

It has been documented that when $n \geq 8$, the statistic S is approximately normally distributed with the mean. $E(S) = 0$, the variance statistic is given as

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} t_i(i)(i-1)(2i+5)}{18} \quad (3)$$

Where t_i is considered as the number of ties up to sample i. The test statistics Z_o is computed as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}, S < 0 \end{cases} \quad (4)$$

Z_c follows a standard normal distribution. A positive/negative value of Z signifies an upward/downward trend. A significance level α is also used for testing either an upward or downward monotone trend. If Z_c is greater than $Z_{\alpha/2}$, where α depicts the significance level, then the trend is considered as significant. Here the test is conducted at 5% significant level. If the test value $Z_c > 1.96$ or $Z_c < -1.96$, then the trend is significant at a 95% confidence level (Thomas et al., 2015).

Sen's Slope Estimator Test

The magnitude of the trend is predicted by Sen's estimator. Here, the slope (β) of all data pairs is computed as (Sen, 1968)

$$\beta = \text{Median}\left(\frac{X_i - X_j}{i - j}\right) \text{for } i = 1, 2.........N \quad (5)$$

Where,

β = slope between data points x_i and x_j,

x_i = data measurement at time i,

x_j = data measurement at time j; and j = time after time i.

A positive value of β indicates an 'upward trend', and negative value depicts a 'downward trend'(Taxak et al., 2014).

Inverse Distance Weighted (IDW)

This method of interpolation estimates points values by averaging the values of sample data points in the area. This method for spatial distribution is based on the assumption that the effects that are close to one another are more alike than those that are farther apart. When a large set of data is available then this method is compatible. The IDW method performs well and is thus recommended to fill in the gaps in spatial distribution. An inverse distance weighting (IDW) method of interpolation in Arc GIS is used to the geospatial distribution of the trends over the entire basin. IDW results are helpful to identify trends in time and space for the study place where the data is not available (Pingale et al., 2014). The spatial distributions of Sen's slope for annual rainfall and monthly rainfall have been developed for three time series in this study.

Results

Trend of Annual Rainfall using SWDC and NCEP-CFSR Datasets

The trend of annual rainfall using station data provided by SWDC and gridded data provided by NCEP-CFSR have been analysed in this study. NCEP-CFSR provides data from January 1979 to July 2014 therefore analysis for annual rainfall trend is carried out from 1979 to 2013 using the MK test and Sen's slope estimation for comparison of results obtained using data from different sources. Figure 4 shows the spatial distribution for the trend of annual rainfall in the Ahmedabad-Gandhinagar district using both the dataset.

The results show an insignificant positive trend of the annual rainfall in the Ahmedabad-Gandhinagar district. The South Zone of the Ahmedabad district shows a higher value for the magnitude of annual rainfall trend. The spatial distribution reveals that results obtained for annual rainfall trend spatial distribution matches in both the dataset but the results obtained from the NCEP-CFSR dataset give a higher value of the magnitude of the trend of annual rainfall.

Trend of Annual and Monthly Rainfall for Three Time Series

SWDC provided rainfall data for the Ahmedabad-Gandhinagar district from 1974 to 2016 (48 years). These data were divided into three equal spans i.e. 1974-1987, 1988-2001 and 2002-2016 and trend analysis of annual and monthly rainfall has been carried out. Results obtained from the MK test are shown in Table 1. Spatial distributions of the Sen's slope value have been shown in Figure 5 for annual rainfall while Figures 6-9 representing the trend of monthly rainfall for months June to September, respectively. The blue colour is an indicative negative trend and red colour is indicative of the positive trend.

The highlighted value shows the trend is significant at 5% significance level.

The annual rainfall trend for the period 1974-1987, 1988-2001 and 2002-2016 shown in Figure 5 is positive in the later span and has higher values in comparison to earlier data span studied almost in the entire area.

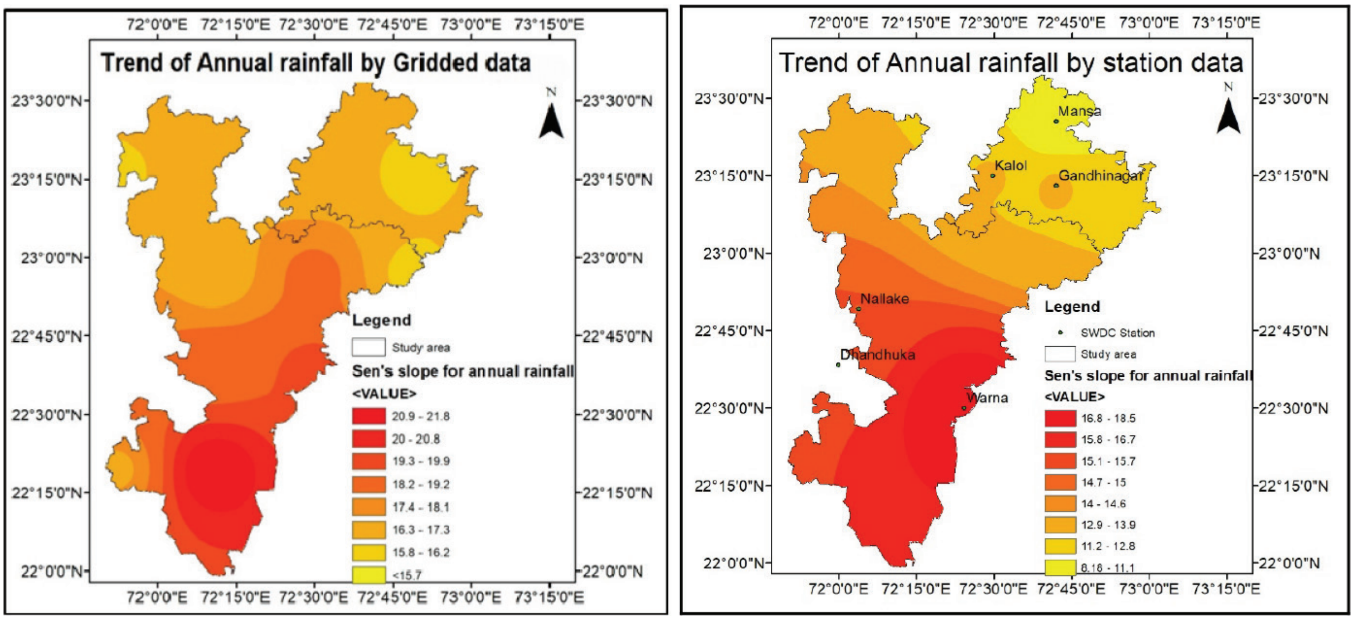

Figure 4: Trend of annual rainfall using gridded data and station data in the Ahmedabad-Gandhinagar district.

Table 1: MK Statistic (Zc) for annual rainfall and monthly rainfall

Year	*Month/Annual*	*Station*					
		Warna	*Mansa*	*Kalol*	*Gandhinagar*	*Nallake*	*Dhandhuka*
	June	0.16	0.39	-1.64	-0.22	-1.89	-1.31
	July	-0.33	-0.66	-0.93	0.11	-1.42	-0.77
1974-1987	Aug	-0.55	-0.77	-1.75	-1.09	-0.99	-0.77
	Sept	-1.04	-1.49	-2.25	-1.1	-1.22	-2.14
	Annual	-0.11	-1.2	-2.63	-0.11	-1.75	-0.77
	June	0.55	1.15	0.82	1.64	0.93	1.31
	July	0	-1.42	-0.93	-1.53	0	-0.99
1988-2001	Aug	-2.19	-2.19	-2.74	-0.88	-0.38	-0.22
	Sept	-1.04	-1.49	-0.77	-0.71	-0.56	-2.14
	Annual	-2.19	-2.3	-0.88	-1.2	-0.88	-0.55
	June	-1.33	-0.27	-2.1	-1.96	-0.87	-1.97
	July	0.82	0.55	0.82	0.44	0.87	1.31
2002-2016	Aug	0.27	-2.52	-1.09	-2.08	-1.11	-2.14
	Sept	0.34	-0.38	1.32	0.22	0.62	0
	Annual	0.07	-1.31	0.11	1.52	0.12	1.3

In the time span 2002-2016, rainfall occurring in June and August shows a significantly decreasing trend at many stations. Figure 5 reveals that the trend of annual rainfall shows a negative trend in first time span (1974-1987) and second time span (1988-2001) with a rate –12.1 mm/year to –11.2 mm/year, respectively. In the third time span (2002-2016), the annual rainfall shows a positive trend with a trend rate up to 13.4 mm/year. It is visualised from Figure 7 that the rainfall trend in the month of July has a negative trend in time span 1974-1987 and 1988-2001, while a positive trend in time span 2002 – 2016.

It is visualised from Figure 8 that the month of August shows a negative trend in all three-time spans. Figure 9 shows that the month of September has a positive trend in 2002-2016.

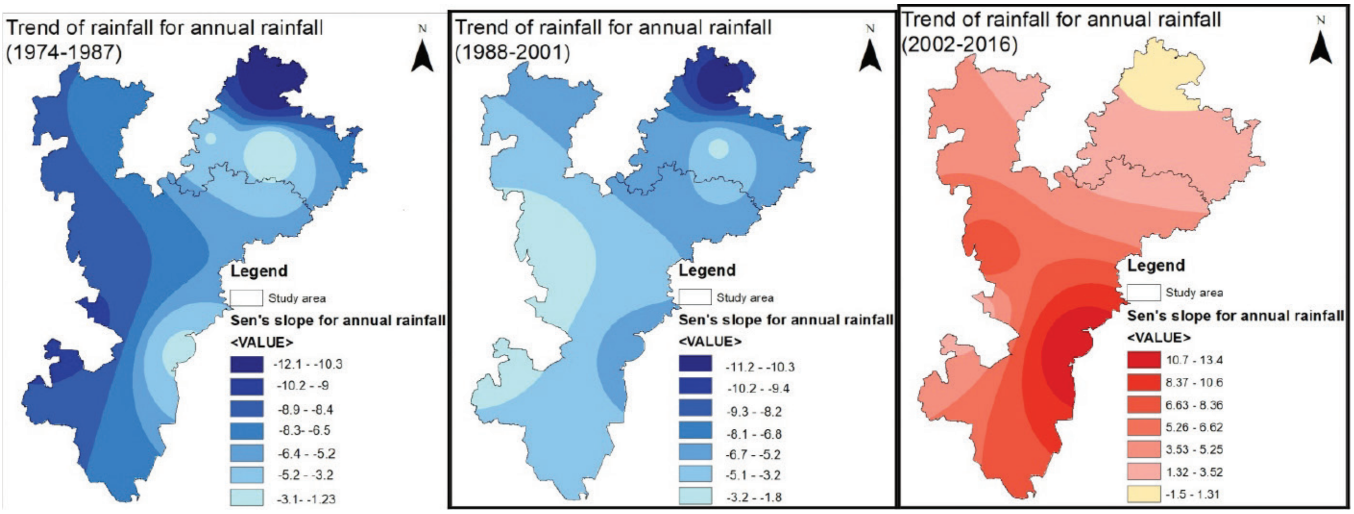

Figure 5: Trend of annual rainfall in the Ahmedabad-Gandhinagar District.

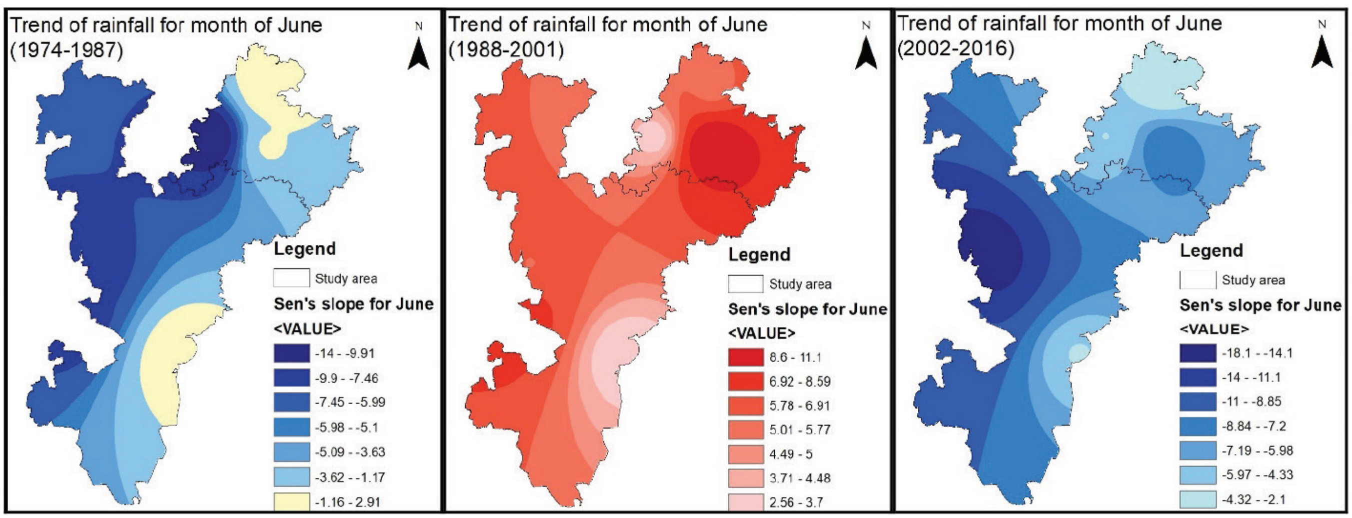

Figure 6: Trend of monthly rainfall for Ahmedabad-Gandhinagar district in month June.

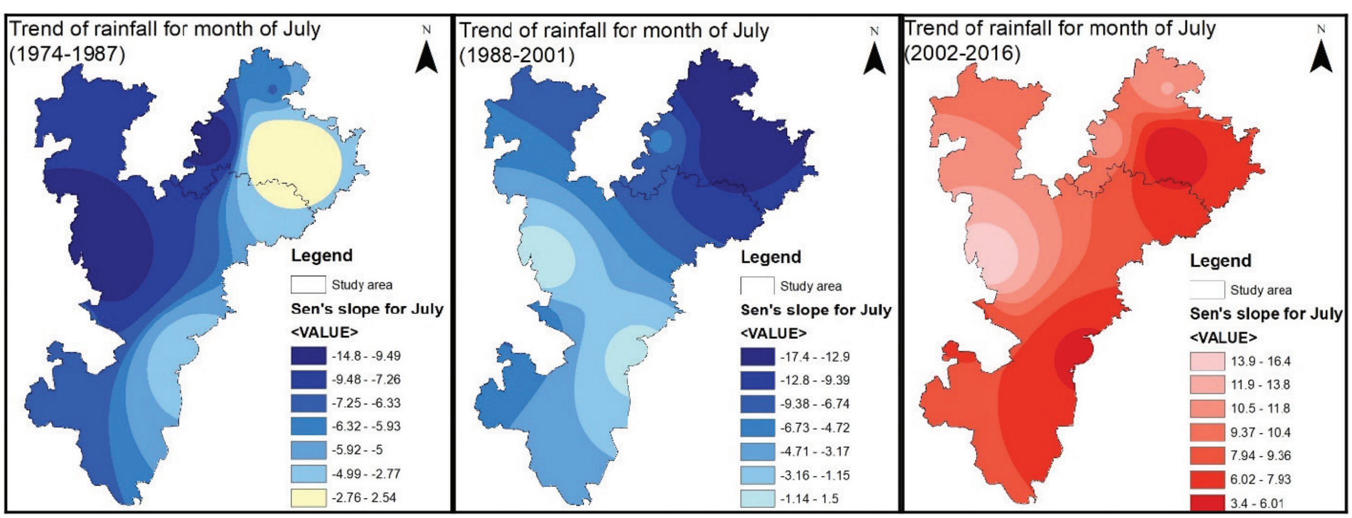

Figure 7: Trend of monthly rainfall for Ahmedabad-Gandhinagar district in month July.

Conclusion

Almost similar results are obtained through CFSR data as well as SWDC data. Thus, the outcome of this study indicated that weather data provided by CFSR can be reliably used as input data substitute of observed traditional data if the observed data is not available due to remote location or missing.

It is observed that the Ahmedabad-Gandhinagar district exhibited a negative trend in 1974-1987 and 1988-2001 in annual rainfall, while Ahmedabad and Gandhinagar district exhibited a positive trend in time span 2002 to 2016. Rainfall in July and September also exhibited a positive trend in the later data span i.e. 2002-2016, and the trend of rainfall in August showed a negative trend in all three-time series.

These impacts could be due to environmental changes, climatic changes, human interferences, etc. Population growth in the previous two decades may have lead to deforestation and reduced agricultural activities along with increment in urbanisation and industrialisation. Such changes may affect temperature, rate of evaporation and rate of evapotranspiration, also the components of the hydrologic cycle.

The spatial distribution maps of trend distribution of annual and monthly rainfall can help water managers and local stakeholders to know the risk and liability associated with climate change.

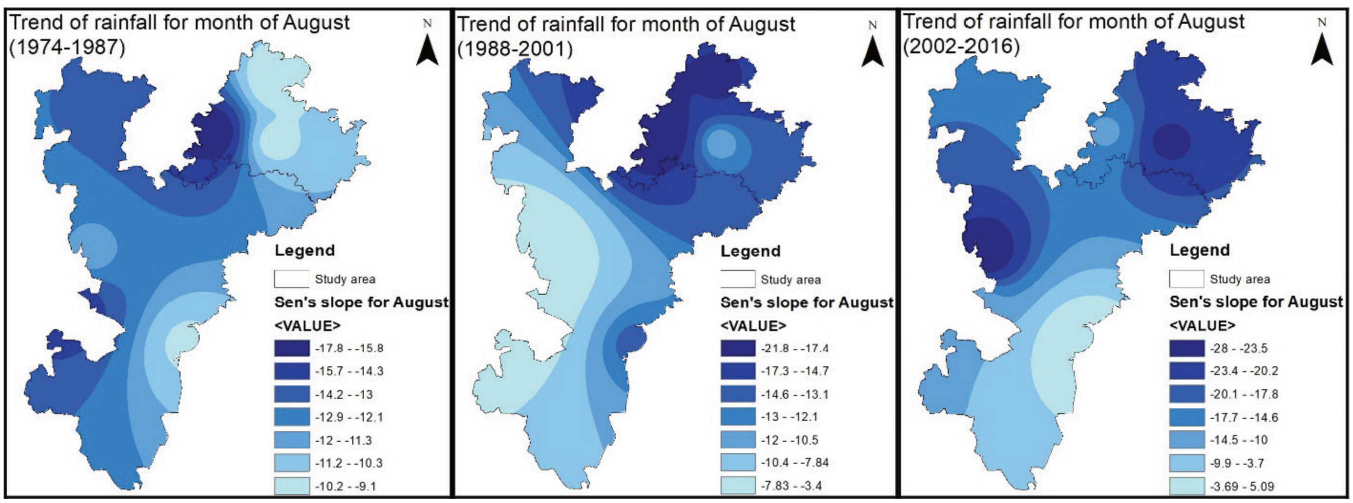

Figure 8: Trend of monthly rainfall for Ahmedabad-Gandhinagar district in month August.

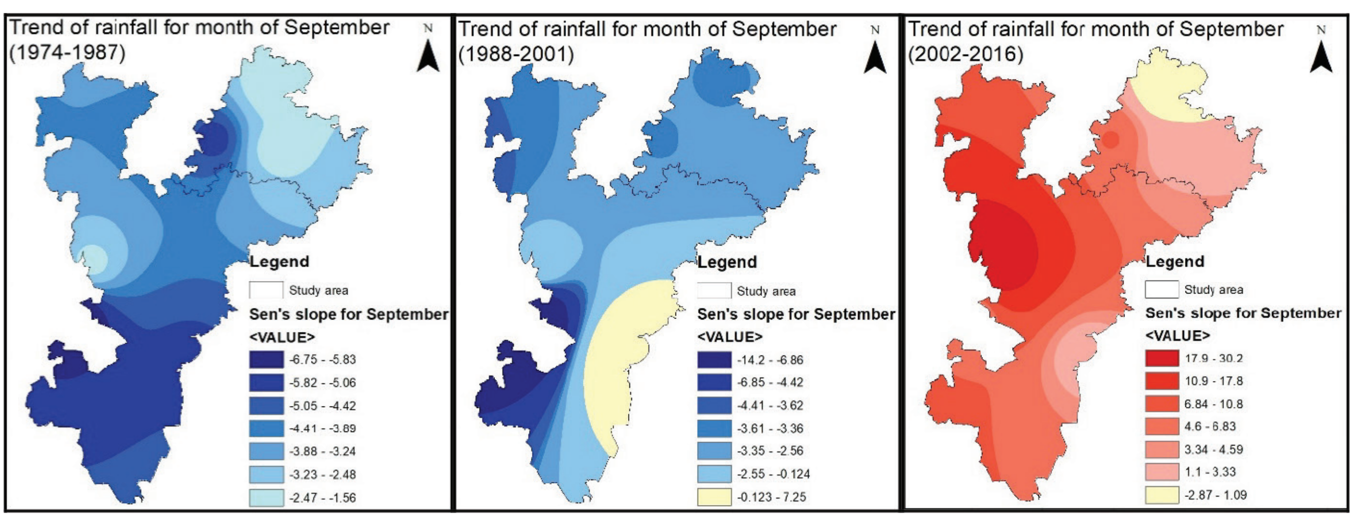

Figure 9: Trend of monthly rainfall for Ahmedabad-Gandhinagar district in month September.

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