SPATIAL PATTERN OF TRENDS IN INDIAN SUB-DIVISIONAL RAINFALL

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ABSTRACT *This paper attempts to bring out patterns of trend over different sub-divisions in India through analysis of long (1872-2005) annual rainfall records. Modified Mann-Kendall test has been applied for assessment of trends. Practical significance of the trend has been addressed. The results show that rainfall has decreased over north India with the exception of Punjab, Haryana, West Rajasthan and Sourashtra; and increased over south India excluding Kerala and Madhya Maharashtra. Rainfall over Gangetic West Bengal also registers an increase. The most conspicuous increase is at Punjab and decrease is at Chattisgarh, both of which are statistically significant at 5% level. A strikingly smooth spatial transition of trends between these two extreme centres is revealed. Further research is needed for attribution.*

Key words Climate change; trend analysis; modified Mann-Kendall test; rainfall

INTRODUCTION

Rainfall variability directly inflicts the agrarian economy as 65% of the cultivated area is still under rain fed agriculture (ICAR, 2006). In a large country like India, 'the place based bottom up perspective' to evaluate climate change and resultant vulnerability, as proposed by Pielke et al. (2007), has particular relevance. Truly, the statement that 'all India summer monsoon rainfall has remained near-normal' can bring little solace to the farmer whose crops are desiccated by drought or decayed by drench. Though drought and floods regularly take their toll in one part of the country or the other, more often than not they fail to leave a mark on the rainfall series prepared by averaging over the nation. Likewise, increasing and decreasing trends prevailing over different areas may get camouflaged in countrywide statistics.

Analyses reveal increasing rainfall trends over Indus, Ganga, Brahmaputra, Krishna, Cauvery basins (Singh et al., 2005), West Coast (Alvi and Koteswaram, 1985), north Andhra Pradesh and northwest India (Rupakumar et al., 1992), Rohtak and Kurukshetra of Haryana (Lal et al., 1992), Delhi (Rao et al., 2004), West Madhya Pradesh (Parthasarathy and Dhar, 1976b), coastal Orissa (Senapati and Misra, 1988), peripheries of Rajasthan desert (Pant and Hingane, 1988); but decreasing trends in Central Indian basins of Sabarmati, Mahi, Narmada, Tapi, Godavari and Mahanadi (Singh et al., 2005), east Madhya Pradesh and adjoining areas, northeast India (Zveryaev and Aleksandrova, 2004) and parts of Gujarat (Rupakumar et al., 1992), south Kerala (Singh et al., 1989; Singh and Soman, 1990), central north Indian divisions (Subbaramayya and Naidu, 1992). Studies of Kothyari and Singh (1996) and Kothyari et al. (1997) bring out a decreasing rainfall trend over the Ganga basin, beginning around the second half of 1960s; elaborated by Singh and Sontakke (2002) to be increasing over western Indo-Gangetic Plains Region and decreasing (statistically insignificant, though) over central part.

METHODOLOGY

The invalidity of the assumptions of classical parametric methods (i.e., normality, stationarity and independence) for hydrologic variables commands use of non-parametric tests. Mann-Kendall (MK) test has maintained its position as the test of choice for long period. However, presence of positive or negative autocorrelation affects the detection of trend in a series (Hamed and Rao, 1998; Serrano et al., 1999; Yue et al., 2003; Cunderlik and Burn, 2004; Novotny and Stefan, 2007; Bayazit and Onoz, 2007). With a positively autocorrelated series, there are more chances of a series being detected as having trend while there may be actually none. The case is reverse for negatively autocorrelated series, where trend fails to get detected. Pre-whitening has been used to detect trend in time series in presence of autocorrelation (Cunderlik and Burn, 2004). However, pre-whitening is reported to reduce the detection rate of significant trend by MK test (Yue et al., 2003). Therefore, in this study, Modified Mann-Kendall (MMK) test (Hamed and Rao, 1998; Rao et al., 2003) has been employed for trend detection.

Autocorrelation

The Autocorrelation Coefficient ρ_k of a discrete time series for lag k is estimated as

$$\rho_k = \frac{\sum_{t=1}^{n-k}(x_t - \overline{x_t})(x_{t+k} - \overline{x_{t+k}})}{\left[\sum_{t=1}^{n-k}(x_t - \overline{x_t})^2 * \sum_{t=1}^{n-k}(x_{t+k} - \overline{x_{t+k}})^2\right]^{1/2}} \quad (1)$$

where $\overline{x_t}$ and $Var(x_t)$ are the sample mean and sample variance of the first (n-k) terms, and $\overline{x_{t+k}}$ and $Var(x_{t+u})$ are the sample mean and sample variance of the last (n-k) terms. The hypothesis of serial independence is then tested by the lag-1 autocorrelation coefficient as

$$H_0 : \rho_1 = 0 \text{ against } H_1 : |\rho_1| > 0 \text{ using } t = |\rho_1|\sqrt{\frac{n-2}{1-\rho_1^2}} \quad (2)$$

where the test statistic t has a Student's t-distribution with (n-2) degrees of freedom (Cunderlik and Burn, 2004). If $|t| \geq t_{\alpha/2}$ the null hypothesis about serial independence is rejected at significance level α (here 10%).

Modified Mann-Kendall test

In this, autocorrelation between ranks of the observations ρ_k are evaluated after subtracting a non-parametric trend estimate like Theil and Sen's Median slope from the data. The test is based on the test statistic S defined as (Yue et al., 2002):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \quad (3)$$

where, x_j are the sequential data values, n is the length of the data set and

$$\text{sgn}(t) = \begin{Bmatrix} 1 \cdots if\,(t > 0) \\ 0 \cdots if\,(t = 0) \\ -1 \cdots if\,(t < 0) \end{Bmatrix} \quad (4)$$

It has been documented that when $n \geq 8$, the statistic S is approximately normally distributed with

the mean E(S) = 0 (5)

$$\text{and variance as } V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad (6)$$

where m is the number of tied groups and t_i is the size of the i^{th} tied group. However, this variance has to be corrected to compensate effects of autocorrelation. Only significant values of ρ_k are used to calculate variance correction factor n/n_S^*, as the variance of S is underestimated when the data are positively autocorrelated:

$$\frac{n}{n_S^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k=1}^{n-1} (n-k)(n-k-1)(n-k-2)\rho_k \quad (7)$$

where n is the actual number of observations, n_s^* is considered as an 'effective' number of observations to account for the autocorrelation in the data and ρ_k is the autocorrelation function of the ranks of the observations.

To account only for the significant autocorrelation in the data, number of lags can be limited to 3 (Rao et al., 2003). The corrected variance is then computed as

$$V^*(S) = V(S) \times \frac{n}{n_S^*} \tag{8}$$

where, $V(S)$ is from equation (6).

Finally, the standardised test statistic Z is computed by

$$Z_{MMK} = \begin{cases} \frac{S-1}{\sqrt{V^*(S)}} \, when S > 0 \\ 0 \cdots when S = 0 \\ \frac{S+1}{\sqrt{V^*(S)}} \, when S < 0 \end{cases} \tag{9}$$

Practical Significance

Some trends may not be evaluated to be statistically significant while they might be of practical interest, and vice versa (Yue and Hashino, 2003). Even if a climate change component is present, it does not need to be detected by statistical tests at a satisfactory significance level (Radziejewski and Kundzewicz, 2004).

For the present study, practical significance has been measured by approximating it with a linear trend, estimating its magnitude by Theil and Sen's median slope and assessing change over the period as percentage of mean of the period concerned, following Yue and Hashino (2003). That is, the change percentage equals median slope multiplied by period length divided by the corresponding mean, expressed as percentage.

Theil and Sen's Median Slope Estimator

This gives a robust estimate of trend (Yue et al., 2002). The slope estimates of N pairs of data are first computed by

$$Q_i = (x_j - x_k)/(j-k) \quad \text{for } i = 1, \ldots N \tag{10}$$

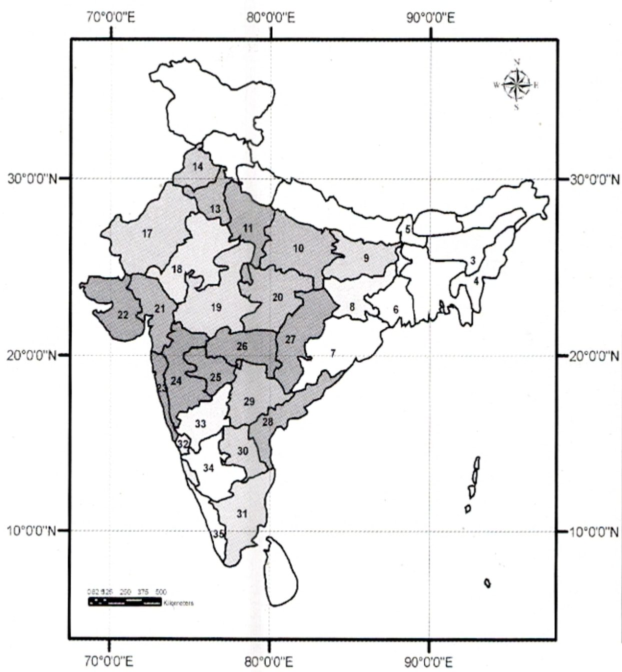
where x_j and x_k are data values at times j and k $(j > k)$, respectively. The median of these N values of Q_i is Sen's estimator of slope.

DATA

This study utilizes freely available (ftp://www.tropmet.res.in) sub-divisional monthly rainfall data prepared by Indian Institute of Tropical Meteorology

(IITM) from rain gauges maintained by India Meteorological Department. A map showing distribution of meteorological sub-divisions considered in the analysis is given in Fig. 1.

The boundaries of meteorological sub-divisions of India mostly match with those of the states, or further subdivide it. States in India have well established administrative and institutional mechanisms that are useful for implementing and monitoring measures. Particularly from inter-basin water transfer point of view, water balance, and as a starting point, rainfall change estimates have a crucial role to play. Sub-divisional estimates thus offer a finer regional scale inventory covering the combined interests of the scientific community and the policy makers.



SDnNo	SubDivn Name
3	Assam & Meghalaya
4	Nagaland Manipur Mizoram & Tripura
5	Sub Himalayan West Bengal & Sikkim
6	Gangetic West Bengal
7	Orissa
8	Jharkhand
9	Bihar
10	East Uttar Pradesh
11	West Uttar Pradesh
13	Haryana Chandigarh & Delhi
14	Punjab
17	West Rajasthan
18	East Rajasthan
19	West Madhya Pradesh
20	East Madhya Pradesh
21	Gujarat
22	Sourashtra Kutch & Diu
23	Konkan & Goa
24	Madhya Maharashtra
25	Marathwada
26	Vidarbha
27	Chattisgarh
28	Coastal Andhra Pradesh
29	Telangana
30	Rayalseema
31	Tamilnadu & Pondicherry
32	Coastal Karnataka
33	North Interior Karnataka
34	South Interior Karnataka
35	Kerala

Fig. 1 Meteorological sub-divisions considered in this study (adopted from IITM).

RESULTS AND DISCUSSION

Autocorrelation is present at only two sub-divisions, namely Madhya Maharashtra and Marathwada, at 5% level of significance. The results of trend analysis are given in Table 1, which also document its practical significance in terms of percentage change.

Table 1 Annual rainfall trend and its practical significance

Sub-division	MMKZ	% Change
Assam & Meghalaya	-0.981	-3.34
Nagaland Manipur Mizoram &Tripura	-1.385	-4.90
Sub Himalayan West Bangal & Sikkim	-0.060	-0.25
Gangetic West Bengal	1.791	9.60
Orissa	-0.708	-3.75
Jharkand	-0.573	-2.91
Bihar	-0.269	-1.55
East Uttar Pradesh	-0.101	-0.64
West Uttar Pradesh	-0.512	-3.44
Haryana Chandigarh & Delhi	1.883	17.37
Punjab	2.103	18.84
West Rajasthan	0.319	4.00
East Rajasthan	-0.673	-6.79
West Madhya Pradesh	-0.508	-3.72
East Madhya Pradesh	-1.388	-8.10
Gujarat	-0.431	-3.29
Sourashtra Kutch & Diu	0.140	1.30
Konkan & Goa	1.534	9.44
Madhya Maharashtra	-0.287	-1.90
Marathwada	0.033	0.23
Vidarbha	-1.122	-7.67
Chattisgarh	-2.181	-14.10
Coastal Andhra Pradesh	1.502	8.95
Telangana	1.625	10.79
Rayalseema	1.329	8.74
Tamilnadu & Pondicherry	0.108	0.53
Coastal Karnataka	1.977	9.56
North Interior Karnataka	0.178	1.31
South Interior Karnataka	0.004	0.04
Kerala	-0.194	-1.01

The spatial distribution of trends is shown in Fig 2. As a recap, the critical values of Z for 10%, 5% and 1% levels of significance are 1.645, 1.96 and 2.326 respectively. The entire northern India excluding Punjab, Haryana, West Rajasthan and Saurashtra depict a declining trend (though not significant statistically) leaving aside Chattisgarh, where it is significant at 5% level. The increase in Punjab and Haryana are significant at 5% and 10% level respectively. To the contrary, southern India portrays a statistically insignificant increasing trend, with the exception of Coastal Karnataka – where it is significant at 5% level.

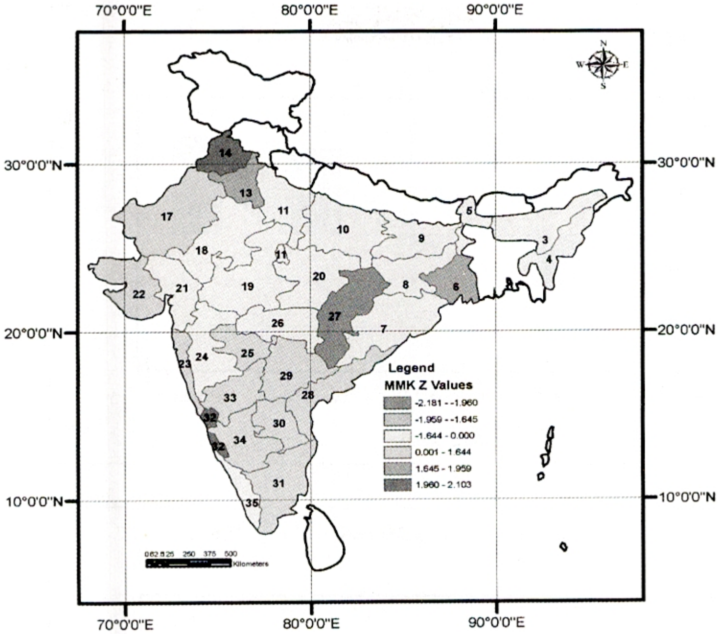


Fig. 2 Annual rainfall trend pattern by MMK test.

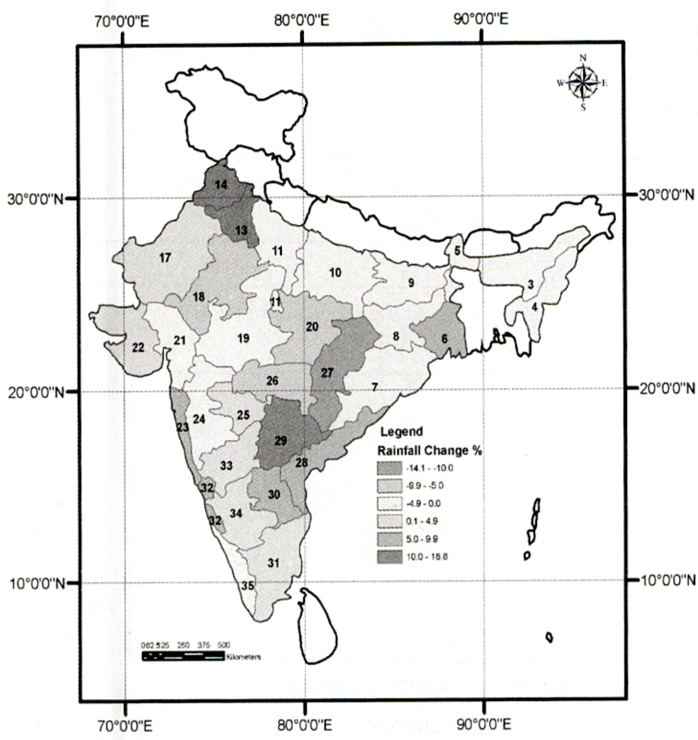


Fig. 3 Percentage change in annual rainfall over mean.

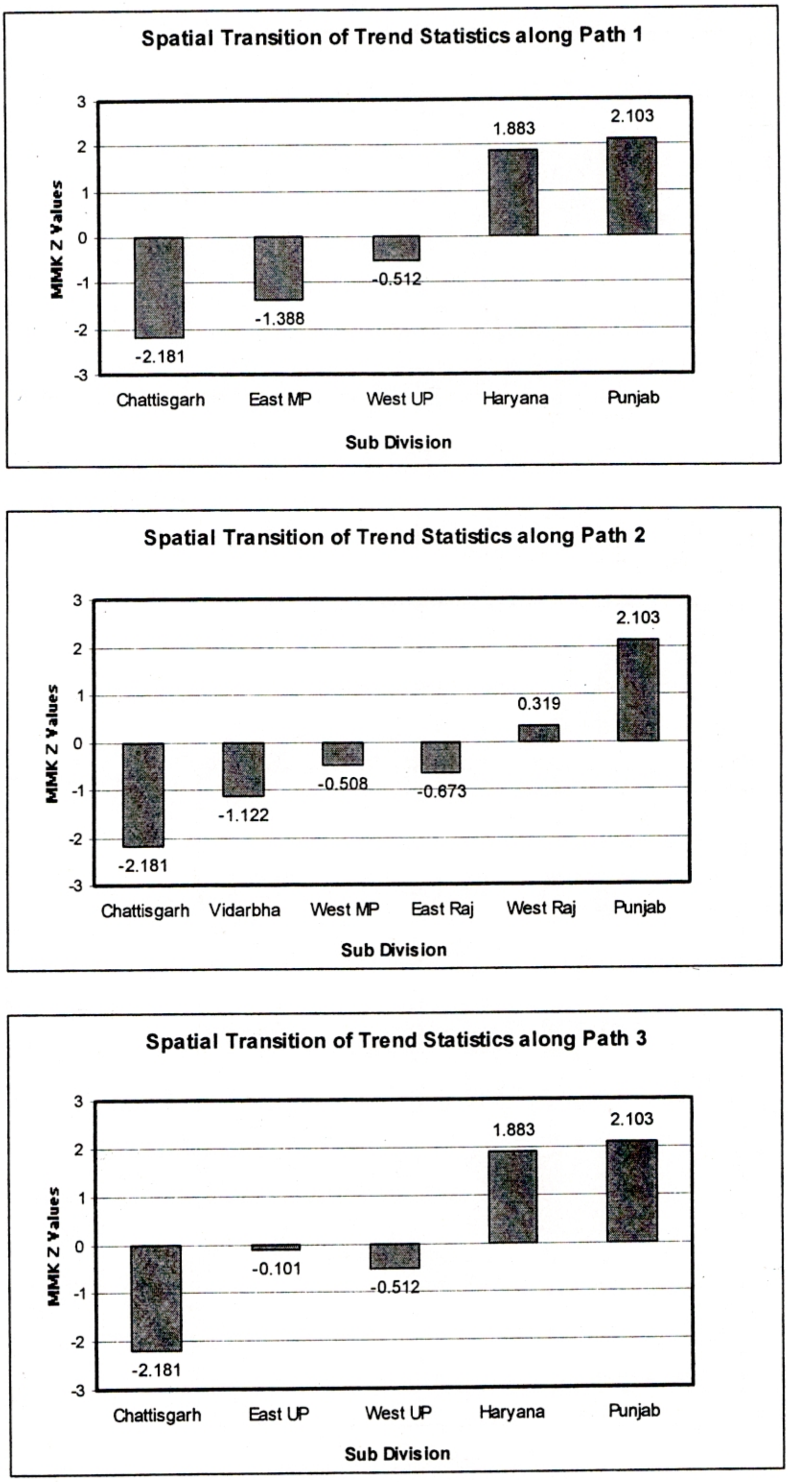
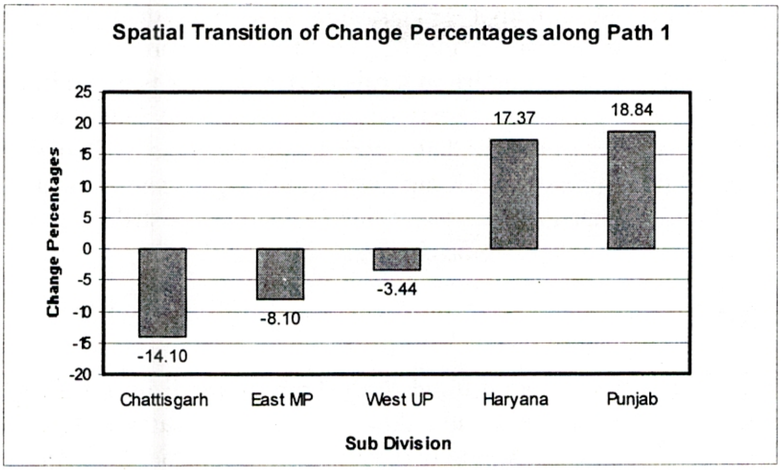
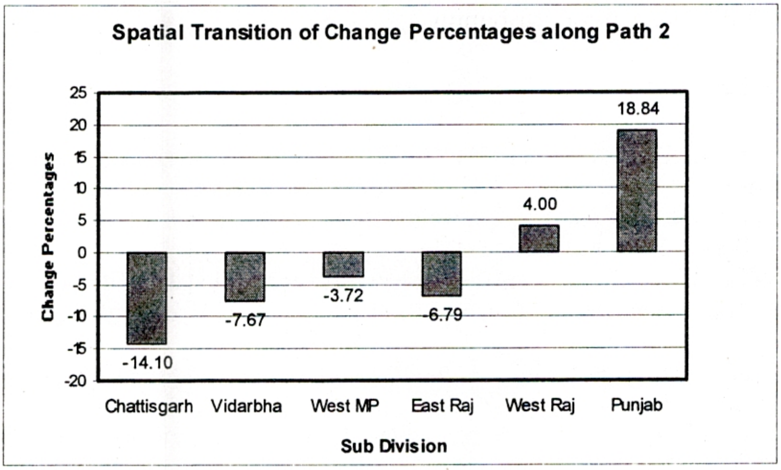


Fig. 4 Spatial transition of trend statistics along three different paths.





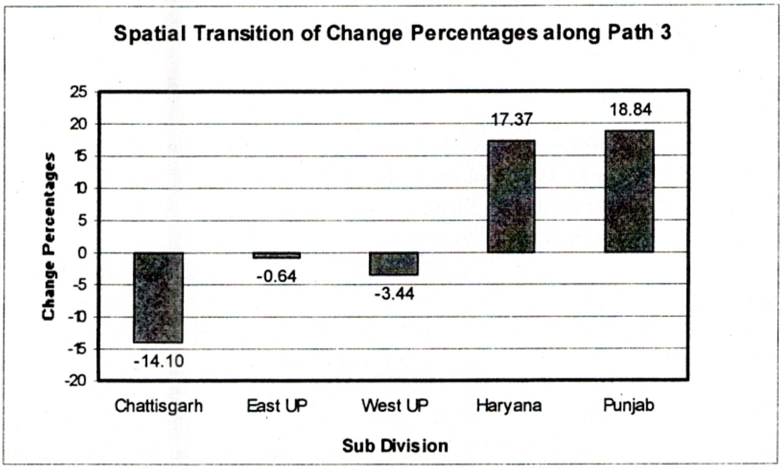


Fig. 5 Spatial transition of change percentages along the three paths.

However, Kerala and Madhya Maharashtra display a decreasing trend, though not statistically significant. Gangetic West Bengal records a rising trend, significant at 10%. The change pattern in terms of percentages is given in Fig. 3. Both the figures show similar patterns, while Fig. 3 brings out the smooth transition from decreasing trend at Chattisgarh to the increase at Punjab more clearly. The spatial transition of trends and corresponding percentage changes in rainfall are explored further in Figs. 4 and 5, which reveal a strikingly smooth changeover between these two extreme centres.

CONCLUSION

This paper brings out a general trend of declining rainfall in northern India contrasting an escalation in the south. Also, there is a characteristic spatial transition in rainfall trends between two centers of extreme – Punjab with increasing trend at one end and Chattisgarh with decreasing trend at the other. Further research is needed for attribution.

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