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Spatial and temporal precipitation trends of proposed smart cities based on homogeneous monsoon regions across India

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Abstract

The conservation of rainwater and augmentation of groundwater reserve is necessary to meet the increased water demands. Precipitation occurring in the smart cities need to be understood for a better water management action plan. Therefore, monotonic precipitation trend analysis was performed for eight smart cities drawn from six monsoon homogeneous regions across India. The precipitation data were investigated for trends using the modified Mann–Kendall (MMK) test and Sen's slope estimator at annual, seasonal and monthly scales. The trend analysis was carried out over 118 years (from 1901 to 2018) at 95% significance level. The Dehradun city (Northern Himalayan region) showed a significant increasing annual precipitation trend (Z = +3.22). Indore and Bhopal cities from West Central region showed significant increasing annual trend (Z = +2.01) and non-significant decreasing annual trend respectively. Although, Vadodara and Jaipur are lying in the same Northwest region, the trends are opposite in nature. Jaipur city showed a significant increasing annual pre-monsoon trend (Z = +2.44). The winter rainfall in the city of Vadodara is showing a significant decreasing trend (Z = –2.16). The pre-monsoon rainfall in Bhubaneswar (Central Northeast region) and monsoon precipitation in Trivandrum (Peninsular region) are showing significant increasing (Z = +2.56) and decreasing (Z = –2.71) trends, respectively. A non-significant decreasing trend was seen in Guwahati city (Northeast region). The eight smart cities selected for investigation are not truly representing the entire country. However, the study is clearly pointing towards the regional disparity existing in the country. These findings will be helpful for water managers and policymakers in these regions for better water management.

Key words: *smart city, trend, modified Mann–Kendall (MMK) test, monsoon homogeneous regions, India*

INTRODUCTION

Smart Cities Mission of the Government of India [SCM 2020], a new initiative, is meant to develop the core infrastructure elements in Indian cities, including adequate water supply. The Government has also launched "Jal Jeevan Mission" to ensure water from the tap for each house in villages in the next five years. By 2020, as many as 21 major Indian cities will face water scarcity. Water demand is predicted to increase significantly over the coming decades in the country. India also ranks poorly in the global water quality index. Water resource management plays a vital role in the successful implementation of these missions in India [NITI AAYOG 2018]. These challenges, coupled with vivid climate change impacts in many parts of the country, put further strained on the water resources. With an unpredictable monsoon and rising heat waves, floods and droughts are recurring in nature in India.

As per the Intergovernmental Panel on Climate Change [IPCC 2018] special report on global warming, human activities will likely to cause 1.5°C rise in global mean temperature between 2030 and 2052. The level of the observed warming was ±20% due to the uncertainty effect of solar and volcanic activity during the historical period.

Due to climate change, the hydrological cycle will also be disturbed considerably due to changes in temperature (e.g. CUNDERLIK and OUARDA [2009]; PRANUTHI *et al.* [2014]; PANTHI *et al.* [2015]; KHATIWADA *et al.* [2016]). A changing annual average precipitation will also significantly influence the runoff. More precipitation tends to floods, and less precipitation tends to prolong the dry conditions. Climate change scenarios project an increasingly skewed water supply and demand due to the spatial and temporal variations of water cycle dynamics [GAJBHIYE *et al.* 2016; PINGALE *et al.* 2016; WU, QIAN 2017; YILMAZ, PERERA 2015].

Many researchers conducted studies on climate change with long-term data (e.g. RODRIGO and TRIGO [2007] LIUZZO *et al.* [2016]). These studies indicated that local weather conditions have considerable effects on the increasing or decreasing nature of precipitation and temperature in a region. These impacts are also different for different seasons in a year. The average temperature of India is rising at a rate of 0.05°C per decade during the periods from 1901 to 2003 [KOTHAWALE, RUPA KUMAR 2005]. However, the temperature in the northern parts of the country is falling at the rate of 0.38°C [ABEYSINGHA *et al.* 2016].

According to the CWC [2019] report, the average annual water resource of the Indian basins for the periods from 1985–2015 has been assessed as 1999 billion cubic metres (BCM). The mean annual precipitation of these basins for the same period is 3880 BCM indicating a decline in the mean annual rainfall by 120 BCM. The per capita water availability in India has been estimated approximately to 1367 $m^3 \cdot y^{-1}$ by the year 2031 based on the projected population of 1463 million by the Planning Commission, a decline of 3811 $m^3 \cdot y^{-1}$ since 1951 (361 million population). Therefore, if any changes found in the precipitation trends in the country, it will have a significant effect not only on the availability of surface and groundwater resources of the country, but also in the planning and management of water resources [LACOMBE, MCCARTNEY 2014; ONGOMA, CHEN 2017].

Urban and sub-urban water management aims to create cities that are 24×7 water-secure through efficient use of the diverse water sources available. Climate change and urbanization are key factors affecting the future of water quality and quantity in urbanized catchments. A study by ASTARAIE-IMANI *et al.* [2012], demonstrated that climate change, combined with increasing urbanization is likely to deteriorate the river water quality. Urban flood risk is another challenge and requires proper attention in developing cities. In view of smart city development, the flood risk assessment tool is needed for rainwater management and adaptation to climate change in newly urbanized areas. Further, it is also required location based intelligence system for pluvial flooding risk assessment, identification of stormwater pollutant sources from urban roads, drainage arrangement, soil sealing, urban traffic management [GUERREIRO *et al.* 2017; SZEWRAŃSKI *et al.* 2015; 2018].

When the country is gearing up for the future planning of smart cities, trend studies are crucial to provide useful input for estimating urban flooding. Many researchers studied trend analysis of precipitation in different parts of World including India [ALDRIAN, DJAMIL 2008; BISHT *et al.* 2018; PALIZDAN *et al.* 2015; RODRIGO, TRIGO 2007]. However, there are no studies available on long-term trend analysis of precipitation (annual, seasonal and monthly scale) for the proposed smart cities considering homogeneous monsoon regions across India. Therefore, the main objective of this study is to investigate the monotonic precipitation trends of eight selected cities representing six monsoon homogeneous regions of the country (viz. Indore, Bhopal, Vadodara, Jaipur, Dehradun, Guwahati, Trivandrum, and Bhubaneswar). This is a timely endeavour for proper management of water resources. The precipitation trends were carried out for 118 years (1901 to 2018) using the Modified Mann–Kendall (MMK) test and Sen's slope estimator at annual, seasonal and monthly scales.

MATERIALS AND METHODS

STUDY AREA

India is a large country with diverse climate. Precipitation and its distribution over different parts of the country have a strong influence on agriculture. India mostly receives precipitation during the southwest summer monsoon, which lasts for four months from June to September. India Meteorological Department (IMD) has divided the country into six homogeneous monsoon regions based on the precipitation patterns: (i) Hilly Regions (HR), (ii) Northeast (NE), (iii) Central Northeast (CNE), (iv) Peninsular (P), (v) West Central (WC), and (vi) Northwest (NW) as shown in Figure 1. Hilly regions are non-homogeneous in monsoon precipitation and varies considerably from western to eastern parts of Himalaya. Eight smart cities are selected, one each from four regions (HR: Dehradun, NE: Guwahati, CNE: Bhubaneswar, P: Trivandrum) and two each from remaining regions (WC: Indore, Bhopal, and NW: Vadodara, Jaipur). These cities are one of those fastest-growing cities in India with major industrial activities, and are considered under Smart Cities Mission. All cities are coming under the monsoon region of Asia. Most of the precipitation received in these regions during the months from June to September. The monsoon strikes in the first week of June in the state of Kerala where Trivandrum city is located. By the time, it reaches northern parts of India (Dehradun city), a lag of one month is generally seen. Dehradun and Guwahati lie in the Himalayan region. Jaipur is located in the desert region. Indore-Bhopal represents mid-region. Trivandrum represents Peninsular region.

DATA SOURCE

In this study, daily precipitation gridded datasets were obtained from Indian Meteorological Department (IMD) and National Aeronautics and Space Administration (NASA) power portal (https://power.larc.nasa.gov/) for 115 years (from 1901 to 2015) and 2 years (2016–2018), respectively. IMD has developed a daily precipitation gridded datasets ($0.25^{o} \times 0.25^{o}$) from 6955 networks of

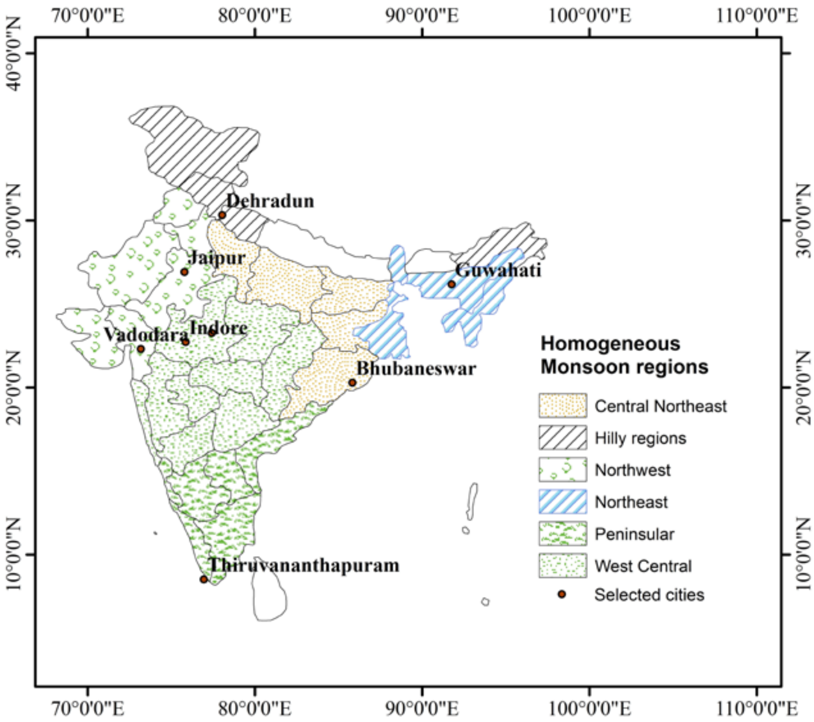

Fig. 1. Location of smart cities across Homogeneous Monsoon Regions in India; source: own elaboration based on MAHARANA and DIMRI [2014] and PATHWATHAN *et al.* [2018]

rain gauge stations spread over in different parts of India. IMD has processed and provided good quality gridded datasets. Further, these datasets were subjected to different quality checks such as consistency, homogeneity and missing data. The daily data were processed to generate monthly data, and then to four prominent seasonal series viz. pre-monsoon (March–May), monsoon (June–Sept.), post-monsoon (Oct.–Nov.) and winter (Dec.–Feb.) before investigating the trends.

STUDY METHODS

In this study, monotonic trend analysis was performed in a time series using a non-parametric rank-based modified Mann–Kendall (MMK) test and Sen's slope estimator. MMK test is distribution-free, and robust against outliers. On the other hand, outliers considerably affect while assessing the magnitude of the possible changes by computing means (moments), linear regression, and other parametric tests. Before the application of non-parametric tests, autocorrelation was tested for the time series to detect the randomness in the data. When a series is of considerable length ($n > 70$), pre-whitening is not required [YUE, WANG 2002]. MMK test is the most appropriate test for the identification of monotonic trends in persistent data and is considered better than other parametric tests [KENDALL 1975; MANN 1945]. It is one of the most commonly used non-parametric trend detection methods (*e.g.* PINGALE *et al.* [2015]). Theil–Sen's estimator has quantified the magnitude of trend and positive and negative values of magnitude showed increasing and decreasing trends, respectively (e.g. DUHAN and PANDEY [2013]; KUNDU *et al.* [2015]).

Autocorrelation. Autocorrelation was used to check any serial dependence, randomness and periodicity in the data [MODARRES, SILVA 2007]. Lag-1 autocorrelation is a normal coefficient of correlation between observations. On the other hand, reverse negative autocorrelation in the series, where the trend is not found. The autocorrelation γ_k for discrete-time series for lag k was calculated as follows:

$$\gamma_k = \frac{\sum_{t=1}^{n-k}(x_t-\bar{x}_t)(x_{t+k}-\bar{x}_{t+k})}{\left(\sum_{t=1}^{n-k}(x_t-\bar{x}_t)^2 \times \sum_{t=1}^{n-k}(x_{t+k}-\bar{x}_{t+k})^2\right)^{\frac{1}{2}}} \qquad (1)$$

Where, $\bar{x}_t$ and $\mathrm{Var}(x_t)$ are considered as the sample mean and sample variance of the first $(n - k)$ values and $\bar{x}_{t+k}$ and $\mathrm{Var}(x_{t+k})$ is the sample mean and sample variance of last $(n - k)$ terms. More, the hypothesis of serial independence was tested by the lag-1 autocorrelation coefficient as M_0: $\mu_1 = 0$ against M_1: $|\mu_1| > 0$ using,

$$t = |\mu_1|\sqrt{\frac{n-2}{1-\mu_1^2}} \qquad (2)$$

Where, the t-test of the statistic is a Student's t-distribution with $(n - 2)$ degrees of freedom if $|t| \geq t_{\alpha/2}$ then the null hypothesis about serial independence was rejected at the significance.

Modified Mann–Kendall test. The MK statistic (S) was estimated by MANN [1945] and KENDALL [1975],

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\mathrm{sgn}\left(x_j - x_i\right) \qquad (3)$$

The analysis of the trend was performed using time series x_i, ranked from $I = 1, 2, 3, \ldots, n - 1$ and x_j which is ranked from $j = i + 1, 2, 3, \ldots. n$. Each data is series x_i which was taken as a reference point and then compared with the rest of other data in x_j, so that,

$$\mathrm{Sgn}(x_j - x_i) = \begin{cases} +1, (x_j - x_i) > 0 \\ 0, (x_j = x_i) \\ -1, (x_j - x_i) < 0 \end{cases} \quad (4)$$

When $n \geq 8$, the statistic S is around normally distributed with the mean $E(S) = 0$.

The variance was given as:

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

Trend Z_c was calculated as:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} \\ 0, S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}}, S < 0 \end{cases} \quad (6)$$

Where, Z_c is a standard normal distribution, the negative or positive value of Z signifies an increasing or decreasing trend. Significant level α is also considered for downward or upward two-tailed trends with 95% level of significance.

Pre-whitening was used to reduce the rate of detection of a significant trend in Mann–Kendall test (e.g. RODRIGO and TRIGO [2007], NASRI and MODARRES [2009], and BISHT *et al.* [2018]). Therefore, a modified trend test was used for trend detection of auto-correlated series. In this study, the autocorrelation between rank and observed values was estimated after subtraction and estimate of a non-parametric trend as Sen's slope estimator. The significant value of the MK test was used for calculation of variance and correlation factor, as the variance of S was underestimated for the positively auto-correlated data:

$$\frac{n}{n_z^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{m=1}^{n-1} (n-k)(n-k-1)(n-k-2) m_k \quad (7)$$

Where, n represents the actual number of observations, and n_z^* represents an effective number of observations to count for the autocorrelation in the data and m_k was considered as the auto-correlated function for the ranks of the observation. The corrected variance was then calculated as:

$$V(S) = V(S)\frac{n}{n_z^*} \quad (8)$$

Where $V(S)$ is from Equation (5). Rest of the procedures in MMK test are adopted the same as in the MK test.

Sen's slope estimator. The magnitude of the trend was calculated by the Sen's slope estimator [SEN 1968]. The slope (S_i) of data pair was calculated as:

$$S_i = \frac{x_i - x_j}{i - j} \text{ for } i = 1, 2, 3, \ldots, N \quad (9)$$

Where, x_i and x_j were considered as data value at the time i and j $(i < j)$, respectively. The median of these N values of T_i is represented as Sen's slope estimator, which is described by:

$$W_i = \begin{cases} S_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(S_{\frac{N}{2}} + S_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \quad (10)$$

Sen's slope estimator was calculated as $W_{med} = T(N+1){:}2$ if N appears odd and it was considered as $W_{med} = [S_{N/2} + S_{(N+2)/2}]{:}2$ if N appears even. At the last of W_{med} was calculated by two-sided test at 100% confidence interval, and then a slope was calculated by the non-parametric test. A positive value of W_i represents an increasing trend, and the negative value of W_i represents a downward trend in the time series.

RESULTS AND DISCUSSION

STATISTICAL ANALYSIS

Trend analysis of the eight proposed smart cities were analysed in this study. A total of 118 years (1901–2018) data of precipitation were considered in investigating the trends using the MMK test and Sen's slope estimator. Basic statistics from all regions represent that Jaipur (NW) has the lowest (581 mm) annual average precipitation followed by Indore (816 mm) and Vadodara (975 mm) which are situated in the western part of India. Trivandrum, representing the Peninsular region with monsoon precipitation occurring early in June, and receives highest mean annual precipitation (2101 mm) followed by Guwahati (1788 mm) and Bhubaneswar (1487 mm). The annual average precipitation of all the cities is presented in Table 1. The box plots

Table 1. Monthly and annual average precipitation over selected smart cities

Month	Precipitation (mm) in city							
	Dehradun	Bhopal	Indore	Jaipur	Vadodara	Guwahati	Bhubaneswar	Trivandrum
Jan.	29.36	9.26	3.50	5.23	1.36	11.70	11.03	20.00
Feb.	29.26	5.84	1.23	6.61	1.05	20.07	24.75	21.23
Mar.	22.55	6.04	2.80	5.04	0.67	50.45	21.62	51.50
Apr.	15.19	3.94	1.35	5.20	1.18	144.87	30.53	156.84
May	24.73	9.30	8.24	12.67	4.79	226.72	84.89	223.30
Jun.	110.15	113.52	123.42	58.91	155.19	325.18	208.97	393.40
Jul.	300.90	363.41	259.25	207.58	367.19	362.40	323.71	291.23
Aug.	299.99	315.26	206.17	175.96	237.60	314.06	333.09	189.89
Sep.	148.11	210.91	162.06	85.45	173.04	203.41	245.15	179.06
Oct.	17.68	18.10	26.76	9.16	19.36	107.73	157.31	313.23
Nov.	6.17	20.24	17.28	5.83	12.93	16.12	42.12	207.19
Dec.	11.08	8.42	4.36	3.84	1.24	5.61	4.20	54.17
Total	1 015.16	1 084.24	816.42	581.47	975.61	1 788.34	1 487.38	2 101.02

Source: own study.

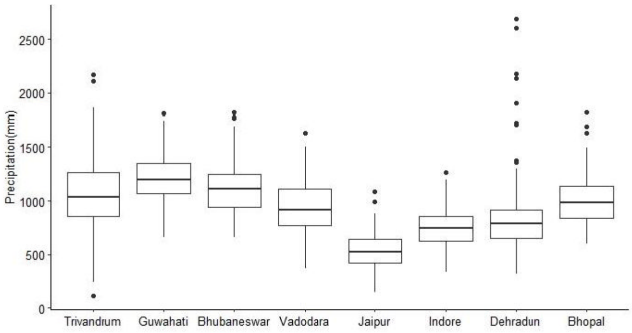

Fig. 2. Box plots of precipitation for selected smart cities; source: own study

showing precipitation of all the eight cities, shown in Figure 2. Dehradun city situated in the Terai region of Himalaya receives an annual average precipitation of 1015 mm. Central India represented by the two cities Bhopal and Indore receives 1084 mm and 816 mm precipitation, respectively.

Figure 3 indicates the time series plot of precipitation received by the eight cities for the periods from 1901 to 2018. Figure 3 also indicates the linear regression trends of the respective time series. The lowest precipitation (425 mm) and the highest precipitation (3603 mm) for the Trivandrum city was recorded in the years 1983 and 1960, respectively (Fig. 3). The linear regression plot for the city was showing a decreasing trend.

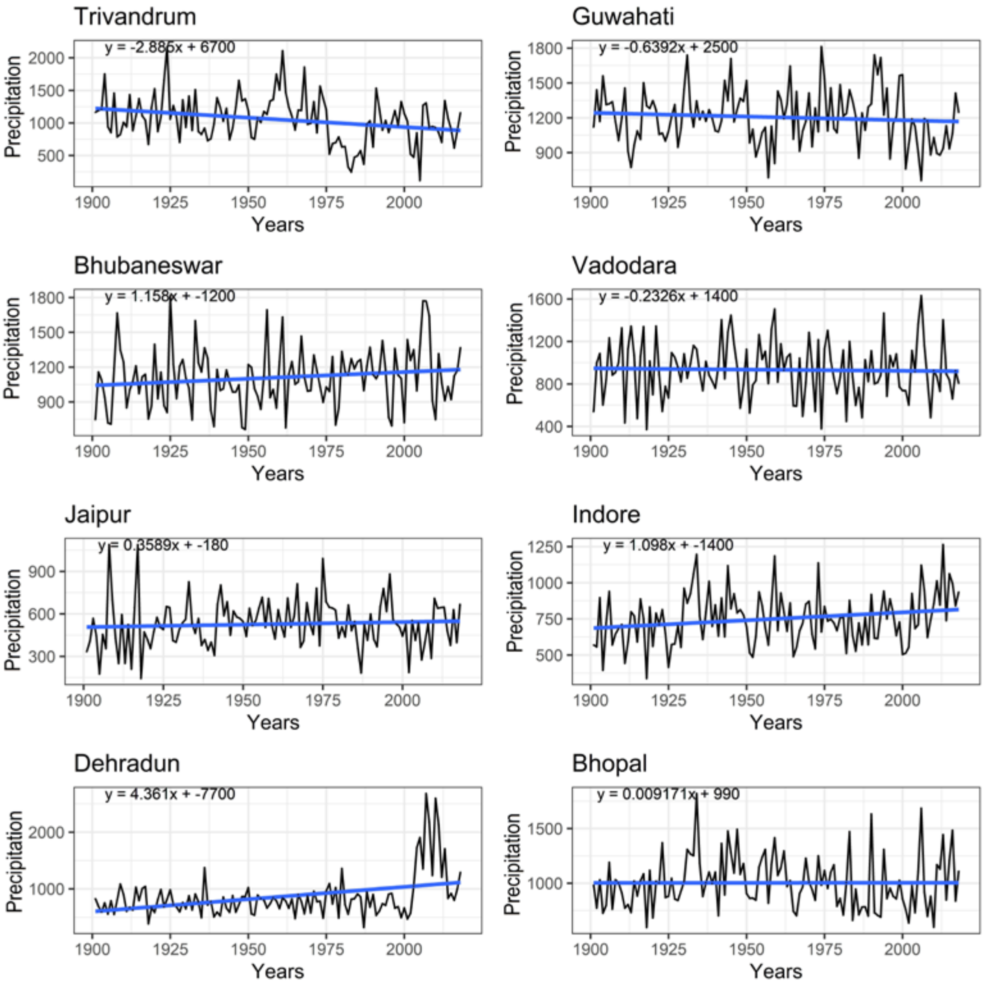

Fig. 3. Time series plots of precipitation of the smart cities with linear regression lines; source: own study

Dehradun is located in the Hilly region in the state of Uttarakhand. The precipitation was mostly received during monsoon. The maximum monthly average precipitation for the city occurs in the month of July and August. Both months receive almost the same monthly average precipitation of 300 mm and 299 mm, respectively. The minimum monthly average precipitation occurs in the month of November (6.37 mm). Maximum annual average precipitation (2940 mm) occurred in the year 2007, and minimum precipitation (460 mm) was recorded in 1987.

Guwahati, representing the Northeast region, receives monsoon precipitation from the last week of June to September. The precipitation records for the city indicated that the lowest (1040 mm) and the highest (2800 mm) precipitation was received in the years 1957 and 1974 respectively. The mean monthly precipitation for the month of July was found to be 362 mm, and lowest (5.61 mm) in the month of December.

Bhubaneswar lies in the Central Northeast monsoon region. The analysis of precipitation data for the Bhubaneswar city indicated that the highest precipitation (2274 mm) was received in the year 1956. The lowest precipitation was recorded in the year 1996 with 844 mm. The average maximum monthly precipitation was observed in the month of August with 420 mm and the minimum monthly precipitation in the month of December (333 mm).

Vadodara is a metropolis city of Gujarat state, located in the Northwest monsoon region of India. It receives most of the precipitation during the four monsoon months (June to September). The remaining months were considered as dry months with very low precipitation. July was the wettest month with an average monthly precipitation of 367 mm, and March was the driest month with least precipitation. The precipitation records further indicated that Vadodara has maximum and minimum annual precipitation range between 1600 mm and 400 mm. It received the highest annual precipitation (1656 mm) long back in 1959. The historical data indicated that in the 1918, the city witnessed its lowest annual precipitation of 390 mm. The regression trend for the city indicates a decreasing trend in the precipitation.

Jaipur is situated in the Rajasthan State, and lies in the Northwest region. It has a hot semi-arid climate. Jaipur is otherwise known as 'Pink City of India', and one of the cities with the highest tourist influx in the country. This part of the country is dry with less precipitation. The city is located at a distance of 475 km from the Thar Desert. The maximum monthly average precipitation was received in the month of July (207 mm) and the least in the month of December (3.84 mm). The annual maximum precipitation (1244 mm) was recorded in 1917, and minimum precipitation (218 mm) was recorded in 1918. The regression analysis for the city indicates an increasing trend in the precipitation.

Indore is the metro city of the West Central region. It receives precipitation mainly during the monsoon months from June to September. Table 1 shows the maximum monthly average precipitation (259 mm) received in the month of July, and the least was received in the month of February. Bhopal is the capital city situated in the central part of India in the state of Madhya Pradesh. It lies in the West Central monsoon homogeneous region. Bhopal usually receives the highest precipitation from June to September. July was the wettest month with a maximum average precipitation of 363 mm, and April was the driest month with precipitation as low as 3.94 mm. From the annual precipitation records, it was revealed that the maximum precipitation (1939 mm) occurs in 2006 and the minimum precipitation (649 mm) witnessed in 1918. There was no significant variation observed in the precipitation trend (Fig. 3).

TREND ANALYSIS

Trend analysis of the eight smart cities representing different monsoon homogeneous regions were carried out using MMK test and Sen's slope estimator. Further, the MK statistics (Z value) were interpolated using the Inverse Distance Weighted (IDW) method [PINGALE *et al.* 2014] to prepare a graphical representation of seasonal precipitation trends across the country (Fig. 4). A schematic showing the increasing and decreasing order of the annual precipitation trends of the selected eight smart cities representing six regions is shown in Figure 5. Most of the precipitation in the country is received during four monsoon months from June to September. The annual precipitation is significantly contributed by the monsoon season. Therefore, in most of the cities, it can be observed that the annual precipitation trend is a reflection of the monsoon trend (Tab. 3).

Dehradun city representing the northern Hilly Region (NR) was showing a significant increasing annual trend ($Z = +3.22$). Similarly, the pre-monsoon trend was also significantly positive ($Z = +4.34$). However, during the post-monsoon and winter season, the city witnessed a decreasing but non-significant trend. The over precipitation trend for the Dehradun city was increasing. In the Himalaya, in the last few decades, the extreme precipitation events like cloud bursts

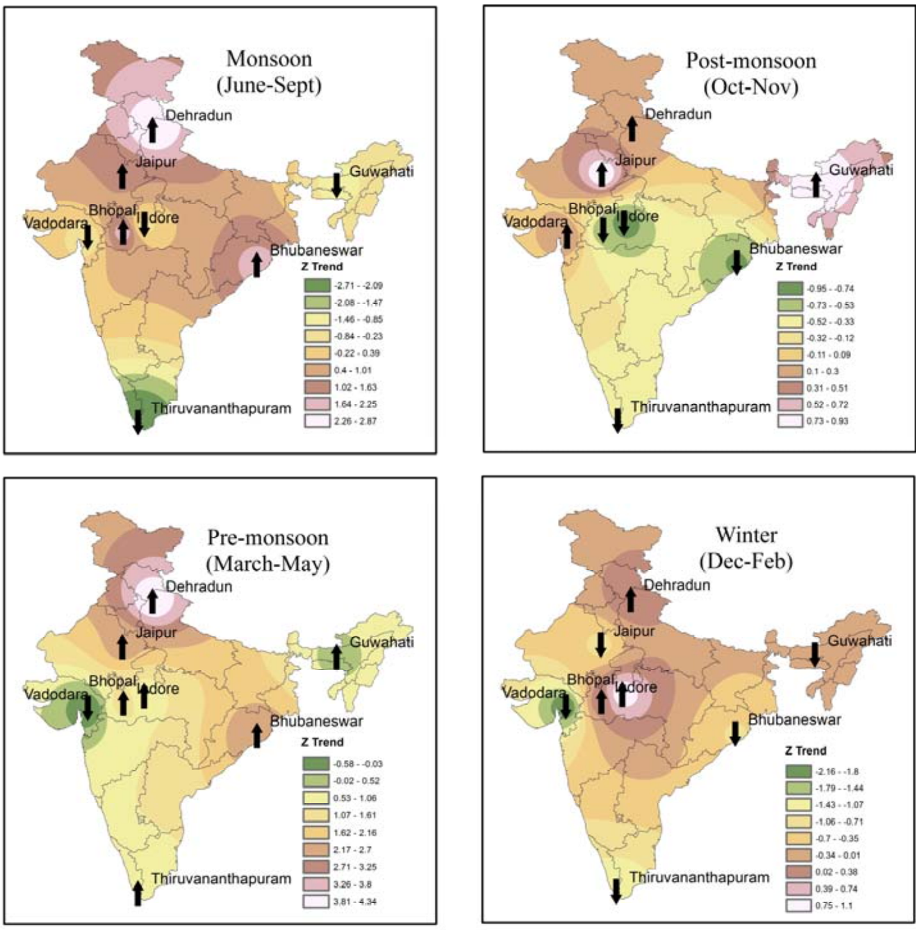

Fig. 4. Z statistics showing seasonal trends of eight cities across India

Table 2. Seasonal statistics of precipitation (mm)

Location	Mean					Standard deviation				
	AN	PM	MS	PS	WT	AN	PM	MS	PS	WT
Dehradun	1015.2	62.5	859.1	23.8	69.7	417.0	39.5	389.2	22.5	37.5
Bhopal	1084.2	19.3	1003.1	38.3	23.5	255.0	22.7	242.8	45.3	23.7
Indore	816.4	12.4	750.9	44.0	9.1	189.8	12.3	179.1	39.5	11.5
Jaipur	581.5	22.9	527.9	15.0	15.7	176.5	19.3	169.3	18.2	12.5
Vadodara	975.6	6.6	933.0	32.3	3.6	271.1	10.6	267.2	41.4	4.8
Guwahati	1788.3	422.0	1205.1	123.9	37.4	331.4	119.5	235.8	104.3	29.9
Bhubaneswar	1487.4	137.0	1110.9	199.4	40.0	300.8	82.8	252.5	147.0	40.0
Trivandrum	2101.0	431.6	1053.6	520.4	95.4	551.1	195.7	357.6	212.1	66.9

Explanations: AN = annual, PM = pre-monsoon, MS = monsoon, PS = post-monsoon, WT = winter.
Source: own study.

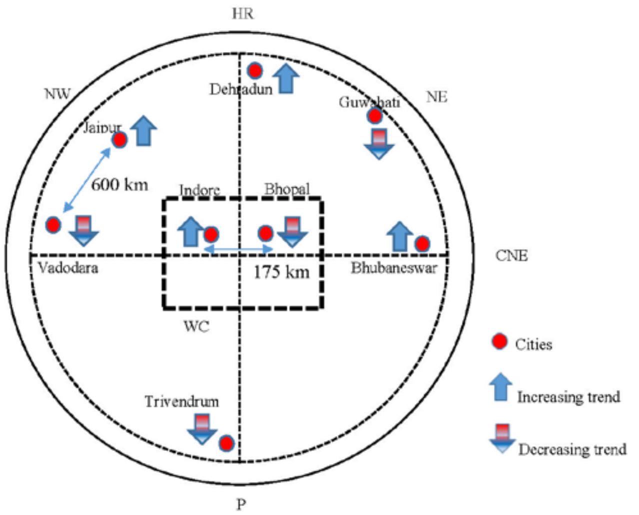

Fig. 5. Schematic showing the trends of eight selected smart cities in different Monsoon Homogeneous Regions; HR, WC, NW, NE, CNE, P as in Fig. 1; source: own study

Table 3. Trend analysis of precipitation as per different seasons and regions

Region	Name	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
HR	Dehradun	**4.34***	**2.87***	0.25	0.33	**3.22***
WC	Bhopal	0.71	–0.53	–0.95	1.10	–0.24
WC	Indore	1.27	**2.00***	–0.66	0.26	**2.01***
NW	Jaipur	**2.44***	1.19	0.92	–0.85	1.69
NW	Vadodara	–0.58	–0.71	0.30	**–2.16***	–0.82
NE	Guwahati	0.37	–1.01	0.93	–0.17	–0.01
CNE	Bhubaneswar	**2.56***	1.82	–0.77	–0.74	1.68
P	Trivandrum	0.66	**–2.71***	–0.53	–1.25	–1.58

Explanations: HR, WC, NW, NE, CNE, P as in Fig. 1; * significant trend at 95% significance level.
Source: own study.

were widely seen. Many researchers (e.g. DAS [2015]) labelled it due to the impact of climate change. The present trend analysis with a significantly increasing (positive) precipitation will further trigger these extreme events in the coming days. The decreasing trend was found in two months of winter, i.e. December and January with Z values of –0.51 and –0.44, respectively. The rest of the months were showing an increasing trend.

Jaipur city representing the Northwest region of the country was showing an increasing monsoon (Z = +2.44) and annual (Z = +1.69) trends. The winter precipitation was decreased in the region. Although, this part of the country is generally, dry with less precipitation. In the last few years, the region witnessed considerable precipitation, especially during the non-monsoon season [PINGALE *et al.* 2014].

Trivandrum representing the southern Peninsular region showed a decreasing monsoon (Z = –2.71) and annual (Z = –1.58) precipitation trends. The monthly trends were also pointing mostly to decreasing trends. Based on the Sen's slope estimate (Tab. 4), the overall annual trend of Trivandrum was found decreasing at the rate of –1.58 and 2.15 mm·y^{-1}. However, the pre-monsoon trend was increasing at 0.28 mm·y^{-1}, and the post-monsoon trend was decreasing at 2.47 mm·y^{-1}.

Table 4. Sen's slope (mm·year^{-1})

Smart city	Value for season				
	annual	pre-monsoon (Mar.-May)	monsoon (Jun.-Sept.)	post-monsoon (Oct.-Nov.)	winter (Dec.-Feb.)
Dehradun	2.53	0.32	1.94	0.01	0.03
Bhopal	–0.14	0.02	–0.31	–0.05	0.04
Indore	1.10	0.03	1.07	–0.04	0.00
Jaipur	0.78	0.09	0.53	0.01	–0.03
Vadodara	–0.62	0.00	–0.55	0.01	0.00
Guwahati	0.00	0.13	–0.71	0.16	–0.01
Bhubaneswar	1.49	0.47	1.24	–0.28	–0.06
Trivandrum	–2.15	0.28	–2.47	–0.32	–0.21

Source: own study.

Guwahati falling in the Northeast region of the country showed a decreasing trend during monsoon and annual scale with Z values of –1.01 and –0.01, respectively. Winter precipitation was also decreasing in the region. However, the post-monsoon was following a non-significant increasing trend (Z = +0.93) [DAS *et al.* 2015]. The overall annual trend of precipitation was slightly decreasing, although not significant. The monthly trend analysis provided a mixed trend of 6 months increasing and 6 months decreasing trend. August has the most decreasing trend (Z = –1.94) – Table 5.

Bhubaneswar is located in the Central Northeast region of homogeneous monsoon region. It is in the eastern coastal plains (Bay of Bengal), along the axis of the Eastern Ghats Mountains. The annual precipitation trend for the Bhubaneswar city was found to be increasing with a Z value of +1.68. The monsoon precipitation trend was also pointing towards an increasing trend. The pre-monsoon

Table 5. Monthly trend (MK statistics, Z) of selected smart cities

Month	*Z* value for city							
	Dehradun	Bhopal	Indore	Jaipur	Vadodara	Guwahati	Bhubaneswar	Trivandrum
Jan.	–0.51	0.47	0.68	–0.72	–1.65	–0.11	0.76	–1.03
Feb.	1.61	0.65	0.00	0.13	–1.76	–0.17	–1.67	–0.59
Mar.	2.12*	1.70	1.28	1.27	–0.17	0.09	1.96	0.59
Apr.	1.79	0.38	0.67	1.45	–1.03	0.21	3.01*	1.11
May	2.71*	0.53	0.69	2.29*	–0.21	0.14	1.14	–0.18
Jun.	1.70	1.10	0.05	1.90	–0.39	0.00	0.50	–3.83*
Jul.	2.89*	–0.54	0.56	–0.10	–1.27	–0.65	0.88	–3.21*
Aug.	2.47*	1.79	3.74*	1.47	1.72	–1.94	1.96	–1.16
Sep.	1.84	–3.01*	–0.78	–0.27	–0.22	–0.23	1.12	0.31
Oct.	0.46	0.79	0.71	0.90	0.77	0.98	–0.43	–1.00
Nov.	0.10	–1.92	–1.77	0.01	–0.61	–0.23	0.78	0.69
Dec.	–0.44	–0.71	–0.70	–1.07	0.00	0.85	0.15	–0.80

Explanation: * indicate significant trend at 95% significance level.
Source: own study.

precipitation trend (Z = +2.56) was significantly increased in the region. This may be due to the occurrence of increasing numbers of summer cyclones in the region. One such cyclone namely "Cyclone Fani" made landfall near Puri, Odisha on 3rd May 2019, and turned into an "extremely severe cyclonic" storm. Pre-monsoon cyclones occur regularly, but they do not have much impact, but extremely severe cyclonic storms like Fani are rare in this season. However, post-monsoon cyclonic events are regularly occurred in the region, causing large-scale devastation. PATRA *et al.* [2011] also indicated an increasing post-monsoon precipitation over the state of Odisha during the years 1871–2006.

North-West city Vadodara was following negative trends for most of the months in a year. Only August was shown a positive trend (Z = 1.72). Negative trends found for January, February, April, and July with Z values of –1.65, –1.76, –1.03 and –1.27, respectively. The overall annual precipitation trend was decreasing (Z = –0.82). Trends for pre-monsoon and monsoon were also found to be decreasing with Z values of –0.58 and –0.71, respectively. The winter trends (Z = –2.16) were significantly decreasing in the region. North-West part of the country receives less precipitation. Therefore, a further decrease in the winter and post-monsoon precipitation will bring additional moisture stress into the region.

The monthly trend analysis for the Indore city indicated decreasing trends in the case of four months viz. January, July, September, and December in a year. The rest of the months in the year were found an increasing (positive) trend. The seasonal trend analysis confirmed an increasing trend during pre-monsoon, monsoon, and winter with Z values of 1.28, 2.01 and 0.27 respectively. The post-monsoon trend was decreasing (Z = –0.67). The overall annual precipitation was indicated a significant increasing trend (Z = 2.01) for the city. The city of Bhopal was shown non-significant decreasing trends in the case of annual and monsoon series with Z values of –0.24 and –0.53, respectively. However, the winter series was indicating an increasing trend, although not significant. A study conducted by KUNDU *et al.* [2015] also obtained non-significant decreasing annual precipitation trend for the Bhopal city. Region wise MK Z statistics are also shown in Figure 6. Finally, the findings of this study is vital for water policy-makers, especially for administration engaged for city planning. It provides valuable input whether the amount of precipitation will increase or decrease in future. An increasing precipitation trend suggests for proper management of water resources in the regions. In contrast, cities with decreasing precipitation trends are required to foresee looming water crisis to take timely interventions in future.

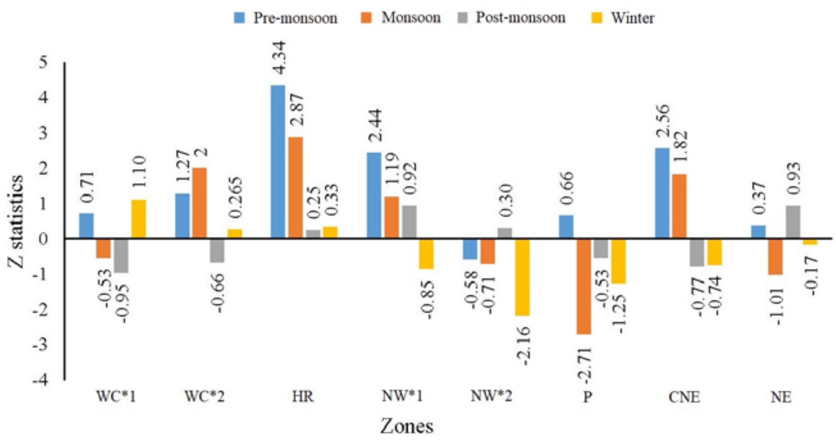

Fig. 6. MK (Z) statistics of smart cities located in different regions; WC*1 = West Central (Bhopal), WC*2 = Indore, HR = Hilly Regions, NW*1 = Nortwest (Jaipur), NW*2 = Vadodara, P = Peninsular, CNE = Central Northeast, NE = Northeast; source: own study

CONCLUSIONS

The trend analysis is a valuable tool to investigate the behaviour of historical data. The parametric trend analysis (linear regression) often misconstrued the trends due to the presence of outliers in a series. However, non-parametric trend analysis methods such as the MK test, MMK test are robust and not affected by the outliers. Government of India is recently launched many ambitious water management action plans like Smart Cities Mission, Jal Jeevan Mission, etc., which will result in increased water demands. Climate change will also add additional pressure on the water resources of the country. The present study is undertaken to perform monotonic precipitation trend analysis for eight smart cities across India (i.e., Indore, Bhopal, Vadodara, Jaipur, Dehradun, Guwahati, Trivandrum, and Bhubaneswar) drawn from different monsoon homogeneous regions in view of the Smart Cities Mission by the Government. Many Indian cities are already witnessing water deficit during the summer season. Therefore, any increase or decrease in the precipitation pattern for these cities will have significant effects on the availability of water. Therefore, precipitation trend analysis for these cities were carried out using the MMK test and Sen's slope estimator at annual, seasonal and monthly scales. The trend analysis was carried out for 118 years (from 1901 to 2018) at 95% significance level. Out of eight smart cities identified for trend analysis, the city of Dehradun (HR) and Indore (WC) showed a significant increasing trend with Z values +3.22 and +2.01, respectively. Jaipur (NW), Bhubaneswar showed a significant increasing annual precipitation trend. The remaining four cities viz. Bhopal (WC), Vadodara (NW), Guwahati (NE), and Trivandrum (P) showed non-significant decreasing annual precipitation trends. The seasonal trend analysis gives a different picture of these cities. The monsoon trends in case of Dehradun and Indore were showing a significantly increasing trend whereas a significant decline in precipitation trend was observed for the Trivandrum city. Summer precipitation was found to be increasing in all the cities except Vadodara. A significant decreasing trend was also found for the Vadodara city for the winter series. Significant increasing trends were found for the pre-monsoon series in the case of Dehradun, Jaipur, and Bhubaneswar. The eight smart cities selected for investigation are not truly representing the entire country. However, the study is clearly pointing towards the regional disparity in the precipitation trends existing in the country.

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