Trans. Inst. Indian Geographers
ISSN 0970-9851
Indexed in Scopus

# Assessment of the long term change in climatic variables and future prediction using coupled statistical-machine learning techniques for Haryana, India

Manish Kumar, Haryana; Swati Thakur*, New Delhi; Ankur Yadav, Haryana; Akash Tiwari, Haryana; Tamanna, Haryana and Dinesh Kumar Tripathi, Uttar Pradesh

## Abstract

*Rainfall characteristics are exceedingly important in water availability affecting agriculture and the economy at a regional scale. The state of Haryana is facing the brunt of lower water availability and a reduced supply of water for irrigation. The present study investigated long term spatiotemporal rainfall trends (1901 - 2020) during different seasons for Haryana using gridded rainfall data from the India Meteorological Department. Mann Kendall Test (MK) and Sen's slope are used to calculate the magnitude of change. It was observed that the western part of the state experienced a significant decrease in annual rainfall in sharp contrast to its eastern counterpart that shows an increase. Over 82 percent of the districts received decreasing rainfall during the monsoon while pre-monsoonal rainfall recorded a significant increase. The predicted rainfall by 2050 is further to decrease by 3.13 percent along with the increase of mean temperature to 1.13 degrees during 2020 to 2050. The reduction is much higher in monsoon with potential impact on kharif cropping.*

**Keywords:** *Rainfall trend, parametric test, spatial variation, machine learning, artificial neural networl*

## Introduction

The key aspect of climate change is centered on the magnitude, frequency and amplitude of the changing condition. In recent years there has been significant change in precipitation pattern, intensity and magnitude across the globe due to climate change and its variability (Gergis & Henley 2017; Talae, 2014). During 1901 to 2019 India experienced a 1.0°C increase in temperature as per the India Meteorological Department (IMD). There has also been a decreasing trend in rainfall of 0.04 mm/year and an increasing trend in the annual average temperature of 0.003°C/year (Mondal *et al.* 2015) along with a significant shift in the arrival of southwest monsoon (Pal and Al-Tabbaa 2009). Rainfall has become more uncertain along with amplified frequencies of extreme weather events including heavy rainfall, floods, cloud bursts and draughts (Dore 2005; Nikumbh *et al.* 2019). The uncertainty of southwest monsoon influences the fate of the entire economy (Vishwa *et al.*, 2013) affecting the socio-economic conditions, biodiversity, agriculture and ecosystem (Handmer *et al.* 2012).

Studies on precipitation dynamics and climatic variability due to climate change at the global scale are many and varied (Mcquate & Hayden 1984; Partal & Kahya 2006, Cinco *et al.* 2014; Akinsanola *et al.* 2019). No less important are the local and regional scale studies which have improved our understanding of the spatio-temporal dynamics of rainfall (Joshi & Rajeevan 2006; Guhathakurta & Rajeevan 2008; Pal & Al-Tabbaa 2010; Sanikhani *et al.* 2018; Gajbhiye *et al.* 2016). Consequences of climate variability and global warming over the past century have been noted in terms of increasing drought and declining rainfall events by several scholars (Gizaw & Gan 2017; Cook *et al.* 2018; Dai *et al.* 2018).

Haryana ranks high among the states of India for agricultural production predominantly producing paddy as summer crop and wheat as winter crop. The declining groundwater tables at a mean rate of 4.0±1.0 cm/year over the past decades (Chaudhuri & Roy, 2016) pose serious challenges to the availability of water for irrigation to all the regions in Haryana. It is imperative therefore to understand the changing rainfall patterns in the state for optimal use of the water resources in diverse regions. It is also equally important for diligent preparedness during times of water scarcity and adverse weather conditions like droughts. With this broad aim, the objective of this study is (i) to examine the long-term seasonal and annual rainfall trend for 120 years (1901-2020) for Haryana and (ii) to predict its regional distribution for 2021-2050.

## The study area

The Haryana state comes under Agro-Climatic Zone VI in the Trans-Gangetic Plain region as classified by the National Commission on Agriculture 1971. With only 1.34 percent geographical areas of the country and located in a semi-arid climatic regime, the state contributes 3.86 percent to India's Gross Domestic Product (GDP). The share of the primary sector in the GSDP is 19.6 percent (Press Release, 23rd February 2023, CM office, Haryana https://haryanacmoffice.gov.in/23-february-2023#). Administratively the state is located between 27° 37' N to 30° 35' N latitude and 74° 28' E to 77° 36' E longitude (Fig. 1) and has altitudinal variations ranging from 700ft to 3600ft from msl. The rainfall with a mean annual average of 560 mm, ranges from less than 300 mm in the south-west to over 1000 mm in hilly tracts of Shivalik hills. The state predominantly lies in the temperate zone. The state enjoys a sub-tropical monsoon continental climate with hot summers and cold winters according to the Koeppen-Geiger classification. The average annual temperature is 24.8°C which rises up to 45°C in summers while the minimum temperature in winters goes down to 2°C. Monsoon is important for autumn harvest with an 80 percent share of total rainfall whereas the extra-tropical weather phenomena associated with western disturbances are important for spring harvest.

Haryana is a water deficit state both in surface and groundwater. Overexploitation of groundwater resources coupled with a decline in the water table due to poor recharge is a serious concern in certain parts of Haryana.

## Data and methods

### *Data base*

Monthly and annual rainfall data for the period 1901-2020 were obtained from India Meteorological Department (IMD, Pune) and the annual temperature data from the Climatic Research Unit (CRU) Google Earth Download (crudata.uea.ac.uk) and CRU TS VERSION 4.04 cruts_4.06_gridboxes.kml with the help of Google Earth Engine (GEE) of Haryana State for the period 1901-2019. Annual and seasonal pattern of rainfall was examined with reference to IMD based inter-seasonal spread of rainfall as pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November), and winter (December to February). The spatial attribute data were obtained from the Landsat data and elevation was extracted from Bhuvan Portal using Carto DEM version-1 with 16 tiles latitude 74°E to 77°E and longitude 27°N to 30°N.

## Non-parametric test analysis

### *Mann Kendall trend analysis and Sen's slope estimator*

The Mann-Kendall (MK) test detects the trend in the data series to any sudden changes. To detect the trend, it is necessary to check the availability of serial correlation in the data series (Wu *et al.* 2013). The following equation was followed:

$$\mathrm{S} = \sum_{m=1}^{n-1} \sum_{l=m+1}^{n} sgn(x_l - x_m)$$

$$\mathrm{sgn}\ (x_{l\,\_}\ x_m) = \{+1, if(x_l -\ x_m) > 0\ 0,$$
$$if(x_l -\ x_m) = 0\ -1, if(x_l -\ x_m) < 0$$

Where n represents the length of the sample. $x_l$ and $x_m$ are from l=1, 2,…, n-1 and m= l+1, …, n respectively. For a normal distribution when *n* is less than or equal to 8, S is normally distributed and the variance of S is:

V (S) =[n(n−1)(2n+5)−∑mi=1Tii(i−1)(2i+5)] /18

where $T_i$ is the number of data in the tied group and $m$ is the number of groups of tied ranks.

Z-statistics follows with the equation:

$$\mathrm{Z} = \{\frac{S-1}{\sqrt{var(S)}}, if\ S > 0\ 0, \quad if\ S > 0\ \frac{S+1}{\sqrt{var(S)}}, if\ S < 0$$

The value of Z, if greater than 0 is an indicator of increasing trend. At the 95 percent confidence limit, if the value of Z is greater than α (0.05), any trend is denied whereas a value higher than the α is where the trend exists.

Sen's slope (SS) estimator is used to calculate the magnitude of the trend (Sen 1968).

$$SS = \frac{1}{n} \sum_{i=1}^{n} \frac{10(y-x)}{n}$$

Where SS indicates the trend having positive and negative values, n represent the number of the collected data product.

### *Rainfall forecasting*

The complexity of rainfall data in terms of its non-linearity makes rainfall forecasting difficult to predict (Darji *et al.*, 2015). The use of Artificial Intelligence models (ANN) has widely been used by researchers based on wireless technologies and the Internet of Things (IoT) capable of handling large datasets (Liu et.al, 2019a; Mishra & Sharma 2018). The artificial neural network model is applied in this research to forecast and predict climate variability for meteorological stations. This AI model uses a parallel information distribution system to set up connections between input and output information. It works with a three layer structure including

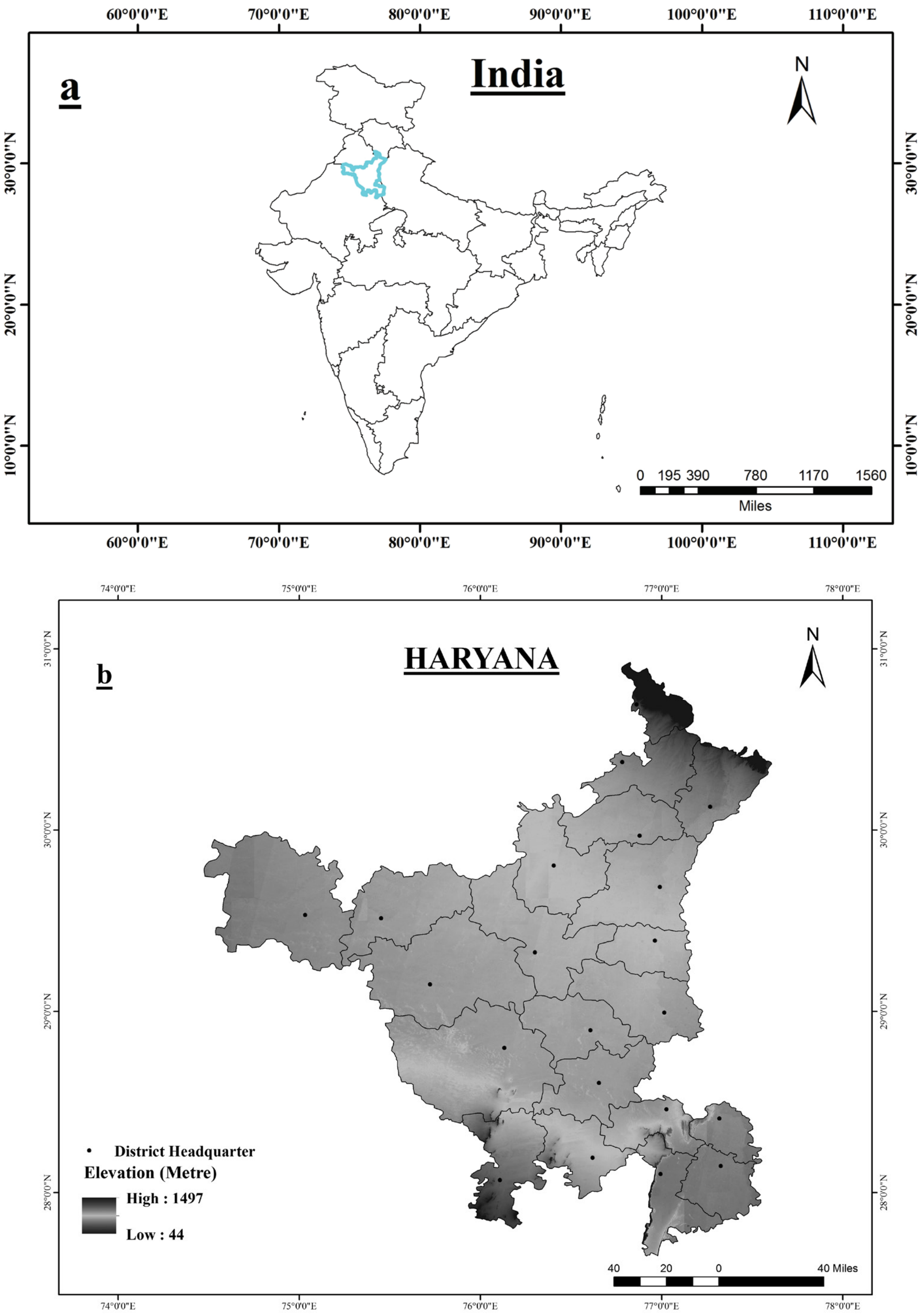


Fig. 1: Location of the study area.

input, output and hidden layer structures using a perception algorithm. On the basis of the trial and error method, the neurons are chosen which can further use neural network typologies (Multi Layer Perception) for pattern classification. The layer characterized as such is capable of feeding the other layers. The back propagation algorithms used by Multi Layer Perception (MLP) is capable of detecting unseen error and their adjustments (Samantaray, et.al 2020).

The study divides the climate variable dataset into training and testing sets and ANN was run several times which changes in momentum and learning rates. The best result obtained by comparing root mean square error was fixed and later used to forecast the variable up to 2050. The entire procedure has been adopted from a study of Praveen *et al.*,(2020). The open source software (https://weka.informer.com/3.9/) was used for forecasting and the mapping was done based on the interpolation kriging method using ArcGIS 10.3.

## Results and discussion

### *Descriptive analysis of annual rainfall*

The average annual rainfall calculated for 120 years is 565 mm though extremely uneven both temporally and spatially (Table 1) ranging from 332 mm to 1328 mm across the meteorological stations. Figure 2 shows that three stations in the foothills of the Shiwalik hills in the northern region registered high average annual rainfall of 1050 mm to1330 mm while stations those in the south and south-west like Sirsa (332mm), Fatehabad (379mm) and Mahendergarh (468mm) received the lowest. The standard deviation ranged between 127 mm to 300 mm. The highest SD was recorded in Panchkula (300.19 mm) followed by Yamunanagar (298.02 mm) while Sirsa (127.7 mm), Hisar (145.73 mm) and Bhiwani (148.13mm) had the lowest values. The positioning of monsoon troughs has always been detrimental to the rainfall pattern in India (Pai *et al.* 2011). Furthermore, the fluctuations in rainfall have much wider implications for agricultural decisions.

The Coefficient of Variation (CV) exhibits a similar pattern of high variations in lower altitude southern districts like Fatehabad and Mahendragarh ranging from 39 percent to 68 percent, while, the northern upland (Panchkula 22.59%, Yamunanagar 25.14%) have lower variations (Fig. 3). Kumari & Rai (2021) found variations between 42 percent to more than 80 percent for the period 1980-2017 in southern Haryana. The skewness value is 0.425 indicating a greater number of larger variation values whereas kurtosis was less than 1.

The monsoon contributes around 82 percent of the annual rainfall of the region followed by post-monsoon season. The post-monsoon months experience (Fig. 3) maximum variability in the amount of rainfall in the western (Karnal, Panipat, and Yamunagar) followed by central and southeastern districts of Rohtak, Faridabad, and Palwal. However, higher rainfall variability is also evident in the winter season in northwestern (Sirsa) and southern districts (Bhiwani and Rewari). These observations necessitate proper planning in the management of water during *rabi* season. Lower rainfall variations in CV (less than 30%) have a continuum in the districts of Nuh, Palwal, and Mahendragarh in the south and Ambala and Panchkula in the extreme north. Adjacent districts of Kaithal, Karnal, and Sonipat also have lower variability in comparison to other parts of the state.

Table 1: Annual rainfall, standard deviation, and coefficient of variation district-wise (1901-2020)

| Station | Rainfall (mm) | SD (mm) | CV (%) |
|---|---|---|---|
| Kaithal | 547.96 | 165.98 | 30.33 |
| Rohtak | 517.96 | 170.59 | 32.93 |
| Gurgaon | 588.18 | 178.79 | 30.4 |
| Mahendragarh | 468.29 | 172.48 | 36.83 |
| Sirsa | 332.06 | 127.7 | 38.46 |
| Palwal | 553.18 | 196.07 | 35.44 |
| Rewari | 530.51 | 165.67 | 31.23 |
| Ambala | 1066.33 | 281.33 | 26.38 |
| Faridabad | 626.45 | 209.19 | 33.39 |
| Panipat | 644.2 | 207.95 | 32.28 |
| Panchkula | 1328.86 | 300.19 | 22.59 |
| Karnal | 690.11 | 188.07 | 27.25 |
| Fatehabad | 379 | 147.05 | 38.8 |
| Jhajjar | 503.69 | 176.27 | 35 |
| Kurukshetra | 773.25 | 206.13 | 26.66 |
| Hisar | 427.3 | 145.73 | 34.1 |
| Bhiwani | 424.74 | 148.13 | 34.88 |
| Jind | 487.35 | 155.24 | 31.85 |
| Yamunanagar | 1185.58 | 298.02 | 25.14 |
| Sonipat | 601.35 | 172.92 | 28.76 |
| Mewat | 554.4 | 178.38 | 42.17 |

*Source: Calculated by the author from IMD data*

The whisker plots for the seasonal variation across the districts (Fig. 4) indicate that the data set during post-monsoon (b) and pre-monsoon (c) months have a large number of outliers indicating more erroneous values in the data set indicative of variation from the mean value. Three stations including Panchkula, Yamunagar and Ambala indicate lower variations in both seasons. The monsoon months (Fig. 4a) have longer whiskers and box plot indicating higher rainfall and spread of variability with the quartiles than any other seasons. Still, the variation in 3 districts namely Yamunagar, Ambala and Faridabad is high. The rainfall deficit of (-29%, -43%, and -34%) from normal in 2022 (Oct 23rd, 2022 https://mausam.imd.gov.in/chandigarh) amidst excess rainfall in 60 percent of the state is one of the testimonies to this observation. A crescent like belt covering about 35 percent of the total area of the state in northeastern, western and southeastern districts continues to exhibit large variations. Winter months (Fig. 4a) indicate the variation of consistency across the districts having small whiskers with the exception of Kurukshetra and Ambala.

### *Trends in rainfall*

Seasonal and annual rainfall trends for meteorological stations using the

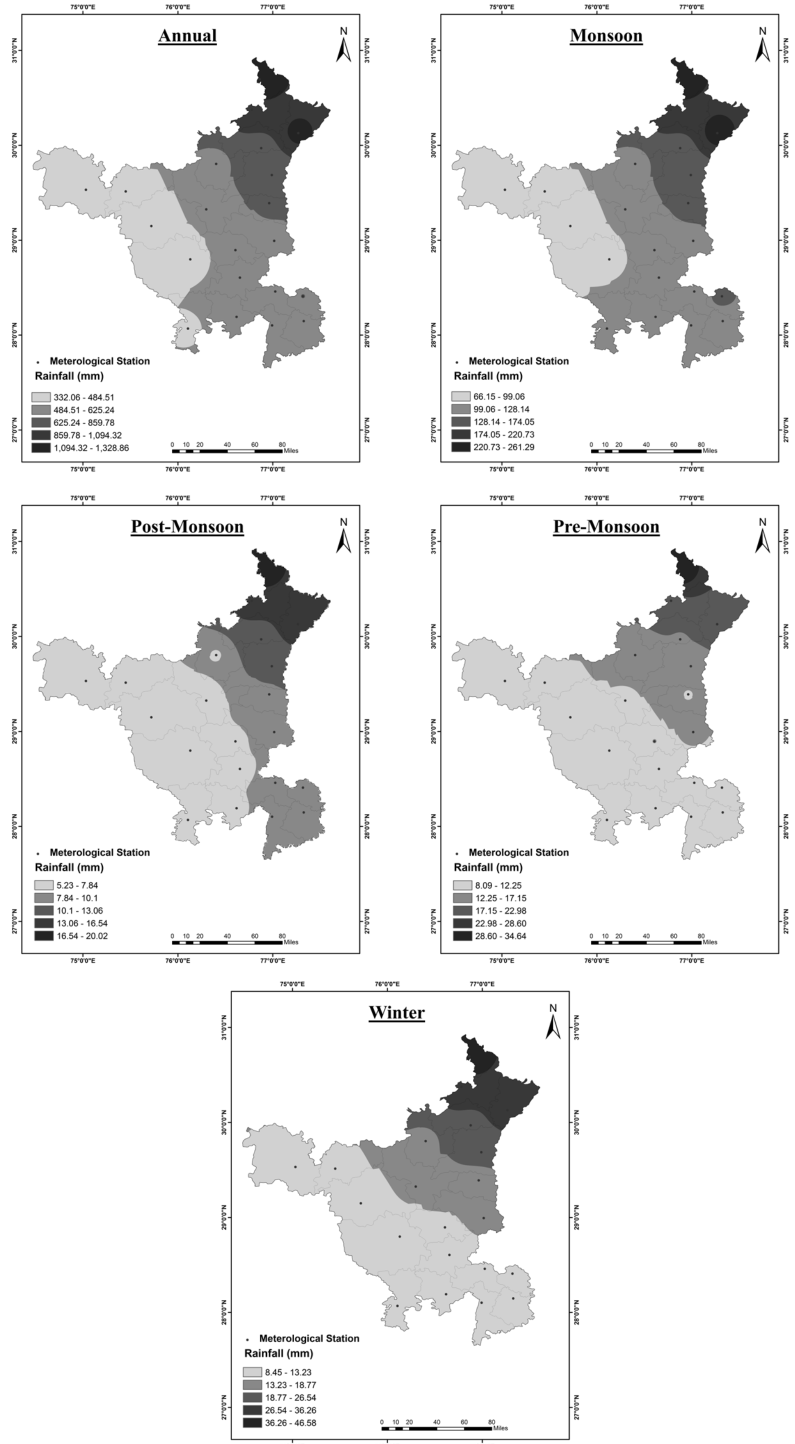


Fig. 2: Mean rainfall distribution (a) Annual, (b) Monsoon, (c) Post-Monsoon, (d) Pre-Monsoon and (e) Winter

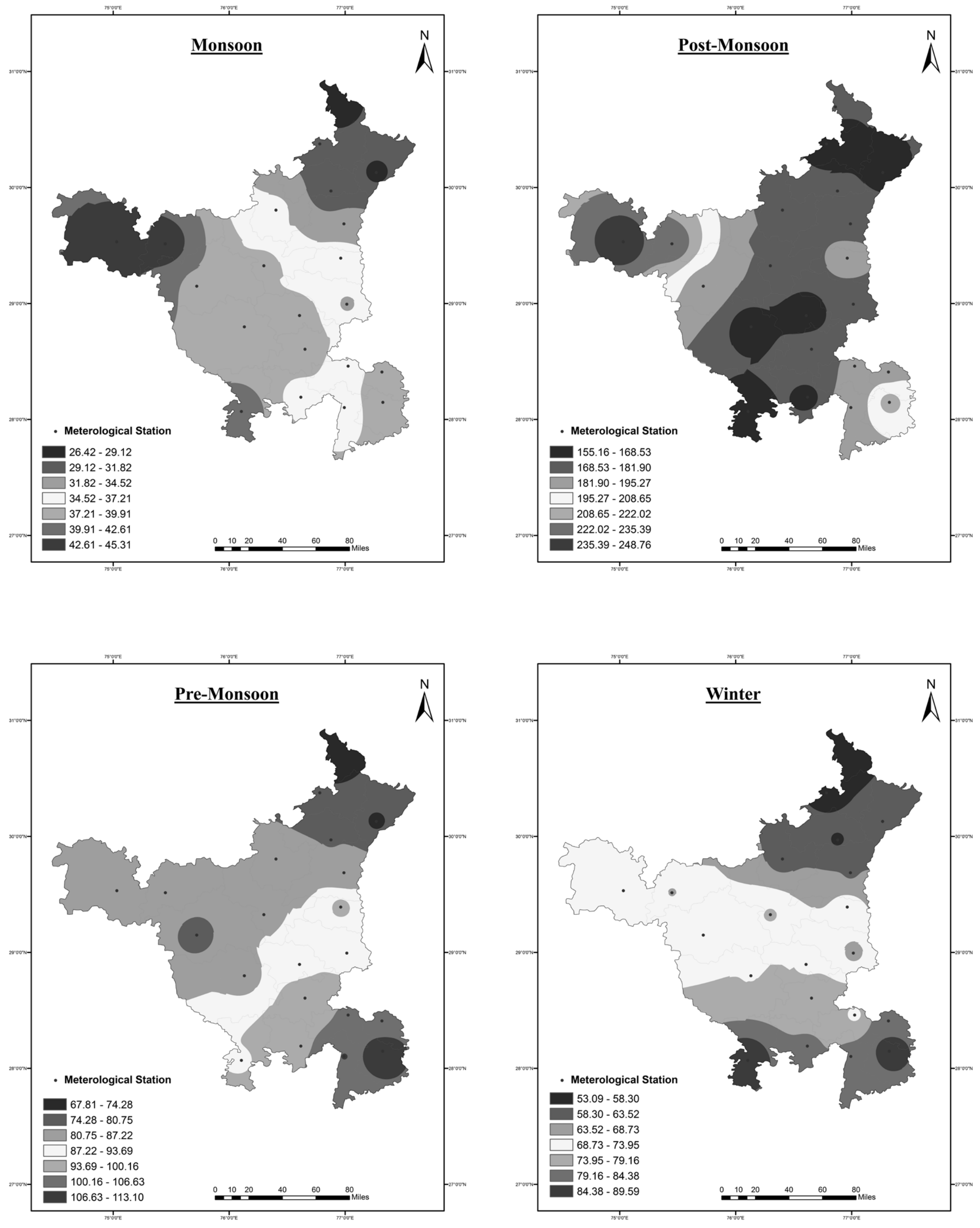


Fig. 3: Spatial mapping of coefficient of variation (CV) for seasonal rainfall of Haryana (1901-2021). (a) Monsoon. (b) Post Monsoon, (c) Pre-Monsoon and (d) Winter

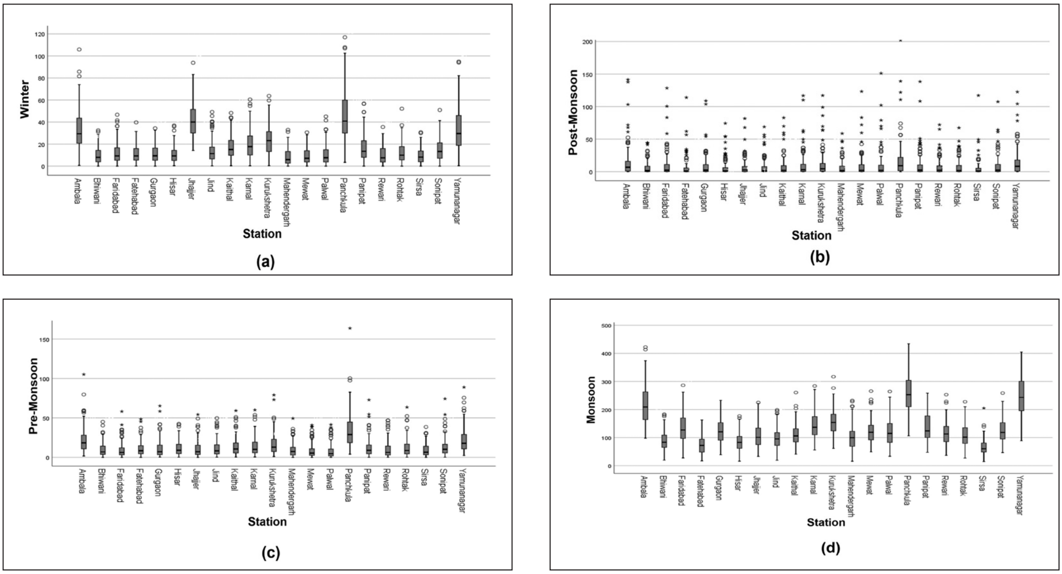


Fig. 4: Box-Whisker Plot of seasonal rainfall in mm (a) Winter (b) Post-monsoon (c) Pre-monsoon (d) Monsoon

Non-Parametric Mann-Kendall test are shown in Table 2 whereas the Sen's slope estimator represents the magnitude of annual and seasonal rainfall (1901-2021). The results indicate that the Tau's value for most of the districts across the season is less than that of α value (0.05) reflecting the existence of a trend in the series. Pre-monsoon season shows higher value exhibiting variations but no significant trend as such. The negative values for monsoon months in 15 of the districts in the state demonstrate 68 percent of the area with a decrease in the total amount of monsoon rainfall in 120 years of observation.

With the exception of Gurgaon (0.08), all the other districts show negative trend values depicting a decrease in rainfall challenging the *rabi* cropping in the state. Equally evident is the trend of winter months with all the districts in negative value denoting a decrease in non-monsoon rainfall. The districts in the southern and northwestern parts of the state exhibit a significant decreasing trend in monsoon months (Fig 5).

To study the annual and seasonal intensity of the trend, the Sen Slope trend test (1901-2020) is performed (Table 3). As shown in Fig 6, the annual rainfall trend is negative, less than the value of α (0.05) in six out of 21 stations in the state, with no significance at a 95 percent confidence level. Although, the negative trend implies that the rainfall has decreased, but the magnitude (mm/year) is insignificant except in the case of Kaithal, Panipat, Sirsa and Jind. Post-monsoon season shows an increase in rainfall with positive values but the magnitude of change was negligible.

The spatial distribution of changes in rainfall characteristics reveals that the decline is from the west to the southern region. On a seasonal account, monsoon rainfall decline is prominent in the alluvial plain covering Ambala, Yamunagar, Kaithal and the northern part of Rohtak which poses a serious concern

Table 2: Results of Mann-Kendall (Tau Value) for seasonal and annual rainfall (1901-2020)

| Station | Annual | Pre-Monsoon | Monsoon | Post-Monsoon | Winter |
|---|---|---|---|---|---|
| Palwal | -0.176 | 0.094 | -0.147 | -0.031 | -0.105 |
| Gurgaon | 0.012 | 0.102 | 0.017 | 0.08 | -0.092 |
| Panchkula | -0.061 | 0.153 | -0.093 | -0.019 | -0.015 |
| Kurukshetra | 0.01 | 0.117 | 0.023 | -0.032 | -0.062 |
| Fatehabad | -0.034 | 0.055 | -0.038 | -0.013 | -0.037 |
| Jind | -0.046 | 0.081 | -0.065 | -0.024 | -0.041 |
| Yamunanagar | 0.071 | 0.184 | 0.052 | -0.047 | -0.034 |
| Mahendergarh | -0.01 | 0.176 | -0.015 | -0.015 | -0.059 |
| Kaithal | 0.006 | 0.081 | 0.015 | -0.026 | -0.02 |
| Panipat | -0.166 | 0.058 | -0.093 | -0.047 | -0.067 |
| Rewari | 0.028 | 0.116 | 0.027 | -0.029 | -0.083 |
| Sonipat | -0.051 | 0.095 | -0.047 | -0.038 | -0.078 |
| Hisar | -0.057 | 0.081 | -0.059 | 0.025 | -0.09 |
| Ambala | 0.135 | 0.165 | 0.113 | -0.02 | -0.023 |
| Faridabad | -0.15 | 0.039 | -0.142 | -0.013 | -0.147 |
| Bhiwani | 0.002 | 0.117 | -0.011 | -0.003 | -0.081 |
| Jhajjar | 0.007 | 0.101 | -0.001 | -0.009 | -0.099 |
| Mewat | -0.142 | 0.088 | -0.177 | -0.046 | -0.159 |
| Rohtak | 0.012 | 0.128 | -0.002 | 0 | -0.085 |
| Karnal | -0.098 | 0.07 | -0.093 | -0.05 | -0.058 |
| Sirsa | -0.011 | 0.075 | -0.038 | 0.052 | -0.051 |

for the agricultural sector. Post-monsoon variability is more in Aravali outliers and the Shiwalik zone. Widespread negative slopes across the state reveal a declining trend and hence a forecast to unveil the future pattern is pertinent.

### *Mean temperature pattern and linear trend*

Changes in temperature do impact the water equilibrium and hence agro-economic condition of an area. The mean annual temperature of the entire state for a period of 120 years shows an increasing trend as depicted in Fig 7. The seasonal variation is prominent for post-monsoon and winter months with a higher $R^2$ - value.

### *Climatic variables forecasting*

An increase in temperature affects several climatic variables like water holding capacity further affecting microclimatic conditions at the local scale. The regional distribution must be explored in order to fully explore the pattern and prediction of the diurnal range of temperature. It is evident from Fig 8 that there has been a rise of 0.7°C in mean annual temperature in the last 120 years. The increase (1.13°C) is likely to be even more conspicuous in the recent bloc of 30 years (2020-2049) at a 95 percent confidence level.

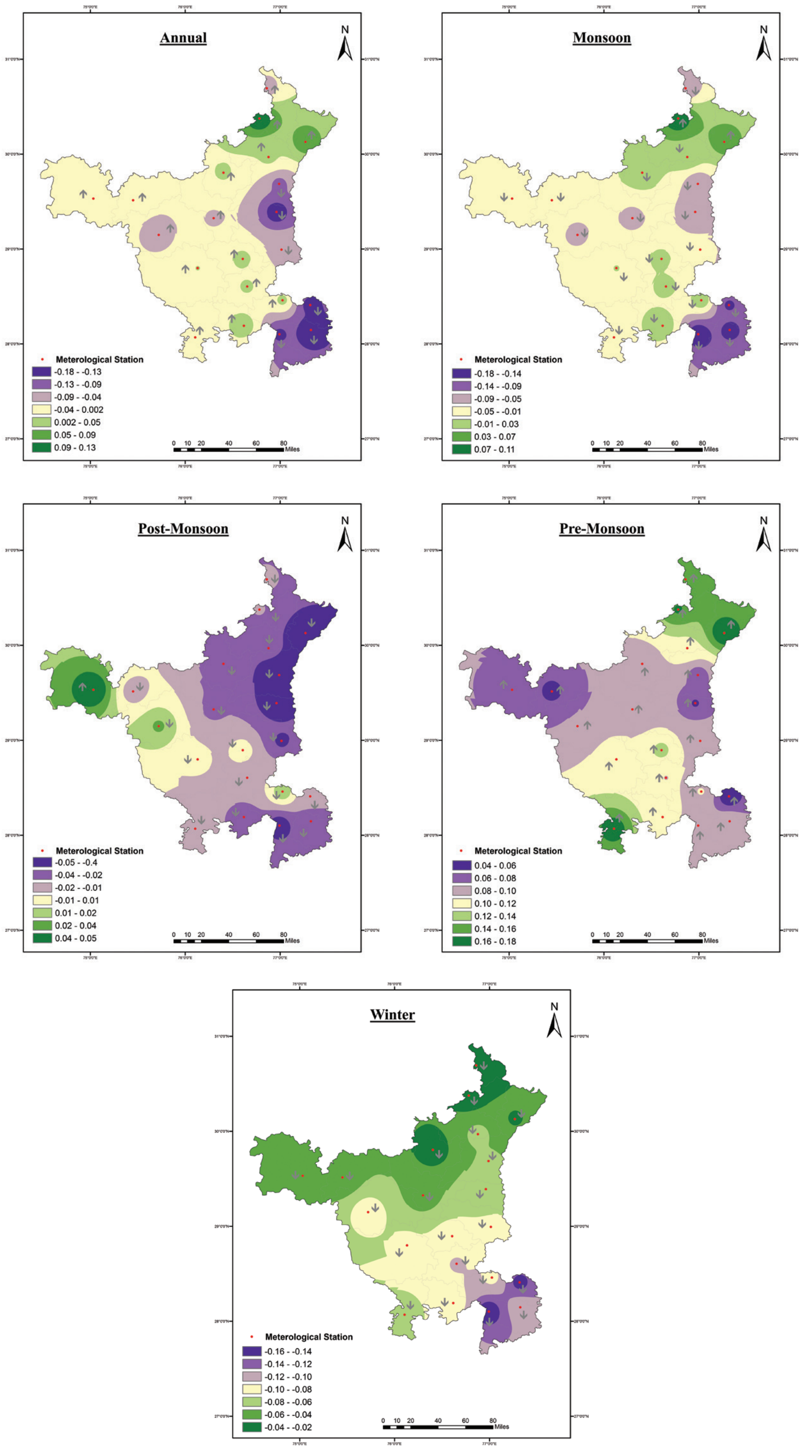
Both temperature and rainfall predictions are important to evaluate climatic patterns and human activities. The changes in

Table 3: Sen's Slope trend analysis

| Station | Annual | Pre-Monsoon | Monsoon | Post-Monsoon | Winter |
|---|---|---|---|---|---|
| Palwal | 0.036 | 0.017 | -0.293 | -0.020 | -0.035 |
| Gurgaon | 0.079 | 0.028 | 0.032 | 0.070 | -0.032 |
| Panchkula | 0.121 | 0.117 | -0.28 | -0.020 | -0.011 |
| Kurukshetra | -0.097 | 0.049 | 0.044 | -0.04 | -0.041 |
| Fatehabad | -0.068 | 0.019 | -0.066 | 0.001 | -0.011 |
| Jind | -1.39 | 0.227 | -0.092 | -0.041 | -0.014 |
| Yamunanagar | 0.238 | 0.096 | 0.176 | -0.092 | -0.029 |
| Mahendergarh | 0.603 | 0.251 | -0.015 | 0.050 | -0.014 |
| Kaithal | -1.358 | 0.031 | 0.542 | -0.043 | -0.009 |
| Panipat | -1.507 | 0.016 | -0.532 | -0.011 | -0.028 |
| Rewari | -0.812 | 0.033 | 0.056 | 0.460 | -0.025 |
| Sonipat | -0.789 | 0.037 | -0.087 | -0.012 | -0.031 |
| Hisar | -0.187 | 0.026 | -0.082 | 0.091 | -0.026 |
| Ambala | 0.054 | 0.086 | 0.335 | -0.061 | -0.018 |
| Faridabad | 0.089 | 0.009 | -0.338 | 0.090 | -0.054 |
| Bhiwani | -0.342 | 0.434 | -0.012 | 0.04 | -0.024 |
| Jhajjar | 0.202 | 0.028 | -0.003 | 0.023 | -0.031 |
| Mewat | -0.291 | 0.018 | -0.219 | -0.001 | -0.046 |
| Rohtak | 0.191 | 0.044 | -0.005 | 0.004 | -0.03 |
| Karnal | -1.395 | 0.025 | -0.391 | -0.005 | -0.033 |
| Sirsa | -0.031 | 0.418 | -0.04 | 0.0003 | -0.014 |

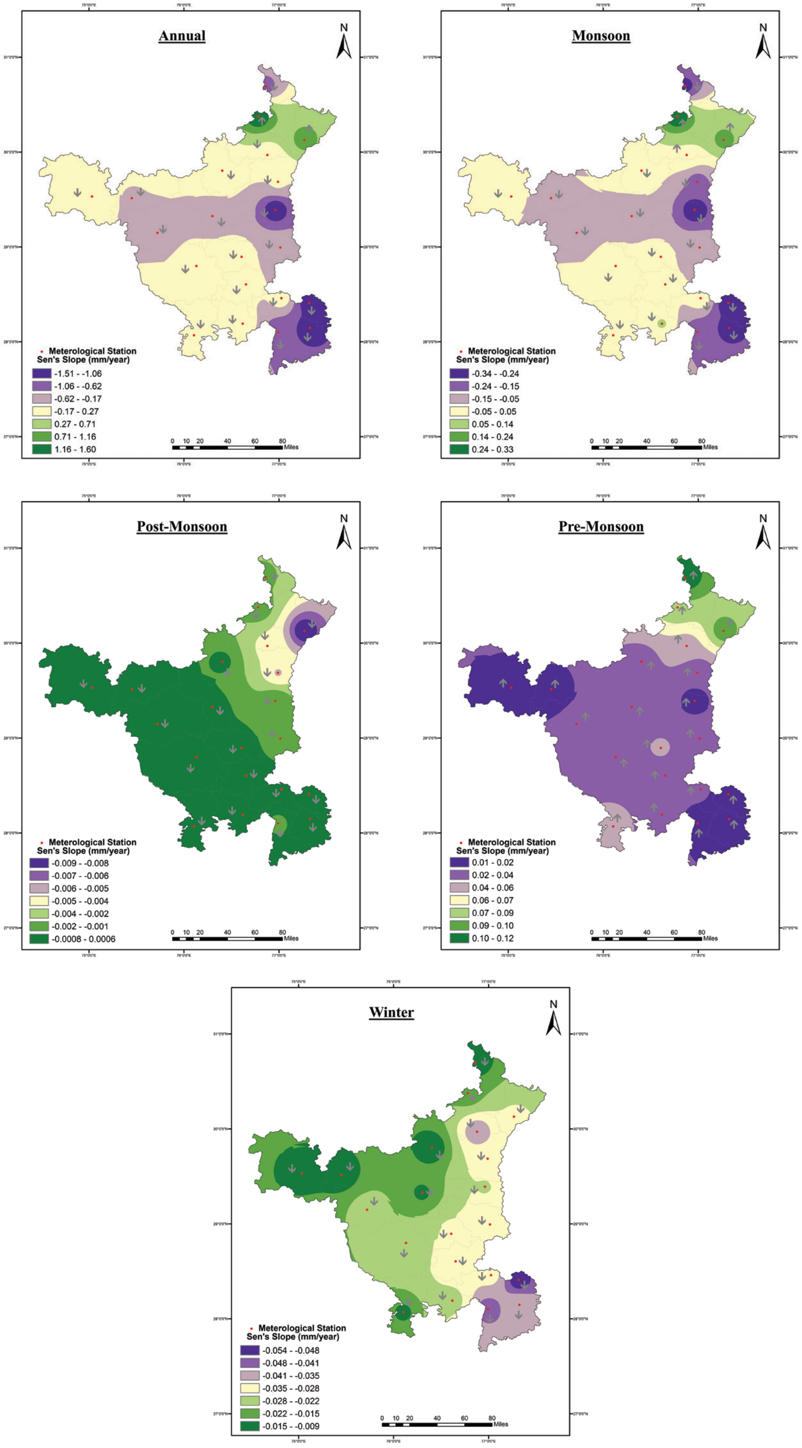
rainfall distribution notably distress farming production. Furthermore, prediction will help augment the preparedness and resilience strategy under variable climatic regimes. The annual rainfall in the last 120 years (Fig 9) has decreased by 8.57 percent and is predicted to further decrease by 3.31in the next three decades (2021-2050). A linear trend line graph shows the decrease in rainfall including the prediction period.

Figure 10 reveals that the northern and eastern Haryana meteorological stations are predicted to receive more rainfall (Fatehabad, 1260.39 mm Yamunanagar, 1029.88 mm and Ambala, 848.17 mm) whereas the south-western region (Hisar, 381.47 and Sirsa 342.8 mm) is predicted to receive the least annual totals. In general, 68 percent of meteorological stations will experience a progressive decrease in rainfall events in predicted years. A similar study depicting seasonal variations and the probability of less normal rainfall in the monsoon season and an increase in pre-monsoon rainfall are predicted for all districts across the state by Chauhan *et al.*, (2022). An increase in the frequency of extreme rainfall events and a decrease in rainfall intensity below normal predicting an overall decrease in rainfall (Aryal *et al.*, 2020) also advocates the change in pattern. The decreasing strength of the tropical easterly jet stream and its effect on the formation of monsoon depressions



↑ = Significant upward ↓ = Significant downward ↑ = Insignificant upward ↓ = Insignificant downward

Fig. 5: Result of Mann-Kendall test for annual and seasonal rainfall (1901-2021): (a) Annual, (b) Monsoon, (c) Post-Monsoon, (d) Pre-Monsoon, and (e) Winter



↑ = Significant upward ↓ = Significant downward ↑ = Insignificant upward ↓ = Insignificant downward

Fig. 6: Annual and seasonal distribution of Sen Slope trend (1901-2020): (a) Annual, (b) Monsoon, (c) Post-Monsoon, (d) Pre-Monsoon, (e) Winter

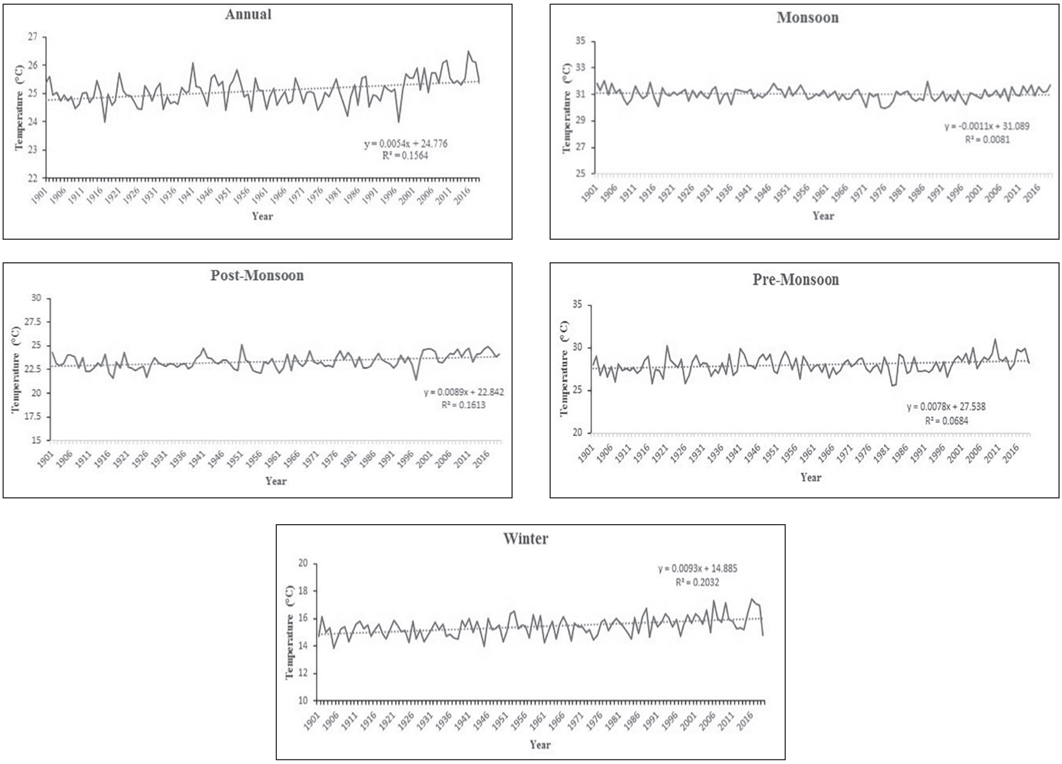


Fig. 7: Trends of mean annual and seasonal temperature in Haryana (1901-2020)

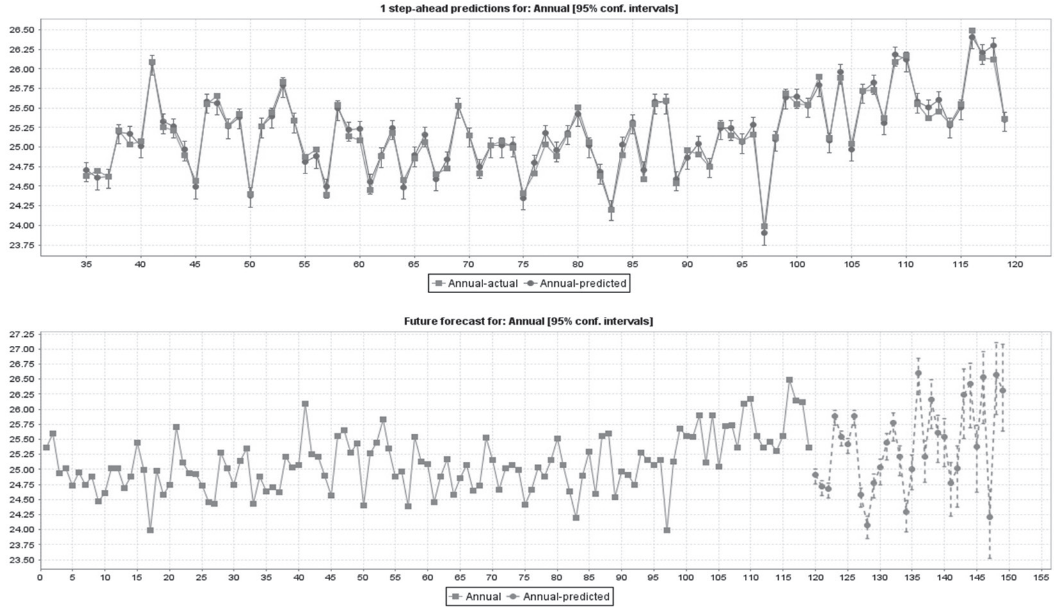


Fig. 8: Temperature forecasting using MLP-ANN for 2020-2050.

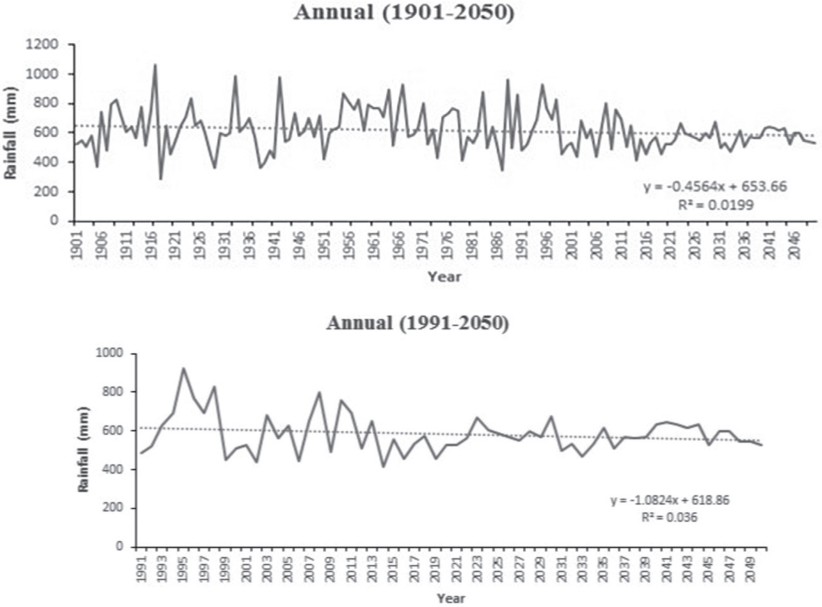


Fig. 9: Rainfall trend predictions (a) 1901-2050 (b) 1991-2050. (2021-2050).

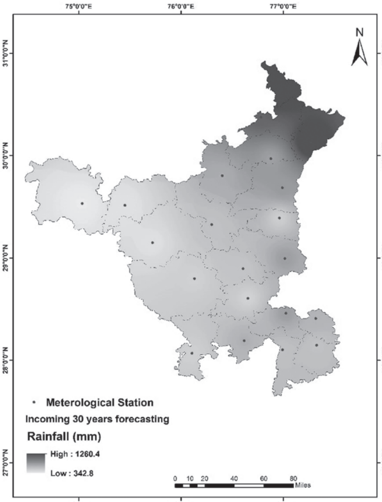


Fig. 10: Spatial distribution of predicted rainfall variability for the upcoming 30 years (2021-2050).

affecting the rain bearing capacity are reported by Sathyamurthy (2005); and Rao, S. *et al.*, (2014). The changing nature of vertical integrated moisture transport, precipitable moisture content and wind velocity was closely studied by Chauhan *et al.* (2022) relating to the extreme rainfall events in Haryana. These weather system changes may be attributed to the changing nature of rainfall and temperature in the state.

## Conclusions

Rainfall and temperature trends are important climate variables to understand the changing behavior of climate in a region. The arid and semi-arid climatic conditions of Haryana are sensitive to fluctuations thereby influencing weather variables which further relate to the availability of water requirements. This study evaluates the dynamics of average monthly rainfall temporal data over a 120 years long period of time for the state of Haryana. The result of Mann Kendall tests indicates a decrease in annual rainfall trend in 82 percent of sub-divisions with the exception of eastern districts of the sandy plain where positive rainfall trends were recorded. The maximum magnitude of decrease (-0.5432) was found in the monsoon season followed by winter and post-monsoon. Pre-monsoon rainfall shows an increasing trend (highest in +0.418 mm/year in Sirsa) across all stations. The slope of the downward trend ranged from -0.054 mm/year to -1.507 mm/year as per Sen's value. Districts like Fatehabad, Mahendragarh, Jind and Bhiwani show an increase in pre-monsoon rainfall of 0.93 mm/year in the observed period. The coefficient of variation was more pronounced in the western part of districts along the alluvial plain or Ghaggar region in comparison to the hilly track of Shiwalik and Aravali also showing the decline prominently from west to east. The predicted climate changes include (i) a higher mean annual temperature rise of 1.13 degrees from 0.7 degrees by 2049 (ii) reduced rainfall up to 3.31 percent and a positive increase in pre-monsoon rainfall events. The changes will hamper the total food and cereal crop output of the state but at the same time, it can give opportunity to the eastern districts with changes in associated livelihood options. It is also imperative for policymakers to comprehensively plan for the changing irrigation requirements and disaster preparedness associated with changes in weather extremes. The research can be further strengthened by taking adjoining states as study units to detail the changes in climate variables and associated linkages with global weather phenomena and to comprehend the analysis with advancements in prediction techniques.

## Competing interest

The authors declare that they have no conflict of interest.

## References

Akinsanola, B. K., Tsidu, G. M., Stoffberg, G. H., & Tadesse, T. (2019). Climate change and population growth impacts on surface water supply and demand of Addis Ababa, Ethiopia. *Climate Risk Management, 18*, 21–33.

Aryal, J. P., Jat, M. L., Sapkota, T. B., Rahut, D. B., Rai, M., Jat, H. S., Sharma, P. C., & Stirling, C. (2020). Learning adaptation to climate change from past climate extremes; Evidence from recent climate extremes in Haryana, India. *International Journal of Climate Change Strategies and Management, 12(1)*, 128–146. https://doi.org/10.1108/IJCCSM-09-2018-0065

Auerbach, L. W., Goodbred, S. L., Mondal, D. R., Wilson, C. A., Ahmed, K. R., Roy, K., Steckler, M. S., Small, C., Gilligan, J. M., & Ackerly, B. A. (2015). Flood risk of natural and embanked landscapes on the Ganges–Brahmaputra tidal delta plain. *Nature Climate Change*, 5(2), 153–157. https://doi.org/10.1038/nclimate2472

Chaudhuri, S., & Roy, M. (2016). Reflections on groundwater quality and urban–rural disparity in drinking water sources in the state of Haryana, India. *International Journal for Scientific Research and Development, 4(4)*, 837–843.

Chauhan, A. S., Singh, S., Maurya, R. K. S., Kisi, O., Rani, A., & Danodia, A. (2022). Spatio-temporal analysis of rainfall dynamics of 120 years (1901–2020) using innovative trend methodology: A case study of Haryana, India. *Sustainability, 14(9)*, 4888. https://doi.org/10.3390/su14094888

Cook, B. I., Mankin, J. S., & Anchukaitis, K. J. (2018). Climate change and drought: From past to future. *Current Climate Change Reports, 4(2)*, 164–179. https://doi.org/10.1007/s40641-018-0093-2

Cook, B. I., Seager, R., & Smerdon, J. E. (2014). The worst North American drought year of the last millennium: 1934. *Geophysical Research Letters, 41(20)*, 7298–7305. https://doi.org/10.1002/2014GL061661

Dai, A., Zhao, T., & Chen, J. (2018). Climate change and drought: A precipitation and evaporation perspective. *Current Climate Change Reports, 4(3)*, 301–312. https://doi.org/10.1007/s40641-018-0101-6

Darji, M. P., Dabhi, V. K., & Prajapati, H. B. (2015). Rainfall forecasting using neural network: A survey. *IEEE International Conference on Advances in Computer Engineering and Applications Ghaziabad* (pp. 706–713). https://doi.org/10.1109/ICACEA.2015.7164782

Dore, M. H. (2005). Climate change and changes in global precipitation patterns: What do we know? *Environment International, 31(8)*, 1167–1181. https://doi.org/10.1016/j.envint.2005.03.004

Gajbhiye, S., Meshram, C., Mirabbasi, R., & Sharma, S. K. (2016). Trend analysis of rainfall time series for Sindh River basin in India. *Theoretical and Applied Climatology, 125(3–4)*, 593–608. https://doi.org/10.1007/s00704-015-1529-4

Gergis, J., & Henley, B. J. (2017). Southern Hemisphere rainfall variability over the past 200 years. *Climate Dynamics, 48(7–8)*, 2087–2105. https://doi.org/10.1007/s00382-016-3191-7

Gizaw, M. S., & Gan, T. Y. (2017). Impact of climate change and El Niño episodes on droughts in sub-Saharan Africa. *Climate Dynamics, 49(1–2)*, 665–682. https://doi.org/10.1007/s00382-016-3366-2

Guhathakurta, P., & Rajeevan, M. (2008). Trends in the rainfall pattern over India. *International Journal of Climatology, 28(11)*, 1453–1469. https://doi.org/10.1002/joc.1640

Handmer, J., Honda, Y., Kundzewicz, Z. W., Arnell, N., Benito, G., Hatfield, J., Mohamed, I. F., Peduzzi, P., Wu, S., Sherstyukov, B., Takahashi, K., Yan, Z., Vicuna, S., Suarez, A., Abdulla, A., Bouwer, L. M., Campbell, J., Hashizume, M., Hattermann, F., & Yamano, H. (2012). Changes in impacts of climate extremes: Human systems and ecosystems. In *Managing the risks of extreme events and disasters to advance climate change adaptation: Special Report of the Intergovernmental Panel on Climate Change (pp. 231–290).* Cambridge University Press. https://doi.org/10.1017/CBO9781139177245.007

Joshi, U. R., & Rajeevan, M. (2006). *Trends in precipitation extremes over India. Mausam Bhavan, Lodhi Road, New Delhi: National Climate Centre (NCC), India Meteorological Department (IMD) (No. 3, pp. 10-11).* NCC research report.

Liu, Q., Zou, Y., Liu, X., & Linge, N. (2019a). A survey on rainfall forecasting using artificial neural network. *International Journal of Embedded Systems, 11(2)*, 240–249. https://doi.org/10.1504/IJES.2019.098300

Liu, Wang, L., Lai, Z., Tian, Q., Liu, W., & Li, J. (2019b) Innovative trend analysis of annual and seasonal air temperature and rainfall in the Yangtze River Basin, China during. *Journal of Atmospheric and Solar-Terrestrial Physics, 164*, 48-59, 1960–2015.

McQuate, G. T., & Hayden, B. P. (1984). Determination of intertropical convergence zone rainfall in northeastern Brazil using infrared satellite imagery. *Archives for Meteorology, Geophysics, and Bioclimatology Series B*, 34(4), 319–328. https://doi.org/10.1007/BF02269445

Mishra, S. K., & Sharma, N. (2018). Rainfall forecasting using backpropagation neural network. In *Innovations in computational intelligence* (pp. 277–288). https://doi.org/10.1007/978-981-10-4555-4_19

Nikumbh, A. C., Chakraborty, A., & Bhat, G. S. (2019). Recent spatial aggregation tendency of rainfall extremes over India. *Scientific Reports, 9(1)*, 10321. https://doi.org/10.1038/s41598-019-46719-2

Pai, D. S., Bhate, J., Sreejith, O. P., & Hatwar, H. R. (2011). Impact of MJO on the intraseasonal variation of summer monsoon rainfall over India. *Climate Dynamics, 36(1–2)*, 41–55. https://doi.org/10.1007/s00382-009-0634-4

Pal, I., & Al-Tabbaa, A. (2009) Trends in seasonal precipitation extremes – An indicator of ‘climate change’ in Kerala, India. *Journal of Hydrology, 367(1–2)*, 62–69. https://doi.org/10.1016/j.jhydrol.2008.12.025

Pal, I., & Al-Tabbaa, A. (2010). Long-term changes and variability of monthly extreme temperatures in India. *Theoretical and Applied climatology, 100*, 45-56.

Partal, T., & Kahya, E. (2006). Trend analysis in Turkish precipitation data. *Hydrological Processes, 20(9)*, 2011–2026. https://doi.org/10.1002/hyp.5993

Praveen, B., Talukdar, S., Shahfahad, Mahato, S., Mondal, J., Sharma, P., Islam, A. R. M. T., & Rahman, A. (2020). Analyzing trend and forecasting of rainfall changes in India using non-parametrical and machine learning approaches. *Scientific Reports, 10(1), 10342.* https://doi.org/10.1038/s41598-020-67228-7'

Rao, S. V. B., Sreekala, P. P., Arunachalam, M. S., & Harikiran, C. (2014). A study on the decreasing trend in tropical easterly jet stream (TEJ) and its impact on Indian summer monsoon rainfall. *Theoretical and Applied Climatology, 118, (1–8).*

Samantaray, S., Tripathy, O., Sahoo, A., & Ghose, D. K. (2020). Rainfall forecasting through ANN and SVM in Bolangir Watershed, India. *In Smart Intelligent Computing and Applications: Proceedings of the Third International Conference on Smart Computing and Informatics, Volume 1* (pp. 767-774). Springer Singapore.

Sanikhani, H., Kisi, O., Mirabbasi, R., & Meshram, S. G. (2018). Trend analysis of rainfall pattern over the Central India during 1901–2010. *Arabian Journal of Geosciences, 11(15)*, 437. https://doi.org/10.1007/s12517-018-3800-3

Sathiyamoorthy, V. (2005). Large scale reduction in the size of the tropical easterly jet. *Geophysical Research Letters, 32(14)*, n/a–n/a. https://doi.org/10.1029/2005GL022956

Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association, 63(324)*, 1379–1389. https://doi.org/10.1080/01621459.1968.10480934

Talaee, P. H. (2014). Iranian rainfall series analysis by means of nonparametric tests. *Theoretical and Applied Climatology, 116(3–4)*, 597–607. https://doi.org/10.1007/s00704-013-0981-2

Vishwa, B., Chandel, S., & Karanjot, K. (2013). Drought in Himachal Pradesh, India: A historical analysis. *Geographical Perspectives*, 260–273.

Wu, J., Liu, Y., Yu, Y., & Yan, W. (2013). A prediction of precipitation data based on support vector machine and particle swarm optimization (PSO-SVM) algorithms. *Algorithms, 10(2)*, 57.

**Manish Kumar**
Assistant Professor
Department of Geography
Central University of Haryana

**Swati Thakur***
Associate Professor
Department of Geography
Dyal Singh College, University of Delhi
**Akash Tiwari**
Department of Geography
Central University of Haryana

**Ankur Yadav**
Department of Geography
Central University of Haryana

**Tamanna**
Department of Geography
Central University of Haryana

**Dinesh Kumar Tripathi**
Principal,
Rana Pratap Post Graduate College,
Sultanpur, Uttar Pradesh

*Author of Correspondence
E-mail: swatithakur@dsc.du.ac.in