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The spatial distribution of rainfall, extreme indices in Haryana (INDIA) using geographic information system

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Abstract
A study was conducted to analyze rainfall, extreme indices pattern change in Haryana, India is considering five stations *viz.*, Ambala, Bawal, Hisar, Karnal and Sirsa use observed data for total daily rainfall for the period 1985-2014 with an underlying objective of the better understanding of regional planning under anticipated climatic variability and change. The annual values of rainfall indices were plotted using the inverse distance weighted (IDW) interpolation technique in Geographic Information System (GIS) to analyze the spatial distribution of these indices. Different zones shown on maps indicate the magnitude of each index over the state. Spatial distribution of eleven annual rainfall indices suggested a varied pattern over the state that decreases diagonally from the northeast towards a southwest direction. The northern parts of the state (Panchkula and Yamunanagar districts) had highest rainfall occurrence and western parts (Sirsa, and parts of Fatehabad, Hisar and Bhiwani districts) had the least rainfall occurrence. GIS helps to interpolate and delineate zones for these indices on the basis of stations (point) data for future planning purposes as well as integrated spatial analysis to achieve sustainable agricultural development.

Keywords: Spatial distribution, climate change, rainfall extremes, indices and GIS

Introduction
The climate of the world is changing in a tragic manner; the evidence of these changes is very clear according to most recent climate researchers from different regions around the world (Funk *et al*., 2012, IPCC, 2013a) [6, 9]. Using high resolution daily gridded rainfall data for the period 1951–2003, Goswami *et al*. (2006) showed that there were significant rising trends in the frequency and magnitude of extreme rain events over central India during the monsoon season. Kumar *et al*. (2010) [12], while considering the data for the period of 1871-2005, found the highest increase in the monsoonal rainfall in Konkan and Goa, Coastal Karnataka, and Punjab whereas a maximum decrease in Chattisgarh, Kerala, and Nagaland, Manipur, Mizoram, and Tripura. Besides, they noted a wide variability in the annual series also. The similarity in the monsoonal trend and the annual trend was also observed recently in the work of Pingale *et al*. (2014) in the Rajasthan state of India. Dash *et al*. (2007) [4] reported the highest decline of rainfall in Nagaland, Manipur, Mizoram, Tripura, East Madhya Pradesh and Orissa over the period from 1871 to 2003.The extreme precipitation events over most of the mid-latitude land masses and the wet tropical region will very likely become more intense and more frequent and have a significant impact on farming activities on a regional scale (IPCC, 2014) [10] and have a significant impact on farming activities on regional scale (Shekhar *et al*. 2009) [19]. Geographic information systems (GIS) have become critical tools in agricultural research and natural resource management (NRM), yet their utilization in the study area is minimal and inadequate. A GIS provides the decision maker with a logical and graphic representation of geographically-referenced information. Over the past decade, Geographic Information Systems (GIS) have been used for data integration, analysis, and decision-making in many societal sectors and academic disciplines and also addresses issues of spatial data management, interoperability, and geoinformatics in climate change research (Rong and Fenech, 2007) [17]. The Systems are incredibly helpful in being able to map and project current and future fluctuations in precipitation, temperature, crop output and more.

Material and Methods
Eleven extreme indices related to annual rainfall were computed using the RClimDex 1.0 software using 30-years daily data (1985-2014) for five locations (Ambala, Bawal, Hisar, Karnal, and Sirsa) in Haryana. These indices are useful for understanding the regional climate changes, their trends and the likely impact on agriculture and related economy.

Analytical or statistical techniques employed to calculate the annual values for the climatic change indices results so obtained were that plotted using the inverse distance weighted (IDW) interpolation technique for rainfall indices using the Geographic Information System (GIS) on maps to depict the spatial distribution of these indices. Different zones shown on maps indicate the magnitude of each index over the state**.** Additionally, the same data for some surrounding stations *viz*., Bhatinda, Patiala in Punjab; Chandigarh; Delhi; Churu, Pilani and Sri Ganganagar in Rajasthan; and Mathura and Saharanpur in UP were also used for the same parameters for better spatial analysis in GIS for weather parameters. The entire GIS task was done out using ArcGIS 10.4 software for extreme rainfall related weather risk mapping and agricultural risk management strategies.

Result and Discussion

The spatial distribution of rainfall climate change indices: Haryana state extends between 27°39' N to 30°55' N latitudes and 74°27' E to 77°36' E Longitudes covering an area of 44,214 sq. km. Geographically the state lies in the Trans Gangetic Plain Region (Zone-6 as per FAO Agroclimatic Regions). It is also the transition zone between the hot, dry climate of *Thar* Desert where rainfall is low (western and southwestern parts of the state) and cold sub-humid climate of the Himalayas with fairly good rainfall (northeastern parts of the state). Owing to its geographical situations, this area is probably more susceptible to climate change and variability (Anurag *et al,* 2009) [2] and it becomes more important to analyze spatial as well as temporal climatic pattern dynamics for better utilization of natural resources in regional planning for ecological restoration and water management. After quality control and homogeneity tests, eleven core indices for extreme rainfall from ETCCDMI (Zhang and Yang, 2004) were selected and having been applied widely to evaluate extreme rainfall shifts in five stations of Haryana state. The results obtained have been depicted in maps prepared in a GIS environment and described below.

I. Percentile based indices: The spatial distribution of very wet days (R95p) and extremely wet days (R99p) is shown in Fig. 1. The results indicated that the northernmost parts in Panchkula and Yamunanagar districts in the state had highest rainfall occurrence of 240-275 mm and 72-85 mm on very wet and extremely wet days, respectively. While on the other hand the western parts comprising of Sirsa, and parts of Fatehabad, Hisar, and Bhiwani districts had the least rainfall occurrence of 100-135 mm and 30-41 mm on very wet and extremely wet days, respectively. Most of the state lies in the range of 135-240 mm and 41-72 mm in both of indices, respectively.

II. Absolute indices: The spatial distribution of RX1day and RX5day has been drawn in Fig. 2. The maximum amount of rainfall received in a single day and consecutive five day total was higher in the northernmost parts with corresponding values of 106-126 mm and 185-205 mm for RX1day and RX5day, respectively. The western parts of the state had the lowest rainfall amount which varies from 68-81 mm and 105-125 mm for RX1day and RX5day, respectively.

III. Threshold indices: The spatial distribution of the number of days with rainfall amounts of heavy (≥ 10 mm); very heavy (≥ 20 mm) and rainy day (≥ 2.5 mm) (R10mm, R20mm and R2.5mm, respectively) displays that the northernmost parts *viz.*, Panchkula and Yamunanagar districts had number of rainfall days of various categories with values in the range of 23-28 days, 13-16 days and 42-46 days for R10mm, R20mm, and R2.5mm, respectively (Fig. 3). On the other hand, the western parts comprising of Sirsa and adjoining districts had less number of days ranging from 8-13 days, 4-7 days and 22-28 days for R10mm, R20mm, and R2.5mm, respectively.

IV. Duration indices: Consecutive wet days (CWD) and consecutive dry days (CDD) have been demarcated in Fig.4. The results indicated that a part of Yamunanagar district had a lengthy wet spell of 5.6-6.3 days, whereas the western parts comprising of Sirsa, and parts of Fatehabad, Hisar and Bhiwani districts have the shortest wet spell of 3.5-4.2 days. The spatial distribution for consecutive dry days (CDD) was reverse to that of CWD and the western parts had the longest dry spell of 88-92 days and northernmost parts had the shortest dry spell of 62-72 days.

V. Other indices: Spatial distribution of annual total wet-day precipitation (PRCPTOT) in mm/year and the simple daily intensity index (SDII) in mm/day/year are demarcated in fig. 5. The map demonstrates that the annual total rainfall on wet days amounted to 890-1000 mm for Panchkula, Yamunanagar areas and highest in the state. While, the annual total rainfall was very low (340-450 mm) in the westernmost parts, mainly in Sirsa district. The simple daily intensity index, which indicated rainfall intensity for wet days in the year was also highest in the northern parts of the state with a value between 16.3 – 17.3 mm/day, whereas, the lowest value (12.3–13.3mm) of SDII was noted in a contiguous area mainly forming part of Hisar and Bhiwani districts in the state.

The spatial distribution of rainfall indices on annual scale as observed in the state suggested that the northern most parts in the state (Panchkula and Yamunanagar) had highest rainfall occurrence viz., very wet days (R95p), extremely wet days (R99p), rainy days (R2.5mm), number of heavy precipitation days (R10mm), number of very heavy precipitation days (R20mm), maximum 1-day precipitation amount (RX1day), maximum consecutive 5-day precipitation amount (RX5day), consecutive wet days (CWD), simple daily intensity index (SDII) and annual total wet day precipitation amount (PRCPTOT) have 240-275 mm, 72-85 mm, 42-46 days, 23-25 days, 13-16 days, 106-26 mm, 185-206 mm, 5.6-6.3 days, 16.3-17.3 mm/day and 890-1000 mm, respectively per annum, while the western parts (Sirsa and parts of Fatehabad, Hisar and Bhiwani districts) had the least rainfall occurrence with values of same indices as 100-135 mm, 30-41mm, 22-26 days, 8-13 days, 4-7 days, 68-81mm, 105-125 mm, 3.5-4.2 days, 12.3-13.3mm/day and 340-450 mm respectively per annum. A less spatial coherence in trends was observed in precipitation indices across the region and fewer trends were found locally significant. Similar results were also observed other parts of the world, including southwestern Pakistan (Hussain and Lee, 2013) [8], the Hawaiian Islands (Chen and Chu, 2014) [3], and northwestern Iran (Najafi and Moazami, 2016) [14] that are amply corroborating the findings of this regional study. In some cases where statistically significant trends in precipitation indices were identified for regions and sub-regions, the trend is towards wetter conditions which confirm the global results as appeared in findings of Manton *et al.* (2001) [13], Singh *et al.* (2014) [18], Alexander *et al.* (2006) [1], Klein *et al.* (2006) [1, 11] and Prasad *et al*., (2017) [16].

Table 1: List of Extreme Rainfall Indices

Sr. No.	Indices ID	Parameters	Description	Units
1	R95p	Very wet days	Annual total precipitation from days >95th percentile	Mm
2	R99p	Extremely wet days	Annual total precipitation from days >99th percentile	Mm
3	RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	Mm
4	RX5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	Mm
5	R2.5	Number of rainy days	Annual count when precipitation ≥ 2.5 mm	Days
6	R10	Number of heavy precipitation days	Annual count when precipitation ≥ 10 mm	Days
7	R20	Number of very heavy precipitation days	Annual count when precipitation ≥ 20 mm	Days
8	CDD	Consecutive dry days	Maximum number of consecutive days when precipitation <1 mm	Days
9	CWD	Consecutive wet days	Maximum number of consecutive days when precipitation ≥1 mm	Days
10	SDII	Simple daily intensity index	The ratio of annual total precipitation to the number of wet days (≥ 1 mm)	mm/day
11	PRCPTOT	Annual total wet-day precipitation	Annual total precipitation from days ≥1 mm	Mm

(Source: http:// cccma.seos.uvic.ca/ETCCDI/list_27_indices.html)

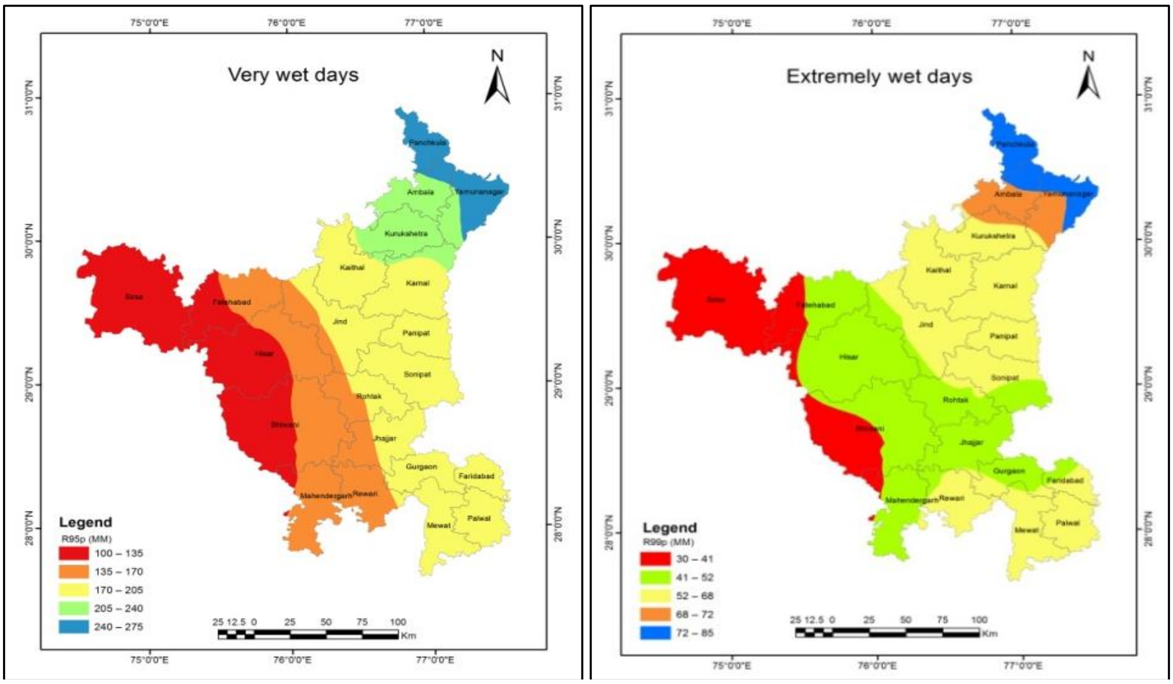

Fig 1: Very wet days (R95p) and extremely wet days (R99p) in Haryana, India

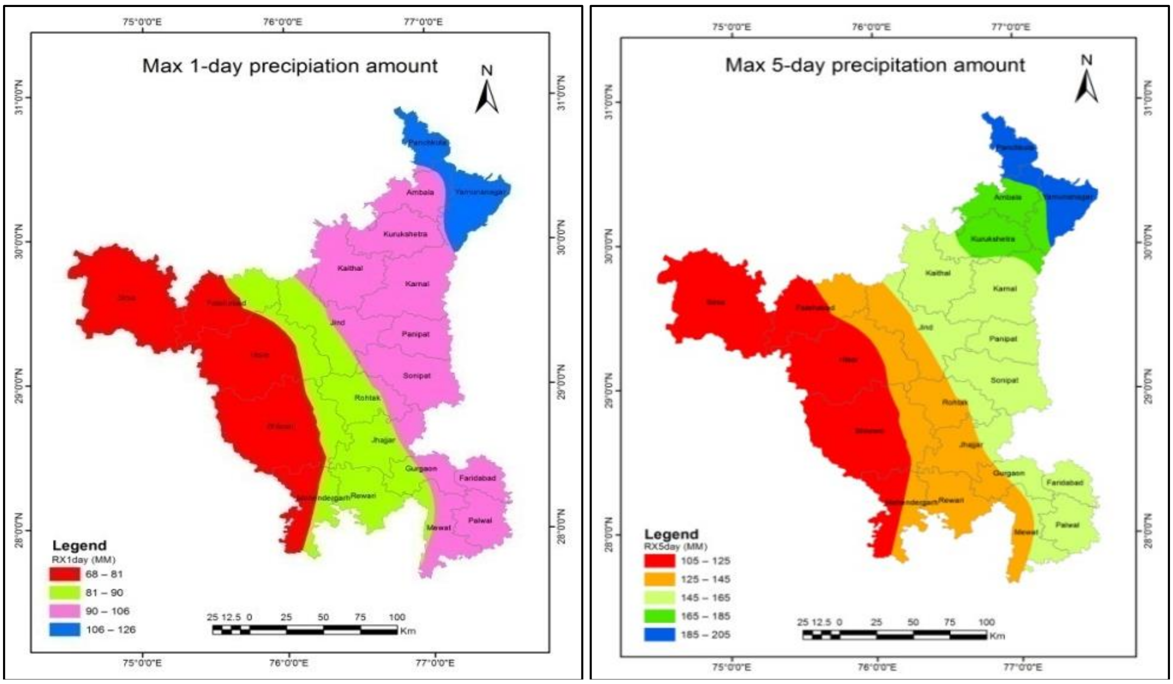

Fig 2: Maximum 1 day precipitation amount (RX1day) and maximum 5 day precipitation amount (RX5day) in Haryana, India

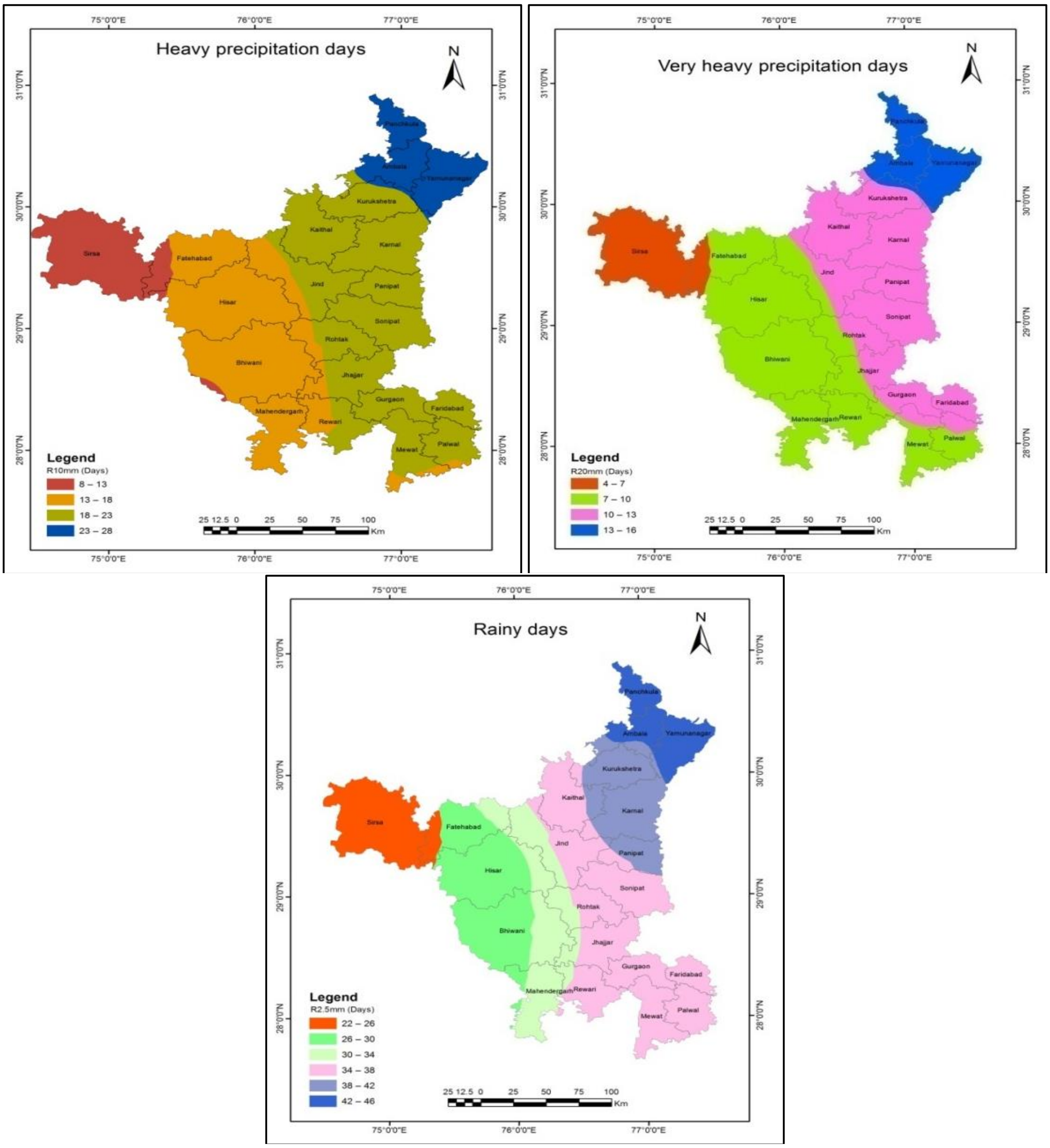

Fig 3: Heavy precipitation days (R10mm), very heavy precipitation days (R20mm) and rainy days (R2.5mm) in Haryana, India

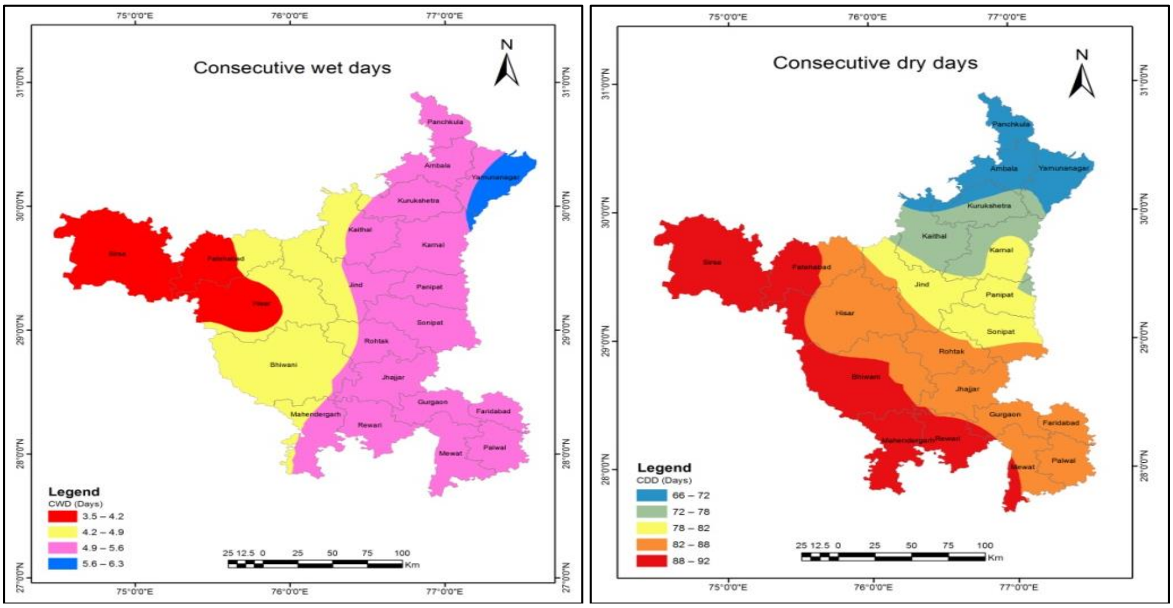

Fig 4: Consecutive wet days (CWD) and consecutive dry days (CDD) in Haryana, India

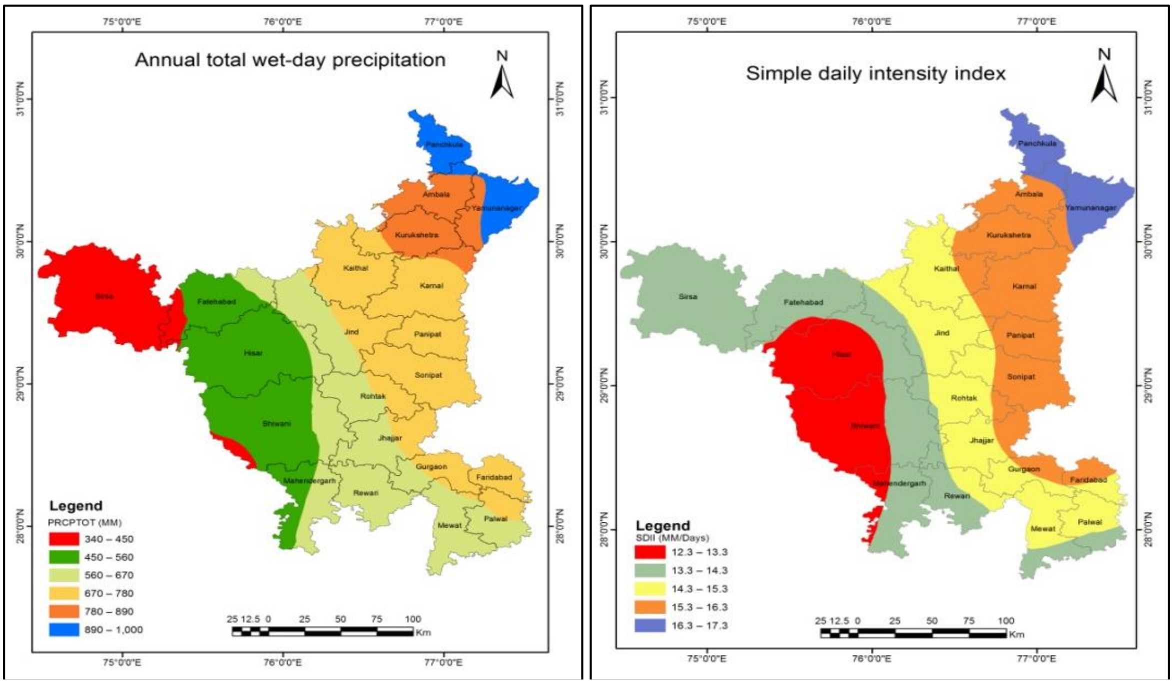

Fig 5: Annual total wet-day precipitation (PRCPTOT) and Simple daily intensity index (SDII) in Haryana, India

Conclusions

The spatial distribution of eleven rainfall indices on an annual scale showed a gradual decreasing pattern from northeast to southeast direction in the state of Haryana. The northern parts in the state *viz*., Panchkula and Yamunanagar districts had the highest rainfall (890-1000 mm) occurrence and western parts *viz*., Sirsa, and parts of Fatehabad, Hisar and Bhiwani districts) had the least rainfall (340-450 mm) occurrence. Surface level water management practices are required in the entire province to manage the excess and low rainfall occurrence. The better understanding of extreme rainfall may be useful in comprehensive agricultural planning for ecological restoration and water management to achieve sustainable development in the region.

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