accumulated helio thermal units with accuracy of 70, 80 and 95%, respectively (Kaur *et al*. 2009). The poor relationships were found with photo thermal units (Table 3).

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Trend Analysis of Annual Rainfall and Rainy Days Over Pune District of Maharashtra

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Abstract

Rainfall analysis would enhance the management and effective utilization of water resources. Analysis of trend is useful to examine the long term trends in rainfall and rainy days over. The present study has been undertaken in fourteen Tehsils of the Pune district to study rainfall and rainy days trend using Mann-Kendall Test and Sen's Slope method and GIS based maps are prepared. The annual rainfall trend over the most of tehsils has been increased with increasing rainy days while, rainfall trend in Ambegaon, Baramati tehsils decreased with increasing rainy days and in Junnar and Purandar tehsils it was decreased with decreasing rainy days. Spatial variation in trends of annual rainfall showed in a map prepared in the GIS environment.

Key words : Rainfall, Rainy days trend, Mann-Kendall Test, Sen's Slope method, GIS.

The Indian monsoon is highly erratic both in quantum as well as distribution. The monsoon characteristics relating to its time of onset, withdrawal and distribution control agricultural production and in turn the livelihood of the people. In India, rainfall received from southwest monsoon (June to September) is a major source of water for agriculture. However, it is most

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uneven, erratic and its distribution is inconsistent at a particular place for different years. The average annual rainfall in the country is 119.4 cm, about 60 per cent of the country's total cultivable land remained as rainfed (Guhathakurta and Rajeevan, 2008). In Maharashtra rainfall starts normally in the first week of June. July is the wettest month in Maharashtra, while August also gets substantial rain. The rainy season starts its retreat with the coming of September to the state. Rainfall in Maharashtra differs from region to region. A highly variable rainfall ranging from 400 to 4500 mm occurs from 40 to 100 rainy days in the state.

Pune district lies on the western side of the Deccan plateau in the Maharashtra state and it is divided into four agro-climatic zones by NARP; Western Ghat Zone (includes Lonawala and Khandala tahsils of the district), Sub Mountain Zone (includes Khed, Ambegaon and Junnar tahsils of the district), Western Maharashtra Plain zones (includes the central part of Bhor, the western part of Haveli and eastern parts of Maval, Khed, Ambegaon and Junnar tahsils of the district) and Scarcity Zone (includes Purandar, Baramati, Indapur, Daund, Shirur, Junnar, Ambegaon, Khed, Haveli and Bhor tahsils of the district).

Various studies were carried out to determine the trend of rainfall and rainy days (Atre and Deore 2013; Murumkar and Arya 2014; Chinchorkar *et al*. 2015; Deulkar *et al*. 2015; Jagadeesh *et al*. 2015; Mandal *et al* 2015; Pandit 2016; Upadhye *et al*. 2016; Zende *et al*. 2017; Jedhe *et al*. 2018; Kalunge 2018 and Wale *et al*. 2020. Mann Kendall test (Mann, 1945 and Kendall, 1975) is one of the commonly used non-parametric test for determining a trend in hydrologic time series. The advantage of a non-parametric test is that it only requires data to be independent and can tolerate outliers in the data. Various studies on GIS based trend maps have been carried out (Sashikkumar *et al*. 2013; Admasu *et al*. 2014; Agnihotri *et al*. 2017; Srividhya 2017 and Sanjay *et al*. 2018). Geographic Information System (GIS) applications are commonly used to generate rainfall patterns in visual formation with a combination of characteristics of rainfall data and then can be used by stakeholders to facilitate the process of analysis and forecasting rainfall (Kadir *et al*. 2016). GIS is described as an organized collection of computer hardware and software, geographical data and personnel, designed efficiently to capture, store, update, manipulate, analyze and display all forms of geographically referenced information. GIS has three major components: Spatial position, attribute and time. GIS is software designed primarily to support referenced data for solving complex planning and management problems. It interprets spatial and other kinds of data as well within a single system. Two very important aspects, which characterize the GIS are; defining the absolute location of earth features over a co-ordinate system like the latitudes and longitudes and the ability to relate the geographical information that describes a feature.

Materials and Methods

Study area : Pune district lies on the western side of the Deccan plateau in the Maharashtra state. The latitudinal and longitudinal extension of the district lies from 17°54' to 19°24' N and 73°10' to 75°10' E. It is situated at 557.17 m height above the mean sea level. The Sahyadri runs in the North-South direction of the district. There are 14 tehsils in Pune district viz., Ambegaon, Baramati, Bhor, Daund, Haveli, Indapur, Junnar, Mulshi, Pune city, Rajgurunagar, Purandar, Shirur, Vadgaon maval and Velhe. The district has a hot semi-arid climate bordering with tropical wet and dry. Pune experiences three seasons: summer, monsoon and winter. The maximum temperature of the Pune district ranges between

34°C to 41°C from April to May, while the minimum temperature varies between 5°C to 10°C in the month of November to January. The warmest month in Pune is May. The monsoon lasts from June to October with moderate rainfall.

Fig. 1. Tehsilwise map of Pune district

Software/Programme : Microsoft office sub-module MS-Excel was used for data analysis. The formulation and conditional statements were also executed in MS-excel. MAKESENS excel template was used for trend detection and estimation of the magnitude of trend (Salmi *et al*., 2002). ARC GIS software was used for the preparation of the tehsilwise GIS-based maps of the rainfall trend.

Data collection : The daily rainfall data of all 14 tehsils of Pune district from the month of January to December were collected from, Department of Agricultural Meteorology, College of Agriculture, Pune; State Agriculture Department, Pune; India Meteorological Department, Pune and Downloaded from www.maharain.gov.in (www.krishi.maharashtra.gov.in). These data were used for trend analysis. The geographical area of rain gauge stations and duration of rainfall data collected is presented in Table 1.

Rainfall and rainy days trend analysis : Trend analysis (increase or decrease) of all the independent weather parameters (e.g. annual rainfall and rainy days) was statistically examined by the non-parametric Mann-Kendall test and Sen's slope method (Choudhury *et al*., 2012).

Table 1. Geographical location and availability of data for study

Location of station	Latitude	Longitude	Period (year)		No. of years
			From	To	
Ambegaon	19.112° N	73.730° E	1980	2018	39
Baramati	18.150° N	74.576° E	1980	2018	39
Bhor	18.145° N	73.842° E	1961	2018	58
Daund	18.463° N	74.578° E	1961	2018	58
Haveli	18.520° N	73.856° E	1980	2018	39
Indapur	18.117° N	75.023° E	1961	2018	58
Junnar	19.209° N	73.872° E	1980	2018	39
Khed	17.718° N	73.396° E	1980	2018	39
Mulshi	18.505° N	73.518° E	1961	2018	58
Pune city	18.520° N	73.856° E	1980	2018	39
Purandar	18.344° N	74.031° E	1961	2018	58
Shirur	18.830° N	74.380° E	1961	2018	58
Vadgaon maval	18.748° N	73.641° E	1980	2018	39
Velhe	18.297° N	73.636° E	1980	2018	39

The Mann Kendall test applied to the detection of a monotonic trend of rainfall and rainy days time series and Sen's slope method was used to determine the magnitude of rainfall and rainy days trend. The negative values of results indicated a decreasing trend and positive values indicated the increasing trend. The significance levels of rainfall trend and corresponding values of test Z and the notation used is given in Table 2.

Mann-Kendall method : The Mann-Kendall test statistic (S) is calculated using the formula that follows (Mann, 1945);

$$S = \sum_{k-1}^{n} \sum_{j-k-1}^{n} \text{sign } (Xj - Xk)$$

Where, X_j and X_k are the annual values in year's j and k, j > k respectively and X_k represent the data point at time k.

The value of sign (x_j - x_k) is computed as number follows

$$\text{Sign} = \begin{cases} +1 & if \quad xj - xk > 0 \\ 0 & if \quad xj - xk = 0 \\ -1 & if \quad xj - xk < 0 \end{cases}$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N>10), the test is conducted using a normal approximation (Z statistics) with the mean and the variance as follows:

$$\text{Variance (S)} = \frac{(n(n-1)(2n+5) - \sum_{p=1}^{p=g}(tp(tp-1)(2tp+5))}{18}$$

Where, n = number of years,g = number of tied groups (A tied group is a set of sample data having the same value) and tp = number of items in the tied group

Calculate a normalized test statistic Z by the following equation

$$Z = \frac{(S+1)}{\sqrt{\text{Varience}(S)}} \quad \text{If} \quad S > 0$$

$$z = 0 \quad \text{If} \quad S = 0$$

$$Z = \frac{(S-1)}{\sqrt{\text{Varience}\ (S)}} \quad \text{If} \quad S < 0$$

Where, S = p - q, p = number of (+1) values and q = number of (-1) values

The statistic Z has a normal distribution. In the present study, at a confidence level of 99, 95 and 90 per cent the positive or negative trends are determined by the test statistic.

Sen's Slope Method : Sen's slope method has been used for predicting the magnitude of hydro-meteorological time series data. This method uses a linear model for the trend analysis by using a simple non-parametric procedure developed by Sen, (1968).

To derive an estimate of the slope Qt, the slope of all data pairs was calculated;

$$Q_t = \frac{Xj - Xk}{j - k}, \; i = 1, 2, 3, N, \; j > k$$

If there are n values of Xj in the time series then as many as N = n(n-1)/2 slope estimates, Qt is to be computed. The Sen's estimator of the slope is the median of these N values of Qt. The N values of Qt were ranked from the smallest to the largest and the sen's estimate was calculated as;

$$Q_t = \begin{cases} Q_{\frac{N+1}{2}} & \text{if N is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) & \text{if N is even} \end{cases}$$

The median of all slope values gives Q, which is the magnitude of the trend. A positive value indicates increasing and negative values indicate a decreasing trend of rainfall and rainy days.

Geographical Information System (GIS) : The rainfall data, map of Pune district and GPS coordinates for rainfall stations were

used. Analysis of rainfall data was based on the analysis of space and time. For the analysis of space, the location of rainfall stations was plotted by using GPS, then the amount of annual, seasonal, monthly rainfall and rainy days trends were plotted by each rainfall station. After that, the maps that represented the annual, seasonal and monthly rainfall and rainy days trends for each year were predicted by using the interpolation method in GIS software. This interpolation is the procedure used to predict cell value for the location that lack of sample points. Map development using GIS aimed to identify the distribution of rainfall patterns and to compare the rainfall distribution between years, seasons and months (Kadir *et al*., 2016).

Result and Discussion

The Mann Kendall trend and the magnitude of Sen's slope for rainfall and rainy days data is shown in Table 2. The results showed that annual rainfall and rainy days didn't exhibit any statistically significant trend in Ambegaon, Baramati, Bhor, Daund, Indapur, Khed, Mulshi, Purandar and Shirur tehsil. Haveli and Pune city tehsils showed statistically significant increasing trend in annual rainy days whereas, Junnar tehsil showed statistically significant decreasing trend in annual rainy days. Only Vadgaon maval and Velhe tehsils showed statistically significant increasing trend in both annual rainfall rainy days. In Ambegaon and Baramati tehsils (Z = -0.63 and -1.40) showed decreasing trend in annual rainfall whereas, showed increasing trend (Z= 0.71 and Z= 0.94) in annual rainy days. Bhor tehsil showed increasing trend in both annual rainfall (Z= 1.46) and rainy days (Z=1). Daund tehsil showed increasing trend annual rainfall (Z= 0.13) as well as in annual rainy days (Z=0.07). Haveli tehsil showed increasing trend annual rainfall (Z= 1.48) and statistically significant increasing trend (Z= 4.25) in rainy days at 99 per cent confidence level.

Indapur tehsil showed increasing trend (Z= 0.13) in rainfall whereas, showed decreasing trend in annual rainy days (Z= -0.85). Both annual rainfall (Z= -1.31) and rainy days (Z= -1.97) showed decreasing trend at Junnar tehsil.

Table 2. Trend analysis of annual rainfall and rainy days over Pune district

Tehsil	First year	Last year	Rainfall			Rainy days		
			Test Z	Signific.	Q	Test Z	Signific.	Q
Ambegaon	1980	2018	-0.63		-3.69	0.71		0.10
Baramati	1980	2018	-1.40		-4.21	0.94		0.11
Bhor	1961	2018	1.46		4.10	1.00		0.09
Daund	1961	2018	0.13		0.30	0.07		0
Haveli	1980	2018	1.48		4.06	4.25	**	0.59
Indapur	1961	2018	0.13		0.30	-0.85		-0.06
Junnar	1980	2018	-1.31		-6.04	-1.97	*	-0.36
Khed	1980	2018	1.00		2.26	1.08		0.15
Mulshi	1961	2018	0.66		3.55	0.34		0.07
Pune city	1980	2018	0.53		3.51	2.49	*	0.50
Purandar	1961	2018	-1.09		-2.08	-1.19		-0.08
Shirur	1961	2018	0.31		0.34	1.48		0.08
Vadgaon Maval	1980	2018	5.15	**	37.800	4.71	**	1.333
Velhe	1980	2018	4.28	**	46.45	4.39	**	1.79

*Significance at 95 per cent confidence level, **Significance at 99 per cent confidence level and +Significance at 90 per cent confidence level

Khed tehsil showed increasing trend in both annual rainfall (Z= 1.00) and rainy days (Z=1.08). Both annual rainfall (Z= 0.66) and rainy days (Z= 0.34) showed increasing trend at Mulshi tehsil. Pune city tehsil showed increasing trend annual rainfall (Z= 0.53) and statistically significant increasing trend (Z= 2.49) in rainy days at 95 per cent confidence level. Purandar tehsil showed decreasing trend in both annual rainfall (Z= -1.09) and rainy days (Z= -19). Both annual rainfall (Z= 0.31) and rainy days (Z= 1.48) showed increasing trend at Shirur tehsil. In Vadgaon maval and Velhe tehsils, annual rainfall (Z=5.15 and Z= 4.28) and annual rainy (Z= 4.71 and Z= 4.39) days showed statistically significant increasing trend at 99 per cent confidence level.

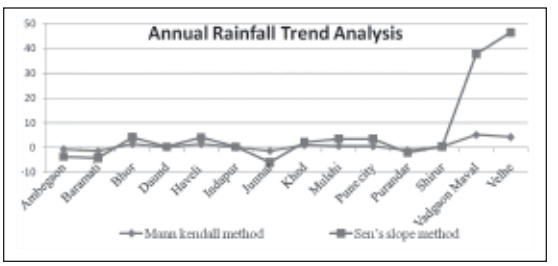

Fig. 2. Trend analysis for annual rainfall

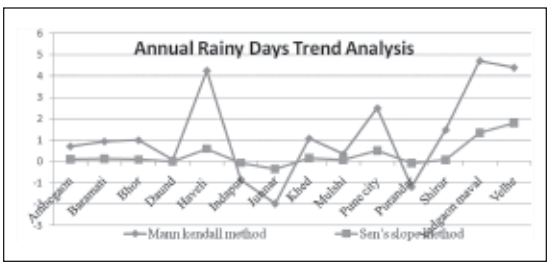

Fig. 3. Trend analysis for annual rainy days

Conclusion

The trend in annual rainfall over Bhor, Daund, Haveli, Khed, Mulshi, Pune city, Shirur, Vadgaon maval and velhe tehsils has been increased with increasing rainy days while, rainfall in Ambegaon, Baramati tehsils decreased with increasing rainy days and in Junnar and

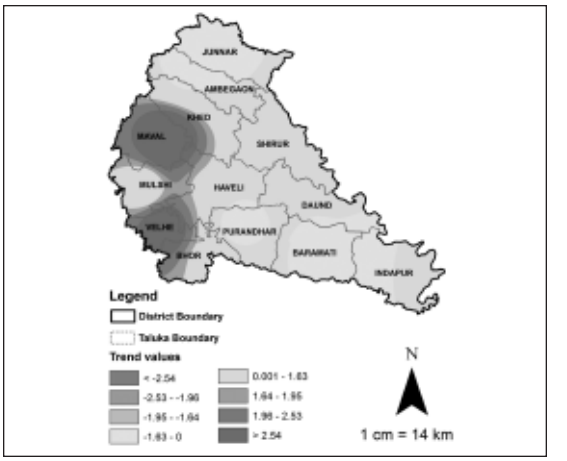

Fig. 4. Spatial variation in trends of annual rainfall shown through GIS based map

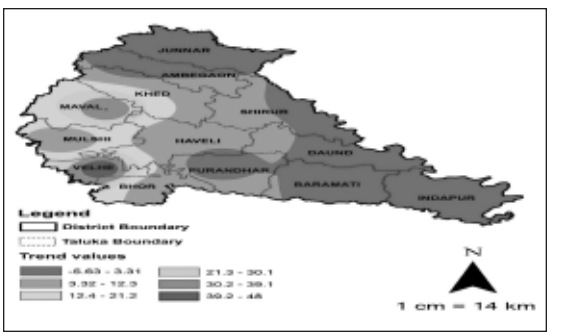

Fig. 5. Spatial variation in magnitude of trends in annual rainfall shown through GIS based map

Purandar tehsils it was decreased with decreasing rainy days. Indapur tehsil showed increasing annual rainfall trend with decreasing trend in rainy days. This shows the variation in rainfall trend in the overall district.

Appliation of Research: To study variation in rainfall, rainy days and giving tehsilwise suitable crop planning in the Pune district. The GIS based maps are useful in finding the spatial variation of trends over district.

Research category : Quantitative research

Abbreviation : IMD: India Meteorological Department; GIS: Geographical Information

System; et al: et alli (and others); Km: Kilometre; Km2: Kilometre square; No. : Number; mm: Millimetre; and 0C: Degree Celsius

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