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Estimation and evaluation of trend analysis of the Penman-Monteith reference evapotranspiration of Raipur region, Chhattisgarh central India

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सार – जल चक्र अध्ययन, प्रतिरूप और पानी के उपयोग के लिए वाष्पोत्सर्जन और इसके दीर्घकालिक प्रवृत्ति को समझना आवश्यक है। इसलिए जल संसाधनों के प्रबंधन के लिए वाष्पोत्सर्जन का कालिक विश्लेषण विशेष रूप से जलवायु परिवर्तन के संदर्भ में महत्वपूर्ण है। इस अध्ययन का उद्देश्य FAO द्वारा विकसित एक्वाक्रॉप मॉडल का उपयोग करके रायपुर क्षेत्र में वाष्पोत्सर्जन का मूल्यांकन करना है और वाष्पोत्सर्जन (ET_0) की प्रवृत्ति का विश्लेषण करना है। ET_0 में प्रवृत्तियों और आयाम परिवर्तनों का पता लगाने के लिए मान-केंडल परीक्षण और सेन ढलान का उपयोग किया गया था। औसत मासिक ET_0 मई में अधिकतम (8.91 मिमी/दिन) पाया गया, जबकि औसत न्यूनतम ET_0 दिसंबर में (1.91 मिमी/दिन) अनुमानित किया गया। अध्ययन क्षेत्र में औसत दैनिक संदर्भ वाष्पोत्सर्जन 2.49 मिमी प्रति दिन से लेकर 7.61 मिमी प्रति दिन तक होता है। मासिक समय के पैमाने पर परिणाम यह दर्शाते हैं कि अधिकांश महीनों में ET_0 डेटा में घटते रुझान की पहचान की गई। मार्च, अप्रैल और मई के लिए महत्वपूर्ण नकारात्मक प्रवृत्ति का परिमाण पाया गया। यह अध्ययन विभिन्न ऋतुओं में विभिन्न फसलों को उगाने के लिए पानी की जरूरतों पर वायुमंडलीय मांग पर आवश्यक जानकारी प्रदान करता है। विभिन्न ऋतुओं में सिंचाई समय-निर्धारण, सिंचाई जल प्रबंधन अध्ययन की योजना बनाने में शोधकर्ताओं और किसानों के लिए यह जानकारी बहुत महत्वपूर्ण होगी।

ABSTRACT. Understanding evapotranspiration and its long-term trends is essential for water cycle studies, modeling and for water uses. Temporal analysis of evapotranspiration is therefore important for the management of water resources, particularly in the context of climate change. The objective of this study is to evaluate reference evapotranspiration using the AquaCrop model developed by FAO and analyze the trend of reference evapotranspiration (ET_0) in the Raipur Region. Mann-Kendall test and Sen's slope were used to detect trends and amplitude changes in ET_0. The average monthly ET_0 was found maximum in May (8.91 mm/day), whereas the average minimum ET_0 was estimated in December (1.91 mm/day). The mean daily reference evapotranspiration ranges from 2.49 mm per day to 7.61 mm per day in the study area. Results show on the monthly time scale, decreasing trends were identified in ET_0 data in most of the months. A significant negative trend magnitude was found for March, April and May. This study provides the necessary information on atmospheric demand on water requirements for growing different crops in different seasons. This information will be very important for researchers and farmers in planning irrigation scheduling, irrigation water management studies in different seasons.

Key words – AquaCrop, Mann-Kendall, Sen's slope, Evapotranspiration, FAO.

1. Introduction

Reference crop evapotranspiration is a key component in hydrological studies. Accurate reference evapotranspiration (ET_0) data are essential to various investigations such as agricultural and forest meteorology, irrigation system and design, irrigation scheduling, drainage studies, hydrologic water balance, crop water requirement and water resources planning and management (Banihabib *et al.*, 2012, Kumar *et al.*, 2002). Rapidly growing population and limited water resources urge the need for efficient and sustainable use of water. This necessitates accurate estimation of evapotranspiration which forms the base point of precise assessment of crop water requirement and efficient irrigation water management. The availability of quality meteorological data is essential for precise ET_0 estimation since it is sensitive to changes orerrors in climatic parameters (Laberzki *et al.*, 2011; Aziz and Burn, 2006).

Crop water requirement in a region varies with the variation in these parameters. Studies suggest that crop water requirements would change in the future as a result of global warming and climate change (Patle *et al.*, 2019; Rai *et al*., 2010). As direct (lysimeter-based) field measurement of ET_0 is rarely available, ET_0 is generally estimated from theoretical predictive equations requiring meteorological data. There are several methods are available for the estimation of ET_0 in different climatic conditions. Among the various existing methods, Penman-Monteith was recommended by FAO as a standard method because of its performance under different types of climate (Bakhtiari *et al*., 2011; Kampata *et al*., 2008; Allen *et al.*, 1998). Reference evapotranspiration (ET_0) was estimated using the AquaCrop model developed by FAO.

In the present study, the procedure described by Mann (1945) for the non-parametric test of trend detection and the test statistic distribution given by Kendall (1945) for testing of nonlinear trends were adopted. The combined method is popularly known as the Mann-Kendall test (Partal and Kahya, 2006). The Mann-Kendall trend test, being a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers (Abiye *et al*., 2019; Jiao and Wang, 2018). This method is commonly used for trend analysis of meteorological and hydrological time series data. The change per unit time within the time series was estimated by non-parametric Sen's slope estimator (Sen, 1968). The major advantage of the Mann-Kendall test is that it is free from statistical distributions that are required for the parametric method. Due to its simplicity and broader application, World Meteorological Organization (WMO) has recommended this method to assess the monotonic trend in hydro-meteorological time-series (Bandyopadhayay *et al.*, 2009). Furthermore, most of the literature studies conducted in that area have focused on studying time changes in temperature and or rainfall (Chakraborty *et al.*, 2013; Jaiswal *et al*., 2015; Swain *et al*., 2015; Khavse *et al*., 2015). Therefore, identifying changes in ET_0 is necessary for future planning of agriculture water projects in this area. We used the historical climate data of 28 years to calculate ET_0, using the Penman-Monteith equation. The analyses of monthly ET_0 changes were carried out using Mann-Kendall and Sen Slope tests. These tests are used to demonstrate any presence of possible trends against the null hypothesis of having no trends.

2. Materials and method

The study was conducted using climatic data of Raipur district in Chhattisgarh state of India. The study area is located between 21°00' to 21°59' North latitudes and 82°27' to 82°13' East longitudes. Rice and wheat are the major cropping system practiced in the district. The climate of the district is subtropical monsoon type. It is characterized by hot summer and cold winter. The temperature starts rising from March and continues till June end. A major portion of the rainfall is received from July to September under the influence of the southwest monsoon.

The normal annual rainfall of the district is 1209 mm based on the record. The average annual minimum and maximum temperatures are 20.17 °C and 32.82 °C. The average annual relative humidity is 79.55%.

2.1. *Climate data collection*

The weather data required by the AquaCrop model for prediction of reference evapotranspiration of the study area were collected from the observatory of the Department of Agrometeorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur. The weather data set includes daily maximum temperature, minimum temperature, rainfall, mean relative humidity, wind speed and solar radiation for periods of 28 years (1992-2019). Other parameters like geographic location, *viz*., latitude, longitude and elevation were also obtained for the respective station.

2.2. *Estimation of Reference evapotranspiration*

AquaCrop is an empirical process-based, dynamic crop growth model developed to simulate biomass and yield response of herbaceous crops (*i.e*., field and vegetable crops) to water under varying management and environmental conditions (Mondall *et al*., 2012). It was developed by the Land and Water Division of Food and Agriculture Organization (FAO), Rome, Italy use as a practical tool for users such as farmers, agronomists, engineers and water managers. A model is also a valuable tool for conceptualization and analysis for research scientists (Hsiao *et al*., 2009). The model carries the calculation of evapotranspiration, crop productivity, water requirement and water use efficiency under water limiting

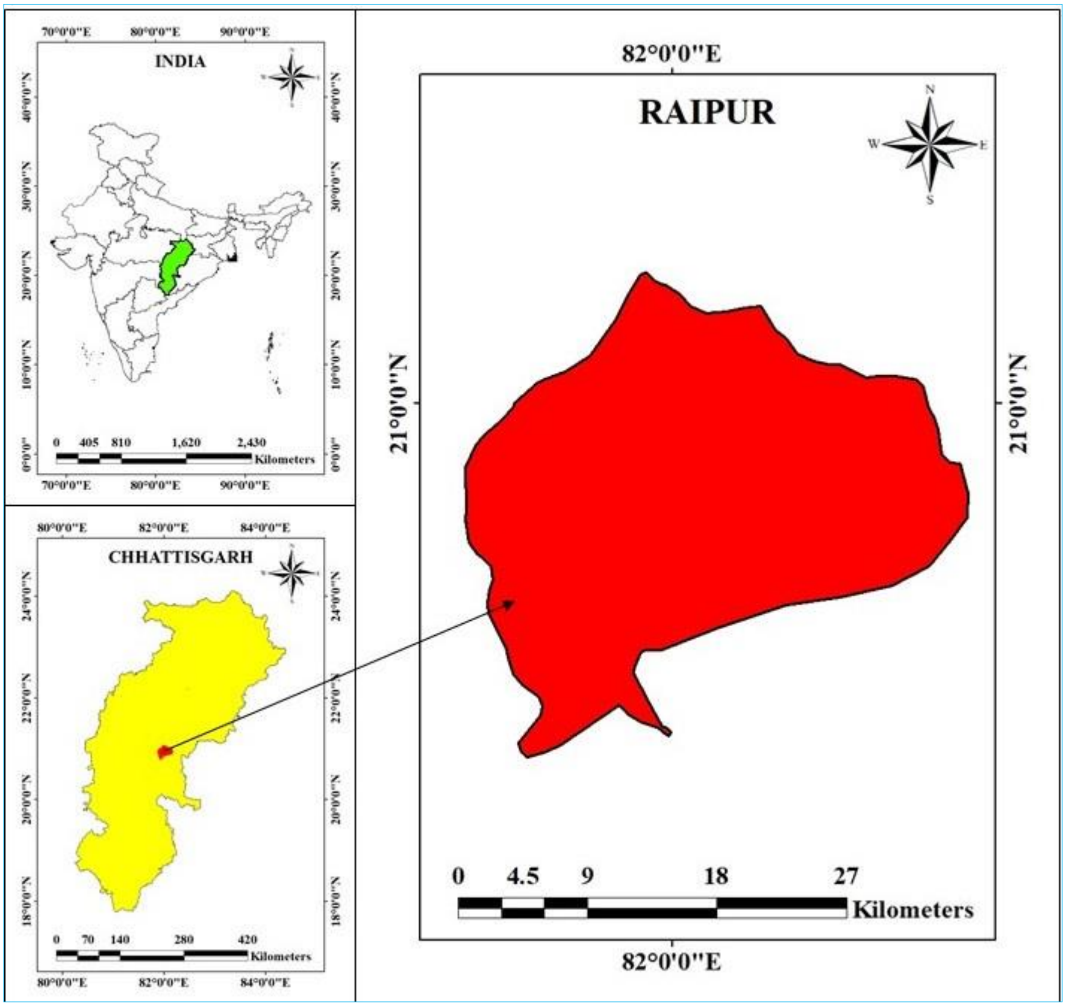


Fig. 1. Study area

conditions. AquaCrop can also be used to assess the effect of weather and climate on crop production and water used (Yadav *et al*., 2017).

AquaCrop uses the FAO Penman-Monteith method to calculate reference evapotranspiration. Among the various existing methods for estimating ET_0, Penman-Monteith is recognized as a standard method in all climatic conditions of the globe (Allen *et al.,* 1998). Reference evapotranspiration is derived from daily weather data sets includes maximum and minimum temperature (°C), mean relative humidity (%), wind speed (km/hr) and solar radiation ($MJ/m^2/day$). These data were tabulated in an excel sheet and converted to a text file to import into the model to use as an input parameter. An ET_0 calculator is available on the model that uses the FAO Penman-Monteith equation for the estimation of reference evapotranspiration (Phad *et al.*, 2020). The calculator accepts weather data given in a wide variety of units.

2.3. *Trend analysis*

Trend analysis of a time series consists of the magnitude of the trend and its statistical significance. This is a statistical method that is being used for studying the temporal trends of hydro-climatic series. The magnitude of trend in a time series is determined either using regression analysis (parametric test) or using Sen's estimator method (non-parametric method). Both these methods assume a linear trend in the time series (Salmi *et al*., 2002). Alinear equation, y = mt + c, defined by c (the intercept) and trend m (the slope), can be fitted by regression. The linear trend value represented by the slope of the simple least-square regression line provided the rate of rising/fall in the variable.

Sen's estimator has been widely used for determining the magnitude of trends in hydro-meteorological time series (Tabari *et al.*, 2011).

TABLE 1

Statistic of estimated reference evapotranspiration

Parameter	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum (mm)	1.93	3.18	4.02	5.59	6.46	4.25	3.00	2.89	2.91	3.02	2.51	1.81
Maximum (mm)	2.98	3.93	5.62	7.47	8.91	7.86	5.14	5.14	4.09	3.95	3.65	2.73
Mean (mm)	2.58	3.55	4.84	6.51	7.61	6.02	3.68	3.54	3.63	3.57	2.92	2.40
Std. Deviation (mm)	0.25	0.21	0.38	0.51	0.63	0.82	0.41	0.45	0.32	0.22	0.23	0.21

TABLE 2

Mann-Kendal trend test and Sen's slope estimator parameters

Months	Mann-Kendal trend test			Sen's slope					
				Slope			Intercept		
	Kendall's tau	S	*p*-value	Value	Lower bound (95%)	Upper bound (95%)	Value	Lower bound (95%)	Upper bound (95%)
Jan	-0.146	-55	0.286	-0.007	-0.019	0.004	15.998	5.562	28.104
Feb	-0.226	-85	0.097	-0.023	-0.041	-0.004	52.011	32.425	69.330
Mar	-0.307	-116	0.023	-0.022	-0.046	-0.002	49.877	30.653	74.275
Apr	-0.287	-108	0.034	-0.036	-0.064	-0.005	79.441	48.182	107.479
May	-0.321	-121	0.018	-0.014	-0.051	0.025	34.078	-5.418	71.513
Jun	-0.103	-39	0.453	-0.004	-0.021	0.011	11.562	-3.740	28.773
Jul	-0.077	-29	0.580	-0.014	-0.033	0.002	31.970	16.106	50.907
Aug	-0.239	-90	0.079	-0.009	-0.023	0.006	21.998	6.787	36.243
Sep	0.138	52	0.313	0.010	0.020	0.002	23.650	11.935	33.660
Oct	0.207	78	0.128	0.005	0.015	0.005	12.245	2.576	23.097
Nov	0.133	50	0.332	0.005	0.015	0.005	12.245	2.576	23.097
Dec	-0.126	-47	0.363	-0.003	-0.012	0.003	9.090	2.407	17.684

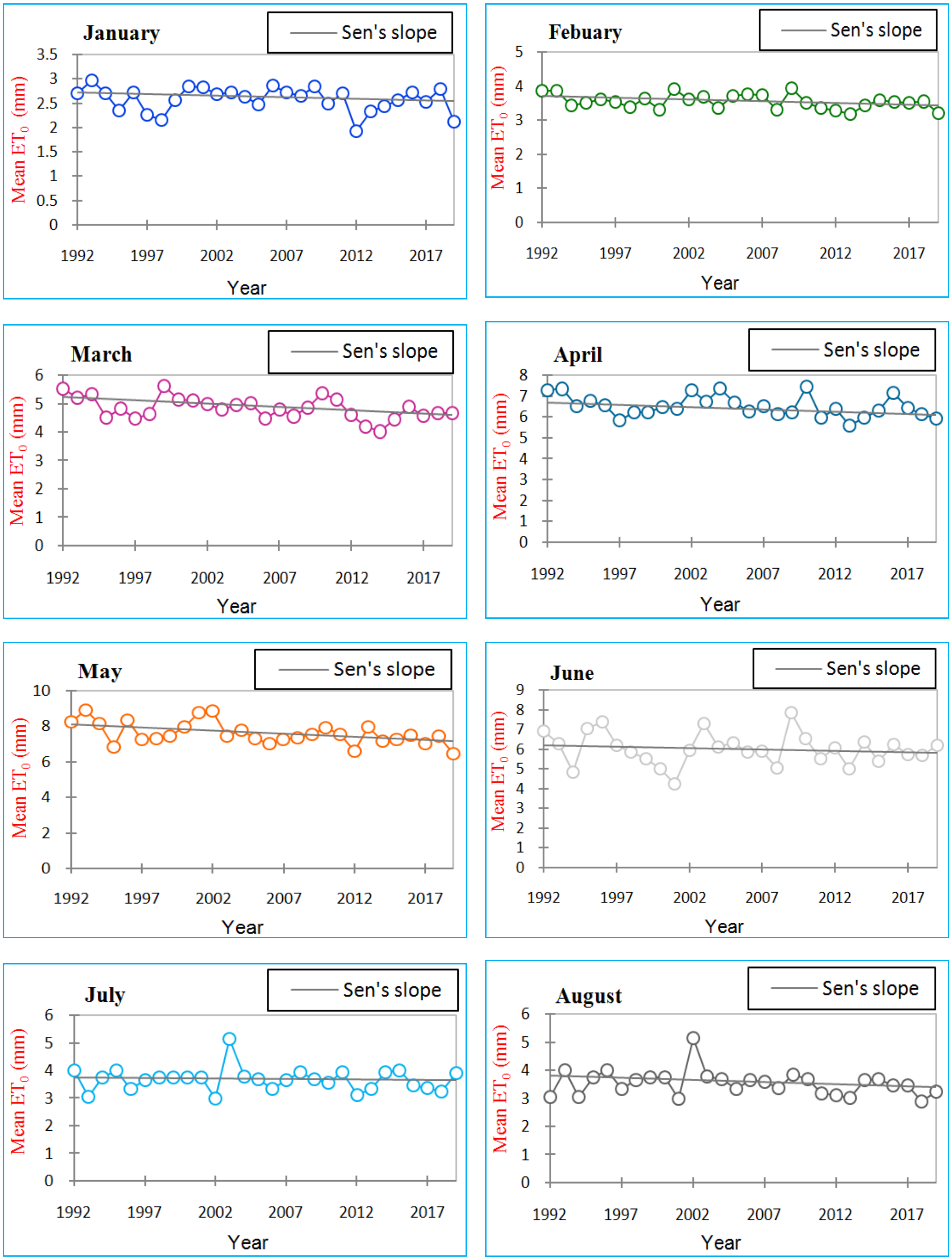
2.4. *Significance of trend*

The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of an increasing or decreasing trend (Mann, 1945; Kendall, 1945). Mann-Kendall test is preferred when various stations are tested in a single study (Bodian *et al*., 2020; Azizzadeh and Javan, 2015; Diop *et al*., 2018; Xu *et al*., 2006). Mann-Kendall test had been formulated as a non-parametric test for trend detection and the test statistic distribution had been given for testing non-linear trend and turning point (Hamed and Rao, 1998). The null hypothesis (H_0) for the Mann-Kendall test is that there is no trend or serial correlation among the analysed population against the alternative hypothesis (H_1), which assumes an increasing or decreasing monotonic trend. Mann-Kendall's statistical S is given by the following formula:

$$S = \sum_{j=1}^{j=n-1} \sum_{i=j+1}^{i=n} \operatorname{sign}\left(X_i - X_j\right)$$

where, X_i is the value of the variable at the time i and X_j is the value of the variable j, n is the length of the series and sign (X_i- X_j) is a function that is calculated as follows:

$$\operatorname{sign}\left(X_i - X_j\right) = \begin{cases} 1 & \text{if } \left(X_i - X_j\right) > 0 \\ 0 & \text{if } \left(X_i - X_j\right) = 0 \\ -1 & \text{if } \left(X_i - X_j\right) < 0 \end{cases}$$


January
Sen's slope
Mean ET0 (mm)
Year
Febuary
Sen's slope
Mean ET0 (mm)
Year
March
Sen's slope
Mean ET0 (mm)
Year
April
Sen's slope
Mean ET0 (mm)
Year
May
Sen's slope
Mean ET0 (mm)
Year
June
Sen's slope
Mean ET0 (mm)
Year
July
Sen's slope
Mean ET0 (mm)
Year
August
Sen's slope
Mean ET0 (mm)
Year

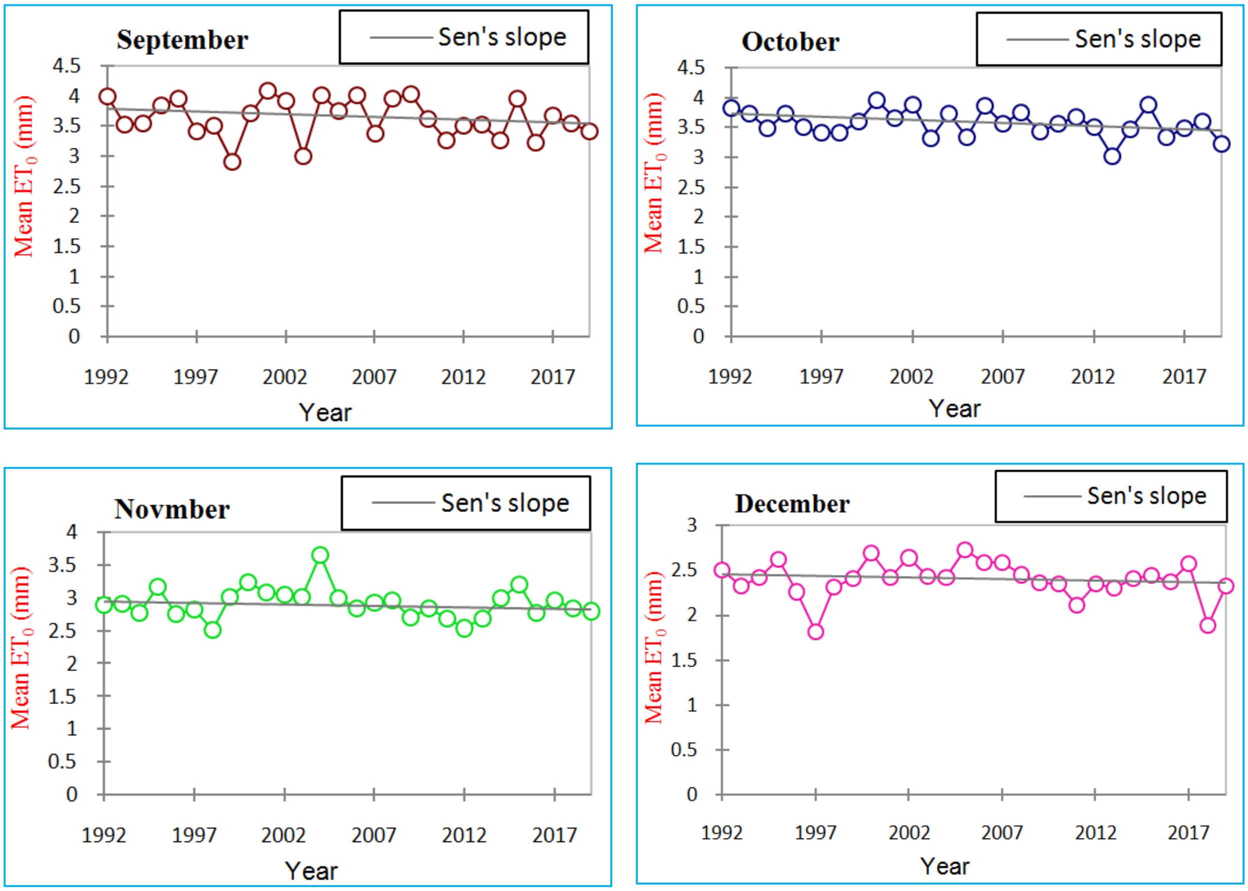


Fig. 2. Sen's slope estimator of the study area for 1992-2019

An upward or downward trend is given by the sign of the value Z (positive or negative) which is obtained from the variance of S which is obtained by this formula:

$$\text{Var}(s) = n(n\text{-}1)(2n + 5)/18$$

For n> 10, Z follows approximately a normal distribution and can be calculated as follows:

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{\text{var}(s)}} & \text{if } s > 0 \\ 0 & \text{if } s = 0 \\ \dfrac{s+1}{\sqrt{\text{var}(s)}} & \text{if } s < 0 \end{cases}$$

The trend obtained is measured according to its level of significance, *i.e.*, the probability associated with the rejection or not of the null hypothesis. In this study, the significance level of 0.05 is used. When $|Z|> 1.96$ the null hypothesis is rejected and the trend is significant at 5%. If a trend is noted in the data series, its amplitude can be determined by the slope of the trend (noted β). The method of Sen (Sen, 1968) is generally used to estimate the slope of the trend:

$$\beta = \text{Median}\left(\frac{X_i - X_j}{i - j}\right) \forall i < j$$

Where X_i and X_j are the data values at times i and j, respectively. A positive β value indicates an upward trend and a negative value indicates a downward trend.

3. Results and discussion

3.1. *Reference evapotranspiration*

From daily weather data, the monthly reference evapotranspiration ET_0 of the study area was calculated from 1992 to 2019. It can be seen (Table 1) that the monthly average reference evapotranspiration is highest during the month of May (8.91 mm per day) due to higher temperature, low relative humidity, high wind speed and more solar radiation in a summer month. Whereas minimum ET_0 was estimated at 1.81 mm per day in the month of December. Statistical analysis of estimated reference evapotranspiration is given in Table 1.

In the case of reference evapotranspiration, Mann-Kendall test parameters namely Kendall's tau, S statistic, Zc statistic and *p*-value of monthly reference evapotranspiration were calculated at a 95% confidence level. The results of the application of the Mann-Kendall and Sen's slope tests for trend identification of monthly ET_0 were summarized in Table 2. As shown, the ET_0 had a mixture of increasing and decreasing monthly trends. The results show that in the Mann-Kendall test the Zc statistics revealed the trend of the series for 28 years for individuals 12 months from January to December which is -0.146, -0.226, -0.307, -0.287, -0.321, -0.103, -0.077, -0.239, 0.138, 0.207, 0.133 and -0.126 respectively. The highest positive trend is observed during October which is 0.207. The highest negative trend (-0.321) is shown in January. The trend tests revealed that the decreasing trend was found during March, April and May were statistically significant. In summary, the results showed that the average monthly ET_0 for 28 years has an increasing trend for September, October and November and the rest of the months (January, February, June, July, August and December) showed a decreasing trend which is statistically not significant because of*p*-value is greater than the level of significance alpha (α = 0.05; 95% confidence level) for these months, which infers that there is no strong evidence to reject Null Hypothesis; H_0: there is no trend. The overall result of the study area shows that most of the months were in decreasing trend with no significance.

In this regard, Chakraborty *et al.*, 2013 used the Mann-Kendall test to analyzed reference evapotranspiration variability and trends in the shivnath river basin Chhattisgarh. Their result showed a significant increase in monthly ET_0 in September, October, November and the rest of the months show a decreasing trend with high variability.

4. Conclusions

The FAO Penman-Monteith method is recommended as the standard method for estimating reference evapotranspiration. The new method has been proved to have global validity as a standardized reference for grass evapotranspiration. This eliminates the use of other methods and increases the transparency and consistency of reference evapotranspiration. Results showed that the minimum and maximum values of ET_0 fluctuate around 1.81 and 8.91 mm/day. The highest values were observed in May and the lowest in December. Overall, the results of this study show that for a better estimation of ET_0, attention is required in the measurement of radiation and maximum temperature and the wind speed must also be taken seriously because it has a considerable impact on evapotranspiration. An increase in the ET_0 will increase crop water requirements, accentuate the water losses by evaporation in surface reservoirs, reduce the hydroelectricity producible and may lead to increased competition between different water uses. This research is based on a 28-year reanalysis dataset. Therefore, the short time series of climate data used may be a limitation of this study. Thus, it would be important to extend the time series when data are available for future researches. It would also be interesting in further investigation, to evaluate the impact of the topography, the dynamics of land use and hydraulic infrastructures and climate change on the trend of evapotranspiration in the study area.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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