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Trend Analysis of Reference Evapotranspiration (ETo) Using Mann-Kendall for South Konkan Region

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Abstract

The study explore trend of short crop ETusing 24 years dataand estimated using method suggested by Penman–Monteith method. The trends analysis was done by Mann–Kendall method and the Sen's Slope estimator. The study found that the south Konkan region has decreasing trend for all stations except the Harnai station. The magnitude of the trend was high for Wakawali and Mulde stations. The present study is very advantageous for development of existing water assets, irrigation system design, and irrigation scheduling and water balance studies of the study area.

Keywords: Evapotranspiration, M-K model, Sen's slope, Konkan region.

Introduction

In hydrological cycle, evapotranspiration is one of the most important components in addition to rainfall and runoff. In terrestrial ecosystems and atmosphere factor controlling energy and mass exchange, evapotranspiration is the third most important climatic variable. The reliable and accurate estimation of ETo is essential for many studies, e.g. water balance, rainfall-runoff modelling, farm water structure design and irrigation planning.

The trend detection of evapotranspiration time series impacts locality and seasonal distribution of water resources and help in proper management of water resources and hydrological studies[1]. The parametric and non-parametric approaches are used to detect distribution or trend at a fix level of importance. Various types of test such as non-parametric tests are used for trend detection along with some advantages and limitations. The M-K test and Sen's slope are widely used to detect trends and degree or concentration in time series of climatic and hydrological variables. In existing study the Mann-Kendall test (M-K test) is used for trend detection. The Mann-Kendall test, a function of the ranks of the observations rather than their actual values. The test is not affected by actual distribution of the data and less sensitive to outliers.

In recent years, different researchers examined and investigated possible influence of climate change on reference evapotranspiration (ET_0) and explored trends in ET_0. The study conducted by Xu *et al.* regarding trends for annual ETo and pan evaporation for Changjiang catchment. They found that there is a significant reduction in the net total radiation significant decline in the wind speed in Changjiangcatchment[2]. The M-K test was used to find the trend of reference evapotranspiration for different stations in India. The found that significant decreasing trend in evapotranspiration all over India. The decrease in trend is due significant rise in the relative humidity and reduction in wind speed[3].

The annual, seasonal and monthly trends of reference evapotranspiration in the western half of Iran were examined by Tabari *et al.* The study indicated a positive trend in ET in seventy per cent of the station. In winter and summer stronger increasing trends were identified in ETo data[4].

The abilities of MK and SR tests at the 5% significant level were used by Shadmani *et al* to find the ETo trends on temporal basis. The results claimed that ETo trends for some stations were positive and for some sites negative trends[5].

Gocic and Trajkovic analysed the trends atusing linear regression, MK and SR tests at the different significant level on temporal scales. The analysis showed that all trends were increasing at both 1 and 5 per cent level of significance. For most the stations significant increasing trends was observed in summer and 70% of the stations were increasing trends inseasonal and annual scale[6].

Koffi and Komla performed trend analyse using non-parametric statistics tests. The study found that significant increase in annual ETo at Tabligbo and Sokode stations. The declining trend was observed for precipitation/ETo ratio which results in increasing severity of the aridity index for all stations[7].

These researchers emphasized about the knowledge of evapotranspiration and its trend is essential for long-term water resources planning and proper water management. These studies also showed great importance of Mann-Kendall trend test for trend analysis. Considering the importance of these studies performed it was notice that the vital study on the trend in the changes in the evapotranspiration in Konkan region has not been performed. The study objective was to identify the temporal trends of short crop reference evapotranspiration and to find the magnitude using Theil-Sen's slope(β).

Methodology

Study area: The study was conducted for Konkan region. The Konkan region located between $15^{0}60'$ N to $20^{0}22'$ N latitude and $72^{0}39'$ E to $73^{0}48'$ E longitude. The Konkan region is a narrow terrain with width 60 km and length of 500 km with sea coast of 720 km in length. The region comprises districts of Thane, Raigad, Ratnagiri and Sindhudurg. The region spread over in two agro climatic zones of Maharashtra state. In present study the southern portion consisting Ratnagiri and Sindhudurg districts are considered. Three meteorological stations for each district are selected for trend analysis. The details of each station are depicted in Table-1.

Collection of meteorological data: The meteorological data required for estimation of evapotranspiration for different stations will be collected India Meteorology Department, Pune; Unit of Hydrology, Department of Water Resources (MS), Nasik; and Agricultural Meteorological Observatories, Dr. B.S.K.K.V., Dapoli. The meteorological data includes daily temperature (Tmax, Tmin.), Relative humidity (RHmax, RHmin.), sunshine hours (BSS), and wind velocity (WS) at 2 m height for a period of 24 years (1991 to 2014). Other parameters like geographic locations, viz, latitude, longitude and altitude were also obtained for respective stations.

Estimation of Reference Evapotranspiration (ETo): Reference evapotranspiration (ETo): In the present study the computation of reference evapotranspiration from meteorological data was done by FAO Penman-Monteith method (P-M method)[8].

The reference evapotranspiration was computed by assuming a short crop reference surface i.d. grass as hypothetical reference and as define by Allen[8].

$$ET_o = \frac{0.408\,\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma\left(1 + 0.34\,u_2\right)} \quad (1)$$

Where: ET_o is reference evapotranspiration [mm day^{-1}], T is mean daily air temperature at 2m height [ºC], R_n is net radiation at the crop surface [MJ m^{-2} day^{-1}], G is soil heat flux density [MJ m^{-2} day^{-1}], u_2 is wind sped at 2m height [m s-1], e_s is saturation vapour pressure [kPa], e_a is actual vapour pressure deficit [kPa], Δ is Slope vapour pressure curve [kPa ºC-1] and γ is psychrometric constant [kPa ºC-1].

Mann-Kendall test: Mann- Kendall non parametric test is used for trend analysis. This test method taken into consideration over the parametric one since it avoid the problem of data skewed. Mann-Kendall test had been formulated by Mann[9]and Kendall for testing non-linear trend. The Mann-Kendall statistic S is given as:

$$S = \sum_{t=1}^{n-1} \sum_{j=t+1}^{n} \left(sgn\left(x_j - x_i\right)\right) \quad (2)$$

The trend test is applicable to time series xi that is ranked from i = 1,2,………n-1 and xj, which is ranked from j = i+1,2,……….n. Each of the data point xi is taken as a reference point which is compared with the rest of the data point's xj so that,

$$sgn\left(x_j - x_i\right) = \begin{cases} +1 > (x_j - x_i) \\ 0 = (x_j - x_i) \\ -1 < (x_j - x_i) \end{cases} \quad (3)$$

When: n ≥, ∞ the statistic S is approximately normally distributed with the meanis zero. The variance statistic is given by var(s) where ti is considered as the number of ties up to sample i.

$$\text{Var (S)} = \frac{n(n-1)(2n+1) - \sum_{i=1}^{m} t_i (t+1)(2i+5)}{18} \quad (4)$$

A positive value of s indicates that there is a rising trend and vice versa. The critical test statistic values for various significance levels for observations are considered for different probability levels. The Zc is computed as

$$Z_C = \frac{|S|}{6^{0.5}} \quad (5)$$

Table-1
Salient features of different stations

District	Station	Latitude	Longitude	Altitude (m)	Data Period (Y)
Ratnagiri	Dapoli	17°54' N	72°5' E	250 m	24
	Wakawali	17°45' N	72°5' E	249 m	24
	Harnai	17°49' N	73°06' E	20 m	24
Sindhudurg	Vengurle	15°43' N	73°42' E	11 m	24
	Awalegaon	16°26' N	73°16' E	33 m	24
	Mulde	16°26' N	73°16' E	17 m	24

Theil-Sen's estimator: It estimates trend magnitude. The slope of n pairs of data points was estimated by Theil-Sen's estimator as follows

$$\beta = Median\ \frac{x_j - x_i}{j - i} \quad (6)$$

Results and Discussion

Reference evapotranspiration: The reference evapotranspiration for different stations was estimated using P-M method on daily basis arranged according the season and annual series. The seasonal analysis found that summer season contributes nearly 40 percent of reference evapotranspiration and remaining two seasons i.e. winter and rainy contributes nearly 30 per cent of ETo. The mean annual ETo was ranged from 1323.27 mm to 1523.19 mm for Harnai and Dapoli station. The coefficient of variation, which measures the distribution of data around the mean, of annual ETo varies from 2.25 to 7.02 per cent. The coefficient of variation was more for wakawali station for different seasons as compared to other stations. The skewness for different series was found between -2.11 to 0.94. For Wakawali and Mulde stations showed near normal distribution of ETo. The Kurtosis of all series ranged from -1.35 to 7.50. Positive value showed a peaked distribution while negative shows the flat distribution. The detailed statistics is depicted in Table-1.

Trend analysis: The summary of Mann-kendall analysis of different series is given in Table-3.The computed Z statistics shown in Table-3 with different levels of significance. The trend of ETo during summer was falling for all stations except the Harnai. The falling was highly significant for Wakawali and Mulde at 0.001 level of significance. The raising trend in ETo for Harnai station was not significant. The rainy season shows a decreasing trend for all stations except the Harnai. The Dapoli and Vengurle station shows no significant trend during the rainy season. The Wakawali and Mulde station shows decreasing trend at 0.05 level of significance. During the winter season all stations shows falling trend at different level of significance. The Vengurle station indicates no trend during winter season. The annual ETo trend for all stations was decreasing and highly significant except the Harnai station. These results showed that the annual reference evapotranspiration was declining over regions with significant level.

Magnitude of trends is estimated and depicted in Table-4. The positive value represents the increasing trend and vice-versa. From Table-4, it is observed that annual and seasonal ETo series, the Sen's slope is decreasing trend except the Harnai station. The maximum magnitude of annual ETo -12.43 mm/year was observed for Wakawali station followed by Mulde station and least for Dapoli (-0.857 mm/year). Sen slope estimator for Harnai station during summer, rainy and annual series is not significant. The maximum magnitude of ETo during summer was observed for Mulde station while for rainy season it observed for Awalegaon. For winter season the maximum decreasing trend of magnitude-5.028 mm/year was observed for Wakawali station.

Table-2
Statistical properties of ETo at different stations

Season	Mean	Max	Min	Median	Std. Dev	C.V.	Skew	Kurt	% cont
Dapoli									
Summer	535.37	581.18	479.23	536.93	24.97	4.66	-0.46	0.21	40.46
Monsoon	383.25	418.07	354.02	385.73	17.47	4.56	0.22	-0.69	28.96
Winter	404.65	424.58	355.73	408.83	15.16	3.75	-1.53	3.47	30.58
Annual	1323.27	1407.59	1268.80	1320.07	34.75	2.63	0.55	0.06	100.00
Wakawali									
Summer	549.79	636.13	488.84	549.35	43.40	7.89	0.32	-0.95	41.12
Monsoon	385.98	426.65	343.17	379.24	23.95	6.20	0.15	-1.15	28.87
Winter	401.35	478.72	344.56	395.03	37.47	9.34	0.44	-0.65	30.02
Annual	1337.12	1535.75	1202.80	1334.26	93.83	7.02	0.27	-0.75	100.00

Season	Mean	Max	Min	Median	Std. Dev	C.V.	Skew	Kurt	% cont
Harnai									
Summer	580.64	612.70	525.20	584.45	20.32	3.50	-1.15	1.63	38.12
Monsoon	433.94	475.11	386.63	429.56	25.71	5.92	-0.14	-0.79	28.49
Winter	508.61	546.99	458.82	508.72	25.97	5.11	-0.24	-1.15	33.39
Annual	1523.19	1595.09	1438.22	1520.89	49.43	3.25	0.07	-1.35	100.00
Vengrule									
Summer	569.26	619.89	536.74	564.16	22.96	4.03	0.80	-0.34	38.74
Monsoon	455.17	490.93	416.97	453.57	16.90	3.71	-0.11	0.08	30.98
Winter	444.89	469.28	379.69	447.94	17.71	3.98	-2.11	7.50	30.28
Annual	1469.33	1539.72	1408.64	1462.52	32.92	2.24	0.39	-0.24	100.00
Awalgaon									
Summer	589.08	647.43	551.13	585.11	29.42	4.99	0.47	-0.96	39.93
Monsoon	437.84	492.51	381.16	440.61	29.42	6.72	-0.35	-0.47	29.68
Winter	448.41	487.48	375.86	452.31	24.53	5.47	-0.97	1.89	30.39
Annual	1475.33	1575.47	1369.32	1469.93	64.52	4.37	-0.10	-1.10	100.00
Mulde									
Summer	547.55	640.14	493.72	545.25	36.31	6.63	0.57	0.36	39.91
Monsoon	398.46	447.07	357.41	400.64	26.15	6.56	0.21	-0.93	29.05
Winter	425.80	501.07	382.46	420.31	30.59	7.18	0.94	0.34	31.04
Annual	1371.81	1517.13	1248.54	1357.89	79.63	5.80	0.37	-0.77	100.00

Table-3
Mann-Kendall trend analysis of ETo (Z value)

Season	Dapoli	Wakawali	Harnai	Vengurle	Awalegaon	Mulde
Summer	↓	↓***	↑	↓*	↓*	↓***
Rainy	↓	↓*	↑	↓	↓**	↓*
Winter	↓	↓***	↓*	↔	↓***	↓***
Annual	↓	↓***	↔	↓*	↓***	↓***
↑ Rising ; ↓ Falling; ↔ No trend; * 0.05 level of significance						

Table-4
Sen's slope estimator (β) of ETo

Season	Dapoli	Wakawali	Harnai	Vengurle	Awalegaon	Mulde
Summer	-0.943	-5.820	0.66	-1.219	-2.144	-3.755
Rainy	-0.147	-1.677	0.702	-0.479	-2.726	-2.045
Winter	-0.138	-5.028	-1.793	-0.014	-1.990	-3.563
Annual	-0.857	-12.43	0.011	-1.908	-7.256	-9.942

Conclusion

The study has been carried out to explore the trend of ETo for different stations of south Konkan region. The trend analysis is carried using the M-K test and Sen's slope. The analysis found that, trend of ETo in summer, rainy, winter and annual series is decreasing for all stations expect the Harnai station. The magnitude of trend is more for Wakawali and Mulde stations with significant level. The study found usefulness of trend analysis in terms of irrigation water management and irrigation scheduling and also helps for planning of water resources of the region.

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