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Estimation of Pan Evaporation Using Mean Air Temperature and Radiation for Monsoon Season in Junagadh Region

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ABSTRACT
The significance of major meteorological factors, that influence the evaporation were evaluated at daily time-scale for monsoon season using the data from Junagadh station, Gujarat (India). The computed values were compared. The solar radiation and mean air temperature were found to be the significant factors influencing pan evaporation (E_p). The negative correlation was found between relative humidity and (E_p), while wind speed, vapour pressure deficit and bright sunshine hours were found least correlated and no longer remained controlling factors influencing (E_p). The objective of the present study is to compare and evaluate the performance of six different methods based on temperature and radiation to select the most appropriate equations for estimating (E_p).
The three quantitative standard statistical performance evaluation measures, coefficient of determination (R^2), root mean square of errors-observations standard deviation ratio (RSR) and Nash-Sutcliffe efficiency coefficient (E) are employed as performance criteria. The results show that the Jensen equation yielded the most reliable results in estimation of (E_p) and it can be recommended for estimating (E_p) for monsoon season in the study region.
Keywords - *Pan* evaporation, Meteorological variables; evaporation estimation methods.

I. INTRODUCTION

Evaporation is influenced by many meteorological parameters and it is major component of the hydrological cycle. Estimation of evaporation amount is very important in water resources planning and management, design of reservoirs, assessment of irrigation efficiency, evaluation of future drainage requirements, quantification of deep percolation losses and water supply requirements of proposed irrigation projects. The rate of evaporation from a saturated soil surface is approximately the same as that from an adjacent water surface of the same temperature (e.g. [1]). Therefore, in many studies the estimation methods of free-water evaporation are also used for estimating potential evaporation (e.g. [2]; [3]). Moreover, potential evapotranspiration, together with precipitation, are the inputs to most hydrological models. Evaporation depends on the supply of heat energy and the vapour pressure gradient, which, in turn, depends on meteorological factors such as temperature, wind speed, atmospheric pressure, and solar radiation, quality of water and the nature and shape of evaporation surface (e.g. [4]). These factors also depend on other factors, such as geographical location, season, time of day, etc. Thus, the process of evaporation is rather complicated.

Because of its nature, evaporation from water surfaces is rarely measured directly, except over relatively small spatial and temporal scales [5]. Evaporation can be directly measured from pan evaporation (E_p) and lysimeter. But, it is impractical to place evaporation pans in inaccessible areas where accurate instruments cannot be established or maintained. A practical means of estimating the amount of evaporation where no pans are available is of considerable significance to the hydrologists, agriculturists and meteorologists.

In the direct method of measurement, Class A Pan evaporimeter and eddy correlation techniques were used [1], whereas in indirect methods, the evaporation is estimated from other meteorological variables like temperature, wind speed, relative humidity and solar radiation [6]. Many methods for estimation of evaporation losses were reported and which can be classified into five groups: (i) water budget [7], (ii) mass-transfer [8], (iii) combination [9], (iv) radiation [10], and (v) temperature based (e.g. [11]; [12]). Overviews of many of these methods are found in review papers or books (e.g., [13]; [14]; [15]; [16] and [17]).

In an earlier study, [18] evaluated and compared 13 evaporation equations, belonged to the category of mass-transfer method, and a generalized model form for that category was developed. [19] further examined the sensitivity of mass-transfer-based evaporation equations to evaluate errors in daily and monthly input data. [20] analysed the dependence of evaporation on various meteorological variables at different time scales. Radiation-based and temperature based evaporation methods were evaluated and generalised in the study of ([21] and [22]).

In this study, dependency of controlling variables is analysed, compared and then based on dependency, appropriate equations are selected. The selected methods are compared and evaluated, with their optimised parameters values. Finally, the overall applicability of the selected methods is examined in the order of their predictive ability for the study region.

II. STUDY AREA AND DATA

Data of the Junagadh meteorological station located in the Gujarat state of India were used in this study. This station is located at latitude of 21^0 $31^{'}$ N and a longitude of 70^0 $33^{'}$ E, 61 m msl. The region (**Fig. 1**) is situated in semi-arid region; the mean annual precipitation for the region varies from a maximum of 1689.70 mm to minimum of 425 mm with an average value of 940 mm. The Junagadh region is characterized by a semi-arid climate, with warm and dry summers and mild winter conditions. Mean maximum temperature ranges from 33.23 ^{0}C to 34.91 ^{0}C and Mean minimum temperature ranges from 19.44 ^{0}C to 29.67 ^{0}C. The highest annual wind speed was 13.6 km/h occurred in April, 2000 and 14.1 km/h in April, 2001 whereas the lowest annual wind speed was 8.6 km/h which occurred in October, 2001. The humidity has been changed between 88 % and 63%.

Daily meteorological data, including air temperature, wind speed, relative humidity, bright sunshine hours and evaporation for monsoon season for period of 21 years (1992-2012) were collected from Agro meteorological Cell, Junagadh Agricultural University. The associate parameters like solar radiation and vapour pressure deficit were computed with standard meteorological formula as described in FAO.

III. DEPENDENCE OF EVAPORATION ON METEOROLOGICAL VARIABLES

For better comparative evaluation, the dimensionless standardized values of each variable were computed and compared by using the transformation shown in equation (1).

$$Z_i = \frac{(X_i - \mu)}{\sigma} \quad (1)$$

Where X is a variate, i is the i^{th} value, μ is the mean of X and σ is the standard deviation of X. In view of the above considerations, this paper first analysed and compared the roles of controlling variables influencing (E_p) with daily time-scale for monsoon season. The dominating factors affecting evaporation for daily time-scales are determined, which then forms the basis for choosing the evaporation estimation method suitable for monsoon season. Dependence of evaporation on different meteorological variables at daily time-scales is presented in (**Fig. 2-7**). The dependence of evaporation on mean air temperature (T_{mean}) and radiation (R_s) are shown in **Fig. 2 and 3** for daily time-scales. It is readily apparent that, mean air temperature (T_{mean}) and radiation (R_s) with R^2 values 0.88 and 0.68 respectively, remain as controlling factors of evaporation. Hence, the temperature and radiation based methods for evaporation estimation comparatively gives good results. The dependence of evaporation on relative humidity (RH) is shown in (**Fig. 4).** A negative correlation exists between RH and (E_p) with R^2 value 0.32. It is perceived from (**Fig. 5), (Fig. 6)** and (**Fig. 7)** that vapour pressure deficit (VPD) (R^2 value 0.45), wind speed (WS) (R^2 value 0.17) and bright sunshine hours (BSS) (R^2 value 0.17) are no longer remain a significant factors. Based on the previous discussion and the availability of meteorological data, temperature-based method and radiation-based method were selected for investigation of their suitability for estimation of evaporation. The equations and the climatological data requirements for each of these methods are shown in (**Table 1)**.

IV. STATISTICAL CRITERION

To assess the performances of selected methods, three quantitative standard statistical performance evaluation measures, coefficient of determination (R^2), root mean square of errors-observations standard deviation ratio (RSR) and Nash-Sutcliffe efficiency coefficient (E) are employed as performance criterion. In general, model simulation can be judged as ''satisfactory'' if (R^2 and E) > 0.50 and RSR < 0.70.

V. RESULT AND DISCUSSION

The performances of temperature based methods ([11], [23] and [24]) and radiation based methods ([25], [26] and [27]) against mean daily observed pan evaporation data were evaluated by using selected statistical performance criterion and the results are presented in **(Table 2)**. The original empirical formulae may be reliable in the areas and over the periods for which they were developed, but large errors, can be expected when they are extrapolated to other climatic areas without recalibrating their parameters. Accordingly, modifications are made to the original equations used here to improve the results. The parameters of equations are computed and optimised using Microsoft Excel spread sheet, Microsoft Excel built-in optimisation tool Solver [28]. The optimised values of parameters of selected methods are presented in **(Table 3).**

As far as (E) values are concerned, Fooladmand method yielded lowest (E) values (0.40 and 038 in calibration and in simulation respectively). Turc method produced (E) value 0.41 in simulation.

When the R^2 values are compared, except Turc method (R^2 value 0.36 in calibration and 0.49

in simulation), remaining all the methods correlated well with pan evaporation.

The Fooladmand and Turc methods have the highest RSR values 0.79 in calibration and 0.81 in simulation respectively. The radiation based Jensen method has the lowest RSR values 0.37 in calibration and 0.26 in simulation.

It can be seen that the radiation based Jensen method is yielded the highest (E) values 0.86 in calibration and 0.93 in simulation respectively and the lowest RSQ values 0.37 in calibration and 0.26 in simulation respectively. This means radiation based Jensen method has a strong relationship with evaporation for monsoon season. The fitted equations for monsoon season with optimised parameter values are expressed in equation (2).

Fitted (Jensen Equation)

$$\mathbf{E_p} = (0.2203\ \mathbf{T_a} - 4.7588)\mathbf{R_s} \quad (2)$$

In order to examine performance of the Jensen methods, its estimated results in calibration and in simulation versus the corresponding observed evaporations are plotted in (**Fig. 8)** and (**Fig. 9)** respectively.

VI. CONCLUSION

The evaporation estimates obtained from six selected methods viz. Thornthwaite, Kharrufa, Fooladmand, Turc, Jensen and Hargreaves are compared to the observed pan evaporation, for Junagadh region of Gujarat (India). Three statistical criterions (E), RSR and R^2 have been used to evaluate the performance of the selected methods and to establish the optimal parameters. Among the selected six methods, the radiation based Jensen method is found to be the most suitable for estimating (E_p) in this study area, for monsoon season based on the entire evaluation criterion. Therefore, a practical point of view, this method can be considered suitable to serve as a tool to estimate evaporation for rainfall-runoff models in this region.

VII. ACKNOWLEDGEMENTS

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Fig. 1 Junagadh Region of Gujarat State

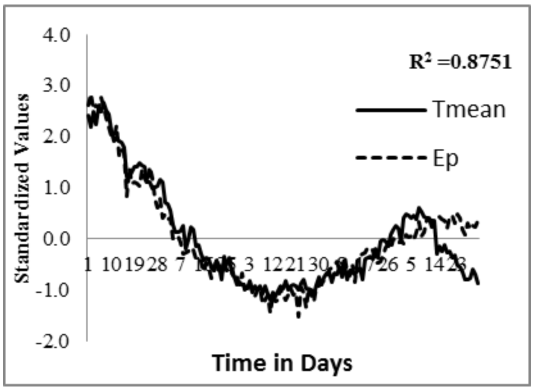

Fig. 2 Dependence of E_p on T_{mean} at Daily time-scale

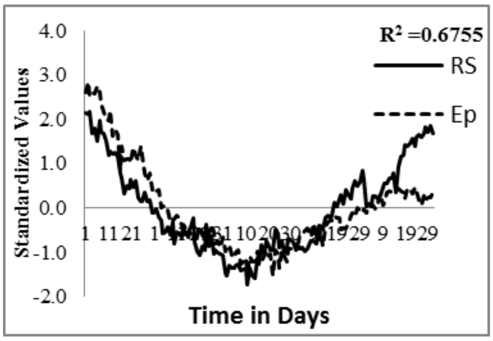

Fig. 3 Dependence of E_p on R_s at Daily time-scale

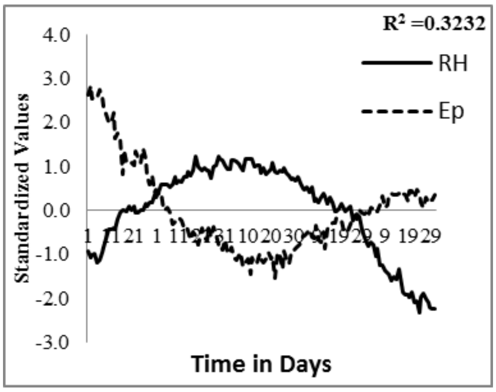

Fig. 4 Dependence of Ep on RH at Daily time-scale

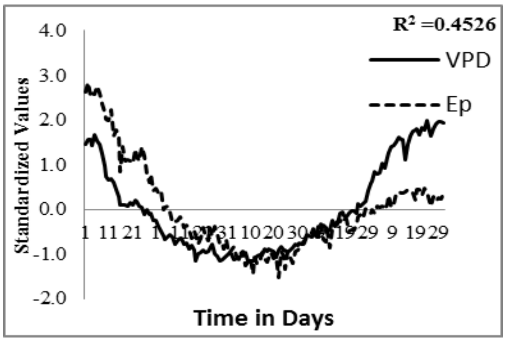

Fig. 5 Dependence of Ep on VPD at Daily time-scale

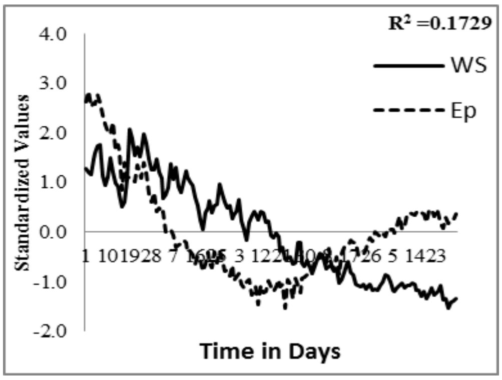

Fig. 6 Dependence of Ep on WS at Daily time-scale

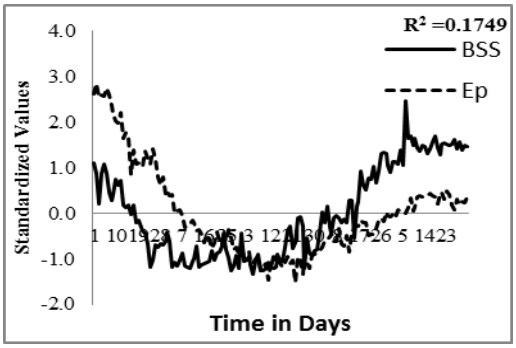

Fig. 7 Dependence of Ep on BSS at Daily time-scale

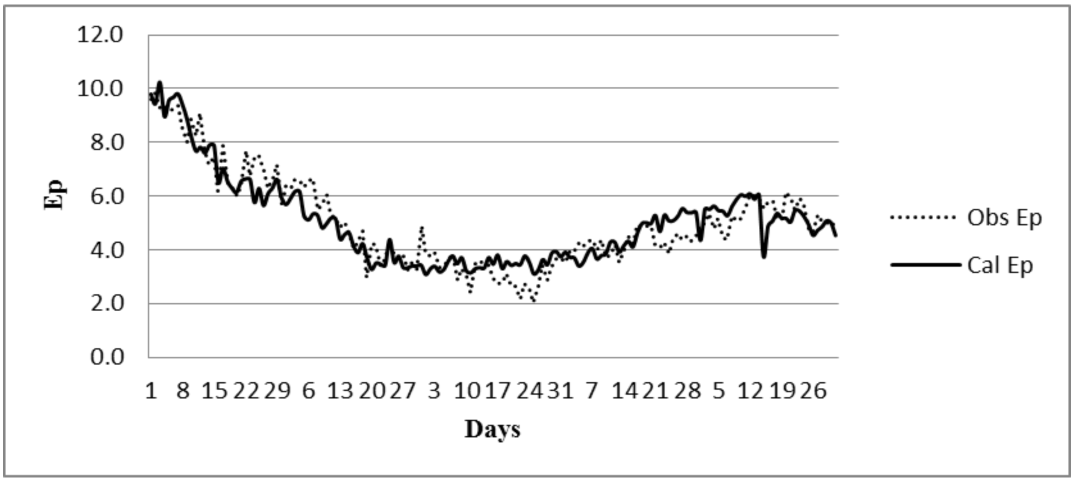

Fig. 8 Performance of fitted Jensen equation in Calibration

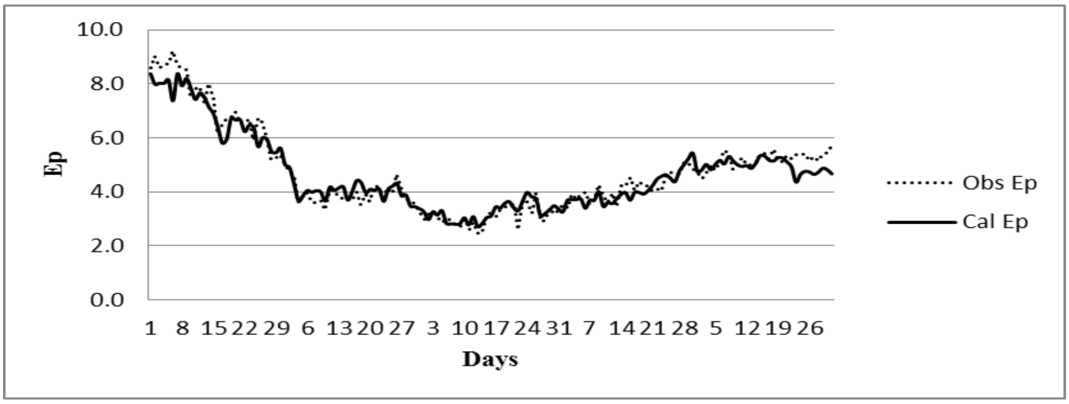

Fig. 9 Performance of fitted Jensen equation in Simulation

Table 1. Equations and Climatological data requirements of selected methods for calculation of evaporation

Reference	Equation	Climatological data requirements
Thornthwaite (1948)	$ET = C\left(\frac{10T_a}{I}\right)^a, I = \sum_{j=1}^{12} i_j, i = \left(\frac{T_a}{5}\right)^{1.51}$, C=16 $a = 67.5 X 10^{-8} I^3$-$77.1 X 10^{-6} I^2 + 0.179I + 0.492$	Temperature
Kharrufa (1985)	$ET = 0.34\, p(T_a)^{1.3}$	Temperature
Fooladmand and Ahmadi (2009)	$ET = (a + 8.13bp) + (0.46p)T_{eff}$ $T_{eff} = \frac{1}{2}\, k\,(3T_{max} - T_{min})$	Temperature
Turc (1961)	$when\ RH < 50\%$ $ET = 0.0133\frac{T_a(R_s + 50)}{(T_a + 15)}$ $when\ RH > 50\%$ $ET = 0.0133\frac{T_a(R_s+50)}{(T_a+15)}(1 + \frac{50-RH}{70})$	Radiation, Relative Humidity and Temperature
Jensen and Haise (1963)	$PE = (0.14\, T_a - 0.37)R_s$	Radiation and Temperature
Hargreaves (1994)	$ET = 0.0023\,(T_{max} - T_{min})^{0.5}(T_{max} + 17.8)R_a$	Radiation and Temperature

T_a = Mean Air temperature in ^{0}C, R_s = Solar radiation in MJ/m^2/day, RH = Relative humidity in %, R_a = Extra-terrestrial radiation in in MJ/m^2/day, p = Monthly percentage of hours of bright sunshine in the year, I = Heat Index, T_{eff} = Effective temperature, T_{max} = Maximum air temperature in ^{0}C, T_{min} = Minimum air temperature in ^{0}C and ET = Evaporation in (mm)

Table 2. Performance of selected Methods

Methods	Calibration			Simulation		
	E	RSR	R^2	E	RSR	R^2
Thornthwaite	0.82	0.42	0.83	0.79	0.45	0.83
Kharrufa	0.78	0.46	0.78	0.74	0.51	0.75
Fooladmand	0.40	0.77	0.78	0.38	0.79	0.81
Turc	0.82	0.81	0.36	0.41	0.76	0.49
Jensen	0.86	0.37	0.86	0.93	0.26	0.95
Hargreaves	0.63	0.61	0.76	0.68	0.56	0.88

Table 3. Selected Equations with optimised parameters	
Reference	**Equation**
Thornthwaite (1948)	$ET = 12.0312\left(\frac{10T_a}{I}\right)^{4.7734}$, $I = \sum_{j=1}^{12} i_j$, $i = \left(\frac{T_a}{5}\right)^{1.51}$, $a = 67.5\,X\,10^{-8}I^3$-$77.1\,X\,10^{-6}I^2 + 0.179I + 0.492$
Kharrufa (1985)	$ET = 0.0000017\ p(T_a)^{4.7687}$
Fooladmand and Ahmadi (2009)	$ET = (8.13\ X\ 0.041p) + (0.46p)T_{eff}$ $T_{eff} = \frac{1}{2}\ 0.0439\ (3T_{max} - T_{min})$
Turc (1961)	$when\ RH < 50\%$ $ET = 0.1648\frac{T_a(R_s + 50)}{(T_a + 15)}$ $when\ RH > 50\%$ $ET = 0.1648\frac{T_a(R_s+50)}{(T_a+15)}(1 + \frac{50-RH}{70})$
Jensen and Haise (1963)	$PE = (0.2203\ T_a - 4.7588)R_s$
Hargreaves (1994)	$ET = 0.0095\ (T_{max} - T_{min})^{0.5}(T_{max})R_a$