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# Dependence of evaporation on meteorological variables at daily time-scale and estimation of pan evaporation in Junagadh region

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***Abstract: -*** The significance of six major meteorological factors, that influence the evaporation were evaluated at daily time-scale using the data from Junagadh station, Gujarat (India). The computed values were compared. The solar radiation, maximum air temperature and vapour pressure deficit 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 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 four different methods to select the most appropriate equations for estimating ($E_p$).

The Nash-Sutcliffe efficiency coefficient (E) and refined Willmott's index ($d_r$) are used as performance criterion. The results show that the Jensen equation (radiation based) yielded the most reliable results in estimation of ($E_p$), especially for monsoon season. The Linacre equation (temperature based) produced reliable estimates for summer and post-monsoon season. The Penman equation (mass transfer based) and the Jensen equation resulted better for winter season while the Romanenko equation (humidity based) found comparatively less reliable. The prediction equations fitted for different seasons and annual basis can be recommended for estimating ($E_p$) in the study region.

***Keywords: -*** *Pan evaporation; Meteorological variables; Evaporation estimation methods*

## I. INTRODUCTION

Evaporation is influenced by number of agro-meteorological parameters and it is one of the integral major components of the hydrological cycle. Estimation of evaporation amount is very important for monitoring, survey and management of water resources, especially in arid and semi-arid areas where resources are scares and seriously endangered by overexploitation [22]. Usually, estimates of evaporation are needed in a wide array of problems in agriculture, hydrology, agronomy, forestry and land resources planning, such as water balance computation, irrigation management, crop yield forecasting model, river flow forecasting, ecosystem modelling. Irrigation can substantially increase crop yields, but again the scheduling of the water application is usually based on evaporation estimates. It 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, solar radiation, quality of water, and the nature and shape of evaporation surface (e.g. [14]). 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 [12]. 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.
Numerous investigators developed models for estimation of evaporation. Unfortunately, reliable estimates of evaporation are extremely difficult to obtain because of its complexity. Many methods for estimation of evaporation losses from free water surfaces were reported and it can be divided into several categories including: empirical methods (e.g. [24]), radiation (e.g. [2]), water budget methods (e.g. [33], [20]), energy budget methods (e.g. [10]), mass-transfer methods (e.g. [17]); temperature based (e.g. [4]; [18]); and

combination methods (e.g. [19]). In the direct method of measurement, the observation from Class A Pan evaporimeter and eddy correlation techniques were used [27], whereas in indirect methods, the evaporation is estimated from other meteorological variables like temperature, wind speed, relative humidity and solar radiation [23]. Overviews of many of these methods are found in review papers or books (e.g., [32]; [29]; [26]; [15] and [13]). Many equations for determining evaporation are available. The wide range of data types and expertise are needed to use these equations correctly, hence, it is difficult to select the most appropriate evaporation method for a given study. Therefore, there is a need to analyse and compare the different existing popular evaporation models and to develop a generalized model form.

In an earlier study, [30] evaluated and compared 13 evaporation equations, belonged to the category of mass-transfer method, and a generalized model form for that category was developed. [31] further examined the sensitivity of mass-transfer-based evaporation equations to evaluate errors in daily and monthly input data. [5] 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 [6 and 7]. In this study, the existing 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 COLLECTION

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 (Figure 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 21 years (1992-2012) were collected from Agro meteorological Cell, Junagadh Agricultural University. The associate parameters like solar radiation, dew point temperature 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 (01).

$$Z_i = \frac{(X_i - \mu)}{\sigma} \qquad (01)$$

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 analyses and compares the roles of controlling variables influencing pan evaporation with daily time-scale. The dominating factors affecting evaporation for daily time-scales are determined, which then forms the basis for choosing the evaporation estimation method suitable for different seasons. After that, different methods, which include temperature, humidity, mass-transfer, and radiation methods, are examined and compared. The comparisons are shown in (Figure 2-7). (Figure 2-4), show that the radiation ($R_s$), maximum air temperature ($T_{max}$) and vapour pressure deficit (VPD) with $R^2$ values 0.86, 0.75 and 0.66 respectively, remain as controlling factors of evaporation. Hence, the radiation based, temperature based and mass transfer based methods for evaporation estimation comparatively give good results. The dependence of evaporation on relative humidity (RH) is shown in (Figure 5). A negative correlation exists between RH and ($E_p$) with $R^2$ value 0.25. It is perceived from (Figure 6) and (Figure 7) that wind speed (WS) ($R^2$ value 0.17) and bright sunshine hours (BSS) ($R^2$ value 0.38) are no longer remain a significant factors.

## IV. EVAPORATION ESTIMATION METHODS

Many forms of the equation have been applied for estimating evaporation around the world. They can be categorised into five major types of approach - based on water budget methods, temperature methods, humidity methods, radiation methods, mass transfer (or aerodynamic) methods or combination (energy budget and aerodynamic) methods. Unfortunately, most of the reliable methods are parameter rich methods and therefore, not feasible for application in data scarce regions. On the other hand, accuracy and reliability of simple methods vary widely according to regional climate conditions. Therefore, it is difficult for many scientists to select the most suitable equation to use for a given study. Due to inaccuracy and unreliability in estimation of the seepage rate, the water budget method was not used in the study. The equations and climatological data requirements of selected methods are shown in (Table 1).

## V. STATISTICAL CRITERION

To assess the performances of selected methods, dimensionless statistic Nash-Sutcliffe efficiency coefficient (E) [21] is used. (E) is computed as shown in equation (02).

$$E = 1 - \frac{\sum_1^n (O_i - P_i)^2}{\sum_1^n (O_i - \overline{O_i})^2} \qquad (02)$$

Where $O_i$ is the observed $E_p$ at time t = i; $P_i$ is simulated $E_p$ at time i; $\overline{O_i}$ mean observed $E_p$ and n is the number of observations. Values of (E) between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values less than 0.0 indicate unacceptable performance. (E) is recommended for two major reasons: (i) it is recommended by [1] and [8], and (ii) it provides extensive information on reported values.

The refined Willmott's index [3] method is applied to quantify the degree to which observed values of evaporation are captured by the selected methods. The refined Willmott's index ($d_r$) is expressed as shown in equation (03).

$$d_r = 1 - \frac{\sum_1^n |O_i - P_i|}{2\sum_1^n |O_i - \overline{O_i}|}, \text{ when } \sum_1^n |O_i - P_i| \le 2\sum_1^n |O_i - \overline{O_i}|$$

$$d_r = \frac{2\sum_1^n |O_i - \overline{O_i}|}{\sum_1^n |O_i - P_i|} - 1, \text{ when } \sum_1^n |O_i - P_i| > 2\sum_1^n |O_i - \overline{O_i}| \qquad (03)$$

The range of ($d_r$) is from -1.0 to 1.0. A ($d_r$) of 1.0 indicates perfect agreement between model and observation, and a ($d_r$) of -1.0 indicates either lack of agreement between the model and observation or insufficient variation in observations to adequately test the model.

## VI. PARAMETER ESTIMATION

In this study, the objective function of minimising sum of squares errors between observed and computed $E_p$ (equation (04)) is selected to optimise the values of model parameters.

$$\mathbf{E_{min}} = \mathbf{Min} \sum_{i=1}^{n} \left| \mathbf{E_{po}} - \mathbf{E_{pc}} \right|^2 \qquad (04)$$

Where $E_{po}$ is the observed $E_p$; $E_{pc}$ is calculated $E_p$ and n is the number of observations. The parameters of equations are computed and optimised using Microsoft Excel spread sheet, Microsoft Excel built-in optimisation tool Solver [16].

## VII. RESULT AND DISCUSSION

The performances of [11], [25], [19] and [28] methods against observed pan evaporation data were evaluated by using Nash-Sutcliffe efficiency coefficient (E) and the refined Willmott's index (dr) statistical parameters and the results are presented in (Table 2). Mean daily values of evaporation are computed for different seasons with the four selected equations. 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 original and optimised parameter values of selected methods are presented in (Table 3).

It can be seen that the radiation based Jensen method is yielded the highest (E) and ($d_r$) values 0.96 and 0.90 respectively, especially for monsoon season. For summer and post-monsoon seasons, the temperature based Linacre method is earned (E) and ($d_r$) values 0.80, 0.76 and 0.18, 0.79 respectively. The Penman and Jensen methods are produced (E) and ($d_r$) values 0.82, 0.81 and 0.83, 0.80 respectively for winter season, which are much closer. The humidity based Romanenko method is yielded the lowest performance values for all seasons. This means humidity based method has a poor relationship with evaporation. When methods are compared on annual basis, the Penman method is found more appropriate that resulted (E) and ($d_r$) values 0.85 and 0.83 respectively. The high variability of weather variables indicates their responsibility to influence pan evaporation during different seasons (Fitzpatrick, 1963).

The fitted equations for different seasons with optimized parameter values are expressed as

Winter Season (Penman Equation)

$$E_p = 0.1293\,(1 + 0.24\,u_2)(e_s - e_o) \qquad (05)$$

Summer Season (Linacre Equation)

$$E_p == \frac{\frac{975.3827\ T_m}{(100-L)} + 5.4454\ (T_a - T_d)}{(80 - T_a)} \quad (06)$$

Post-monsoon Season (Linacre Equation)

$$E_p = \frac{\frac{475.3079\ T_m}{(100-L)} + 8.5453(T_a - T_d)}{(80 - T_a)} \quad (07)$$

Monsoon Season (Jensen Equation)

$$E_p = (0.2478\ T_a - 5.5146)R_s \quad (08)$$

When above equations are applied for annual basis, they produced (E) and ($d_r$) values 0.98 and 0.93 respectively (Figure 8).

## VIII. CONCLUSION

The evaporation estimates obtained from four selected methods viz. Linacre, Jensen, Penman and Romanenko are compared to the observed pan evaporation for Junagadh region of Gujarat (India). Two statistical criterions (E) and ($d_r$) have been used to evaluate the performance of selected methods and establish the optimal parameters. From the above analysis, it can be concluded that there is no single method to cover all the seasons of the year in the study area. Among the selected four methods, the radiation based Jensen method is found to be the most suitable for estimating ($E_p$) for monsoon season in this study area based on the entire evaluation criterion. From a practical point of view, this method can be considered suitable to serve as a tool to estimate evaporation for hydrologic models. It is observed that for winter season the Jensen and Penman methods are best fitted while for summer and post-monsoon seasons, the Linacre method is found better. Consequently, Linacre method is good choice for calculating evaporation in the study region for summer and post-monsoon seasons. The Romanenko method has the lowest performance among all selected methods. The parameters we determined will indeed be provided useful information for estimating evaporation in Junagadh region. In view of the above we may infer that either and different methods need to be developed for this location which may hold for all seasons, or additional factors need to be included in conventional methods. It is hoped that the study, in general, will assist to select better methods in accordance to the availability of meteorological data.

## IX. ACKNOWLEDGEMENT

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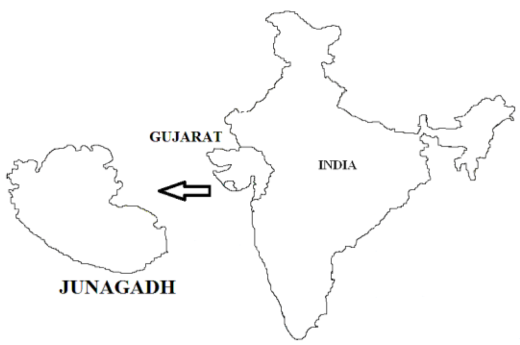


**Figure 1 Junagadh Region of Gujarat State**

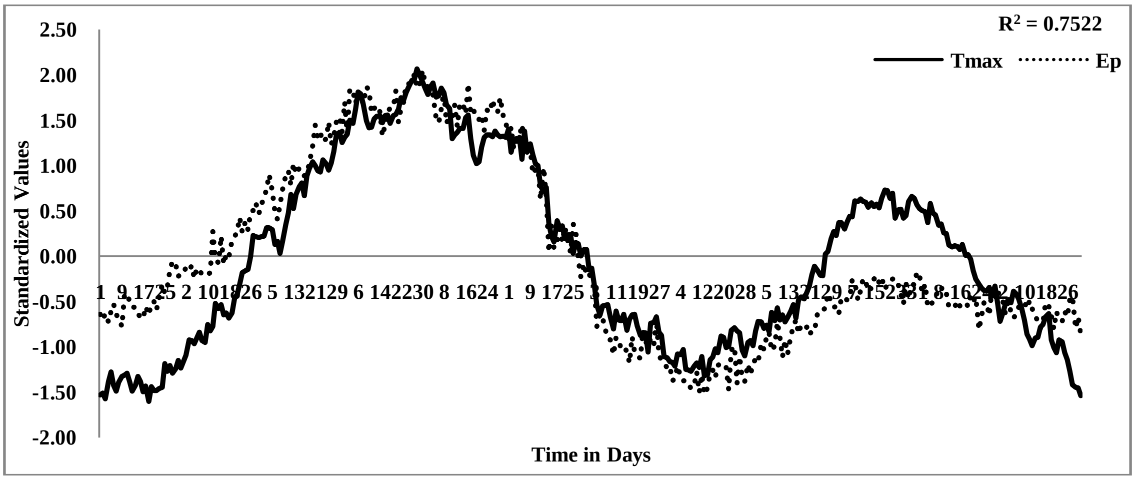


Figure 2 Dependence of $E_p$ on $T_{max}$ at Daily time-scale

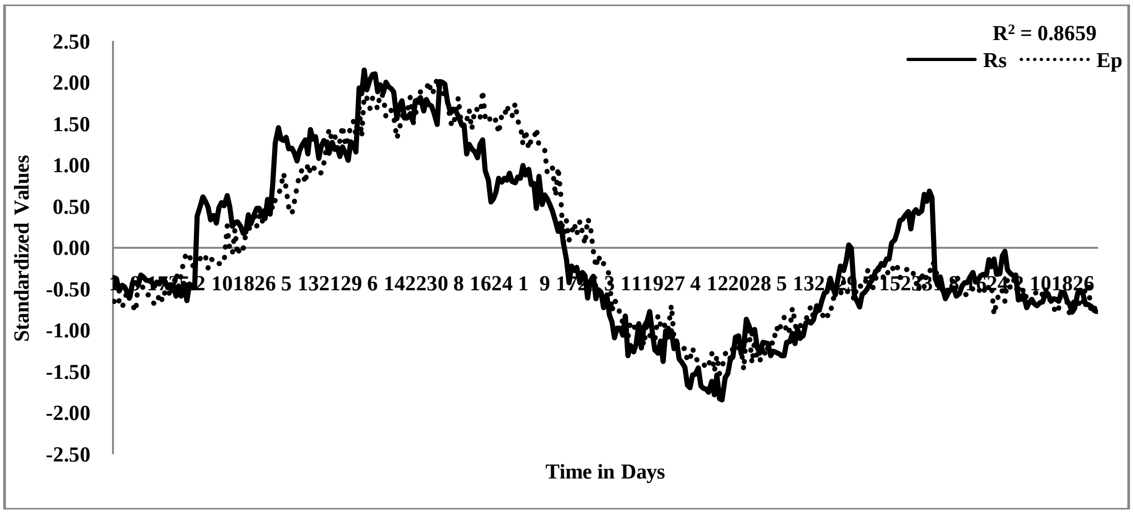


Figure 3 Dependence of $E_p$ on $R_s$ at Daily time-scale

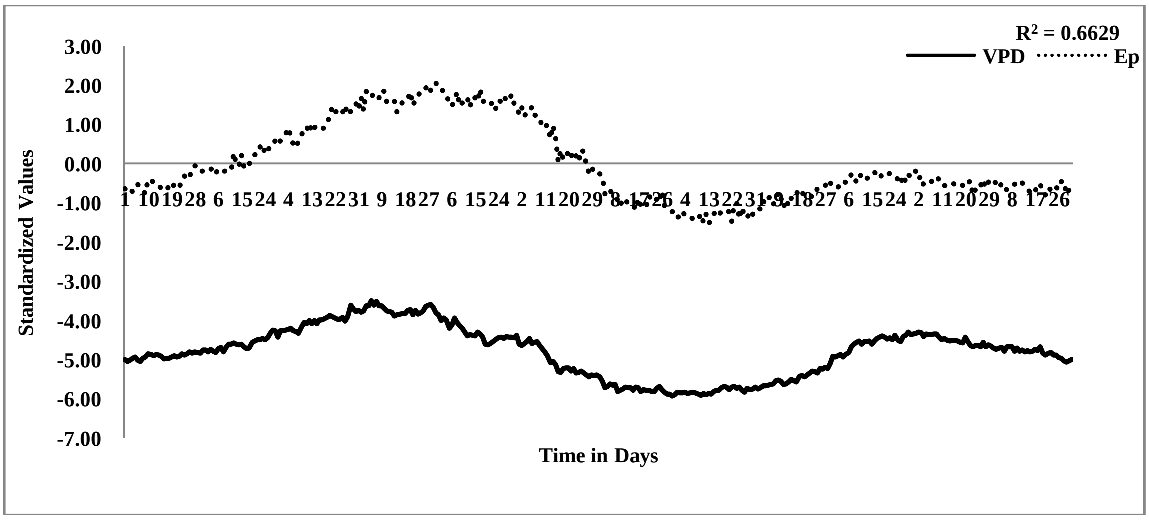


Figure 4 Dependence of $E_p$ on VPD at Daily time-scale

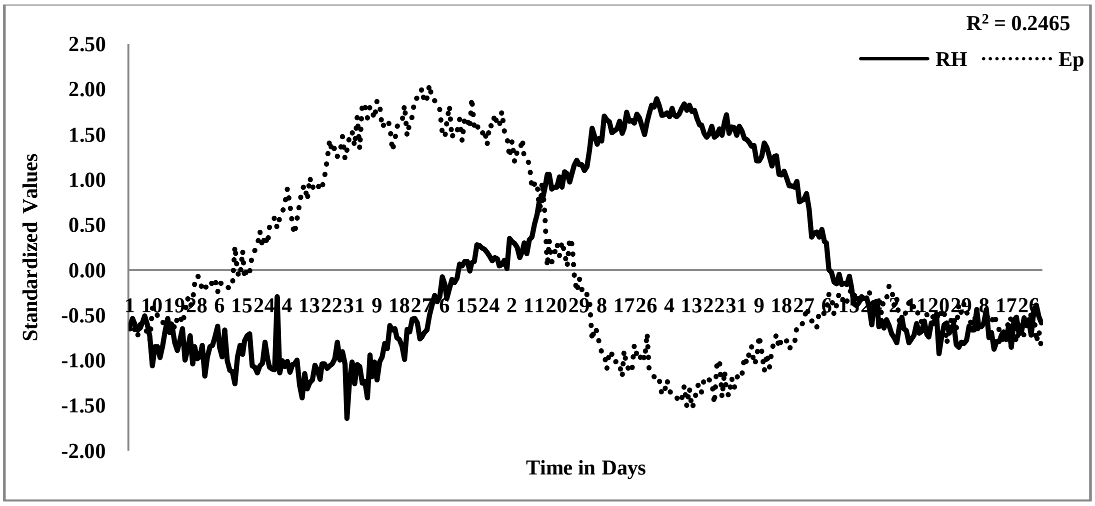


**Figure 5 Dependence of $E_p$ on RH at Daily time-scale**

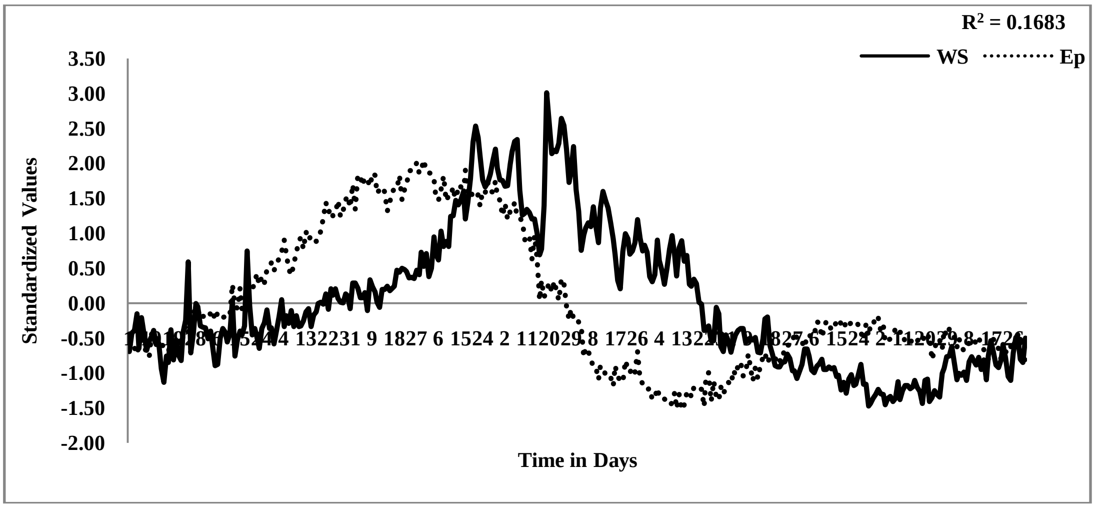


**Figure 6 Dependence of $E_p$ on WS at Daily time-scale**

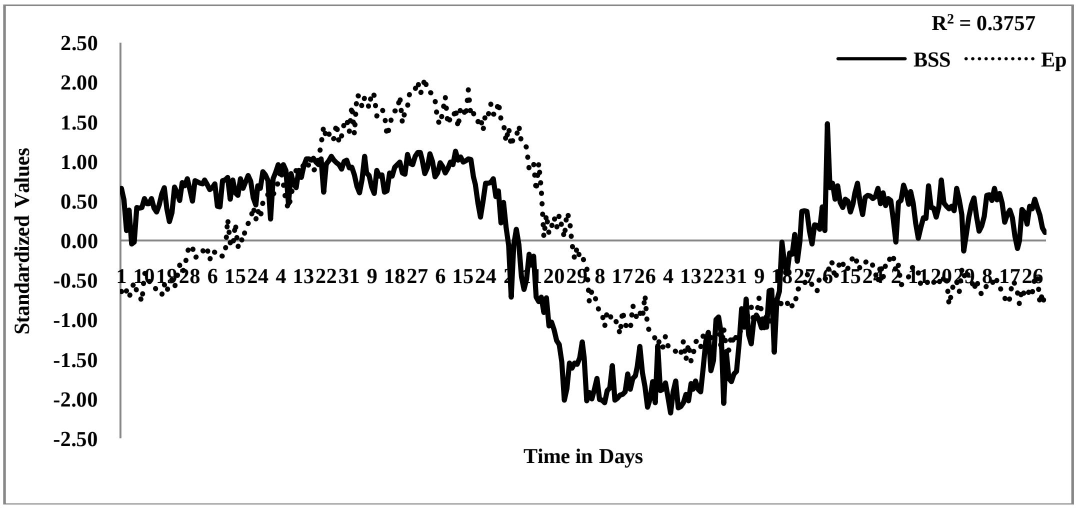


**Figure 7 Dependence of $E_p$ on BSS at Daily time-scale**

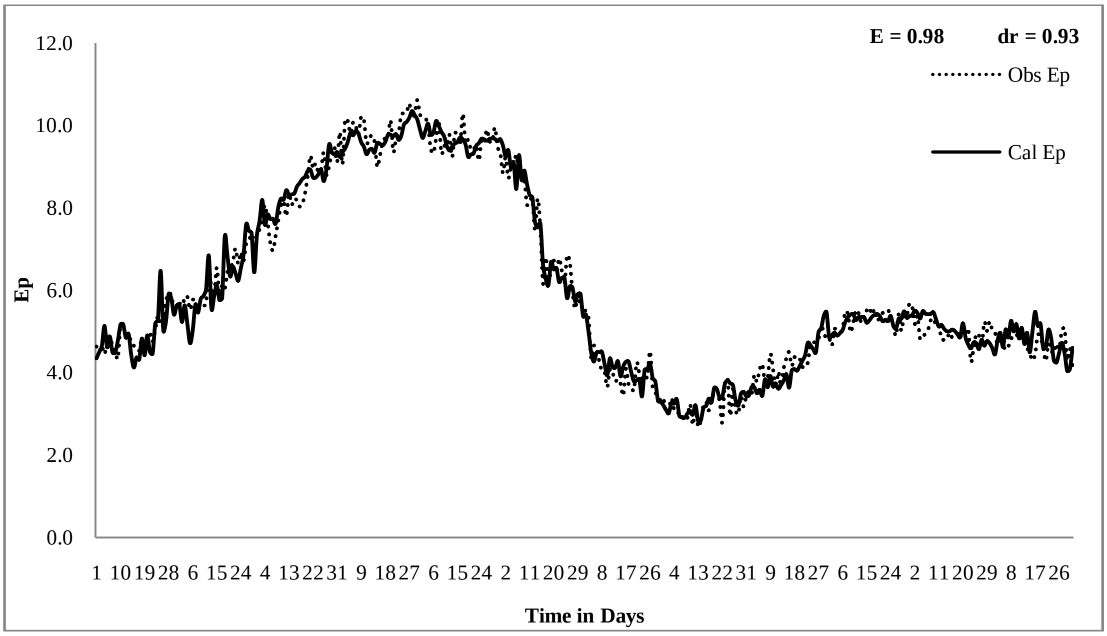


**Figure 8 Performance of fitted equations for annual basis**

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

| Method | Reference | Equation | Climatological data requirements |
|---|---|---|---|
| Radiation | Jensen and Haise (1963) | $PE = (0.14\,T_a - 0.37)R_s$ | Solar radiation and Temperature |
| Temperature | Linacre (1977) | $ET = \frac{\frac{500\,T_m}{(100-L)} + 15(T_a - T_d)}{(80 - T_a)}$ | Temperature |
| Mass transfer | Penman (1948) | $ET = 0.35(1 + 0.24\,u_2)(e_s - e_o)$ | Wind speed and vapour pressure |
| Humidity | Romanenko (1961) | $PE = 0.0018\,(25 + T_a)^2(100 - RH)$ | Temperature and humidity |

$T_a$ = Air temperature in $^0$C, $R_s$ = Solar radiation in MJ/m$^2$/day, RH = Relative humidity in %, $u_2$ = Wind speed at 2 m height in m/s, $e_s$ and $e_o$ = Saturation and actual vapour pressure in mb, $T_m = (T_a + 0.006h)$, h = the elevation (m), L = the latitude (degree), $T_d$ = Mean dew point, $T_m$ and $T_d$ are in $^0$C, PE = Potential evaporation (mm) and ET = Free water evaporation (mm)

*Table 2. Mean seasonal and annual estimated evaporation using selected methods for Junagadh region*

| Sr. No. | Season | Obs $E_p$ mm | Jensen and Haise | | | Linacre | | | Penman | | | Romanenko | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cal $E_p$ mm | E | $d_r$ | Cal $E_p$ mm | E | $d_r$ | Cal $E_p$ mm | E | $d_r$ | Cal $E_p$ mm | E | $d_r$ |
| 1 | Winter | 501.24 | 501.32 | 0.83 | 0.80 | 503.40 | 0.73 | 0.74 | 499.54 | 0.82 | 0.81 | 503.43 | 0.71 | 0.74 |
| 2 | Summer | 849.63 | 848.68 | 0.72 | 0.71 | 850.25 | 0.80 | 0.76 | 847.59 | 0.66 | 0.69 | 836.51 | -2.13 | 0.01 |
| 3 | Monsoon | 547.28 | 547.09 | 0.96 | 0.90 | 550.97 | 0.83 | 0.79 | 489.52 | 0.58 | 0.65 | 538.52 | 0.82 | 0.79 |
| 4 | Post-Monsoon | 323.34 | 321.25 | -1.04 | 0.32 | 322.95 | 0.18 | 0.57 | 322.46 | -0.19 | 0.47 | 321.61 | -1.26 | 0.26 |
| 5 | Annual | 2221.49 | 2262.21 | 0.78 | 0.76 | 2271.35 | 0.71 | 0.73 | 2112.80 | 0.85 | 0.83 | 2155.2 | 0.52 | 0.65 |

*Table 3. Original and Optimised Parameter values of selected methods before and after calibration*

| | Jensen and Haise | | Linacre | | Penman | Romanenko |
|---|---|---|---|---|---|---|
| **Original Values** | 0.14 | 0.37 | 500 | 15 | 0.35 | 0.0018 |
| **Season** | **Optimised Values** | | | | | |
| Winter | 0.0777 | 0.0000 | 196.8945 | 18.2719 | 0.1293 | 0.0013 |
| Summer | 0.0831 | 0.1493 | 975.3827 | 5.4454 | 0.1203 | 0.0018 |
| Monsoon | 0.2478 | 5.5146 | 232.5008 | 34.8545 | 0.1504 | 0.0022 |
| Post-Monsoon | 0.0606 | 0.0000 | 475.3079 | 8.5453 | 0.1263 | 0.0012 |
| Annual | 0.0735 | 0.0890 | 522.2668 | 13.3739 | 0.0016 | 0.0016 |