Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

December 2018, Volume 31, Issue 2, Page 295-303

Comparision of various models for calculation of reference evapotranspiration with reference to Penmann-Montieth equation

Vinay Kumar* • Shafat Khan

Division of Agricultural Engineering, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar campus- 190001, Jammu and Kashmir

ARTICLE INFO

Article history:
Received 25 July 2017
Revision Received 12 January 2018
Accepted 8 March 2018

Key words:
Evapotranspiration, Empirical, Penmann-Montieth equation.

ABSTRACT

Studies have evaluated and compared various popular empirical evapotranspiration equations that belonged to three categories: (1) mass-transfer based methods, (2) radiation based methods, and (3) temperature-based methods; and the best and worst equations of each category were determined for the study regions. In this study a comparison of the best or representative equation forms selected from each category was made from the FAO-56 Penman-Monteith model using data given at the required station Daily and monthly output from six evapotranspiration models (ASCE Standardised Evapotranspiration , FAO-24 Blaney-Criddle, Hargreaves-Samani, Priestly-Taylor, Makkink, and FAO Pan Evaporation) have been tested against reference evapotranspiration data computed by the FAO- 56 Penman-Monteith model to assess the accuracy of each model in estimating grass reference evapotranspiration in an experimental field in Shalimar. A pan evaporation to reference evapotranspiration model (FAO-24 Pan Evaporation) was also tested against daily grass reference Evapotranspiration were evaluated and compared with the Penman-Monteith equation using daily meteorological data from the Skuast-k observatory field. Seven representative empirical potential evapotranspiration equations selected from the three categories, namely: Hargreaves and Blaney-Criddle (temperature-based), Makkink and Priestley-Taylor (radiation-based) and Pan Evaporation (mass-transfer-based). The calculations of the Penman-Monteith equation followed the procedure recommended by FAO (Allen *et al*., 1998). The comparison was first made using the original constant values involved in each empirical equation and then made using the recalibrated constant values. The study showed that the original constant values involved in each empirical equation worked quite well for the study region, except that the value of α = 1.26 in Priestley-Taylor was found to be too high and the Further examination of the performance resulted in the following rank of accuracy as compared with the Penman-Monteith estimates: and ASCE Standardised Evapotranspiration Priestley-Taylor and Makkink (Radiation-based), Hargreaves and Blaney-Criddle (temperature-based) and Pan Evaptranspiration and method.

*Corresponding author: vinaykumarmangotra27@gmail.com

1. Introduction

There exist a multitude of methods for the estimation of reference evapotranspiration *ET* and free water evaporation E, which can be grouped into five categories: (1) water budget (*e.g.* Guitjens, 1982), (2) mass-transfer (*e.g.* Harbeck, 1962), (and (5) temperature-based (*e.g.* Thornthwaite, 1948; Blaney-Criddle, 1950). The availability of many equations for determining evaporation, the wide range of data types needed, and the wide range of expertise needed to use the various equations correctly make it difficult to select the most appropriate evaporation method for a given study 3) combination (*e.g.* Penman, 1948), (4) radiation (*e.g.* Priestley and Taylor, 1972), An ongoing research programme has been underway since 1996, with the main objective of undertaking evaluation and generalisation of existing evaporation models. The research programme differs from other researchers reported in the literature. At the first stage of the study, the most commonly used methods for estimating *E* and *ET* were evaluated and compared within each category and the best and good methods are ranked for every category. At the second stage of the research only the best models from each category are selected and a cross comparison is made. The results of the first stage study have been reported where evapotranspiration equations belonging to the categories of mass-transfer based, radiation-based and temperature based, respectively, were evaluated and generalized. Some of the results of the second stage study, *i.e.* select one or seven best equation forms from each category and do a comparison. Following the recommendation of FAO (see Allen *et al.*, 1994a, b, 1998), the Penman-Monteith equation was used as a comparison criterion for the selected empirical equations. Included in the study is a discussion of existing methods, evaluation and comparison of the selected models with the original values of the constants involved in each equation, and with locally calibrated values of the constants. Finally, the overall applicability of the selected methods is examined and their predictive ability for the study region is discussed.

Graphical Representation of Comparison of Various Models With Reference To Penmam Montieth Method

Penman Vs Hargreaves

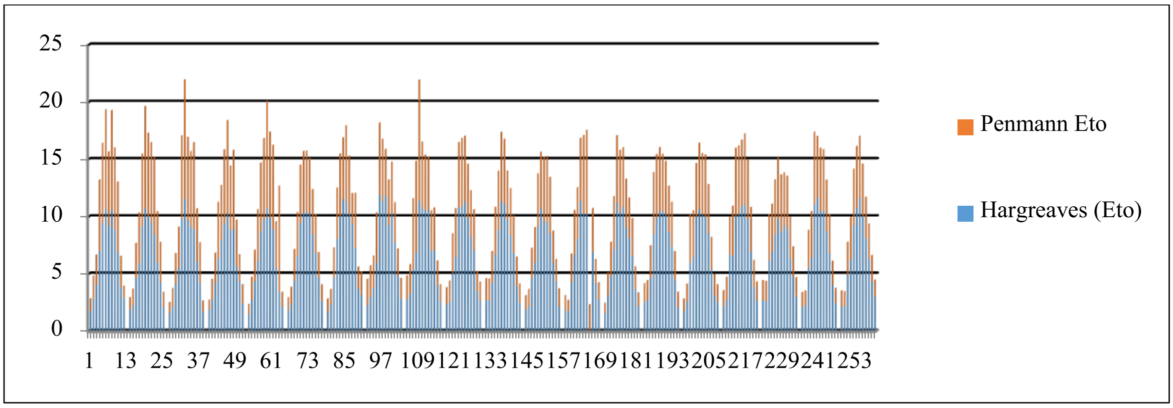


Table 1. Monthly Values of Evapotranspiration from Different Models for the Year 2012

Month	Penmen-Montieth	Priestly-Taylor	Makkinks	Hargreaves-Samani	Asce Method	Fao Blaney Criddle	Fao Pan Evaporation
January	1.340626	0.85004	0.767682	2.19509	1.950089	1.917097	0.592
February	1.337832	1.173583	0.952141	2.107088	1.768788	2.098384	0.688
March	2.861222	2.209759	1.603987	4.921581	4.031955	3.156663	1.12
April	3.716653	2.77904	1.967948	6.239182	5.225545	3.660054	2.2
May	4.947582	3.902708	2.611409	9.211503	6.846641	4.198338	2.312
June	5.425629	4.185519	2.815859	10.72405	7.423415	5.258214	2.616
July	5.353387	4.381573	2.919671	11.6608	7.092665	6.065799	2.76
August	4.544463	4.209571	2.782602	10.04365	5.717549	5.936357	2.816
September	3.573411	3.288055	2.267112	8.142106	4.524568	5.092938	2.36
October	3.064399	2.14429	1.632356	6.297985	4.288466	4.472258	2
November	2.306705	1.327396	1.137182	4.310179	3.37369	3.809856	1.736
December	1.461205	0.917582	0.834101	3.010123	2.106291	2.403403	1.448
Et(Total)Mm Annual	39.93311	31.36912	22.29205	78.86334	54.34966	48.06936	22.648

2. Material and Methods

2.1 Methods Description

Penman-Montaith Method

The FAO Penman-Monteith method for calculating reference (potential) evapotranspiration *ET* can be expressed as (Allen *et al*., 1998):

$$ET = E_T = \frac{0.408\Delta\,(R_N - G)\; + \;\gamma.\,900/T + 273\,.\,u_2(e_s - e_a)}{\Delta\; + \gamma(\,1 + 0.34u_2)}$$

Where,

ET = reference evapotranspiration (mm day−1);

Rn= net radiation at the crop surface (MJ m−2 day−1);

G = soil heat flux density (MJ m−2 day−1);

T = mean daily air temperature at 2 m height (°C);

*u*2 = wind speed at 2 m height (m s−1);

es= saturation vapour pressure (kPa);

ea= actual vapour pressure (kPa);

es− *ea*= saturation vapour pressure deficit (kPa);

_ = slope vapour pressure curve (kPa°C−1);

γ = psychrometric constant (kPa°C−1).

2.2 Temperature-Based Methods

Those potential evapotranspiration (ET) estimation methods that require only temperature as an input variable are considered as temperature-based methods in this study. The temperature-based methods are some of the earliest methods for estimating ET. The relation of ET to air temperature dates back to 1920s (Jensen *et al*., 1990). Most temperature-based equations take the form:

$ET = c(Ta)n$ (14)

or

$ET = c1dlTa(c2 - c3h)$ (15)

in which

ET = potential evapotranspiration;

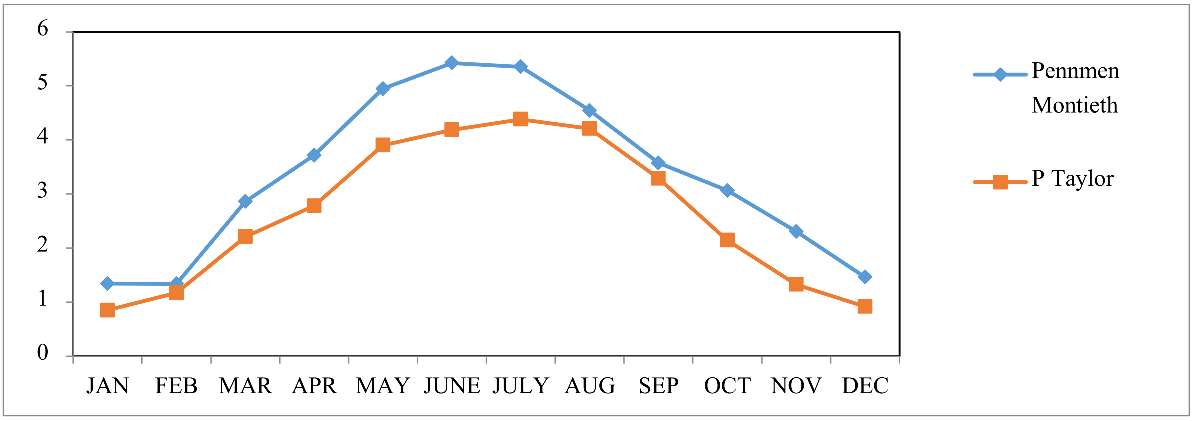
Ta = air temperature;

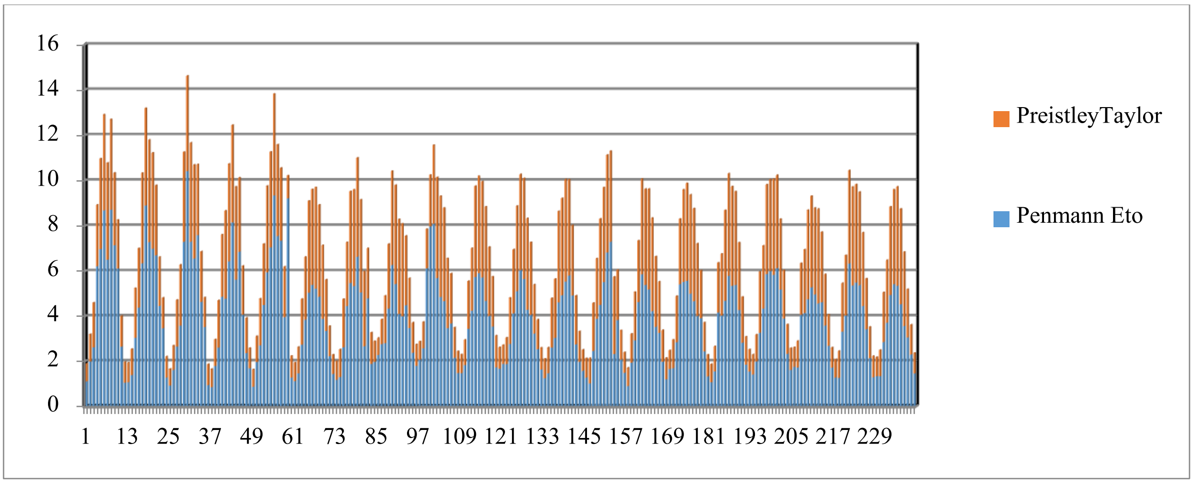
h = a humidity term;

*c*1, *c*2, *c*3 and *c* are constants;

dl= day-length.

Penmen-Montieth Vs Priestly Taylor





FAO Blaney-Criddle Method

The Blaney-Criddle model is one of the older models available to calculate evapotranspiration. Blaney and Criddle (1950) developed their model for use in arid farmlands of the western U.S. while working as engineers for the Soil Conservation Service (SCS) (Hansen *et al.,* 1980). The model's relationships were derived from experimental data for a variety of crops over the western U.S (Blaney and Criddle 1950). The original model is similar to the classic Thornthwaite model, requiring only temperature and a function of sunlight hours as data input. The original model as described by Blaney and Criddle (1950) is:

$$ET = kf .5$$

Hargreaves Method

The Hargreaves-Samani 1985 model is one of the more represent versions of one of the older evapotranspiration models (Hargreaves and Allen 2003).

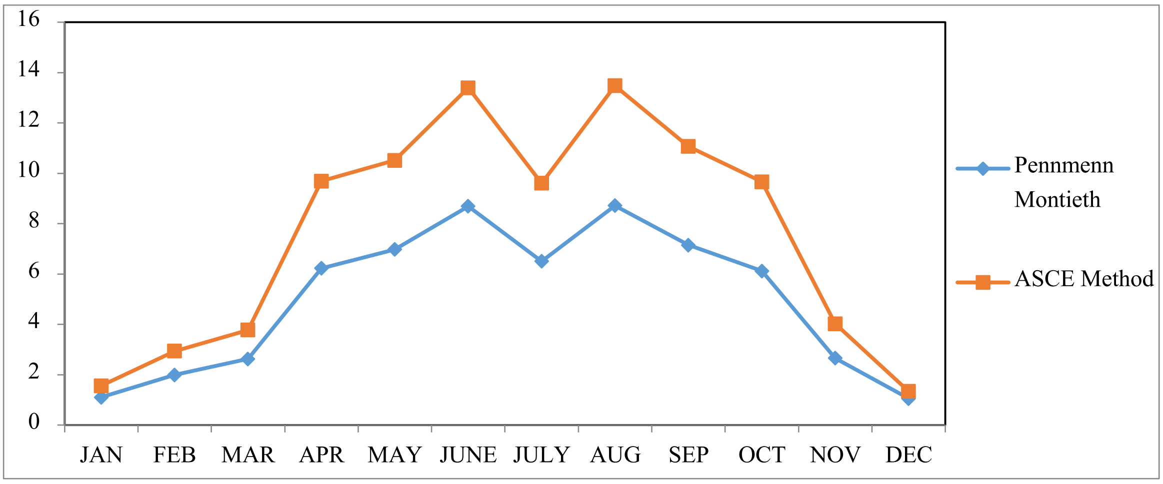
The H/S model used in this study has conceptually similar versions (Hargreaves 1974, Hargreaves and Samani 1982), which intended to be computationally simple and applicable to a variety of climates using only commonly available meteorological data.

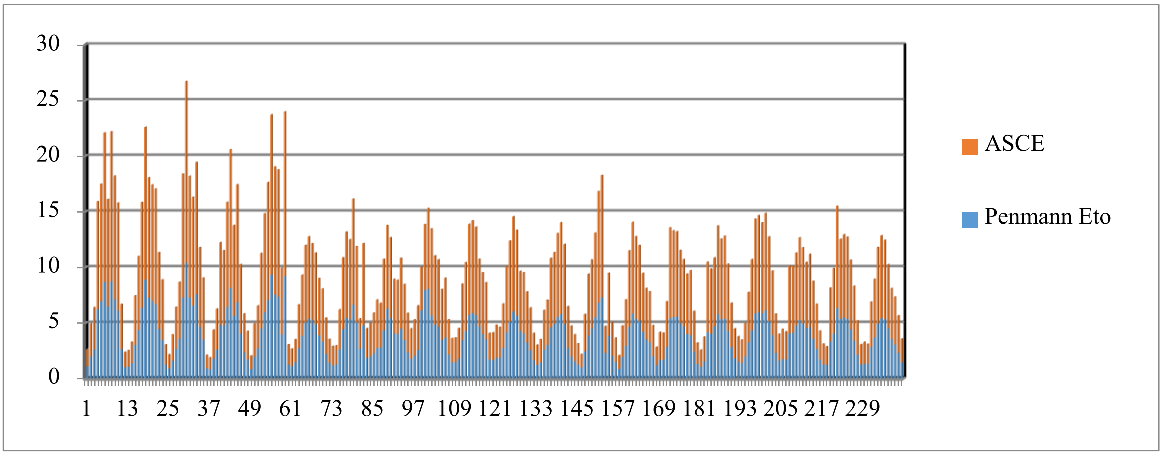
Makkink Method

The Makkink model was designed in 1957 in the Netherlands as a modification of Penman after comparing the Penman model to lysimetric data (Allen 2003, Makkink 1957). Currently, Makkink is popular in western Europe (Allen 2003) and has been used successfully in the U.S (see Amatya *et al.,* 1995). Allen (2003) gives the operational form of the Makkink model as: where ETo is evapotranspiration (mm day-1), Rs is solar radiation (MJ m-2 day-1), and and arethe same variables defined for

$$ET_o = \frac{\Delta}{(\Delta + \Upsilon)} \frac{R}{\lambda} - 0.12$$

Penmen Montieth Vs Asce Model





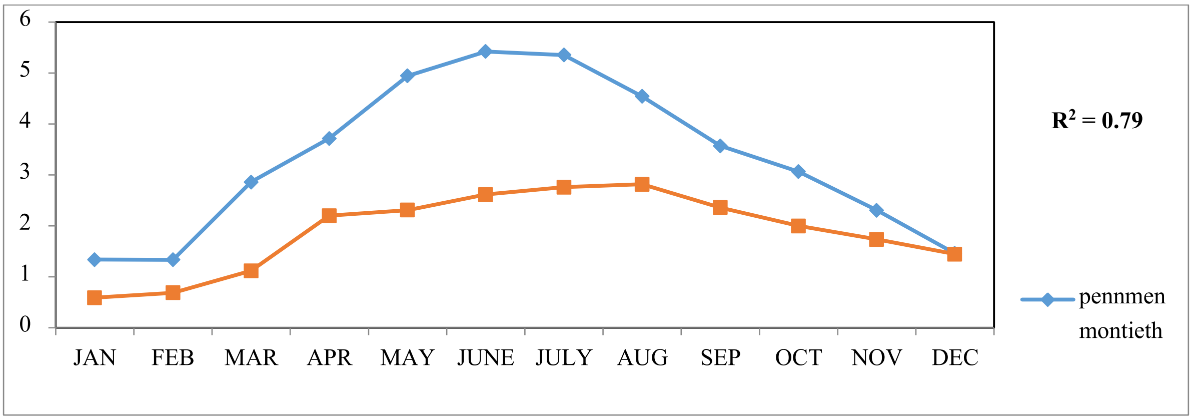
Priestley and Taylor Method

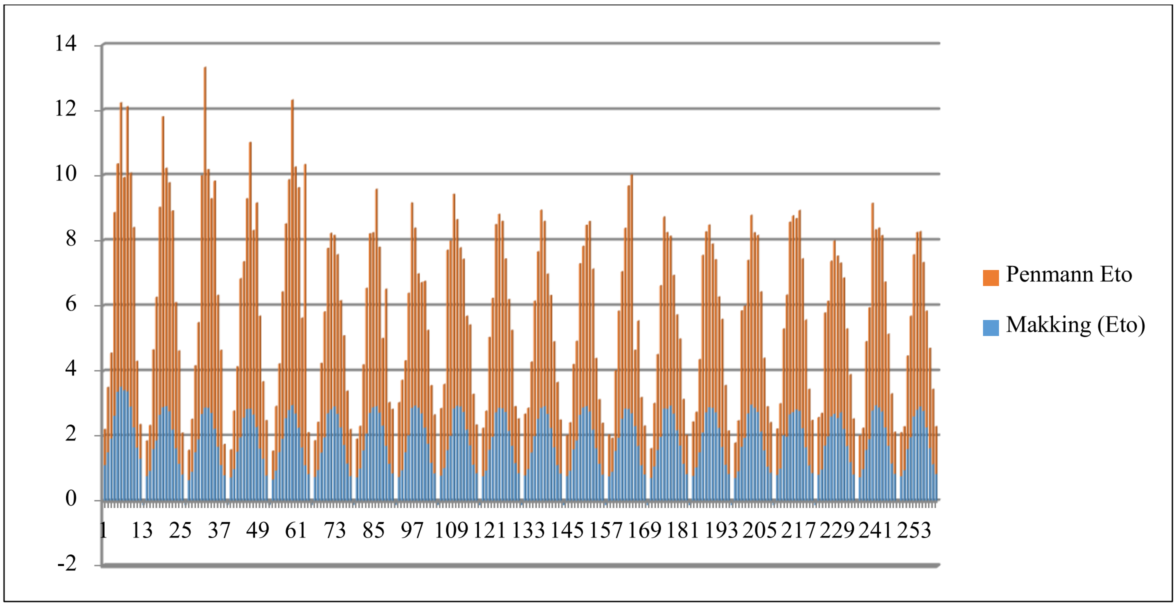
The Priestley-Taylor model is essentially a shortened version of the original 1948 Penman combination equation (Priestley and Taylor 1972, Jensen *et al.,* 1990). The original intent of the model was for use in large-scale numerical modeling where it is assumed that advection is small, thus allowing the aerodynamic component of the original Penman equation to be reduced to a coefficient that modifies the remaining equation (Priestley and Taylor 1972, Jensen *et al.,* 1990, McAneney and Itier 1996). The P/T model was designed to be used in humidareas where surfaces were usually wet (Priestley and Taylor 1972; Jensen *et al.,* 1990).

ASCE Standardised Reference Evapotranspiration:

ASCE-ET recommends that the equation be referred to as the "Standardized Reference Evapotranspiration Equation" (ETsz). ASCE-ET is of the opinion that use of the terms *standard* or *benchmark* may lead users to assume that the equation is intended for comparative purposes (*i.e.* a level to be measured against). Rather, the use of the term "standardized" is intended to infer that the computation procedures have been fixed, and not that the equation is a standard or a benchmark or that the equation has undergone the degree of review in the approval process necessary for standards adopted by ASCE, ASAE, American National Standards Institute, or the International Organization for Standardization. ETref from each of the two surfaces is modeled using a single Standardized Reference Evapotranspiration equation with appropriate constants and standardized computational procedures.

Penmen Vs Makkinks

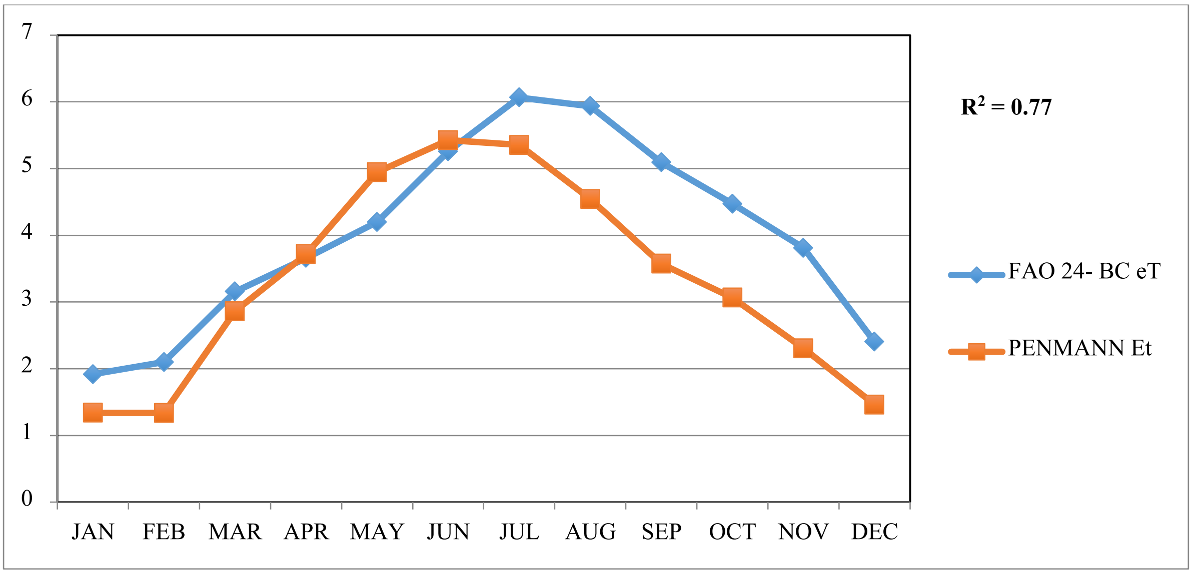


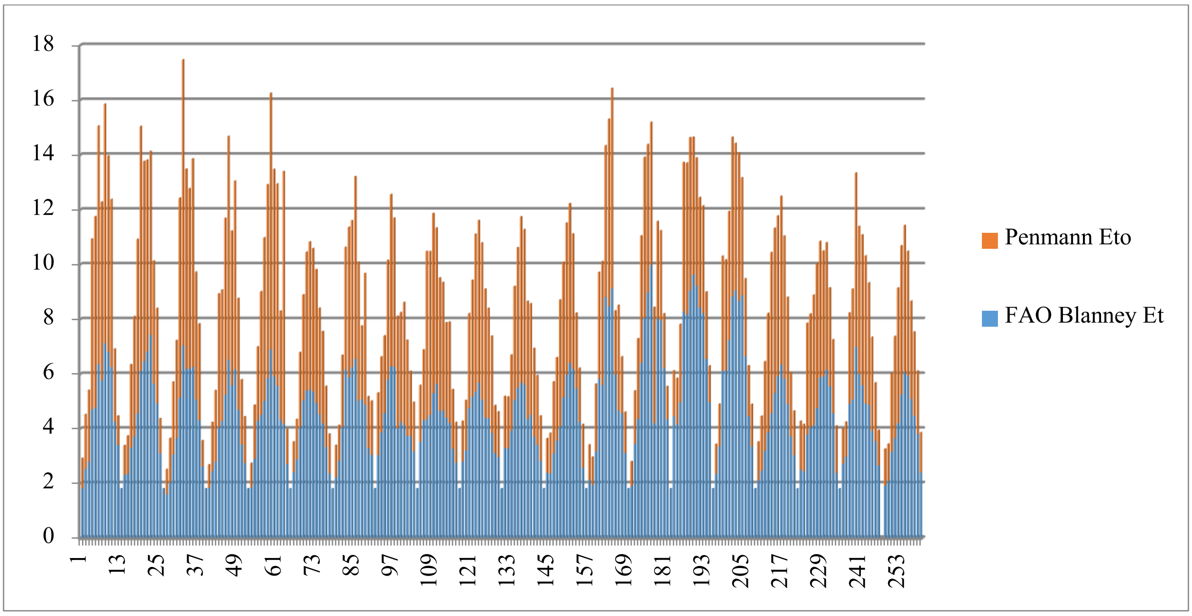


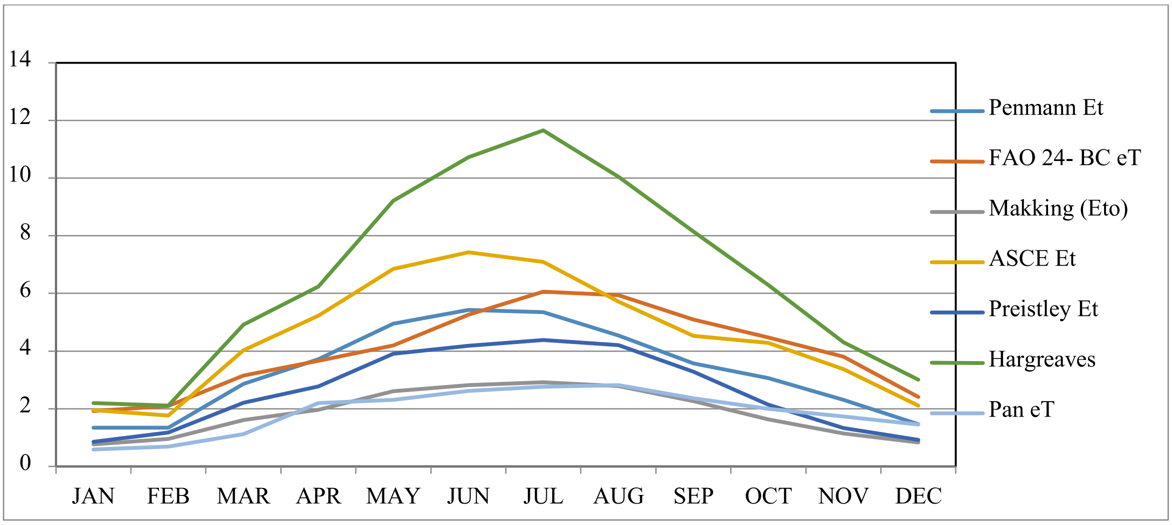
When the determination coefficient R^2 values are concerned ASCE standardized reference Evapotranspiration equation gave the highest value with R^2 = 0.99. Blaney Criddle gave the lowest R^2 value of 0.77. Hargreaves mod^{el} and Taylor-Priestly gave a coefficient of determinant value of 0.96. Pan Evaporation method gave a value of R^2 value of 0.79. in order to check seasonality of the estimation errors mean monthly Evapotranspiration values averaged over 20 years (1991-2011) from six empirical methods which are computed and compared with that of PenMen Montieth Estimates. It can be seen that ASCE standardized reference Evapotranspiration, Priestly-Taylor method and Hargreaves method followed the same trend as PenMen Montieth Equation.

The Pan Evaporation Model underestimated Evapotranspiration in April, May and June as well as the yearly value. Blaney Criddle estimates showed differences with that of PenMen Montieth Method in three months that is it overestimates Evapotranspiration in April, September and underestimates in march. The reason in two values of consumptive co-efficient k = 0.85 for growing season of April to September and 0.45 for rest of the months. Figure reveals that it is necessary to define March, April and September as a transition period having a value of k lies between 0.45 and 0.85. also it is found using different value of k value for every month will improve the result but it will result in too many free parameters as compared to other methods.

Fao Blaney Criddle Vs Penmen Montieth







ASCE Standardised Reference Evapotranspiration, Makkinks, Priestly-Taylor, Hargreaves-Samani, Pan Evaporation and FAO Blaney Criddle showed coherence in efficiency in the respective order of their enumeration.

Conclusion

Seven empirical methods namely Hargreaves Samani, FAO Blaney Criddle, Makkinks, Priestly-Taylor, FAO Pan Evaporation, ASCE Standardised Reference Evapotranspiration were evaluated using Meteorlogical data from an experimental field in Shalimar. The Penman Montieth Method as recommended by by FAO was taken as standard in evaluating the six methods. A comparative analysis was made and the original constant values involved in each equation were used while calculating Evapotranspiration. It can be concluded that using locally determined parameters values of all six empirical methods gave acceptable estimates of yearly Reference Evapotranspiration as compared with that of PenMan Montieth Equation Keep in mind that these models are recent models from their category. Further examination of the results of Regression analysis between the Penmen Montieth estimates and the other six methods resulted in the following rank of the performance.

Table 2. Coefficient of determinant.

Model	**Value of R^2**
Taylor-Priestley Method	0.95
Hargreaves Samani Method	0.95
FAO Blaney-Criddle Model	0.77
Makkinks Model	0.96
ASCE Standardized Equation	0.99
FAO Pan Evaporation Method	0.79

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Penmen Vs Fao Pan Evaporation