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# Comparison of Potential Evapotranspiration Models and Establishment of Potential Evapotranspiration Curves for Temperate Kashmir Valley

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Authors LA and Sabah Parvaze designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SSM, Saqib Parvaze and BSD managed the analyses of the study. Authors MM and FSW managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Potential evapotranspiration (PET) is a crucial indicator of hydrologic regime of a region. It is an important variable in the estimation of actual evapotranspiration (AET) in hydrological and ecosystem modeling. Evapotranspiration affects the amount of runoff and thus the irrigation water requirements of crops as well as water resources management. The present study has been carried out to compare the commonly used PET methods for the Shalimar weather station in district Srinagar of Kashmir Valley. FAO-56 Penman-Monteith equation is a standard method in estimating

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the PET. Other methods of PET estimation namely Modified-Penman, Hargreaves, Turc, Blaney Criddle, Christiansen, and Open Pan were compared with reference to Penman-Monteith method. Modified-Penman method was most correlated with the FAO-56 PM method with the coefficient of determination ($R^2$) as high as 0.99. Modified-Penman method was followed by Hargreaves method with $R^2$ of 0.98. Hargreaves method was then used to establish PET curves for other districts of Kashmir valley namely, Anantnag, Budgam, Baramulla, Kulgam, Kupwara and Pulwama where only data on air temperature is available. The highest annual PET was obtained for District Budgam being 951 mm and the least was obtained for district Baramulla being 759 mm.

*Keywords: Potential evapotranspiration; PET curves; FAO-56 Penman-Monteith; Kashmir Valley.*

## 1. INTRODUCTION

The evaporative phase of the cycle purifies water which then replenishes the land with freshwater. The flow of liquid water and ice transports minerals across the globe. It is also involved in reshaping the geological features of the Earth, through processes including erosion and sedimentation. The water cycle is also essential for the maintenance of most life and ecosystems on the planet. Evapotranspiration (ET) is one of the chief components of the water cycle. Physically, it is the sum of the evaporation from the surface of water and soil and the quantity of water transpired by plants, transpiration. The amount of evaporable water in the soil influence the rate of evapotranspiration along with soil and vegetation characteristics. Evaporation returns nearly 64% of land-based average yearly precipitation back to atmosphere due to process of evaporation [1,2,3]. Small changes in precipitation or evapotranspiration can heavily impact runoff, water quality and ecological processes, especially in coastal areas [4].

Potential Evapotranspiration (PET) is described in many ways but generally it is defined as the amount of water evaporated and transpired from a vegetated surface when sufficient water is available to meet the needs of the vegetation [5, 6,7]. The concept of Potential Evapotranspiration (PET) provides a suitable index for the estimation of the maximum atmospheric water loss [5]. Management of irrigation and water resources projects necessitates the quantification of evapotranspiration [7].

Lysimeters can be used to measure the evapotranspiration directly but generally theoretical or empirical equations are used for its estimation. However, the method is usually difficult, costly and time consuming. Therefore, for practical purposes, climate variables like solar radiation, air temperature, wind speed, and relative humidity can be used for estimation of PET [8]. Pan evaporation data can also be used to derive PET by multiplying it by a coefficient [9].

A number of methods have been developed for PET estimation but the values are inconsistent, either due to their different assumptions or their application to specific climate regions only [9]. FAO-56 Penman-Montieth method is amongst a few reliable methods for estimation of PET over a broad variety of climates throughout the world [10]. The equation is based on sound theoretical reasoning and obtained by a combination of the energy balance and mass transfer approach. However, the major limitation of this method is that it requires extensive climatological data of air temperature, air pressure, relative humidity, wind speed, and solar radiation. However, all the parameters are not recorded in many meteorological stations. This is particularly true of Kashmir Valley where only few meteorological stations are present and most of them record only air temperature and precipitation. Further, quality of data and problems in gathering all of the necessary weather parameters pose substantial limitations especially in high altitude areas of the Valley. Therefore, the application of air temperature based or other simple methods in the PET estimation is necessary.

The present study was therefore carried out to establish an alternative method of PET estimation in Kashmir Valley which can be used when availability of climatological data is limited. Six different methods of PET estimation namely FAO-24 Modified-Penman, Hargreaves, Turc, Blaney Criddle, Christiansen, and Open Pan were compared with the FAO-56 Penman-Moteith Method. The most suitable method was used then to compute the PET curves for other stations were one or more of these parameters are not available.

### 1.1 Study Area

The State of Jammu and Kashmir is located between 32°17' and of 37°5' North latitudes and

73°26' and 80°30' and 81° East longitudes. Kashmir valley lies in the temperate zone of the state and comprises 10 districts. The valley has an elevation range of 1500 m a.s.l to 4200 m a.s.l. The meteorological data for the Srinagar District was obtained from Agro-Meteorological Field Unit (AMFU) Shalimar. The data set consisted of daily values of maximum temperature, minimum temperature, morning relative humidity, afternoon relative humidity, sunshine hours and wind speed. For other districts, namely Budgam, Kulgam Anantnag, Pulwama, Kupwara and Baramulla, the data was obtained from Regional Meteorological Centre Srinagar. The study area has been shown in Fig. 1. The observatories in these districts record only maximum temperature, minimum temperature and precipitation. The dataset for all the stations was obtained for a period of 25 years (1992-2016).

### 1.2 Climatic Parameters Required by Each Equation

An important consideration in establishing an alternative and simple method to the standard the FAO 56-PM is the high likelihood of unavailability and unreliable weather data measurement. Further, FAO 56-PM involves complex calculations and unit conversions. The input data required for different methods of PET estimation is given in Table 1.

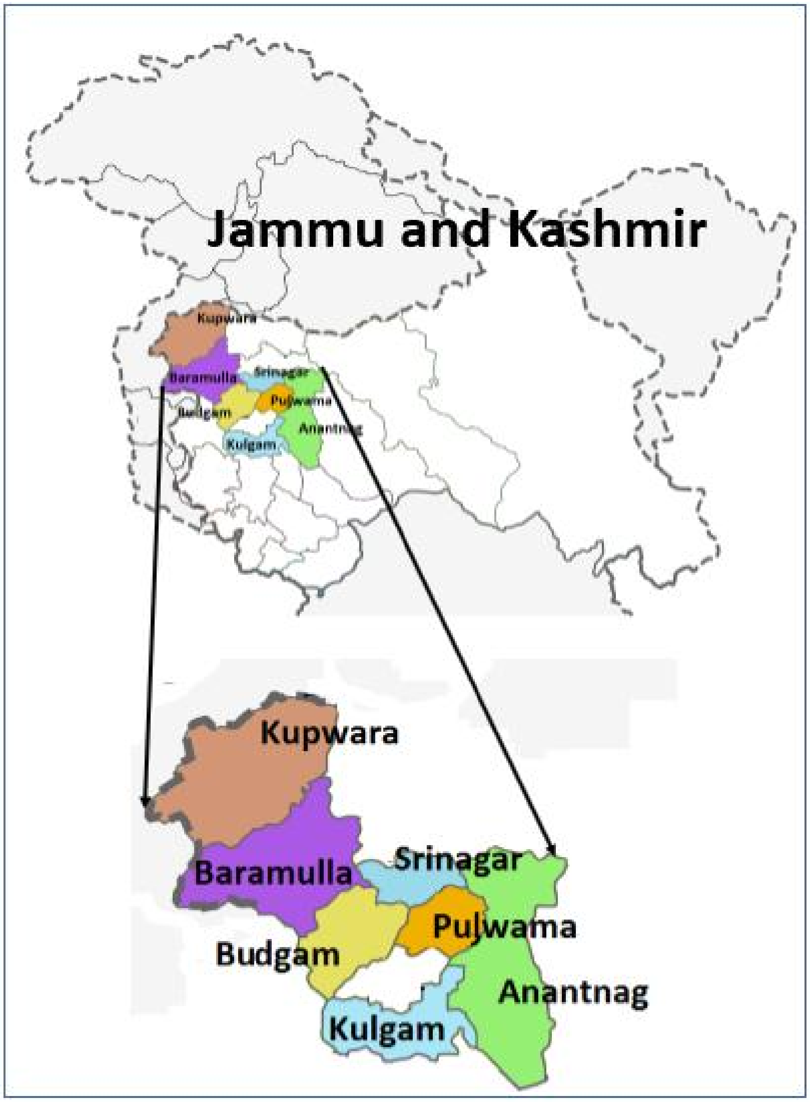


**Fig. 1 Study area**

**Table 1. Input data requirements of different PET estimation methods**

| S. No. | PET estimating method | Input data requirement | |
|---|---|---|---|
| | | **Estimated/ Derived** | **Measured** |
| 1 | FAO 56 Penman-Monteith | Solar radiation | Air temperature, wind speed, relative humidity, hours of bright sun shine |
| 2 | FAO-24 Modified Penman | Solar radiation | Air temperature, wind speed, relative humidity, hours of bright sun shine |
| 3 | Hargreaves | Extra- terrestrial radiation | Air temperature |
| 4 | Turc | Solar radiation | Air temperature, hours of bright sun shine |
| 5 | FAO-24 Blaney-Criddle | - | Air temperature, wind speed, relative humidity, hours of bright sun shine |
| 6 | Christiansen | - | Open pan evaporation, air temperature, wind speed, relative humidity |
| 7 | FAO-24 Open pan | - | Open pan evaporation, wind speed, relative humidity |

## 2. METHODOLOGY

### 2.1 FAO-56 Penman-Monteith Method

The penman method was developed to calculate the evaporation from open water surfaces [6]. The model was then modified by Monteith for its application to cropped surfaces as well [11]. The equation of modified Penman-Monteith method also known as FAO-56 Penman-Monteith method is given as:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean}+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where,

$ET_0$ = Potential evapotranspiration [mm day$^{-1}$]
$R_n$ = Net radiation at the crop surface [MJ m$^{-2}$ day$^{-1}$]
$G$ = Soil heat flux density [MJ m$^{-2}$ day$^{-1}$]
$T_{mean}$ = Mean daily air temperature at 2 m height [°C]
$U_2$ = Wind speed at 2 m height [ms$^{-1}$]
$e_s$ = Saturation vapor pressure at the mean air temperature in °C [kPa]
$e_a$ = Mean actual vapor pressure of the air [kPa]
$(e_s - e_a)$ = Vapor pressure deficit for measurement at 2 m height [k Pa]
$\Delta$ = Slope vapor pressure curve [kPa°C$^{-1}$]
$\gamma$ = Psychrometric constant [kPa°C$^{-1}$]

The equation has been accepted as a standard method of PET estimation by American Society of Civil Engineers (ASCE), the International Irrigation and Drainage Committee and the Food and Agriculture Organization (FAO) of the United Nations. The method has also been found suitable for different climates of the globe [12, 13,14,15].

### 2.2 FAO-24 Modified-Penman Method

The FAO-24 Modified Penman (MP) method was proposed by Doorenbos and Pruitt [16,17]. The Modified Penman equation is given as (FAO 24, 1977):

$$ET_0 = c[W.R_n + +(1 - W).f(u).(e_s - e_a)$$

Where,

$ET_0$ = Potential evapotranspiration [mmday$^{-1}$]
$e_s$ = Saturation vapor pressure at the mean air temperature in °C[mbar]
$e_a$ = Mean actual vapor pressure of the air [mbar]
$f(u)$ = A wind related function
$(1 - W)$ = A temperature and elevation related weighting factor for the effect of wind and humidity on $ET_0$
$W$ = A temperature and elevation related weighting factor
$R_n$ = Net radiation [mm day$^{-1}$]
$c$ = Adjustment factor to compensate for the effect of day and night weather conditions

### 2.3 Turc Method

The Turc formula [18] can be used for estimation of PET whenever a full set of climatic data is not available It is based on some easily available climatic data such as radiation, air temperature and relative humidity. The Turc equation for daily PET calculation is given by:

$$ET_0 = a.C.(R_G + b)\frac{T_m}{T_m + 15}$$

Where,

$ET_0$ = The reference crop evapotranspiration [mm day$^{-1}$]
$T_m$ = Daily mean air temperature [°C]
$R_G$ = The global radiation [MJ m$^{-2}$ day$^{-1}$]
$a, b$ = Empirical constants (a=0.31, b = 2.094) [MJ m$^{-2}$ day$^{-1}$].
$C$ = A parameter constrained by the relative humidity RH [%] as:

$$C = 1 + \frac{50 - RH}{70}, if RH < 50\%$$

$$C = 1, if RH \geq 50\%$$

The global solar radiation can be estimated from sunshine duration as

$$R_G = R_a\left(0.19 + 0.55 \times \frac{S}{S_o}\right)$$

Where,

$R_a$ = The extraterrestrial radiation [MJ m$^{-2}$ day$^{-1}$]
$S$ = Sunshine duration (h)
$S_o$ = The astronomic possible sunshine duration (h)

### 2.4 Hargreaves Method

Hargreaves et al. [19] proposed the following equation based on his work on grass lysimeters:

$$ET_0 = 0.0023(T_m + 17.8)(\sqrt{T_{max} - T_{min}})R_a$$

Where,

$ET_0$ = The reference crop evapotranspiration [mm day$^{-1}$]
$T_m$ = Daily mean air temperature [°C]
$T_{max}$ = Daily maximum air temperature [°C]
$T_{min}$ = Daily minimum air temperature [°C]
$R_a$ = Extraterrestrial radiation [MJ m$^{-2}$ day$^{-1}$]

$R_a$is calculated from information on location of the site and time of the year. Therefore, for using Hargreaves equation only air temperature is to be measured continuously.

### 2.5 Blaney Criddle Method

Blaney and Criddle [20] correlated evapotranspiration with monthly mean temperatures and daylight hours. Using Blaney Criddle Method (BCM) PET can be expressed as follows:

$$ET_0 = p(0.46\bar{T} + 8)$$

Where,

$ET_0$ = The reference crop evapotranspiration [mm day$^{-1}$]
$p$ = Monthly percent of total daytime hours of the year
$\bar{T}$ = Mean monthly air temperature [°C]

### 2.6 Christiansen Method

The method was developed by Christiansen [21] in order to estimate PET using pan evaporation data. Pan evaporation data was used because it is more consistent as well as readily available.

$$ET_0 = 0.755E_pC_{T2}C_{W2}C_{H2}C_{S2}$$

Where,

$E_p$ = Open pan evaporation[mm]
$C_{T2}$ = $0.862 + 0.179 + \left(\frac{T_m}{20}\right) - 0.041\left(\frac{T_m}{20}\right)^2$
$T_m$ = Mean air temperature [°C]
$C_{W2}$ = $1.189 - 0.240 + \left(\frac{W}{6.7}\right) - 0.041\left(\frac{W}{6.7}\right)^2$
$W$ = Mean wind speed 2 m above ground level [km hr$^{-1}$]
$C_{H2}$ $0.499 + 0.620\left(\frac{H_m}{0.60}\right) - 0.119\left(\frac{H_m}{0.60}\right)^2$
$H_m$ = Mean relative humidity, expressed decimally
$C_{S2}$ = $0.904 + 0.0080\left(\frac{S}{0.8}\right) + 0.088\left(\frac{S}{0.8}\right)^2$
$S$ = Percentage of possible sunshine, expressed in decimals.

### 2.7 FAO-24 Open Pan (1977) Method

PET can be estimated from open pan evaporation as:

$$ET_0 = K_pE_p$$

Where,

$E_p$ = Open pan evaporation[mm]
$K_p$ = Pan coefficient

The values of the pan coefficient ($K_p$) depend on the type of pans used in measurements. However, fetch, relative humidity and wind speed have a more pronounced effect on the $K_p$ values.

Pan coefficient as computed by Allen and Pruitt [22] for green and dry fetch is adopted in this study which is:

*Green Fetch*

$$K_p = 0.0.108 - 0.000331U_2 + 0.0422ln(F) + 0.1434ln(RH_{mean}) - 0.000631[\ln(F)]^2 2[ln(RH_{mean})]$$

*Dry Fetch*

$$K_p = 0.61 + 0.00341RH_{mean} - 0.00000187U_2RH_{mean} - 0.000000111U_2(F) + 0.0000378U_2 ln\ (F) - 0.0000332U_2 ln(U_2) - 0.0106\ [ln(U_2)][ln(F)] + 0.00063\ [ln(F)]^2\ [ln(U_2)]$$

Where,

$U_2$ = The wind speed at 2 m above the ground (m/s).

$F$ = Distance field/area cultivated or uncultivated land around the basin to a barrier against the wind (m), it may take from 1 to 1000 m;

$RH_{mean}$ = Mean relative humidity (%)

## 2.8 Statistical Analysis

The methods were compared statistically with the standard FAO-56 PM method for Shalimar Station on the basis of Coefficient of Determination ($R^2$), Root Mean Square Error (RMSE), Average Relative Discrepancy (ARE) and Mean Percentage Error (MPE). These values are cultivated as:

$$RMSE = \left[\frac{\sum(E_{pm} - E_p)^2}{n}\right]^{0.5}$$

$$MPE = \left(\frac{100}{n} \times \sum \frac{(E_{pm} - E_p)}{E_{pm}}\right)$$

$$ARE = \frac{\sum(E_p - E_{pm})^2}{n|\overline{E_p}|}$$

Where,

$E_{pm}$ = PET as estimated by Penman-Monteith method

$E_p$ = PET as estimated by empirical relation in question

$n$ = Number of observations

A high degree of association between the observed and simulated values is indicated by a value of $R^2$ close to one. RMSE and MPE provide a measure of deviation between simulated and observed values, whereas ARE statistics quantify the extent to which the computed values overestimate (positive ARE) or underestimate (negative ARE) the measured values.

## 3. RESULTS AND DISCUSSION

The meteorological data of 25 years at the Shalimar station was analyzed for purposes of calculating evapotranspiration by the different methods. Monthly PET values at Shalimar station were computed using FAO-24 Modified-Penman (MP), Hargreaves (Hrg), Turc, Blaney Criddle (BC), Christiansen (Christ), and Open Pan (OP) as well as FAO 56 PM method. The values of PET obtained from the empirical equations were compared with those obtained by FAO-56 PM method on a monthly basis.

The normal monthly PET (1992-2016) at Shalimar Station in district Srinagar by different methods is given in Table 2. The PET is minimum during the winter months of January and February while it is maximum in summer during June and July.

Comparison of monthly PET values at Shalimar station using different methods is given in Fig 2. The PET estimated by FAO-56 PM Method on monthly basis showed significant differences from those estimated by other methods. While Modified Penman method was found to overestimate PET values, other methods underestimated the same. The methods were then evaluated using statistical parameters like $R^2$, RMSE and ARE. The values of statistical parameters used for evaluating the methods are given in Table 3.

The coefficient of determination values was high for all the methods. The highest value was found for Modified Penman method being 0.99 and the least for Christiansen method as 0.86. The RMSE values indicate higher errors associated with Christiansen and Blaney-Criddle Method. Low RMSE values were obtained for all other methods least being observed in Hargreaves and open pan method. The high correlation of PET estimated by the modified Penman-Monteith method, Hargreaves and other radiation based methods under study based methods reflects the importance of the incident solar radiation in the estimation of PET.

The MPE values were highest with Blaney-Criddle (41.68%), Christiansen (41.35%) followed by Turc (32.49%), modified Penman (26.93%). Hargreaves (20.88%) and PET derived from Open pan (15.05%). The ARE values suggest that all methods except the Modified Penman method underestimate the PET values in comparison to the FAO-56 PM method.

Most of the meteorological stations in Kashmir Valley record only rainfall and air temperature data. This necessitates the application of temperature based or other simple methods inthe PET estimation. In the present study

**Table 2. Mean monthly PET at Shalimar Weather station using different methods**

| Month | Average monthly PET (mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **FAO 56 PM** | **MP** | **Hrg** | **Turc** | **BC** | **Christ** | **OP** |
| Jan | 28.5 | 32.1 | 11.4 | 6.8 | 6.6 | 7.9 | 23.1 |
| Feb | 39.6 | 42.8 | 24.5 | 18.8 | 10.8 | 12.3 | 32.4 |
| Mar | 72.5 | 79 | 55.6 | 49.7 | 32.6 | 34.5 | 60.7 |
| Apr | 99.5 | 114.3 | 84.9 | 78.1 | 57.8 | 58.8 | 84.8 |
| May | 130.1 | 155.1 | 117.4 | 111.7 | 85.4 | 82.6 | 113.3 |
| Jun | 146.8 | 172.7 | 135 | 138.1 | 111.2 | 103.2 | 129.1 |
| Jul | 146.8 | 173.3 | 136.6 | 139 | 125.7 | 114.5 | 130.1 |
| Aug | 130.9 | 156.3 | 125.3 | 122.7 | 121.4 | 111.1 | 116.2 |
| Sep | 103.2 | 129.1 | 103.8 | 99.4 | 92.5 | 86.8 | 91.3 |
| Oct | 71 | 95.6 | 74.3 | 68.3 | 60.8 | 60.8 | 62.2 |
| Nov | 40.4 | 55 | 37.4 | 30.7 | 30.1 | 32.8 | 33.7 |
| Dec | 27.3 | 35.7 | 16.8 | 8.7 | 13.2 | 15.4 | 22.2 |
| **Annual** | **1036.6** | **1241** | **923** | **872** | **748.1** | **720.7** | **899.1** |

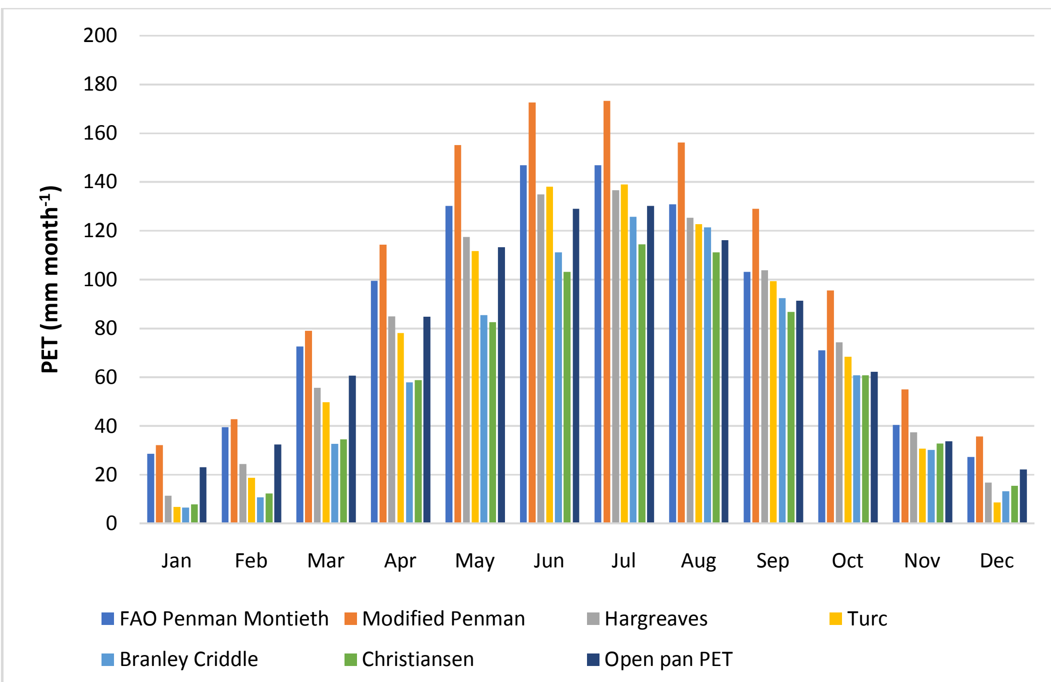


**Fig. 2. Monthly PET estimation at Shalimar weather station (1992-2016) using different methods**

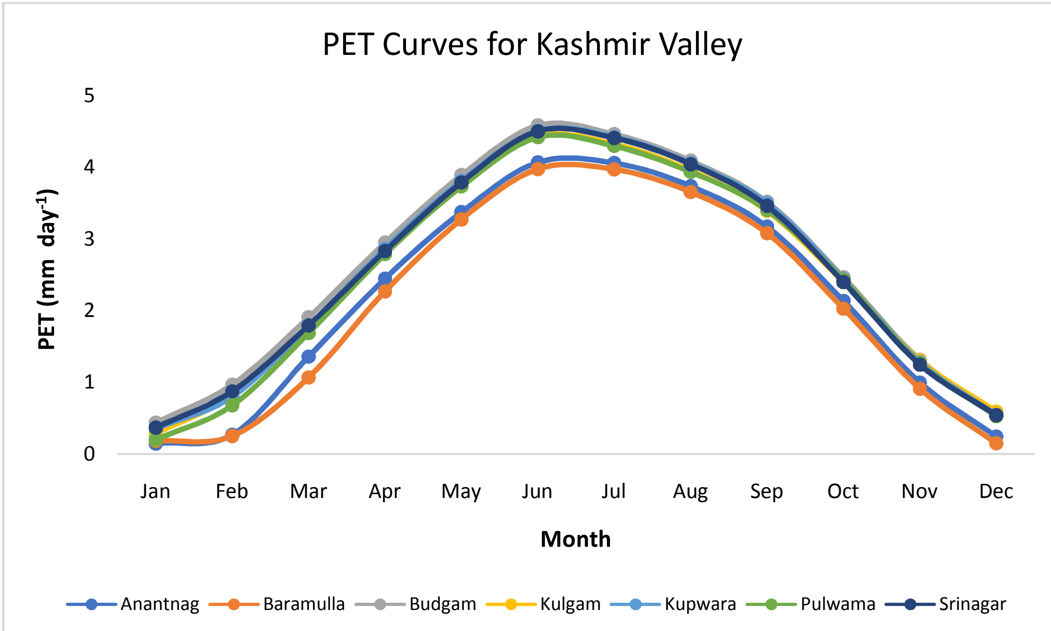


**Fig. 3. PET curves (mm day$^{-1}$) for different districts of Kashmir valley using Hargreaves method**

Hargreaves method was found to be efficient in estimation of PET requiring minimum set of parameters. The method was thus applied for the calculation of PET at other stations of Kashmir Valley.

**Table 3. Statistical parameters for performance evaluation of different PET estimation methods at Shalimar Weather station (1992-2016)**

| | $R^2$ | RMSE | MPE | ARE |
|---|---|---|---|---|
| MP | 0.99 | 0.80 | 26.93 | 0.2 |
| HRG | 0.98 | 0.45 | 20.88 | -0.1 |
| Turc | 0.97 | 0.65 | 32.49 | -0.2 |
| BC | 0.97 | 1.14 | 41.68 | -0.3 |
| CHR | 0.86 | 1.20 | 41.35 | -0.3 |
| OP | 0.87 | 0.43 | 15.05 | -0.1 |

### 3.1 Estimation of PET at Different Locations of Kashmir Valley

Hargreaves method is recommended for the estimation of PET when only air temperature data are available [23]. The HS equation is an alternative method and one of the simplest equations to determine PET, which only requires average, maximum, and minimum daily values of temperature and extraterrestrial radiation. This fact is also supported by many studies which reveal that the Hargreaves method is nearly as accurate as the FAO56-PM method in estimating PET [24,25,26] Hargreaves method was thus used to calculate PET for Anantnag, Budgam, Baramulla, Kulgam, Kupwara and Pulwama districts of Kashmir Valley. The observatories in these districts record only Maximum Temperature, Minimum Temperature and precipitation.

The variation of monthly PET in seven districts of Kashmir valley is given in table…. PET is minimum during December and January while it is maximum during June and July at all the stations. The daily PET values vary from a minimum of 0.1 mm day-1 during December and January to a maximum of 4.6 mm day-1 during the month of June. The daily PET curves for different districts of Kashmir valley are given in Fig 2. The average annual PET in the Kashmir Valley was 880 mm. PET was high in urban and low altitude districts of Budgam, Kupwara, Kulgam, Pulwama and Srinagar being nearly 900 mm annually. However, in Baramulla and Anantnag districts the observatories are located in very high altitude and cold regions having abundance of vegetation. Thus, PET in these districts was low being of the order of 700 mm. The monthly and annual values of PET at the seven stations is given in Table 4.

**Table 4. Monthly and annual PET values (mm) for different districts of Kashmir valley using Hargreaves method**

| Month | Monthly PET (mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Anantnag | Baramulla | Budgam | Kulgam | Kupwara | Pulwama | Srinagar |
| Jan | 4.5 | 5.7 | 13.5 | 9 | 11 | 6.2 | 11.4 |
| Feb | 7.5 | 7.1 | 27.1 | 23 | 22.4 | 19 | 24.5 |
| Mar | 42.1 | 33.2 | 59.1 | 55.1 | 55.3 | 52.3 | 55.6 |
| Apr | 73.4 | 68.1 | 88.5 | 85 | 85.9 | 83.7 | 84.9 |
| May | 104.6 | 101.5 | 120.6 | 116.1 | 118.1 | 115.7 | 117.4 |
| Jun | 122 | 119.3 | 137.5 | 132.9 | 135.2 | 132.6 | 135 |
| Jul | 125.8 | 123.1 | 138.3 | 134 | 137.1 | 133.2 | 136.6 |
| Aug | 115.8 | 113.3 | 126.8 | 122.5 | 125.7 | 122 | 125.3 |
| Sep | 95.1 | 92.4 | 105.5 | 101.8 | 104.9 | 102.1 | 103.8 |
| Oct | 66.2 | 62.9 | 76.4 | 74.4 | 75.6 | 75.3 | 74.3 |
| Nov | 29.9 | 27.4 | 39.4 | 39.2 | 38.4 | 37.9 | 37.4 |
| Dec | 7.6 | 4.7 | 18.2 | 18.4 | 16.9 | 16.4 | 16.8 |
| **Annual** | **795** | **759** | **951** | **911** | **927** | **896** | **923** |

## 4. CONCLUSIONS

The 25-year meteorological data derived from Shalimar weather station in Srinagar district of Kashmir Valley was used for estimation of PET at the station using different methods. The efficiency of these methods was determined by comparing with the PET estimates of FAO-56 PM method. However, due to absence of all meteorological parameters at other stations in Kashmir Valley, Hargreaves method was employed to calculate the daily, monthly and annual PET estimates in Anantnag, Budgam, Baramulla, Kulgam, Kupwara and Pulwama districts of Kashmir Valley. The highest annual PET was obtained for the Budgam district (951 mm) while the least was obtained for Baramulla district (759 mm). Thus, Hargreaves method can be applied for PET calculation in other regions of Kashmir Valley where few meteorological parameters are available.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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