

COMPARISON OF DIFFERENT METHODS FOR ESTIMATION OF POTENTIAL EVAPOTRANSPIRATION

*M. NAZEER

*Department of Water Management, NWFP Agriculture University, Peshawar, Pakistan

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Evapotranspiration can be estimated with different available methods. The aim of this research study to compare and evaluate the originally measured potential evapotranspiration from Class A pan with the Hargreaves equation, the Penman equation, the Penman-Monteith equation, and the FAO56 Penman-Monteith equation. The evaporation rate from pan recorded greater than stated methods. For each evapotranspiration method, results were compared against mean monthly potential evapotranspiration (PET) from Pan data according to FAO ($ET_o = K_{pan} \times E_{pan}$), from daily measured recorded data of the twenty-five years (1984-2008). On the basis of statistical analysis between the pan data and the FAO56- Penman-Monteith method are not considered to be very significant ($R^2 = 0.98$) at 95% confidence and prediction intervals. All methods required accurate weather data for precise results, for the purpose of this study the past twenty five years data were analyzed and used including maximum and minimum air temperature, relative humidity, wind speed, sunshine duration and rainfall. Based on linear regression analysis results the FAO56 PMM ranked first ($R^2 = 0.98$) followed by Hergreaves method ($R^2 = 0.96$), Penman-Monteith method ($R^2 = 0.94$) and Penman method ($R^2 = 0.93$). Obviously, using FAO56 Penman Monteith method with precise climatic variables for ET_o estimation is more reliable than the other alternative methods, Hergreaves is more simple and rely only on air temperatures data and can be used alternative of FAO56 Penman-Monteith method if other climatic data are missing or unreliable.

Keywords : Evapotranspiration, Hydrological cycle, Rainfall, Canopy, Spatial

1. Introduction

One of the major components of hydrological cycle is the evapotranspiration. Potential evapotranspiration (PET) is an important index of hydrologic budgets at different spatial scales and is a critical variable for understanding regional biological processes [1]. Over the entire land surface of the globe, rainfall averages around 750 mm year⁻¹, of which some two thirds is returned to the atmosphere as evapotranspiration, making evapotranspiration the largest single component of the terrestrial hydrological cycle [2].

Evapotranspiration has always been difficult to measure. Methods have been developed to measure evapotranspiration at the leaf level, the tree level and the stand level. At the stand level, instruments mounted on a tower above the canopy are routinely used to measure humidity and wind velocities at high frequency, with water fluxes out of the forest canopy calculated by the eddy covariance method. Since the majority of moisture

supplied by precipitation returns to the atmosphere as evapotranspiration and because evapotranspiration is one of the most difficult processes to evaluate in hydrologic analysis, estimates are generally considered to be a significant source of error [3]. Effective characterization of the evapotranspiration process is critical for completing the water balance in terrestrial ecosystems, and accurately predicting the effects of global climate and land use change. A process-based understanding of evapotranspiration is needed to quantify likely changes in evapotranspiration due to climate and land surface change [4,5].

The current modeling approach for estimating evapotranspiration is to calculate potential evapotranspiration (PET) using methods driven by meteorological data and/ or vegetation characteristics and to scale this estimate down to actual evapotranspiration (AET) based on limitations in available water (i.e. soil moisture)

*Corresponding author : hydro_shah12@yahoo.com.

Table 1. Average monthly climatic data (1984-2008).

Country :Pakistan		Station/Basin: Tarnab, Peshawar					
Altitude : 348m (Above M.S.L)		Latitude : 34.32 Deg (North)		Longitude :72.25 Deg (East)			
Month	Max. Temp. (°C)	Min. Temp. (°C)	Humidity (%)	Wind Speed (Km/d)	Sunshine (Hours)	Solar Rad (MJ/m2/d)	Total Rainfall (mm/month)
January	18.6	2.2	53.3	50.7	5.8	10.1	38
February	20.7	4.8	50.7	63.2	6.3	12.7	54.4
March	25	9.3	51.7	61.6	6.5	15.7	73.9
April	30.8	13.8	48.2	61.3	7.3	19.2	45
May	36.6	18.6	39.4	78	8.2	21.9	19
June	39.4	22.2	39.9	84.3	8.4	22.6	15.1
July	36.9	24.6	54.4	93.2	7.7	21.3	53.9
August	35.5	24.5	59.9	82.6	7.2	19.5	72
September	34.6	21.4	55	56.8	7.3	17.6	27.8
October	31	14	55.3	42	7.3	14.7	18.4
November	25.5	7.6	58.3	34.6	6.5	11.2	14.7
December	20.5	3.2	57.9	38.8	5.7	9.3	23.8

[6,7,8]. PET has been used to describe the evapotranspiration that would occur given an adequate water supply at all times [9]. However, the term PET is somewhat ambiguous, because the upper limit to evapotranspiration is dependent on vegetation type as well as soil water and climatic conditions [10].

Evapotranspiration is one of the main requirements to improve water management. Almost all of the methods estimating ET utilize potential or reference evapotranspiration. A large number of scientists have developed numerous number of equations to compute ETo in the last 50 years [11]. These equation range from the most complex energy balance equation requiring detail climatological data to simpler equations requiring limited data [12]. Among these methods, FAO Penman-Monteith is one of them, which have global validity. Therefore, it is necessary to evaluate various evapotranspiration methods employed in the modeling efforts. The aim of this research study is to compare different potential evapotranspiration estimation methods with actual evapotranspiration data from class A pan. For this purpose the climatic data of the past twenty-five years (1984-2008) were used.

2. Materials and Methods

2.1. Site description

The monthly average climatic data of the past twenty five years (1984-2008) for the research site were collected, analyzed and interpreted were used, including maximum and minimum air temperature, relative humidity, wind speed, sunshine duration, rainfall (Table 1) and Class A pan data (Figure 2). The statistic Department of Agriculture Research Institute provided this data. The Peshawar district lies from 34degrees 05 to 34degrees 32 north latitudes and 71 degree 48 to 72 degree 25 east longitudes with an altitude of 348 meters with 459 mm annually rainfall, the soil of the whole basin is clay to clay loam in texture.

2.2. Methods used

2.2.1. Pan evaporation

Evaporation pans provide a measurement of the combined effect of temperature, humidity, wind speed and sunshine on the reference crop evapotranspiration. To convert class A pan evaporation into ETo, a coefficient (K_p) is used, which depends on the fetch distance around the pan (F), wind speed (Ws) and air relative humidity (RH). To determine K_p , charted values or equations can be employed, where K_p is a function of F, Ws and RH [13]:

$$ET_0 = K_{Pan} \times E_{Pan} \quad (1)$$

Generally E_{pan} is taken (0.85) for class A pan.

2.2.2. Hargreaves' method

The Hargreaves equation provides reference evapotranspiration (ET_0) estimates when only air temperature data are available, although it requires previous local calibration for acceptable performance. Hargreaves equation [14] is recommended by [15] as one of the few valid temperature-based estimates of potential evaporation, though it was designed for estimating potential evaporation for agricultural systems. It gives an estimate of potential evaporation ($mm\ d^{-1}$) which can be averaged to obtain monthly values:

$$E = 0.0023S_0(T + 17.8)\sqrt{\delta_T} \quad (2)$$

Where T temperature [$^{\circ}C$], δ_T difference between mean monthly maximum temperature and mean monthly minimum temperature [$^{\circ}C$] (i.e. the difference between the maximum and minimum temperature for the given month, averaged over several years and S_0 the water equivalent of extraterrestrial radiation [$mm\ d^{-1}$] for the location.

2.2.3. Penman method

Penman's equation [16] estimates evaporation from the free surface of a body of water (potential evaporation) by considering what is necessary to balance the energy budget at the water surface. The potential evaporation [$mm\ d^{-1}$] is a fairly complex function of humidity, wind speed, radiation, and temperature:

$$E_{\gamma} = \frac{\Delta}{\Delta + \gamma} (R_n + R_h) + \frac{\gamma}{\Delta + \gamma} \frac{6.43(1 + 0.53U_2) D}{\gamma} \quad (3)$$

Where Δ slope vapour pressure curve [$kPa\ ^{\circ}C^{-1}$], R_n net radiation exchange (water equivalent) at the surface of the body of water [$mm\ d^{-1}$], A_h energy advected to the water body (water equivalent) [$mm\ d^{-1}$], γ Psychrometric constant [$kPa\ ^{\circ}C^{-1}$], D average vapor pressure deficit ($e_s - e_a$) over the estimation period [kPa] and U_2 wind speed measured at 2m elevation [$m\ s^{-1}$]

2.2.4. Penman-Monteith method

Various derivations of the Penman equation included a bulk surface resistance term [17-20].

The resulting equation is now called the Penman-Monteith equation, which may be expressed for daily values as

$$ET_0 = \Delta(R_n - G) + \frac{86,400\rho_a C_p (e_s - e_a)}{\Delta + \gamma \left[1 + \frac{r_s}{r_{av}} \right]} \quad (4)$$

Where Δ slope vapor pressure curve [$kPa\ ^{\circ}C^{-1}$], R_n net radiation at the crop surface [$MJ\ m^{-2}\ day^{-1}$], G soil heat flux density [$MJ\ m^{-2}\ day^{-1}$], ρ_a air density in $kg\ m^{-3}$, C_p specific heat of dry air [$\sim 1.013 \times 10^{-3} MJ\ kg^{-1}\ ^{\circ}C^{-1}$], e_s saturation vapour pressure [kPa], e_a actual vapour pressure [kPa], r_{av} the bulk surface aerodynamic resistance for water vapor in $s\ m^{-1}$ and r_s the canopy surface resistance in $s\ m^{-1}$

The Penman-Monteith equation represents the evaporating surface as a single "big leaf" [21] with two parameters – one of which is determined by the atmospheric physics (r_{av}) influenced only slightly by the crop canopy architecture while the other one (r_s) depends on the biological behavior of the crop canopy surface and is related to both crop specific parameters (light attenuation, leaf stomatal resistances, etc.) and environmental parameters (irradiance, vapor pressure deficit, etc.).

2.2.5. FAO-56 Penman-Monteith method

In this method, most of the equation parameters are directly measured or can be readily calculated from weather data. The equation can be utilized for the direct calculation of any crop evapotranspiration (ET_c). The FAO Penman-Monteith method to estimate ET_0 is:

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34u_2)} \quad (5)$$

Where ET_0 reference 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 daily air temperature at 2 m height [$^{\circ}C$], U_2 wind speed at 2 m height [$m\ s^{-1}$], e_s saturation vapour pressure [kPa], e_a actual vapour pressure [kPa], $e_s - e_a$ saturation vapour pressure deficit [kPa], Δ slope vapour pressure curve [$kPa\ ^{\circ}C^{-1}$] and γ psychrometric constant [$kPa\ ^{\circ}C^{-1}$].

2.3. Statistics methods

Statistical comparison of all the methods was done at 95% class interval for 95% prediction intervals.

3. Result and Discussion

Figure 1 illustrates the originally measured daily ET_o data from class A pan for the past twenty five years (1984-2008). From figure 1 it is clear that highest daily ET_o value was observed in the mid of the year. In South Asian countries lies on 32-36 °N at equator the summer season starts from May and ends at September. During summer the highest wind velocity with highest air temperature, long sun shine duration and low humidity accelerated the rate of ET_o that was observed 6, 7.4, 6.7 mm/day for the months of May, June and July respectively.

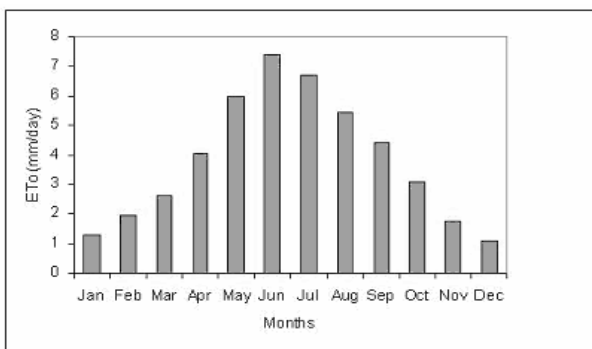


Figure 1. Measured daily ET_o from class A pan (1984-2008)

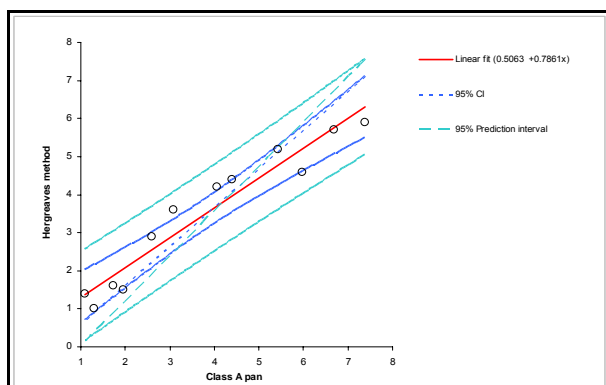


Figure 2. Comparison between daily average Potential evapotranspiration estimated by Hergreaves method with class A pan.

The comparison between the variations of originally measured ET_o from Class A pan and estimated by Hergreaves method is presented in Figure 2. The statistical analysis based on a linear

regression study applied to observe and calculated ET_o rates, reveals the feasibility of the proposed methodology for the site in study, whose accuracy is confirmed by high coefficients of determination ($R^2=0.96$) and also by small dispersion of the data around the fitted 1:1 lines of 95% confidence and prediction intervals. When comparing both methods, the proposed approach against originally measured ET_o from Class A pan and Hergreaves estimated ET_o measurements it was possible to observe that the standard error was, 0.46 mm day⁻¹.

The comparison between the variations of originally measured ET_o from Class A pan and estimated by Penman-Monteith method is shown in Figure 3. The ET_o measured with highly accuracy from class A pan and estimated by Penman-Monteith method points out a fairly consistent agreement. A fact that can be statistically confirmed by coefficients of determination ($R^2=0.94$), as well as by a some dispersion of the data around the linear fit between the 1:1 of 95% confidence and prediction intervals.

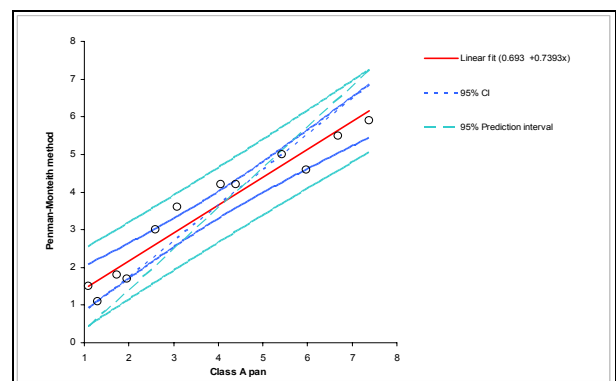


Figure 3. Comparison between daily average Potential evapotranspiration estimated by Penman-Monteith method with class A pan

The FAO56 Penman-Monteith approach produced highly significant performance at the research site, with a high degree of accuracy shown in Figure 4. The coefficients of determination and correlation indicate the degree of accuracy. The statistical analysis based on a linear regression confirmed the closeness of the originally measured ET_o data from class A pan and estimated by FAO56 Penman-Monteith approach with highest regression coefficient (0.98) and less value of standard error 0.26 mm day⁻¹ around the

liner fit between the 1:1 of 95% confidence and prediction intervals.

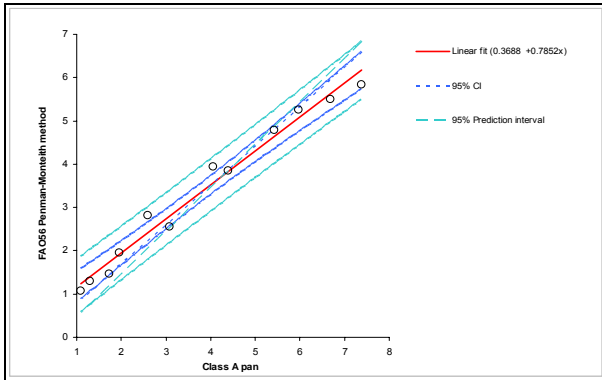


Figure 4. Comparison between Daily average Potential evapotranspiration estimated by FAO56 Penman-Monteith method with class A pan

Lower value of statistical analysis from linear regression model ($R^2=0.93$) was observed when comparisons were made between originally measured class A pan ET_o data with Penman method. The value of standard error in this case was observed the highest 0.49 mm day^{-1} among other compared methods as shown in Figure 5.

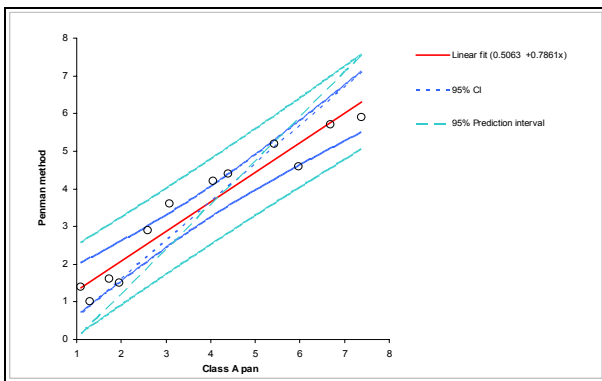


Figure 5. Comparison between daily average Potential evapotranspiration estimated by Penman method with class A pan.

FAO56 Penman-Monteith method is used throughout the world as a standard method for the computation of potential evapotranspiration. Its limitation in practical terms is, however, related to a large number of environmental variables that are necessary to determine ET_o . Furthermore, the lack of automatic weather station systems available to monitor the atmospheric parameters in many developing countries justifies the use of alternative methods for determining ET_o as a function of fewer

measured parameters. Mainly if the result has a precision comparable to standard methods, such as lysimetric measurements or Penman-Monteith estimates [22]. Further investigations should be carried out to examine the performance of the different methods at other sites.

4. Conclusion

The potential evapotranspiration value estimated from all methods seems to have better association with originally measured potential evapotranspiration data from class A pan. Results showed that FAO56 Penman-Monteith method was highly correlated with class A pan originally measured data followed by Hergraeves. While the Penman-Monteith and Penman methods also have appropriate correlation with originally measured data. It is concluded from the study that the use of FAO56 Penman-Monteith method to estimate potential evapotranspiration is best as comparable to other stated methods in the absence of originally pan data.

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