The Nucleus **48**, No. 4 (2011) 331-337

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

EVALUATION OF DIFFERENT METHODS FOR POTENTIAL EVAPOTRANSPIRATION ESTIMATION

*M. NAZEER and H. ALI[1]

Department of Water Management, Khyber Pakhtunkhwa Agricultural University, Peshawar, Pakistan

[1]Agriculture Research Institute (ARI), Tarnab, Peshawar, Pakistan

(Received July 27, 2011 and accepted in revised form October 17, 2011)

Accurate and reliable potential evapotranspiration estimation depends on the method through which it is estimated. The aim of this research study is to compare and evaluate different potential evapotrasnpiration estimation methods against the standard FAO Penman -Monteith equation (FPM). The methods evaluated included simple Penman -Monteith equation (SPM), Hergreaves's method (HM), Priestly Taylor method (PTM) and Makkink method (MM). Mean monthly data of all the climatic variables including maximum and minimum air temperature, relative humidity, wind speed, solar radiation and rainfall was recorded during 2010 from weather station installed inside the Agriculture Research Institute (ARI) Tarnab, Peshawar, Pakistan. Results revealed that all methods underestimated potential evapotranspiration value except the HM. A t and paired t-test was applied on overall means of the all methods and individually monthly means against FPM. There was no overall significant difference for all methods when compared against FPM annually. Significant differences were observed for all methods when subjected to paired t-test for individual monthly mean subjected against FPM. The SPM is considered best after FPM (R^2=0.99), but it also need high numbers of climatic parameters. While the HM which worked on only temperature variable and PT on solar radiation showed high correlation (R^2=0.98) with FPM. HM and PT are simpler and rely only on temperature and radiation data, can be used as an alternative to FPM if some of climatic data are missing or unreliable.

Keywords: Evapotranspiration, Climatic variables, Evaluation, T-test, Tarnab

1. Introduction

Evapotranspiration is the combination of two processes, evaporation and transpiration. Both processes work on the principle of converting liquid water to water vapour, however the evaporation is the removal of water from bare surfaces while transpiration from vegetation. One of the major components of the hydrological cycle is evapotranspiration. Reference or potential evapotranspiration (PET) is an important index of hydrologic budgets at different spatial scales and a critical variable for understanding regional biological processes [1]. Over the entire land surface of the globe rainfall averages around 750 mm year, of which some two thirds are returned to the atmosphere as evapotranspiration thus making evapotranspiration the largest single component of the terrestrial hydrological cycle [2]. Evapotranspiration is not only an important component of water cycle but also an indicator of irrigation planning. Its accurate estimation is of crucial importance for proper irrigation planning schemes. A process-based understanding of evapotranspiration is needed to quantify possible shift in the processes due to climate and land surface change [3,4].

Evaporation and transpiration occur simultaneously therefore, there is no easy way to measure the two processes individually. Evapotranspiration is one of the most difficult processes to evaluate in hydrological analysis, estimates are generally considered to be a significant source of error [5]. Specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters are required to determine evapotranspiration. The methods are often expensive, complex, demanding in terms of accuracy of measurement and can only be fully exploited by well-trained research personnel. Many mathematical equations are

* Corresponding author : nazeer_aup@yahoo.com

developed to estimate evapotranspiration but none of these can be universally recommended and adopted. Sometimes error upto the unacceptable limits appears when applied in climates different than where they were originally developed. It requires several measurements of climatic variables such as air temperature, relative humidity, solar radiation and wind speed. Unfortunately, there are a limited number of sites over the world where complete meteorological stations are installed for routine measurements of these climatic variables. This lack of meteorological data leads to the development of simpler approaches to estimate PET that requires only a few climatic parameters. In this context, several methods have been reported in the literature to estimate PET. Some of these methods are based on a single climatic variable, i.e. solar radiation [6], or temperature [7]. While some methods are based on different combinations of climatic parameters involving solar radiation, air temperature, humidity and wind speed [8-10]. FAO Penman -Monteith equation is recommended by many scientists [11-13] due to it accurate estimation of PET. The main aim of this study is to compare different PET estimation methods against FAO Penman - Monteith equation in order to find it alternative for the study locality.

2. Materials and Methods

2.1. Site Description and Data Collection

The daily weather data (converted to monthly) of 2010, for the research site were recorded, analyzed and interpreted from weather station installed inside the research institute, including maximum and minimum air temperature, relative humidity, wind speed, sunshine duration, and rainfall. A complete dataset used in this study are shown in Table 1. The Peshawar district lies between 34° 05' to 34° 32' north latitude and 71° 48' to 72° 25′ east longitudes, with an altitude of 348 meters.

2.2. Methods used in PET Estimation

The FAO Penman –Monteith, the simple Penman- Monteith, the Hargreaves, the Priestley-Taylor and the Makkink methods were used in this study. Separate Excel spreadsheets were prepared for each method.

2.2.1. FAO-56 Penman-Monteith Method (FPM):

In this method, most of the equation parameters are directly measured or can be readily calculated from weather data. FPM to estimate PET is:

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

Where Rn is the net radiation (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C) U_2 the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), es - ea is the saturation vapour pressure deficit (kPa), Δ is the slope vapour pressure curve (kPa °C^{-1}) and γ is the psychrometric constant (kPa °C^{-1}).

2.2.2 Simple Penman-Monteith Method (SPM)

Various derivations of the Penman equation included a bulk surface resistance term [14-17], are incorporated. The resulting equation is now called the Penman-Monteith equation, which may be expressed as;

$$ET_o = \Delta(R_n - G) + \frac{86,400\rho_a C_p (e_s - e_a)}{\Delta + \gamma\left[1 + \frac{r_s}{r_{av}}\right]} \quad (2)$$

Where ρ_a air density in kg m^{-3}, C_p is the specific heat of dry air [~1.013 x 10-3MJ kg^{-1} ºC^{-1}], 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}.

2.2.3. Hargreaves' Method (HM)

The Hargreaves equation provides reference to evapotranspiration (PET) estimates when only air temperature data are available, although it requires previous local calibration for acceptable performance. The Hargreaves equation [18] is recommended by Shuttleworth [19] 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:

$$E = 0.0023S_o(T + 17.8)\sqrt{\delta_T} \quad (3)$$

Table 1. Mean monthly climatic variables (2010).

Months	Temperature (°C)		Relative Humididty (%)		Wind Velocity (km/day)	Solar Radiation (Ca/ cm^2 /day)	Rainfall (mm)
	Max	Min	8 am	5pm			
January	20.8	0.80	72.7	38.1	17.5	178.2	11.7
February	19.2	5.03	69.9	43.7	37.3	156.8	12.85
March	30.2	11.6	65.1	34.4	31.3	235.2	0.33
April	33.3	15.0	57.5	34.8	45.9	210.1	3.39
May	36.5	18.9	51.4	35.6	46.9	267.4	4.26
June	38.1	20.9	54.5	35.5	42.2	282.6	17.3
July	38.2	23.5	66.5	42.8	40.7	229.7	45.3
August	36.0	24.0	72.4	47.9	30.0	183.8	17.3
September	34.8	20.0	70.1	48.6	43.0	232.4	9.00
October	32.5	16.1	70.3	46.2	26.2	243.2	0.00
November	28.0	6.40	55.2	39.8	17.0	232.4	0.00
December	18.9	0.30	57.9	40.2	9.10	191.1	13.4

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

2.2.4. Priestly Taylor Method (PTM)

Priestly and Taylor [20] developed an equation for low advective conditions. The priestly and Taylor equation is given as :

$$PET = 0.408\alpha \frac{\Delta(R_n - G)}{\Delta + \gamma} \quad (4)$$

Where α is constant (1.26).

2.2.5. Makkink Method (MM)

Makkink [21] developed method for PET estimation using solar radiation. The equation is given as;

$$PET = C_m \frac{\Delta}{\Delta + \gamma} R_s \quad (5)$$

Where Rs is solar radiation and Cm is constant (0.65).

2.3. Statistical Analysis

Statistical comparison of all the methods was performed at 95% confidence interval against FAO Penman-Monteith method, while differences between comparisons were statistically analyzed by using t and paired t-test for overall and individual means respectively.

3. Result and Discussion

Monthly average potential evapotranspiration values estimated through different methods is shown in Figure 1. Most of these methods showed the same trend throughout the year**.** All the methods underestimated PET except HM. The under and over estimation was further clarified by root mean square error (RMSE) of the residuals between FPM and the related PET estimation methods. The lower RMSE value for HM (0.28) and PT (0.26) indicated higher deviation from FPM estimated value, while low deviation was observed for PM and MM against FPM, had 0.33 and 0.47 RMSE values respectively. It is clear that the

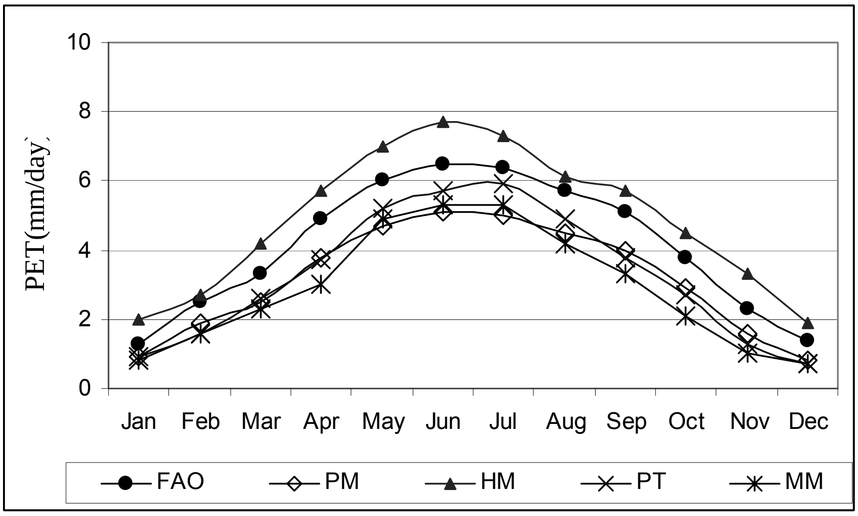

Figure 1. Comparison of all PET methods.

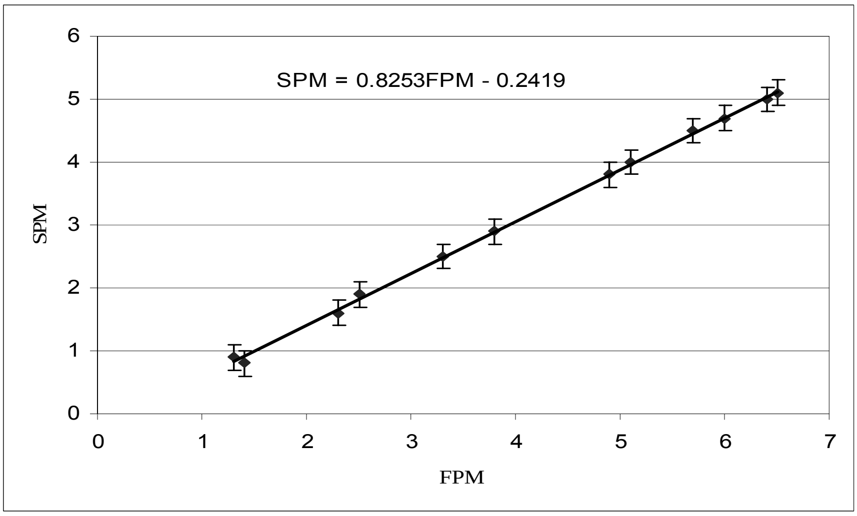

Figure 2. FPM vs. SPM derived PET.

highest daily PET value was observed in the middle of the year. In South Asian countries at the 32-36 °N of the equator the summer season starts in May and ends in September. During the summer, the highest wind velocity with highest air temperature, long sun shine duration and low humidity accelerated the rate of PET.

PET estimated through FPM and SPM is shown in Figure 2. A slight under estimation was noticed at lower and higher range while it is good agreement between the FPM and SPM (R^2=0.99) in middle. Over all the difference in the mean values of the two methods is not great enough to reject the possibility of difference due to random sampling variability. No statistically significant difference was observed between the two methods (P = 0.196) using t-test. FPM and SPM methods give almost the same value of PET. small differences among two methods was observed which may be due to wind function used in each method. As these methods use data of maximum number of weather variables data to estimate PET, it is possible to make that these methods give good estimate of PET [22]. However, using paired t-test for individual mean values the Shapiro-Wilk normality test was passed for t-9.773 with 11 degrees of freedom. The 95 percent confidence interval for differences of means ranged from 0.743 to 1.174. The differences that occurred with the mean monthly individual values when compared was significant (p=<0.001).

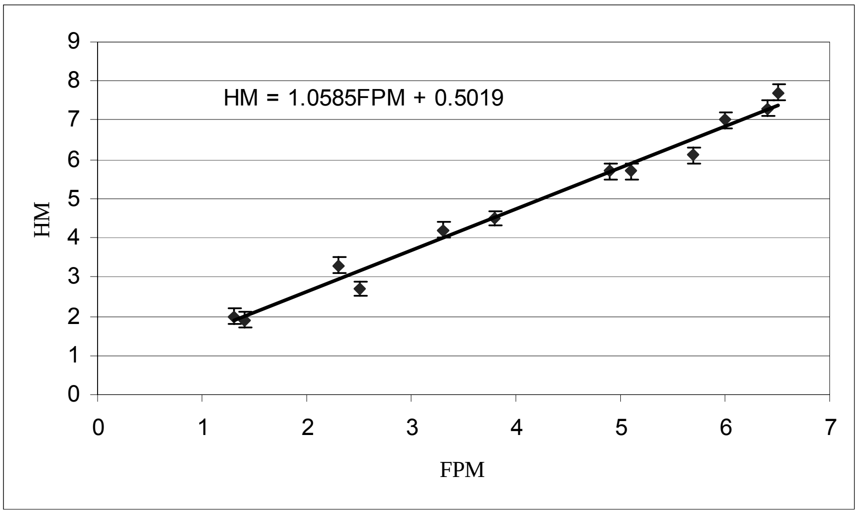

Figure 3. FPM vs HM derived PET.

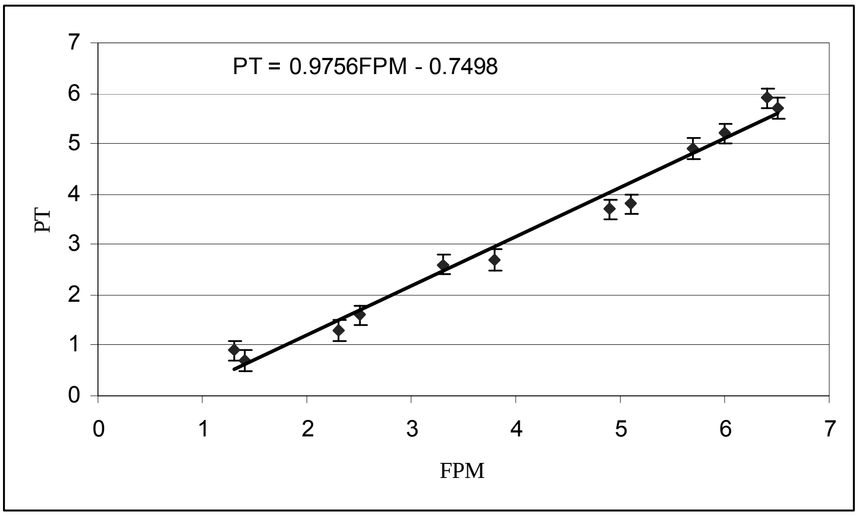

Figure 4. FPM vs. PT derived PET.

The comparison between the variations of PET estimated through FPM and HM is presented in Figure 3. Overestimation was observed at middle and higher range similarly underestimation was also observed for two-three values at the middle. The over and underestimation may be due to the negligence of aerodynamic as well as radiation terms in HM equation [22]. The statistical analysis, based on t-test, reveals that the overall difference in the mean values of the two methods is not significant (R^2=0.98) to reject the possibility of differences due to random sampling variability. There is no significant difference between the input groups (P = 0.370). However paired t-test for individual mean monthly values was found significant (p=<0.001) when the comparison was made.

Figure 4 described that much over estimation was observed by PT at lower and higher range along the fit. However much underestimation was observed in the middle range of the fit curve. The fluctuation of the values across the fit may be due to the neglected aerodynamic term [22]. The overall difference between the two methods to estimate PET is non significant using t-test (P = 0.286). The difference in the mean values of the two groups is not great enough to reject the possibility that the difference is due to random sampling variability (R^2=0.98). While paired t-test indicated that the difference in individual mean is significant.

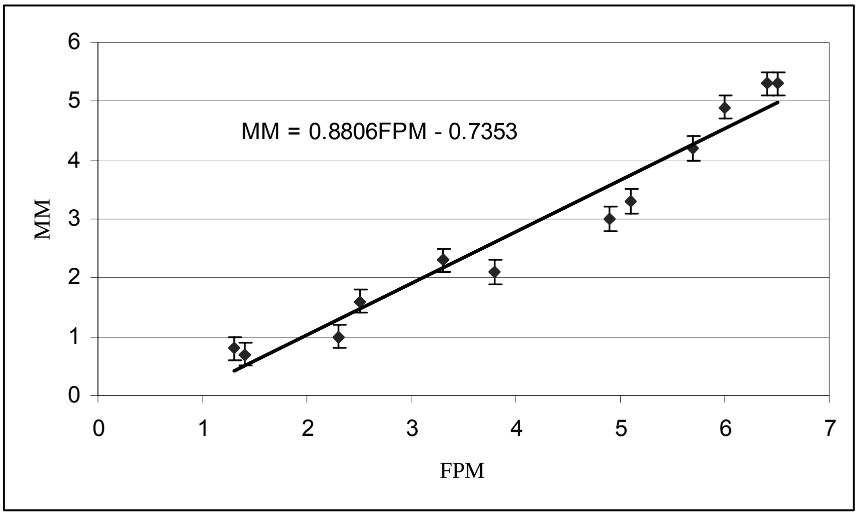

Figure 5. FPM vs. MM derived PET.

The PET estimated by MM showed higher deviation at lower as well as higher range of fit against FPM as shown in Figure 5. Higher underestimation is observed in this case at middle range while in some cases overestimation is also observed against the fit curve. The main reason for this variation is the negligence of aerodynamic component in equation [22]. The overall differences in the mean values of the two methods are not great enough to reject the possibility that the difference is due to random sampling variability (R^2=0.94). There is no significant difference between the input groups (P = 0.115) using t-test. However the paired t-test revealed that the difference that occurred with the treatment is greater than would be expected by chance (P = <0.001) at 95% confidence interval for difference of means: 0.949 to 1.501.

4. Conclusion

Potential evapotranspiration estimation totally depends on climatic parameters including temperature, humidity, solar radiation and wind speed. FAO Penman-Monteith equation has all these parameters and has been recognized the standard equation for potential evapotranspiration estimation. No methods give reliable results against FAO Penman-Monteith equation except simple Penman-Monteith. As it incorporate all climatic variables but it also require large number of data for all variables. The equations worked on only solar radiation component like Priestly Taylor and Makkink method underestimated the potential evapotranspiration. The Hargreaves's method showed overestimation as it is based on only temperature and ignore the stress caused by other components of climatic variables. Priestly-Taylor and Hargreaves-Radiation showed high R^2 value implies that they can be used in the research site of FPM alternative, when data for some variables are missing or unreliable.

Acknowledgements

The authors wish to render their heartfelt gratitude to the staff of Statistics Department of the Agriculture Research Institute (ARI), Tarnab, Peshawar (KPK) for helping in climatic data recording of the area.

References

[1] J. Lu, Ge Sun, S. G. McNulty and D.M. Amatya, J. Amer. Water Resources Assoc. **41**, No. 3 (2005) 621.

[2] A. Baumgartner and E. Reichel. World Water Balance: Mean Annual Global, Continental and Maritime Precipitation, Evaporation and Run-off. Elsevier, Amsterdam (1975) p. 179.

[3] R.J.C. Burnash. The NWS river forecast system catchments modeling. In: Singh, V.P. (Ed.), Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, CO (1995) pp. 311.

[4] B.J. Choudhury and N.E. Di Girolamo, Journal of Hydrology **205** (1998) 164.

[5] G. Rasul and A. Mahmood, Pak. J. of Meteorology **5**, No. 10 (2009) 12.

[6] G.F. Makkink, J. Inst. Water Eng. **11**, No. 3 (1957) 288.

[7] G.H. Hargreaves and Z.A. Samani, Appl. Engr. Agric. **1** (1985) 96.

[8] R.G. Allen, L.S. Pereira, D. Raes and M. Smith, Paper 56, Food and Agric. Orgn. of the United Nations, Rome, Italy (1998) 300.

[9] J. Doorenbos and W.O. Pruitt, Paper 24, FAO, United Nations, Rome (1975) 115.

[10] H.L Penman, Proc. Roy. Soc. London A**193** (1948) 146.

[11] H.A.R. De Bruin and J.N.M. Stricker, Hydrol. Sci. **45**, No. 3 (2000) 406.

[12] M. Hussein and Al-Ghobari, Irrig. Sci. **19**, No. 2(2000)81.

[13] M. Nazeer, The Nucleus **47**, No. 1 (2010) 41.

[14] H.L Penman, The Physical Basis of Irrigation Control. Rep. 13th Intl. Hort. Congr. **2** (1953) p. 913-914.

[15] W. Covey, Testing a Hypothesis Concerning The Quantitative Dependence of Evapotranspiration on Availability of Moisture. Soil Physics, A. & M. College of Texas, College Station, M.S. Thesis (1959) 58.

[16] P.E. Rijtema, Analysis of Actual Evapotranspiration. Agric. Res. Rep. No. 69, Centre for Agric. Publ. and Doc., Wageningen (1965) 111.

[17] J.L Monteith, Evaporation and Environment, in G.E. Fogg (ed.) Symposium of the Society for Experimental Biology, The State and Movement of Water in Living Organisms Academic Press, Inc., NY **19** (1965) pp. 205.

[18] G.H. Hargreaves and Z.A. Samani, Appl. Engr. Agric. **1** (1985) 96.

[19] W.J Shuttleworth, Evaporation Models in Hydrology. In: Schmugge, T.J., Andre´, J.C. (Eds.), Land Surface Evaporation: Measurement and Parameterization. Springer, New York (1991) pp. 93.

[20] C.H.B Priestley and R.J. Taylor, Monthly Weather Review **100** (1972) 81.

[21] G.F.J. Makkink, Institute of Water Engineering **11** (1957) 277.

[22] S. Er- RAK, G. Chehbouni, N. Guemouria, J. Ezzahar, B. Duchemin, G.B Oulet, R. Hadria1, A. Lakha, A. Chehbouni and J.C. Rodriguez, Actes du Seminaire Modernisation de l'Agriculture Irrigu´ee Rabat, du 19 au 23 avril 2004.