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RE- EXAMINING THE VALIDITY OF REFERECE EVAPOTRANSPIRATION ESTIMATION IN HERAT, AFGHANISTAN

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ABSTRACT: The aim of this study is to contribute in irrigation scheduling by proposing adaptable models that are widely used for the estimation of reference evapotranspiration (ET_0) in Herat, Afghanistan. Six well-known models, The Penman-Monteith (ET_{0PM}), Hargreaves (ET_{0Hrg}), Hamon (ET_{0Ham}), Thornthwaite (ET_{0Trw}), solar radiation based (ET_{0Rs}) and Net radiation based (ET_{0Rn}) were compared, and the pan evapotranspiration $\left(ET_{pan}\right)$ model was used as indicator. The pan coefficient (k_P) proposed by Pereira was used to convert pan evaporation (E_{pan}) to ET_{pan}. Results obtained showed that, the ET_0values estimated by all the methods were shown to be close to those of ET_{pan} in the second period (spring, fall and winter). However, large differences emerged in the first period (the windy summer), with the exception of ET_{0PM}. This method displayed a small difference only in June and July. Pearson's correlation (R) showed that the estimates produced by all the simpler methods were significant correlated with those of ET_{pan} in the second period, but weakly correlated in the first period. The ET_{0PM} method produced the lowest value of 1.3 mm day^{-1}, based on the standard error estimation (SEE). The seasonally-based average difference between ET_{pan} and ET_{0PM} was smaller than that of the other methods in the first period, at 1.9 mm day^{-1}. The ET_{0PM} estimation rate was therefore closest to ET_{pan}. It is concluded that the methods that used wind factor are more adaptable than those not used wind factor especially in Herat, Afghanistan. The wind might be the reason of the differences between ET_{pan} and ET_{0PM} in the windy summer.

Keyword: 120-day winds, Pan evaporation, Reference evapotranspiration, Herat, Afghanistan

1. INTRODUCTION

Evapotranspiration(ET) is defined as a physical processes whereby liquid water vaporized into the atmosphere from evaporating surfaces [2]. The ET rate varies with weather conditions. Because of this variability, water managers who are responsible for planning and adjudicating the distribution of water resources need to have a thorough understanding of the ET process, and knowledge of its spatial and temporal rates.

ET is defined in different concepts, one of which is reference evapotranspiration. The concept of ET_0 is used to introduce the evaporative demand of the atmosphere apart from the crop type, crop development and management practice [2].

Many different methods have been developed for measuring the ET_0 based on their daily performances under the given climatic conditions in the world. In this study, six well-known models, as well as the ET_{pan} method were selected to estimate the ET_0 based on their daily performance under the climatic condition of Herat, Afghanistan.

The United Nations Food and Agriculture Organization (FAO) introduced a model for estimating the standard ET_0, known as the Penman-Monteith model as given by Eq. (1) Table 1 [2]. The accuracy of the FAO model is sufficiently high to be recommended as the sole method for calculating ET_0 in cases where the necessary data are available [2]. The only limitation to the Penman family of models is that they require many meteorological dataset, thereby limiting their utility in data-sparse areas [6].

The Penman-Monteith method was simplified by Irmak et al. (2003) as expressing a multi-linear regression function that only net radiation (R_n) and solar radiation (R_s) are needed as requires input parameters for estimation [9] Eq. (2) and (3).

Thornthwaite (1944) popularized the concept of ET and proposed a method which requires monthly average temperature data this method due to the requirements is simpler method [3]. Eq. (4).

The Hargreaves-Samani (1985) method is one of the older ET methods. It was first introduced by Allen and Hargreaves and is given by Eq. (5). The requirement components for this method is simpler as it needs only measured temperature data [8].

The Hamon Method is another simple method that is applicable for estimating the ET_0 on monthly or annual basis. According to Haith and Shoemaker (1987), this method requires only the average number of daylight hours per day and the saturated vapor pressure [7]. It is given by Eq. (5).

Finally, the method described by Allen et al. (1991), known as FAO 24 Pan Evaporation (24-PAN) is given by Eq. (7). To estimate ET_0, the measured pan evaporation is adjusted by a coefficient k_P, given by Eq. (8).

Most organizations working in the field of agriculture and water supply, estimate the ET_0 rate using software developed by FAO, called CROPWAT. However, no method has yet been recommended for estimating the ET_0 rate in Herat province. It means that, still no research has been conducted to contrast different well-known methods to find whether any other model is adaptable for estimation of the ET_0 or not, because the application of the CROPWAT is not easy for everyone due to its complexity. Thus, in order to contribute in terms of irrigation scheduling by proposing adaptable models for ET_0 estimation, the objective of this study is to contrast six well-known methods with ET_{pan} which are different based on their requirements and performance in a given climatic condition. This research was based on the following hypothesis:

The estimation of ET_0 value would be more adaptable in Herat, Afghanistan with the methods those require wind factor than those that do not.

1.1 Estimation Methods

Table 1 shows the equations of the six methods and the pan method. Table 2 lists the different atmospheric parameters that are required by each model.

Based on the requirements, in this study we compare ET_0 estimation using three temperature-based methods (ET_{0Trw}, ET_{0Hrg} and ET_{0Ham}), two radiation-based methods (ET_{0Rs} and ET_{0Rn}), and one aerodynamic plus energy budget approach (ET_{0PM}).

The temperature-based methods are simple models and are easy apply in areas where the required input data are available, whereas the aerodynamic plus energy budget approach is a complex method which requires various input dataset. Therefore, its application is not easy in the areas where the input dataset is limited. Based on the different requirements of the models, six well-known models were selected for comparison with ET_{pan} to identify those that are suitable for use in Herat.

Herat is characterized by strong winds (an aerodynamic factor) an arid climate. It was therefore re-examining the temperature based models and aerodynamic plus energy budget approach give us a better understanding of the models which are more adaptable.

As very little of the E_{pan} data was available, the data from the year 2009 was only used to estimate the ET_{pan}value. Variety of sources that are listed in Table 3 were used for data collection. It should be noted that, there is a metrological station in Herat province, Urdu Khan Research Farm, operated by the department of Agriculture irrigation and livestock.

The Urdu Khan regional agricultural research station has a total area of 225 hectares and is located at a latitude of 34° 31' N and a longitude of 62° 22' E with an elevation of 964 meters. It lies in Urdu Khan village, 5.8 kilometers southeast of Herat city (Fig 1). A strong wind known as the “120-day winds” persists from early June until late September with a strong average force of 7.01 m/sec [5]. Based on data measured data in 2009, the maximum mean annual temperature is around 37.5°C, and the minimum mean temperature is 0.5°C. The total precipitation is 345.6 mm, and the daily average relative humidity is 41.3%.

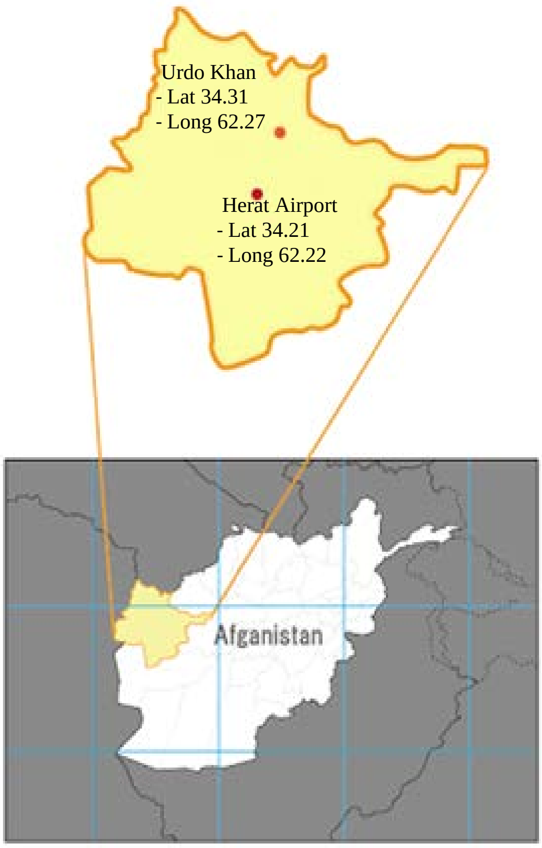


Fig 1 Location of Urdu Khan Farm and Airport in Herat, Afghanistan

2. RESULTS AND DISCUSSION

The difference between the ET_{pan} and ET_0 rates was seen mainly in the first period (windy summer). The reasons might be due to the seasonal variation in the climatic condition, and particularly the strong wind speed that prevails in Herat during the summer season, in one hand, and the differences of the models, in the other hand.

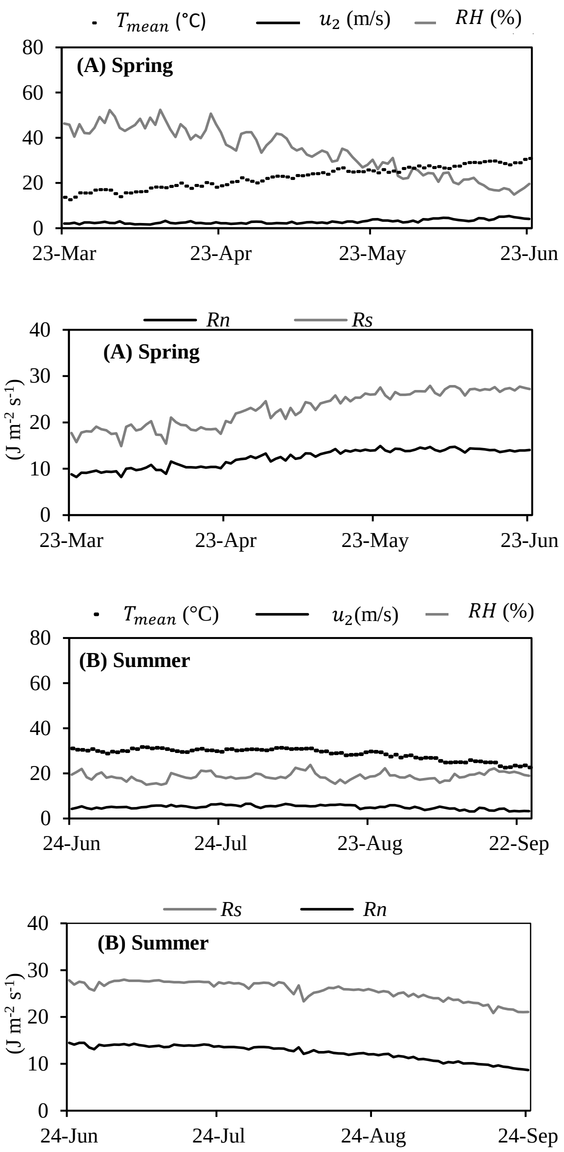
2.1 Seasonal Variation of Metrological Factor

The region in a year has four seasons: spring (March-June), summer (June-September), fall

(September-December), and winter (December-March). Daily variations in the meteorological variables across the four seasons are shown in Fig. 2 A to D. The daily variations in temperature(T), wind speed (u_2) , relative humidity (RH) , solar radiation (R_s), and net radiation (R_n) are the main variables used for ET_0 estimation. The average values of these were derived from measurements taken over six years. RH ranged from above 10% and less than 60% in the spring, above 40% to less than 80% in the winter, above 20% to less than 70% in the fall. The summer season was characterized by significantly lower humidity of less than 30%.

Throughout the summer, the wind speed was higher than in the other seasons, by more than 5 m/s on average. The temperature also higher in summer, at more than 30°C, dropping below 30 % from the early part of December until the middle of spring.

R_n is decreasing by early fall and again increasing from late winter on.



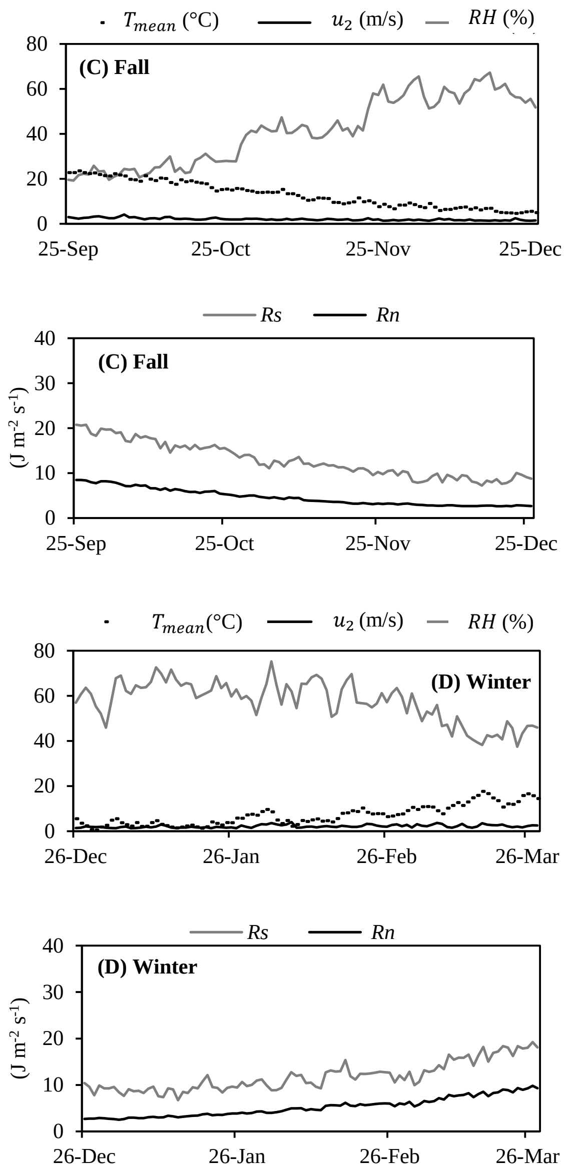


Fig. 2 (A) spring season; (B) summer season; (C) fall season and (D) winter season; daily average temperature, wind speed, relative humidity, net radiation and solar radiation, 2006-2012

2.2 Estimation of The Daily Average ET_0

The ET_0 value estimated by methods were compared with the ET_{pan} result based on the 2009 data. The result shown in Figs. 3 to 8. All methods showed higher rates in the summer season.

The ET_{0PM} produced rates close rate to the ET_{pan} rates throughout the year, and from August to June the rates from both were almost identical. In the summer season, and especially June and July, ET_{pan} gave lower rates than ET_{0PM} (Fig 3). One of the reasons might be due to the strong “120-day winds” which blows thought the summer season with high speed in Herat province.

The difference between the ET_{pan} results and those of the other methods was significantly larger in the period approximately from June to November, while in the other months were smaller Figs. 4 to 8.

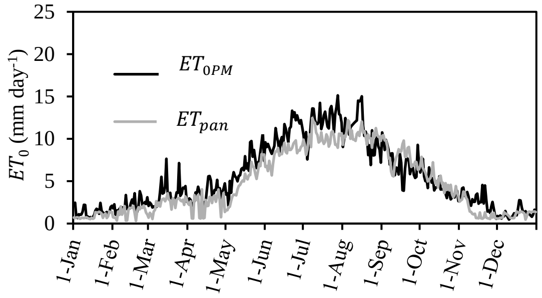


Fig. 3 Daily average value estimated by ET_{pan} and ET_{0PM}, 2009

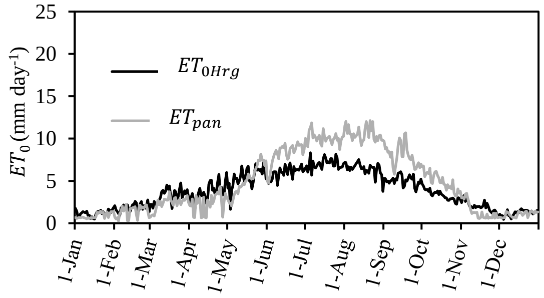


Fig. 4 Daily average value estimated by ET_{pan} and ET_{0Hrg}, 2009

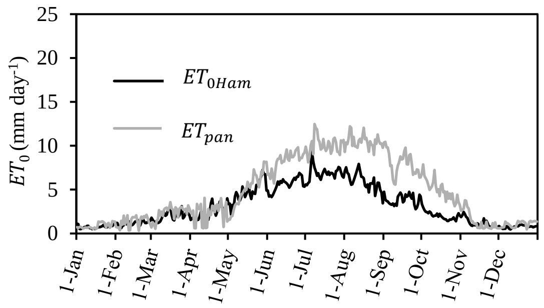


Fig. 5 Daily average value estimated by ET_{pan} and ET_{0Ham}, 2009

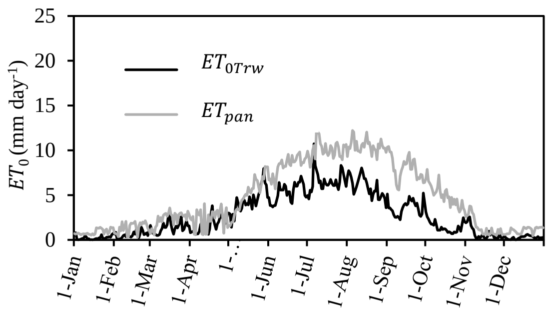


Fig. 6 Daily average value estimated by ET_{pan} and ET_{0Trw}, 2009

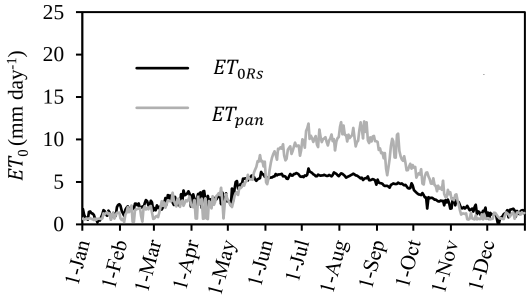


Fig. 7 Daily average value estimated by ET_{pan} and ET_{0Rs}, 2009

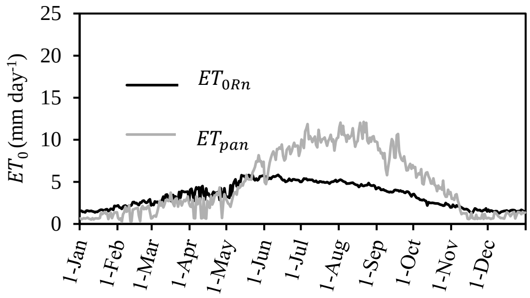


Fig. 8 Daily average value estimated of ET_{pan} and ET_{0Rn}, 2009

2.3 Total Annual Estimation of ET_0 Value

The total annual ET_0 values estimated by the seven methods are shown in Fig. 9. ET_{0Hrg},ET_{pan}, and ET_{0PM} produced higher total annual values compare to the four other methods.

ET_{0PM} produced the highest value of 2000 mm year^{-1}, while ET_{0RS} , ET_{0Rn} , ET_{0Ham} , and ET_{0Trw} produced lower value respectively. ET_{0Trw} produced the lowest value at less than 1000 mm year^{-1}.

Variations in the ET_0 estimation reflect the differences in the variables applied in each method.

The ET_{pan} method was considered as the indicator, the estimated ET_{0PM} value were closet to the ET_{pan} values. Therefore, the ET_{0PM} method can be considered as the most useful method for designing of irrigation planning.

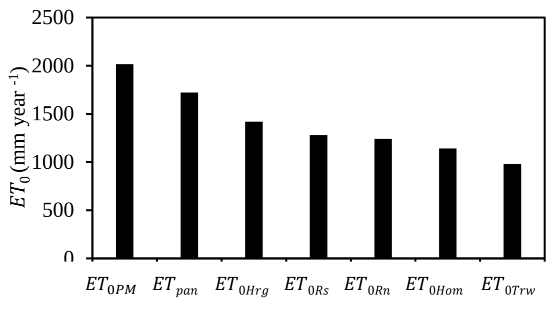


Fig. 9 Total annual ET_0 estimates given by the different methods based on 2009 data

2.4 Relationship Between ET_{pan} And ET_0

Brutsaert and Parlange (1998) indicated that, ET_{pan} is often taken as a good indicator for ET_0 compression. Because all the methods are influenced by some of the same parameters, a linear relationship exists among them. Therefore, Pearson's correlation was used to test the relationship between ET_{pan} and each of the other methods to identify the periods in which correlation was strongest. Pearson's correlation coefficient is often used when measuring the influence of one time-dependent variable on another in bivariate climate time series data [10].

In this paper, each selected method was correlated with the ET_{pan} results in two periods to identify the seasonal differences. The two periods were distinguished based on wind speed.

2.4.1 First period

The triangles in the Figs. 10 to 15 depicts the first period that is from June to September (the windy summer). During this period, no statistically significant correlation was found between ET_{pan} and the other methods.

Table 4 shows that the p values for all methods were greater than 0.05 %. The seasonally-based average difference between ET_{pan} and the other methods showed ET_{0PM} to have the smallest value of 1.9 mm season^{-1} as well as the smallest SEE value of 1.3 mm day^{-1}.

It should be noted that, ET_{0PM} requires wind as the main factor. As Herat is characterized by strong winds in the summer season this condition might be one of the reasons that the ET_{0PM} method has greater adaptability compare to the other methods.

The ET_{pan} method, which includes Pereira's k_P, can be used for ET_0 estimation if the required factors for ET_{0PM} calculation are not available in the summer season.

The k_p proposed by Pereira uses the wind factor as one of the component in the calculation, making it more applicable.

2.4.2 Second period

The round dots in the Figs. 10 to 15 represent the second period that is from October to May characterized by a light wind speed (the fall, spring and winter seasons). In this period, the wind speed is lower than in the first period (the windy summer).

All the methods correlated more strongly with ET_{pan} in this period compare to the first period, and are appropriate for estimating ET_0 in the resion.

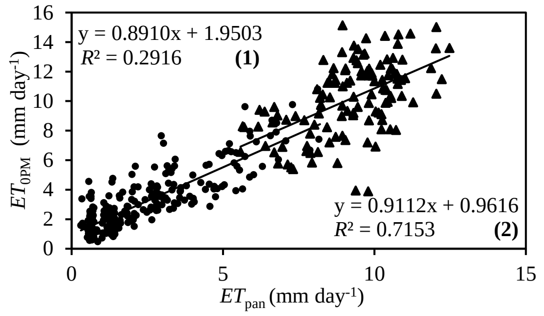


Fig. 10 Relationship between daily averages estimated by ET_{pan} and ET_{0PM}, 2009

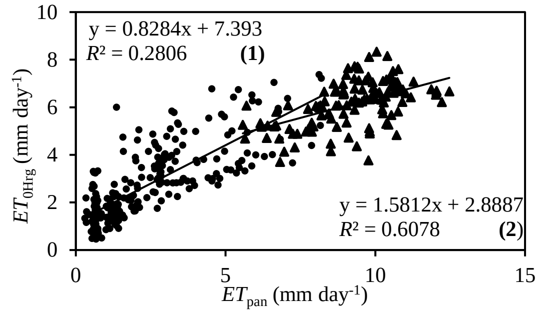


Fig. 11 Relationship between daily averages estimated by ET_{pan} and ET_{0Hrg}, 2009

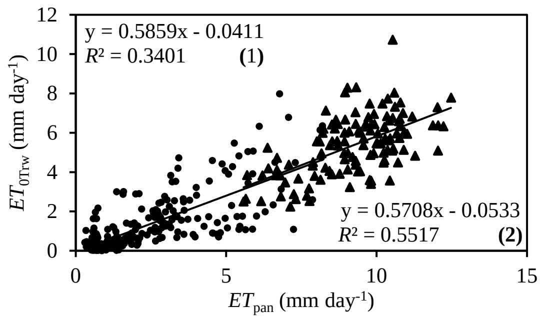


Fig. 12 Relationship between daily averages estimated by $ET_{pan}$and ET_{0Trw}, 2009

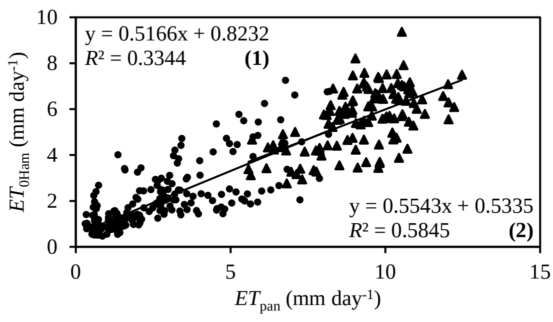


Fig. 13 Relationship between daily averages estimated by ET_{pan} and ET_{0Hom}, 2009

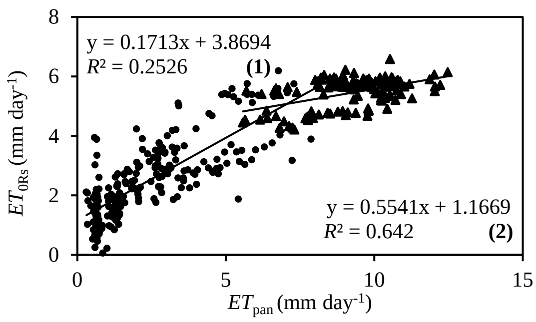


Fig. 14 Relationship between daily averages estimated by ET_{pan} and ET_{0Rs}, 2009

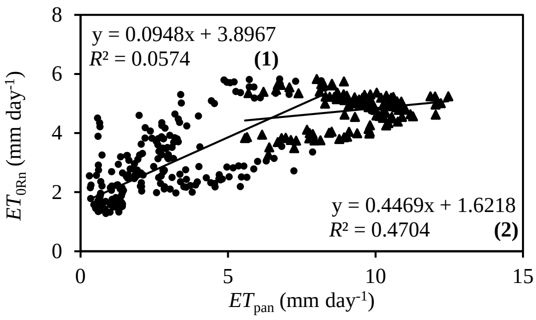


Fig. 15 Relationship between daily averages estimated by ET_{pan} and ET_{0Rn}, 2009

3. CONCLUSION

The ET_0 value given by the different methods were different in the first period (the windy summer), whereas in the second period (the fall, winter and spring) were in the rate, when applied in Herat province. The difference in the first period may be due to the strong wind speed that blows during the summer. Although, different methods use different metrological factors for estimations that can be one of the reasons of the differences.

1. The summer season is characterized by low humidity due to low precipitation, while the wind speed is higher by more than 5 m/s on average when compared with the other seasons. Temperature is also higher in the summer season, dropping in the early days of the fall season and rising again in the middle of the spring season.

Net radiation drops by the beginning of the fall season and increases again in the late winter season.

2. All methods produced estimates that were significantly different from those of ET_{pan} in the first period (summer season), with the exception of the ET_{0PM} method, which showed close agreement with ET_{pan}, except in the months of June and July. In the second period (the spring, fall and, winter seasons), all six methods produced values close to those from ET_{pan}. This suggests that they are applicable to ET_0 estimation in this period.

3. The total annual ET_0 values estimated by the tested methods ranged from 1000 to 2000 mm year^{-1}, with ET_{0PM}, ET_{pan}, and ET_{0Hrg} producing higher values than the four others.

None of the six simpler methods produced results that were significantly correlated with those of ET_{pan} in the first period, but better correlations were found in the second period. The ET_{0PM} method had the best correlation, producing the closest results to those of ET_{pan} in both periods. Based on a SEE calculation and seasonally-based averaged differences, ET_{0PM} also produced the lowest values in the first period.

The ET_{pan} method, which includes Pereira's k_P, can be used for ET_0 estimation if the data required for ET_{0PM} calculation are not available in the summer season.

Finally, our hypothesis that methods that use the wind factor are more adaptable than those that do not was supported.

4. ACKONWLEDGEMENT

Our warm thanks fall to the staff of Urdu Khan Research farm for their support in terms of providing some necessary data.

Table 1 Different model's equations

Model	Equation	No
Penman-Monteith	$ET_{0PM} = \dfrac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	[1]
R_n - based radiation	$ET_{0Rn} = 0.489 + 0.289R_n + 0.023 \times T_{mean}$	[2]
R_s – based radiation	$ET_{0Rs} = 0.611 + 0.149\, R_s + 0.079 \times T_{mean}$	[3]

Table 1 continuing…

(Thornthwaite)	$ET_{0Trw} = 16 \times \left(\frac{10\,Ti}{I}\right)^{a}\left(\frac{N}{12}\right)\left(\frac{I}{30}\right)$ $I = \sum_{i=1}^{12}\left(\frac{Ti}{5}\right)^{1.514}$ $a = (492390 + 17920I - 77.1I^2 + 0.675I^3) \times 10^{-6}$	[4]
(Hargreaves)	$ET_{0Hrg} = 0.0023\,(T_{mean} + 17.8)(T_{max} - T_{mix})^{0.5}R_a$	[5]
(Homan)	$ET_{0Hom} = \frac{2.1 \times {H_t}^2 e_s}{(T_{mean} + 273.3)}$	[6]
Pan Evapotranspiration	$ET_{pan} = k_p \times E_{pan}$	[7]
$\boldsymbol{k_P}$ Pereira	$k_p = \frac{0.85\,(\Delta + \gamma)}{[\Delta + \gamma(1 + r_c/r_a)]}$	[8]

Where: $\boldsymbol{ET_0}$ is grass reference evapotranspiration (mm day^{-1}); $\boldsymbol{R_n}$is net radiation (MJ m^{-2} day^{-1}); G is soil heat flux (MJ m^{-2} day^{-1}); γ is the psychometric constant (kPa °C^{-1}); $\boldsymbol{e_s}$ is the saturation vapor pressure (kPa); $\boldsymbol{e_a}$ is the actual vapor pressure (kPa); Δ is the slope of the saturation vapor pressure (kPa °C^{-1}); $\boldsymbol{T}$ is the average daily air temperature (°C); $\boldsymbol{u_2}$ is the mean daily wind speed at 2 m height above the ground level (m s^{-1}). $\boldsymbol{T_i}$ is the mean monthly temperature (°C); $\boldsymbol{N}$is the mean monthly sunshine hour; $\boldsymbol{T_{max}}$ is the daily maximum temperature (°C); $\boldsymbol{T_{mean}}$is the daily minimum temperature (°C); $\boldsymbol{R_a}$ is the daily extraterrestrial radiation (mm day^{-1}); $\boldsymbol{k_P}$ is the pan coefficient, $\frac{r_c}{r_a} = 0.34\boldsymbol{u_2}$; $\boldsymbol{E_{pan}}$ is the pan evaporation (mm day^{-1}); $\boldsymbol{H_t}$ is average number of daylight (hr day^{-1}); $\boldsymbol{R_s}$ is solar shortwave radiation (MJ m^{-2} day^{-1}).

(): Temperature-based models

Table 2 Metrological parameters for different methods

Methods	Variables					
	Temperature	Humidity	Wind speed	Radiation	Daylight hours	Saturated vapor pressure
Penman-Monteith	necessary	necessary	necessary	necessary		necessary
$\boldsymbol{R_n}$-based radiation	necessary	necessary	-	necessary	necessary	-
$\boldsymbol{R_s}$-based radiation	necessary	necessary	-	necessary	necessary	-
(Thornthwaite)	necessary	-	-		necessary	
(Hargreaves)	necessary	-	-	necessary	-	-
(Hamon)	necessary	-	-		necessary	-
$\boldsymbol{ET_{pan}}$	necessary	necessary	necessary	necessary	necessary	necessary
$\boldsymbol{k_P}$ Pereira	necessary	-	necessary	-	-	-

(): Temperature-based methods

Table 3 Accessible online database for irrigation planning [4]

Source name	Features	Usage
NCDC (NOAA)	Air temperature, dew point, and wind speed	Basically used data
Weatherspark.com	Cloud cover, wind velocity, air temperature and humidity at the airport.	Supplementary used data
Urdu khan Research Farm	Data of E_{pan}, air temperature, sun shine	Supplementary used data

Table 4 Correlation coefficient, standard error, and seasonally-based average difference in ET_0

Methods	Coefficients						SEE	$\lvert ** (\boldsymbol{model}) - \boldsymbol{ET_{pan}} \rvert$	**P-value
	$**R^2$	R^2	$**a$	a	$**n$	n	mm day^{-1}	mm day^{-1}	%
Penman-Monteith	0.29	0.71	0.89	0.91	122	243	1.3	1.9	0.9
$\boldsymbol{R_s}$-based radiation	0.25	0.64	0.17	0.55	122	243	1.5	3.8	4.1
$\boldsymbol{R_n}$- based radiation	0.05	0.47	0.09	0.44	122	243	2.6	4.5	6.8
(Hamon)	0.33	0.58	0.51	0.55	122	243	1.5	3.6	0.6
(Hargreaves)	0.28	0.60	0.82	1.58	122	243	3.6	3.1	6.2
(Thornthwaite)	0.34	0.55	0.58	0.57	122	243	1.62	3.9	4.0

**: Indicates the first period (cover summer season).
n: Number of days
( ): Temperature based models

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