

Impact of Alternative Data on the Penman-Monteith Method Considering Windy Conditions in the Semi-Arid Area

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Abstract When real data are unavailable, the standard Penman-Monteith method for estimating reference evapotranspiration can be calculated using alternative input data: wind speed from a nearby station, the default global average wind speed, solar radiation based on temperature and vapour pressure based on the minimum temperature. These alternative data are recommended in FAO paper 56. In this study, we assessed the accuracy achieved when using these alternative data for reference evapotranspiration estimation in a semi-arid region characterised by a strong persistent wind speed. Western Afghanistan was selected as the study site, as it is exposed to strong winds over the 120-day period from June to September. Significant differences were found in the estimates produced using full data and those obtained using wind speed data from a nearby station, the default global average wind speed, and vapour pressure based on the minimum temperature. Root Mean Square Error (*RMSE*) was found 1.51 mm d⁻¹, 1.27 mm d⁻¹ and 1.07 mm d⁻¹, respectively. Errors were especially significant on days with strong wind. The smallest *RMSE* of 0.36 mm d⁻¹ was found when basing solar radiation on temperature. The assumption that the dew point temperature will be close to the minimum temperature was shown to be unreliable on days of strong wind.

Keywords: reference evapotranspiration, Penman-Monteith, alternative data, strong wind, semi-arid

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1. Introduction

A number of methods for estimating reference evapotranspiration (ET_0) have been reported in the literature [1,2]. Empirical equations are one of the simpler methods and are used worldwide.

The empirical methods have mainly been based on climatological data, because of the difficulty of making direct measurements of ET_0 . These methods can be divided into four groups, based on their requirements. One of the most accurate methods currently available is the Penman-Monteith method, which has been widely accepted by the international scientific community [3,4].

The Penman-Monteith equation is recommended by the United Nations Food and Agriculture Organisation (FAO) as the only method offering high accuracy. However, to estimate ET_0 using the Penman-Monteith equation, complete input data are required [5]. The Penman-Monteith method was found to be the most accurate of the six well-known methods used to estimate ET_0 in the western region of Afghanistan [6].

The Penman-Monteith method requires data on the maximum and minimum temperature (T_{max} and T_{min}), relative humidity (RH) and/or dew point temperature (T_{dew}) for estimating actual vapor pressure (e_a) net radiation (R_n), and wind speed (u_2) measured at a height of two metres above ground level [5].

Few weather stations in the world are equipped to supply this complete set of weather variables [7]. This places a severe restriction on the application of the Penman-Monteith method [8]. FAO paper 56 supplies alternative workarounds that allow the missing RH , u_2 and solar radiation (R_s) to be estimated.

When T_{dew} and/or RH data are unavailable, actual vapor pressure based on temperature ($e_{a(Alt)}$) can be estimated using Equation 14 from Table 1, on the assumption that T_{min} is close to T_{dew} . This is true in humid areas, where the difference between T_{min} and T_{dew} is small. In arid areas, however, there is often a large difference between T_{min} and T_{dew} [9].

When R_s is missing, Hargreaves' radiation formula as a function of T_{max} and T_{min} is recommended for the calculation of solar radiation based on temperature $R_{s(Alt)}$. This is shown as Equation 15 in Table 1. Hargreaves' radiation formula assumes that the difference between

T_{max} and T_{min} is governed by the daily solar radiation at the given location.

When u_2 data are lacking, two alternative approaches are recommended, one in which the default world average value of u_2 as 2 m s^{-1} is used, and one in which u_2 data from a nearby station are used, if such data are available [5]. In this study, the data of wind speed from airport was used as it was the only available data. The wind speed data from the airport ($u_{2(Apt)}$), adjusted at 2 meters height, using Equation 8 from Table 1.

All the proposed methods have been tested at a variety of sites worldwide. It has been shown that the results are different in different climate regimes.

Popova *et al.* [8] found the procedures proposed by FAO to be accurate when applied in Southern Bulgaria. In a study conducted in Southern Ecuador, Cordova *et al.* [10] found that the use of alternative u_2 data has no significant effect on the calculation of ET_0 , but that when the R_s data were missing, the ET_0 calculations became erroneous. A study in Southern Ontario, Canada reported similar results [11]. When RH and u_2 were missing, the FAO Penman-Monteith method still provided very good estimates of ET_0 .

Although these procedures are suboptimal, when working in areas where the required data are lacking or of questionable quality, their use is recommended [5].

The aim of the present study was to contribute to irrigation planning by evaluating the performance of the Penman-Monteith method both when complete input data ($ET_{0(PM)}$) are available, and when some are missing. The study was conducted in Herat, Afghanistan. No previous studies have quantified the effect of applying these alternative procedures in climates with strong winds and semi-arid conditions, in Afghanistan or in any other region.

2. Methods

2.1. Site and Data Collection

The study site was selected for their semi-arid climate and exposure to strong winds over a continuous 120-day period from June to September.

Two locations in the west of Afghanistan were selected for data collection: Urdu Khan agricultural farm and Herat airport, in Herat province. The locations of the two sites are shown in Figure 1.

Urdu Khan research farm is located approximately 11 kilometres from Herat airport. The climate is semi-arid, with warm, windy and low humidity conditions in the summer. Annual average precipitation is low, and mainly limited to the winter and spring seasons. The lowest ratio of cloud cover occurs in the summer season, and the highest ratio in the winter season.

A significant factor at the study site is what is known locally as the '120-day winds'. This strong winds persist from June to September, with speeds exceeding 450 km d^{-1} . Such winds have been shown to be the most significant factor in the ET_0 estimation.

Herat Airport is located 11 km to the north of the Urdu Khan Farm at an elevation of 973 m above sea level. The height of the wind speed measurement was 10 m above

the ground level, therefore, it was converted in 2 m for Herat Airport. The weather conditions are very similar to those at Urdu Khan, characterised by strong winds that blow continually from May to September, with a daily average peak exceeding 14 m s^{-1} in 2016.

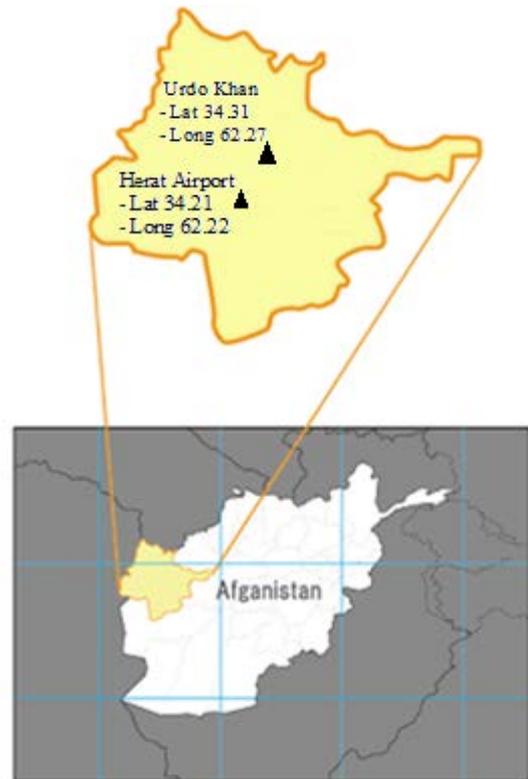


Figure 1. Locations of Urdu Khan Farm and Herat Airport, Afghanistan

2.2. Estimation and Analyzing

The Penman-Monteith equation was used to estimate ET_0 both with complete and incomplete input data, as shown in Table 1.

When complete input data were available, recorded at the Urdu Khan site, the calculation was done using $ET_{0(PM)}$, which is mainly associated with u_2 , e_a and R_s measured at Urdu Khan Farm (Eq. 1).

When the u_2 data were missing, the calculations were done using $ET_{0(u_2(Apt))}$ and $ET_{0(u_2(Alt))}$ which are associated with $u_{2(Apt)}$ and $u_{2(Alt)}$, respectively (Eqs. 2-3).

When e_a were missing, the calculation was done using $ET_{0(e_a(Alt))}$, associated with $e_{a(Alt)}$ (Eq. 9).

Finally, when R_s data were missing, $ET_{0(R_s(Alt))}$ was calculated using $R_{s(Alt)}$ (Eq. 11).

Regression analysis was used to assess the validity of the results given by the ET_0 estimation. The regression slope (a) was used as the measure of accuracy, and the coefficient of determination (R^2) was used as the measure of exactness. The values $a = 1$ and $R^2 = 1$ suggest perfect results. The root mean square error ($RMSE$) and mean bias error (MBE) were also calculated to evaluate the impact of the proposed methods on the ET_0 results. A smaller $RSEM$ and MBE value would mean a better result. This allows the impact of applying the alternative procedures on ET_0 estimation to be quantified.

Table 1. Model's equations

Equations	No.
$ET_{0(PM)} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	(1)
$ET_{0(u_2(Apt))} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(Apt) (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2(Apt))}$	(2)
$ET_{0(u_2(Alt))} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(Alt) (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2(Alt))}$	(3)
$R_{ns} = (1 - 0.23)R_s$	(4)
$R_{nl} = \sigma \left(\frac{T_{\max} K^4 + T_{\min} K^4}{2} \right) (0.34 - 0.14\sqrt{e_a}) \left(1.35 \frac{R_s}{R_{so}} - 0.35 \right)$	(5)
$R_s = \left(a_s + b_s \frac{n}{N} \right)$	(6)
$e_a = 0.611 \times e^{\left(\frac{17.27 \times T_{dew}}{T_{dew} + 273.3} \right)}$	(7)
$u_2 = \frac{4.87}{\ln(67.8z - 5.42)} u_z$	(8)
$ET_{0(e_a(Alt))} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a(Alt))}{\Delta + \gamma(1 + 0.34u_2)}$	(9)
$R_{nl} = \sigma \left(\frac{T_{\max} K^4 + T_{\min} K^4}{2} \right) (0.34 - 0.14\sqrt{e_a(Alt)}) \left(1.35 \frac{R_s}{R_{so}} - 0.35 \right)$	(10)
$ET_{0(R_s(Alt))} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	(11)
$R_n = R_{ns} - R_{nl}$	(12)
$R_{ns} = (1 - 0.23)R_s(Alt)$	(13)
$R_{nl} = \sigma \left(\frac{T_{\max} K^4 + T_{\min} K^4}{2} \right) (0.34 - 0.14\sqrt{e_a}) \left(1.35 \frac{R_s(Alt)}{R_{so}} - 0.35 \right)$	(14)
$e_a(Alt) = 0.611 e^{\left(\frac{17.27 \times T_{\min}}{T_{\min} + 273.3} \right)}$	(15)
$R_s(Alt) = k_{R_s} \sqrt{(T_{\max} - T_{\min}) R_a}$	(16)
$RMSE = \sqrt{\frac{1}{m} \sum_{i=1}^m \left(ET_{0(Alt)} - ET_{0(PM)} \right)^2}$	(17)
$MBE = \frac{1}{m} \sum_{i=1}^m \left(ET_{0(Alt)} - ET_{0(PM)} \right)$	(18)

Where, $ET_{0(PM)}$ is Penman-Monteith reference evapotranspiration obtained from a complete input data set (mm d^{-1}); R_n is net radiation ($\text{MJ m}^{-2} \text{d}^{-1}$); G is soil heat flux ($\text{MJ m}^{-2} \text{d}^{-1}$); γ is psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$); e_s is saturation vapour pressure (kPa); e_a is actual vapour pressure based on daily

average sunshine hours; $e_{a(Alt)}$ is the actual vapour pressure based on the daily minimum temperature (kPa). Δ is the slope of the saturation vapour pressure curve (kPa °C⁻¹); T is the average daily air temperature (°C); u_2 is the mean daily wind speed at 2 m height above ground level (m s⁻¹); R_{ns} is net shortwave radiation (MJ m⁻² d⁻¹); R_{nl} is net outgoing longwave radiation (MJ m⁻² d⁻¹); σ is the Stefan-Boltzmann constant (4.903 10⁻⁹ MJ K⁴ m⁻² d⁻¹); R_{so} is the calculated clear-sky radiation (R_{so} can be calculated using Equation 36 or 37 in FAO paper 56) (MJ m⁻² d⁻¹); R_s is incoming solar radiation based on daily sunshine hours; $R_{s(Alt)}$ is incoming solar radiation based on daily minimum and maximum temperature (MJ m⁻² d⁻¹); $a_s + b_s$ is the fraction of extraterrestrial radiation reaching the earth on clear days ($n = N$). When no solar radiation data are available and no calibration has been carried out to improve the a_s and b_s parameters, the values $a_s = 0.25$ and $b_s = 0.50$ are recommended; n is daily sunshine (hours); R_a is extraterrestrial radiation (MJ m⁻² d⁻¹) (R_a can be estimated using Equation 21 in FAO paper 56); RH is mean relative humidity (%); $e^0(T_{max})$ and $e^0(T_{min})$ are the saturation vapor pressure at daily maximum and minimum temperatures, respectively (kPa); $k_{R_s} = 0.16$ is the adjustment coefficient for an interior area; T_{max} is daily maximum temperature (°C); T_{min} is daily minimum temperature (°C); m is the number of data points; u_z is measured wind speed at z m above ground surface (m s⁻¹); z is height of measurement above ground surface (m); $ET_{0(u_2(Apt))}$ is Penman-Monteith reference evapotranspiration obtained using $u_{2(Apt)}$ (mm d⁻¹); $ET_{0(e_{a(Alt)})}$ is Penman-Monteith reference evapotranspiration obtained using $e_{a(Alt)}$ (mm d⁻¹); $ET_{0(R_{s(Alt)})}$ is Penman-Monteith reference evapotranspiration obtained using $R_{s(Alt)}$ (mm d⁻¹); $ET_{0(e_{a(Alt)})}$ is Penman-Monteith reference evapotranspiration obtained using $e_{a(Alt)}$ (mm d⁻¹); and $ET_{0(Alt)}$ is Penman-Monteith reference evapotranspiration obtained with alternative data (mm d⁻¹).

3. Results and Discussion

3.1. Daily Average Weather Variables

The mean air temperature (T_{mean}), u_2 , T_{dew} , RH and hours of sunshine (n) were measured from January 24th to December 28th in 2016. u_2 was measured and adjusted at 2 meter height at both locations, whereas the other data were measured at Urdo Khan only.

The period from May to September was warm, with T_{mean} greater than 20°C. The hottest days were recorded in June, with a T_{mean} greater than 30°C. The cold period lasted from November to February, with T_{mean} less than 10°C. The lowest temperature was recorded in early November, with a T_{mean} below 0°C (Figure 2).

Over the course of the year, u_2 ranged from 0 m s⁻¹ to above 14 m s⁻¹ at both study sites though the daily average was higher at the airport site. The daily average u_2 was approximately 2 m s⁻¹ in the period July to August, with an average daily maximum of almost 6 m s⁻¹. The daily average u_2 fell below 2 m s⁻¹ in the period from September to May, with a range between 6 and 2 m s⁻¹ at Urdo Khan station. The maximum reading at the airport exceeded 10 m s⁻¹, recorded in June (Figure 3).

RH ranged from approximately 10% to above 80%, over the course of the year. The period May to August were drier. The driest air was recorded in August, at which time the RH dropped below 20% (Figure 4).

The estimation of R_s is related to the length of the day over the course of the year. The highest value of above 25 MJ m⁻² d⁻¹, was recorded in the period May to July, while in the lowest value was recorded in November. A difference between $R_{s(Alt)}$ and R_s was only found in the period May to August; in the other months, their rates were identical (Figure 5).

The Application of $e_{a(Alt)}$ produced results that were different from those estimated using T_{dew} . The difference was particularly pronounced in the period from April to September. Over the full year, e_a produced a lower estimate than $e_{a(Alt)}$ (Figure 6). These large differences reflected the difference between T_{min} and T_{dew} , especially between April and September. This difference was greater than 10°C (Figure 7).

3.2. Daily Average Estimation of ET_0

The rate of $ET_{0(PM)}$ ranged from 0 mm d⁻¹ to above 10 mm d⁻¹ over the course of the year. The highest rate was recorded in the period from June to August, with a

peak of above 10 mm d⁻¹ in June.

When only the daily average u_2 data were missing, two alternatives were used. First, the default world average value of $u_{2(Alt)} = 2 \text{ m s}^{-1}$ was used to estimate $ET_{0(u_2(Alt))}$. The result was close to that produced by $ET_{0(PM)}$. Over the course of the year, $ET_{0(u_2(Alt))}$ produced a small overestimate, though in the period May to August it produced a lower rate than $ET_{0(PM)}$ (Figure 8a).

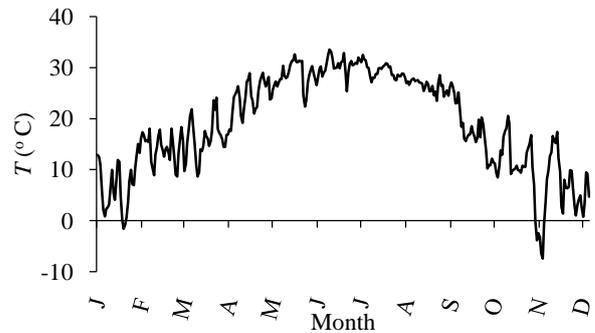


Figure 2. Daily average temperature, 2016

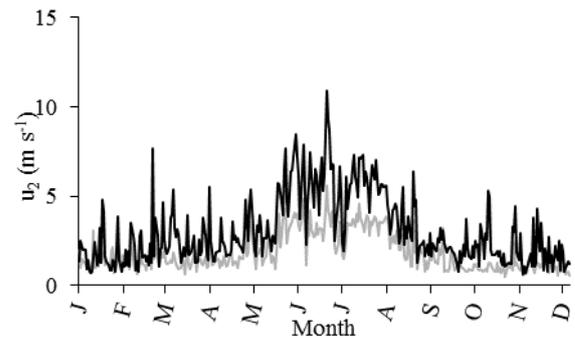


Figure 3. Daily average of wind speed, 2016

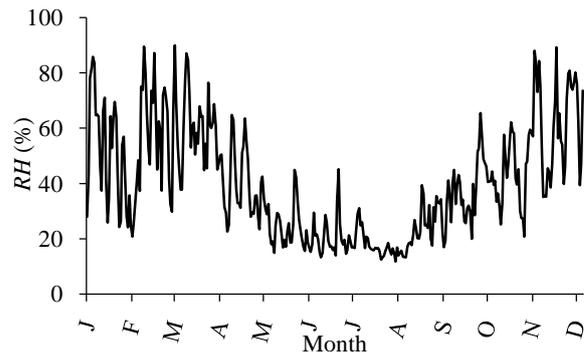


Figure 4. Daily average of relative humidity, 2016

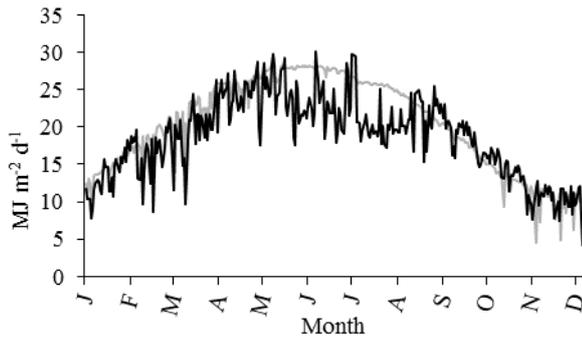


Figure 5. Daily average of solar radiation, 2016

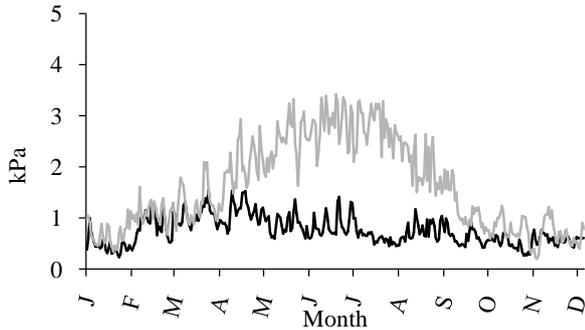


Figure 6. Daily average of actual vapor pressure, 2016

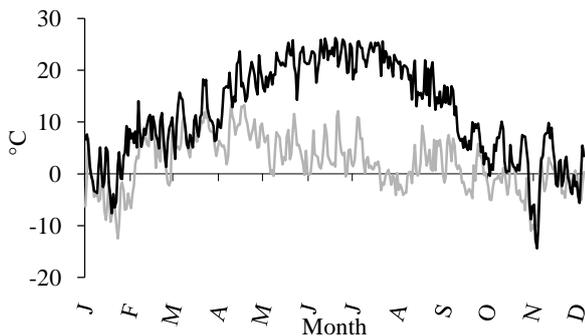


Figure 7. Daily average of T_{min} and T_{dew} , 2016

This is because the value of $u_{2(Alt)}$ is lower than the daily average wind rate at Urdo Khan Farm between June and August. The annual average value of u_2 at this location was 1.84 m s^{-1} , however, in the period June to August exceeded 3 m s^{-1} .

The $u_{2(Apt)}$ data from the airport near Urdo Khan were then used in the calculation. The result is shown in Figure 8b. It can be seen that $ET_{0(u_{2(Apt)})}$ was greater than 6 mm d^{-1} from May to September, with a peak in June of almost 15 mm d^{-1} . For the period from May to October, the use of $ET_{0(u_{2(Apt)})}$ produced a higher estimation than $ET_{0(PM)}$. The difference was largest in the period from June to August. This difference arose because the $u_{2(Apt)}$ rate was higher than that at the nearby station. The impact of the wind speed on the ET_0 results was therefore relatively large, especially on days that were dry and windy.

The ‘120-day winds’ was found a very important factor in this region, especially when estimating ET_0 . The wind speed may vary, even over short distances. Although, the two study locations were within 11 km of each other, the

wind speeds was not identical, and the wind speed had a significant impact on the estimation of ET_0 .

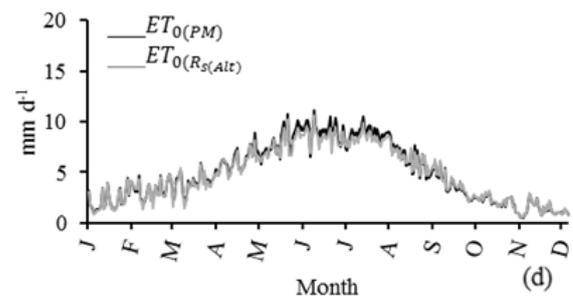
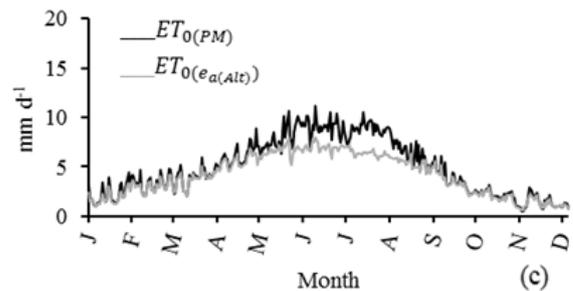
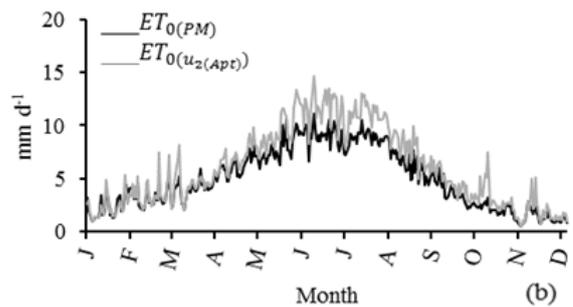
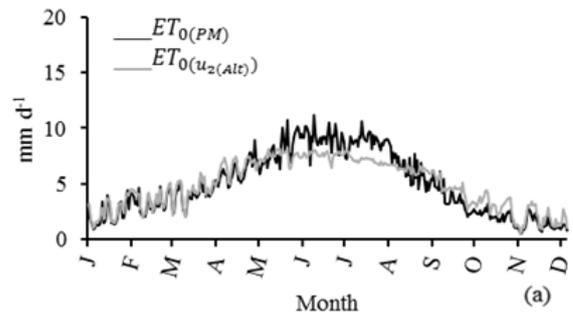


Figure 8. From (a) to (d) daily average estimation of ET_0 given by $ET_{0(PM)}$ and when input data are missing. Herat, 2016

A higher rate of ET_0 was produced on days of strong wind, so that there was a positive correlation between wind speed and ET_0 .

When only e_a was missing, $e_{a(Alt)}$ data were used to estimate $ET_{0(e_{a(Alt)})}$. The results produced by $ET_{0(e_{a(Alt)})}$ and $ET_{0(PM)}$ were similar over the course of the full year, however, relatively large differences were found in the period from June to September, $ET_{0(e_{a(Alt)})}$ produced a lower rate than $ET_{0(PM)}$ (Figure 8c).

This suggested that $e_{a(Alt)}$ is not a good substitute for e_a when deriving ET_0 on days when the wind is strong.

When only the R_s data was missing, $R_{s(Alt)}$ data were used in their place, producing satisfactory results, as the $ET_{0(PM)}$ and $ET_{0(R_{s(Alt)})}$ rates were identical over the course of the year (Figure 8d). This method of estimating $R_{s(Alt)}$ when the R_s data are missing appears to produce good results.

3.3. Relationship between Actual and Alternative Weather Variables

Relationship between the u_2 from Urdo Khan and $u_{2(Apt)}$ was weak ($R^2 = 0.75$ and $a = 0.47$). The data were widely dispersed, particularly on windy days (Figure 9-(a)). The significant differences in wind speed between the two sites were attributed to the site elevation and surrounding terrain. The airport station is bounded by desert on all four sides and is 33 metres higher than the Urdo Khan site. The Urdo Khan site is surrounded by agricultural land, gaining protection from trees, walls, and fences. This might explain the lower wind speed.

No significant relationship was found between the estimates of e_a and $e_{a(Alt)}$. Figure 9-(b) shows the relatively weak relationship between the two datasets ($R^2 = 0.12$ and $a = 0.11$). This reflects differences between T_{min} and T_{dew} over the course of the year, and especially on windy days.

The relationship between T_{min} and T_{dew} is shown in Figure 9-(c), where $R^2 = 0.27$ and $a = 0.29$, suggesting a weak relationship. The assumption that T_{dew} will be close to T_{min} was not supported, and was shown to be especially unreliable on days of strong wind at the research sites. The relationship between R_s and $R_{s(Alt)}$ is shown in Figure 9-(d). Here $R^2 = 0.72$ with $a = 0.99$, indicating a significant correlation. The use of $R_{s(Alt)}$ was confirmed to be applicable for ET_0 calculation when R_s data are missing.

3.4. Regression Analysis and Error Estimation

The relationship between $ET_{0(PM)}$ and cases where alternative data used ($ET_{0(Alt)}$), was shown by statistical indices given in Table 2.

When the data of u_2 was missing, $u_{2(Apt)}$ which was measured 11 km from the site was used in the calculation. The value of $R^2 = 0.95$ confirms a significant correlation between $ET_{0(u_{2(Apt)})}$ and $ET_{0(PM)}$, however, the value of $a = 1.25$ shows a low accuracy of the estimation. On the other hand, $ET_{0(u_2)}$ yielded the largest $RMSE$ of 1.51 mm d⁻¹, and MBE showed an overestimation of 1.07 mm d⁻¹ (Table 2). This was due to the higher rate of $u_{2(Apt)}$. It was confirmed that the u_2 rate was different at the two locations, particularly on days when the wind was strong. This suggested that the distance between two locations is important when collecting u_2 data in the semi-arid areas characterised by strong winds, such as the West region of Afghanistan.

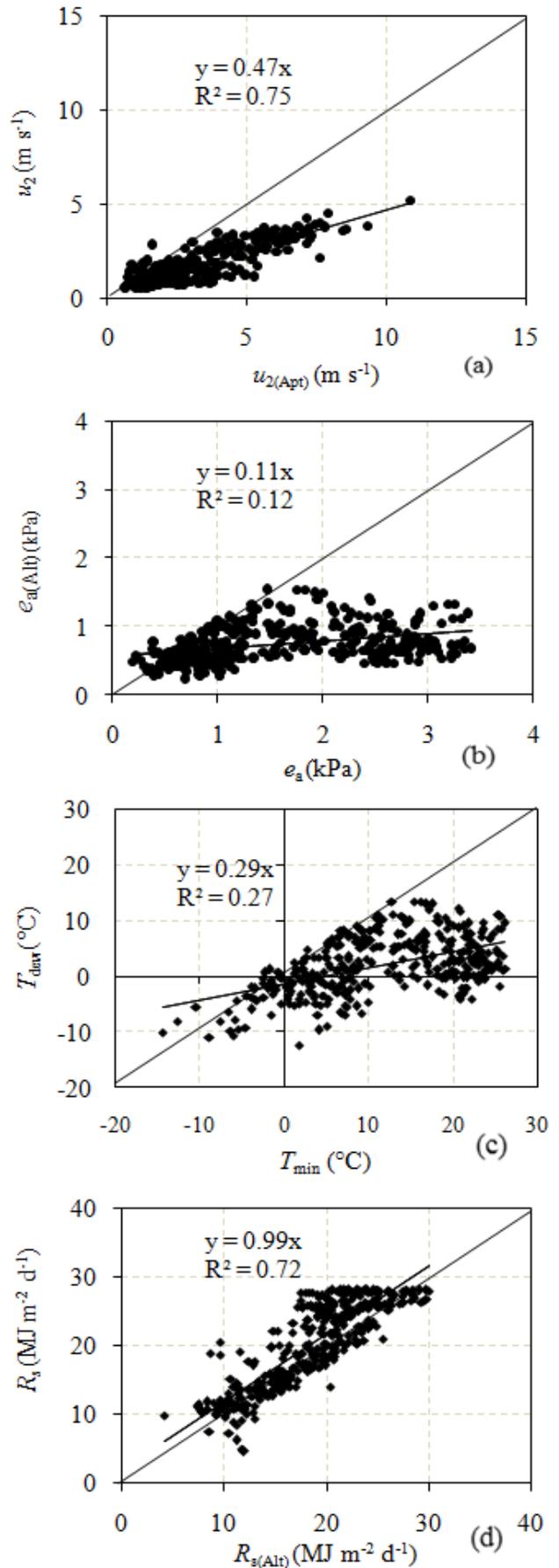


Figure 9. Relationship between; (a) u_2 at the two stations; (b) e_a and $e_{a(Alt)}$; (c) T_{min} and T_{dew} ; (d) R_s and $R_{s(Alt)}$

For the condition in which $u_{2(Alt)}$ was used in the calculation, the result produced by $ET_{0(u_{2(Alt)})}$ had the third largest *RMSE* of 1.07 mm d^{-1} and an *MBE* of -0.02 mm d^{-1} , indicating an underestimation (Table 2).

When *RH* data were missing, $e_{a(Alt)}$ was used in the calculation. Considering the value of $R^2 = 0.93$ a significant agreement was found between $ET_{0(PM)}$ and $ET_{0(e_{a(Alt)})}$, however, the value of $a = 0.70$ indicates low accuracy between the estimates. On the other hand, The associated error ($RMSE = 1.27 \text{ mm d}^{-1}$) was high in comparison with the results reported by Jabloun and Sahli (2008) in the semi-arid conditions of Tunisia. The value of $MBE = -0.78 \text{ mm d}^{-1}$ confirmed an underestimation estimates (Table 2).

When only $R_{s(Alt)}$ was missing, the results yielded by $ET_{0(R_{s(Alt)})}$ produced values of $R^2 = 0.98$ and $a = 0.93$, confirming that the estimation of ET_0 using $R_{s(Alt)}$ data is applicable when R_s data are unavailable. The $ET_{0(R_{s(Alt)})}$ yielded an *RMSE* of below 0.36 mm d^{-1} , the smallest value, and an *MBE* of -0.15 mm d^{-1} , representing an underestimation (Table 2). The results yielded by $ET_{0(R_{s(Alt)})}$ was almost in line with the result reported by Jabloun and Sahli (2008) in the semi-arid conditions of Tunisia.

Table 2. Determination Coefficient, Slope of Regression, *RMSE*, and *MBE* for Daily Average ET_0 Given by the Penman-Monteith method with Complete and Incomplete Data

Method	R^2	a	<i>RMSE</i> mm d^{-1}	<i>MBR</i>
$ET_{0(u_{2(Apt)})}$	0.95	1.25	1.51	1.07
$ET_{0(e_{a(Alt)})}$	0.93	0.70	1.27	-0.78
$ET_{0(u_{2(Alt)})}$	0.89	0.71	1.07	-0.02
$ET_{0(R_{s(Alt)})}$	0.98	0.93	0.36	-0.15

4. Conclusions

The unavailability of complete weather data in most locations in Afghanistan means that the data obtained through alternative procedure can be used to estimate ET_0 via Penman-Monteith method.

Alternative procedures set out in FAO paper 56 allow estimates to be made when real data are lacking. In this study, we quantified the ET_0 estimates obtained when using these alternative data in a semi-arid region characterised by strong winds.

The evaluations compared the performance of the Penman-Monteith method when using complete and incomplete data for estimating ET_0 . The study was carried out in the west of Afghanistan, where is exposed to strong winds over the 120-day period.

The results demonstrated that the largest error (an overestimate of 1.51 mm d^{-1}) arose when using $u_{2(Apt)}$

data. This reflected the large difference in u_2 at the two sites, even though they were separated by only 11 km. This suggests that u_2 data from a nearby location should not be used if an accurate estimate of ET_0 is expected. When using the default average $u_{2(Alt)} = 2 \text{ m s}^{-1}$ in the ET_0 estimation, an underestimate of 1.07 mm d^{-1} was produced.

When $e_{a(Alt)}$ was used instead of e_a , the Penman-Monteith method performed poorly over the period May to September, when there were many strongly windy days. A divergence between $ET_{0(PM)}$ and $ET_{0(e_{a(Alt)})}$ was noted only on windy days. In the period when winds were light, from September to May, the results were good. We do not, therefore, recommend the use of $e_{a(Alt)}$ as a substitute for missing e_a when estimating ET_0 on windy days.

The lack of R_s was shown to be of least importance, as significant ET_0 estimates were achieved using $R_{s(Alt)}$ instead.

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