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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 10 (16): 2665-2669, 2007
ISSN 1028-8880

Assessment of CropWat Model Accuracy for Estimating Potential Evapotranspiration in Arid and Semi-arid Region of Iran

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Abstract: The aim of this research was estimating the accuracy of CropWat software to calculating potential evapotranspiration (ET_0) in arid and semi-arid region of Iran. For this purpose, 9 locations of arid and semi-arid regions of Iran selected and the grass lysimeter data collected too. The lysimeter data are collected duration of May through November during 1988-1997. For the comparisons of the ET_0 lysimeter data and ET_0 resulted CropWat software in different point, three statistical parameters were used include Mean Absolute Relative Error (MARE), Root Mean Square Difference (RMSD) and correlation coefficient (R^2). The results of this research show that the average of MARE, RMSD and R^2 computed about 31%, 2.3 and 0.7, respectively in the study areas. In addition, the results of this research show that when the average of wind speed was less than 1 m sec^{-1} or wind speed was more than 1 m sec^{-1} with low ET_0 lysimeter (ET_0 less than 6 mm per day), CropWat has a low sensitive for estimating ET_0 and it's necessary to improve the results for these areas. In concluded, the results of this research were showed that in these area because of intensive temperature and solar radiation, CropWat can not be estimated ET_0 exactly.

Key words: CropWat, potential evapotranspiration, Iran, arid and semi-arid region, lysimeter

INTRODUCTION

Potential evapotranspiration is a required parameter for hydrological and agricultural projects (Maule *et al*., 2005). The process known as evapotranspiration, ET, is one of the main requirements to improve water management in arid and semi-arid regions. Almost all of the methods, estimating ET utilize potential or reference crop ET in the intermediate step. A large number of scientists have developed numerous numbers of equations to compute the ET_0 in the last 50 years (Allen *et al*., 1998). These equations range from the most complex energy balance equations requiring detailed climatological data (Allen *et al*., 1998) to simpler equations requiring limited data (Samani, 2000). Among these methods, FAO Penman-Monteith is one of them which have a global validity.

In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed (Allen *et al*., 1998). The Penman method was generalized to a significant extent by Monteith (1965). Monteith's variation of Penman method involves the use of a plant resistance parameter and a more general use of an aerodynamic resistance parameter (Burman *et al*., 1994). After that, a consultation of experts organized by FAO recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 sm^{-1} and an albedo of 0.23, closely resembling the evaporation of an extensive surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman-Monteith method was developed (Allen *et al*., 1998) as follows:

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

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	=	air temperature at 2 m height [°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],
γ	=	Psychometric constant [kPa°C^{-1}],
Δ	=	Slope vapour pressure curve [kPa °C^{-1}] (ASCE, 2002):

$$\Delta = \frac{2504 \exp((17.27\,T)/(T+237.3))}{(T+237.3)^2} \qquad (2)$$

The analysis of the performance of the various calculation methods reveals the need for formulating a standard method for the computation of ET_0. For this purpose, Allen *et al*. (1998) recommended FAO Penman-Monteith as a standard method. The FAO Penman-Monteith equation is requires to detailing climatologic data (Samani 2000; Maule *et al*., 2005). So, computing ET_0 by this method without using software is very difficult. CropWat 4 Windows is a program that uses FAO Penman-Monteith for calculating reference crop evapotranspiration. In addition, the FAO Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements recommended that empirical methods should be calibrated or validated using the Penman-Monteith equation as reference (Smith *et al*., 1991; Gavila´n *et al*., 2006).

CropWat is a computer program for irrigation planning and management. Its main functions are to calculate reference evapotranspiration, crop water requirements, crop irrigation requirements to develop irrigation schedules under various management conditions, scheme water supply to evaluate rain fed production and drought effects efficiency of irrigation practices. CropWat is meant as a practical tool to help agro-meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and the assessment of production under rain fed conditions or deficit irrigation. Calculations of crop water requirements and irrigation requirements are carried out with inputs of climatic and crop data.

Based on above mention subject, many irrigation research projects in Iran are used CropWat software for estimating Crop water requirements of crops. But it is necessary to assessment the variation of this method for different point of Iran. The aim of this research to determine accuracy of CropWat for calculating ET_0 in arid and semi-arid regions of Iran. For this purpose, grass evapotranspiration from lysimeters and climatologically data for 9 locations in 1988 to 1997 were used.

MATERIALS AND METHODS

In general, the climate of Iran is dry and desert-like. Although more than 50 million ha of land in Iran are arable, agricultural activity is limited by water availability for irrigation. Thus, agricultural activity is concentrated in provinces where water resources are adequate for irrigation.

For this research, 9 farms were selected from different points of arid and semi-arid regions of Iran. Table 1 shows some of the climatologic and geographic conditions of these locations and Fig. 1 shows the location of stations in Iran map. Almost, all of these locations have hot dry summers and rainfalls are not or very little occurring in summers. Also, means of annual rate of wind speed are less than 2 m sec^{-1} in these locations.

In experimental farms, three drainable lysimeters were installed in an open grass field and were used for ET_0 measurements. The lysimeter data were conducted at research farm of the Agricultural Engineering

Fig. 1: The location of studied station based on number of station in Iran map

Research Institute of Iran, duration 1988 until 1997 based on Table 1. Table 2 shows the time period of lysimater data collection in each station.

Irrigation frequency and amount in each lysimeter was based on soil moisture monitoring using the tensiometers. Irrigation was scheduled to occur when tensiometers show 40 cbar. Grass reference crop evapotranspiration in lysimeter computing by Eq. (3):

$$ET_0 = P + I - D + \Delta S \quad (3)$$

where:

P = Precipitation [mm],
I = Irrigation water [mm],
D = Drainage water [mm] and
ΔS = Different of soil moisture after irrigation and before next irrigation [mm].

Monthly meteorological data, including maximum mean air temperature (T_{max}), minimum mean air temperature (T_{min}), mean relative humidity (RHmean), actual sunshine (n), possible sunshine (N), atmospheric pressure site (P_0), precipitation (p) and mean wind speed at a height of 2 m (u_2) were collected from nearest weather station of experimental farms.

To find the accuracy of model to estimating ET_0, the results of CropWat was compared with actual evapotranspiration lysimeter data. For these comparison and determination of accuracy of the models, three statistical parameters were used (Kotsopoulos and Babajimopoulos, 1997; Jacovides and Kontoyiannis, 1995.):

$$MARE = \frac{\sum_{i=1}^{N} \frac{ABS(L_i - PM_i)}{L_i}}{N} \times 100 \quad (4)$$

$$RMSD = \sqrt{\frac{\sum_{i=1}^{N} (L_i - PM_i)^2}{N}} \quad (5)$$

Table 1: Some of the climatologic and geographic conditions of experimental regions

Station	Latitude	El[1] (m)	T_{max}[2] (°C)	T_{min}[3] (°C)	P[4] (mm)
Yazd	31°54	1230	26	12	46
Isfahan (Kobootar Abad)	32°31	1545	23	6	120
Karaj	35°50	1312	25	5	237
Mashhad	36°16	990	22	9	239
Mian Doub	36°58	1314	19	6	280
Hamedan	34°52	1730	19	2	312
Share Kord	32°20	2061	19	3	329
Arak	34°60	1708	19	6	367
Sanandaj	35°12	1373	21	5	492

1-Elevation, 2-Mean of Maximum Temperature, 3-Mean of Minimum Temperature, 4-Precipitation

Table 2: The time period of lysimeter data collection in each station

Station	Study years	Study months
Yazd	1997	May-Nov
Isfahan (Kobootar Abad)	1993-1998	Jan-Dec
Karaj	1995-1998	May-Nov
Mashhad	1988-1993	May-Dec
Mian Doub	1994-1998	May-Nov
Hamedan	1991-1993	Apr-Nov
Share Kord	1995-1998	Apr-Nov
Arak	1991-1993	May-Nov
Sanandaj	1996	May-Nov

$$R = \frac{\sum_{i=1}^{N} L_i PM_i - nLPM}{\sqrt{\left(\sum_{i=1}^{N} L_i^2 - NL^2\right)\left(\sum_{i=1}^{N} PM_i^2 - NPM^2\right)}} \quad (6)$$

Where:

MARE = Mean of Absolute Relative Error,
ABS = Absolute,
L = ET_0 lysimeter data (mm day^{-1}),
PM = ET_0 calculated in CropWat model,
N = Number of data,
RMSD = Root mean square error and
R = Correlation Coefficient.

RESULTS

Table 3 shows the average of ET_0 estimated by lysimeter and CropWat software in the study locations. Based on this table in all of stations, ET_0 which computing by CropWat software (PM) estimated less than lysimeter ET_0 (L). Also this table shows that estimating error of CropWat are between 21 and 39% when the average of MARE is 31%. In addition, RMSD estimated between 1.5 and 3.1 where the average of this parameter is 2.3. The results of this study show that error estimating in summery months is increasing. It means that the CropWat has a low sensitive in high potential evapotranspiration.

In addition, in the regions, which have higher mean temperature, CropWat error's estimate was increased. For example, Fig. 2-4 are showing the comparison of measured and estimated ET_0 in three different climates (Yazd, Isfahan and Arak). Based on these figures, on the peak of lysimeter curves are occurred the main differences between CropWat and lysimeter. These maximum differences are in summer months, when the temperature is high and the wind speed, rainfall and relative humidity are low. For example, based on Fig. 2, the average of ET_0 lysimeter values were estimated 9.1 mm per day in August while at the same time, CropWat was calculated this value about 5.7 mm per day in Yazd station. Figure 3 shows that in July the average of measured ET_0 by lysimeter was about 7.5 mm day^{-1} while the CropWat value of this parameter was calculated about

Table 3: Comparison of ET_0 lysimeter and ET_0 CropWat in the study stations

Station	L (mm day^{-1})	PM (mm d^{-1})	MARE (%)	RMSD	R^2
Yazd	8.3	5.3	35.3	3.0	0.38
Isfahan (Kobootar Abad)	5.5	4.4	21.6	1.5	0.78
Arak	7.2	4.4	37.2	2.8	0.70
Karaj	6.4	3.9	26.7	2.2	0.89
Hamedan	5.8	4.2	27.5	1.7	0.90
Mashhad	5.8	3.7	32.7	2.0	0.79
Mian Doub	6.2	4.5	31.2	2.4	0.82
Sanandaj	5.7	3.9	29.5	1.8	0.75
Share Kord	7.6	4.6	39.2	3.1	0.34
Average	6.5	3.8	31.2	2.3	0.70

Table 4: Effect of wind speed in two level grass reference evapotranspiration on CropWat software accuracy

Wind speed m sec^{-1}	ET_0 mm day^{-1}	MARE (%)	RMSD
<1	<6	26	1.2
<1	>6	22	2.3
>1	<6	15	0.9
>1	>6	28	2.4

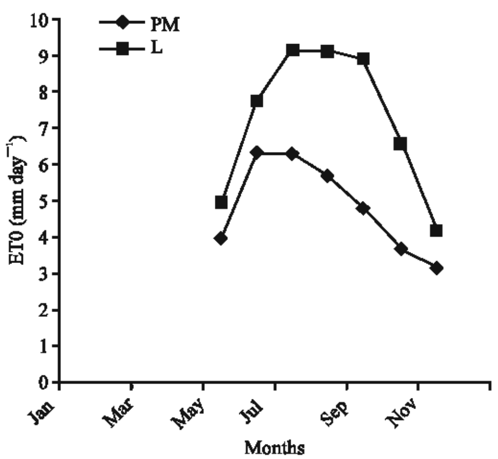

Fig. 2: Comparison of measured ET_0 by lysimeter and estimated ET_0 by CropWat in Yazd station

5.5 mm day^{-1}. In other hand, these values were about 3.6 and 3.8 in May for lysimeter and CropWat, respectively in the Isfahan station. The same event has happened in Fig. 4. In Arak station the maximum distance between lysimeter and CropWat curve has happened in August. In this month the average of maximum temperature, minimum temperature, relative humidity, wind speed and rainfall were estimated 34°C, 18°C, 22%, 0.7 m sec^{-1} and 0 mm, respectively. Therefore, it seems that the CropWat has a low sensitivity to various temperatures in dry condition especially in high temperatures.

The collected data reanalyzed with the Excel software synchronize with the meteorological data. The spreadsheet analysis shows that the Wind speed (W) affected clearly on estimation of the ET data. In each case (W>1, W<1 m sec^{-1}), the data and models reanalyzed

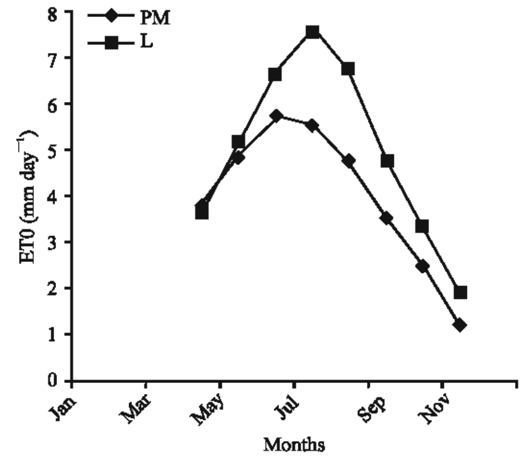

Fig. 3: Comparison of measured ET_0 by lysimeter and estimated ET_0 by CropWat in Isfahan station

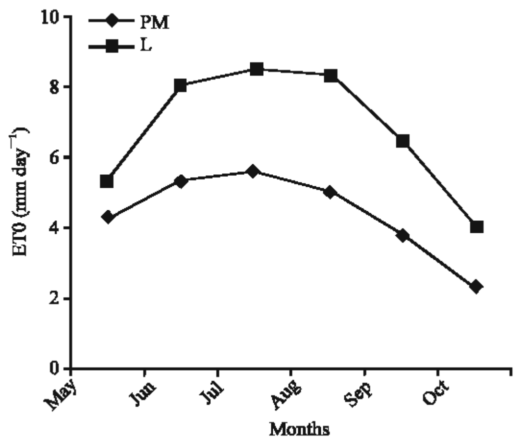

Fig. 4: Comparison of measured ET_0 by lysimeter and estimated ET_0 by CropWat in Arak station

for ET <6, ET>6 mm day^{-1}. The Table 4 shows the statistical parameters for both case of ET<6 and ET>6 mm day^{-1}, respectively in two level of wind speed. This table shows that with increasing of ET, the error value of CropWat model increase noticeably. In addition, when the average of wind speed was less than 1 m sec^{-1} or wind speed was more than 1 m sec^{-1} and ET_0 was less than 6 mm day^{-1}, CropWat has a low sensitive for estimating ET_0 and it's necessary to improve the results for these areas. In opposite, when ET<6 mm day^{-1} and W>1 m sec^{-1}, CropWat estimated ET_0 suitable.

ACKNOWLEDGMENT

The author wish to render his heartfelt gratitude to Mr. Mostafa Sattar, the member of Iranian Agricultural and Natural Research Center, for considering the lysimeter data.

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