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Validation of Reference Evapotranspiration Models Using Lysimeters Under Arid Climatic Conditions

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Abstract:

Efficient utilization of available water resources in the arid region of Egypt such as, The New Valley is crucial. Toward having a good and high efficient water management the determination of crop water requirement is appreciable. Many methods has been adopted to be used and needed to be validated. The objectives of this study were to calibrate and validate some ET_o models using lysimeter under the New Valley conditions. Estimation of accurate ET_o under these climatic conditions was also considered. Nine drainage lysimeters were installed, planted with alfalfa as a reference crop. Daily and monthly values of twelve ET_o models were compared with Lys-ETo during February 1st 2013 to January 31st 2015. The comparison was first made using original constant values in each ET_o model, then the selected models were calibrated as second step using data of first year through modified constant values involved in each model. In the last step, calibrated models were validated using both measured and estimated ET_o data of second year.

The comparative study indicated that the original FAO-24 Radiation and Blaney-Criddle models gave the lowest values of RMSE and RRMSE as compared with Lys-ET_o, they were 0.90 mm day^{-1} and 10.24% for FAO-24 Radiation and 1.37mm day^{-1} and 15.58% for Blaney-Criddle, respectively. Also, locally calibrated FAO-24 pan model was the best model and gave the excellent coinciding as compare with the Lys-ETo observations under the New Valley conditions.

Keyword: *ETo Models, Validation, Calibration, Lysimeter*

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1. Introduction:

The climate of the New Valley is hyper arid. In this region, the agricultural activity is limited due to inadequate water resource. Where, groundwater is the only source of water, which is very expensive. Therefore, accurate evapotranspiration estimates are required for irrigation management in this region and the resembling conditions (Yoder *et al.,* 2005, Grazhdani, *et al.,* 2010, Cobaner, 2011 and Fooladmand 2011). The ET_o is usually estimated through direct measurements or indirect methods. The direct methods (e.g. lysimeters) are precise and accurate; but it is difficult to directly measure under widely conditions, laborious, costly and time consuming (Alkaeed *et al.,* 2006). Therefore, the scientists used indirect methods to estimate it. These methods involve the estimation of ET_o from metrological data using empirical or physically based models. These models can be grouped into six categories: energy budget, mass-transfer, combination, radiation, temperature and pan evaporation-based. There is no universal consensus on the suitability of any given model for a given climate. Consequently, they require accurate local calibration and validation before they used to calculate ET_o (Jensen *et al.,* 1990, Smith *et al.,* 1996, Allen *et al.,* 1998 and Ventura *et al.,* 1999). Therefore, the objective of this study was calibration and validation of some ET_o models using lysimeter under the New Valley conditions to estimate accurate ET_o under these climatic conditions.

2. Materials and Methods:

2.1. Experimental site and climatic data

This study was carried out at the Agricultural Research Station, El-Kharga, New Valley Governorate, Egypt, which was located at 25° 27' 88.48" N latitude 30° 32' 43.38" E longitudes and 73 m altitude. The objective of this study was calibration and validation of some ET_o models using lysimeter under the New Valley conditions to estimate accurate ET_o under these climatic conditions. Daily meteorological data, including maximum air temperature, minimum air temperature, mean relative humidity, sunshine hours and wind speed at a height of 2 m were collected from El-Kharga weather station (The Egyptian- Meteorological Authority), located near the Agricultural Research Station. Table (1) shows monthly averages some climatic parameters of El-Kharga from 1990 to 2014.

Table (1): Monthly averages of some climatic parameters of El-Kharga from 1990 to 2014.

Month	Min Temp (°C)	Max Temp (°C)	Mean Temp (°C)	Relative humidity (%)	Precipitation (mm)	Wind speed (km/day)
1	7.1	22.8	14.8	51.2	0.04	219.6
2	8.4	24.8	16.6	44.3	0.00	241.2
3	11.9	28.9	20.6	36.8	0.01	279.8
4	17.0	34.5	25.9	29.3	0.04	303.8
5	21.8	38.4	30.3	27.3	0.05	311.4
6	24.3	40.3	32.7	27.6	0.04	331.3
7	24.6	41.1	33.5	29.3	0.01	259.1
8	24.6	40.9	33.3	30.5	0.00	265.7
9	23.4	38.6	31.1	34.2	0.01	328.4
10	19.6	34.7	27.1	39.4	0.00	306.6
11	13.6	28.8	21.1	47.1	0.01	256.2
12	8.7	24.2	16.2	50.7	0.04	217.9

2.2. Preparation and plantation of lysimeter

Nine drainage lysimeters were used, having inner diameter of 1.06 m, depth 1.10 m and thickness 0.003 m. The lysimeters were constructed using plastic containers (figure, 1). Each lysimeter was provided with plastic sheet at bottom; on top of this sheet were placed sheath fiber of date palm, then 0.10 m of gravel (0.005-0.010 m in diameter) were covered with another plastic sheet and sheath fiber of date palm 0.10 m sand, then plastic sheet with sheath fiber of date palm, then soil. Each lysimeter was filled with sandy loam soil (Table, 2) till 0.05 m before top edge. Lysimeters were provided with a drain PVC pipes, 0.05 m in diameter by 1.5 m long at the bottom to collect the drained water. The depth of drained water was measured using volumetric method.

Fig. 1. Preparation and plantation of lysimeters

Table (2): Some physical and chemical characteristics of lysimeters soil.

Characteristics	**Depth (cm)**	
	0-30	**30-60**
Sand %	54.41	56.12
Silt %	28.21	24.37
Clay %	17.38	19.51
Soil texture	Sandy loam	Sandy loam
Water Saturation % (v v^{-1})	42.95	43.39
Field Capacity% (v v^{-1})	21.40	22.79
Wilting point% (v v^{-1})	11.34	11.69
Available water% (v v^{-1})	10.06	11.10
Bulk density (g cm^{-3})	1.50	1.48
$CaCO_3$ %	3.25	3.53
pH (1:1 suspension)	7.70	7.66
EC (1:1 extract) dS m^{-1}	1.04	0.79

Lysimeters were saturated with water and allowed to drain and reach equilibrium after filling it with the soil; irrigation and drainage were repeated twice before the start of the experiment. The amount of applied water to each lysimeter was recorded.

The lysimeters were situated in meddle 1.2 feddan field. They were planted with alfalfa as a reference crop. Alfalfa seed were planted in the 1st of November 2012 with a rate of 25 kg fed^{-1}. All cultural practices were followed as recommended through the two growth seasons.

The Lys-ET$_o$ data were recorded after first cut and when alfalfa plants reached to 0.5 m as standard height (Jensen *et al.,* 1990) using three replications. To keep alfalfa plants at standard height, the lysimetrs were divided into three groups. Each group was containing three lysimeters. Alfalfa plants in each group were cut in the same time. The cut interval was 15 days between each group.

2.3. Soil water balance and irrigation scheduling

According to Allen *et al.* (1998) the soil water balance method was used to calculate ET$_o$ during experiment period as follows:

$$ETo = I + P - D - R \pm \Delta S$$

where, ET$_o$, I, P, D, R and ΔS are evapotranspiration, irrigation, precipitation, drainage water, runoff in mm and ΔS is the change in soil water content, respectively. R was equal to zero because of no surface runoff from lysimeter.

Irrigation water scheduling and amount were occurred when 30% available soil moisture was depleted (DehghaniSanij *et al.,* 2004) in 60 cm depth using the following model:

$$I = \frac{(\theta_{FC} - \theta_{PWP})}{100} \times d \times MAD$$

Where, θ_{FC}= volumetric soil moisture at field capacity, θ_{PWP}= volumetric soil moisture at wilting point, d= soil depth (mm), MAD= maximum allowable depletion which was equal to 30%. The accumulative values of monthly irrigation, drainage water, rain and ET$_o$ for alfalfa lysimeter are given in Table (3).

Table (3): The water balance components of alfalfa lysimters.

Month	Monthly irrigation water depth (mm)		Precipitation (mm)		Monthly drainage water depth (mm)		Monthly ET$_r$ (mm)	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
February	237.53	237.78	0.0	0.0	64.62	66.58	172.92	171.20
March	353.88	327.62	0.0	0.0	113.91	98.30	239.97	229.32
April	378.67	401.06	0.0	0.0	114.60	114.14	264.06	286.92
May	509.80	459.05	0.0	0.0	152.67	124.72	357.14	334.34
June	492.88	487.48	0.0	0.0	146.41	152.83	346.47	334.65
July	470.29	510.49	0.0	0.0	139.94	154.76	330.35	355.73
August	518.85	508.11	0.0	0.0	178.06	165.88	340.79	342.23
September	414.11	441.91	0.0	0.0	124.06	124.07	290.06	317.84
October	331.15	360.26	0.0	0.0	94.04	102.68	237.12	257.57
November	266.68	263.14	0.0	0.0	85.81	78.65	180.87	184.48
December	218.10	219.79	0.0	0.0	53.21	62.15	164.90	157.64
January	222.76	202.11	0.0	0.0	64.93	55.25	157.83	146.86

2.4. Comparison of ET_o with lysimeter

Twelve ET_o model values were compared with Lys-ET_o measurements. These models were divided to four categories: combination, radiation, temperature and pan evaporation-based. Daily weather data were collected to calculate ET_o values for each model in the first year (February 1st 2013 to January 31st 2014). This comparative study was done with the original constant and coefficient values involved in each model. The best model was selected based on root mean square error (RMSE), relative root mean square error (RRMSE) and correlation coefficient (R) under El-Kharga, New Valley conditions. The Microsoft® Excel 2007 (Microsoft, 2007) was used to calculate ET_o model.

Combination based models

Grass Penman-Moteith model (Allen *et al.,* 1998)

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

Alfalfa Penman-Moteith model (Maulé *et al.*, 2006)

$$ET_o = \frac{0.408\Delta\left(R_n - G\right)\gamma\frac{1600}{T+273}u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.38u_2\right)}$$

Priestley-Taylor model (Jensen *et al.,* 1990)

$$ET_o = \alpha\frac{\Delta}{\Delta + \gamma}\left(R_n - G\right)\frac{1}{\lambda}$$

where

ET_o = Reference evapotranspiration (mm day $^{-1}$)
R_n = Net radiation at the crop surface (MJ m^{-2} day^{-1})
G = Soil heat flux density (MJm^{-2} day^{-1}) G=0 for daily periods
T = Mean daily air temperature (°C)
λ = Latent heat of vaporization (λ= 2.45 MJ kg^{-1} at 20.7 °C)
γ = Psychrometric constant (kPa°C^{-1})
Δ = Slope of the saturation vapor pressure curve (kPa°C^{-1})
u_2 = Daytime wind 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)
α = Coefficient (without calibration α = 1.26)

Temperature based models

Blaney-Criddle model (Jensen *el al.,* 1990)

$$ET_o = a + bf$$

$$f = p\left(0.46T + 8.13\right)$$

$$a = 0.0043RH_{\min} - n/N - 1.41$$

$$b = 0.82 + (-0.0041RH_{\min}) + (1.07\,n/N) + (0.066U_d)$$
$$+ (-0.006RH_{\min}\,n/N) + (-0.0006\,RH_{\min}\,U_d)$$

Hargreaves-Samani model (Allen *et al.,* 1998)

$$ETo = 0.0023\left(T_{mean} + 17.8\right)\left(T_{\max} - T_{\min}\right)^{0.5}R_a$$

Modified Hargreaves model (Salah, 2007)

$$ETo = 0.0023R_a\left(T_{mean} + 17.8\right)\left(T_{\max} - T_{\min}\right)^{0.2}\left(1 - RH\right)^{0.2}\left(1 + u_2\right)^{0.2}$$

where
ET_o = Reference evapotranspiration (mm day $^{-1}$)
p = Mean daily percentage (for the month) of total annual daytime hours
T = Mean daily air temperature (^{o}C)
n/N = The ratio of possible to actual sunshine hours
RH = Mean relative humidity (%)
U_d = daytime wind at 2-m height (m s^{-1})
R_a = Extraterrestrial radiation (MJ m^{-2} day^{-1})
T_{mean} and T = Mean daily air temperature (^{o}C)
T_{max} = Maximum daily air temperature (^{o}C)
T_{min} = Minimum daily air temperature (^{o}C)

Radiation based models

Turc model (Jensen *el al.,* 1990)

For RH > 50%

$$ET_o = 0.013\left(\frac{T}{(T+15)}\right)(R_s+50)$$

For RH < 50%

$$ET_o = 0.013\left(\frac{T}{(T+15)}\right)(R_s+50)\left(1+\frac{(50-RH)}{70}\right)$$

Makkink model (Alexandris *el al.*, 2008)

$$ET_o = 0.61.\frac{\Delta}{\Delta+\gamma}.\frac{R_s}{\lambda}-0.12$$

FAO-24 Radiation model (Jensen *el al.*, 1990)

$$ET_o = a + b\frac{\Delta}{\Delta+\gamma}R_s$$

$$a = -0.3\,mm\,day^{-1}$$

Jensen-Haise model (Jensen *el al.,* 1990)

$$ETo = \frac{C_T(T-T_x)Rs}{\lambda}$$

$$C_T = \frac{1}{C_1 + C_2C_H}$$

$$C_H = \frac{5}{(e_2-e_1)}$$

$$C_1 = 38 - \left(\frac{2Elev}{305}\right)$$

$$C_2 = 7.3$$

$$T_x = -2.5 - [1.4(e_2-e_1)] - \left(\frac{Elev}{550}\right)$$

$$b = 1.066 - 0.13\times10^{-2}RH_{mean} + 0.045U_d - 0.20\times10^{-3}RH_{mean}U_d$$
$$-0.315\times10^{-4}RH_{mean}^2 - 0.11\times10^{-2}U_d^2$$

Where
ET_o = Reference evapotranspiration (mm day $^{-1}$)
R_s Turc model = Solar radiation (Cal m^{-2} day^{-1})
R_s Makkink model = Solar radiation (MJ m^{-2} day^{-1})
R_s FAO Radiation model = Solar radiation (mm day^{-1})
T_{mean} = Mean daily air temperature (^{o}C)
T_x = Intercept of the temperature axis (26.4 for temperature ^{o}F and -3 for temperature ^{o}C)
RH or RH_{mean} = Mean relative humidity (%)
U_d = Mean daytime wind speed (m s^{-1})
U_d, λ, γ and Δ = as defined for previous models

Evaporation based models

Christiansen Pan Evaporation model (Jensen *el al.,* 1990)

$$E_{to} = 0.755\, E_v C_{T2} C_{w2} C_{H2} C_{S2}$$

$$C_{T2} = 0.670 + 0.476\left(T/T_o\right) - 0.146\left(T/T_o\right)^2$$

$$C_{T2} = 0.862 + 0.179\left(T_c/T_{co}\right) - 0.041\left(T_c/T_{co}\right)^2$$

$$C_{W2} = 1.189 - 0.240\left(W/W_o\right) + 0.051\left(W/W_o\right)^2$$

$$C_{H2} = 0.499 + 0.620\left(H_m/H_{mo}\right) - 0.119\left(H_m/H_{mo}\right)^2$$

$$C_{S2} = 0.904 + 0.0080\left(S/S_o\right) + 0.088\left(S/S_o\right)^2$$

FAO-24 Pan Evaporation model (Allen *et al.*, 1998)

$$ET_o = K_p . E_{pan}$$

Class A pan with dry fetch

$$K_p = \beta + 0.00341 RH_{mean} - 0.000162 u_2\, RH_{mean} - 0.00000959 u_2 FET + 0.00327 u_2 In(FET) - 0.00289 u_2\, In(86.4u_2) - 0.0106 In(86.4u_2) In(FET) + 0.00063\left[In(FET)\right]^2 In(86.4u_2)$$

where

ET_o = Reference evapotranspiration (mm day $^{-1}$)

E_v = Measured Class A pan evaporation in the same unit. The coefficients are dimensionless.

T = The mean temperature in °F

T_0 = 68°F

T_c = The mean temperature in °C

W = The mean wind velocity 2 m (miles day^{-1} or km hour^{-1})

Wo = 100 miles per day or 6.7 km per hour

H_m = The mean relative humidity, expressed decimally, and

H_{mo} = 0.60

S = The percentage of possible sunshine, expressed decimally, and

S_o = 0.80

E_{pan} = pan evaporation (mm day $^{-1}$)

K_p = Pan coefficient can be calculated as following:

RH_{mean} = average daily relative humidity [%] = (RHmax + RHmin)/2

FET = fetch, distance of bare soil upwind of the evaporation pan (m)

β Constant (without calibration β = 0.61)

u_2 = as defined for previous models

2.5. Calibration of ETo models

After comparing between studied models with lysimeter, the ET_o models were calibrated and validated in order to assess the quality of the calculated ET_o values. These models were calibrated using daily weather data in the first year.

2.6. Validation of calibrated ETo models

The calibrated models were validated in the second year (1/2/2014 to 31/1/2015) using daily weather data in this year and previous statistical tests. This validating help to assess the degree of accuracy of the selected models.

2.7. Statistical analysis

According willmott (1982) both the measured ETo and calculated by studied models were compared using the root mean square error (RMSE), relative root mean square error (RRMSE) and correlation coefficient

(R). In this study, the comparative study was depended on RMSE and RRMSE values. These statistical parameters were calculated as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{N}(P_i - O_i)^2}$$

The optimal value is 0.0.

$$RRMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{N}(P_i - O_i)^2} \times \frac{100}{\bar{O}}$$

According Abou El Enin (2012), it can arrange values of RRMSE as follows: excellent if RRMSE<10%, good if RRMSE 10-20%, fair if RRMSE 20-30% and poor>30%.

$$r = \frac{\sum_{i=1}^{n}(x-\bar{x})(y-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x-\bar{x})^2 \sum_{i=1}^{n}(y-\bar{y})^2}}$$

Where r, x, $\bar{x}$, y, $\bar{y}$ and n are correlation coef., Lys-ET$_o$ (mm day^{-1}), Lys-ET$_o$ mean value, ET$_o$-model (mm day^{-1}), ET$_o$-model mean and number of observations.

3. Results and Discussion:

3.1. Comparison of selected models with lysimeter

The comparative study was made in this part through comparing calculated daily ET$_o$ values by the studied models with daily Lys-ET$_o$ in the first year (1/2/2013 to 31/1/2014) based on RRMSE under the New Valley conditions. The best models were had the lowest RMSE and RRMSE. According to these statistical parameters, the models were ranked from the best to the worst as shown in Table (4). Results indicated that FAO-24 Radiation, Blaney-Criddle and Christiansen pan models good coincided with observed data from lysimeter. While, Hargreaves-Samani and FAO-24 pan models fair coincided. The rest models provide poor coincided with observed data from lysimeter.

Table (4): Evaluation of original ET_o models as compared with lysimeter.

Models	RMSE	RRMSE	R
FAO-24 Radiation	0.90	10.24	0.95
Blaney-Criddle	1.37	15.58	0.93
Christiansen pan	1.57	17.89	0.92
Modified Hargreaves-Samani	1.79	20.35	0.95
FAO-24 pan	1.95	22.19	0.95
Penman-Moteith for short crop	3.02	34.34	0.96
Turc	3.30	37.45	0.84
Priestley-Taylor	3.47	39.44	0.87
Penman-Moteith for tall crop	4.48	50.83	0.96
Makkink	4.54	51.58	0.78
Hargreaves-Samani	5.77	65.54	0.84
Jensen-Haise	7.04	79.96	0.79

Both daily measured and calculated ET_o values were accumulated to produce monthly values in the first year. Comparison of monthly ET_o measured by lysimeter and ET_o models was graphically (Figure, 2). As seem, the ET_o values were increased from January to May, then decreased from June to December with unexpected decrease in July. This decrease may due to decrease in air temperature as well as increasing relative humidity in this month. Also, the models ET_o values partially followed the same trend. The figure showed that Hargreaves-Samani model overestimate ETo, while Grass Penman-Moteith, Alfalfa Penman-Moteith, Priestley-Taylor, Makkink and Jensen-Haise models underestimate ETo at all months of year. In addition, FAO-24 pan and Christiansen pan models were very close with Lys-ET_o at September and October and overestimate at the rest months. FAO-24 Radiation was very close with Lys-ET_o at May, June, July, November and December. It underestimates ETo at August, September and October, while it overestimates at the rest months when compared with Lys-ET_o. Modified Hargreaves-Samani overestimates ETo at January, Febraury, March and April and underestimates ETo at the rest months. Turc overestimates at Febraury and underestimates at the rest months. Blaney-Criddle overestimates at Febraury and April; it underestimates at the rest months.

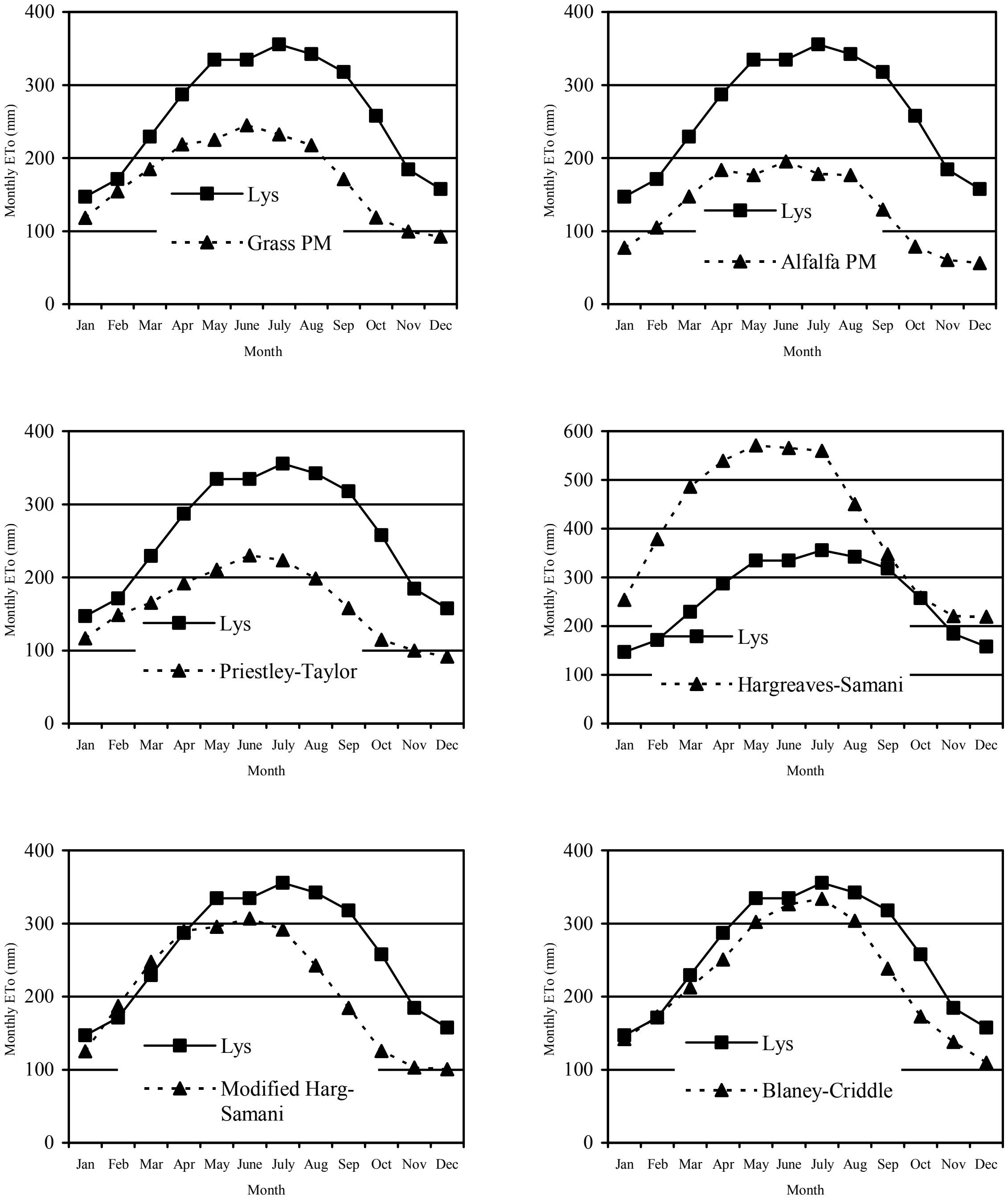

Fig. 2. Comparison of monthly values of Lys-ETo and uncalibrated ET_o models.

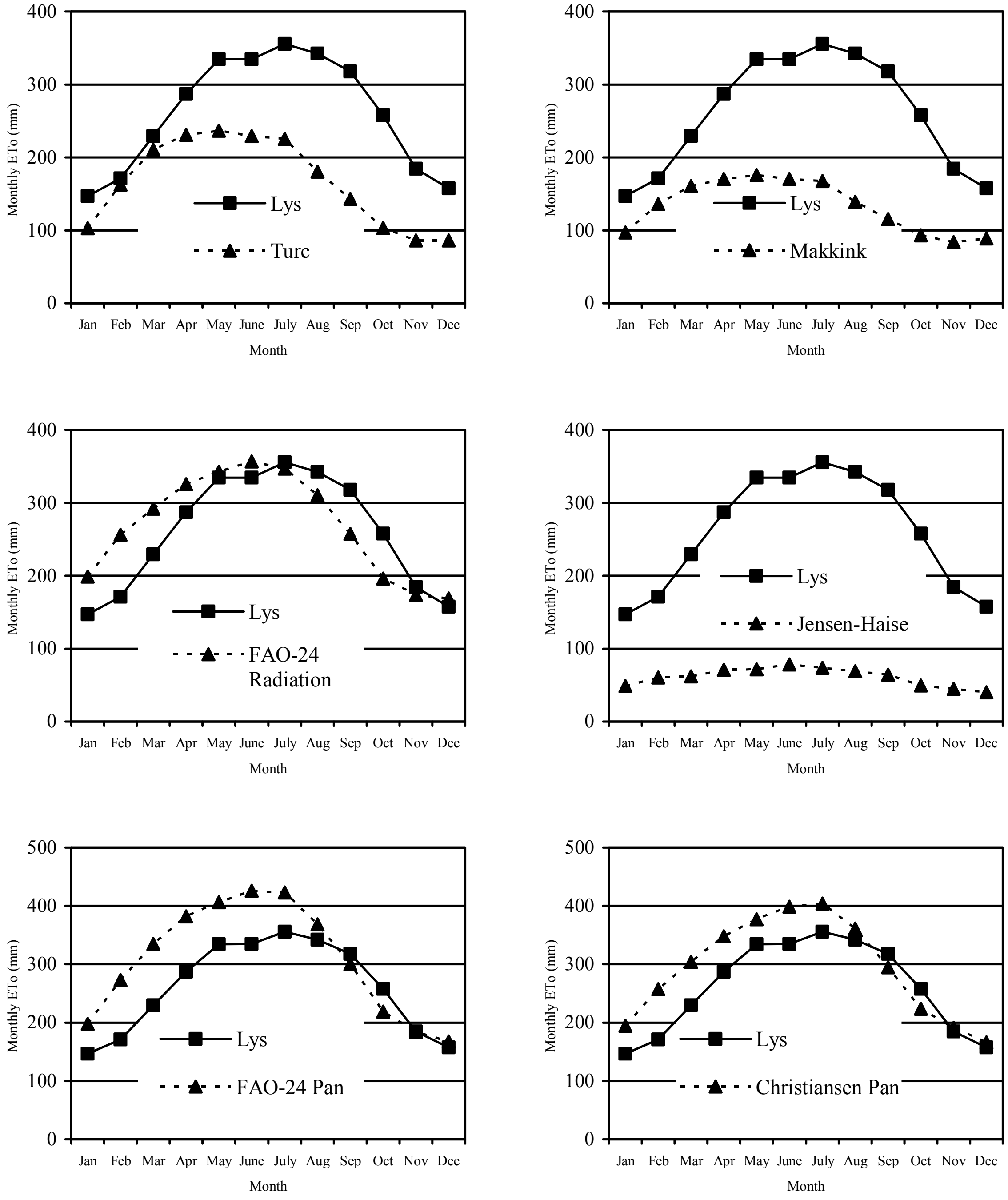

Fig. 2. Continued, Comparison of monthly values of Lys-ETo and uncalibrated ET$_o$ models.

3.2. Calibration of selected models

The comparative study in the previous part proved that studied ETo models may be unsuitable to use without recalibration of these models. Consequently, the original constant and coefficient values involved in each model were modified to improve those results. Data in Table (5) showed that the constant and coefficient of most models were increased, while they were decreased in the rest models under the same climatic condition. The constant values of 900, 1600, 1.26, 0.013 and 0.61 in Grass Penman-Moteith, Alfalfa Penman-Moteith, Priestley-Taylor, Turc and Makkink models were recalibrated and the modified values were 2000, 3550, 1.80, 0.020 and 1.10, respectively. Moreover, the two constant and coefficient values, i.e. 0.46 and 8.13, used in Blaney-Criddle model were changed to 0.51 and 8.80, respectively. The exponential values used in Modified Hargreaves-Samani were modified from 0.20 to 0.25. On the other hand, constant and coefficient values used in FAO-24 Radiation, Jensen-Haise, Christiansen Pan and FAO-24 Pan were changed from -0.3, 7.3, 0.755 and 0.61 to -0.54, 0.05, 0.67 and 0.51, respectively. Also, the exponential value (0.50) in Hargreaves-Samani model was modified to 0.33. In arid condition, Mohammed (1997) revealed that the Penman model gave highest correlation with the Lys-ETo. In similar condition, Mostafazadeh-Fard *et al.* (2009) showed that the FAO-Blaney-Criddle, FAO-24 Radiation and Turc-Radiation models estimate the lysimeter ET_o values most closely. Although, these previous studies were conducted in similar climatic conditions; but they haven't consensus on applying the same model in these regions. Therefore, it must be calibrating ET_o models under local conditions for each climatic zone.

Table (5): Calibrated and un-calibrated values parameters of studied ET_o models

Models	Original	Recalibrated
Combination based		
Grass Penman-Moteith	$C_n=900$	$C_n=2000$
Alfalfa Penman-Moteith	$C_n=1600$	$C_n=3550$
Priestley-Taylor	$\alpha=1.26$	$\alpha=1.80$
Temperature based		
Blaney-Criddle	$f=p(0.46T+8.13)$	$f=p(0.51T+8.80)$
Hargreaves-Samani	$(T_{\max}-T_{\min})^{0.5}$	$(T_{\max}-T_{\min})^{0.33}$
Modified Hargreaves	$(T_{\max}-T_{\min})^{0.2}(1-RH)^{0.2}(1+u_2)^{0.2}$	$(T_{\max}-T_{\min})^{0.25}(1-RH)^{0.25}(1+u_2)^{0.25}$
Radiation based		
Turc	$a=0.013$	$a=0.020$
Makkink	$a=0.61$	$a=1.10$
FAO-24 Radiation	$a=-0.3$	$a=-0.54$
Jensen-Haise	$C_2=7.3$	$C_2=0.05$
Evaporation based		
Christiansen pan	$a=0.755$	$a=0.67$
FAO-24 pan	$\beta=0.61$	$\beta=0.51$

3.3. Validation of selected models

This step was done on second year data (1/2/2014 to 31/1/2015); daily ETo computed models with the calibrated models were compared with Lys-ETo values after calibration of ET_o models. Data in Table (6) indicated that all calibrated models gave satisfactory results. Where, locally calibrated FAO-24 pan model was the best model and gave the excellent coinciding as compare with the Lys-ETo observations under the New Valley conditions. Meanwhile, the rest models present good coinciding. Mostafazadeh-Fard *et al.* (2009) proved that the Penman-Monteith 56, Penman-Kimberley, FAO-Corrected-Penman, FAO-24 Radiation and FAO-Blaney-Criddle models the adjustment factors can be used to nearly overlap the prediction of any of the above methods to the lysimetric measurement. As well as (Al-Ghobari, 2000) mentioned that calibrated Penman-SA method can be transferred successfully to other locations, and this method could be used for the estimation of ETr values in all areas in the southern region of Saudi Arabia.

Table (6): Evaluation of calibrated ET_o models as compared with lysimeter.

Models	RMSE	RRMSE	R
FAO-24 pan	0.89	9.96	0.94
Grass Penman-Moteith	0.95	10.66	0.97
FAO-24 Radiation	0.96	10.71	0.94
Christiansen pan	0.98	11.00	0.93
Modified Hargreaves-Samani	1.07	11.94	0.95
Blaney-Criddle	1.30	14.63	0.90
Hargreaves-Samani	1.40	15.66	0.87
Jensen-Haise	1.45	16.25	0.91
Turc	1.65	18.53	0.84
Priestley-Taylor	1.68	18.78	0.86
Alfalfa Penman-Moteith	1.74	19.48	0.93
Makkink	1.78	19.95	0.78

Data in Figure (3) show the comparison between monthly ETo estimated by the calibrated models and Lys-ET_o. This comparison showed that the calibrated models were more closely with Lys-ET_o as compared with data in in the first year. It shows the effective of calibration step. The lysimeter values indicate the ETo was increased from January to July and then decreased exhibiting an open bell-shape response with time of the year. Partially, the models ET_o values followed the same trend. Hargreaves-Samani, Modified Hargreaves-Samani, Turc, FAO-24 Radiation, Christiansen pan and FAO-24 pan models overestimate the ETo in January to June/August and underestimate the ETo in July/September to December. Mean while, the rest models followed different trends compared with the lysimeter values, over or and underestimations of ET_o.

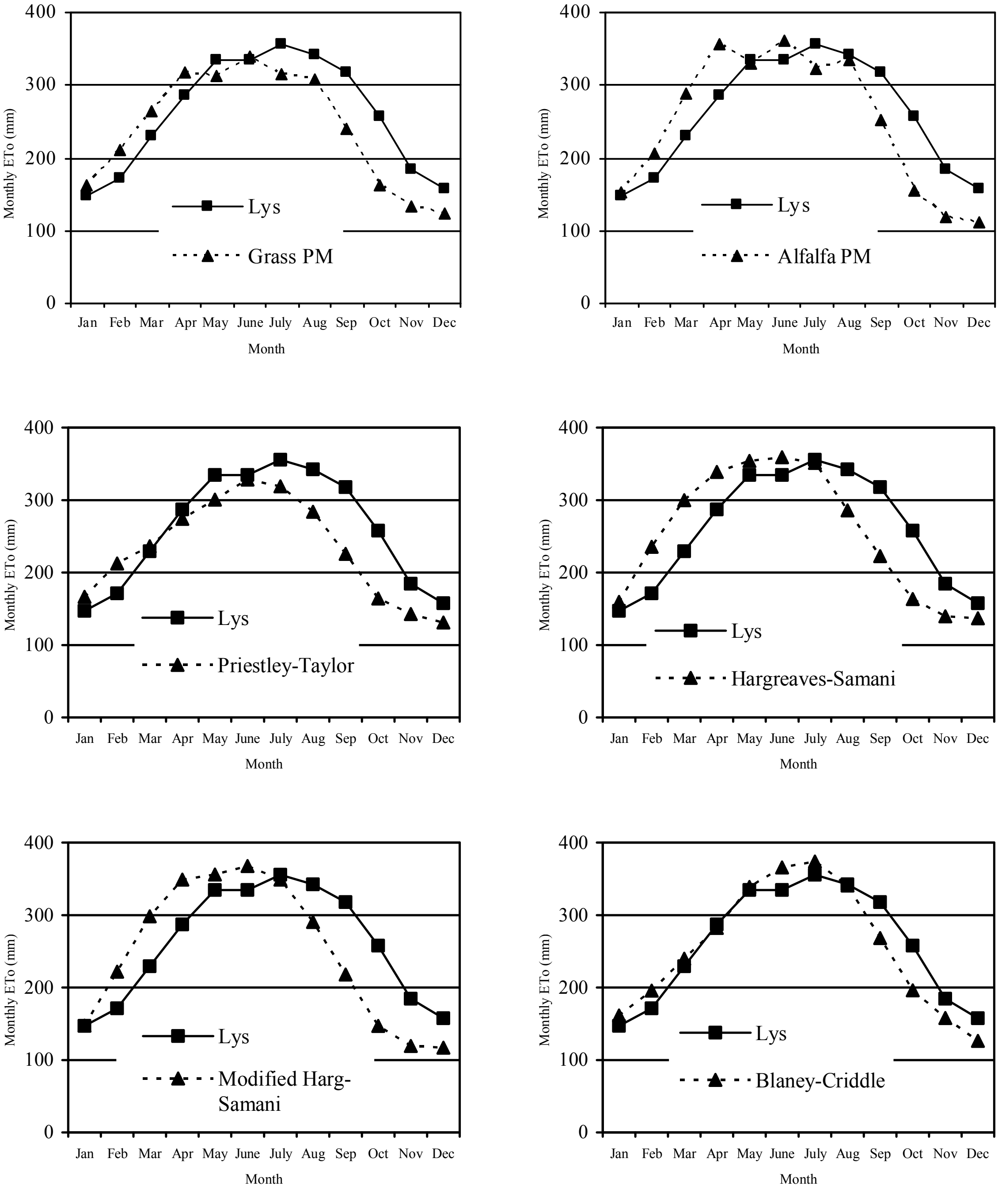

Fig. 3. Comparison of monthly values of Lys-ETo and calibrated ET_o models.

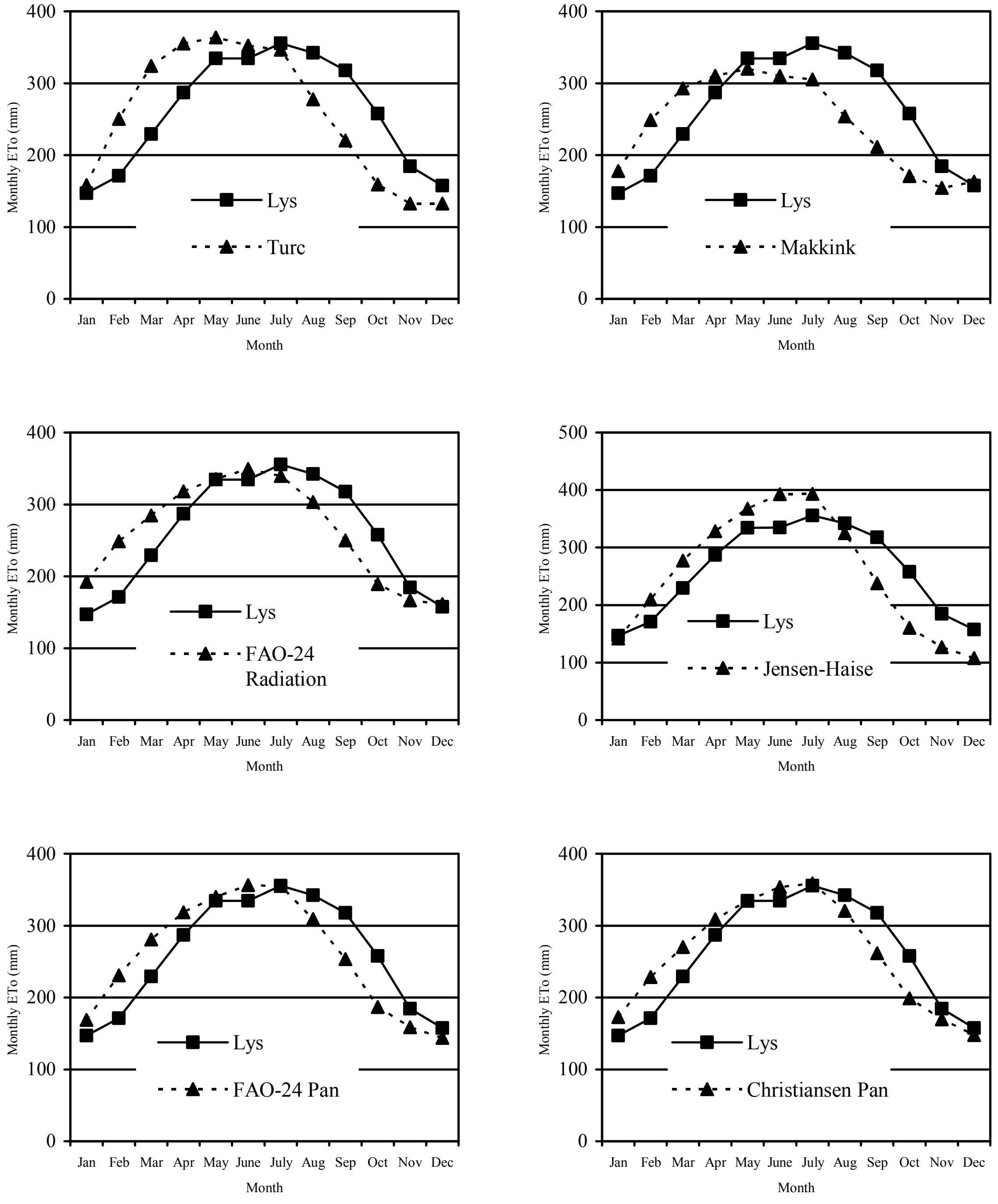

Fig. 3. Continued, Comparison of monthly values of Lys-ETo and calibrated ET_0 models.

4. Conclusions:

It can be concluded that using locally calibrated parameter values of all studied ET_0 models gave acceptable estimates as compared with Lys-ETo under the New Valley condition.

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تدقيق نماذج البخر نتح المرجعي باستخدام الليسميترات تحت الظروف المناخية الجافة

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الملخص:

تهدف هذه الدراسة الى معايرة وتدقيق نماذج البخر نتح المرجعي باستخدام الليسميتر تحت ظروف الوادي الجديد للحصول على تقديرات دقيقة من هذه النماذج تحت هذه الظروف المناخية. وعليه، استخدمت تسع ليسميترات وزرعت بالبرسيم الحجازي كمحصول مرجعي. تم مقارنة البيانات اليومية والشهرية الناتجة من ١٢ نموذج مع قيم البخر نتح المرجعي الناتج من الليسميترات خلال الفترة من ١/٢/٢٠١٣ الى ٣١/١/٢٠١٥. في البداية تم مقارنة نماذج البخر نتح المرجعي باستخدام قيم الثوابت الاصلية في كل نموذج وبعدها تم معايرة هذه النماذج كخطوة ثانية باستخدام بيانات السنة الاولى من خلال تعديل الثوابت لهذه النماذج. في الخطوة الاخيرة، تدقيق النماذج التي تم معايرتها باستخدام بيانات البخر نتح المقاسة والمقدرة.

توضح الدراسة المقارنة ان نموذج الاشعاع المقرر بواسطة الفاو٢٤ ونموذج بلاني كريدل أعطى اقل قيم RMSE وRRMSE مقارنة ببيانات الليسميتر وكانت ٠,٩مم/يوم و١٠,٢٤٪ لنموذج الإشعاع وكانت ١,٠٣٧مم/يوم و١٥,٥٨٪ لنموذج بلاني كريدل على الترتيب. ايضا، كان نموذج وعاء البخر المقرر بواسطة الفاو٢٤ المعاير محليا أفضل نموذج حيث اعطى توافق ممتاز مع قيم الليسميتر تحت ظروف الوادي الجديد.