

**Evaluation of a Few Evapotranspiration Models
using Lysimetric Measurements in a Semi Arid
Climate Region**

ABSTRACT

The determination of reference evaporation method in a region with different simple or complex equations requires a wide range of meteorological data. It is difficult task particularly in regions with lacking data collection facilities. One of the common methods for this purpose is the use of lysimeters. In the present study, daily lysimetric data for two years (2012 to 2013) from April to July in each year were used to evaluate nine different grass evapotranspiration models including FAO-56 Penman-Monteith, Penman-Kimberly 1996, FAO-Penman equation, Blaney-Criddle, FAO-24 Radiation, Makkink, Turc, Priestley-Taylor, and Hargreaves in Kermanshah western part of Iran with semi-arid climate. Finally, the values of RMSE indicate that, the FAO - Penman-Monteith, Makkink and Hargreaves and Samani were found to be the most appropriate models for the studied region. Penman-Kimberly and FAO-Penman methods had the worst results among the studied models. FAO - Penman-Monteith, Makkink and Hargreaves-Samani methods recommended for reference evaporation estimation, irrigation planning and scheduling, dams reservoirs design and different surface or pressurized irrigation projects water requirement application under different crop patterns in Kermanshah region, while weather, radiation and temperature data have been available. Based on RMSE values, the FAO -Penman-Monteith, Makkink and Hargreaves & Samani methods estimated the lysimeter reference evaporation values most closely and Penman-Kimberly and FAO-Penman methods had the worst results in the region.

Keywords: evapotranspiration, ETo equations, Lysimeter, Semi-arid climate.

1. INTRODUCTION

Evapotranspiration (ET), a term to denote evaporation and transpiration together, is the most important component of environmental systems and accomplishes the energy (heat) and mass (water vapor) transfers between atmosphere and land surface (primarily including soils and vegetations) [6].

Reference evaporation (ETo) is defined in as the rate of evapotranspiration from hypothetical crop

35 with as assumed crop height (12cm), an albedo of 0.23, and a fixed canopy resistance (70 Sm^{-1})
36 which would closely resemble evapotranspiration from an extensive surface of the green grass cover
37 of uniform height actively growing, completely shading the ground with no shortage of water [2]. The
38 plant growth and productivity are directly related to the availability of water [29]. ETo can be measured
39 directly by lysimeter. However, it is generally estimated by theoretical or empirical equations, or
40 derived simply by multiplying the standard pan evaporation data by a pan coefficient [12]. Direct
41 measurement of ETo can be difficult and expensive both economically and in time investments while
42 basic measurements of the atmosphere are easy to collect and available at numerous locations. For
43 this reason and to overcome inaccurate ETo estimation, numerous methods have been developed for
44 various types of climatic conditions over the years.

45 FAO-56 Penman–Monteith (PM) equation is the most commonly used and accurate model to
46 determine the ETo by the United Nations Food and Agriculture Organization (FAO) and by the World
47 Meteorological Organization (WMO) [1]. However, ranking and selecting of the best method to
48 estimate ETo to local conditions is required for water resources and irrigation management and
49 scheduling purposes.

50 Five ETo estimation methods evaluated by comparing the estimated with results obtained from the
51 PM 56 equation under humid conditions [32]. They showed that Turc's method gave the best ETo
52 estimates and ranking first, and the other equations ranking in a decreasing order were as Priestley–
53 Taylor, Jensen–Haise, Thornthwaite, and Hargreaves. The ETo measured in lysimeter in Campos dos
54 Goytacazes compared with ETo estimated by PM method [24]. The researchers found that PM
55 method satisfactorily estimated ETo values.

56 Four simpler models based on monthly performance for various climates in Iran evaluated [31]. They
57 reported that the Makkink and Priestley-Taylor models estimated ETo values less accurately than
58 Turc and Hargreaves and Samani models for all climates. The performance of 20 different methods
59 against the lysimeter measuring ETo analyzed for 11 stations located under different climatic
60 conditions around the world [18]. The Penman-Monteith ranked the best method for all climatic
61 condition; however, ranking of the other methods varied depending on their adoption to local
62 calibrations and conditions. The performance of Turk, Priestley–Taylor compared to PM 56 methods
63 to estimate potential evapotranspiration in humid climates in Florida [11]. They concluded that the
64 Priestley–Taylor performance appeared to be superior to the other two methods for a variety of land
65 covers in Florida.

66 Nine different equation for ETo estimation evaluated by using lysimeter in a semi-arid region in the
67 south of Iran [28]. They concluded that the FAO-Radiation was the most suitable method to estimate
68 ETo for irrigation planning and scheduling in regions where radiation and temperature data are
69 available.

70 The performance of nine ETo methods with FAO56-PM output data evaluated and compared [27].
71 The best results after calibration were produced by Blaney-Criddle method while Thornthwaite
72 method had the worst results. Moreover, the determination of evaporation in a region with different
73 simple or complex equations required a wide range of meteorological data. This again proved the
74 difficulty of choosing the most appropriate method.

75 Moreover, the most common and widely used methods for reference evapotranspiration estimation by
76 local agricultural and water resources organizations and consulting engineers in the region based on
77 climatic availability data was the base reason for different selected method and comparison with
78 lysimetric reading data. Therefore, Daily lysimetric data for two years from April to July were used in
79 the present study to evaluate simple or complex nine ETo models including FAO-56 Penman-
80 Monteith (PM), Penman-Kimberly 1996 (Pk), FAO-Penman equation (PM), Blaney-Criddle (BC),
81 FAO-24 Radiation (FR), Makkink (MA), Turc-radiation (TR), Priestley-Taylor (PT), and Hargreaves
82 and Samani (HG) in a region with semi-arid climate. Different methods were compared with
83 experimentally determined values and drainage lysimeters data to find the best and the worst
84 methods in the region for practical irrigation planning purposes.

85

86 2. MATERIAL AND METHODS

87

88 2.1. EXPERIMENTAL SITE AND WEATHER STATION, SOIL, AND IRRIGATION WATER DETAILS

89 The Lysimetric experiments were carried out in two years from 2012 to 2013 from April to July at the
90 Irrigation and Water Resources Engineering Research Lysimetric Station No. 3 located at 47°9'E and
91 34°21'N, with an elevation of 1319 m (asl), as part of the Campus of Agriculture and Natural
92 Resources of Razi University in Kermanshah, Iran. The region under study has a semi-arid climate.
93 The daily meteorological data were obtained from the regional meteorological station located 100 m
94 off the lysimetric station. (Table 1) shows the average monthly meteorological data during both years
95 of the study. The soil texture in the lysimeters was silty clay composed of different clay, silt, and sand
96 percentages. Tables (2) and (3) show the physical and chemical properties of the soil and the
97 chemical properties of the irrigation water used in this study. The pressure plate and sampling

98 methods were used to determine $\theta(fc)$, $\theta(pwp)$ and bulk density in different lysimeters soil depths,
 99 respectively.

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Table 1. Meteorological Data for growing period 2012-2013

Year	Month	Mean temperature (C)	Mean relative humidity (%)	Mean wind speed (m/s)	Mean monthly sunshine (h)	Total precipitation (mm)
2012	April	11.8	53.9	7.1	6.9	45.7
	May	18.4	36.5	7.7	8.3	0.0
	June	24.8	21.4	7.9	9.7	0.0
	July	28.1	19.6	7.6	10.2	0.0
2013	April	13.4	42.5	7.3	7.3	10.7
	May	15.1	54.2	8.4	5.3	63.3
	June	23.3	27.4	7.4	9.2	0.0
	July	29.1	14.7	7.4	11.6	0.0

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Table 2. Physical and Chemical Properties of Soil

Soil Texture	Sand (%)	Silt (%)	Clay (%)	EC (dS/m)	$\Theta(Fc)$ (%)	$\Theta(PWP)$ (%)	pH	Bulk density (g/cm ³)	Soil depth (cm)
Silty Clay				0.61			7.63	1.3	0-30
	54	42.3	3.7	0.61	27.6	17.2	7.61		30-60
				0.59			7.73		60-90
				0.58			7.73		90-120

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Table 3. Physical and Chemical Properties of Irrigation Water

SO ₂ ⁻ (Meq/L)	Cl ⁻ (Meq/L)	HCO ₃ ⁻ (Meq/L)	CO ₃ ²⁻ (Meq/L)	TDS (Meq/L)	pH	EC (dS/m)	Anions (Meq/L)	Mg ²⁺ (Meq/L)	Na ⁺ (Meq/L)	Ca ²⁺ (Meq/L)	Cations (Meq/L)
1.25	1.90	6.15	0	390	7.2	0.61	9.30	3.1	1.15	5.05	9.30

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113 **2.2. DETAIL OF DRIANABLE LYSIMETERS**

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115 In this study three drainable lysimeter with depth of 1.40 m and internal diameter of 1.20 m were
 116 used. The lysimeters were constructed with 3-mm-thick mild steel. To prevent rusting phenomenon
 117 both inside and outside parts of lysimeters were painted with epoxy material. By using tarry material
 118 all parts of lysimeters were also isolated carefully. For extra drainable water collection, the bottom of
 119 each lysimeter was inclined towards the center. In the bottom of each lysimeter an stainless steel
 120 screen was used with mesh size of 0.2 mm. In the above of stainless steel screen, 10-cm layer of
 121 gravel and a 10-cm layer of sand were used. In each lysimeter to measure of extra drained water
 122 collection by a graded container a steel pipe with diameter of 2.50 cm fixed with a control gate valve
 123 was used. In all lysimeters a silty clay soil consisting of 54, 42.3, and 3.7% clay, silt, and sand was
 124 used. All lysimeters were filled with air-dried soil and compacted manually to reach a bulk density of
 125 1.30 gcm⁻³ according to [25] method. Soil moisture characteristic curves was determined by using
 126 [19] method. Lawn grass with 12 cm height inside and also in an area of (50×50m) was planted
 127 around the lysimeters respectively.

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129 **2.3. SOIL MOISTURE MEASUREMENT**

130

131 A TDR system (Trime-Fm with P2G probes) was used to measure soil moisture. TDR probes were
 132 0.60 cm in diameter and 16 cm long and were installed in all lysimeters at 6 different depths of 20, 40,
 133 60, 80, 100, and 120 cm. The irrigation was carried out in all lysimeters after 20% depletion of
 134 available soil moisture in order to avoid any water stress during grass growing period.

135

136 **2.4. LYSIMETER MEASUREMENT**

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138 Three lysimeters were used to estimate grass evapotranspiration; also, potential evapotranspiration
 139 (ET_o) was calculated using Equation (1) as follows:

$$140 \quad ET_o = P + I - D - R + \Delta s \quad (1)$$

141 Where, ETo = reference evapotranspiration (mm); P = precipitation (mm); I = irrigation (mm); D =
 142 amount of drained water (mm); R = runoff (mm); and ΔS = changes in soil water storage during the
 143 period for which ETo was computed (mm). The precipitation was measured with a rain gauge *in situ*.
 144 The irrigation (I), D, and R for the lysimeters were measured with a precession graded container and
 145 rain gauge. The changes in soil moisture were obtained from soil moisture readings at different
 146 depths. Daily meteorological data including minimum and maximum temperatures, sunshine hours,
 147 wind speed, and average relative humidity were also collected from a regional meteorological station.
 148 Different equations for estimation of ETo were as follows:

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150 2.5. METHODS OF COMPUTING ETo

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152 Different nine methods were chosen to estimate ETo for the study area as follows:

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154 2.5.1. FAO-PENMAN METHOD, Doorenboss [8,9, 10]

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$$ET_o = c \left[\left(\frac{\Delta}{\Delta + \gamma} \right) (R_n) + \left(\frac{\gamma}{\Delta + \gamma} \right) (2.7) (W_f) \left(e_z^{\frac{156}{157z}} - e_a \right) \right] \quad (2)$$

158

159 Where, ETo, ($e_z^{\circ} - e_a$), γ , Δ , R_n , W_f and c are reference evapotranspiration (mm day^{-1}), vapor
 160 pressure deficit at height z (kPa), psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), slope vapor pressure curve (kPa
 161 $^\circ\text{C}^{-1}$), net radiation (MJ m^{-2} per day), the wind function and adjustment factor which is equal to 1
 162 respectively.

163

164 2.5.2. PENMAN-KIMBERLY METHOD, Wright [34]

165

$$ET_o = \frac{1}{\lambda} \left[\left(\frac{\Delta}{\Delta + \gamma} \right) (R_n - G) + \left(\frac{\gamma}{\Delta + \gamma} \right) (6.43) (W_f) \left(e_z^{\frac{166}{167z}} - e_a \right) \right] \quad (3)$$

168 where, G and λ are soil heat flux density ($\text{MJ m}^{-2} \text{day}^{-1}$) and latent heat of vaporization in (MJ kg^{-1}).

169

170 2.5.3. FAO-PENMAN-MONTEITH METHOD, Allen [1,2]

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + .034u_2)} \quad (4)$$

173

174 where, u_2 and $(e_s - e_a)$ are wind speed at 2 m height ($m s^{-1}$) and saturation vapor pressure deficit
 175 (kPa).

176

177 **2.5.4. TURC-RADIATION METHOD ,Turc [33]**

178

$$ET_o = a_T (0.013) \frac{T_{mean}}{T_{mean} + 15} \left(\frac{23.8856 R_s + 50}{\lambda} \right) \quad (5)$$

180

181 where, T_{mean} and R_s are mean daily air temperature ($^{\circ}C$), and solar radiation ($MJ m^{-2} d^{-1}$), a_T is
 182 equal 1.0 for $RH_{mean} \geq 50\%$ and it is equal $1 + (50 - RH_{mean}) / 70$ for $RH_{mean} < 50\%$.

183

184 **2.5.5. HARGREAVES AND SAMANI METHOD, Hargreaves [13, 14]**

185

$$ET_o = \frac{1}{\lambda} (0.0023) R_A T D^{1/2} (T + 17.8) \quad (6)$$

188 where, R_A , T and D are extra-terrestrial solar radiation received on earth's surface ($MJ m^{-2} d^{-1}$),
 189 difference of mean maximum and mean minimum air temperatures ($^{\circ}C$) and mean daily air
 190 temperature at 2 m height ($^{\circ}C$) respectively.

191

192 **2.5.6. MAKKINK METHOD [22]**

193

$$ET_o = 0.61 \frac{\Delta}{\Delta + \gamma} \frac{R_s}{2.45} - 0.12 \quad (7)$$

195

196 **2.5.7. FAO-RADIATION METHOD, Doorenboss [9, 10]**

$$ET_o = b \left[\frac{\Delta}{\Delta + \gamma} \frac{R_s}{\lambda} \right]^{197} - 0.3 \quad (8)$$

$$b = 1.066 - 0.13 \times 10^{-2} RH + 0.045 U_d - 0.2 \times 10^{-2} R H U_d - 0.315 \times 10^{-4} R H^2 - 0.11 \times 10^{-2} U_d^2 \quad (9)$$

200

201 where, RH is mean relative humidity (%).

202

203 **2.5.8. PRIESTLEY AND TAYLOR METHOD [26]**

$$ET_o = \frac{1}{\lambda} \alpha \frac{\Delta}{\Delta + \gamma} (R_n - G) \quad (10)$$

205

206 where, α is a constant ($\alpha = 1.26$).

207

208 **2.5.9. BLANEY-CRIDDLE METHOD , Blaney [4, 5], Doorenboss [9, 10]**

209

$$ET_o = a + bf$$

210

(11)

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

212

$$b = 0.82 - 0.41 \times 10^{-2} RH_{\min} + 1.07 \times \frac{n}{N} + 0.066U_d - 0.6 \times 10^{-2} RH_{\min} \times \frac{n}{N} - 0.60 \times 10^{-3} RH_{\min} \times U_d$$

213

$$f = p(0.46T + 8.13)$$

214

215 where, RH_{\min} , n , N , p and U_d are minimum relative humidity (%), actual daily sunshine hours (h),

216 maximum possible daily sunshine hours (h), monthly percentage of daytime hours and daytime wind

217 speed (ms^{-1}) respectively.

218

219 **2.6. DATA ANALYSES**

220

221 The method suggested by [16,17] were used for statistical analyses. The following equations were

222 used to compute the regression coefficients (r), root mean square error (RMSE), mean bias error

223 (MBE) and t-statistic test (t).

224

$$r = \frac{\sum_{i=1}^n (x - \bar{x})(y - \bar{y})}{\sqrt{\sum_{i=1}^n (x - \bar{x})^2 \sum_{i=1}^n (y - \bar{y})^2}} \quad -1 \leq r \leq 1 \quad (12)$$

226

$$MBE = \frac{\sum_{i=1}^n d_i}{n} \quad (13)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n d_i^2}{n}} \quad (14)$$

$$t = \frac{(n-1) MBE}{\sqrt{RMSE^2 - MBE^2}} \quad (15)$$

232 where, x = the measurement value, \bar{x} = the mean measurement value, y = the predicted value, \bar{y} =

233 the mean predict value, d_i = difference between i^{th} predicted and i^{th} measured values, n = number of

234 data pairs i .

235 The regression equations computed from below formula:

236 $Y = mX + C$ (16)

237 where, Y represents the daily ETo measured; X is the daily ETo estimated from each of the other nine
238 methods; and m (slope) and C (intercept) are the regression constants.

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240 3. RESULTS AND DISCUSSION

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242 The daily evapotranspiration was computed based on water-balance data collected from lysimeters
243 using Equation (1) the computed ETo values from the lysimeter data for grass which was the
244 reference crop, from the months of April to July and were compared to the ETo values computed by
245 nine different methods. The average ETo values of lysimeter were obtained as 73,122,173 and 222
246 mm per month for April, May, June and July during 2012 and 2013, respectively. The values of
247 monthly measured ETo, the total values of ETo for lysimeter data and the predicted values from each
248 of the nine methods are presented in (Table 4). As shown in (Figure 1), the ETo increased from April
249 to July for both lysimeters and other chosen methods.

250 The cross correlation (R^2), slope, intercept and RMSE, MBE and t-test statistical methods were used
251 to compare the lysimeter ETo values with the ETo values by nine other methods. According to the
252 [17], the performance of each method in the present study was based on t values. Lower t-values
253 showed a better performance of the method indicating that the differences between the measure and
254 the estimated values were lower. Also, the negative sign of the MBE indicates that the computed ETo
255 values were lower than ETo values measured by the lysimeter while positive MBE shows
256 overestimation of the lysimeter ETo values; the absolute value is also an indicator of method
257 performance. The slope near to unity indicates a parallelism of the measured and the calculated ETo
258 curves, while the lower intercept of the regression equation indicates proportionality between the two
259 methods. For statistical analysis, it was assumed that the best methods were those with the lowest
260 RMSE. The results of these comparisons for the above parameters are shown in (Table 5). The
261 methods in (Table 5) are ranked according to RMSE. The estimated ETo values by the PF, PK, PM,
262 TR, HG, MA, FR, PT and BC methods were evaluated with lysimeter ETo values having RMSE
263 values as 12.96, 8.74, 1.34, 2.67, 2.03, 1.48, 3.55, 2.34, 2.58 mm/day, respectively. Based on RMSE
264 and MBE values presented in (Table 5) and also as shown in Figure 2, the PM, MA and HG methods
265 estimated the lysimeter ETo values most closely and PK and PF methods did not show any close
266 agreement with the lysimeter values and had the worst results. Other methods (including PT, BC, TR,
267 and FR) showed reasonable agreement with the lysimeter values.

268 A comparison of the results show that the PK, PF, HG and FR methods overestimated while PM, TR
 269 and MA equation underestimated potential evapotranspiration compared to lysimetric estimation
 270 method.

271

272 **Table 4. Lysimetric and different estimating potential evapotranspiration methods**

Methods	ETo (mm)				
	Month				Total
	April	May	June	July	
Lysimetric measurement	73.0	122.1	173.4	222.7	591.2
FAO-Penman (PF)	365.8	469.3	583.4	669.1	2087.6
Penman-Kimberly(PK)	469.8	269.9	293.7	345.1	1378.6
FAO - Penman-Monteith(PM)	57.5	90.3	154.6	213.4	515.8
Turc-Radiation (TR)	40.0	53.2	89.6	115.7	298.5
Hargreaves & Samani (HG)	123.1	170.4	233.9	277.4	804.9
Makkink (MA)	87.1	107.1	143.6	170.4	508.2
FAO-Radiation (FR)	153.8	192.9	281.3	338.2	933.3
Priestley and Taylor (PT)	141.2	173.2	231.8	275.2	821.3
Blaney-Criddle (BC)	112.2	156.2	251.2	316.6	836.2

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Table 5. The comparing of different methods with Lysimetric measurement in daily scale

Methods	Lysimeter measurement							Ranking
	Performance Indicator							
	Slope of the regression line	Intercept of the regression line	R ²	RMSE (mm)	MBE	t	R/t	
Lysimetric measurement	1	0	1	-	-	-	-	-
FAO - Penman-Monteith(PM)	1.045	-0.933	0.841	1.34	-0.66	6.27	0.14	1
Makkink (MA)	0.534	1.531	0.701	1.48	-0.74	6.42	0.12	2
Hargreaves & Samani (HG)	0.985	1.726	0.843	2.03	1.77	19.87	0.04	3
Priestley and Taylor (PT)	0.86	2.489	0.710	2.34	1.79	13.16	0.06	4
Blaney-Criddle (BC)	1.361	0.130	0.853	2.58	1.96	13.01	0.07	5
Turc-Radiation (TR)	0.504	-0.045	0.836	2.67	-2.42	23.85	0.04	6
FAO-Radiation (FR)	1.206	1.968	0.757	3.55	2.98	17.24	0.05	7
Penman-Kimberly(PK)	-0.607	14.27	0.080	8.74	6.57	12.67	-0.03	8
FAO-Penman (PF)	1.846	7.997	0.473	12.96	11.77	24.06	0.03	9

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282 R = regression coefficients

283 RMSE= root mean square error

284 MBE= mean bias error

285 t = t-statistic test

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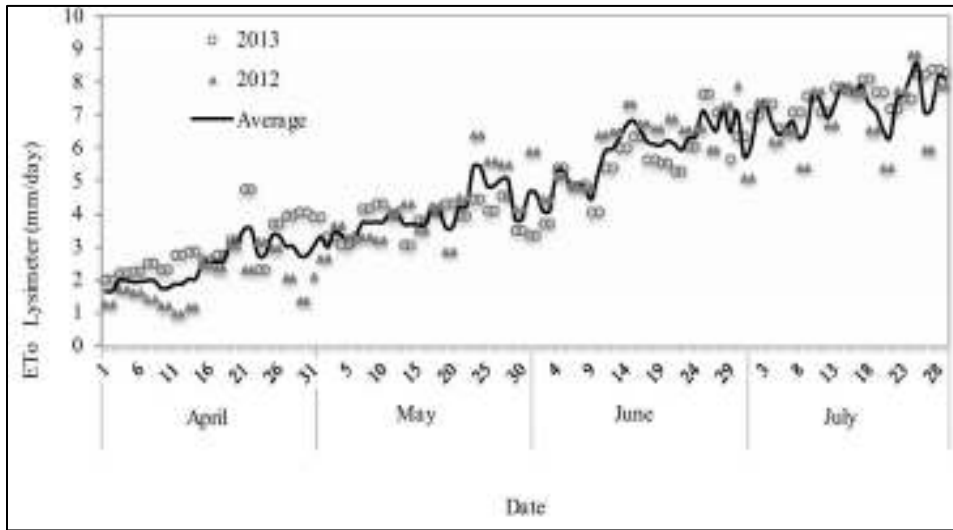


Figure 1. Daily ETo measurement values

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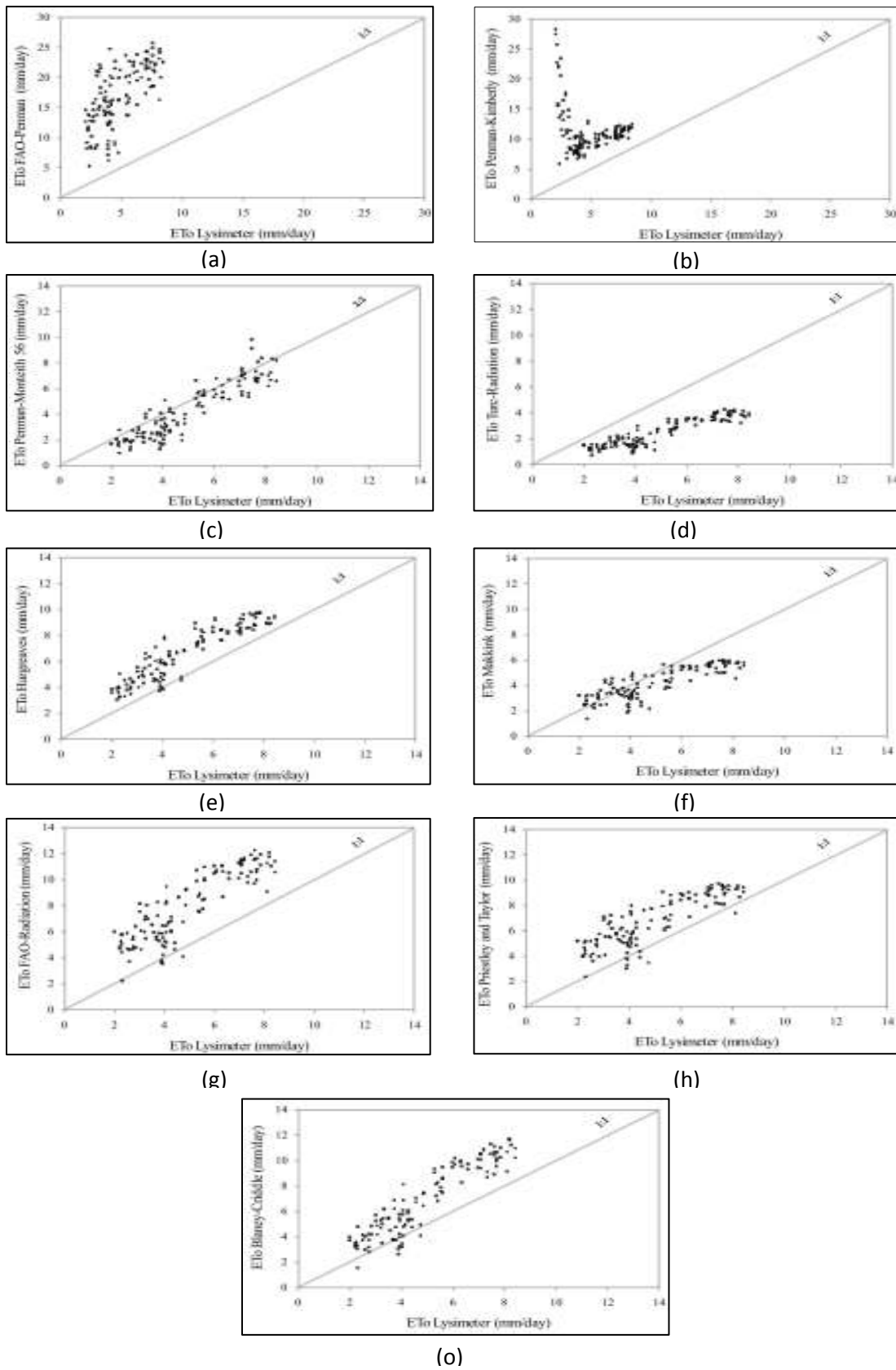


Figure 2. Comparison of ET0 measurement with different estimation methods

329 The capabilities of models found in this study, while reported by others, were different. Although, for
330 daily, smoothed daily, mean 10-day and mean monthly ETo were estimated by Penman-Monteith,
331 Hargreaves-Samani, Jensen- Haise, Turc, Priestley-Taylor, FAO-Blaney-Criddle, FAO-Radiation and
332 Pan Evaporation equations and a linear regression equation was obtained for the estimated and
333 measured values [28]. They compared the results of the equations with ETo data from a weighing
334 type lysimeter and ranked results of different methods according to statistical and error analysis. The
335 results indicated that the FAO-Radiation and Hargreaves-Samani were the most appropriate methods
336 while the Priestley-Taylor method was the least appropriate. The Penman-Monteith ranked in third to
337 fifth on the list according to the duration of mean values.

338 The estimated ETo by Hargreaves-Samani method was more appropriate than those obtained by the
339 Penman-Monteith method while the FAO-Radiation method showed the best results [20]. The slope
340 of linear relationships between ETo estimated by the Hargreaves-Samani and Penman- Monteith
341 methods and measured ETo by lysimeter were close to 1.0 [15].

342 Hourly ETo estimations obtained by Penman-Monteith under the semiarid climate of Kerman, Iran.
343 Hourly ETo estimations obtained from the proposed method were compared with measured ETo
344 values by using a large weighing electronic lysimeter during the months of April to September, 2005.
345 The results showed that FAO-56 Penman-Monteith underestimated ETo values by 18.4, 19.3, 26.3,
346 20.4, 21.4 and 22.1% for the months of April to September, respectively [3].

347 ETo calculation by seven different equations and comparison with lysimeter data in a semi-arid
348 climate and that the PM method obtained the best and most accurate equation [23]. The same results
349 also were reported by [1]; [30] and [7]. They reported that the PM performed much better in humid
350 regions. Although, the PM has a weakness of meteorological data as compared to input demands
351 among the other models, particularly in the developing countries with the shortage of sufficient data.
352 The results of this study and their comparison with those of other researches showed that the perfect
353 selection of simple and complex methods in a region based on available meteorological data needs to
354 consider results and calibrations either by lysimetric or by PM method for precise regional practical
355 purposes because, as suggested by [21] human activity and natural factors have a certain influence
356 on the spatial variation of ETo, and a decisive role in the spatial variation character of reference
357 evapotranspiration in an investigated area.

358

359 **4. CONCLUSIONS**

360 The performance of nine ETo methods were evaluated and compared with Lysimeter measurement
361 data to choose the appropriate methods with the best results to estimate and project ETo in a semi-
362 arid climate area. The Lysimetric experiments were carried out in two years from 2012 to 2013 from
363 months of April to July. The cross correlation (R^2), slope, intercept and RMSE, MBE and t-test
364 statistical methods were used to compare the lysimeter ETo values with the ETo values computed by
365 nine different methods. The methods were ranked according to RMSE. Based on RMSE values, the
366 PM, MA and HG methods estimated the lysimeter ETo values most closely and PK and PF methods
367 had the worst results. The use of PM, MA and HG methods for ETo estimation, irrigation planning
368 and scheduling, dams reservoirs design and different surface or pressurized irrigation can help project
369 water requirement application under different crop pattern conditions in the semi-arid region under
370 study where complete weather data and only radiation and temperature records are available.

371 5. REFFERENCES

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