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Developing Pan Evaporation to Grass Reference Evapotranspiration Conversion Model A Case Study in Khuzestan Province

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Abstract: In the present study, pan evaporation data and the data required for estimating reference evapotranspiration were collected from 10 meteorological stations in Khuzestan Province using the Penman-Monteith method. Three first, second and third order polynomial models were studied for conversion of pan evaporation data to grass reference evapotranspiration with pan evaporation, wind speed and air humidity as the main variables. The results obtained from the Penman-Monteith method were used as the basis for conversion. The results showed that the second and third order polynomials enjoyed higher and equal accuracy levels. Thus, the second order polynomial was recommended for use under the conditions of Khuzestan Province as it required fewer input variables. The determination coefficient for this model was found to be 0.93, its root mean square error was 0.9 mm day^{-1} and its correlation slope was 0.98.

Key words: Evaporation pan, evapotranspiration, meteorological data, correlation model, Khuzesatn

INTRODUCTION

Evapotranspiration (ET) is one of the most important components in the natural water cycle whose precise determination is essential for water balance, irrigation, water supply planning and water resources management purposes. Actual evapotranspiration from a given vegetated surface is the product of grass reference evapotranspiration (ET_0) and a given coefficient for the special vegetative cover. Reference evapotranspiration is directly measured by a weighing lysimeter or indirectly estimated from either meteorological data or from pan evaporation. There are around 50 different methods used to estimate reference evapotranspiration, all of which often yield different results due to varying assumptions and meteorological data used in them (Grismer *et al.*, 2002). It should also be mentioned that evaporation pan has had the highest ranking in most studies carried out to compare various methods of estimating ET_0 (Raghuwanshi and Wallender (1998).

Class A evaporation pan is widely used due to its simplicity and ease of data interpretation and has come to be known as the most precise and accurate measure of reference evapotranspiration in humid areas (Irmak *et al.*, 2002). Although evaporation intensity from Class A evaporation pan is different from the evapotranspiration intensity from vegetated surfaces due to climatic differences affecting evaporating surfaces and also due to differences in their locations, a number of studies have shown a high correlation between these two intensities (Doorenbos and Pruitt, 1975). A pan coefficient (K_p) is used to relate the two intensities as follows:

$$K_p = \frac{ET_0}{E_{pan}} \qquad (1)$$

Based on the conditions of the vegetative cover and the location where the evaporation pan is installed, Doorenbos and Pruitt (1977) proposed two tables to determine K_p. One table belongs to the situation where the evaporation pan is located amid the vegetative cover and the other belongs to the conditions where the pan is installed on arid land but the vegetative cover is at a given distance. In these Tables, pan coefficient depends on distance of the vegetative cover from the evaporation pan (F), wind speed (U) and Relative Humidity (RH). The values for F are presented quantitatively but those of U and RH are presented as classifications in the Tables. At the time of proposing these Tables, no computers were available but later on when computers and data loggers were developed and when electronic data transmission became possible, automatic conversion of E_{pan} to ET_0 and the elimination of search operations became possible (Snyder, 1992). These developments led to other

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advances by researchers who used statistical regression methods to develop linear and non-linear polynomials or combinations thereof in lieu of the original Tables (Allen and Pruitt 1991; Cuenca 1989; Snyder 1992). These equations are functions of F, U and RH.

Doorenbos and Pruitt's Tables for determining K_p were based on ET_0 measurements using large weighing lysimeters in which grass had been grown up to a height of 7 to 15 cm (Snyder *et al*., 2005). More recently, however, definition of ET_0 has changed from evaporation from a grass cover as described above to the evapotranspiration estimated from Penman-Monteith equation with grass assumed to have a fixed height of 12cm, a bulk stomatal resistance of 70 s/m^{-1} and an aerodynamic resistance of $U_2/208$ in which U_2 is the wind speed at 2-meter height from ground surface (Snyder *et al*., 2005). FAO recommended the above equation as the standard equation for determining ET_0 and assessment of other estimation methods (Allen *et al*., 1998). Thus, the above-mentioned tables and equations derived thereof do not comply with new standards and, hence, it essential to develop new equations based on ET-PM equation for conversion of E_{pan} to ET_0.

Evaporation pans used in Iran are typically installed on barren land without standard vegetative cover. Some of the pans belonging to the Meteorological Organization of Iran are installed at airports. This state of affairs requires a study on the correlation between E_{pan} and ET_0 measured by these stations and the development of a model for converting E_{pan} to ET_0 using pan evaporation data, wind speed and air humidity. The present study aims to achieve these objectives.

MATERIALS AND METHODS

Sources of data: The data required for the purposes of the present study were collected from 10 meteorological stations of the Iranian Meteorological Organization in Khuzestan Province. The data covered a period of 10 years from 1990 to 2000 and included daily pan evaporation as well as the data required for the ET-PM equation (maximum and minimum air temperature, relative humidity, sunshine hours and wind speed). The days with inadequate data were removed from the records. The heights measured in the study are 2m (for air temperature and relative humidity) and 10m (for wind speed) above ground surface. To convert wind speed to a height of 2m, the logarithmic wind profile was used (Allen *et al*., 1998). Table 1 presents stations, station codes, height above sea level, average minimum and maximum daily temperatures, relative humidity and wind speed observed over the study years. It is seen that parameter averages for these stations do not have very significant differences. The average maximum and minimum annual temperatures vary from 33.5 to 35.8 and 17.0 to 22.4°C, respectively, the highest belonging to Aghajari and the lowest to Safiabad. Average relative humidity varies from 31.2 to 42.9% and average wind speed varies from 0.8 to 2.8 m sec^{-1}. Figure 1 shows the spatial distribution of the stations used in this study. These stations cover most of the farmland in central and southern Khuzestan.

Table 1: Average annual values measured at study meteorological stations

Station	Code	Height (m)	Max. temp (°C)	Min. temp (°C)	Rel. humidity (%)	Wind speed (m sec^{-1})
Abadan	AB	6.6	35.1	19.7	40.5	2.2
Ahwaz	AH	22.5	34.9	20.4	38.7	2.0
Masjed Soleiman	MS	320.5	34.3	21.2	33.3	1.5
Boustan	BO	7.8	34.2	17.9	43.4	2.6
Shushtar	SH	67.0	34.8	22.4	31.2	2.1
Safi-Abad	SA	82.9	33.5	17.0	42.9	0.8
Ramhormoz	RA	150.5	35.7	21.8	31.8	1.6
Behbahan	BE	313.0	34.9	18.6	35.0	1.1
Mahshahr	MA	6.2	34.0	19.7	42.5	2.8
Aghajari	AG	27.0	35.8	19.3	38.5	1.9

Penman-Monteith equation: The ET-PM equation recommended by FAO as the standard method of estimating ET_0 and comparison of other methods was used in this study as a variable in developing a model of converting E_{pan} to ET_0. The Equation is as follows:

$$ET_O = \frac{0.408\Delta R_n + \gamma \frac{900}{T_a + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

where, ET_0 is grass reference evapotranspiration (mm/day); T_a, air temperature (°C); U_2, wind speed at 2m height (m see^{-1}); R_n, net radiation flux at ground surface (MJ/m^2/day); e_s-e_a, saturation vapor pressure deficit (kPa); Δ slope vapor pressure curve (kPa/°C); and γ is a psychrometric constant [kPa/°C]. The relations proposed by Allen *et al.* (1998) have been used to determine the values for R_n, e_s-e_a, Δ and γ.

E_{pan} to ET_0 conversion equations: Three first, second and third order correlation models were studied for E_{pan} to ET_0 conversion. Pan evaporation, wind speed and relative humidity were used as independent variables and grass reference evapotranspiration estimated from ET_PM Equation was used as the dependent variable. The first order model was derived from linear regression of the following independent variables:

$$ET\_PAN = b_0 + b_1E_{pan} + b_2U_2 + b_3RH \quad (3)$$

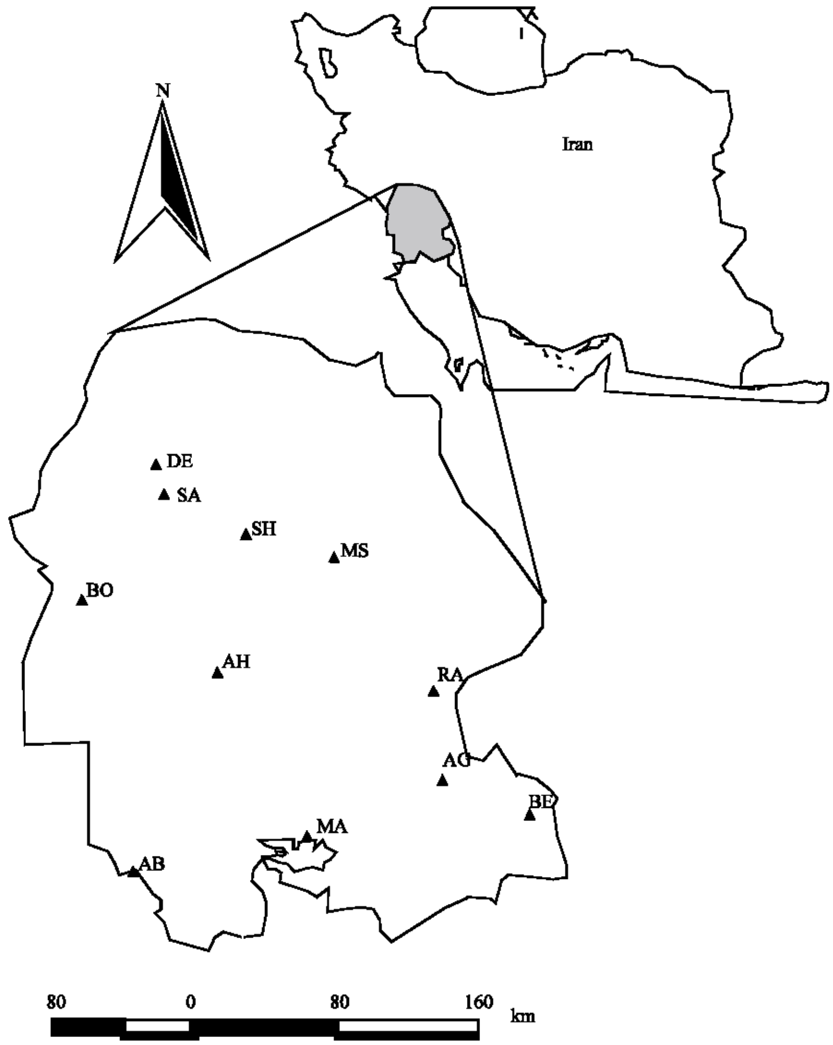

Fig. 1: Location of the study meteorological stations in Khuzestan Province

where, ET_PAN is the evapotranspiration calculated from the above relation based on E_{pan}, U and RH data and b, b_1 and b_3 are coefficients. The second order model was derived from regressions of second and third powers and the third order model was derived from the regressions of the first through to the third powers of the above independent variables. These equations have a general form along the following lines:

$$ET\_PAN = b_0 + \sum_{i=1}^{n} b_i F_i \tag{4}$$

where, F_i is the dependent variable obtained from regression of the first to third powers of the variables E_{pan}, U and RH; and n is the number of variables in the second and third order models with values of 9 and 19, respectively.

RESULTS

Grass reference evapotranspiration was estimated for all the stations used in this study using Eq. (2) and the results were compared with the evaporation pan measured values (Fig. 2). It is shown in this Figure that despite the non-standard conditions of the evaporation pan locations in the study stations, a high linear correlation holds between ET_PM and E_{pan} (R^2 = 0.77). This is due to identical effects of air temperature and solar radiation on

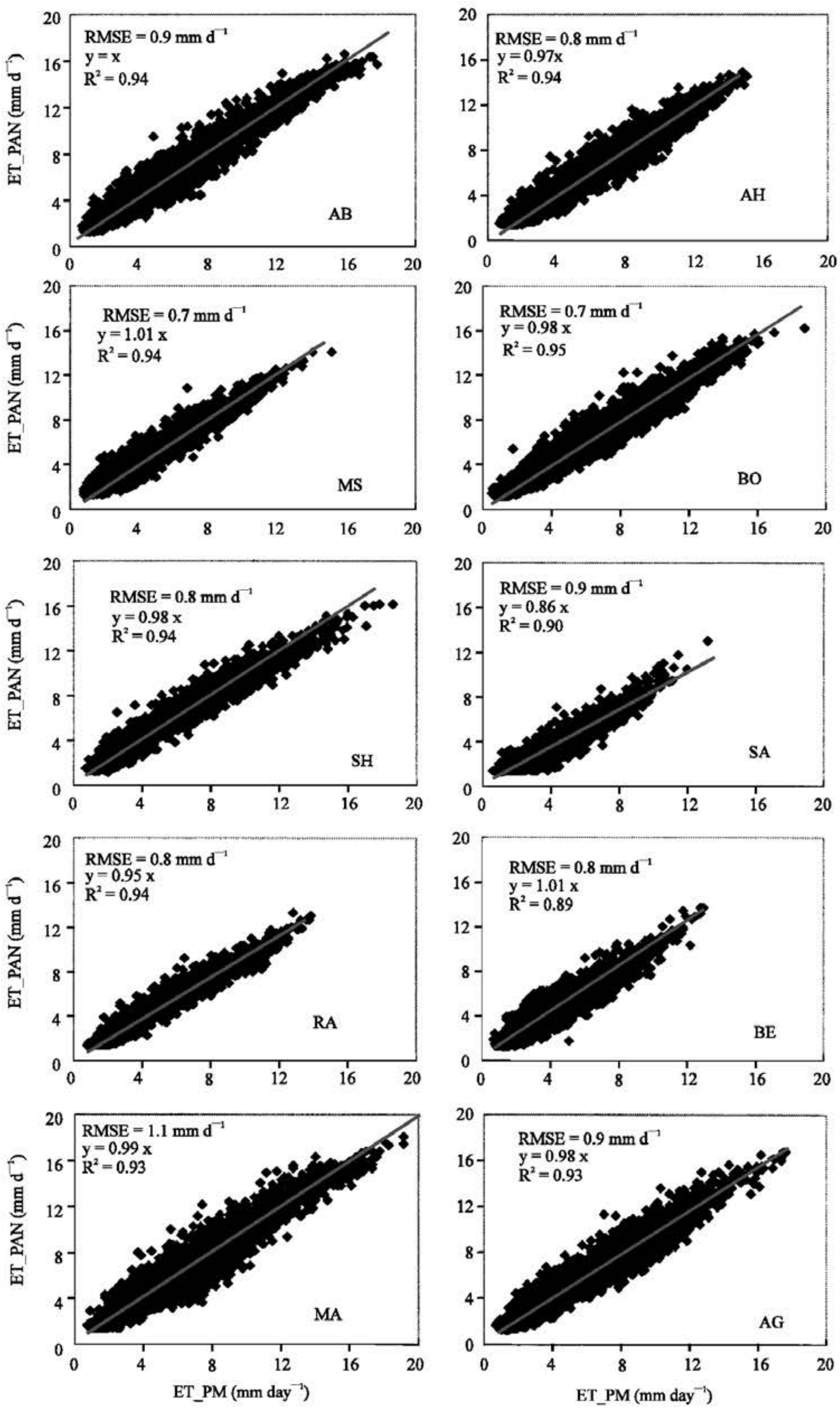

Fig. 2: Dispersion and statistical results from reference evapotranspiration values obtained form Penman-Mantieth method versus those from the proposed model

Table 2: Variables and coefficients of the third order reference evapotranspiration model

Main parameters	F_i	b_i
		$b_0 = -0.73475$
	$F_1 = E_{pan}$	$b_1 = 0.018523$
$(mm/d)^x{}_1 = E_{pan}$	$F_2 = U$	$b_2 = 0.613348$
$(m/s)^x{}_2 = U$	$b_3 = RH$	$b_3 = 1.796463$
$(\%)^x{}_3 = RH$	$F^4\ E_{pan}{}^3$	$b_4 = 0.000189$
$ET\_PAN = b_0 = +\sum_{i=1}^{14} b_i F_i$	$F_5 = E_{pan}{}^2 RH$	$b_5 = 0.000115$
	$F_6 = RH^2\ U$	$b_6 = 0.000303$
	$F_7 = RH^2\ E_{pan}$	$b_7 = -7.8E-05$
	$F_8 = U^2\ E_{pan}$	$b_8 = -0.007$
	$F_9 = E_{pan}{}^2$	$b_9 = -0.02542$
	$F_{10} = E_{pan}\ RH$	$b_{10} = 0.0022497$
	$F_{11} = E_{pan}\ U$	$b_{11} = 0.7717$
	$F_{12} = RH\ U$	$b_{12} = -0.04789$

Table 3: Statistical results from E_{pan} to ET_0 conversion models

Model	Determination coefficient R^2	Correlation slope	Root mean square Error (mm day^{-1})
First order	0.88	0.97	1.2
Second order	0.93	0.98	0.9
Third order	0.94	0.98	0.8

both reference evapotranspiration and pan evaporation. The coefficient obtained (0.77) indicates that the combination of air temperature and solar radiation alone account for 77% of the evaporation process taking place. This observation means that factors other than temperature and solar radiation must also be included when developing a reference evapotranspiration model based on evaporation pan data. In this study, we also included wind speed and relative humidity.

Using SPSS, the coefficients for first, second and third order models were estimated. Those input variables which were not significant at 0.05 were eliminated from the model (second and third order models) using the step-by-step method. The effect was reduction input variables to 5 for the second order model and to 12 in the case of the third order model. Table 2 presents the coefficients for the third order model. The results from the first and second order models were as follows:

$$ET\_PAN = 3.104 + 0.271E_{pan} + 0.953U - 0.050RH \quad (5)$$

$$ET\_PAN = -0.008E_{pan}{}^2 + 0.453E_{pan} - 0.0054U^2 + 2.258U - 0.026U \cdot RH + 0.021 \quad (6)$$

The statistical results obtained from the as one models are presented in Table 3. The it is seen (Table 3) that the second and third order models yield better results compared to the first order model but no significant differences are observed between the second and third order models. Therefore, the second order model with fewer variables is recommended as the one superior to others for E_{pan} to ET_0 conversion in Khuzestan region. The determination coefficient for this model is 0.93 and its root mean square error is 0.9 mm day^{-1}. The application of this model to all study stations yielded almost identical results such that the determination coefficient in all cases varied from 0.89 to 0.95, correlation slope passing through the intercept of coordinates varied between 0.86 and 1.01 and root mean square error ranged between 0.7 to 1.1 mm day^{-1}.

CONCLUSIONS

In the present study, pan evaporation values from meteorological stations without vegetative cover in khuzestan Province were compared with results from Penman-Monteith grass reference evapotranspiration. The results showed that despite the differences in conditions between the pan evaporation and reference evapotranspiration, a high correlation holds between these types of evaporation (R^2 = 0.77) and that if other effective parameters are introduced into polynomial correlation models, improved estimations of reference evapotranspiration will be possible on the basis of pan evaporation data. For this purpose, three first, second and third order polynomials were studied with pan evaporation, wind speed and air humidity as the main variables. The second and third order models showed higher accuracy levels but regarding the fact that the two models yielded almost similar results, the second order model was recommended for the conditions in Khuzestan on the grounds that this model required fewer input variables.

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