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Районирования территории и оценка репрезентативности расчетных методов величины эвапотранспирации для условий аридного климата

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© Махмуд Мохамед Али Абдель-Азим, Али Габер Махмуд
 Университет Файюма, г. Файюм, Арабская Республика Египет

Аннотация. Эталонная эвапотранспирация (ET_o) является жизненно важным фактором в управлении водными ресурсами и их планировании. Для различных климатических регионов и по имеющимся данным разработаны различные методы оценки. Поэтому надежность таких методов зависит от климатических условий. В настоящем исследовании оцениваются четыре метода, основанные на температурных данных: методы ФАО Блэйни-Кридла (BC), Тюрка, Дженсен-Хейза (JH) и Харгривза (HG), и два метода, основанных на радиационном балансе: ФАО-радиация (FAO-rad) и Пристли-Тейлора (PT) по сравнению с методом ФАО-РМ. Оценка проводилась для аридных условий Ливии. Для выбора наилучшего метода определения величины ET_o были рассчитаны процентная ошибка оценки (PE), среднеквадратичная ошибка (RMSE) и средняя ошибка смещения (MBE). Полученные значения ET_o (FAO-PM и среднеемесячное значение наилучших оценок величины ET_o) были использованы для составления карт пространственной изменчивости ET_o с помощью метода Кригинга. Статистический анализ полученных результатов показал, что уравнение Тюрка хорошо подходит для северной части исследуемой территории, которые включают территории в Налуте, Зуаре, Мосрате, Сырте, Шахате, Дерне, Тюрбюке, Хоне, Гале и Гагбубе. Для южной части исследуемой территории подходят следующие зависимости: уравнение HG для Опари и Тазибру, уравнение BC для Куфры и Гадамеса, уравнение FAO-Rad для Себхи; уравнение JH для Гхаты.

Ключевые слова. Эвапотранспирация, аридный климат, метод Пенмана-Монтейта (FAO-PM), кригинг.

Mapping and evaluation of reference evapotranspiration methods under arid conditions

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© Mahmoud Mohamed Ali Abdel-Azim, Ali Gaber Mahmoud
 University Of Fayoum, Arab Republic of Egypt

Abstract. Reference evapotranspiration (ET_o) is a vital factor in water resources managing and planning. Various estimation methods have been developed for different climatic regions and according to the available data. Therefore, the reliability of such methods depends upon climatic conditions. The present investigation evaluates four temperature based methods: FAO Blaney-Criddle (BC), Turc, Jensen-Haise (JH) and Hargreaves (HG), and two radiation based methods: FAO-radiation (FAO-rad) and Priestley-Taylor (PT) in comparison with the FAO-PM method under arid conditions of Libya. In order to select the best ET_o method, the percentage error of estimate (PE), the root mean square error (RMSE), and mean bias error (MBE) were calculated. The obtained ET_o values (FAO-PM and the average of best-estimated monthly ET_o) were utilized to generate spatial distribution maps of ET_o with the aid of Kriging technique. Statistical analysis of the obtained results revealed that, Turc equation fitted well for the northern part of the study area, which include Nalut, Zuara, Mosrata, Sirt, Shahat, Derna, Tubruk, Hon, Galo and Gagbub. While for southern zone, HG equation performed better for Opari and Tazirbu, BC equation for Kufra and Ghadames, FAO-Rad equation for Sebha; and JH equation for Ghat.

Keywords. Evapotranspiration, arid climate, FAO Penman-Monteith method (FAO-PM), kriging

Introduction. Reference evaporation processes in a soil-plant evapotranspiration (ET_o) is the system (Tabari et al., 2011). ET_o has a synchronized transpiration and great importance in irrigation scheduling,

together with climatological and hydrological studies (Sentelhas et al., 2010). Several methods have been developed to estimate ET_o and they vary in required climatic-data. For many regions and climatic conditions, the Penman-Monteith method (P-M) has proved to be the best method and gives consistent ET_o values (Allen et al. 2005, 2006). Thus, it is widely applied in various fields, among which are agronomy and irrigation management (Alexandris et al. 2006; Landeras et al, 2008; Du, et al., 2010; Hassanli, et al., 2010; Sentelhas et al. 2010).

In case of limited data required for P-M method, especially in the developing countries, significant attention has been paid to the evaluation of simple ET_o methods and their application. The FAO-Penman-Monteith method (P-M) has proved of superior performance (Jensen et al. 1990; Allen et al. 1998; Abdelhadi et al., 2000; Hargreaves and Allen 2003; LopezUrrea et al., 2006; Gavilan et al., 2007; Trajkovic and Kolakovic, 2009; Martinez Thepadia, 2010). Therefore, the P-M method was used in this study to evaluate the reliability of the other ET_o estimating methods. P-M method uses temperature, relative humidity, wind speed and solar radiation/sunshine to estimate ET_o . The main limitation of the P-M method is the necessity for various weather data parameters (i.e., air temperature, humidity, wind speed, and solar radiation) which might be not available. Such limitation may exist particularly in developing countries (Droogers and Allen, 2002; Gocic and Trajkovic 2010; Maeda et al. 2011; Tabari et al. 2011). This is because of the difficulties in setting-up of weather stations, their maintenance and expenses (Sentelhas et al. 2010). One way to overcome such problem, is to utilize the ET_o equations that require fewer meteorological parameters, several methods are developed to estimate ET_o . But the simpler methods might give inconsistent ET_o values (George et al., 2002; Xu and Singh, 2002; Lu et al., 2005; Temesgen et al., 2005; Nandagiri and Koor, 2006). Therefore, simpler equations must be evaluated against the P-M method or lysimetric measurements in order to find out the most suitable ET_o method for each region where weather data are inadequate to apply the P-M method (Trajkovic and Kolakovic, 2009).

The present work was carried out to assess the performance of six simple ET_o methods that require less readily available data against the P-M method in order to select the most suitable method to estimate ET_o values in Libya. Maps representing the distribution of the ET_o values and their relation to elevation above sea level is performed.

Materials and methods. The present investigation was carried out in the country of Libya (area of 1,760,000 km²) with a Mediterranean Coastline of nearly 1,800 kilometers. Seventeen meteorological stations were selected to represent the different regions of the country. Figure 1 shows the distribution of chosen stations (as a point map); the geographic characteristics of these stations are presented in Table 1.

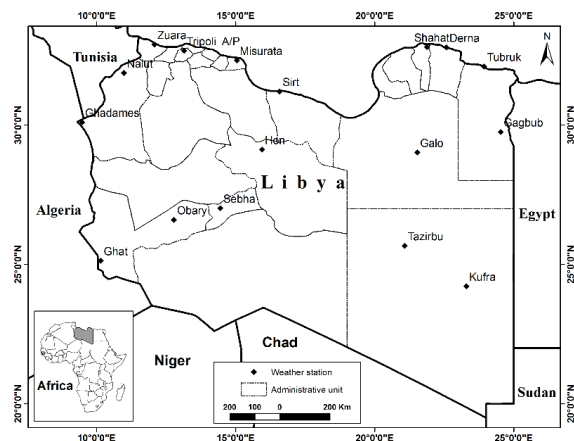


Figure 1. Study area and location of the weather stations.

The climatic data of the study area showed that the monthly mean-temperature varies from 12 to 30 °C. While the relative humidity ranges between 15 to 60 % (Figure 2).

Reference evapotranspiration (ET_o) calculations. Seven different methods were used to estimate (ET_o) at the studied seventeen locations. Applied methods were classified into their major methods as follows; a) one combination method [1- FAO 56-Penman-Monteith (PM)], b) four temperature methods [2- FAO Blaney-Criddle (BC), 3- Turc, 4- Jensen-Haise (JH) and 5- Hargreaves (HG)]; c) two radiation methods [(6- FAO radiation (FAO-Rad), and 7- Priestley Taylor (PT)].

Table 1
Location, elevation, latitude and longitude of the studied meteorological stations

Station Name	Elevation (m) (Above sea level)	Latitude (Degrees and Minutes)	Longitude (Degrees and Minutes)
Nalut	621	31° 52'	10° 59'
Zoara	3	32° 53'	12° 05'
Tripoli	81	32° 40'	13° 09'
Mosrata	32	32° 19'	15° 03'
Sirt	13	31° 12'	16° 35'
Shahat	649	32° 48'	21° 53'
Derna	26	32° 47'	22° 35'
Tubruk	50	32° 06'	23° 56'
Ghadame	346	30° 06'	09° 29'
s	432	27° 01'	14° 27'
Sebha	263	29° 07'	15° 57'
Hon	45	29° 01'	21° 32'
Galo	01	29 45'	24° 32'
Gagbub	463	26° 36'	12° 47'
Opari	692	25° 08°	10° 09'
Ghat	261	25° 40°	21° 05'
Tazirbu	436	24° 13°	23° 18'
Kufra			

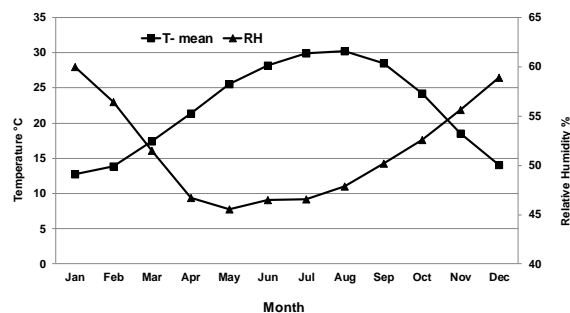


Figure 2. Average mean temperature and relative humidity in Libya.

The combination methods for *ETo* estimation depends upon recorded temperature, relative humidity, wind speed and solar radiation or sunshine. If such data are available, the P-M method ranked the first to estimate (*ETo*) between all other combination methods. As mentioned above, FAO 56-PM method was selected in this study to be the reference method. The equations of each method are presented in Table 2

Table 2
Methods and equations used to estimate reference evapotranspiration (*ETo*)

Method	Equation	Explication
Combination_method		
FAO 56-PM	$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{(T_{mean} + 273)} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$	T_{max} : maximum air temperature. T_{min} : minimum air temperature. u_2 : wind speed. R_n : net radiation. R_s : solar radiation. n : actual Daily Sunshine duration (hours). N : maximum possible daily sunshine hours. e_a : actual vapor pressure. e_s : saturation vapor pressure (kPa). $e_s - e_a$: saturation vapour pressure deficit [kPa].
Temperature methods		
BC	$ET_o = a + b_p * P(0.46T + 8.13),$ $a = 0.0043.RH_{min} - n/N - 1.41$	RH_{min} : minimum relative humidity.
TURC	$ET_o = 0.013 \frac{T_{mean}}{(T_{mean} + 15)} (R_s + 50)$ if $RH > 50\%$ $ET_o = 0.013 \frac{T_{mean}}{(T_{mean} + 15)} (R_s + 50) \left(1 + \frac{(50 - RH)}{70}\right)$ if $RH < 50\%$	
JH	$ET_o = C_T (T - T_x) R_s$	
HG	$ET_o = 0.0023 R_A \sqrt{TD} (T_{mean} + 17.8)$	
Radiation_methods		
FAO-Rad	$ET_o = a + b \left(\frac{\Delta}{\Delta + \gamma} R_s \right)$	Δ : slope vapour pressure curve [kPa °C ⁻¹]. γ : psychrometric constant [kPa °C ⁻¹].
PT	$ET_o = \alpha \frac{1}{\lambda} \frac{\Delta}{(\Delta + \gamma)} (R_n - G)$	

Statistical analysis. In order to evaluate *ETo* values using the different methods in comparison with FAO P-M method. Data of all methods were tested on basis of the following statistical parameters (El-Mageed, T.A.A. and El-Wahed, M.A., 2014).

Percentage error of estimates (PE) calculated by the following equation:

$$PE = \frac{ETo \text{ values calculated by different methods}}{ETo \text{ value calculated by P-M method}}$$

To evaluate The *RMSD* criterion was used to compare the estimated *ETo* values by different methods and P-M *ETo* method. The *RMSD* was selected as an appropriate ranking criterion because of the fact that this statistical parameter indicates the ability of equations and adjusted equations to accurately estimate reference evapotranspiration during all months (Trajkovic and Kolakovic, 2009:

$$RMSD = \left[\frac{(\sum_{i=1}^n [PM(ETo) - ETo_{estimated}]^2)}{n} \right]^{0.5}$$

where *n* – total number of observations.

Mean bias error (*MBE*):

$$MBE = \frac{\sum_{i=1}^n [PM(ETo) - ETo_{estimated}]}{n}$$

$$MBE = \frac{\sum_{i=1}^n [PM(ETo) - ETo_{estimated}]}{n}$$

According to these statistical parameters, the criteria used to select the best method is to have the smallest

absolute deviation value. The criteria applied to select the more suitable method was associated with the smallest absolute deviation value obtained.

GIS application. Elevation Data. The digital elevation model (DEM) used in this study is the SRTM (NGA SRTM «finished» 3arcsec) data, which was retrieved freely from <https://lpdaac.usgs.gov>. Then, it was clipped to the boundary of the study area.

Geostatistical analysis. Kriging analysis was applied to generate the *ETo* maps of the study area. Where the point map of the stations was utilized in geostatistical analysis to generate spatial distribution maps of *ETo*. Where one map was generated to represent the *ETo* values of the P-M method. On the other hand, the estimated *ETo* values for each station based on the relevant best-method were used to generate *ETo* map for the study area.

Results and discussion. *Evaluation of estimation methods.* For the studied stations, the monthly *ETo* values were estimated using the tested seven equations. Then, the obtained values from the six simple *ETo* method were compared with that values of P-M method. The calculated statistical parameters i.e., *PE*, *MBE* and *RMSD* for all methods in each station as compared to the P-M method are given in Table 3.

Table 3

Summary statistics of PE, MBE and RMSD and best *ETo* estimation method for the studied locations

Station	Best method:					
	Based on PE	PE	Based on RMSD	RMSD	Based on MBE	MBE
Nalut	Turc	1	BC	0.46	Turc	0.02
Zoara	Turc	1.01	HG	0.20	Turc	-0.05
Tripoli	HG	1.01	Turc	0.42	HG	-0.05
Mosrata	PT	0.98	Turc	0.21	PT	0.07
Sirt	Turc	1.01	Turc	0.22	Turc	-0.03
Shahat	Turc	1.01	Turc	0.07	Turc	-0.01
Derna	PT	0.99	Turc	0.35	PT	0.04
Tubruk	Turc	1.02	Turc	0.21	Turc	-0.09
Ghadames	BC	1.02	BC	0.41	BC	-0.10
Sebha	FAO-Rad	1	FAO-Rad	0.33	FAO-Rad	0.02
Hon	Turc	1.01	Turc	0.45	Turc	-0.05
Galo	Turc	1.02	Turc	0.49	Turc	-0.11
Gagbub	BC	1	HG	0.20	BC	0.00
Opari	HG	1.07	HG	0.37	HG	-0.35
Ghat	Turc	1.05	Turc	0.60	JH	0.16
Tazirbu	HG	1.1	HG	0.49	HG	-0.48
Kufra	BC	1.03	FAO-Rad	0.45	BC	-0.21

As shown in Table 3, most of the best methods exceeded *ET_o* values estimated by the P-M method. The overview of all results revealed that the

Turc and B-C methods perform better among the stations. The selection of the best method was done according to the values of *PE*, *MBE* and *RMSD* statistical parameters. Thus, for each station, the method having best values in two or three statistical parameters were assigned as the best method. Furthermore, generally, the study area could be divided into two zones; Northern and Southern ones (Figure 3).

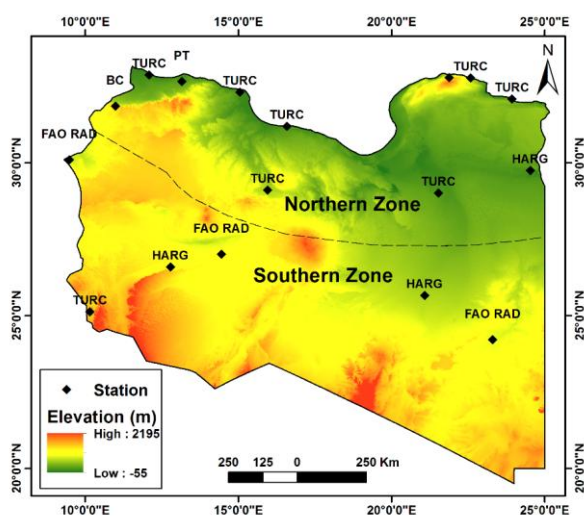


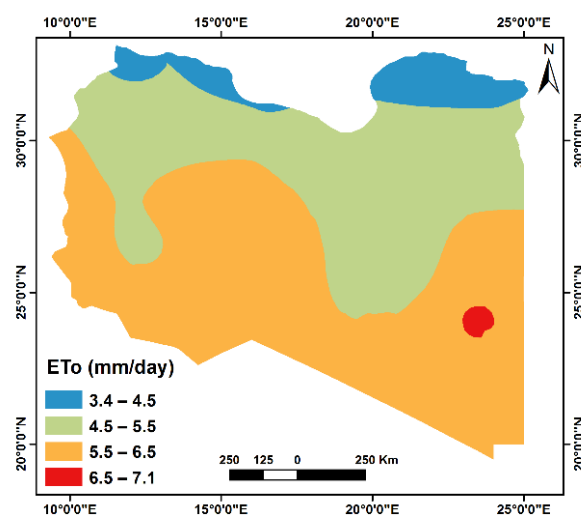
Figure 3. *ET_o* zones and the best *ET_o* methods overlaid on DEM of the study area

(A) Northern zone: which extended from the coastal line towards south including the following locations: Nalut, Zuara, Mosrata, Sirt, Shahat, Derna, Tubruk, Hon, Galo and Gagbub where the best method was Turc, while for Tripoli the best method was HG.

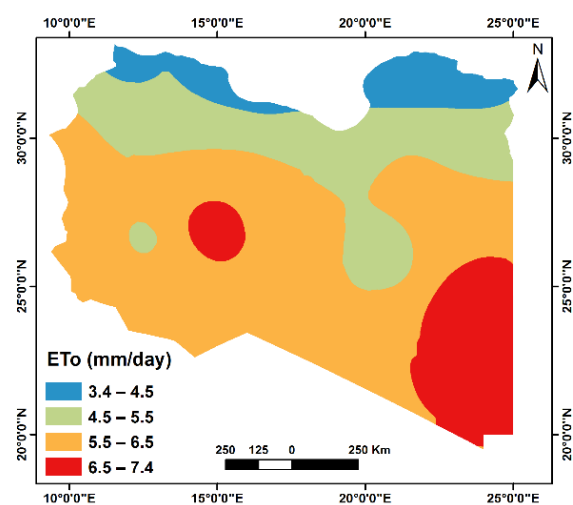
(B) Southern zone: as for Opari and Tazirbu, the best method was HG; BC for Kufra and Ghadames; FAO-Rad for Sebha; and JH for Ghat. The poor performance of the J- H method obtained in this study is in a good agreement with the results found in Serbia (Trajkovic and Kolakovic 2009), Florida (Irmak et al. 2003a, b) and Iran (Tabari et al. 2011).

ET_o Mapping. Values of evapotranspiration estimated by the P-M method and by the best method for each station were interpolated using ordinary kriging to generate *ET_o* maps of the study area, Figure 4. As shown in Figure 4a, the *ET_o*

value ranges from 3.4 to 7.1 (mm day⁻¹), while in case of the best methods (Figure 4b) *ET_o* ranges between 3.4 and 7.4 (mm day⁻¹), and generally, *ET_o* value increases from north to south. This could be resulted as the distribution of mean air-temperature that also increases towards south.



a



b

Figure4. Spatial distribution of *ET_o* (mm day⁻¹) in the study area: a – using P-M method; b – most reliable estimation method for each station

Conclusion

Seven methods were applied to estimate reference evapotranspiration using weather data from seventeen stations separated at whole Libya. The FAO P-M method was used as the standard of comparison for evaluating the other six methods for all stations. It was concluded that there are two regions

of different climatological characteristics namely: Region (1): Nalut, Zuara, Mosrata, Sirt, Shahat, Derna, Tubruk, Hon, Galo and Gagbub where the most reliable method was Turc. Region (2): Opari and Tazirbu with HG as best method, BC for Kufra and Ghadames, FAO-Rad for Sebha; and JH for Ghat. Furthermore, the estimated *ET_o* values by P-M method and by the best method for each location were interpolated to generate *ET_o* maps of the study area which could be employed in various decisions at regional scale. Finally, realized *ET_o* equations can be used according the meteorological data availability for each region.

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Дополнительная информация

Сведения об авторах:

Махмуд Мохамед Али Абдель-Азим, кандидат технических наук; кафедра агроинженерии факультета сельского хозяйства; Университет Файюма; г. Файюм, Арабская Республика Египет; e-mail: mma12@fayoum.edu.eg.

Али Габер Махмуд, кафедра почвоведения и водных ресурсов факультета сельского хозяйства; Университет Файюма; г. Файюм, Арабская Республика Египет.



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Additional Information

Information about the authors:

Mahmoud Mohamed Ali Abdel-Azim, candidate of technical sciences, Agricultural Engineering Department, Faculty of Agriculture; University Of Fayoum; University zone, Fayoum, Arab Republic of Egypt; e-mail: mma12@fayoum.edu.eg.

Ali Gaber Mahmoud Soil and Water Department, Faculty of Agriculture; University Of Fayoum; University zone, Fayoum, Arab Republic of Egypt.



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