Estimation of Evapotranspiration Using Different Climate Models: A Case Study in Semi-arid Region-Libya

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Abstract

Evapotranspiration (ET) has a critical role in agricultural activity, water management and hydraulic engineering. Estimation of Evapotranspiration in arid and semi-arid regions, in particular, Libya is a very crucial issue. This paper aim to evaluate ET using three climate models (FAO-Penman-Monteith (P&M), Hargreaves-Samani and Penman). The daily and monthly meteorological data were collected from the year 2004 and 2005 from the study area. The measured meteorological variables include daily observations of air temperature, relative humidity, and wind speed. The statistical analysis was undertaken to verify the accuracy of the studied models. The results of the Hargreaves-Samani and Penman models are compared with FAO-Penman-Monteith model. Based on the model testing the statistical analysis show that the Penman model gave a better estimation than Hargreaves-Samani model.

Key words: *Evapotranspiration, modeling, semi-arid region, statistical analysis and Libya.*

1. Introduction

Water resource managers are faced with the great challenge of scarcity. Scarcity is increasingly becoming the most important environmental constraint limiting plant growth in many regions. For example, over 30 countries in arid and semi-arid regions are expected face water scarcity in 2025 [1]. This will consequently slow development, threaten food supplies, and aggravate rural poverty [2]. As a result of growing populations, the demand for irrigation and drinking water is expected to increase by 20% over the next 25 years [3]. Since most developing countries' economies depend on agriculture, a shortage of fresh water can lead to food shortages in several regions of the world. In addition, improper management of water resources has reduced crop production to a large extent, damaged soil texture considerably, and precipitated the rate of water usage [4].

The green revolution and the rise in global food production between the 1960s and 1980s to a great extent caused expansion in the world's irrigated areas; from 140 million hectares to 240 million hectares [5]. Up to one third of the world's food is now produced on the 17% of the world's irrigated croplands. Today there are around 250 million hectares of irrigated land, approximately three quarters of it in developing countries. A half of the world's irrigated land is located in China, India, the United States of America and Pakistan, while the other two thirds of all food are produced in rained area (1,250 million hectares) [6].

The crop water requirement can be defined as the amount of water that must be provided throughout the various stages of growth to achieve the maximum productivity under specific environmental conditions and prevailing agricultural practices. Evapotranspiration (ET) is often the most important, especially in arid and semi-arid regions. Therefore, it plays the main role in many hydrological aspects, such as irrigation design and water resource management. Evapotranspiration is the total amount of water lost via plant transpiration and soil evaporation per unit soil area where a crop is growing [7]. The success and sustainability of irrigation operation essential depends on the correct estimates of consumption of water for crops planted. The exact estimate for ET rates depends largely on the availability of data for different climatic factors which involved in the calculation process.

Direct measurements of ET around the world are rarely used put apply to provide an opportunity to improve the quality of ET which has collected by different hydrologic model [8] because direct measurement of ET implement by high-cost meteorological techniques. Veihmeyer from University of California had represented data and information on crop evapotranspiration, using the gravimetric method [9]. For the past 50 years, almost 700 registered empirical methods for different weather had been used by scientist to determine ET [7]. These methods widely express the amount of ET by a mathematical formula [10] , such as Penman, Food and Agriculture Organization (FAO) Penman-Monteith, Blaney-Criddle, Hargreaves-Samani, Turc, Makkink, Penman-Monteith (P&M), Priestley-Taylor, and Thornthwaite can be used at varying locations and climatic conditions [11].

Different factors which always affect ET are: weather parameters, crop factors and management and environmental conditions [7]. Due to the mutual dependence of these factors and variability in different part of earth surface, it is difficult to introduce an equation that can calculate ET under different weather parameters [12]. Another difficulty in calculation of ET is the lack of accurate and precise raw data from various sites in the study area. Most of the sites do not have continuously measured climate data for basic weather parameters The uncertainty in these parameters can lead to significant errors in the estimated ET [13].

The objective of this study was to examine two ET estimation methods (Hargreaves-Samani and Penman) and compared with the FAO-PM method. The FAO-PM method was chosen for comparison in this study because there were no measured ET data in the study area.

2. Materials and Methods

2.1 Study Area Descriptions

The study area is located within the semi-arid zones which the annually rate of rain is no more than 150 mm [14]. It stretches on the northern coast of Central Libya and located 10 km south east of the City of Sirte, and adjacent to the coastal highway. The location was chosen as the study area because it represents the most important area that contain many of the irrigated agriculture projects. In this study, Algardabiya Reservoir was chosen as a study reservoir in a semi-arid region. The study area (Sirte-Libya, 31^{o} 09' 30.71" N; 16^{o} 40' 58.02" E, 50 m.a.s.l) is a part of the Man-made River Project as shown in Figure 1.

Figure 1. The Location of the Study Area in Sirte, Libya

Meteorological data for the study area was acquired from the Meteorological Observatory of the Man-made River Authority, Sirte, Libya, and used to estimate evapotranspiration. The meteorological data included daily values for two consecutive years (2004-2005) of maximum and minimum air temperature, relative humidity, wind speed, and solar radiation. Two years of daily meteorological data were obtained from weather station records 2004 and 2005 were used to study the evapotranspiration. Table 1 shows the various meteorological data and their descriptive statistics collected from study area.

Table 1: Descriptive statistics of the study area

Variables	**Units**	**Minimum**	**Maximum**	**Mean**	**SD**
Max T	^{o}C	4	41	25.8	6.6
Min T	^{o}C	3	25	15.1	5.5
Ave T	^{o}C	18	19	18.6	0.3
WS	km/hr	5	50	15.2	7.8
RH	%	30	97	62	12
Rs	$(MJ/m^2/d)$	18.1	19.2	18.7	0.2

2.2 Evapotranspiration Models

2.2.1 FAO Penman-Monteith Model

The FAO-P&M model is described as [7]:

$$ET_{FAO-PM} = \frac{(0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a))}{(\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where:

R_n = The net radiation at the crop surface (MJm^{-2} day^{-1}), G = The soil heat flux density (MJm^{-2} day^{-1}), T = The mean daily air temperature at 2 m height (°C), U_2 = The wind speed at 2 m height ($m\ s^{-1}$), e_s = The saturation vapor pressure (kPa), e_a = The actual vapor pressure (kPa), e_s-e_a = The saturation vapor pressure deficit (kPa), Δ = The slope of the vapor pressure curve ($kPa°C^{-1}$), G = The psychometrics' constant ($kPa\ °C^{-1}$)

2.2.2 Hargreaves-Samani Model

Hargreaves-Samani derived a model which requires meteorological data to estimate evapotranspiration. This model is described as [15]:

$$ET_{HGS} = 0.0023R_a(T_{mean} + 17.8)(T_{\max} - T_{\min})^{0.5} \quad (2)$$

Where:

T_m = Daily mean air temperature (°C), T_{max} = Daily maximum air temperature (°C), T_{min} = Daily minimum air temperature (°C), R_a = Extraterrestrial radiation

2.2.3 Penman Model

Penman [16] presented theory and a method for the estimation of evapotranspiration from meteorological data. The Penman formula can be written as follows:

$$ET_{PEN} = \frac{\Delta}{\Delta + \gamma} \times R_n + \frac{\gamma}{\Delta + \gamma} \times f(u)\, D \tag{3}$$

The variables in Equation (3) from readily available data as recommended by [17,7] are as follows:

$$\Delta = 4098\, e_s / (237.3 + T_a)^2 \tag{4}$$

$$\gamma = 0.00163 \frac{P}{\lambda} \tag{5}$$

$$R_n = R_s(1 - \alpha) \tag{6}$$

$$\lambda = 2.501 - T_a\, 2.361 \times 10^{-3} \tag{7}$$

$$f(u) = 2.62\,(1 + 0.536\, u_2) \tag{8}$$

$$e_a = 0.6108 \times \exp\left[\frac{17.27\, T_a}{T_a + 237.3}\right] \tag{9}$$

$$e_s = e_a / RH \tag{10}$$

Where:

T_a (°C) is the average air temperature, P (kPa) is the air pressure; λ is the latent heat of vaporization (MJ/kg); R_s (MJ/m^2/d) is the incoming solar radiation; α is the reflection coefficient or albedo constant; u_2 (m/s) is the wind speed at 2 m height; and RH (%) is the relative humidity.

2.3 Statistical Analysis

The performance of each model was studied by evaluating its statistical performance. To ensure a rigorous comparison of the models, an extended analysis was performed using different statistical indices of the estimated values. The three most widely used statistical indicators in estimation models are the coefficient of determination R^2, the root mean square error (RMSE) and the mean bias error (MBE) [17,18]. The above statistical indicators used are defined as:

$$R^2 = \frac{ET_o - ET}{ET_o} \tag{11}$$

$$ET_o = \sum_{i=1}^{n} \left(ET_{i,FAO} - ET_{mean}\right)^2 \tag{12}$$

$$ET = \sum_{i=1}^{n} \left(ET_{i,FAO} - ET_{i,pred}\right)^2 \tag{13}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n} \left(ET_{i,pred} - ET_{i,FAO}\right)^2\right]^{1/2} \tag{14}$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n} \left(ET_{i,pred} - ET_{i,FAO}\right) \tag{15}$$

where:

$ET_{i,FAO}$ is the FAO-P&M evapotranspiration, mm/day, $ET_{i,pred}$ is the predicted evapotranspiration from Penman and P&M model, mm/day , ET_{mean} is the mean evapotranspiration, and n is the number of data pairs.

3. Results and Discussion

To examine the climate models in the study area, a total of 730 data (2004 to 2005) was used. The performances of Hargreaves-Samani and Penman models against FAO-P&M model were evaluated using RMSE, MBE and R^2 statistical parameters and the results are presented in Table 2. The RMSE values ranged from 4.65 to 3.45 mm/day, the smaller RMSE value indicates a better model performance according to Willmott [18] and Jacovides and Kontoyiannis [19]. From Table 2 RMSE values indicate that Penman model consistently produced the most appropriate evapotranspiration estimation for the study area.

The MBE values ranged from – 4.37 to 1.07 mm/day (Table 1). Positive value indicates overestimation of evapotranspiration from the study area and vice versa. The MBE values indicate that the overall evapotranspiration estimates by Hargreaves-Samani model was underestimation while Penman model was overestimation during the study period. Based on the MBE values (Table 2) the penman model performed best since the MBE value is the lowest (sign considering over or under estimation).

Furthermore, Table 2 shows the coefficient of determination R^2 for the three models. For example the value of R^2 between the estimated evapotranspiration from the study area using Hargreaves-Samani and Penman models are 0.61 and 0.75 respectively. So the Penman model is the best predicted evapotranspiration among selected models.

Table 2. Statistical Analysis of the Model

Model	RMSE	MBE	R^2
Hargreaves-Samani	4.65	-4.37	0.61
Penman	3.45	1.07	0.75

4. Conclusions

Evapotranspiration in semi-arid region, i.e. Libya was estimated by three most commonly used models. The selected models were the FAO-Penman-Monteith, Hargreaves-Samani and Penman. Two years of daily meteorological data (2004-2005) were used. The outputs of last two models were compared to the FAO-Penman-Monteith model. Statistical measures such as the Root Mean Square error (RMSE), the Mean Bias Error (MBE) and coefficient of determination (R^2) were used to evaluate the performance of the selected models. Based on the tests, the Penman model performed best with RMSE of 3.45 mm/d and absolute MBE of 1.07 mm/d and R^2 of 0.75. The Penman model produced the better reliable estimates of evapotranspiration in study area .

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