A method to calculate evaporation and evapotranspiration in Iraq

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सार — स्थितिक वाष्पोत्सर्जन, स्वतंत्र सतह जल वाष्पन और पैन वाष्पन के परिकलन के लिए एक विधि को प्रस्तुत किया गया है। इन प्राचलों के प्राप्त मूल्यों का उपलब्ध वास्तविक मापों के साथ अल्प सार्थक सह-संबंध और सही मेल दिखाई पड़ता है। इन प्राचलों के लिए अन्य विभिन्न अनुभूति मूलक सूत्रों से प्राप्त मूल्य वास्तविक मापों की अपेक्षा अधिक उच्च पाये गए हैं।

ABSTRACT. A method is presented to calculate potential evapotranspiration (PE), free surface water evaporation (E_0) and pan evaporation (EPAN). The values of these parameters obtained show highly significant correlation and good agreement with the available actual measurements. The values obtained for these parameters by other different empirical formulae are found to be higher than the actual measurements.

1. Introduction

Potential evapotranspiration (PE) is a principal parameter in the calculation of the water available for plants. Generally, there are very few direct measurements of potential evapotranspiration. For this reason, empirical or semi-empirical formulae are being used (Gangopadhyaya *et al.* 1965). These formulae are based on some meteorological parameters, like global radiation and duration of sunshine (which are available only at three locations for the whole of Iraq, namely, Baghdad, Basrah and Mosul). Data of these three stations are not enough to represent PE over Iraq and similar data are not available for other stations. Also, methods like that of Penman (1948) contains some constants which are valid for the places. They were originally derived for and are not necessarily valid for Iraq because of the different geographic and climatic conditions.

Kettaneh *et al.* (1974) used some of the constants derived for Jodhpur in India (Gangopadhyaya *et al.* 1969) with a climate similar to that of Iraq when calculating the PE by Penman's formula.

In the above study a conversion factor is used to convert the PE values obtained by the Thorthwaite's method to the corresponding values obtained by the Penman's method for those stations which do not have enough meteorological data.

Abou-Khalid and Al-Hassani (1982) calculated (PE) for four sites, namely, Baghdad Air port, Abu-Ghraib,

Khalis project and El-Wahda station using meteorological data also. They applied the original Penman's formula, the Blaney and Criddle (1950), the modified Blaney-Criddle method (Kharrufa *et al.* 1980) and the modified formula of Blaney-Criddle by FAO (Doorenbos & Pruitt 1977). They show that the two methods of modified Blaney-Criddle give comparable results for PE, while the original Penman's method gives lowest values. This comparison shows that the highest PE is in July. The modified formulae have higher values than the original Penman's formula during May–September, while in April and October all methods gave approximately the same values for PE. For the remaining months, the modified formulae gave lower values than the original. Penman's formulae results indicate that Penman's original formula underestimates PE in summer and overestimates it in winter.

The class "A" Pan evaporimeter at Baghdad Airport which is situated in bare soil, is found to give higher value than the Pan at Abu-Ghraib, where the soil is covered with vegetation. This is mainly due to higher temperature and lower relative humidity at the airport compared to the Abu-Ghraib location assuming all other parameters have the same values. This aspect should be kept in mind for the physical approach of the method proposed in this paper.

All the above methods for calculating E_0 and PE are designed for application in some specific climatic zones and even some modification of these methods have

limited application for other areas with different climates. Also, these methods need meteorological data which are not always available which makes it difficult to utilise these methods.

In this study an attempt is made to present a simple model based on :

(*i*) Class "A" Pan evaporation,

(*ii*) Air temperature,

(*iii*) Relative humidity of air and

(*iv*) Relative aridity to estimate PE and E_0 for different climatic zones in Iraq.

2. Materials and methods

Mathematical forms of the model used

$$RA = 1 - RH \tag{1}$$

$$PE = \beta\, EPAN \tag{2}$$

$$E_0 = \gamma\, EPAN \tag{3}$$

$$E_0 = 1/\alpha\; PE \tag{4}$$

$$\beta = \alpha\gamma \tag{5}$$

$$\alpha = \gamma = \sqrt{\beta} \tag{6}$$

$$\beta = f\,[\text{converted P.E}/T].\ f\,[a_0 + \sum_{i=1}^{n} a_i\, T^{\,i}] \tag{7}$$

$$EPAN.1 = EPAN.2\ (T_1/T_2).\ (RH_1/RH_2) \tag{8}$$

$$RH = a_0 + \sum_{i=1}^{n} a_i\, T^{\,i} \tag{9}$$

$$EPAN = a_0 + \sum_{i=1}^{n} a_i\, (TRA)^{\,i} \tag{10}$$

where,

RA = relative aridity.

RH = relative humidity

PE = potential evapotranspiration (mm/day/month)

E_0 = free surface water evaporation (mm/day/month)

EPAN = class "A" pan evaporation (mm/day/month)

β, α, γ = transformation factors

T = mean monthly or daily temperature (°C)

$$Y = Ae^{BX} \tag{11}$$

$$Y = A\,X^B \tag{12}$$

$$Y = A + BX + CX^2 \tag{13}$$

where,

$Y = T/RH$

$X = T$

$Y = EPAN$

$X = T*RA/RH$

2.1. *Data* — The mean monthly temperature, relative humidity, class "A" Pan evaporation and other meteorological data for six selected meteorological stations representing different climatic zones of Iraq for the period 1941 to 1970 are used as input data.

2.2. Methods

2.2.1. *Potential evapotranspiration and Pan evaporation* — Physically both parameters are related through temperature, relative humidity and relative aridity as shown in Eqn. (2). Also, the free surface water evaporation (E_0) is related to EPAN by the same parameters using Eqns. (3) and (4) as shown above. From Eqns (2), (3) and (4) the relationships between the transformation factors β, α and γ as shown in Eqn. (5) are obtained. To simplify the solution mathematically, we assume the relation of Eqn. (6). These transformation factors are functions of time which are derived from the relation between Thornthwaite's and Penman's values of PE from the method given by Kettaneh *et al.* (1974) combined with temperature, relative humidity and relative aridity (Eqn. 7).

2.2.2. Mathematical model

The long term mean monthly air temperature for the period 1941-1970 over Iraq increases from February reaching maximum values in July/August. From August, the temperature decreases reaching minimum values in January. This represents a distribution with two limbs, which are not identical images. Those limbs are the falling limb (August to January) and the rising limb (February to July).

In a given meteorological station when the long term average of RH and temperature are known and its EPAN values are not available or questionable then the EPAN can be calculated from a relation with the nearest station as shown in Eqn. (8).

The long term averages of the temperature T, relative humidity (RH) and the pan evaporation (EPAN) are used to predict RH from T and EPAN from T, RA and RH.

The aim of this method is to calculate EPAN and to use it in the calculation of PE and E_0 by Eqns. (2) and (3). In case RH is unknown, then the temperature is used to calculate it, if RH is known, then it can be converted directly to RA by using Eqn. (1). Then RA is used in Eqn. (10) combined with the temperature in calculating EPAN. EPAN calculated as above or directly measured is used in calculating PE and E_0 and using Table 1.

In calculating monthly values of EPAN for sites with short term averages for temperatures (*e.g.*, mean monthly from one year observation), the rising limb of temperature (February to July) is used directly in Eqn. (10) as that for long term averages (*e.g.*, mean monthly from more than one year observations) with less than 10% variation. In the case of falling limb of temperature (Aug to Jan) a correction must be introduced when the
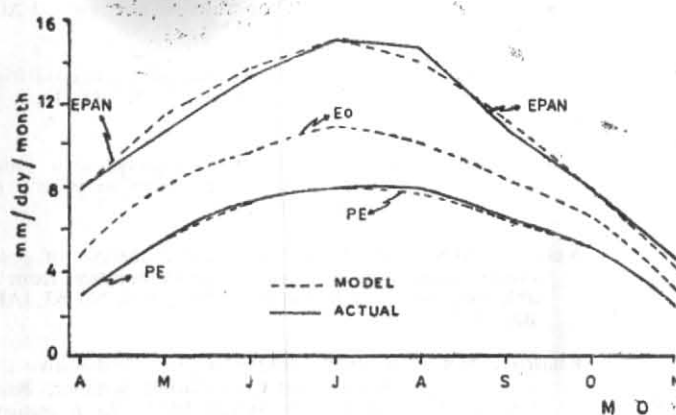
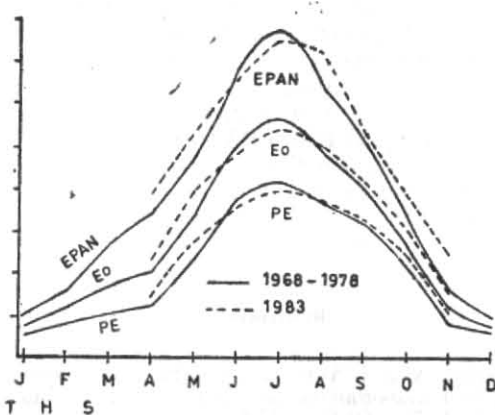Fig. 1. Mean monthly EPAN, PE and E_0 for the EL-Raid project (1983)

Fig. 2. Correlation of PE, E_0 & EPAN for 1968-78 and 1983

TABLE 1

Monthly distribution of β and γ for Iraq

Month	β	γ	Month	β	γ
Feb	0.50	0.707	Aug	0.58	0.762
Mar	0.40	0.633	Sep	0.61	0.781
Apr	0.36	0.600	Oct	0.65	0.806
May	0.50	0.707	Nov	0.52	0.721
Jun	0.55	0.742	Dec	0.67	0.819
Jul	0.53	0.728	Jan	0.58	0.762

variation between the two averages is more than or equal to 10%. This correction is equal to the ratio between the two averages, and approximately equal to the shift between the falling limb and the image of the rising limb. A computer program is built in for this model using HP 9830 minicomputer with aid of basic language.

3. Results and discussion

The relative humidity and temperature are represented by Eqns. (9), (11), (12) & (13). The EPAN, relative aridity and temperature are represented by Eqns. (10), (11), (12) & (13).

The mean monthly values of transformation factors are given in Table 1.

Statistical tests for these equations are carried out using the reduced chi-square test and the t-test, The reduced chi-square test which is the ratio of the fitted function variance to the sample distribution variance shows that it is nearly unity which represents the best fit, but for population, there is uncertainty in sample variance.

Linear correlation is performed between the actual data (relative humidity and EPAN) with the calculated data by the method used. Significant linear correlation is obtained using a two tail t-test at 0.1% confidence level (polynomial fitting).

To test the results of the calculated potential evapotranspiration, measured potential evapotranspiration from El-Raid Project is obtained for the period April to November 1983. Potential evapotranspiration is calculated by the suggested model for the same period using the temperature correction. The results are shown in Fig. 1. Statistical test is carried out using the reduced chi-square and tow-tail t-test between the calculated and measured potential evapotranspiration. The result shows a highly significant correlation and good fit.

Potential evapotranspiration (PE) and free surface water evaporation (E_0) are calculated by this model in El-Raid Project using eleven year averages from 1968-1978. The results are shown in Fig. 2.

The results are compared with those obtained by different methods given by Abu-Khalid and Al-Hassani (1982). The comparison shows that potential evapotranspiration calculated by the three methods of Blaney and Criddle (original and modified) are higher than potential evapotranspiration and free surface water evaporation using Penman equation. The original Blaney and Criddle values of PE are even higher than the values of EPAN for the two months of January and December. This shows that Blaney and Criddle generally overestimate PE values, whereas original Penman's overestimates PE in the rising limb of temperature curve and underestimate it in the falling limb.

When comparing the PE values obtained by Kettaneh et al. (1974) with that obtained by original Penman, it is found that it is higher. At the same time, it is higher than that obtained by the suggested method in this paper except in Rutbah and Sinjar from August to January.

4. Conclusions

A new method for calculating the potential evapotranspiration (PE) and free surface water evaporation

(E_0) based on temperature, relative humidity and relative aridity data is suggested. The results obtained show that good estimates of these parameters compared with actually measured values. The values of PE and E_0 obtained by other methods generally are overestimated and are even higher than EPAN. So, it is recommended that the suggested method is used to calculate these parameters for stations in Iraq where there are no actual measurement.

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