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Full Length Research Paper

Estimation of actual soil evaporation using E-DiGOR model in different parts of Turkey

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Penman-Monteith Equation was applied to determine potential soil evaporation using standard data of the meteorological stations at 14 locations from 2001 to 2003. Actual evaporation calculations for different climatic conditions were carried out using the E-DiGOR model developed by Aydin (2008). For comparisons of climatic types, the same soil properties were assumed in calculations. The results showed that the model was suitable for calculating potential and actual soil evaporation rates in different locations with satisfactory accuracy. Owing to high variability of both precipitation and potential evaporation, the actual soil evaporation in different parts of Turkey can change from 263 to 592.7 mm/year. The actual soil evaporation, as calculated with the model, accounted for 34.2 to 83.3% of the incoming precipitation.

Key words: Potential soil evaporation, actual soil evaporation, E-DiGOR model.

INTRODUCTION

The water balance of arid zones is important for numerous reasons such as for regional water resource assessment, dry land agriculture and the possible link between the surface energy balance and climate (Wallace and Holwill, 1997). Loss of water from the soil surface through evaporation is often a major component in the soil water balance of agricultural systems in the semi-arid regions. Therefore, soil-water loss by evaporation should be assessed. Some earlier results indicated that estimates of soil evaporation in semi-arid environments ranged from 30 to more than 60% of the seasonal rainfall (Jackson and Wallace, 1999). Similarly, some other results have demonstrated that in regions where summer fallow is practiced, direct evaporation from the soil surface accounted for about 50% or more of total precipitation (Hillel, 1980a; Hanks, 1992).

In assessment of soil water balance in a bare soil, how to account the evaporative demand in modeling often poses a dilemma. The models usually use potential evaporation (Ep) which is mainly a physical concept that lacks a clear definition for soil conditions. In other words, soil evaporation is modeled by limiting potential evaporation (e.g., from Penman–Monteith) with soil and or aerodynamic resistances, although newer approaches (e.g., Aydin model) derive soil evaporation successfully from soil water potential (Aydin et al., 2005; Falge et al., 2005). Many researchers distinguish two different stages of evaporation, related to the soil water content:

(1) When the actual water content is high, evaporation is controlled by the atmospheric evaporative demand and precipitation.
(2) When the amount of water is low, the evaporation is limited by the actual soil water content and, as a consequence, driven by the hydrodynamic characteristics of the soil.

Aydin model is based on energy fluxes and soil properties and experimental data are used to define a threshold separating the two stages of evaporation (Quevedo and Frances, 2007; Romano and Giudici, 2007). More recently, Aydin (2008) presented an interactive way (called E-DiGOR Model by the author) for predicting daily actual soil evaporation (Ea), soil water storage and drainage rates if any. This implies that the model simplifies the water components into three forms: evaporation, drainage and storage. The E-DiGOR Model takes into account the important physical processes to quantify these compo

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nents. The model part was previously validated for actual evaporation by Aydin et al. (2005, 2008) using measured data from different environments in Japan and Turkey and predicted data for a 10-year period (2070-2079) from a regional climate model in Turkey. The model was additionally adapted to provide a method of assessing drainage losses from soil profile using field capacity concepts (Aydin, 2008).

Several earlier works (Aydin et al., 2005, 2008; Aydin, 2008) validating the model, have demonstrated the need to quantify the components of soil water balance in a wide range of environments. However, a consistent set of values suitable for drainage calculations is required. Therefore, the drainage losses were not taken into account in this study and the model was employed for estimating only soil evaporation over a 3-year period (2001-2003) under different climatic conditions in Turkey.

MATERIALS AND METHODS

E-DiGOR model

The input parameters of the E-DiGOR model are climatic data to compute the potential soil evaporation, average diffusivity for the drying soil and volumetric water content at field capacity (Aydin, 2008). Although the E-DiGOR model has proved to be simple to use and is able to give reasonable estimates of daily evaporation, drainage and soil water storage, however some key input parameters are difficult to find. In particular, rainfall data may pose since the model requires effective rainfall which influences other components of soil water balance. The actual parameters need to account for specific soil-climate combinations (e.g. profile depth, soil water content at the beginning of study period, etc.). From locally derived parameters and rainfall data, initial soil water content could be approximated. A consistent set of input data suitable for the E-DiGOR model is required. Therefore, the model was presently tested for estimating soil evaporation only.

Ep rates from bare soils were calculated by the Penman-Monteith Equation with a surface resistance of zero (Allen et al., 1994; Wallace et al., 1999; Aydin et al., 2005) using standard data of the meteorological stations at 14 locations from 2001 to 2003:

$$E_p = \frac{\Delta \times (R_n - G_s) + \dfrac{(86.4 \times \rho \times c_p \times \delta)}{r_a}}{\lambda \times (\Delta + \gamma)} \qquad (1)$$

Where E_p is potential soil evaporation (kg m^{-2} $d^{-1} \cong$ mm d^{-1}), Δ is the gradient of saturated vapour pressure-temperature curve (kPa $^{\circ}C^{-1}$), R_n is the net radiation (MJ m^{-2} d^{-1}), G_s is the soil heat flux (MJ m^{-2} d^{-1}), ρ is the air density (kg m^{-3}), c_p is the specific heat of air (kJ kg^{-1} $^{\circ}C^{-1}$ = 1.013), δ is the vapor pressure deficit of the air (kPa), r_a is the aerodynamic resistance (s m^{-1}), λ is the latent heat of vaporization (MJ kg^{-1}), γ is the psychrometric constant (kPa $^{\circ}C^{-1}$) and 86.4 is the factor for conversion from kJ s^{-1} to MJ d^{-1}.

Ea rates were computed using Aydin Equation (Aydin et al., 2008):

$$E_a = \frac{Log\ |\psi| - Log\ |\psi_{ad}|}{Log\ |\psi_{tp}| - Log\ |\psi_{ad}|} \times E_p \qquad (2)$$

If $|\psi| \le |\psi_{tp}|$, then $E_a = E_p$ or $E_a / E_p = 1.0$

For $|\psi| \ge |\psi_{ad}|$, $E_a = 0.0$

Recall that $E_p \ge 0$.

Where E_a and E_p are actual and potential evaporation rates (mm d^{-1}), respectively, $|\psi_{tp}|$ is the absolute value of soil water potential (matric potential) at which actual evaporation starts to drop below potential one, $|\psi_{ad}|$ is the absolute values of soil water potential at air-dryness and $|\psi|$ is the absolute values of soil water potential. The values of all ψ are in cm of water.

In order to estimate $|\psi|$, the following equation can be used (Aydin, 2008; Aydin et al., 2008):

$$\psi = -[(1/\alpha)\ (10\textstyle\sum E_p)^3 / 2(\theta_{fc} - \theta_{ad})\ (D_{av}\ t/\pi)^{1/2}] \qquad (3)$$

Where ψ is soil water potential (cm of water) at the top surface layer, α is a soil-specific parameter (cm) related to flow path tortuosity in the soil, $\sum E_p$ is cumulative potential soil evaporation (cm) and θ_{fc} and θ_{ad} are average-volumetric water content (cm^3 cm^{-3}) at field capacity and air-dryness, respectively. D_{av} is average hydraulic diffusivity (cm^2 d^{-1}), t is the time since the start of evaporation (days) and π is 3.1416.

For $|\psi_{ad}|$, Kelvin equation can be employed (Brown ve Oosterhuis, 1992; Aydin, 2008):

$$\psi_{ad} = \frac{R_g T}{mg} \ln H_r \qquad (4)$$

Where ψ_{ad} is the water potential for air-dry conditions (cm of water), T is the absolute temperature (K), g is the acceleration due to gravity (981 cm s^{-2}), m is the molecular weight of water (0.01802 kg mol^{-1}), Hr is the relative humidity of the air (fraction) and R_g is the universal gas constant (8.3143 × 104 kg cm^2 s^{-2} mol^{-1} K^{-1}).

Study areas

Turkey is situated between the Black Sea and Mediterranean Sea, linking Europe and Asia. The climate varies from arid to very humid. About 40% of Turkey's 78 million ha land area is semi-arid (Aydin, 1995). The country is subject both to a continental type of climate characterized by rainy weather throughout the year and a subtropical climate distinguished by dry summers. Average annual precipitation (P) for all over Turkey is 643 mm (DSI, 1999). The average annual temperature varies between 18-20°C on the south coast, 14-15°C on the west coast, and 4-18°C in the interior areas (Avcı, 1999). The climate data for the study areas were obtained from Turkish State Meteorological Service. Some long-term climatic data for the study locations are given in Table 1. For comparisons of different climatic types, the same soil properties were assumed for the whole locations. The soil properties used in the model were as described by Aydin (2008): The soil has fine texture with sand of 331, silt 122 and clay 547 gkg^{-1} of soil mass at the layer of 0-40 cm.

Table 1. Some long-term climatic data for the study locations (DIE, 2001).

Location	Temperature (°C)	SunshineDuration (h)	Humidity (%)	Precipitation (mm)
Artvin	12.2	4.90	67	778.1
Ankara	11.7	7.19	60	377.7
Antalya	18.5	8.28	64	1052.3
Aydın	17.5	7.42	63	657.7
Bursa	14.6	6.35	69	696.3
Diyarbakır	15.8	8.00	54	491.4
Erzurum	5.9	7.05	64	447.0
Gaziantep	14.5	8.00	60	548.8
Konya	11.5	7.29	60	325.9
Malatya	13.6	7.40	54	387.5
Samsun	14.0	4.46	75	560.3
Tekirdag	13.8	5.40	76	575.4
Trabzon	14.5	4.36	72	833.8
Zonguldak	13.2	5.54	72	1220.2

Dry bulk density varies between 1.20 and 1.27 g cm^{-3}. On average, volumetric water content at field capacity is 0.35 cm^3 cm^{-3}. In this study, albedo of the bare soil was assumed to be 0.15 (van Dam et al., 1997; Ács, 2003). In the calculations of soil water potential, tortuosity parameter (α) which can be defined as the actual round about flow path, for the clay soil was taken as 1.1 cm. The tortuosity is always greater than 1 and may exceed 2 (Hillel, 1980b). The volumetric water content at air-dry condition and hydraulic diffusivity were assumed to be 0.05 cm^3 cm^{-3} and 95 cm^2 d^{-1}, respectively. Hydraulic diffusivity is defined as the ratio of unsaturated hydraulic conductivity to specific water capacity. The advantage of using the diffusivities in the analysis of flow lies in the evidence that the range of their values against water content is relatively narrow, and this makes numerical treatment of flow easy (Baruah and Hasegawa, 2001). We used 60.0 cm of water as Ψ_{tp} for the clay soil as suggested by Aydin (2008).

RESULTS

A comparison of annual potential soil evaporation in different provinces of Turkey is shown in Figure 1. Owing to the differences in climatic regimes, the potential soil evaporation in semi-arid locations (e.g. Aydın province) is quite different from that in the humid locations (e.g. Artvin province).

Actual evaporation from bare soils in semi-arid regions was much lower than in humid regions (Figure 2) due to frequency and amount of rainfall which makes it difficult to compare the size of potential and actual evaporations. The magnitude of Ea was closer to that of Ep for humid locations.

Amount of rainfall during study period accounted for most of the variation in actual soil evaporation, irrespective of potential evaporation (Figure 3). In other words, actual soil evaporation accounted for 34.2 to 83.3% of the incoming precipitation.

The magnitudes of annual P, Ep and Ea are compared in Figure 4 for different provinces of Turkey. The highest Ep values were found in south region, while the lowest values were determined in Northeast. The highest Ea values were estimated for Northern coastal areas, whereas the lowest values were computed for interior parts of the country. The magnitude of Ea was usually consistent with rainfall pattern.

DISCUSSION

The Ep rates were higher in hot-dry locations and lower in mild-rainy sites due to evaporative demand of the atmosphere. No relationship between potential soil evaporation and size of rainfall event was reflected, as also reported by Monzon et al. (2006). The results were consistent with our understanding of the physical process controlling evaporation.

For bare soils, Ea was lower than expected in locations with higher potential evaporative demand and lower rainfall events. Due to extremely variable precipitation and potential evaporation, actual soil evaporation in different regions of Turkey showed wide range of variation from 592.7 to less than 264 mm/year. The rates of Ea were mainly depended on rainfall pattern, and presumably soil wetness in addition to atmospheric evaporative demand. The Ea values in east, west and south regions were comparable in terms of their magnitude, but especially in north part (Black Sea region) differs considerable.

The observed differences were partly due to different rainfall pattern. The lowest Ea value was found for in the interior part of Turkey (e.g. Konya Province). This result could be related to soil dryness. Unfortunately, there are no directly measured observations of actual soil evaporation to evaluate if the model has high predictive capacity.

However, a previous work with the same model (Aydin et al., 2008) demonstrated that the simulated and mea-

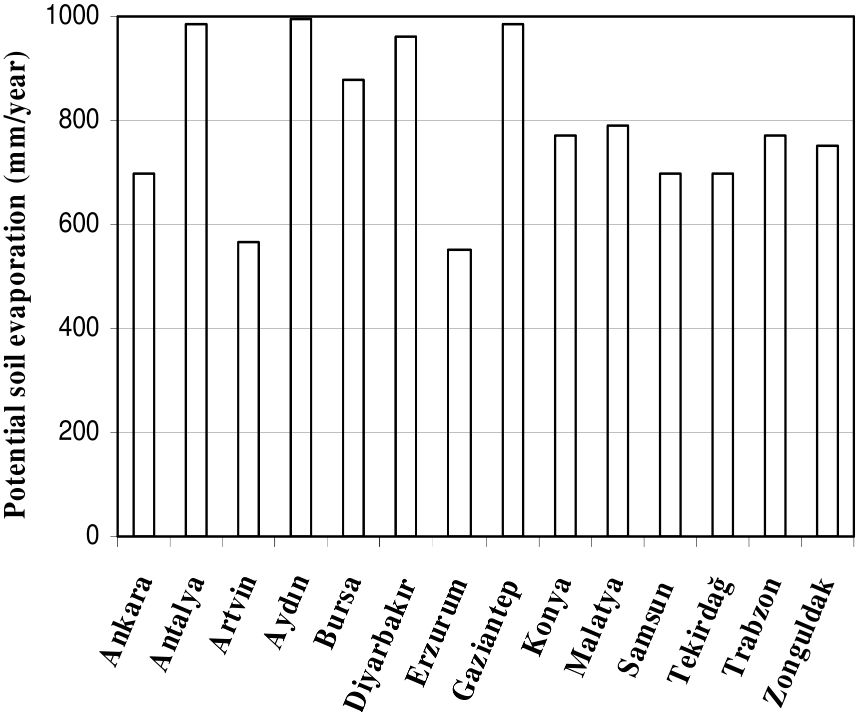

Figure 1. Comparison of annual potential evaporation from bare soils in different parts of Turkey.

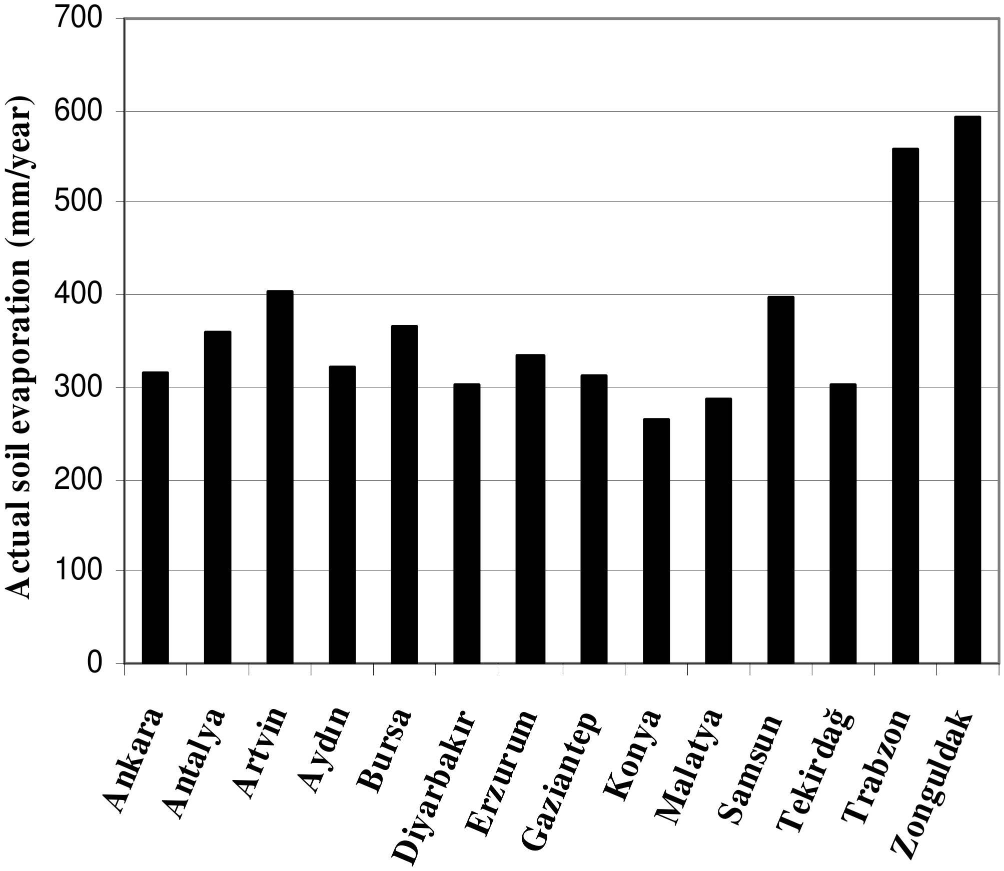

Figure 2. Comparison of yearly actual evaporation from bare soils in different parts of Turkey.

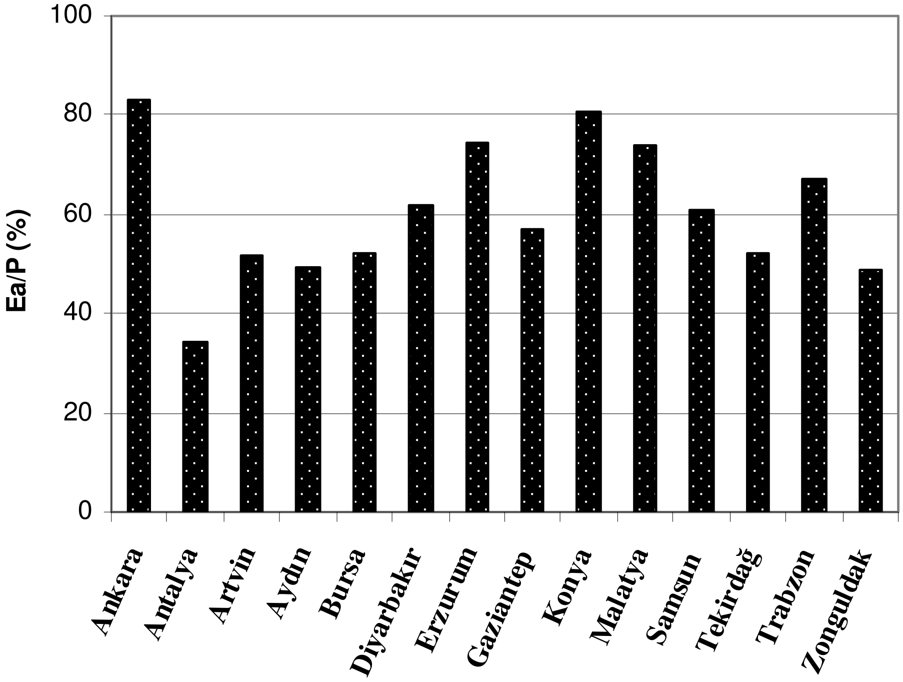

Figure 3. The soil water evaporation accounts for most of the incoming precipitation in Turkey.

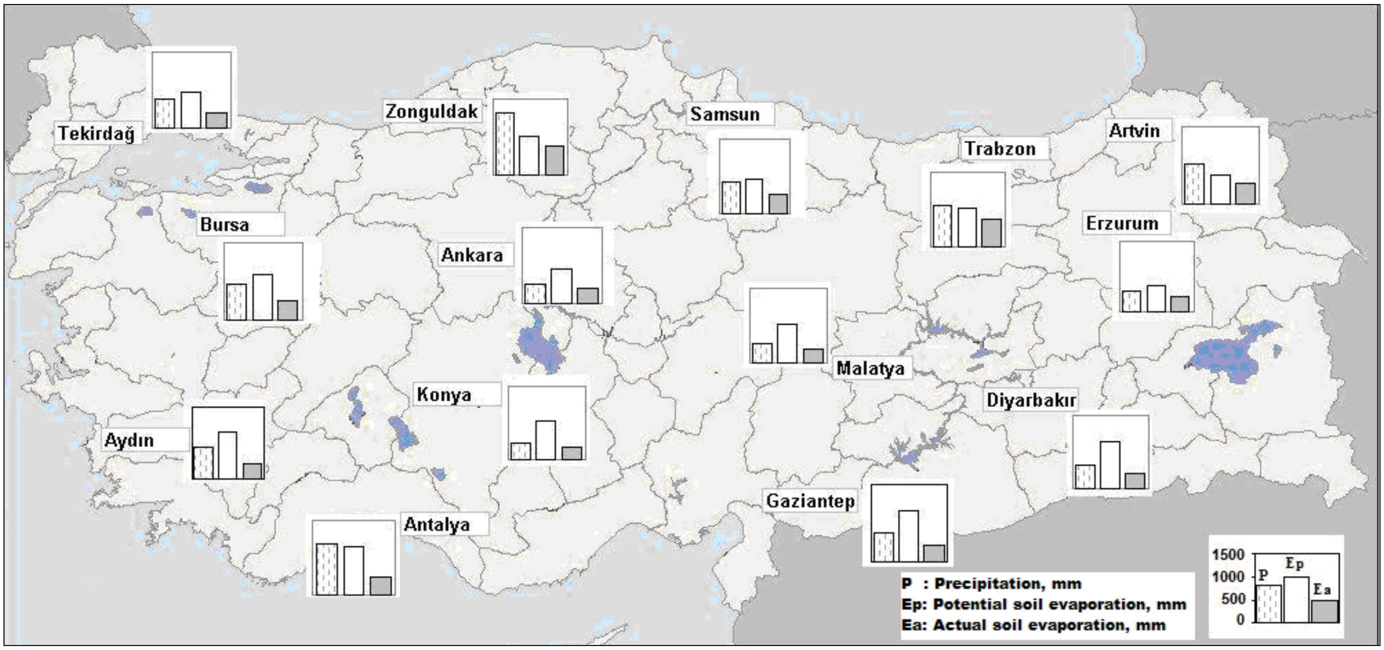

Figure 4. The histograms for the components of soil-water balance in different parts of Turkey.

sured soil evaporation compared reasonably well (R^2 = 94.0%; $P < 0.001$). To this effect, a recent report comparing the estimated and measured actual evaporation (R^2 = 91.4%; $P < 0.01$) was given by Aydin (2008) for semi-arid environment in Turkey.

The ratio of Ea/P was in agreement with earlier works (e.g., Hillel, 1980a; Hanks, 1992; Jackson and Wallace, 1999). In most of the semi-arid and arid regions of Turkey, the soil evaporation represents a large fraction of the total annual water loss from bare soils. The results showed an increase in Ea values from arid to humid areas. The results from this study not only improved our understanding of the physical processes controlling evaporation, but also provided valuable information of risk assessment and management for water resources. These results may set the basis for prevention of water losses through evaporation and drainage from bare soils and adoption of an effective management strategy for soil water, particularly, in rainfed-areas, as indicated by Aydin (2008). However, the research results were presently limited for long-term monitoring of soil-water content in such regions (Warrick et al., 1998; Dong et al., 2003).

Conclusions

Although the E-DiGOR model is simple to use and can give reasonable estimates of daily components of soil water balance, some input parameters such as rainfall give problems of definition since the model requires the infiltrated rainfall. Where measured runoff data are available, the data can be used for calibration of the model. Since the model was designed to evaluate soil water losses, it may be reasonable to neglect the upward water flux by capillarity from deeper zones if the soil profile was wet. However, the assumption for neglecting the capillary flux would not hold, particularly when upper parts of the soil were dry and lower layers were wet. In spite of the mentioned draw backs, the results from such studies not only improve our understanding of water transport processes, but also may provide valuable information to adapt a strategy for soil-water conservation.

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