A Study of Local Evapotranspiration (II)
- Characterization of Local Evapotranspiration -

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1. Introduction

Identifying the important meteorological variables on actual evapotranspiration (AET) in the environment with the limited water supply is the major consideration of this study. Simple and multiple linear regression (MLR) analyses were employed to evaluate the order of importance of the meteorological and soil water factors involved. The meteorological and soil water data were used for MLR model development.

2. Data

The site chosen for the experiment is the well-instrumented Walnut Gulch experimental watershed (31° 43'N, 110° 41'W) operated by the Southwest Watershed Research Center of the U.S. Department of Agriculture's Agricultural Research Service (ARS). It is located in southwestern Arizona about 120 km southeast of Tucson, Arizona (Fig. 1).

The daily meteorological, flux and soil water content data were collected over native rangeland shrub at Lucky Hills and over grass at Kendall during the summer rainy period (1990) and winter period (1991-1992). Data used for this study were measured during the summer rainy period from DOY (Day of Year) 90198 through DOY 90227 at Lucky Hills watershed, and from DOY 90202 through DOY 90223 at Kendall watershed. During the winter period, data were measured from DOY 92015 through DOY 92070 at Lucky Hills watershed, and from DOY 91347 through DOY 92070 at Kendall watershed.

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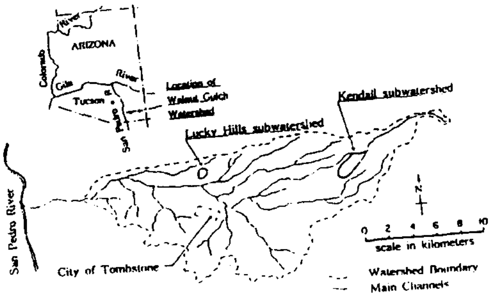

Fig. 1. USDA-ARS Walnut Gulch Experimental Watershed Location Map.

3. Analyses and Results

Simple and multiple linear regression analyses were employed to evaluate the order of importance of the meteorological and soil water factors involved and finally to develop equations for the calculation of AET. Multiple linear regression analysis is often used for modeling relationships between a dependent variable and more than one independent variables.

The multiple linear regression model assumes that for each set of values for k independent variables (X_1, X_2, . . ., X_k) there is a distribution of Y values such that the mean of the distribution is on the surface represented by the equation (Berry and Feldman, 1985)

$$Y = A + B_1 \cdot X_1 + B_2 \cdot X_2 + . . . + B_k \cdot X_k \qquad (4)$$

where the coefficients A, B_1, B_2, . . ., B_k represent population parameters. B_i is called a partial slope coefficient which is the slope of the relationship between the independent variable X_i and the dependent variable Y holding all other independent variables constant. B_i represents the change in Y associated with one unit increase in X_i when all other independent variables in the model are held constant. If only dependent variable Y and one independent variable X_1 are considered, the model is said to be simple, linear in parameters, and linear in the independent variable

$$Y = A + B_1 \cdot X_1 \qquad (5)$$

For this study, dependent variable Y is AET (mm/day), and independent variable X_1 is the respective meteorological or environmental factor.

3.1 Identifying Useful Variables for MLR Analysis of AET

To identify the useful variables for MLR analysis of AET, there are two major factors which should be considered on the rate of AET from watershed. These are: (a) soil moisture content, and (b) amount of energy available to convert liquid water to water vapor. Vegetation in semiarid rangeland such as the Walnut Gulch watershed is fairly sparse compared to humid regions, so the soil plays a major role in the radiative and hydrologic balance (Kustas et al., 1991).

The available energy (Q_n+Q_g) affects ET and soil water content. High available energy creates a high ET rate if there is available soil water. Conversely, low available energy limits the evaporation rate even though there may be available soil water. It is widely recognized that soil moisture suction increases as soil moisture decreases. Therefore, dry surface soils evaporate less, and the surface air becomes drier.

Layers of still air which form immediately above an evaporating surface offer resistance to the diffusion of water molecules into the atmosphere. Wind (u) decreases the resistance by carrying water vapor away from the surface of the still layer, and therefore increases the vapor pressure deficit (VPD) from the evaporating surface. Wind also transports sensible energy horizontally as air that is heated over dry areas to cooler, evaporating surfaces.

The meteorological variables that interact to produce VPD are air humidity and air temperature (T_a). As T_a increases, VPD increases. As air humidity increases, VPD decreases. Thus, the VPD tends to decrease with high soil water content, and increase as soil dries.

Variables suitable for a MLR prediction model therefore appear to be those that index the available energy term (Q_n+Q_g) and those associated with the aerodynamic or mass transfer term (VPD, T_a, and/or u). These variables are major components of Penman potential evapotranspiration (PET). Since PET is only a "potential" for evaporation, an additional index of the soil moisture content is needed to link the supply of moisture to the actual evaporation rate.

The effects of soil water content and meteorological conditions on AET estimation have also been found elsewhere to be important in the evaporation process (Kucera, 1954; Owe and Griend, 1990; and others). Plants with equal available moisture have more moisture stress on days with larger evaporability (Q_n+Q_g, VPD and u) (Denmead and Shaw, 1962). The explanation of this lies in the fact that when evaporation demand is low, moisture is able to move to the evapotranspiring surface in accordance with the atmospheric demand. But when evaporation demand is large, transport of moisture to the evaporating surface can lag behind the demand, and the actual loss of moisture by evapotranspiration can fall much below the potential ET rate. Based on Kristensen and Jensen (1975), the influence of soil dryness is reduced as evaporability (Q_n+Q_g, VPD and u) is decreased. On the other hand, the influence of soil dryness is increased as evaporability (Q_n+Q_g, VPD and u) is increased.

3.2 Effects of Single Meteorological and Soil Water Factors as Components Influencing Evaporation

In order to determine the relative importance of the various components of meteorological and environmental factors affecting water losses, simple linear regression analyses were performed for the actual ET (AET, mm/day) on net radiation (Q_n, MJ/m^2/day), available energy (Q_n+Q_g, MJ/m^2/day), air temperature (T_a, ℃), vapor pressure deficit (VPD, mb), wind speed (u, m/s), and soil water content (SM, mm) (Table 1). These independent variables are known to directly affect AET.

3.3 Combined Effects of Meteorological and Soil Water Factors on Evaporation

Multiple linear regression (MLR) analysis was employed to evaluate the order of importance of the meteorological and soil water factors involved and finally to develop equations for the calculation of AET (Table 2). Modeling attempts in this study were based on multiple linear regression techniques (stepwise regression method) of the Statistical Package for Social Sciences (SPSS) computer program (Norusis, 1988). To find the parameters for multiple linear regression models, SPSS uses the method of "least squares", and minimizes the objective function to find the optimum parameter values. In this study the objective function to be minimized is the sum of differences between daily observed AET (AET_o) and estimated AET (AET_e) [$= \Sigma(AET_o - AET_e)^2$] for each period (summer rainy and winter) at each watershed (Lucky Hills and Kendall).

4. Conclusions

Meteorological and soil water content data measured from semiarid watersheds of Lucky Hills and Kendall during the summer rainy and winter periods were used to study the interrelationships between the controlling variables of the AET, and to evaluate the effects of variables on daily actual evapotranspiration estimation. Simple and multiple linear regression (MLR) analyses were employed to evaluate the order of importance of the meteorological and

Table 1. Simple Linear Regressions of Daily Evaporation on Meteorological and Soil Water Factors at Lucky Hills and Kendall Watersheds during the Summer Rainy (1990) and Winter Periods (1991-1992).

Model	Regression Equations	r^2	SEE	M	P-value
1	$AET_{LS} = 1.783 + 0.166(Q_n)$	0.400	0.651	3.725	0.000
2	$AET_{KS} = 1.942 + 0.117(Q_n)$	0.330	0.522	3.340	0.006
3	$AET_{LW} = 0.490 + 0.109(Q_n)$	0.200	0.438	1.084	0.001
4	$AET_{KW} = 0.502 + 0.139(Q_n)$	0.243	0.468	1.011	0.000
5	$AET_{LS} = 0.258 + 0.296(Q_n+Q_g)$	0.627	0.514	3.725	0.000
6	$AET_{KS} = 0.707 + 0.221(Q_n+Q_g)$	0.579	0.414	3.340	0.000
7	$AET_{LW} = 0.119 + 0.169(Q_n+Q_g)$	0.376	0.386	1.084	0.000
8	$AET_{KW} = 0.140 + 0.203(Q_n+Q_g)$	0.454	0.398	1.011	0.000
9	$AET_{LS} = 3.669 + 0.005(VPD)$	0.001	0.840	3.725	0.853
10	$AET_{KS} = 3.625 - 0.026(VPD)$	0.042	0.625	3.340	0.374
11	$AET_{LW} = 1.500 - 0.064(VPD)$	0.183	0.442	1.084	0.001
12	$AET_{KW} = 1.274 - 0.052(VPD)$	0.102	0.510	1.011	0.002
13	$AET_{LS} = 3.817 - 0.040(u)$	0.001	0.840	3.725	0.877
14	$AET_{KS} = 3.018 + 0.101(u)$	0.029	0.629	3.340	0.464
15	$AET_{LW} = 0.870 + 0.081(u)$	0.024	0.483	1.084	0.255
16	$AET_{KW} = 0.774 + 0.071(u)$	0.025	0.531	1.011	0.136
17	$AET_{LS} = 1.882 + 0.082(T_a)$	0.058	0.816	3.725	0.199
18	$AET_{KS} = 4.673 - 0.060(T_a)$	0.032	0.628	3.340	0.437
19	$AET_{LW} = 1.401 - 0.037(T_a)$	0.047	0.478	1.084	0.109
20	$AET_{KW} = 1.219 - 0.029(T_a)$	0.027	0.531	1.011	0.127
21	$AET_{LS} = 0.980 + 0.032(SM)$	0.253	0.727	3.725	0.005
22	$AET_{KS} = 0.552 + 0.031(SM)$	0.176	0.579	3.340	0.058
23	$AET_{LW} = -0.734 + 0.020(SM)$	0.032	0.481	1.084	0.189
24	$AET_{KW} = -0.398 + 0.010(SM)$	0.031	0.530	1.011	0.097

LS: summer rainy period at Lucky Hills (n=30)
KS : summer rainy period at Kendall (n=21)
LW : winter period at Lucky Hills (n=56)
KW : winter period at Kendall (n=89)
n : sample size
r^2 : coefficient of simple determination
SEE : standard error of estimate of the regression (mm/day)
M : mean of observed AET (mm/day)
P-value : significance F from F distribution

Table 2. MLR Models for Predicting AET at Walnut Gulch. The Models are for the Summer Rainy Period (1990) and Winter Period (1991-1992) at Lucky Hills and Kendall Watersheds.

Model	Regression Equations	R^2	SEE	M
1	$AET = -1.94-0.03VPD+0.29u+0.31(Q_n+Q_g)+0.02SM$	0.80	0.39	3.73
2	$AET = 0.96-0.05VPD+0.24(Q_n+Q_g)$	0.72	0.35	3.34
3	$AET = -1.72-0.19Q_n+0.05T_a-0.08VPD+0..41(Q_n+Q_g)+0.02SM$	0.76	0.25	1.08
4	$AET = -0.07-0.20Q_n+0.07T_a-0.11VPD+0.44(Q_n+Q_g)$	0.78	0.26	1.01

All the regressions are significant at $P < 0.001$)
1) : summer rainy period at Lucky Hills with all data (n=30)
2) : summer rainy period at Kendall with all data (n=21)
3) : winter period at Lucky Hills with all data (n=56)
4) : winter period at Kendall with all data (n=89)
n : sample size
R^2 : coefficient of multiple determination
SEE : standard error of estimate of the regression (mm/day)
M : mean of observed AET (mm/day)

soil water factors involved. Finally, the information gained was used for MLR model development.

The available energy (Q_n+Q_g) and vapor pressure deficit (VPD) were found to be the important variables to estimate actual ET at both watersheds and during the both periods. The important variables of evaporation process in these watersheds appear to be simply a components of energy term in available energy and aerodynamic term in vapor pressure deficit of Penman potential evaporation equation. Therefore, the general form of MLR equations tested for summer rainy and winter periods at Lucky Hills and Kendall watersheds was:

$$AET = A + B(Q_n+Q_g) + C(VPD) \qquad (7)$$

Multiple regression analyses showed that the combined effects of available energy and vapor pressure deficit were responsible for 74 and 72 % of the observed variations in AET during the summer rainy period at Lucky Hills watershed and Kendall watershed, respectively. The analyses also indicated that the combined effects of available energy and vapor pressure deficit accounted for 68 and 71 % of the observed variations in AET during the winter period at Lucky Hills watershed and Kendall watershed, respectively.

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