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"ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION OVER THE STATE OF QATAR"

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ABSTRACT

Several methods for the estimation of potential evapotranspiration are reported in the literature covering a wide variation in the complexity of calculation and nature of climatic data required. Five of the more commonly used methods (Blaney-Criddle, Thornthwaite, Pan Evaporation, Radiation and Penman) are used to estimate mean monthly potential evapotranspiration values using data from three agro-hydro-meteorological stations sited in the north, central and south-western areas of Qatar. The results are compared and analyzed. Effect of micro-climatic conditions that varies between desert and oasis type environments was found pronounced.

INTRODUCTION

Information on evapotranspitation is needed for planning and design of irrigation and water storage systems. Short term estimates of evapotranspiration can also be used for the scheduling of irrigation. Evapotranspiration rate strongly depends on factors relating to the conditions of the atmosphere such as: temperature, net radiation, humidity and wind speed. It depends also on plant factors relating to the plant species, cover, and stage of growth. The conditions of the soil also affect evapotranspiration rate.

In order to simplify the mathematical computation of evapotranspiration, it is often possible to separate micro-meteorological influences from plant and soil factors by calculating what is called potential evapotranspiration. Potenial evapotranspiration (PET) is defined as the amount of water that could be evapotranspired in a unit time by short green crop of uniform height completely shading the ground and never lacking water. Actual evapotranspiration is calculated from the potential one by introducing correction terms based on soil and plant factors. According to Finkel [3]. There are at least 30 formulas for the estimation of potential evapotranspiration in the literature which cover a wide range of complexity of calculation and nature of climatic data required.

Five of the more commonly used methods were employed to estimate monthly values of potential evapotranspiration using data gathered by the agro-hydro-meteorological (AHM) section of the Department of Agricultural and Water Research at the Ministry of Industry and Agriculture of the State of Qatar for three stations sited in the north, central and southwestern areas of Qatar. The methods employed were; Blaney-Criddle, Thornthwaite, Pan Evaporation, Radiation and Penman.

QATAR AGRO-HYDRO-METEOROLOGICAL DATA BASE

Qatar is an arid peninsula of an overall area of 11,610 square kilometers. It extends in a finger like pattern into the Arabian Gulf from the large Arabian peninsula. The approximate length of Qatar along its (North-South) axis is 180 km. At its widest (West-East) section it has an approximate width of 85 km. In order to collect the data for the hydrological and agricultural needs, an agro-hydrometeorological network was initiated since late 1971. The network consists of three main stations sited in the north, centeral and south-western areas of Qatar. The location, coordinates and elevation above mean sea level of each of these main stations are given respectively as:

– Rodhat Al-Faras	25°	49′	N.	51°	20′	E.	14.10 m
– Al–Utoreyah	25°	31′	N.	51°	12′	E.	33.85 m
– Abu-Samara	24°	44′	N.	51°	50′	E.	3.10 m

The station at Rodhat Al-Faras is situated within an oasis area at the Government Experimental Farm. Al-Utoreyah Station is located at Al-Utoreyah Experimental Farm and Abu-Samara Station is located inside the Sheep Farm within 0.5 km of the west coast. Figure (1) shows the location of the main (AHM)stations in the State of Qatar together with Doha the capital of Qatar on the east coast. In addition to the main stations, the (AHM) network consists also of 29 automatic recording daily type rain gauges sited all over the country.

The type of measurements taken by the three main stations covers daily observations of temperature, relative humidity, solar radiation, sunshine hours, wind speed, soil temperature at three depths, pan evaporation and daily rainfall. All data were originally processed by hand through the (AHM) section staff but since 1979 these have been calculated and stored within the Agricultural and Water Research Department Computer Unit as a part of the national water and agricultural data bank. Mean monthly values of different meteorological parameters used in this study are plotted on Figure (2). The data record used covered a time span of fourteen, thirteen and eleven years respectively for the stations representing the north, central and south-western areas of Qatar.

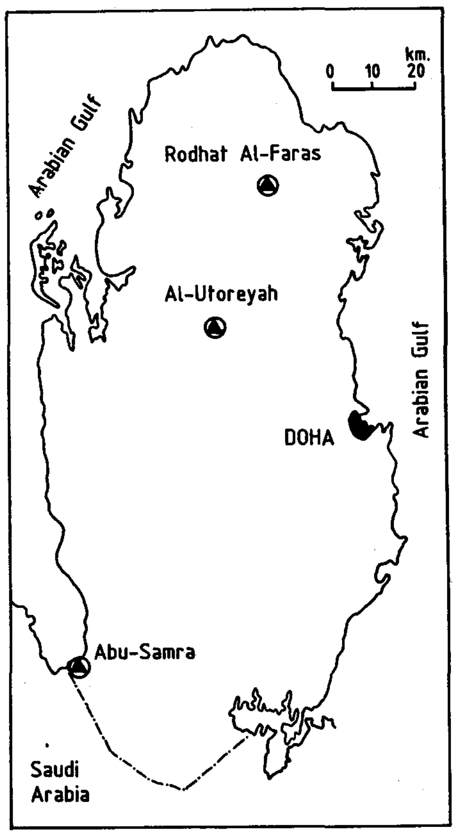

Fig. (1) : Location of the agro-hydro-meterological stations in Qatar.

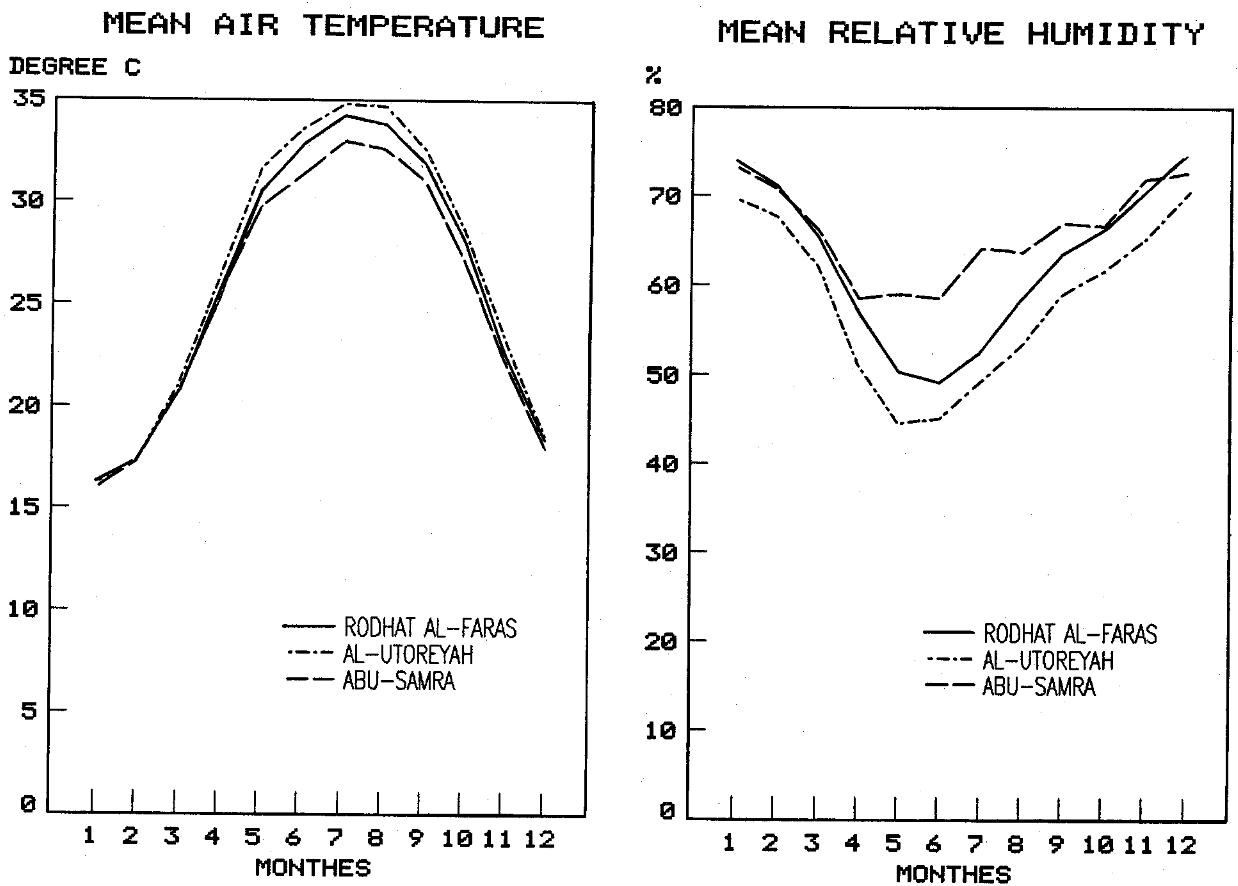

Fig. (2) : Mean monthly meteorological data.

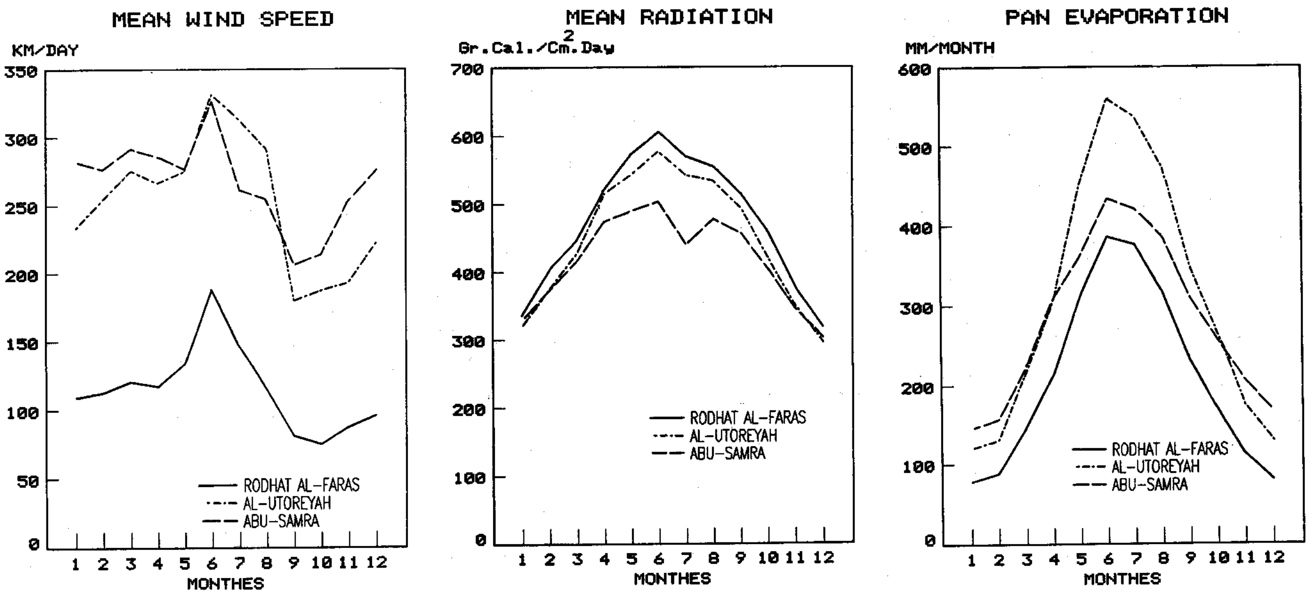

Fig. (2) (continued) : Mean monthly meteorological data.

ESTIMATION METHODS OF POTENTIAL EVAPOTRANSPIRATION

Mean monthly values of the measured meteorological parameters at the three main (AHM) stations representing the north, central and south-western areas of Qatar over the periods (1972 to 1985), (1973 to 1985) and (1975 to 1985) were respectively employed in the computation of the mean monthly values of the potential evapotransiration. Guidelines presented by Doorenbos and Pruitt [2] were utilized in the computation using the methods of Blaney-Criddle, Pan Evaporation, Radiation and Penman. Basic forms of the equation used are given herein.

1. Blaney–Criddle Method

Potential evapotranspiration PET in mm of water per day over a given month is given by:

$$PET = A + B\,(P\,(0.46T + 8.13)) \qquad (1)$$

in which T is the monthly mean temperature in °C, P is the mean daily percentage of maximum possible annual day light hours, a factor of position latitude, A and B are coefficients that depend on the monthly day time minimum relative humidity, the monthly average of the actual sunshine hours divided by the maximum possible sunshine hours, and the monthly average day time wind speed measured at a height of 2 m.

2. Thornthwaite Method

Potential evapotranspiration PET in mm per month is given by Equation (2) according to Withers and Vipond [7],

$$PET = 16.0\,\left(\frac{10T}{I}\right)^{a} \qquad (2)$$

in which T is the mean monthly air temperature in °C, I is the heat index for 12 months in a year and is given by equation (3). The exponent$^{(a)}$ in equation (2) is a function of the heat index as portrayed in equation (4).

$$I = \sum_{1}^{12} \left(\frac{T}{5}\right)^{1.514} \qquad (3)$$

and $a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 0.4924$ (4)

PET values calculated using equation (2) should be adjusted for the number of days in the month and the number of hours between sunrise and sunset.

3. Pan Evaporation Method

Potential evapotranspiration PET is deduced from pan evaporation measurement EP using imperical constant K_p.

$$PET = EP \times K_p \qquad (5)$$

The pan coefficient K_p depends on the type of pan used in measuring evaporation. Other factors that affect K_p are relative humidity, wind speed and the extent of the surrounding vegetation. At the three main (AHM) stations in Qatar class-A pan is being used.

4. Radiation Method

Potential evapotranspiration PET in mm/day over a given month is given by equation (6);

$$PET = a + b.W.R_s \qquad (6)$$

in which R_s is the solar radiation received at the surface of the earth expressed in equivalent evaporation in mm/day. It is only a portion of the radiation received at the top of the atmosphere. W is weighting factor which depends on temperature and altitude. a and b are coefficients that depend on the mean monthly relative humidity and mean day time wind. a is constant and is usually taken −0.3. The weighting factor W is calculated from equation (7) which has the following form:

$$w = \Delta \; / \; (\Delta + \gamma) \qquad (7)$$

in which Δ is the rate of change of the saturation vapour pressure with temperature and γ is the psychrometric constant.

5. Penman Method

Potential evapotranspiration PET in mm/day over a given month is given by the following equation which combines both the energy balance concept and the aerodynamics principles

$$PET = W \cdot R_n + (1-W)\, f(u)\, (e_a - e_d) \qquad (8)$$

in which W is the same weighting factor given by equation (7), R_n is net radiation in equivalent evaporation in mm/day, f(u) is a wind related function given by equation (9) and $(e_a - e_d)$ is the difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air both in millibars. This last term can be expressed as e_a (1−RH), where RH is the relative humidity.

$$f(u) = 0.27 \left(1 + \frac{u}{100} \right) \qquad (9)$$

in which u is the wind speed at a height of 2 m in km/day. The net radiation R_n defined as the difference between the net short wave radiation R_{ns} and the net long wave radiation R_{n1} can be written as follows:

$$R_n = (1 - \alpha) R_s - \left[(\sigma T^4_k)(0.34 - 0.044 \sqrt{e_d})(0.1 + 0.9 (n/N)) \right] \qquad (10)$$

in which R_s is the solar radiation received at the earth surface, α is the reflectivity of the crop surface (albedo), T_k is the mean monthly absolute air temperature in k°, (n/N) is the ratio of the actual to the maximum bright sunshine hours and σ is Stefan-Boltzman constant.

RESULTS

Mean monthly potential evapotranspiration rates in mm/day have been computed for the three main (AHM) stations in Qatar using the five different estimation methods. The results were shown on Figure (3). Again the results were summarized in Table (1) with the average yearly PET rate associated with each method. The variation among the different methods of the monthly estimates of (PET) for each station is noticeable. The parameters and coefficients in these methods were not locally calibrated. In fact some of the variables (like day time wind speed) were not measured at all.

Thornthwaite method being dependent only on the temperature under estimated PET during winter months and over-predicted PET during summer months. The method completely ignored aerodynamic effects. Therefore, in calculating the average monthly potential evapotranspiration for each station results obtained by Thornthwaite method was not considered. Radiation and Penman methods have more sound theoretical background and their use is generally recommended if their data requirements can be met. It appeared. from the average results shown on Table (1) that maximum monthly potential evapotranspiration occured in June while minimum monthly potential evapotranspiration occured in December. Average results of Table (1) also indicated that the total yearly potential evapotranspiration at Al-Utoreyah exceeded that at Abu-Samara and both exceeded that at Rodhat Al-Faras although the three stations have almost the same monthly levels of mean temperature. Table (2) summarizes the differences in the micro-climatic conditions at Al-Utoreyah and Rodhat Al-Faras. The two stations has almost the same mean temperature but the aerodynamic effects of wind speed and relative humidity are significantly different. The resulting potential evapotranspiration at Al-Utoreyah is approximately 27% higher than that at Rodhat Al-Faras. The first station represents a desert like environment while the second represents an oasis type environment.

Figure (4) shows the variation in the mean monthly potential evaportanspiration at the two stations calculated using Penman combination approach. While the contribution of the radiation term at the two sites was comparable, the contribution of the aerodynamic term at Al-utoreyah greatly exceeded that at Rodhat Al-Faras.

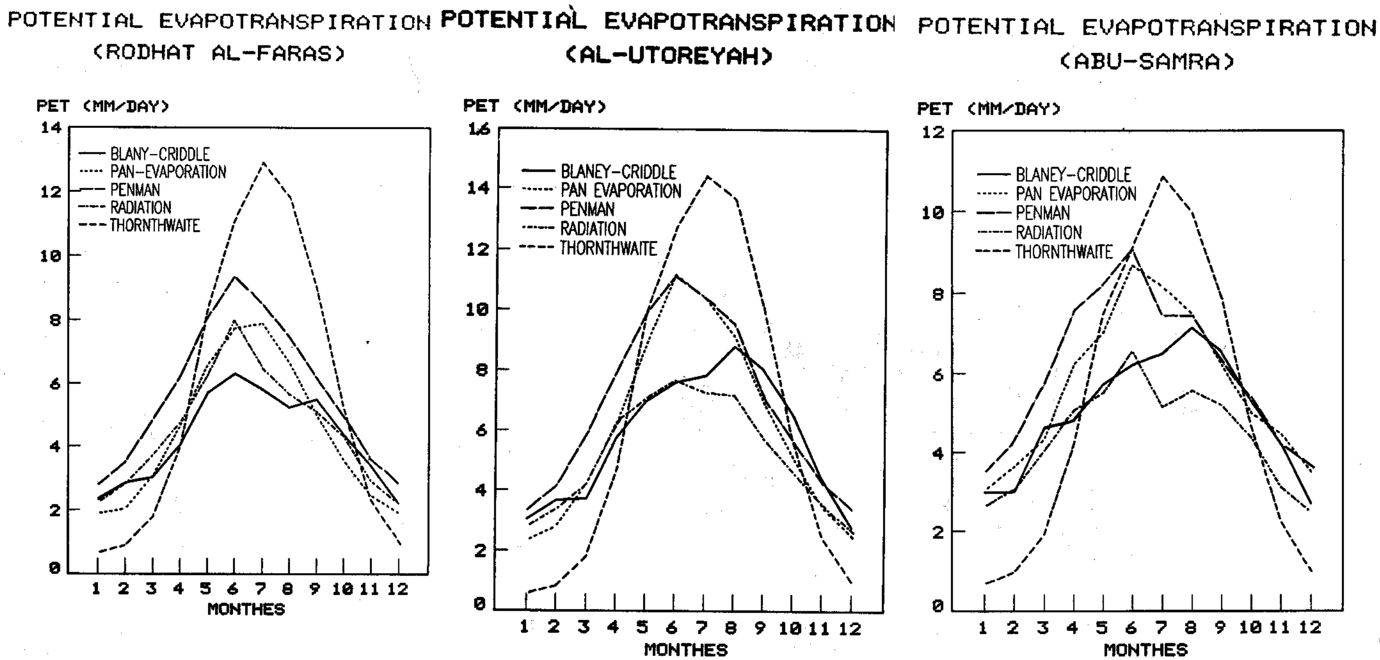

Fig. (3) : Estimates of mean monthly potential evapotranspiration.

Table (1). Calculated mean monthly potential evapotranspiration rates in mm/day.

Station (1): Rodhat Al-Faras						
Month	**Blaney-Criddle**	**Thornth-waite**	**Pan Evap.**	**Radiation**	**Penman**	**Average(1)**
Jan.	2.32	0.67	1.88	2.25	2.77	2.31
Feb.	2.86	0.90	2.03	2.81	3.50	2.80
Mar.	3.02	1.78	3.07	3.71	4.83	3.66
Apr.	4.04	3.97	4.63	4.75	6.18	4.90
May.	5.67	8.31	6.56	6.23	8.04	6.63
Jun.	6.30	11.13	7.73	7.99	9.38	7.85
Jul.	5.79	12.90	7.89	6.49	8.50	7.17
Aug.	5.23	11.82	6.64	5.66	7.47	6.25
Sep.	5.49	8.99	5.01	5.10	6.17	5.44
Oct.	4.38	5.22	3.55	4.31	4.94	4.30
Nov.	3.39	2.29	2.44	2.90	3.62	3.09
Dec.	2.20	1.02	1.92	2.19	2.83	2.29
Average(2)	4.22	5.75	4.45	4.53	5.69	4.72

Station (2): Al-Utoreyah						
Month	**Blaney-Criddle**	**Thornth-waite**	**Pan Evap.**	**Radiation**	**Penman**	**Average(1)**
Jan.	3.03	0.58	2.32	2.77	3.34	2.87
Feb.	3.66	0.81	2.80	3.38	4.13	3.49
Mar.	3.71	1.80	4.22	4.18	5.85	4.49
Apr.	5.75	4.59	6.15	6.25	7.91	6.52
May.	6.95	9.86	8.80	7.06	9.85	8.17
Jun.	7.59	12.68	11.18	7.67	11.11	9.39
Jul.	7.81	14.44	10.38	7.28	10.40	8.97
Aug.	8.81	13.67	9.15	7.16	9.55	8.67
Sep.	8.02	10.08	6.97	5.76	7.12	6.97
Oct.	6.56	5.67	5.14	4.65	5.68	5.51
Nov.	4.39	2.46	3.49	3.53	4.30	3.93
Dec.	2.77	0.79	2.51	2.67	3.41	2.84
Average(2)	5.75	6.47	6.09	5.20	6.89	5.99

Table (1). (continued)

Station (3): Abu-Samara						
Month	Blaney-Criddle	Thornth-waite	Pan Evap.	Radiation	Penman	Average(1)
Jan.	3.00	0.70	3.04	2.61	3.49	3.04
Feb.	2.98	0.97	3.62	3.06	4.25	3.48
Mar.	4.61	1.92	4.32	4.02	5.72	4.67
Apr.	4.81	4.21	6.20	5.05	7.53	5.90
May.	5.71	7.50	7.02	5.50	8.20	6.61
Jun.	6.21	9.12	8.68	6.55	9.09	7.63
Jul.	6.48	10.88	8.16	5.12	7.44	6.80
Aug.	7.13	9.98	7.48	5.55	7.42	6.90
Sep.	6.53	7.89	6.20	5.18	6.30	6.05
Oct.	5.26	4.64	4.99	4.36	5.38	5.00
Nov.	4.22	2.24	4.45	3.12	4.21	4.00
Dec.	2.70	1.03	3.51	2.46	3.64	3.08
Average(2)	4.97	5.09	5.64	4.38	6.06	5.26

(1) Estimates by Thornthwaite method were excluded in computing the average monthly values of each station.

(2) Average potential evapotranspiration in mm/day over the year.

Table (2). Difference in micro-climates between Al-Utoreyah and Rodhat Al-Faras.

Variable	Al-Utoreyah	Rodhat Al-Faras	Ratio
Mean air temperature (°C)	26.6	26.0	1.02
Mean radiation (g/cal./cm^2)	449.6	473.2	0.95
Mean wind speed (km/day)	251.9	115.1	2.19
Mean relative humidity (%)	58.2	62.7	0.93
Total pan evaporation (mm)	3717	2509	1.48
Estimated total (PET) (mm)			
1. Blaney-Criddle	2099	1540	1.36
2. Pan Evaporation	2223	1624	1.37
3. Radiation	1898	1653	1.15
4. Penman	2515	2077	1.21
(Avg. of four Methods)	2184	1723	1.27

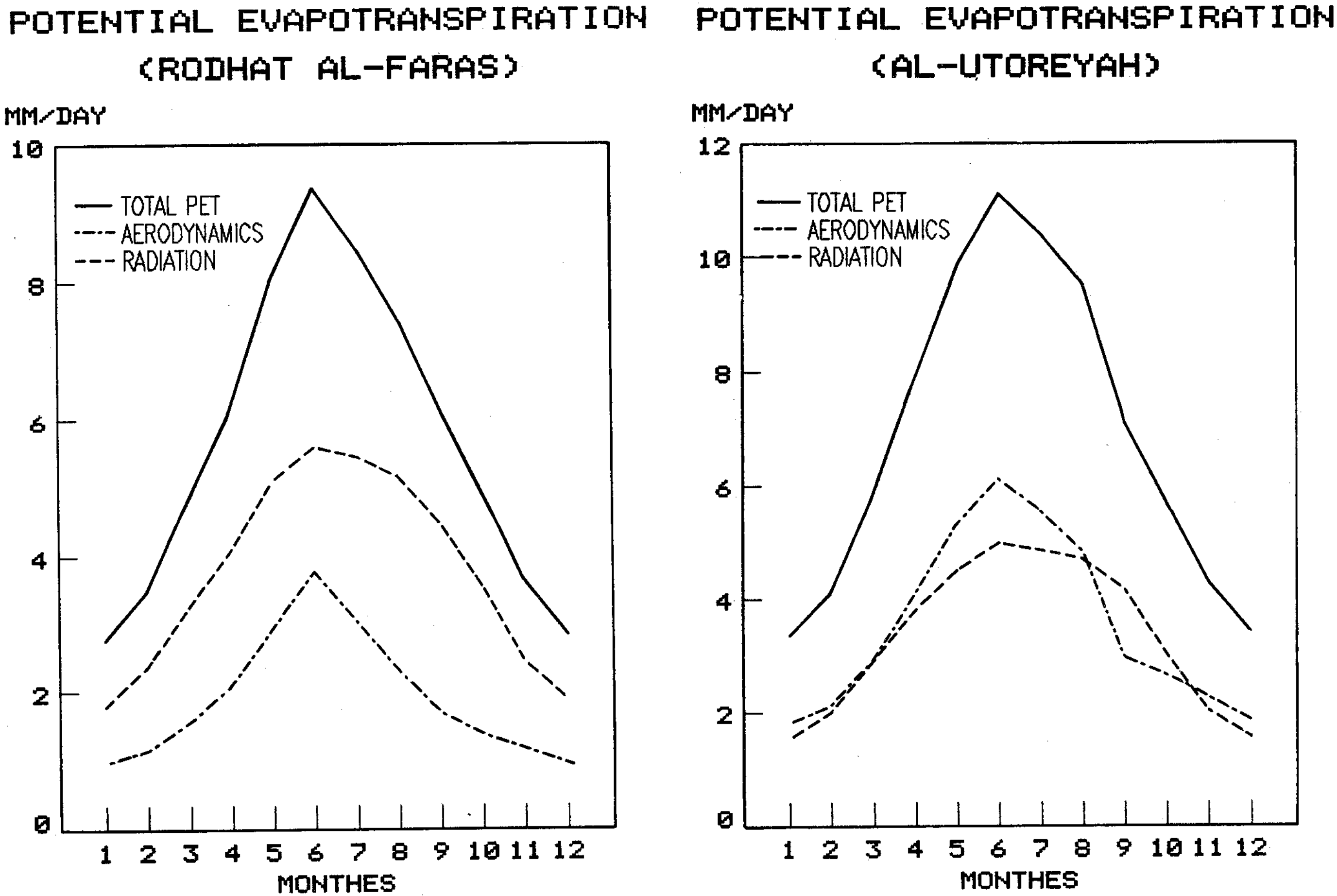

Fig. (4) : Contribution of aerodynamic and radiation terms in Penman combination method.

CONCLUSIONS

The results shown indicated high variability between the five estimation methods considered. This is partially due to inherent differences in the background of each method and also due to the fact that no attempt was made to calibrate parameters in the different equations for local conditions. While the Blaney-Criddle and Thornthwaite are temperature dependent methods, the radiation method is an energy balance expression and the Penmann Method is a combination approach that incorporates radiation and aerodynamic effects.

The different methods systematically gave average higher potential evapotranspiration values for the central part of Qatar followed by south-western areas and finally by the northern areas. While the average monthly temperature remained constant for the three (AHM) Stations, variations in the levels of wind speed, relative humidity and cloud cover (radiation) were noticed. The relative humidity variation could be attributed to the proximity of the sea coast and the existance of surrounding agricultural areas. The comparison of the data of the central and northern areas suggested that 7% decrease in relative humidity and 219% increase in wind speed had created an increase in the total potential evapotranspiration of 27%. This difference illustrated the importance of adjusting the micro-climatic conditions in arid areas. It is very important to establish good wind breakers around irrigation areas within a desert environment. Again, the existance of a small irrigation area surrounded by large desert area could subject it to severe advection effects and would tend to increase evapotranspiration rates. Therefore from the point of view of water economy it is advantageous to have few large irrigation areas instead of many scattered smaller areas which agrees with conclusions made by Eccleston et al [4]. One has to bear in mind the constraint imposed by the limited areal extent of the Rodat in the State of Qatar which varies between few hectares to a maximum of 60 hectares. Rodat (which make up the main agricultural soils of the country) are depressions where colluvial soils are accumulated to depths ranging from 30 cm to 150 cm.

The concept of potential evapotranspiration assumes a water treatment that does not stress the plant. Inherently it assumes a strategy of maximum yield. This can limit the applicability of the concept in arid areas with severe water shortage where a strategy of maximum yield per unit of water may look more attractive from the point of view of water economy. Under such treatment crop and soil coefficients to convert potential evapotranspiration into actual evapotranspiration are more complex to obtain as it introduces factors relating to crop yield response to water availability.

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