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A reference evapotransipiration model for arid region of Rajasthan

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ABSTRACT : A study was conducted to develop a regional reference evapotranspiration (ET_0) model for Jodhpur (28°18'N latitude and 73°01'E longitude at 224 m amsl in arid zone of Rajasthan. Eight standard ET_0 models based on different criteria were used to arrive normal ET_0 estimates of the study area. The normal ET_0 (as standard value) was then used to develop regional model for estimation of ET_0 i.e. ET_0 (mm day^{-1}) = 0.206 T - 0.036 RH + 1.080 WV + 0.223 SSH - 2.333 (r = 0.988) where T, RH, SSH and WV are mean temperature (°C), relative humidity (%), wind velocity (m s^{-1}) and sunshine hours (hrs.) respectively. An attempt has also been made to understand the causative role of specific meteorological parameter (in isolation and in combinations) in expression of ET_0. Study indicates that temperature and wind velocity alone are the governing factors in arid areas to determine the evapotranspiration (r= 0.89 and 0.76, respectively). Duration of sunshine and mean relative humidity in isolation has a very weak relationship with ET_0 (r = 0.22 and 0.03, respectively). Temperature and wind velocity in combination (r = 0.91) explains most of the variation in ET_0. An attempt was also made to develop seasonal ET_0 model for greater accuracy. Models so developed are *'easy to use'* and provide flexibility to an individual for estimation of ET_0 depending on degree of accuracy needed and quantum of climatic data available. The developed regional ET model will be of immense use for estimating water requirement of different crops of arid zone of Rajasthan. The present study is based on analysis on long-term (30 years) measured meteoroligical data of the study area.

Key words : Arid region; Reference evapotranspiration; Regional model; Seasonal bias

Estiamation of evapotranspiration (ET_0) is of great imporatnce for the management of present and future water resources, and for solving many theoretical problems in the field of hydrology and meteorology. In the planning of irrigation project. ET_0 data are used as the basis for estimating the acreage of various crops, or combination of crops that can be irrigated with a given quantity of available water. Directe measurement of ET_0 requires special instrumentation for measurement of various physical parameters associated with it. Methods of direct measurement are often expensive and demanding in tems of accuracy of measurement. Owing to the difficulty of obtaining accurate field measurement, ET is commonly computed from weather data. Campbell (1977) and Eagleson (1978) have provided good description of the primary variables determining dvapotranspiration. They provided extensive mathematical review, which integrate the principle of evapotranspiration in to hydrological cycle. Doorenbos and Poruitt (1977) have defined the term 'reference crop evapotranspiration (ET_0)' to avoid ambiguity involved in the interpretation of evapotranspiration. There are many methods reported by Wilson (1974), Doorenbos and Pruitt (1977), Subramanya (1984), Michael (1986), Mavi (1986), Singh (1989), NIH (1989) etc. for estimation of evapotranspiration. In search of best ET_0 model for global application many researchers (Jensen 1974. Hargreaves and Samani 1985, Al-Sha'lan and Salih 1987, Rao and Murty 1988, Mohan 1991, Amatya *et al.* 1995) have compared different evapotranspiration models. However, no single existing metod using meterological data in universally adaptable under all climatic regimes. Relationships were so developed often subjected to rigorous local calibrations and proved to have limited global validity. Therefore, use of specific method is limited by the conditions in which they have been developed. Large number of data requirement also limits the application of may of these methods. Keeping in view the complexity, accuracy and data requirements of prediction methods an attempt has been made to develop a regional model for estimation of Reference Evapotranspiration (ET_0) for arid region of Rajasthan.

MATERIAL AND METHODS

Study area and its problems

The study has been conducted for Jodhpur (26°18'N latitude and 73°01E longitude at 224 m amsl) located in heart of arid zone of Rajasthan. Rajasthan state account for about 61% of country's total arid zone and is spread over eleven western districts of the state. This is the mosr arid part of the state where the annual rainfall varies from 10 to 40 cm quite often erratic (CV>50%), so much so, that the entire rainfall of the year may fall on a single day and the rest of the year may be dry. The quantity and quality of water available from various sources such as surface water and ground water are not sufficient even for drinking purposes. Over and above insufficient quantity, the ground water is moderately to highly saline over large area. A dominnantly sandy terrain and the disorganized drainage makes the problem more acute. Looking to low irrigation potential being explored and small number of water resources it is utmost necessary to estimate pecisely the amount of water required for crop production and other uses so that appropriate planning can be done for irrigation and other schemes.

Selection of methods for estimation of reference evapotranspiration

The primary choice for selection of particular method for estimation of ET_0 depends on degree of accuracy needed, physics of parameters used in the method, availability of meteorological parameters and last but not least simplicity of the calculation procedure. Based on above criteria eight methods have been selected for estimation of ET estimates. The methods selected for estimation of evapotranspiration includes Blaney-Criddle (BLC), Radiation (RAD), modified Penman (MPM), pan evaporation (PAN), Penman-Moneteith (P-M), Christiansen (CHN), Turc (TRC), and Thornthwaite (THW) methods. FAO Bulletin No. 24 has recommended Blaney-Criddle, Radiation, modified Penman and pan evaporation methods for its worldwide application for estimation of evapotranspiration. Therefore, these four methods are selected for the present study. Later on FAO Bulletin No. 56 has recommended superiority of Penman-Monteith method over others for estimation of evapotranspiration hence this method was also included in the present study. Christiansen methods has a default option for missing meteorological parameter and IMD has used this method for estimation of evapotranspiration for many stations in India. Therefore, it was included for the study. Thornthwaite and Turc method are relatively simple and requires very few parameters, so they were also considered for the present study. Since selected models of ET_0 are standard and well known, their details can be found in FAO Irrigation and Drainage paper no. 24 and 56 or any standard book as referred in introduction part of this paper.

Estimation of reference evapotranspiration

A year was divided into 52 Standard Meteorological Weeks (SMWs) following the CWS-1 format. The weekly records of climatic parameters i.e. temperature, humidity, wind velocity, sunshine hours and pan evaporation were obtained for 30 years (1967-1999, except 70, 75, 76) from Indian Meteorological Department, Pune. These data were checked for the continuity of series. The normal ratio averaging method was employed to fillup the gaps in the data series. For this purpose mean value of meteorological parameter for the same week of the preceeding year and following year was used. Thereafter, the data series for various meteorological parameters for corresponding weeks were added together and average value for respective weeks were found. For temperature and relative humidity, the weekly average of maximum and minimum were obtained. The average value of temperature and relative humidity were then used to determine normal value of temperature and relative humidity. In this way, a 52 week data series for each meteorological parameter i.e. weekly temperature, relative humidity, sunshine hours, wind velocity and pan

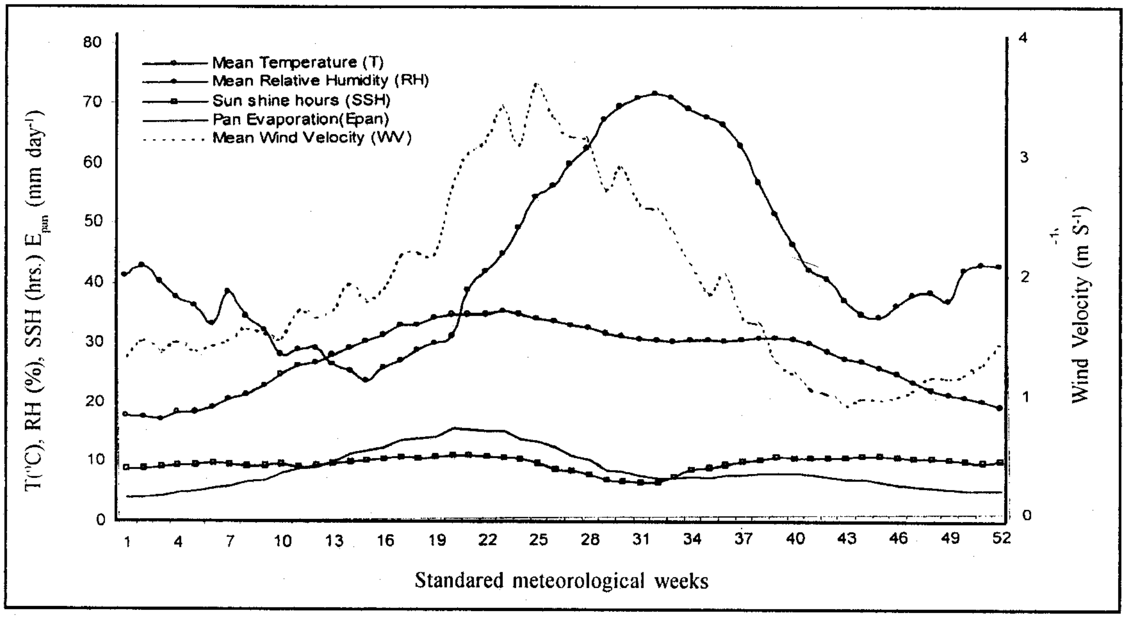

Fig. 1. *Variation of normal meteorlogical parameters for Jodhpur.*

Table 1. ET_0 *of Jodhpur by selected* ET_0 *models (mm day*$^{-1}$*).*

W.No.	P-M	MPM	BLC	RAD	CHN	TRC	THW*	PAN	AVR
1	3.09	3.72	3.72	4.04	3.2	3.37	1.00	2.37	3.36
2	3.15	3.79	3.61	3.97	3.25	3.27	0.92	2.41	3.35
3	3.12	3.95	3.99	4.12	3.17	3.41	0.88	2.46	3.46
4	3.34	4.16	3.96	4.29	3.34	3.64	1.09	2.74	3.64
5	3.77	4.64	4.36	4.98	3.63	4.19	1.05	2.8	4.05
6	3.98	4.94	4.61	5.22	3.73	4.49	1.20	3.07	4.29
7	4.09	5.44	4.68	5.14	3.97	4.28	1.53	3.34	4.42
8	4.31	5.55	4.91	5.32	4.13	4.55	1.75	3.58	4.62
9	5.01	6.26	5.44	6.28	4.72	5.4	2.62	3.76	5.27
10	5.28	6.42	6.02	6.64	4.92	5.91	3.41	4.22	5.63
11	5.68	6.71	6.06	6.6	5.37	5.81	4.21	4.64	5.84
12	5.72	6.93	6.21	6.76	5.41	5.94	4.49	4.79	5.97
13	6.53	7.53	7.06	7.76	6.18	6.84	5.52	5.11	6.72
14	7.13	8.02	7.93	8.11	6.63	7.15	6.37	5.66	7.23
15	7.12	8.17	7.8	8.31	6.7	7.48	7.42	5.98	7.37
16	7.38	8.4	8.05	8.47	6.92	7.46	8.21	6.6	7.56
17	8.04	9.02	8.92	8.77	7.53	7.55	9.90	6.85	8.10
18	8.29	9.5	8.99	8.9	8.02	7.55	10.85	6.98	8.32
19	8.41	10.07	9.29	9.17	8.19	7.68	12.05	7.17	8.57
20	9.32	10.47	9.83	9.4	8.85	7.64	12.83	7.76	9.04
21	9.34	11	9.47	9.22	9.02	6.99	12.80	7.87	8.99
22	9.32	10.91	9.88	9.12	9.27	6.7	12.75	7.87	9.01
23	9.48	10.93	9.71	8.99	9.49	6.42	13.53	7.92	9.02
24	8.65	9.81	8.98	8.42	9.08	5.91	12.68	7.34	8.31
25	8.51	9.62	8.52	7.96	9.29	5.54	11.81	7.08	8.07
26	7.73	8.84	7.55	7.2	9.13	5.17	11.50	6.75	7.48
27	7.17	8.06	7.11	6.83	8.84	5.04	10.60	6.13	7.03
28	6.71	7.96	6.65	6.41	8.68	4.85	10.20	5.72	6.71
29	5.81	6.79	5.76	5.56	8.11	4.49	9.17	4.86	5.91
30	5.66	6.75	5.65	5.4	8.18	4.4	8.52	4.77	5.83
31	5.21	6.34	4.97	4.97	7.4	4.18	7.81	4.37	5.40
32	5.08	6.48	4.84	4.88	7.62	4.13	7.48	4.11	5.31
33	5.21	6.73	5.11	5.3	7.41	4.44	7.39	4.17	5.48
34	5.5	7.16	5.18	5.82	7.21	4.8	7.60	4.33	5.71
35	5.19	6.81	5.16	5.56	6.78	4.59	6.76	4.23	5.47
36	5.32	6.88	5.26	5.78	6.91	4.69	6.64	4.43	5.61
37	5.44	6.9	5.7	6.13	6.6	4.87	6.91	4.47	5.73
38	5.67	6.69	6.13	6.48	6.6	5	7.00	4.54	5.87
39	5.54	6.61	6.18	6.71	6.17	5.12	6.98	4.46	5.83
40	4.77	5.76	5.82	5.96	5.52	4.78	6.62	4.36	5.28
41	4.55	5.58	5.46	6	5.26	5	6.07	4.16	5.14
42	4.41	5.05	5.59	5.97	5.02	5.03	5.05	3.85	4.99
43	4.18	4.96	5.19	5.95	4.75	5.19	4.38	3.57	4.83
44	3.54	4.42	4.93	5.21	4.17	4.7	3.69	3.46	4.35
45	3.43	4.31	4.76	5.15	4.02	4.65	3.13	3.23	4.22
46	3.34	4.11	4.79	4.9	3.92	4.38	2.74	2.97	4.06
47	3.31	3.98	4.49	4.69	3.81	4.12	2.21	2.74	3.88
48	3.02	3.61	4.06	4.25	3.47	3.74	1.75	2.65	3.54
49	2.96	3.75	4.25	4.16	3.37	3.72	1.54	2.5	3.53
50	2.89	3.5	3.7	3.93	3.33	3.37	1.38	2.43	3.31
51	2.92	3.61	3.81	3.82	3.32	3.25	1.25	2.35	3.30
52	2.98	3.59	3.68	3.87	3.3	3.23	1.01	2.37	3.29

* Not included in average

evaporation were generated (Fig. 1). Eight standard methods as mentioned above were used to estimate ET_0. After giving due consideration to the merits and applicability of different methods, normal ET_0 were obtained for the study area (Table1). The normal ET_0 (as standard value) were then used to develop regional model of ET_0 for arid zone of Rajasthan.

RESULTS AND DISCUSSION

Performance of different models for estimation of ET_0 for the study area is presented in Table 1. The models selected for estimation of ET_0 are based on radiation, temperature, combination and multiple correlation approaches. Thus, ET_0 calculated by selected models integrates various approaches towards estimation procedure. Perusal of Table 1 indicated that Thornthwaite methods underestimate ET_0 in winter and over estimate in summer compared to other methods.The obvious reason behind is this that Thornthwaite method considered temperature as an only index of evapotranspiration and average temperature in winter are generally very low and high in summer. The role of other meteorological parameters like wind velocity, relative humidity in conjuction with temperature causes a significant variation in magnitude of evapotranspiration. So Thornthwaite method was excluded while taking average value of all methods for estimating normal evapotranspiration of the study area. The normal values of ET_0 (as standard value) has been then used to develop regional ET_0 model for arid zone of Rajastan. Multiple regression analysis has been duone at 95% level of confidence to develop the relationships between principle climatic parameters and normal ET_0 (equation 1).

$$ET_0 = 0.206\,T - 0.036\,RH + 1.080\,WV + 0.223\,SSH - 2.333 \quad ....(1)$$

Where T, RH, SSH and WV are mean temperature (°C), mean relative humidity (%), mean wind velocity (ms^{-1}) and mean sunshine hours (hrs.) respectively. Comparison of observed and estimated (by Eq. 1) ET_0 for the study area is presented in Fig. 2.

Sensitivity of meteorological parameter for developed model

Each individual meterological parameter has its own contibution towards evapotranspiration. These parameters in isolation and in combination cause different magnitude of evapotranspiration. So the effect of individual climatic parameter was also studied in isolation and incombination, and different sets of equations have been developed for estimation of ET_0 (Equations 2-7).

$$ET_0 = 0.284\,T - 1.961\ (r = 0.893) \quad ....(2)$$
$$ET_0 = 0.339\,SSH + 2.654\ (r = 0.227) \quad ....(3)$$
$$ET_0 = -0.004\,RH + 5.893\ (r = 0.032) \quad ....(4)$$
$$ET_0 = 1.766\,WV + 2.339\ (r = 0.762) \quad ....(5)$$
$$ET_0 = 0.227\,T + 0.579\,WV - 1.524\ (r = 0.910) \quad ....(6)$$
$$ET_0 = 0.180\,T + 1.090\,WV + 0.571\,SSH - 6.372\ (r = 0.975) \quad ....(7)$$

Proposed equations provide an insight to the role of different climatic parameters in isolation and in combination for estimation or evapotranspiration. From equations 3 and 4, it clear that duration of sunshine and mean relative humidity in isolation are not a very clear indicator of ET_0 as indicated by their multiple 'r' values i.e. 0.227 and 0.032 respectively. Similarly, equation 2 and 5 indicate that temperature and wind

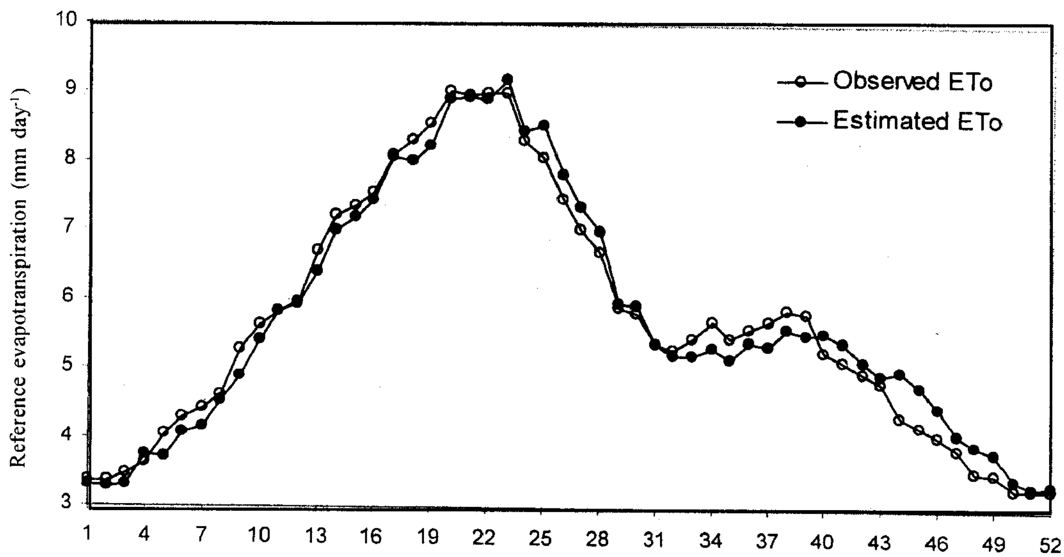

Fig. 2. *Comparison of observed and estimated (four parametric model i.e. Eq. 1) ET_0 for Jodhpur.*

Table 2. *Multiple Regression Equations for Prediction of Evapotranspiration (ET_0) for Jodhpur on annual and seasonal basis with different sets of independent meteoroligical parameters.*

Independent Parameters	Annual (Week No. 1-52)	Summer (Week No. 10-26)	Monsoon (Week No. 27-44)	Winter (Week No. 45-52 and 1-9)
Temperature (T)	ET_0 = 0.284 T - 1.961 (r = 0.893)	ET_0 = 0.320 T - 2.303 (r = 0.963)	ET_0 = 0.352 T - 4.832 (r = 0.925)	ET_0 = 0.144 T + 0.974 (r = 0.578)
Wind Velocity (WV)	ET_0 = 1.766 WV + 3.339 (r = 0.762)	ET_0 = 1.178 WV + 4.837 (r = 0.727)	ET_0 = 0.591 WV + 4.422 (r = 0.745)	ET_0 = 0.764 WV + 2.844 (r = 0.279)
Sunshine Hours (SSH)	ET_0 = 0.339 SSH + 2.654 (r = 0.227)	ET_0 = 1.112 SSH - 3.119 (r = 0.637)	ET_0 = 0.143 SSH + 6.750 (r = 0.354)	ET_0 = 0.905 SSH - 4.471 (r = 0.500)
Relative Humidity (RH)	ET_0 = -0.004 RH + 5.893 (r = 0.032)	ET_0 = 0.041 RH + 6.302 (r = 0.385)	ET_0 = 0.025 RH + 4.125 (r = 0.525)	ET_0 = -0.138 RH + 9.061 (r = 0.834)
Two Parameters	ET_0 = 0.227 T + 0.579WV -1.524 (r = 0.910)	ET_0 = 0.337 T + 0.331WV - 3.245 (r = 0.970)	ET_0 = 0.349 T + 0.007 WV - 4.764 (r = 0.925)	ET_0 = 0.006 T + 0.135WV - 8.840 (r = 0.834)
Three Parameters	ET_0 = 0.180 T + 0.190 WV + 0.571 SSH-6.372 (r=0.975)	ET_0 = 0.234 T + 0.227 WV + 0.560 SSH - 5.629 (r = 0.992)	ET_0 = 0.364 T + 0.187 WV - 0.015 RH - 4.660 (r = 0.944)	ET_0 = 0.025 T - 0.181 RH - 0.754 SSH+17.106 (r= 0.872)
Four Parameters	ET_0 = 0.206 T - 0.036 RH + 1.080 WV + 0.223 SSH - 2.333 (r = 0.988)	ET_0 = 0.220 T - 0.038 RH + 0.809 WV + 0.354 SSH - 3.276 (r = 0.995)	ET_0 = 0.224 T - 0.0008 RH + 0.723 WV + 0.307 SSH - 5.026 (r = 0.982)	ET_0 = 0.171 T - 0.073 RH + 1.878 WV - 0.063 SSH + 1.038 (r = 0.971)

Where

ET_0 = Reference Evapotranspiration in mm day^{-1}

T = Mean Temperature in ^0C

RH = Mean Relative Humidity in %.

SSH = Duration of bright Sunshine Hours in hrs.

WV = Wind Velocity at 2 m height in m s^{-1}

velocity are governing factors in arid areas to determines the evapotranspiration. Temperature and wind velocity in combination (equation 6) explains most of the variation in ETO.

Seasonal biases of prediction equations

Evapotranspiration is an integrated effect of princial meteorological parameters. Contribution of individual parameter for causing evapotranspiration depends on the related magnitude of other parameters, which is turn depends on season or vice versa. Therefore, to minimize the effect of variation of meterological parameters during three seasons, meteorological parameters have been analyzed on seasonal basis. An attempt has been made to develop prediction equation based on main three seasons viz. Winter, Summer and Monsoon. Based on analysis of variation of meteorological parameters, whole year has been divided into treen main seasons. Summer season from 10^{th} to 26^{th} meteorological week (March to June), Monsoon season from 27^{th} to 44^{th} meteorolical week (July to October) and Winter season from 45^{th} to 52^{th} and 1^{st} to 9^{th} meteorological week (November to February) of the year.

Multiple linear regression analysis was carried out with seasonal reference evapotranspiration and normal meteorological parameters of corresponding season. Regression analysis yielded following prediction equations ;

1. Summer season (10^{th} to 26^{th} meteorological week)
   ET_0 = 0.220 T - 0.038 RH + 0.809 WV + 0.354 SSH - 0.276.................. (8) (r = 0.995)
2. Monsoon season (27^{th} to 44^{th} meteorological week)
   ET_0 = 0.224 T - 0.0008 RH + 0.723 WV + 0.307 SSH - 5.026..................... (9) (r = 0.982)
3. Winter season (45^{th} to 52^{th} and 1^{st} to 9^{th} meteorological week)
   ET_0 = 0.171 T - 0.073 RH + 1.878 WV + 0.063 SSH - 1.308..................... (10) (r = 0.971)

Most of the crops are sown in well-defined seasons. Above mentioned prediction equations can be used for further refined estimation of crop water requiremnet for season and region specific. Again in individual seasons effect of individual meteorological parameter in isolation and in combination were studied and different set of equations have developed.. All annual and seasonal evapotranspiration prediction equations so developed for the study area are presented in Table 2.

Estimation of evapotranspiration by empirical formulas is time consuming, costly and laborious process, which involve large number of climatic parameters. This study has provided an useful ready to use tool for estimating principle crop water requirement i.e. evapotranspiration for Jodhpur district of Rajasthan. Proposed parametric relationships provide flexibility to an individual for estimation of ET_0 depending on degree of accuracy needed and quantam of climatic data available for arid zone of Rajasthan.

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