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Comparison of Temperature-Base Methods For Calculating Reference Evapotranspiration With Standard Penman-Monteith Method

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ABSTRACT

Various methods are available to estimate reference evapotranspiration (ETo) from standard meteorological observations. The Penman-Monteith method is considered to be the most physical and reliable method and is often used as a standard to verify other empirical methods. This study estimates and compares the monthly ETo calculated by 4 other methods at Uben weather stations for the last 10 yr climatic data.. The Penman-Monteith method is used here as a reference, and its spatial and temporal differences with the, Thornthwaite , Blaney-criddle,Kharuffa and Romanenko method are evaluated. The results comparision are done by using statistical quantitative measure like Root Mean Square Error (RMSE), Index Of Aggrement(d),Co-efficient of determination(R2), Correlation coefficient(r). Overall Thornthwaite are more correlate with the Penman-Monteith estimates because index of aggrement and coefficient of determination(R2) were high 0.513 and 0.895 compared to other method used for comparison.

Keywords : Reference evapotranspiration, Penman-Monteith • Thornthwaite , Blaney-criddle, Kharuffa and Romanenko method, Statistical quantative measure.

INTRODUCTION

Evapotranspiration (ET) is an important component of the hydrological cycle and is essential for understanding land surface processes in climatology. In ecosystem and agriculture studies productivity is closely linked to actual Evapotranspiration ($ET_{a)}$. In practice, estimation of actual ET is often made by using information about potential ET and soil moisture. The potential ET, defined as 'wet-surface evaporation', is the ET governed by available energy and atmospheric conditions, the water availability is not a limiting factor. Thus, potential ET is a function of atmospheric forcing and surface types. In order to remove the influence of surface types, the concept of reference evapotranspiration (ET_o) was introduced to study the evaporative demand of the atmosphere which is independent of crop type, crop development and management practices (Allen et al. 1998). ET_o is defined as the potential ET of grass. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET_o to a specific surface (grass) provides a reference from which ET for other surfaces can be estimated (Doorenbos & Pruitt 1977, Allen et al. 1998).

NEED TO STUDY: Water is the greatest resource of the humanity. It is, therefore, the responsibility of all concerned to utilize it in the most economical manner. Besides various uses of water, there largest use in the world is made for irrigating lands. With growing population the demand of water for various purposes is ever increasing. Economy in use of water and proper application necessitates measures for limiting supply of water to individual field to that which is required for optimum growth of the crop. The upper limit of crop production is set by the climate conditions and the genetic potential of the crop. The extent to which this limit can be reached will always depend on how finely the engineering aspects of water supply are in tune with biological needs for water in crop production. It is necessary to carry out micro planning through interdisciplinary approach considering the crop water requirement, soil type, climate condition, available soil moisture, the root zone depth of crop, the maximum permitted depletion of available soil moisture and evapotranspiration demand of the crop to achieve optimum production per unit land area and unit volume of water. The efficient use of water in crop production can only be attained with adequate quantity and timely supply schedule.

OBJECT: (1) To find the reference evapotranspiration with FAO-56 Penman-montieth method. Thornthwait method Blaney-Criddle method, Romanenko method,Kharrufa Method .

(2) To compare the various temperature based models to find reference evapotranspiration with FAO-56 Penman-montieth method estimate by using the statistical quantitative measure like Root Mean Square Error (RMSE), Index Of Aggrement(d),Co-efficient of determination(R^2), Correlation coefficient(r).

DATA AND METHODS:

Data On Climate : Monthly climate data from 2001 to 2010 at Uben meteorological stations situated at longitude 70° 38' N and latitude 21° 37' E in India was used in this study. They include the data needed to calculate ET_o, the Minimum Temperature, Maximum Temperature , Relative Huminity,Wind Speed and Rain Fall were collected from State water Data Center, Gandhinagar. State ,Gujarat.

Reference Evapotranspiration Calculation Method

The Penman-Monteith method is recommended as the sole standard by the FAO (Allen et al. 1998). The classic Penman-Monteith method combines both energy and mass balances to model ET_o. It is based on fundamental physical principles, which guarantee the universal validity of the method. However, it needs a number of meteorological variables which may not be available everywhere. In this study, the PenmanMonteith method is used as a standard to evaluate the performance of other methods.

· The combination formula recommended by the Expert Consultation on FAO Methodologies for crop water requirements derived by combining the equation of aerodynamic resistance and surface resistance is started below. The Penman-Montieth equation is given below.

FAO-56 Penman- Montieth Method:

$$ET_0 = \frac{0.408.\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

ET_0=reference crop evapotranspiration

[mm day^{-1}]

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}]

G = soil heat flux density [MJm^{-2} day-1]

As G is negligible here it is taken as 0

T = mean daily air temperature at 2 m height

u_2 = wind speed at 2 m height [m s^{-1}]

e_s = saturation vapour pressure [kPa]

e_s - e_a = saturation vapour pressure deficit [kPa]

Δ = slope of vapour pressure curve [kPa $°C^{-1}$]

γ = psychrometric constant [kPa $°C^{-1}$]

Thornthwaite Method :
Thornthwaite (1948) assumed that an exponential relationship exited between mean monthly temperature and mean monthly consumptive use.Thornthwaite proposed the following formula:

$e = 1.6 (10 t/ I)^a$

where e=unadusted potential evapotranspiration (cm/month) for month of 30 days each and 12 hours day time.

t =mean air temperature.(°C)

I = annual or seasonal heat index ,the summation of 12 values of monthly heat indices (i) = $(t/5)^{1.514}$

a = an empirical exponent computed by the equation

$=0.00000006751 I^3 -0.0000771 I^2 +0.01792 I +0.49239$

The unadjusted values of e are corrected for actual day light hours and day in a month which is ready in table form in appendix-F of book by A.M. Michael.

Blaney-Criddle method:
The Blaney and Criddle (1950) derived the formul for estimating ET_O is well known in the western USA and has been used extensively elsewhere also.

The usual form of the Blaney–Criddle equation converted to metric units is written as

$ET_o = p.(0.46T_{mean} + 8.13)$

Where ET_o= reference evapotranspiration (in mm) for the period in which p is expressed,

T mean= mean temperature in °C,

p = percentage of total daytime hours for the period used (daily or monthly) out of total daytime hours of 12 found from different latitude from book by R.H. Cuenca .

Romanenko method:
Romanenko (1986) derived an evapotranspiration equation based on the relationship using mean temperature and relative humality,

ETo $=0.0018\ (25+T_{mean})^2\ (100 - RH)$ ET_o = reference evapotranspiration (in mm/day)

Tmean= mean temperature in °C,

RH = percentage of mean monthly relative humality.

Kharrufa method:
Kharrufa (1985) derived an equation through correlation of ET_o/p and T in the form of

$ET_o = 0.34p(T_{mean})^{1.3}$

Where ET_o= reference evapotranspiration (in mm) for the period in which p is expressed,

Tmean= mean temperature in °C,

p = percentage of total daytime hours for the period used (daily or monthly) out of total daytime hours of 12 found from different latitude from book by R.H. Cuenca.

The data used for different method are as follow.

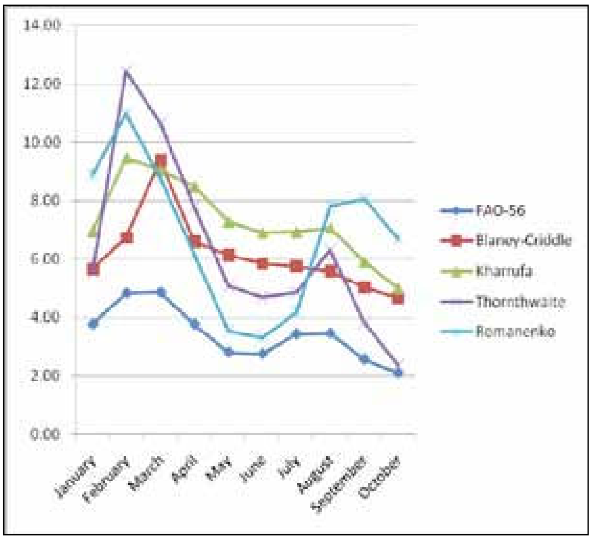
Month	T_{mean} °C	RH %	P	i	Correction factor for 'e'
January	17.48	48.75	0.247	06.65	0.940
February	23.00	46.16	0.280	10.08	0.895
March	27.88	47.04	0.270	13.49	1.030
April	34.18	47.71	0.282	18.36	1.055
May	32.17	55.21	0.292	16.76	1.140
June	29.83	65.65	0.302	14.95	1.120
July	26.52	77.78	0.302	11.80	1.150
August	26.21	79.03	0.290	11.79	1.110
September	27.03	74.18	0.280	12.90	1.020
October	29.07	55.48	0.260	14.37	1.000
November	26.09	48.49	0.250	12.20	0.920
December	22.94	51.51	0.250	10.06	0.930

Comparision of calculation of Reference Evapotranspiration ETo (mm/day) for different method for different month in Table A.

Table A

Month.	Penman-Montieth.	Thornthwaite.	Blaney-Criddle.	Romanenko.	Kharrufa.
January	2.09	0.83	3.99	5.55	3.46
February	2.76	2.28	4.86	7.44	5.21
March	3.77	5.52	5.66	8.89	6.95
April	4.84	12.43	6.73	10.99	9.45
May	4.87	10.63	9.39	8.78	9.05
June	3.77	7.80	6.60	6.19	8.48
July	2.81	5.08	6.14	3.54	7.28
August	2.75	4.69	5.85	3.30	6.89
September	3.43	4.86	5.76	4.19	6.92
October	3.46	6.30	5.59	7.81	7.06
November	2.56	3.82	5.03	8.07	5.90
December	2.09	2.35	4.67	6.69	4.99

Comparision of calculation of Reference Evapotranspiration ETo (mm/day) for different method for different month graphically in graph 1.0



Graph 1.0 X-Axis Month,

Y-Axis ETo (mm/month)

Comparision of evapotranspiration models: The following statistical quantitative measures were used for comparision study.

(I) Root Mean Square Error (RMSE) :

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(Pi\text{-}Oi)^2}{n}}$$

Where Pi = Computed value of ET_o estimated by a particular method.

Oi = Computed value of ETo estimated by a FAO-56 Penman-Montieth method.

(II) Index Of Aggrement (d) :
d= 1-

$$\left[\frac{\sum_{i=1}^{n}(Pi-Oi)^2}{\sum_{i=1}^{n}(Pi"+Oi")^2}\right]$$

Where Pi = Computed value of ETo estimated by a particular method.

Oi = Computed value of ET_o estimated by a FAO-56 Penman-Montieth method. Pi" = l Pi - Oavg. l

Oi"= lOi - Oavg. l

Oavg. = average value of ET_o estimated by a FAO-56 Penman-Montieth method.

(I) Co-efficient of correlation (r) :

$$r= =\frac{N\sum(Pi*Oi)-\sum Pi*\sum Oi}{\sqrt{\{N\sum Pi^2-(\sum Pi)^2\}}*\sqrt{\{N\sum Oi^2-(\sum Oi)^2\}}}$$

(II) Regression coefficient(b ,a) :

$$b = \ \&\ a=\bar{y}-b^*\bar{x} \quad \frac{N\sum(Pi*Oi)-\sum Pi*\sum Oi}{\sqrt{\{N\sum Pi^2-(\sum Pi)^2\}}}$$

(III) Coefficient of determination (R2)
: R2= r2

$$\left[\frac{(N\sum(Pi*Oi)-\sum Pi*\sum Oi)^2}{\sqrt{\{N\sum Pi^2-(\sum Pi)^2\}}*\sqrt{\{N\sum Oi^2-(\sum Oi)^2\}}}\right]$$

Computational Result for statical measures are in Table B

Table ;B

Method	RMSE	D	R	a	b	R2
Thornthwaite	3.325	0.513	0.9458	4.6975	0.261	0.8945
Blaney-Criddle	2.693	0.466	0.8391	3.9810	0.574	0.7040
Kharuffa	3.659	0.381	0.8979	5.2198	0.485	0.8062
Romanenko	3.988	0.355	0.5790	6.0322	0.231	0.3352

The result revealed that Thornthwaite method perform better than other three methods for calculating average monthly ETo values because index of agreement (d) and co-efficient of determination (R2) were high i.e.0.5130 and 0.8945 respectively than other method used in comparison.

The maximum potential yield of a crop is dependent primarily on the climate.The concept of reference evapotranspiration can be visualized as the integral effect of all climatic factors governing the evapotranspiration process.

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