IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

COMPUTATION OF EVAPOTRANSPIRATION - COMPARATIVE STUDY OF EMPIRICAL FORMULAE

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Abstract: Evapotranspiration (ET) is the combined process of evaporation from soil surfaces and transpiration from plant tissues. Its rate is a very significant factor for supporting irrigation management decision. ET is one of the most important components of hydrologic cycle which is calculated from records of climatic data and geographical attributes of a metrological station. Reference Evapotranspiration (RET) is an important index of hydrologic budgets at different spatial scales. This can be treated as a complex process in the hydrological cycle that influences the quantity of simple RET model survey widely according to regional climate conditions. It is often an important variable in estimating Actual Evapotranspiration (AET) in rain fall- run off and ecosystem modelling. Many RET estimation methods have been developed for different types of climatic data, and the accuracy of the method varies with climatic conditions. The international commission for irrigation and drainage(ICID)and food & agriculture organization (FAO) of the united nations have proposed using the Penman- Monteith method a the standard method for estimating Reference Evapotrapiration (RET)and for evaluating other methods.

The objective of the present study is to estimate daily, monthly, annual Reference Evapotranspiration(RET) and to compare different RET models with hat of standard equation Penman-Monteith to ensure the sensitivity. Sensitivity analysis is a useful and common way to study o n regional and seasonal behavior of RET in response to changes in climatic variables. The results were then calibrated with statistical variations like Root mean square error (RMSE),Mean bias error(MBE), Mean percentage error(MPE),Nashco-efficiency of Efficiency (NCE). In this study RET estimated by the Turc (R^2=0.254& NCE = 89.96%) method yielded better comparison onto that of standard Penman-Monteith method.

Index Terms - Reference evapotranspiration, empirical methods, methods comparison, Penman-Monteith formula.

INTRODUCTION:

Water shed is the land area that drains to a single body of water such a stream, lake, wetland or estuary. Hills or ridge lines often bound water sheds interior valleys collect precipitation on streams, rivers, and wet lands. These physical boundaries define the movement of water and delineate the water shed contains thousands of smaller water sheds. As the size of the water way decreases, the drainage area decreases.

A water shed has been chosen as an appropriate unit as it allows measurement conservation utilization of water, critical production Water shed as a unit has the following advantages.

- It allows accurate measurements and monitoring of components of water balance in hydrologic cycle, sediment, energy, heat, carbon and nutrient balances in a water shed ecosystem
- .It can provide network of monitoring stations with in a basin in a nested from or otherwise to track down the status of pollutants at different points.
- .Monitoring at watershed level helps in analysing impacts of current and future activities so as to plan area specific management potions or alternatives.

Evapotranspiration is the process whereby liquid water is converted to water vapour (vaporization)and removed from the evaporated surface. Water evaporates from the variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation. Transpiration consists of the vaporization of liquid water contained in plant tissues and the removal to the atmosphere. Evapotranspiration (ET) is the combined process of evaporation and transpiration from an extensive surface.

Reference evapotranspiration (RET) refers to evapotranspiration from a vegetative surface over which water data are recorded and allow developing a set of crop coefficients to be used to determine ET for other crops.

OBJECTIVES OF THE PROJECT:

The following are the objectives of the present study:

1. To study estimate the values of Reference Evapotranspiration (RET)of Himayathsagar watershed on daily, monthly, annual by using various relations.
2. To compare the performance of estimated RET with standard FAO-Penman-Monteith method by means of linear regression analysis.
3. To assess the statistical performance with the help of various statistical variances like Root Mean Square Error(RMSE). Mean Percentage Error (MPE),Mean Bias Error (MBE)and Co-efficiency Error (NCE).
4. To ensure the comparative study of Himayathsagar with standard FAO-Penman-Monteith Method (PMM)

STUDY AREA:

GENERAL

The present study area Himayathsagar water shed lies in Himayathsagar village of Rajendranagar Mandal in Ranga Reddy District of Telangana state, which has taken up for estimating the Reference Evapotranspiration (RET) by using various relations.

LOCATIONAND EXTENT:

The geographical extends of study arealatitude17^{0} 19$^{|}$,longitude 78^{0} 23$^{|}$. This study area lies in56K/7 numbered toposheet as per Survey of India (SOI).Himayathsagar is surrounded by Rajendranagar towards east, Aziz nagar towards west, Shamshabad towards south, Narsingh towards north. Hyderabad is the nearby city to Himayathsagar. The study area Himayathsagar is located 20 km away towards east from district headquarters Hyderabad and10km away from international air port towards south is well connected with road, railway and telecommunications. Total area of Himayathsagar is around7.6 square miles.

DATA COLLECTION AND PRIMARY ANALYSIS

GENERAL

To estimate the Reference Evapotranspiration (RET) by using various relations, Himayath sagar watershed is chosen which is in Rajendranagar Mandal of Ranga Reddy District. In order to estimate the RET for the chosen study are various metrological parameters like precipitation, maximum and minim temperatures ,high and low humidity, wind velocity, evaporation, duration of sunshine hours are required.

The above said parameters were collected on daily basis from the Walanthary, located at Rajendranagar. The data collected was sorted accordingly by year, month and day wise. All the statistical analyses were then carried out for stored data and were presented in the following sections.

DAILY MEAN S OF METROLOGICAL PARAMETERS:

Rainfall:

Observed daily rainfall data for the month of August during the years2003, 2008 and 2009 respectively was presented in the table 4.1 as a sample. It can be observed hat maximum rainfall was recording during the year 2008 with an intensity of 484.0mm, whereas the actual rainfall was observed to be around 200.00 mm to 450.00 mm during the years2003 and 2008.

Actual daily Rainfall in mm

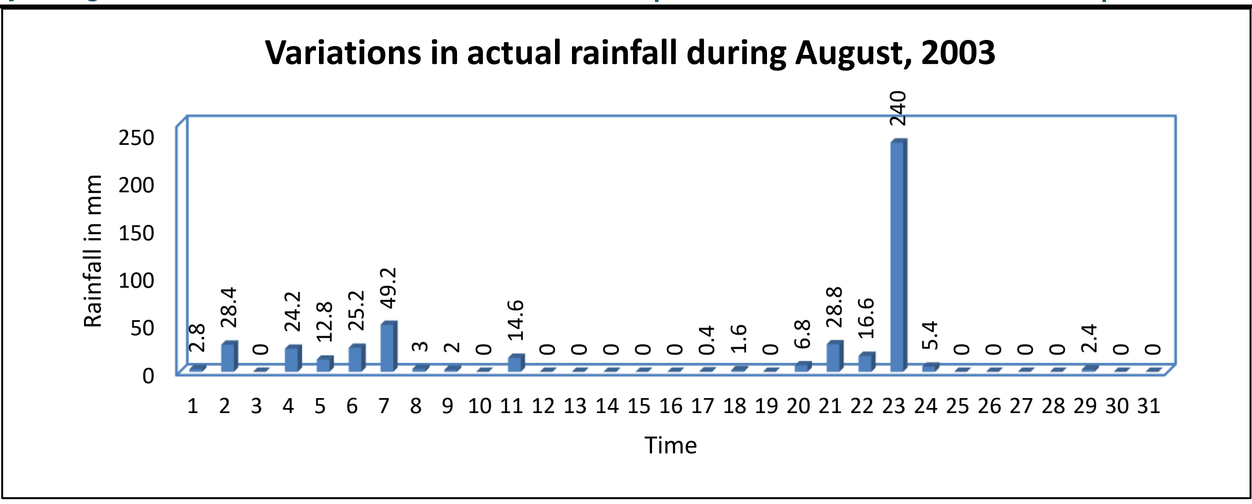
Year & Month	Date	Rain Fall (mm)	Year & Month	Date	Rain Fall (mm)	Year & Month	Date	Rain Fall (mm)
2003 August	1	2.8	2008 August	1	1.6	2009 August	1	0
	2	28.4		2	7.6		2	0
	3	0		3	42		3	0
	4	24.2		4	54		4	0
	5	12.8		5	3		5	0
	6	25.2		6	3.4		6	0
	7	49.2		7	0		7	0
	8	3		8	43		8	0
	9	2		9	70		9	0
	10	0		10	61.2		10	0
	11	14.6		11	4.6		11	1
	12	0		12	1.4		12	1.5
	13	0		13	0		13	1.8
	14	0		14	0		14	0
	15	0		15	0		15	11.8
	16	0		16	0		16	0
	17	0.4		17	21.8		17	1.2
	18	1.6		18	0		18	26.8
	19	0		19	0		19	0
	20	6.8		20	97		20	60
	21	28.8		21	9		21	6
	22	16.6		22	0		22	0
	23	240		23	0		23	1
	24	5.4		24	0		24	1
	25	0		25	0		25	9.6
	26	0		26	34		26	25.8
	27	0		27	0.2		27	16
	28	0		28	0		28	4.8
	29	2.4		29	12.4		29	0
	30	0		30	0		30	0
	31	0		31	17.8		31	35.4
Actual Rain Fall		464.2			484			203.7

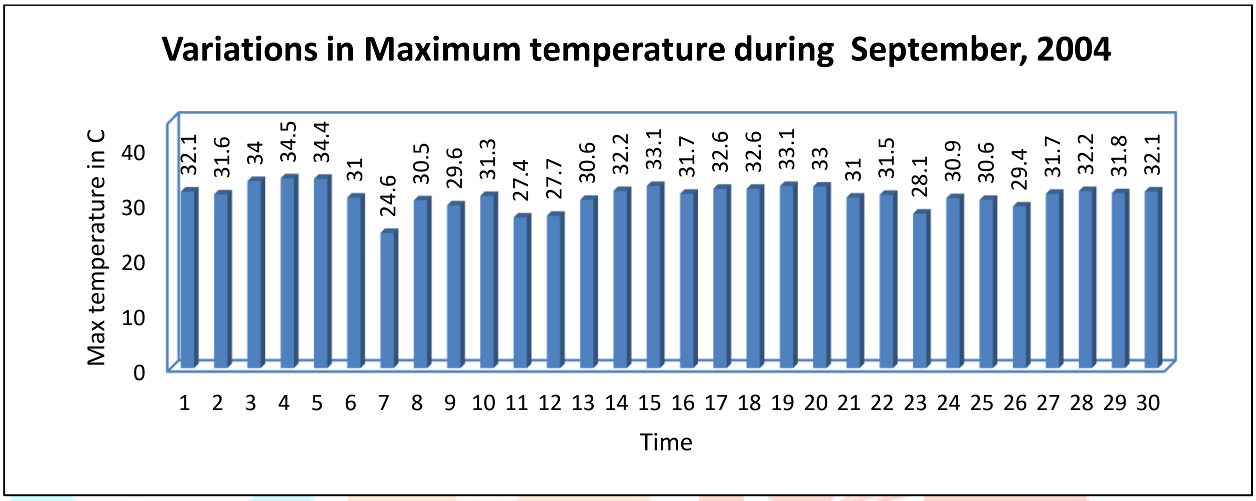
Maximum temperature:

Mean samples of maximum temperature data from 1st September to 31st September, during the years 2004,2006 and 2011 respectively was presented in the table 4.2.It can be observed that maximum temperature was observed to be around 30^{0}C - 32^{0}C during all the three years.

Daily maximum temperature in ^{0}C.

Year & Month	Date	Max Temp. in ^{0}C	Year & Month	Date	Max Temp. in ^{0}C	Year & Month	Date	Max Temp. in ^{0}C
2004 September	1	32.1	2006 September	1	29.6	2011 September	1	30
	2	31.6		2	32.2		2	29
	3	34		3	31.2		3	29.5
	4	34.5		4	31.1		4	29.5
	5	34.4		5	33.3		5	30
	6	31		6	31.9		6	30
	7	24.6		7	31.6		7	29
	8	30.5		8	32.2		8	30
	9	29.6		9	33.1		9	30
	10	31.3		10	32.6		10	30.5
	11	27.4		11	32.3		11	31
	12	27.7		12	32.6		12	31
	13	30.6		13	33.6		13	32
	14	32.2		14	32.4		14	31.5
	15	33.1		15	31.9		15	31
	16	31.7		16	29.6		16	32
	17	32.6		17	29.6		17	29
	18	32.6		18	29.1		18	30
	19	33.1		19	27.2		19	32
	20	33		20	23.7		20	31
	21	31		21	29.1		21	30
	22	31.5		22	28.1		22	31
	23	28.1		23	30.2		23	30.5
	24	30.9		24	29.7		24	30.5
	25	30.6		25	30.1		25	31.5
	26	29.4		26	29.1		26	32
	27	31.7		27	30.1		27	32
	28	32.2		28	30.1		28	33
	29	31.8		29	31.3		29	32.5
	30	32.1		30	31.4		30	30.5
Monthly Means		31.23			30.66666667			30.71666667





METHODOLOGY

RADIATION METHODS:

Solar radiation provides the energy required for the phase change of water and often limits the ET process when water is readily available. The solar radiation may be use directly to estimate Evapotranspiration or indirectly, to provide a measure of the net available radiation. A number of ET equations have been developed based on energy balance. Radiation methods use a measure of solar radiation coupled with air temperature to predict Evapotranspiration.In this section mainly two methods were taken for estimating RET namely Turc method (1961), and Hargreaves methods were considered for the estimation of RET.

1.Hargreaves method:

On the basis of data obtained from grasslysimeters, Hargreaves developed the following expression, which can be written as:

$RET = 0.0023\ R_a\ T_D^{0.5}\ (T_m + 17.8)$

Where,

RET = Reference Evapotranspiration $^{mm}/_{day.}$

R_a=Extra-terrestrial radiation in $^{mm}/_{day.}$

The procedure for the calculation of R_a is explained as above.

T_D = Difference between Maximum and Minimum Temperature (^{0}C).

T_m = Mean Temperature (^{0}C).

$$R_a = \frac{24 \times 60}{\pi} \times GS_C\{d_r[\omega_s \sin(LAT) \sin d + \cos(LAT) \cos d \sin \omega_s]\}$$

d_r = The distance from the earth to sun is calculated as

$d_r = 1 + 0.033 \cos(^{2\pi i}/_{365})$ Where: i = Julian day

Solar declination (d) is computed as

$$d = 0.4093\ sin\left(\frac{2\Pi(284+i)}{365}\right)$$

The sunset hour angle, ω_s is radiation is calculated as

$$\omega_s = arc\cos(-tan(LAT)\tan d)$$

The maximum possible hours of sunshine (N) is simulated using the formula function

$$N = \frac{2}{15}\cos^{-1}(-\tan(LAT)\tan d)$$

$$d = 23.45\ sin\left(360\ \frac{(284+i)}{365}\right)$$

LAT = Latitude of the study area

2. Turc method:

Turc's Equation was ranked the best. In earlier studies by Jensen et al. (1990), the ranking of these empirical methods varied depending upon local calibration and conditions. The Turc method requires fewer input parameters, i.e., mean air temperature and solar irradiance data only.

The equation may be expressed as:

$RET = 0.40\ T_m (R_s + 50) / (T_m + 15)$

Where,

RET = Reference Evapotranspiration in mm/day

R_s = Global solar radiation in Langley's

T_m = Mean air temperature in ^0C

Computation of R_s was same as the procedure explained above.

3. PAN EVAPORATION METHODS:

Many studies have reported a relation between pan evaporation and referenceEvapotranspiration.The coefficient is a function that converts pan evaporation to Evapotranspiration and is a function of the kind of the pan involved,the pan environment and the climate.The ratioof RET to class A pan evaporation;E_{pan} defines the pan coefficients,K_{pan}.K_{pan} is essentially a correction factor that depends on the prevailing upwind fetch distance, average daily wind speed,and relative humidity.The common inputs to these type of equations are humidity,wind speed and fetch distance.In this section,Christiansen method (1968) is considered for estimating RET and was briefly discussed.

4.Christiansen method:

$$RET = 0.755\ \times E_0\ \times\ C_{T2} \times C_{W2}\ \times C_{H2}\ \times C_{S2}$$

Where,

RET=Reference evapotranspiration

E_0 = Open pan evaporation (mm)

$$C_{T2} = 0.862 + 0.179\left(\frac{T_m}{20}\right) - 0.041\left(\frac{T_m}{20}\right)^2$$

$$C_{W2} = 1.189 - 0.240\left(\frac{W}{6.67}\right) + 0.051\left(\frac{W}{6.7}\right)^2$$

$$C_{H2} = 0.499 + 0.620\left(\frac{H_m}{0.60}\right) - 0.119\left(\frac{H_m}{0.60}\right)^2$$

$$C_{S2} = 0.904 + 0.008\left(\frac{S}{0.8}\right) - 0.088\left(\frac{S}{0.8}\right)^2$$

T_m = is the mean temperature in ^0C

W=mean wind speed 2m above ground level in km per hour

H_m=Values of mean humidity, expressed decimally

COMBINATION METHODS:

Penman-Monteith method:

Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. This so-called combination method was further developed by many researchers and extended to cropped surfaces by introducing resistance factors.

The Penman-Monteith approach includes all parameters that govern energy exchange and corresponding latent heat flux (Evapotranspiration) from uniform expanses of vegetation. Most of the parameters are measured or can be readily calculated from weather data. The equation can be utilised for the direct calculation of any crop Evapotranspiration as the surface and aerodynamic resistance are crop specific. The modified Penman-Monteith equation in written as

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

Where,

ET_o = daily reference ET [mm/d]

T = air temperature at 2 m high [°C]

VPD = vapour pressure deficit [kPa] that is (e_s-e_a)

u_2 = wind speed at 2 m high [m/s]

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

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

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

G = soil heat flux density [MJ m^{-2} d^{-1}]

Temperature, T:

$$T_{mean} = \frac{T_{max} + T_{min}}{2}$$

Where,

T_{mean} = mean daily air temperature, °C

T_{max} = maximum daily air temperature, °C

T_{min} = minimum daily air temperature, °C

Climate stations used to make observations for reference ETo should be surrounded by a well-watered crop. As this is not the case with most climate stations in BC. Therefore, the temperatures should be adjusted using the dew point temperature and a correction factor.

Vapor Pressure Deficit, VPD [Kpa]:

VPD = (es-ea)

Mean saturation vapor pressure derived from air temperature (es):

$$e_{(T)} = 0.6108\exp\left[\frac{17.27T}{T + 237.3}\right]$$

Where,

e(T) = saturation vapor pressure at the air temperature T, kPa

T = air temperature, °C.

Saturated Vapor Pressure, es [Kpa]:

Saturated vapour pressure is given however, when calculating for full day, minimum and maximum daily temperatures should be used

$$e_s = \frac{e_{(Tmax)} + e_{(Tmin)}}{2}$$

Actual Vapour Pressure Where RH Is Available, ea [Kpa]

$$e_a = \frac{RH_{mean}}{100}\left[\frac{e_{(T_{max})} + e_{(T_{min})}}{2}\right]$$

Net Radiation, Rn [MJm-2 d-1]

$$R_n = R_{ns} - R_{nl}$$

Net solar or net shortwave radiation, Rns [MJm^{-2} d^{-1}]:

$$R_{ns} = (1 - \alpha)R_s$$

Solar Radiation if Sunshine Hours 'N' Is Available, Rs [MJm^{-2} d^{-1}]:

$$R_s = \left[0.25 + 0.50\left(\frac{n}{N}\right)\right] R_a$$

$$N = \frac{24}{\pi}\omega_s$$

Extra Terrestrial Radiation, Ra [MJm^{-2} d^{-1}]:

$$R_a = \frac{24 \times 60}{\pi} G_{sc} d_r[(\omega_s \sin(\varphi)\sin(\delta)) + (\cos(\varphi)\cos(\delta)\sin(\omega_s))]$$

Clear Sky Solar Radiation, Rso [MJm^{-2} d^{-1}]:

$$R_{so} = [0.75 + 2 \times 10^{-5}z]R_a$$

Net Long wave Radiation, Rnl [MJm-2 d-1]:

$$R_{nl} = \sigma\left[\frac{(T_{max} + 273.16)^4 + (T_{min} + 273.16)^4}{2}\right]\left[034 - 0.14\sqrt{e_a}\right]\left[1.35\frac{R_s}{R_{so}} - 0.35\right]$$

Slope Vapour Pressure Curve, Δ [Kpa °C^{-1}]:

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27 \times T_{mean}}{T_{mean} + 237.3}\right)\right]}{(T_{mean} + 237.3)^2}$$

Psychometric Constant, γ [Kpa°C^{-1}]]:

$$\gamma = 0.665 \times 10^{-3}P$$

$$P = 101.3\left[\frac{293 - 0.0065z}{293}\right]^{5.26}$$

STATISTICAL ANALYSIS:

Root Means Square (RMS):

$$RMSE = \left[\sqrt{(PET_e - PET_p)^2 / n}\right]$$

Mean Bias Error(MBE):

$$MBE = \sum (PET_e - PET_p) / n$$

Mean Percentage Error (MPE):

$$MPE = \left\{\sum (PET_p - PET_e) / (PET_p) \times 100\right\} / n$$

Nash coefficient of Efficiency (NCE):

$$NCE = 1 - \sum_{i=1}^{n} \frac{(PET_e - PET_o)}{\sum(PET_e - PET_o)^2} \times 100$$

ANALYSIS AND INTERPRETATION

In this chapter, results pertaining to estimation of reference Evapotranspiration(RET)by, various methods, and performance evaluation of Reference Evapotranspiration (RET) with the Penman-Monteith method were presented.

A comparison was made between the various methods for estimating RET with the standard penman-Monteith was made by the linear regression analysis. In addition to the above , Statistical errors like Root Mean Square(RMSE),Mean Bias Error (MBE), Mean Percentage Error (MPE) and Nash Coefficient Efficiency (NCE) were also estimated from the period2003to2012forHimayathsagar Watershedon daily, monthly and yearly basis were also presented. But due to unavailability of certain data for estimation of RET following are the certain assumptions are made to carryout the calculations in the present study.

Estimation of Ret by Hargreaves method for January, 2003

Date	Max Temperature	Min Temperature	T mean	T difference	Relative Humidity % I	Relative Humidity % II	Rh mean	Hours of Sunshine	Rain Fall (mm)	Evaporation (mm)	Wind Velocity (m/s)
1.00	31.10	16.30	23.70	14.80	0.73	0.38	0.56	6.50	0.00	3.00	0.53
2.00	28.20	11.40	19.80	16.80	0.80	0.42	0.61	9.30	0.00	4.00	0.97
3.00	28.20	20.30	24.25	7.90	0.86	0.56	0.71	7.60	0.00	4.00	2.25
4.00	27.60	17.40	22.50	10.20	0.82	0.56	0.69	3.70	0.00	2.90	1.89
5.00	27.40	13.40	20.40	14.00	0.83	0.45	0.64	7.80	0.00	2.80	0.78
6.00	29.10	13.40	21.25	15.70	0.90	0.47	0.69	8.70	0.00	2.00	0.86
7.00	29.00	13.00	21.00	16.00	0.90	0.46	0.68	8.70	0.00	4.00	0.25
8.00	29.10	12.80	20.95	16.30	0.79	0.39	0.59	9.10	0.00	3.40	0.78
9.00	28.60	13.70	21.15	14.90	0.81	0.46	0.64	8.90	0.00	4.00	1.00
10.00	28.10	13.20	20.65	14.90	0.87	0.42	0.65	6.90	0.00	3.10	1.08
11.00	28.20	13.70	20.95	14.50	0.94	0.41	0.68	8.20	0.00	3.20	1.11
12.00	29.10	13.80	21.45	15.30	0.58	0.44	0.51	7.40	0.00	2.80	1.08
13.00	27.10	13.40	20.25	13.70	0.80	0.45	0.63	8.10	0.00	2.90	0.72
14.00	29.10	13.90	21.50	15.20	0.69	0.40	0.55	5.50	0.00	2.30	0.64
15.00	29.30	13.40	21.35	15.90	0.87	0.35	0.61	7.20	0.00	2.00	1.11
16.00	27.10	11.80	19.45	15.30	0.83	0.30	0.57	5.70	0.00	3.50	0.92
17.00	25.10	13.60	19.35	11.50	0.60	0.35	0.48	5.80	0.00	2.80	0.83
18.00	26.60	8.90	17.75	17.70	0.75	0.29	0.52	9.70	0.00	2.80	0.81
19.00	28.10	10.30	19.20	17.80	0.56	0.37	0.47	9.40	0.00	3.50	0.97
20.00	29.00	9.80	19.40	19.20	0.81	0.37	0.59	6.90	0.00	1.80	0.83
21.00	30.10	11.30	20.70	18.80	0.94	0.37	0.66	9.00	0.00	3.40	0.81
22.00	31.60	12.30	21.95	19.30	0.81	0.23	0.52	9.60	0.00	3.60	1.06
23.00	32.10	12.30	22.20	19.80	0.79	0.26	0.53	9.10	0.00	3.10	0.64
24.00	34.10	13.80	23.95	20.30	0.60	0.34	0.47	9.50	0.00	4.00	0.56
25.00	34.10	15.80	24.95	18.30	0.56	0.29	0.43	9.20	0.00	3.20	0.78
26.00	34.60	17.00	25.80	17.60	0.66	0.36	0.51	8.70	0.00	3.10	0.78
27.00	31.50	15.80	23.65	15.70	0.78	0.40	0.59	7.50	0.00	4.00	0.92
28.00	31.50	14.30	22.90	17.20	0.80	0.22	0.51	9.20	0.00	3.40	1.19
29.00	32.30	13.80	23.05	18.50	0.43	0.33	0.38	10.00	0.00	5.10	1.42
30.00	32.70	12.80	22.75	19.90	0.70	0.23	0.47	9.40	0.00	2.10	0.50
31.0	34.00	12.70	23.3	21.30	0.71	0.22	0.47	14.50	0.00	3.30	0.53

0			5								

Estimation of Ret by Hargreaves method for January, 2003

Date	Δ	ϒ	Δ+ϒ	δ	ψ	ψ(latitude)	ωs	dr	Ra	N	(Td)^0.5 (2)	Tm + 17.8 (3)	1 X 2 X 3 (4)	RET=0.0023 X 4	Mean RET mm / Day
1.00	0.18	0.06	0.24	-0.40	0.30	17.32	1.44	1.03	27.33	7.89	3.85	41.50	4363.62	10.04	
2.00	0.14	0.06	0.21	-0.40	0.30	17.32	1.44	1.03	27.37	7.89	4.10	37.60	4218.75	9.70	
3.00	0.18	0.06	0.24	-0.40	0.30	17.32	1.44	1.03	27.42	7.89	2.81	42.05	3240.73	7.45	
4.00	0.17	0.06	0.23	-0.40	0.30	17.32	1.44	1.03	27.47	7.89	3.19	40.30	3535.42	8.13	
5.00	0.15	0.06	0.21	-0.39	0.30	17.32	1.44	1.03	27.52	7.89	3.74	38.20	3933.54	9.05	
6.00	0.15	0.06	0.22	-0.39	0.30	17.32	1.44	1.03	27.58	7.89	3.96	39.05	4266.72	9.81	
7.00	0.15	0.06	0.22	-0.39	0.30	17.32	1.44	1.03	27.63	7.89	4.00	38.80	4288.73	9.86	
8.00	0.15	0.06	0.22	-0.39	0.30	17.32	1.44	1.03	27.69	7.89	4.04	38.75	4332.73	9.97	
9.00	0.15	0.06	0.22	-0.39	0.30	17.32	1.44	1.03	27.76	7.89	3.86	38.95	4173.51	9.60	
10.00	0.15	0.06	0.21	-0.38	0.30	17.32	1.44	1.03	27.83	7.89	3.86	38.45	4129.89	9.50	
11.00	0.15	0.06	0.22	-0.38	0.30	17.32	1.45	1.03	27.90	7.89	3.81	38.75	4116.19	9.47	
12.00	0.16	0.06	0.22	-0.38	0.30	17.32	1.45	1.03	27.97	7.89	3.91	39.25	4293.96	9.88	
13.00	0.15	0.06	0.21	-0.38	0.30	17.32	1.45	1.03	28.04	7.88	3.70	38.05	3949.67	9.08	
14.00	0.16	0.06	0.22	-0.37	0.30	17.32	1.45	1.03	28.12	7.88	3.90	39.30	4308.97	9.91	10.37
15.00	0.16	0.06	0.22	-0.37	0.30	17.32	1.45	1.03	28.20	7.88	3.99	39.15	4402.93	10.13	
16.00	0.14	0.06	0.20	-0.37	0.30	17.32	1.45	1.03	28.29	7.88	3.91	37.25	4121.67	9.48	
17.00	0.14	0.06	0.20	-0.36	0.30	17.32	1.45	1.03	28.37	7.88	3.39	37.15	3574.66	8.22	
18.00	0.13	0.06	0.19	-0.36	0.30	17.32	1.45	1.03	28.46	7.88	4.21	35.55	4257.10	9.79	
19.00	0.14	0.06	0.20	-0.36	0.30	17.32	1.45	1.03	28.55	7.88	4.22	37.00	4457.53	10.25	
20.00	0.14	0.06	0.20	-0.35	0.30	17.32	1.46	1.03	28.65	7.88	4.38	37.20	4669.85	10.74	
21.00	0.15	0.06	0.21	-0.35	0.30	17.32	1.46	1.03	28.75	7.87	4.34	38.50	4798.53	11.04	
22.00	0.16	0.06	0.22	-0.35	0.30	17.32	1.46	1.03	28.84	7.87	4.39	39.75	5037.02	11.59	
23.00	0.16	0.06	0.23	-0.34	0.30	17.32	1.46	1.03	28.95	7.87	4.45	40.00	5151.91	11.85	
24.00	0.18	0.06	0.24	-0.34	0.30	17.32	1.46	1.03	29.05	7.87	4.51	41.75	5464.20	12.57	
25.00	0.19	0.06	0.25	-0.33	0.30	17.32	1.46	1.03	29.15	7.87	4.28	42.75	5331.57	12.26	
26.00	0.20	0.06	0.26	-0.33	0.30	17.32	1.46	1.03	29.26	7.87	4.20	43.60	5352.22	12.31	
27.00	0.18	0.06	0.24	-0.33	0.30	17.32	1.46	1.03	29.37	7.86	3.96	41.45	4823.77	11.09	
28.00	0.17	0.06	0.23	-0.32	0.30	17.32	1.47	1.03	29.48	7.86	4.15	40.70	4976.38	11.45	

29.00	0.17	0.06	0.23	-0.32	0.30	17.32	1.47	1.03	29.60	7.86	4.30	40.85	5199.93	11.96	
30.00	0.17	0.06	0.23	-0.31	0.30	17.32	1.47	1.03	29.71	7.86	4.46	40.55	5374.29	12.36	
31.00	0.17	0.06	0.24	-0.31	0.30	17.32	1.47	1.03	29.83	7.86	4.62	41.15	5664.56	13.03	

NOMENCLATURE

ET = Evapotranspiration
RET = Reference Evapotranspiration
PET = Potential Evapotranspiration
AET = Actual Evapotranspiration
T_m = Mean Temperature in ^{0}C
Td = Difference Between Minimum And Maximum Temperature ^{0}C
I = Annual Heat Index
T_i = Temperature In ^{0}C After i^{th} Month
a = An Empirical Exponent
l = Day Length Factor
D = No. of Days in a Month
R_A = Extra-Terrestrial Radiation in mm day^{-1}
R_S = Solar Radiation in Longley's
n = Actual Hours of Bright Sunshine in Hours
N = Maximum Possible Hours Of Sunshine In Hours
G_{SC} = Solar Constant In MJ m^{-2} min^{-1}
d_r = Relative distance of earth from the sun
d = Solar declination in radiance
W_s = Sunset hour angle in radians
LAT = Latitude of the station
E_0 = Open pan evaporation in mm
W = Mean wind at 2 m above ground level in km / hr
S = The percentage of possible sunshine
n / N = Ratio of possible to actual sunshine hours
RH_{min} = Minimum daily relative humidity in %
R_{ns} = Net short wave radiation in MJ m^{-2}day^{-1}
R_{nl} = Net long wave radiation in MJ m^{-2}day^{-1}
e_a = Saturation vapor pressure in k Pa
e_0 (T) = Saturation vapor pressure function in k Pa
T = Air temperature in ^{0}C
Δ = Slope of vapor pressure
RMSE = Root Mean Square Error
MBE = Mean Bias Error
MPE = Mean Percentage Error
N = No. of observations
RET_p = RET estimated by Penman - Monteith method
RET_e = RET estimated by various methods
G = Soil heat flux MJ m^{-2}day^{-1}
γ = Psychometric constant
FAO = Food And Agricultural Organization
C_{H2} = Humidity coefficient
C_{S2} = Sun shine coefficient
C_{T2} = Temperature coefficient
C_{W2} = Wind velocity coefficient
RET_H = RET Estimated by Hargreaves Method

RET_{Cri}	=	RET Estimatedby Christiansen Method
RET_{Tu}	=	RET Estimated by Turc Method
RET_{PMM}	=	RET Estimated by Penman Monteith Method

CONCLUSIONS

The Reference Evaporation (RET) have been estimated on daily, monthly and Annual basis by using various methods based on Radiation, pan evaporation and combinational methods which are shown in earlier chapters.

From the present the following conclusions were observed:

- Of all the methods of estimation of RET on daily basis Turc, Hargreaves methods have shown higher values.
- On the other hand, Hargreaves, Turc, Penman –Monteith, and Christiansen methods shown more values of RET estimation on monthly and Annual basis.
- Christiansen, Hargreavesand Turc Methods shown increasing trend of RET on daily, monthly and annual basis.
- Performance of RET on daily, monthly and annual basis is indicated by the Linear regression analysis whose R^2 values of all the models are almost greater than 0.10
- The value of R^2 on monthly basis is observed to be high compared to the other methods. It is corresponding values ranges from 0.754 in 2003 to 0.925 in 2012.
- Turc and Hargreaves methods intercepts is much higher when compared to Penman – Monteith method at all-time scales.
- Calculation of RMSE, MBE, MPE and NCE on daily and annual basis observed that the Turc & Hargreaves methods better when compared with Penman Monteith method.
- As the value of NCE predicts the good relation between observed and estimated values, Turc method shows more values as when compared to other methods. It mean values are observed to be at different time scales as 88.31%, 87.32% and 89.96% respectively.
- Hence out of all above observations made that the Turc method is concluded the best model when compared with the other models. For estimating the RET for this watershed and also for the local atmospheric conditions of this type.

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