Evapotranspiration Studies for Jhabua District

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Abstract— To plan a proper & feasible irrigation scheme, the knowledge of exact amount of water required by different crops under different climatic condition is necessary. Accurate and exact estimation of crop evapotranspiration is very helpful in the effective design of an irrigation system. In this research work the observations were recorded for Jhabua district of Madhya Pradesh state. These observations were used to calculate the evapotranspiration by using FAO-56 Method, Hargreaves Method, Blaney Criddle Method, Thornthwaite Method, Radiation Method, Turc method and Makkink method. The results of each method are compared with the result of FAO-56 method.

Key words: Evapotranspiration, Jhabua District

I. INTRODUCTION

India, with a geographical area of about 329 Million Hectares (Mha), is a land of many mountains and rivers, some of them figuring amongst the mightiest rivers of the world. Physio-graphically, India may be divided into seven well defined regions. These are: the Northern Mountains comprising the mighty Himalayan ranges; the Great Plains traversed by the Indus, Ganga and Brahmaputra river systems; the Central Highlands, consisting of a wide belt of hills running east-west between the Great Plains and the Deccan plateau; the Peninsular Plateaus; the East Coast, a belt of land of about 100-130 km wide, bordering the Bay of Bengal; the West Coast, a narrow belt of land of about 10-25 km wide, bordering the Arabian Sea; and the islands, comprising the coral islands of Lakshadweep in Arabian Sea and Andaman and Nicobar group of islands in the Bay of Bengal.

Water resources are sources of water that are useful or potentially useful to humans. It is basic human need and a prime national asset. It is important because it is needed for life to exist. Water is a natural resource serving a wide range of uses in modern day society. Beside the basic purpose for support of life, water is also used for other purposes such as Agricultural, industrial, household, recreational, environmental activities, irrigation, hydropower, navigation, pollution abatement etc. Irrigation is the only use of water discussed herein. It is estimated that 70% of world-wide water use is for irrigation in agriculture.

Vast area of India is under tropical climate which is conducive throughout the year for agriculture due to favorable warm and sunny conditions provided perennial water supply is available to cater to the high rate of evapo-transpiration from the cultivated land The availability of water distribution are governed by climatic factors beyond man's control, at the present state of science and technology. Instead of opting for centralized mega water transfer projects which would take long time to give results, it would be cheaper alternative to deploy extensively shade nets over the cultivated lands for using the locally available water sources efficiently to crops throughout the year. Plants need less than 2% of total water for metabolism requirements and rest 98% is for cooling purpose through transpiration. Shade nets or poly-tunnels installed over the agriculture lands suitable for all weather conditions would reduce the potential evaporation drastically by reflecting the excessive and harmful sun light without falling on the cropped area. Optional management of water resources is therefore fundamental in ensuring the continuous availability of water for the benefit of mankind both for the present and the future. The natural availability water is often not sufficient to satisfy the demand and use imposed by society. Control of water has therefore been practiced since the early days of civilization.

The main objective and aim of water resources planning and management is to solve the equation of demand and supply of water for a specific area taking into account considering various dimensions like space, time, economy, politics, environment, and other aspects. An objective of irrigation planners is to obtain a high level of economic efficiency in irrigation development and in water system use. There is an increasing awareness observed in recent times to make the best use of water, a scarce and valuable resource for all economic activities.

A. EVAPO-Transpiration Process

The crop water need (ET crop) is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favorable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need mainly depends on:

- The climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- The crop type: crops like maize or sugarcane need more water than crops like millet or sorghum
- The growth stage of the crop; fully grown crops need more water than crops that have just been planted.

1) Evaporation:

Evaporation is the process whereby liquid water is converted to water vapor (vaporization) and removed from the evaporating surface (vapor removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation.

2) Transpiration:

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere. Generally water lose from crops through stomata.

3) EVAPO-Transpiration:

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. When the crop is small, water is lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. This combination of two separate processes whereby water is lost on one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred as evapo-transpiration (ET).The evapo-transpiration rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month or even an entire growing period or year.

B. EVAPO-Transpiration Concepts

Distinctions are made between reference crop evapo-transpiration (ETo), crop evapo-transpiration under standard conditions (ETc) and crop evapo-transpiration under non-standard conditions (ETc). ETo is a climatic parameter expressing the evaporation power of the atmosphere. ETc refers to the evapo-transpiration from excellently managed, large, well-watered fields that achieve full production under the given climatic conditions. Due to sub-optimal crop management and environmental constraints that affect crop growth and limit evapo-transpiration, ETc under non-standard conditions generally requires a correction.

C. Reference Crop EVAPO-Transpiration (ET_O):

The reference crop evapo-transpiration or reference evapo-transpiration and is denoted by ET_O. The concept of the reference evapo-transpiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is in large quantities available at the reference evapo-transpiring surface, soil factors do not affect ET. ETo values are measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method was recommended as the sole method for determining ETo. This method was selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for estimating missing climatic parameters.

D. Crop Evapo-Transpiration under Standard Conditions (ETo):

The crop evapo-transpiration under standard conditions is denoted as ETo, the evapo-transpiration from disease-free, well-fertilized crops, grown in large fields, under best possible soil water conditions, and achieving full production under the given climatic conditions. The amount of water required to compensate the evapo-transpiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapo-transpiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapo-transpiration refers to the amount of water that is lost through evapo-transpiration. Crop evapo-transpiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapo-transpiration rate, i.e., ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc), are used to relate ETc to ETo or ETc = Kc ETo. Crop coefficient (Kc) is defined as the ratio of ET from a crop or soil surface to ET from a fully vegetated surface covering the soil. ETc is determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ETO and the crop characteristics into the Kc coefficient.

$$\mathrm{ET_c} = \mathrm{K_c ET_O}$$

Where,

ETc =Crop Evapo-transpiration (mm d-1),

Kc-=Crop coefficient (dimensionless),

ETo-=Reference crop Evapo-transpiration (mm d-1).

E. Crop Evapo-Transpiration Under Non-Standard Conditions:

The crop evapo-transpiration under non-standard conditions (ETc) is the evapo-transpiration from crops grown under management and environmental conditions that differ from the standard conditions. The real crop evapo-transpiration may deviate from ETc due to non-optimal conditions such as the presence of pests and diseases, soil salinity, low soil fertility, water shortage or water logging. This may result in scanty plant growth, low plant density and may reduce the evapo-transpiration rate below Etc.

II. Objectives

The purpose of the present study is to workout reference crop Evapo-transpiration for Jhabua district by using various methods and to compare them. To achieve the goal following steps are proposed:

1) Study of the literature for getting an understanding of the subject matter and latest up gradation in the area of crop water requirement.
2) To study various methods for determination of ETO value.
3) Topographical and meteorological data of Jhabua District.
4) Collecting all necessary data from meteorology of the irrigation project for formulae case study.
5) Analyzing the data to compute ETO with different identified methods.
6) Development of statistical relationship between different methods.
7) Analysis and interpolation of results.

III. LITERATURE REVIEW

R Gautam & A. Sinha (2016) focused on evapotranspiration modelling and forecasting, since forecasting would provide better information for optimal water resources management.

Nithya KB and Shivapur AV (2016) determined the crop water requirement of few selected crops for the command area in Tarikere taluk in Karnataka state, India. Dabral & Pandey (2016) identified a suitable alternative to the FAO-56 Penman-Monteith (FAO56PM) equation for calculating reference evapotranspiration (ET_0) from chosen temperature and radiation based models utilizing monthly meteorological data from 30 destinations in diverse agro-ecological regions of the Northeast (NE) India. Adamala S, Rajwade Y & Reddy K (2015) studied an estimation based on Normalized Difference Vegetation Index (NDVI) from LANDSAT images.

IV. ESTIMATION OF EVAPOTRANSPIRATION:

The ET estimation methods are generally grouped into temperature, radiation and combination theory. Following methods were studied under the present title:

- FAO-56Method(Penman-Monteith)
- Hargreaves Method (HGM)
- Blaney Criddle Method(BCM)
- Thornthwaite Method(TWM)

Various meteorological parameters and methods are used in calculation of the crop evapotransipiration detailed below:-

A. FAO-56 Penman-Monteith Method

The FAO-56 Penman-Monteith equation is a modification of the Penman (1963) equation. The main difference is that the Penman-Monteith equation includes the effect of canopy resistance on evapo-transpiration. Allen et al. (1996, 1998) presented the following form of the Penman-Monteith model for estimation of ET_O in mm/day:

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{(T_{mean}+273)}u_2(e_a\_e_d)}{\Delta + \gamma^*}$$

Where,
T_{mean} is average air temperature, [^{0}C];
U_2 is wind speed measured at 2 m height, [m s^{-1}] and
γ = Psychometric constant (kP_a °C^{-1}),
γ^* is a modified psychometric constant, [kPa$^0C^{-1}$].
Δ = slope of saturation vapour pressure curve at air temperature T (kPa °C^{-1}),

In the above equation the modified psychometric constant (γ^*) and slope of saturation vapor pressure curve (Δ) at mean air temperature (Tm) can be calculated as:

$$\gamma^* = \gamma(1 + 0.34u_2)$$

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

B. Hargreaves Method

Hargreaves and Samani (1985) have proposed an equation for estimating grass-related reference ET. Since solar radiation data are not frequently available, this method estimates ET_O from extraterrestrial radiation and mean monthly maximum and minimum temperatures as follows:

$$ET_O = 0.0023\,R_A TD(T_{mean} + 17.8)$$

Where:
TD is the difference between mean daily maximum and minimum temperatures [°C], and R_A is extraterrestrial solar radiation (MJ m^{-2} d^{-1}).

C. Blaney Criddle Method

The original Blaney – Criddle equation involves the calculation of the consumptive use Factor from mean temperature and percentage of the total annual daylight hours occurring during the period being considered. But the effect of the climate on crop water requirements insufficiently defined by temperature and day length. ETO also varies widely with the climatic conditions, which are humidity, sunshine hour, and wind. The relation recommended by FAO representing mean value over the given month is expressed as

$$ET_O = C_P(0.46T + 8.13)$$

Where:
ET_O reference crop evapo-transpiration
T- Daily temperature for the month in ^{0}C
p- Daily percentage of total annual daytime hours
C – Adjustment factors

Only this method is useful where the temperature data is available. The ET_O should be adjusted 10% downward for each 1000m altitude changes above sea level.

D. Thornthwaite Method

Thornthwaite (1948) using metrological observations from the Eastern USA, found that under conditions of limited availability of water there is an explicit relation between the evapo-transpiration and the temperature of atmosphere, longitude and the season .The empirical equation he gave is as given below:

$$ET_O = 16L_d\left[\frac{10T}{I}\right]^a$$

Where,
ET_O=Reference crop evapo-transpiration
T = Temperature in ^{0}C
α= is the empirical coefficient
L_d= Ratio of the mean duration of the days of each month to the 12-hour day [μ/360],
μ = Number of days in each month
I =Annual indicator of the air temperature that is calculated with the equation

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.154}$$

T_i is the mean monthly temperature ^{0}C
Exponent α is the empirical coefficient Estimated from the equation:

$$a = 0.016I + 0.5$$

This method gives good results for climate like one of Eastern USA. The mean characteristic of which is that the rain period takes place at the summer, so there is high humid.

V. METHODOLOGY AND ANALYSIS

The methods for calculating evapo-transpiration from meteorological data require various climatologically and

Physical parameters. Some of the data are measured directly in weather stations for the remaining data India water portal and swat websites were referred.

A. Methodology

Crop evapotranspiration under different methods were calculated using their respective formulas. Parameters were separately calculated using Microsoft excel , then applied to final formulae sheet .Data chart obtained after applying the formulas under different methods are shown :-

MONTH	T max °C	T min °C	RA(mm/day)	√ DIFFERENCE	T mean °C	Eto (mm/day)
JAN.	28.8	11.7	10.8	17.1	20.3	3.91
FEB	30.9	13.2	12.3	17.7	22.1	4.75
MAR	35.5	18.1	13.9	17.4	26.8	5.95
APR	38.8	22.6	15.2	16.2	30.7	6.82
MAY	39.8	25.4	15.7	14.4	32.6	6.91
JUN	36.3	25.5	15.8	10.8	30.9	5.82
JUL	31.6	23.9	15.7	7.7	27.7	4.56
AUG	30.3	23.4	15.3	6.9	26.9	4.13
SEP	32.1	22.7	14.4	9.4	27.4	4.59
OCT	34.7	20.4	12.9	14.3	27.5	5.08
NOV	34.2	16.2	11.2	18	24.2	4.59
DEC	29.6	13	10.3	16.6	24.3	4.06
					Average	5.10

Table 1: Calculation of Monthly Et_0 by Fao-56 Method

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
JAN.	11.7	28.8	39	249	8.6	16.7	4.56
FEB	13.2	30.9	29	264	9.9	20.4	6.32
MAR	18.1	35.5	21	266	10.5	23.7	7.48
APR	22.6	38.8	19	294	10.8	25.7	9.55
MAY	25.4	39.8	26	337	10	24.9	10.11
JUN	25.5	36.3	52	335	6.6	19.8	7.89
JUL	23.9	31.6	81	313	3	14.3	4.22
AUG	23.4	30.3	91	282	2.3	13.1	2.18
SEP	22.7	32.1	81	226	6.6	18.5	4.15
OCT	20.4	34.7	51	191	8.7	19.3	5.17
NOV	16.2	34.2	41	211	9.3	17.9	5.05
DEC	13	29.6	41	236	9	16.5	4.38

Table 2: Calculation of Monthly Et_0 by Hargreaves Method

MONTH	C	P	T	ETo(mm/d)
JAN.	1.04	0.24	20.3	4.32
FEB	1.26	0.26	22.1	5.95
MAR	1.26	0.27	26.8	6.92
APR	1.28	0.28	30.7	7.93
MAY	1.29	0.29	32.6	8.60
JUN	1.26	0.3	30.9	8.4
JUL	0.99	0.3	27.7	6.16
AUG	0.99	0.29	26.9	5.84
SEP	1.16	0.28	27.4	6.69
OCT	1.16	0.26	27.5	6.23
NOV	1.16	0.25	24.2	5.55
DEC	1.04	0.24	24.3	4.8
			Average	6.42

Table 3: Calculation of Monthly Et_o by Blaney Criddle Method

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
JAN.	11.7	28.8	39	249	8.6	16.7	4.56
FEB	13.2	30.9	29	264	9.9	20.4	6.32
MAR	18.1	35.5	21	266	10.5	23.7	7.48
APR	22.6	38.8	19	294	10.8	25.7	9.55
MAY	25.4	39.8	26	337	10	24.9	10.11
JUN	25.5	36.3	52	335	6.6	19.8	7.89
JUL	23.9	31.6	81	313	3	14.3	4.22
AUG	23.4	30.3	91	282	2.3	13.1	2.18
SEP	22.7	32.1	81	226	6.6	18.5	4.15
OCT	20.4	34.7	51	191	8.7	19.3	5.17
NOV	16.2	34.2	41	211	9.3	17.9	5.05
DEC	13	29.6	41	236	9	16.5	4.38

Table 4: Calculation of Monthly Et_o by Thornwaite Method

VI. RESULTS AND DISCUSSION

ET_O values estimated by different methods were used for inter comparison of different methods. The ET_O values obtained by different methods were compared with the FAO-56 Penman-Monteith method.

SEE values were calculated as follows:

$$SEE = \left[\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-1}\right]^{.5}$$

SEE = Standard Error of Estimate; y_i = ET_O estimated by the FAO-56 Penman Monteith method; $\hat{y}_i$ = corresponding ET_O estimated by the comparison method; and n = total number of observations. The SEE gives equal weight to the absolute difference between the standard method and the comparison method. It is a measure of the goodness of fit between ET_O values estimated by the different methods and standard method. The SEE has units of mm/day and (n-1) degrees of freedom.

A. *Standard Error of Estimate by Different Methods*

MONTH	FAO-56 PM	HGM	(FAO-56 PM-HGM)	(FAO-56 PM-HGM)^2
JAN.	4.56	3.91	0.65	0.42
FEB	6.32	4.75	1.57	2.46
MAR	7.48	5.95	1.53	2.34
APR	9.55	6.82	2.73	7.45
MAY	10.11	6.91	3.2	10.24
JUN	7.89	5.82	2.07	4.28
JUL	4.22	4.56	-0.34	0.12
AUG	2.18	4.13	-1.95	3.80
SEP	4.15	4.59	-0.44	0.19
OCT	5.17	5.08	0.09	0.01
NOV	5.05	4.59	0.46	0.21
DEC	4.38	4.06	0.32	0.10
			SUM	31.64
			SEE	1.70

Table 5: Compare of Penman-Monteith Method with Hargreaves Method

MONTH	FAO-56 PM	BCM	(FAO-56 PM-BCM)	(FAO-56 PM-BCM)^2
JAN.	4.56	4.32	0.24	0.06
FEB	6.32	5.95	0.37	0.14
MAR	7.48	6.92	0.56	0.31
APR	9.55	7.93	1.62	2.62
MAY	10.11	8.60	1.51	2.28
JUN	7.89	8.40	-0.51	0.26
JUL	4.22	6.16	-1.94	3.76
AUG	2.18	5.84	-3.66	13.40
SEP	4.15	6.69	-2.54	6.45
OCT	5.17	6.23	-1.06	1.12
NOV	5.05	5.55	-0.50	0.25
DEC	4.38	4.80	-0.42	0.18
			SUM	30.83
			SEE	1.52

Table 6: Compare of Penman-Monteith Method with Blaney Criddle Method

MONTH	FAO-56 PM	TWM	(FAO-56 PM - TWM)	(FAO-56 PM-TWM)^2
JAN.	4.56	4.76	-0.20	0.04
FEB	6.32	4.65	1.67	2.79
MAR	7.48	5.32	2.16	4.67
APR	9.55	5.49	4.06	16.48
MAY	10.11	5.78	4.33	18.75
JUN	7.89	5.49	2.40	5.76
JUL	4.22	5.28	-1.06	1.12
AUG	2.18	4.96	-2.78	7.73
SEP	4.15	5.20	-1.05	1.10
OCT	5.17	5.02	0.15	0.02
NOV	5.05	5.01	0.04	0.00
DEC	4.38	4.62	-0.24	0.06
JAN.			SUM	58.5
			SEE	2.307

Table 7: Compare of Penman-Monteith Method with Thornwaite Method

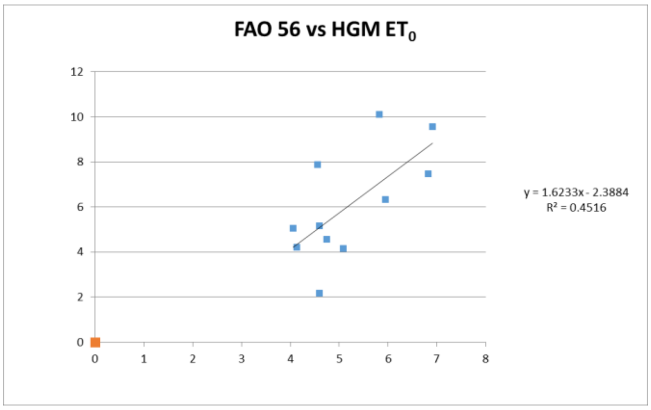

Fig. 1: Comparison between ETO values of FAO 56 and HGM

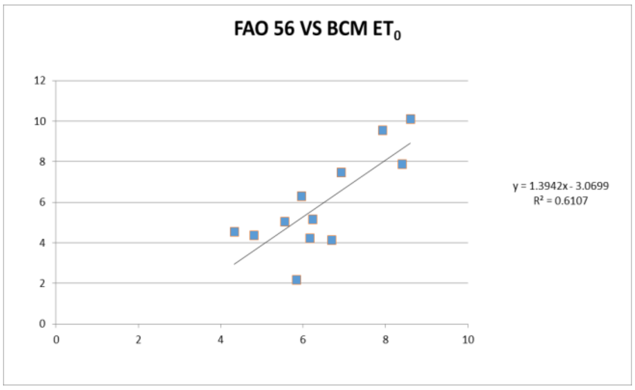

Fig. 2 Comparison between ETO values of FAO 56 and BCM

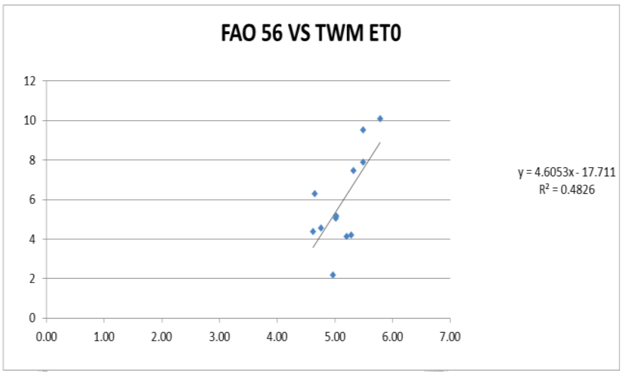

Fig. 3: Comparison between ETO values of FAO 56 and TWM

VII. Conclusion

1) The changing global climate has significant on evapo-transpiration and hence there is a need to estimate continually updated evapo-transpiration. In the present study, the ET_O is calculated by various methods for Jhabua meteorological and the study is also carried out to compare evapo-transpiration by different methods and to develop interrelationship of FAO-56 penman-Monteith method with other methods which facilitate the calculations using FAO-56 pm in case of non-availability of data for the use of MPM. Table (6.15) shows equations for the relationship of various methods with FAO-56PM.
2) HGM method gives the lowest ETo value and in comparison with the Penman-Monteith method.
3) The relationship developed between different methods and Penman-Monteith method can be used to calculate ET_O for Penman-Monteith method under non-availability of data.

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