EVAPOTRANSPIRATION STUDIES FOR NAGPUR DISTRICT

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Abstract: - Knowledge of the exact amount of water required by different crops in a given set of climatic conditions of region is of great help for planning of irrigation schemes, irrigation scheduling and also for mid term planning in case of mid season drought. The effective design and management of an irrigation system requires accurate estimation of crop evapotranspiration. The method selected for estimating evapotranspiration, however, should produce good result with a minimum of climatic data and also be applicable over a wide range of climatic conditions. The multiple correlation and regression analysis is generally used in hydrology to develop a relationship between three or more hydrologic variables by studying the dependence among them.

The research work aims to arrive at a suitable empirical model for reasonable estimation of reference evapotranspiration for Nagpur region (Maharashtra State). In this research work the observations were recorded at Nagpur meteorological station are used to calculate the evapotranspiration with the methods of Blaney-Criddle (BCL), Christiansen Equation(CNM), Hargreaves Method(HGM), Modified Penman method (MPM), Radiation Method (RAD), Thornthwaite Method (THW). The results of each method are compared with the results of the other.

Key-Words: Evapotranspiration Modified Penman Method, Blaney-Criddle, Christiansen Equation.

1. Introduction

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. In the partitioning of evapotranspiration into evaporation and transpiration is plotted in correspondence to leaf area per unit surface of soil below it. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration.

Evapotranspiration is the name given to the combined effect of evaporation and transpiration. In a given agriculture land water losses occur mainly due to evaporation from land and transpiration from the crop. Therefore total crop water required is directly proportional to ET. Estimation of evapotranspiration (ET) is of great importance 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 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 water. Direct measurement of ET requires special instruments for measurement of various physical parameters associated with it.

Methods of direct measurement are often expensive and demanding in terms of accuracy of measurement. Owing to the difficulty of obtaining accurate field measurement, ET is commonly computed from weather data. However, no single existing method using meteorological data is universally adaptable under all climatic regimes. Therefore, use of specific method is limited by the conditions in which they have been developed. Large data requirement also limits the application of many of these methods. Usually limited meteorological data are available. Under such condition, use of specific method become very difficult and application of an alternative method (for which data are easily available) may not yield results with desired accuracy. Therefore, by determining the inter-relationships between the methods enable the user to easily convert values from different methods.

This research work deals with comparative study of reference evapotranspiration of Nagpur by different method and the interrelationship of various method with Modified Penman method.

2. Need for estimation of Evapotranspiration

An estimation of optimal crop water requirement is an integrated aspect of the design and management of an irrigation system. The output of a crop is maximum when water is applied optimally and any deficient or excess amount of water usually reduces the output. The optimal crop water requirement mainly depends on the accurate estimation of evapotranspiration. The formula selected for use, however, should produce good result with a minimum of climatic data and represent the one, which has been calibrated and applied over a wide range of climatic condition.

3. Literature Review

Gupta and Goyal (2001) compared performance of various methods of ET estimation and presented their interrelationships with respect to each other for arid region of Rajasthan State. Kannpan et al. (2002) developed a “reference evapotranspiration model” for certain locations in Tamilnadu with PMM as the standard method. Water and Energy Research Digest of CBIP (2002) indicated that the PMM gave the best results in this sub-humid region and that this method in comparison with the observed Evapotranspiration is the best method to estimate daily and stage-wise crop coefficient (K). Vasan and Shrinivasa Raju (2004) used the CROPWAT model to compare the results of the Decision Support System with other methods developed for the area of Pilani, Rajsathan. Bhakar and Singh (2004) concluded that air temperature is the main factor influencing evaporation. The study also indicated that the influence of relative humidity on evaporation is negative whereas that of wind speed is positive.

4.Estimation of Evapotranspiration:

4.1. Analytical Methods

The evapotranspiration from a reference surface not short of water is called Reference Evapotranspiration (ETo). The reference evapotranspiration concept is used to study the evaporative demand of atmosphere independent of crop type, crop development and management practices. The value thus obtained is then multiplied by coefficients established for particular crop and area to give actual ET value.

The choice of ETo estimation method depends on its suitability in the particular region and available data. Some of the important methods are energy balance method, mass transfer method, soil water balance method, experimental method and empirical method. The weightage given to various factors in different methods vary according to the location and available data. It is also not possible to measure the actual ETo on field

The methods which are widely used to calculate ETo and relevant under Indian condition are discussed here. Following are the few widely used methods for calculating ETo values

1. Blaney-Criddle Method (BLC)
2. Radiation Method (RAD)
3. Modified Penman Method (MPM)
4. Thornthwaite Method (THW)
5. Hargreaves Method (HGM)
6. Christiansen Method (CHR)

4.1.1. The 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 evapotranspiration and the temperature of atmosphere, longitude and the season .The empiric equation he gave is as

$$ET = 16\, L_d [10T/I]^a$$

Where:

ET_o reference crop evapotranspiration

T temperature in degree Celsius

N daylight hours, a function of latitude and the day of year.

L_d is the 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 is the annual indicator of the air temperature that is calculated with the equation

$$I = \sum^{12} i_j = \sum [T_j/5]^{1.154}$$

I_J is I corresponding monthly indicators of heat, Exponent α is the empirical coefficient estimated from the equation:

$\alpha = 0.016\, I + 0.5$

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

4.1.2. Christiansen Method:

Christiansen (1968) proposed a revised empirical formula, originally developed by him in (1966), to estimate pan evaporation from climatic data when reliable measured pa evaporation data are not available for estimating of evapotranspiration. Because of variations in size and shape of pan, their exposure, the presence or of algae in water, the specific methods of measuring the loss of water from the pans, and the protection against use of water by birds and animal, available pan evaporation data may not sometimes be reliable to make estimates of evapotranspiration .In such cases of pan evaporation, estimate by means of a reliable formula may give more accurate results than the reported evaporation. The following is the Christiansen's revised equation develops at Logan (Utah), USA, for estimation pan evaporation:

$$E_s = K_{ev} \,.\, R \,.\, C_t \,.\, C_w \,.\, C_h \,.\, C_s \,.\, C_e \,.\, C_m$$

Where:

E_v is the computed pan evaporation equivalent to Class A pan evaporation

K_{ev} is a dimensionless empirically developed constant, the value of which is given by Christiansen as 0.473, R is the extra-terrestrial radiation in the same evaporation units as E_v and C_t, C_w, C_h, C_s, C_e coefficient for temperature, wind velocity, relative humidity ,percentage of possible sunshine and elevation ,respectively and C_m is a monthly coefficient or basic factor by which all the basic formula would have to be multiplied to obtain the measured evaporation and averaged to obtain mean monthly values of C_m . The values of C_m mostly range between 0.90 to 1.10 and vary from latitude to latitude.

The value of constant K_{ev} depends on the selection of standard values for each climatic factor.

4.1.3 Modified Penman method (1948):

The original equation of Penman consisted of two terms namely, the energy or radiation term and the aerodynamic term. It gives the evaporation from an open water surface due to wind and humidity considered together. A modified method was presented by Doorenbobs and Pruitt (1977) which introduced some what simplified and widely accepted form of equation along with correction factor considering day and night weather conditions and was considered to offer the best results with minimum possible errorsin relation to aliving grass reference crop. This method can be easily adopted and provides most satisfactory result where measured data on temperature, humidity, wind and sunshine hours are available.

It is a fairly accurate method for estimation of evapotranspiration as it utilizes almost all the metrological parameters responsible for the process of evapotranspiration .The FAO Modified Penman formula is given below:

$$ET_o = c\,[W.\,R_n + (1\text{-}W).\,f\,(U)\,(ea - ed)]$$

Where,
ET_O = reference crop evapotranspiration (mm per day)
R_n = net radiation in equivalent evaporation expressed as mm/day
W the temperature altitude related weight age factor for the effect of radiation on ET_o.
f (U)= wind related function
f (U) = 0.27(1+U/100)
Where
U = wind velocity in Km/day measured at 2m height
ea – ed = evaporation pressure deficit (m bar)
c = Adjustment factor (ratio of U day/Unight) to compensate for the day and night weather effect for RH maximum and for R_s
R_n = 0.75 –Rnl
Where
Rs = incoming short wave radiation either measured or estimated as in radiation method
Rnl net long wave radiation (mm/day), which is a function of temperature, vapour pressure and sunshine duration
= f (t) f(ed) f (n/N)
ea = saturation vapour pressure at the mean air temperature in ^{o}/C (mbar)
ed mean actual vapour pressure of air (m bar)
ed= ea (RH mean /100)

Evaporation either from soil or plants surface is initiated by heat developed by solar radiation while its continuity depends on saturation deficit of atmosphere and wind velocity.

If the atmosphere comes to saturation near the site of evaporation, no further evaporation takes the place unless the saturated air is replaced by the unsaturated air. Thus, solar radiation, relative humidity and wind velocity are important for estimating evapotranspiration. The modified Penman formula consists of a radiation term, W.Ro + (1-W) and the aerodynamic term f (U) (ea – ed). The radiation term estimates the intensity of initiation of ET process while aerodynamic term measures the continuity of the process.

4.1.4. Hargreaves Method: (1983)

Hargreaves established that amongst all the climatological data, temperature and radiation given more accurate value of evapotranspiration.

$$ET_o = 0.0023 \times Ra\,(T + 17.8) \times TD \times 0.5$$

ET_o = reference crop evapotranspiration in mm/day
Ra = extraterrestrial radiation
T= mean air temperature
TD= difference of maximum and minimum temperature

This method is comparatively very simple and requires only temperature data apart from latitude. The equation gives more accurate results at interior locations with plain topography where the growing season of the crops are frost free.

4.1.5. Radiation Method:

This method considers the radiation reaching the earth as the major contribution or the influence factor for evapotranspiration. The FAO recommended

$$ET_o = c\,(W \times Rs)$$

Where,
ET_o = reference crop evapotranspiration in mm/day
Rs- Solar radiation in equivalent evaporation (mm/day)
Rs = (0.25 + 0.50 n/ N) Ra
Ra = extraterrestrial radiation in equivalent evaporation in mm/day
n=actual measured bright sunshine hours
N = maximum possible sunshine hours
W- Temperature and altitude dependent weightage factor
c- Adjustment factor made graphically on W

This method is used when the data of air temperature and sunshine hours are available and calculation should be done for each month of record and not for yearly records

4.1.6. Blaney Criddle Method: (1950)

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 requirement is insufficiently defined by temperature and day length. ET_o 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

$$ET_o = cp\,(0.46\,T + 8))$$

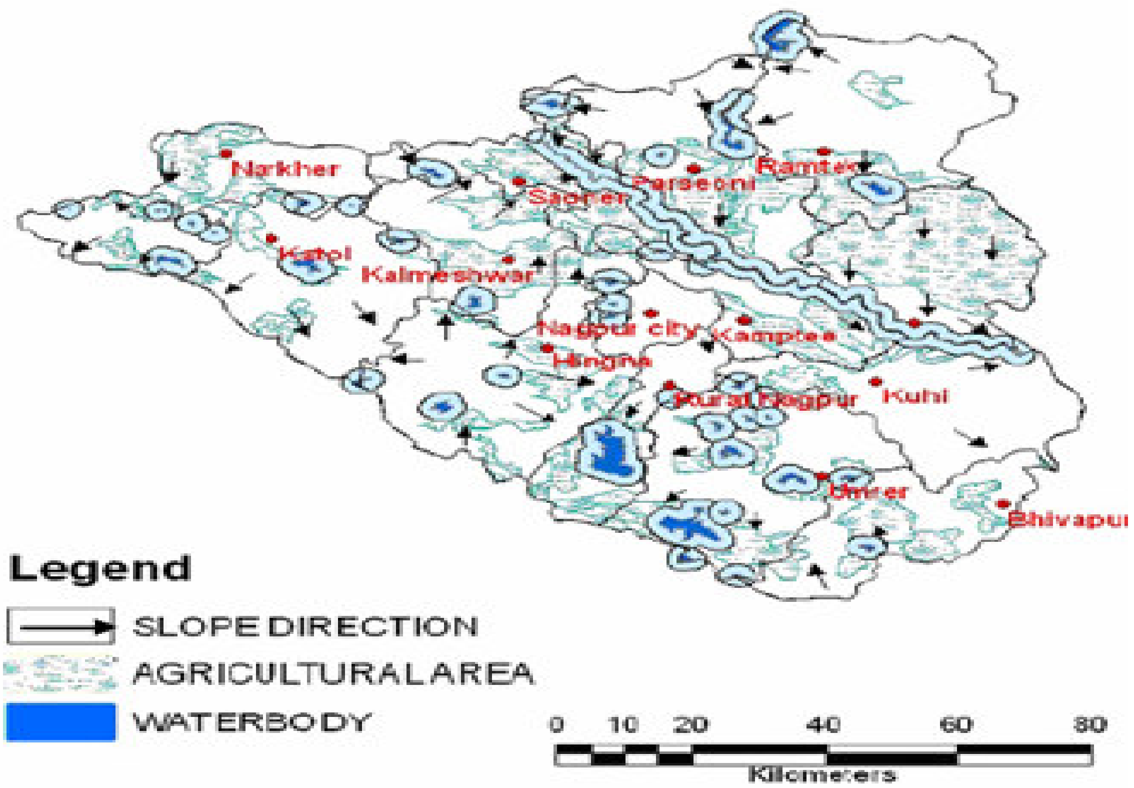
ET_o reference crop evapotranspiration
T- daily temperature for the month in C
p- Daily percentage of total annual daytime hours
c – Adjustment factors

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

5. Methodology

5.1 Study Area

The study has been conducted for "Nagpur District" of Maharashtra state with longitude 79.24 Degree E latitude 21.15 Degree N which is 310 m from mean sea level. The monthly average climatic data of NAGPUR for the period of 2003-2005 was taken for calculation purpose. The data collected are maximum and minimum temperature, maximum and minimum relative humidity, sunshine hours, wind velocity



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5.2. Data Collection

The station characteristics and Hydro-metrology data are collected from Hydrology Project of Irrigation Department, Maharastra i.e. HDUG (Hydrological Data User Group) whish has provided in SWDES software (Surface Water Data Entry System V 1.20). The monthly average climatic data of Nagpur for the period of 2003-2005 is used for study as given in table [1]

Table No 1:
Average Climatic Data of Nagpur Station

Month	Max temp	Min temp	Max RH	Min RH	Win vel	n
January	26.15	14.34	40.60	16.53	3.49	7.49
February	30.30	16.05	47.86	18.62	4.08	9.63
March	34.50	20.60	57.18	20.47	4.71	8.77
April	38.15	25.52	66.17	20.70	5.24	8.46
May	40.89	30.00	73.21	22.66	5.20	8.95
June	38.27	29.75	68.88	24.86	5.90	5.21
July	29.22	24.72	54.17	25.50	5.07	2.15
August	29.21	24.55	54.54	25.17	5.30	3.98
September	30.12	24.63	55.25	25.42	4.77	5.49
October	29.59	21.63	52.44	23.00	3.46	7.40
November	27.67	14.73	42.70	18.00	3.34	9.44
December	26.21	12.67	37.83	15.70	3.33	9.38

6. Result and discussion

It is observed that from table [3], MPM gives average 38.85%, 28.15%. 16.09%lower value of ETo than by BCM, HGM and CNM respectively while RDM and THM gives lower value of ETo than MPM

Average daily ET_o values for each month is determined by using ET_o equations from the available climatologically data by different method as in table [2] The values are then used to develop interrelationship among different empirical methods considering MPM as standard

Table No 2:
ET_o Values Using Different Methods In mm/day

MONTH	MPM	HGM	BCM	RDM	THM	CNM
January	2.44	3.45	3.55	2.09	1.72	3.28
February	2.87	4.39	4.19	2.59	1.81	4.68
March	3.33	5.81	4.90	3.23	2.39	4.94
April	4.36	6.28	5.99	3.57	2.92	5.52
May	4.73	7.00	6.52	3.42	3.36	6.17
June	5.00	5.57	6.33	3.91	3.17	3.47
July	4.54	3.88	5.60	3.21	2.69	1.54
August	4.45	3.39	5.14	3.24	2.50	1.81
September	3.93	3.62	5.05	2.97	2.37	2.54
October	2.94	3.86	4.59	2.81	2.21	3.89
November	2.62	3.58	4.00	2.30	1.84	4.48
December	2.30	3.31	3.44	2.16	1.72	4.10
Average	3.62	4.51	4.94	2.96	2.39	3.86

Fig. 1: Monthwise ETo by Different Method

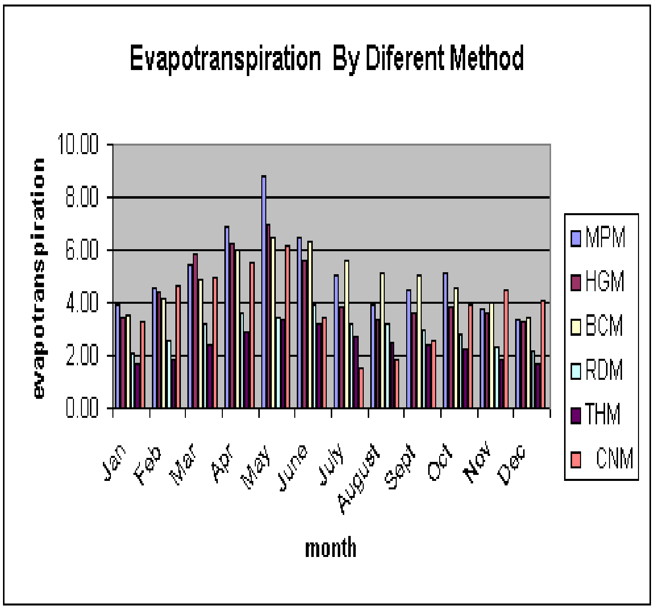


Table No 3:
Percentage Variation Evapotranspiration of Different Methods over MPM

MONTH	HGM OVER MPM	BCM OVER MPM	MPM OVER RDM	MPM OVER THM	CNM OVER MPM
January	41.39	45.49	16.75	41.86	34.43
February	52.96	45.99	10.81	58.56	63.07
March	74.47	47.15	3.10	39.33	48.35
April	44.04	37.39	22.13	49.32	26.61
May	47.99	37.84	38.30	40.77	30.44
June	11.40	26.60	27.88	57.73	-30.60
July	-14.54	23.35	41.43	68.77	-66.08
August	-23.82	15.51	37.35	78.00	-59.33
September	-7.89	28.50	32.32	65.82	-35.37
October	31.29	56.12	4.63	33.03	32.31
November	36.64	52.67	13.91	42.39	70.99
December	43.91	49.57	6.48	33.72	78.26
Average	28.15	38.85	21.26	50.78	16.09

From fig1 it is observed that evapotranspiration is more in the month of April, May, June, and July.
It is also seen that From Table [2] the ETo values obtained from Blaney Criddle Method are maximum and from Thornwaite Method are minimum. Modified Penman Method and CNM methods give values, which are closer to each other
It is observed that from table [3], MPM gives average 38.85%, 28.15%. 16.09%lower value of ETo than by BCM, HGM and CNM respectively while RDM and THM gives lower value of ETo than MPM

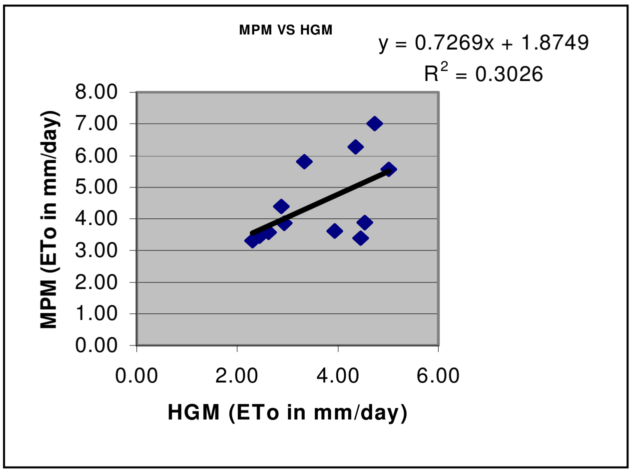
Relationship of various methods for estimation of ET_0 with MPM

For the present case study MPM is used to calculate ETo further the relationship is also developed with other methods to facilitate calculations using in case of of non availability of all required data for the use of MPM. Table [4] gives the equations for relationship of various methods with MPM. It can be noted that coefficient of correlation value is more for BCM, RDM and HGM and therefore more suitable in the absence of adequate climatic data for the use MPM for this climatic region

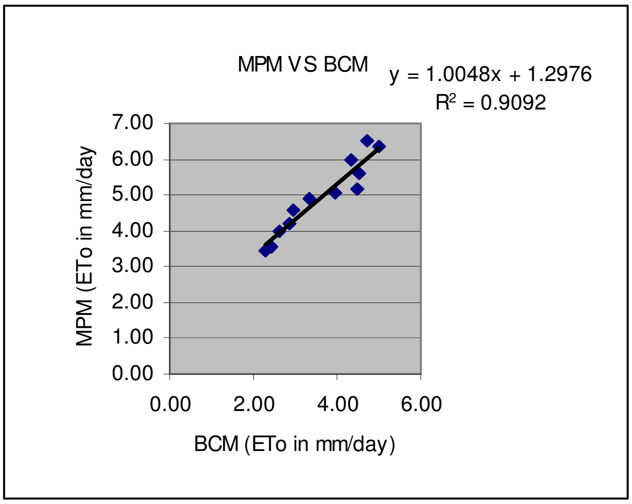
Linear regression analysis has been done using Microsoft Excel to develop interrelation among the result of the selected methods. This interrelationship provides an 'easy to use' method to obtain the ET_0 values by methods for which metrological data are available and then to get accurate results in terms of desired method

Comparision of Different method with MPM

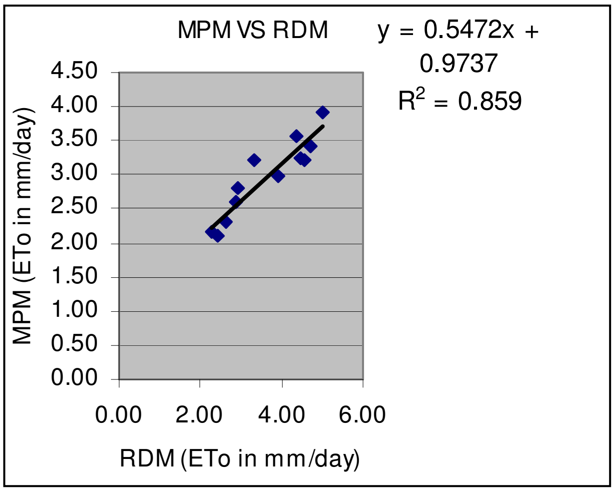
Modified Penman Method and Hargreaves Method



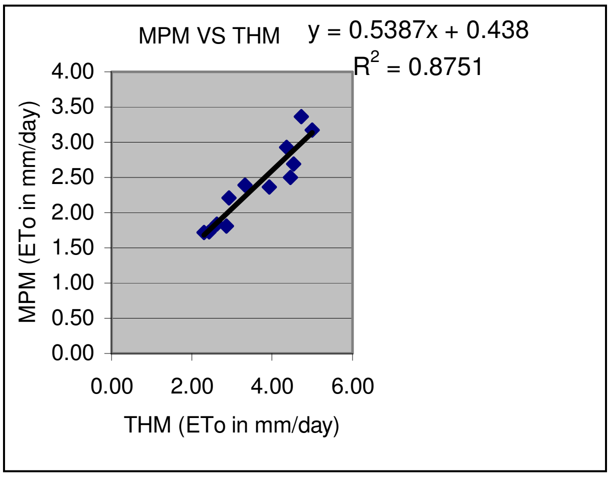
Modified Penman Method and Blaney Criddle Method



Comparison of Between Modified Penman Method and Radiation Method



Modified Penman Method and Thornthwaite Method



Modified Penman Method and Christiansen Method

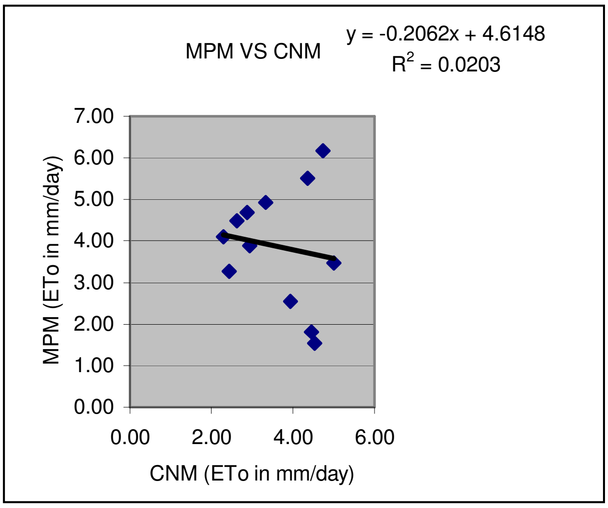


Table No 4:
Relation of Modified Penman Method with other method

S. N.	RELATION	R^2	R
1.	MPM = 0.7269 HGM + 1.8749	0.3028	0.550
2.	MPM = 1.0048 BCM + 1.2978	0.9092	0.953
3.	MPM = 0.5472 RDM + 0.9737	0.8590	0.926
4.	MPM = 0.5387 THM + 0.4380	0.8751	0.935
5.	MPM = 0.2062 CNM + 4.6148	0.0203	0.142

7. Conclusion:

The changing global climate has significant on evapotranspiration and hence there is a need to estimate continually updated evapotranspiation. In the present study, the ETo is calculated by various methods for Nagpur meteorological station and the study is also carried out to compare evapotranspiration by different methods and to develop interrelationship of modified penman method with other methods which facilitate the calculations using MPM in case of non-availability of data for the use of MPM. Table [4] shows equations for the relationship of various methods with MPM. It can be noted that the coefficient of co-relation is high for BCM and RDM and THM and therefore more suitable in the absence of adequate climate data for the use of MPM for this climatic region but HGM and CNM the coefficient of correlation is too low. RDM and THM give lower value of ETo than MPM. But it is recommended to use MPM as a standard method as it consider all the factor concerned with evapotranspiration even though RDM and THM give lower value of ETo

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Notation:-

Eto - Reference evapotranspiration

Kc - Crop coefficient

Etc - Crop evapotranspiration

F.A.O. - Food Agriculture Organization

MPM - Modified Penman Method

BCL - Blaney –Criddle Method

RDM - Radiation Method

CNM **-** Christiansen Method

THM - Thornthwaite Method

HGM - Hargreaves Method