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Estimation of reference evapotranspiration and irrigation requirement of crops by various methods for different regions of Maharashtra

Harish H Deshpande and Harshada P Deshmukh

Abstract
The study on estimation of reference evapo-transpiration (ETo), crop water requirement (CWR) and net irrigation requirement (NIR) by Modified Penman (MP) and Penman Monteith (PM) method was conducted by Faculty of Agriculture, Water And Land Management Institute (WALMI), Aurangabad for various regions of Maharashtra during the period of 2018 to 2021. The main objective is to estimate ETo, CWR and NIR by MP and PM methods. One location from three regions of Maharashtra are selected for study *viz*., Marathwada (Aurangabad), Western Maharashtra (Rahuri Dist. Ahmed Nagar) and Vidarbha (Akola). The weather data's are collected from Agro-meteorological observatories and analysed for the above said objectives. The result of the study revealed that Modified Penman Method was proposed for estimation of ETo, NIR and CWR of crops. Net irrigation requirements are estimated for the cropping Pattern of Gul Medium Project, Jalgaon (Maharashtra) by using three locations weather data. The total net irrigation requirement of crops for above said cropping pattern is highest for Aurangabad region followed Akola and Rahuri regions because of its spatial and temporal variation and distribution of rainfall and other important weather parameters.

Keywords: Evapotranspiration, irrigation requirement, crops, various methods

Introduction

Evapo-transpiration (ET) is the term used to describe the sum of evaporation and plant transpiration from the land surface to atmosphere. It is the second most important variable in the hydrological cycle after rainfall and has an important role as controlling factor of runoff volume or river discharge, irrigation water requirement and soil moisture contents (Mohan & Arumugam, 1996) [5]. Accurate estimation of ET is therefore essential for water budgeting and planning. It has been anticipated that direct impact of climate change on water resources will be mainly through evapo-transpiration. Hydrological changes constitute one of the most significant potential impacts on global climate change in the tropical regions (IPCC, 2007). It is now clear that climate change will cause a steady rise of temperature and changes in rainfall pattern. Higher temperature will induce higher evapo-transpiration which in turn will affect the hydrological system and water resources (Shahid, 2011) [7]. Thus, quantifying the changes in ET due to climate change is very important for the management of long-term water resources. Especially in the crop lands, it is essential to measure the possible changes in ET and probability of water losses due to climate change.

Considering the importance of ET, hydrologists have developed numerous methods for its estimation. Each method has its own perspective and concept and has been developed for specific climatic setup. Some of these methods are basically the modified version of other methods. However, the major concern in estimating ET is the reliability and accuracy of the methods (Burnash, 1995) [2].

As many of these methods have been developed from certain perspective and for a specific climate region, they often fail to estimate the potential evapo-transpiration (PET) in other climatic regions. Nevertheless, there are few methods such as the Penman-Monteith method which are reliable over a broad climatic region. Reliability of these methods has been tested in different parts of the world and they are found to estimate ET very close to field observation. Unfortunately, these methods are parameter rich model and require extensive data and information for reliable estimation of ET. This poses a problem in making accurate future ET projection for data scarce region. Most meteorological stations only measure temperature and rainfall while other meteorological parameters that are required for parameter rich models for

ET estimation are rarely measured.

Selection of a method for estimation of ETo depends on availability of meteorological data and amount of accuracy needed. Modified Penman method, Pan Evaporation, Radiation and Modified Balney-Criddle are mostly used methods for ETo estimation. Among these four methods Modified Blaney- Criddle method is simple, easy to calculate and requires only temperature data of the region. Modified Penman method is reliable and requires data on sunshine hours, wind velocity, relative humidity in addition to temperature. Among these methods Modified Penman method is more reliable with a possible error of 10% only. The possible errors for other methods are 15, 20 and 25% for Pan Evaporation, Radiation and Modified Balney-Criddle methods respectively. But, modified Penman method equation was developed long back mainly to estimate ETo from open water body. Therefore, performance study of simple ET methods is essential for selecting suitable ET method in accordance to regional climate and availability of meteorological data.

Central Water Commission, New Delhi has suggested modified penman method for estimation of Crop Water Requirement (CWR) and Net Irrigation Requirement (NIR) in their guidelines. FAO in the year 1998 has given Penman Monteith Method for computing CWR and NIR, which is simple than Modified Penman method for computation and only average climatic data is required. Therefore, the study was conducted with the objective of estimation of reference evapotranspiration, CWR and NIR for suggested cropping pattern of Gul medium irrigation project by WALMI using weather data from different regions of Maharashtra.

1. Estimation of Reference Evapo-transpiration (ETo) by Modified Penman method and Penman Monteith Method of last 10 years for three stations.
2. Estimation of crop water requirement and irrigation requirement by Modified Penman method and Penman Monteith Method of last 10 years for three stations.
3. Comparison of ETo, CWR and NIR values by Modified Penman method and Penman Monteith Method

Material and Methods

The three Agro-meteorological stations were selected for the study, to estimate reference evapo-transpirations at different parts of Maharashtra. This includes Akola, Aurangabad and Rahuri (District: Ahmednagar). The Rahuri comes under Agro-climatic zone No. 06 (scarcity zone). Major parts of Aurangabad and entire Akola comes under Assured Rainfall Zone i.e. Zone No. 07. The climate of these stations will vary extremely and located in different regions of Maharashtra *viz*., Marathwada Region (Aurangabad), Western Maharashtra (Rahuri - Ahmed Nagar District) and Vidarbha regions (Akola).

The daily weather data pertaining to Temperature (Maximum and Minimum), Relative Humidity (Morning and Noon), Wind Velocity, Bright Sunshine hours, Pan-evaporation and Rainfall of last 10 years (2006 to 2015) was obtained from different weather stations *viz*., 1. Dr. Punjab Rao Deshmukh Krishi Vidyapeeth (PDKV), Akola. The station is located at latitude of 20.40° N and longitude of 77.02° E with an altitude of 282 m above mean sea level (MSL). 2. Water And Land Management Institute (WALMI), Aurangabad. The agro-meteorological observatory is located at Latitude of 19.53° North and longitude of 75° 23' East. It is at an altitude of 581 m above MSL. 3. Mahatma Phule Krishi Vidyapeeth, (MPKV), Rahuri, District - Ahmednagar. The agro-meteorological observatory is located at All India Coordinated Research Project (AICRP) on Water Management in the University. It is located with Latitude of 19.3492° North, longitude of 74° 6461' East with an altitude of 519 m above MSL.

Using daily weather data fortnightly Reference evapotranspiration was worked out by Modified Penman Method and Penman Monteith methods. The Penman - Monteith equation described first by (Allen *et al*., 1989) [1] used for calculation. The Department of Irrigation and Drainage Engineering, Annasaheb Shinde College of Agricultural Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri, located at Ahmednagar District, (Maharashtra) developed a Software for estimation of reference evapotranspiration i.e. "Phule Jal". This software was used to estimate reference evapo-transpiration by Penman Monteith Method.

The equation for estimation of ETo by Penman-Monteith method can be given as –

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma\frac{900}{\mathrm{T}+273}\mathrm{u}\,(\mathrm{es} - \mathrm{ea})}{\Delta + \gamma(1 + 0.34\mathrm{u}_2)}$$

ETo = Potential evapotranspiration (mm day-1)
Rn = Net radiation at the crop surface (MJ m-2day-1)
G =Soil heat flux density (MJ m-2day-1)
T = Mean daily air temperature at 2 m height (°C)
u2 = Wind speed at 2 m height (m s-1)
es = Saturation vapour pressure (kPa)
ea = Actual vapour pressure (kPa)
es - ea = Saturation vapour pressure deficit (kPa)
Δ = Slope vapour pressure curve (kPa °C-1)
γ = Psychrometric constant (kPa °C-1)

The original Penman method, originated in England in 1948, gave the value of potential evaporation from exposed water body surface. However a modified strain of the Penman method introduced by Doorenbos and Pruitt (1977) [3] and simplified the equation along with correction factor, considering the day and night weather conditions. Thus, this modified form of estimation of potential evaporation is known as a Modified Penman method. This method was being used widely till the Penman Monteith method came to be adopted globally in 1998. All factors in the original Penman methodhave been accommodated in the modified formula with weather parameters. Several tables are prepared and mentioned in computation of certain parameters as mentioned in this equation.

The data on temperature (maximum & minimum), Humidity (maximum & minimum), wind velocity and Sunshine hours/radiations are required to estimate ETo by modified Penman method. The Software developed by Water And Land Management Institute, Aurangabad was used to estimate ETo by Modified Penman Method. The form of the equation used in FAO Modified Penman Method, as Caliberated by Doorenbos and Pruitt (1977) [3] is given below.

$$\mathrm{ETo} = c\,\{\underbrace{(W \times \mathrm{Rn})}_{\text{Radiation term}} + \underbrace{(1 - W) \times f(u) \times (ea - ed)}_{\text{Aerodynamic term}}\}$$

Where,
ETo = Reference crop (grass) evapotranspiration (mm/day)
W = Weighting factor for the effect of radiation on ETo at different temperatures and altitudes.
Rn = Net radiation in equivalent evaporation (mm/day)
(1-W) = Weighing factor for the effect of wind and humidity on ETo at different temperatures and altitudes.
F(u) = Wind function or the effect of wind on ETo.
C = Adjustment factor to compensate the effect of day and night weather conditions.
(ea-ed) = Difference between the saturation vapour pressure at mean air temperature (ea) and the mean actual vapor pressure of the air (ed), both expressed in millibars. The term is also referred as vapor pressure deficit.

The 75 percent dependable ETo and fortnightly average Rainfall was worked out.The Reference Evapo-transpiration (ETo) is related to actual Evapotranspiration (ETc) of a particular crop in the different climatic conditions. This relation i.e. ratio of ETc & ETo is always Constant and it is denoted by 'Kc'. The Kc curves are drawn by using standard Kc values of initial stage, developmental stage, mid-season stage and late season stage on Graph sheet as by stage wise crop duration (Table 1) suggested by Doorenbos and Pruitt (1977) [3] and described in the WALMI, Publication No. 11.
Fortnightly crop evapotranspiration (ET crop or ETc) was worked out by multiplying 75% dependable ETo values with Kc values and kr factor (percentage of the field area (ground) covered by cultivation). It is considered as 1 for most of field crops.

ETc = ETo * Kc*kr

Where,
ETc = Reference Crop Evapotranspiration
Kc = Fortnightly Crop coefficient value
ETo = Fortnightly Reference evapotranspiration
kr = Area wetting factor

Cropping Pattern
Proposed cropping pattern by WALMI for Gul Medium Irrigation project, located in Jalgaon District of Maharashtra was selected for the present study. The data pertaining to suggested cropping pattern by WALMI is presented in Table No. 1along with the base period and stage wise crop duration *viz*. Initial stage (I), Development stage (II), Mid-Season stage (III) and Late Season (IV). The crop water requirement and net irrigation requirements were worked out for the same cropping pattern.
Crop Water Requirement was calculated by using the following formula

CWR = ETc + Sp (At root zone)

Where,
CWR= Crop Water Requirement
ETc = Crop Evapo-transpiration
Sp = water needed by crop for special purpose operations

Table 1: Stage wise crop duration and cropping pattern considered for drawing standard Kc curves by Modified Penman and Penman Monteith methods for different weather stations.

		Stage Wise Duration				Total
S.No.	Crop	I	II	III	IV	
	Two seasonal Crops					
1	Cotton L.S	30	50	60	55	195
	Kharif Crops					
1	Hybrid Jowar	15	25	40	25	105
2	Groundnut	20	30	45	25	120
3	Vegetables (Onion)	20	30	40	15	105
	Rabi Crops					
1	Wheat	15	25	50	30	120
2	Gram	20	25	30	30	105
3	Jowar (Local)	20	35	50	30	135
4	Vegetables (Tomato)	20	30	40	30	120
	Hotweather Crops					
1	Groundnut	20	30	45	25	120

Net irrigation requirement (NIR) was calculated by using following formula.

NIR = CWR – (Er + Ge)

Where,
NIR= Net Irrigation Requirement
Er = Effective Rainfall
CWR = Crop Water Requirement (ETc + Sp)
Ge = Ground Water Contribution

Data Analysis
In the present study WALMI-NIR Software programme was used to calculate net irrigation requirement as accepted by Water Resources Department, Government of Maharashtra. The statistical analysis i.e. descriptive statistics was analysed by using MS Excel Applications as per statistical procedures for comparison of Standard deviation and standard error.

Regression Analysis
The multiple regression analysis was carried out with pan evaporation method as independent variable and six weather parameters based ETo calculation methods MP & PM as a dependent variables. ETo calculated by MP and PM methods are used as dependent parameters such as Temperature (maximum and minimum), Relative Humidity (morning and noon), bright sunshine hours and wind velocity. ETo calculated by using Pan evaporation is used as a control which is independent and practically accepted method worldwide. Hence, comparison was done through regression analysis as and assessed the R^2 value (coefficient of determination / regression coefficient). More the R^2 value top will be the

priority/rank. Statistical comparison of both the methods was done at 95% prediction intervals.

The NIR was calculated at root zone head for suggested cropping pattern of Gul Medium Projectby WALMI separately by Modified Penman and Penman Monteith methods, also for three weather stations separately and expressed in ha mm. The percent deviation from MP method was calculated and expressed in mm and in percentage. The percent under prediction by PM was expressed.

Results and Discussion

Analysis of Fortnightly Average Rainfall

The daily average rainfall data was analysed for fortnightly averages from the year 2006 to 2015. The fortnightly averages of last 10 years for Akola, WALMI and Rahuri stations are presented in Fig. 1, 2 and 3. The seasonal rainfall was well distributed between the fortnight number 11 to 20 (May 21 to October 07). Around 89.2, 89.9 and 82.8 percent rainfall was distributing during Kharif season in Akola, WALMI and Rahuri stations. The remaining amount of rainfall in rest of the year. Almost except kharif season rest of the year might be dry and very horrible to meet out ET demands of the crop. Rainfall in the Fortnight number 1 to 10 and 21 to 26 are below the ETo levels and does not full fil the ET demands of the crop. Rabi, Hot weather and Perennial crop requires supportive irrigation during this period. The total annual average rainfall of Akola, WALMI and Rahuri stations are 792.4 mm, 756.3 mm and 630.5 mm respectively.

The fortnightly dependable ETo, average rainfall values were calculated for all the weather station data and presented in Fig 1, 2 and 3 respectively for Rahuri, WALMI and Akola station data. The fortnightly mean ETo values of 4.31 mm, 4.45 mm and 5.05 mm were recorded for Rahuri, WALMI and Akola stations data respectively. The Penman Monteith method under predicted the overall ETo by -20.7 percentage as compared to Modified Penman method. The average deviation of 1.05 mm was under predicted Penman Monteith method in the Akola station data Analysis. The data analysis for WALMI station shows that Penman Monteith method was under predicted by -18.2 per cent ETo values as compared to MP method. The average deviation in ETo was observed up to 0.81 mm/day.The penman Monteith method under predicted the ETo values by -22.3 per cent. The average deviation in ETo was observed up to 0.96 mm/day in the analysis of Rahuri Station data.

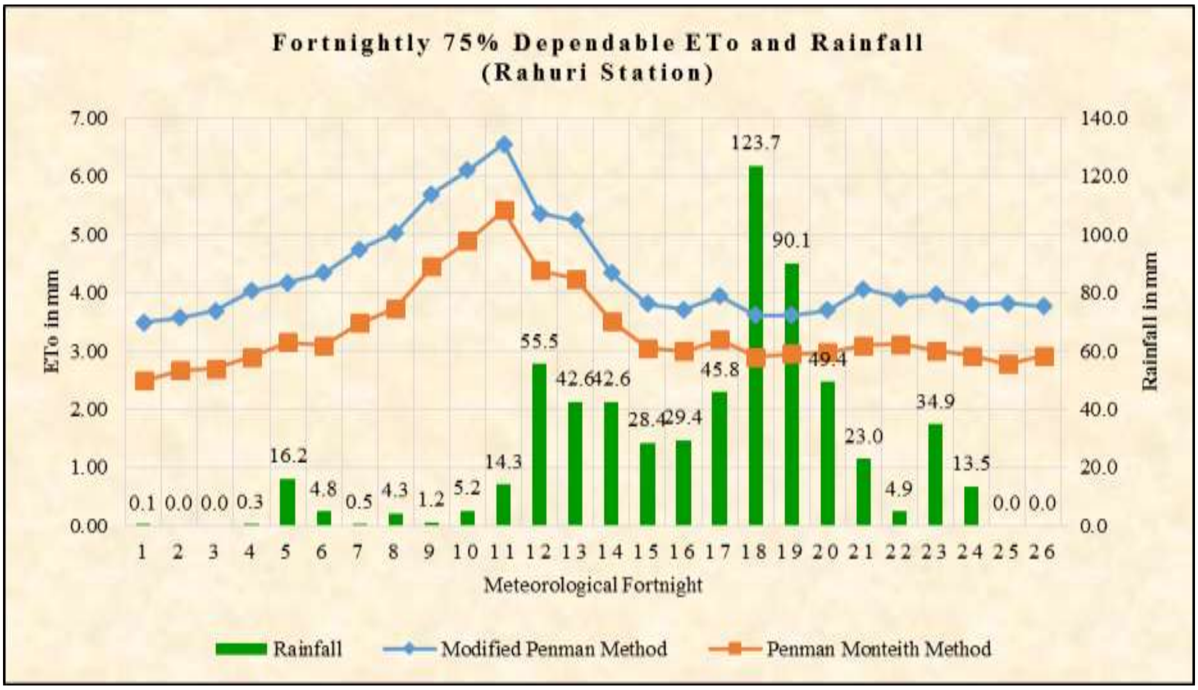

Fig 1: Fortnightly Rainfall (mm) and 75% dependable reference evapo-transpiration (ETo in mm) of MPKV, Rahuri, Station

The comparison of methods showed that Prediction of ETo by Modified Penman method recorded higher standard deviation and standard error values as compared to Penman Monteith method, hence the Penman Monteith method predicted with greater accuracy. The MP and PM methods were compared individually with Pan Evaporation method to infer statistically in accuracy among them. The values of coefficient of determination are presented in Fig. 5.

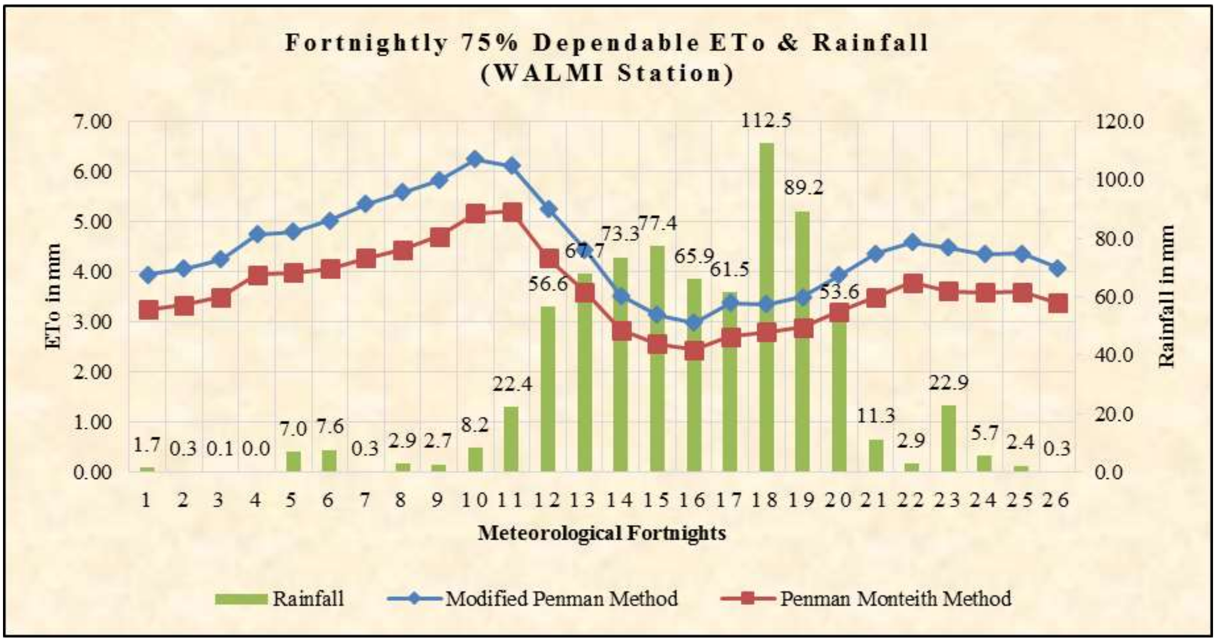

Fig 2: Fortnightly Rainfall (mm) and 75% dependable reference evapo-transpiration (ETo in mm) of WALMI, Station

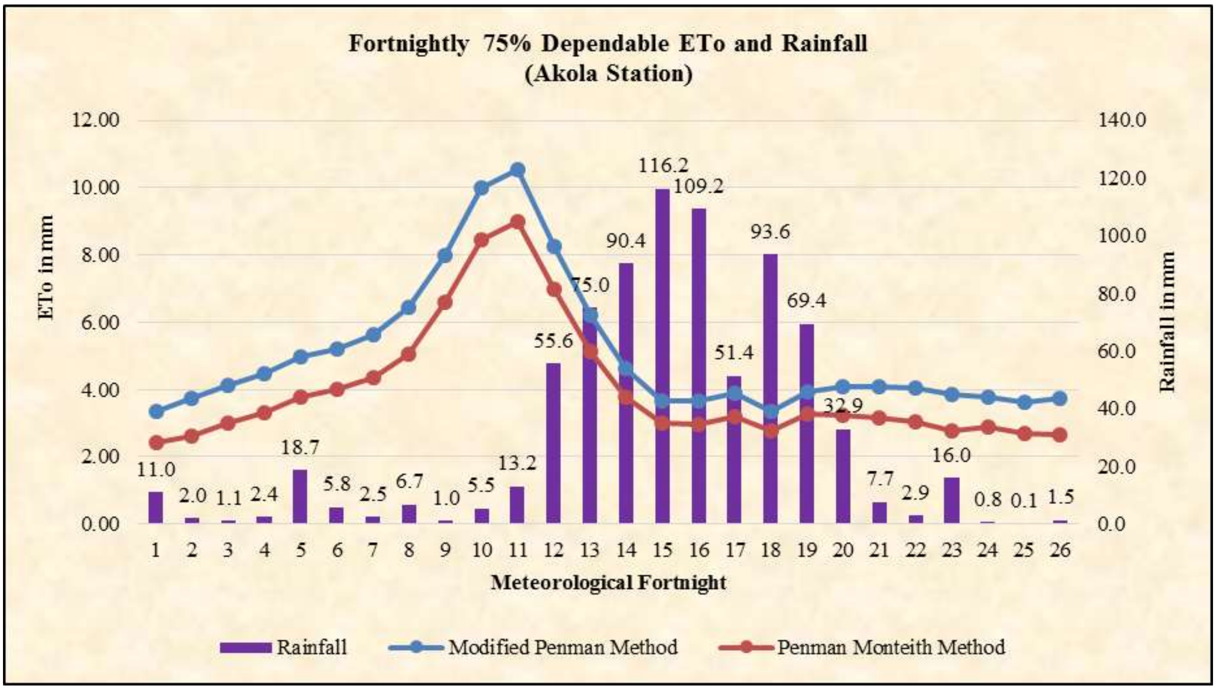

Fig 3: Fortnightly Rainfall (mm) and 75% dependable reference evapo-transpiration (ETo in mm) of Akola, Station

Akola station

The Modified Penman approach produced highly significant performance at the research site, with a high degree of accuracy shown in Fig. 5. The coefficients of determination and correlation indicate the degree of accuracy. The Penman Monteith method under predicted by -22.5 percent in ETo values. The Modified Penman method shows higher accuracy with high coefficient of determination (R^2 = 0.95) with lower RMSE (1.05) as compared to Penman Monteith method with lower R^2 value (0.88) and higher RMSE (1.44). The average deviation was observed to the extent of 1.04 mm/day.

WALMI station

The comparison of regression analysis between the variations of originally measured ETo from Pan Evaporation Method and ETo estimated by Modified Penman and Penman-Monteith methods is shown in Fig. 5. The Modified Penman method predicted ETo values accurately than Penman Monteith method. The accuracy in MP might be due to higher value of coefficient of determination (R^2 = 0.82) with lesser error (0.45) as compared to PM method (R^2 = 0.80 and 0.49 respectively). Average deviation was observed to the extent of 0.49 mm in ETo values with -11.9 percent under prediction by PM method.

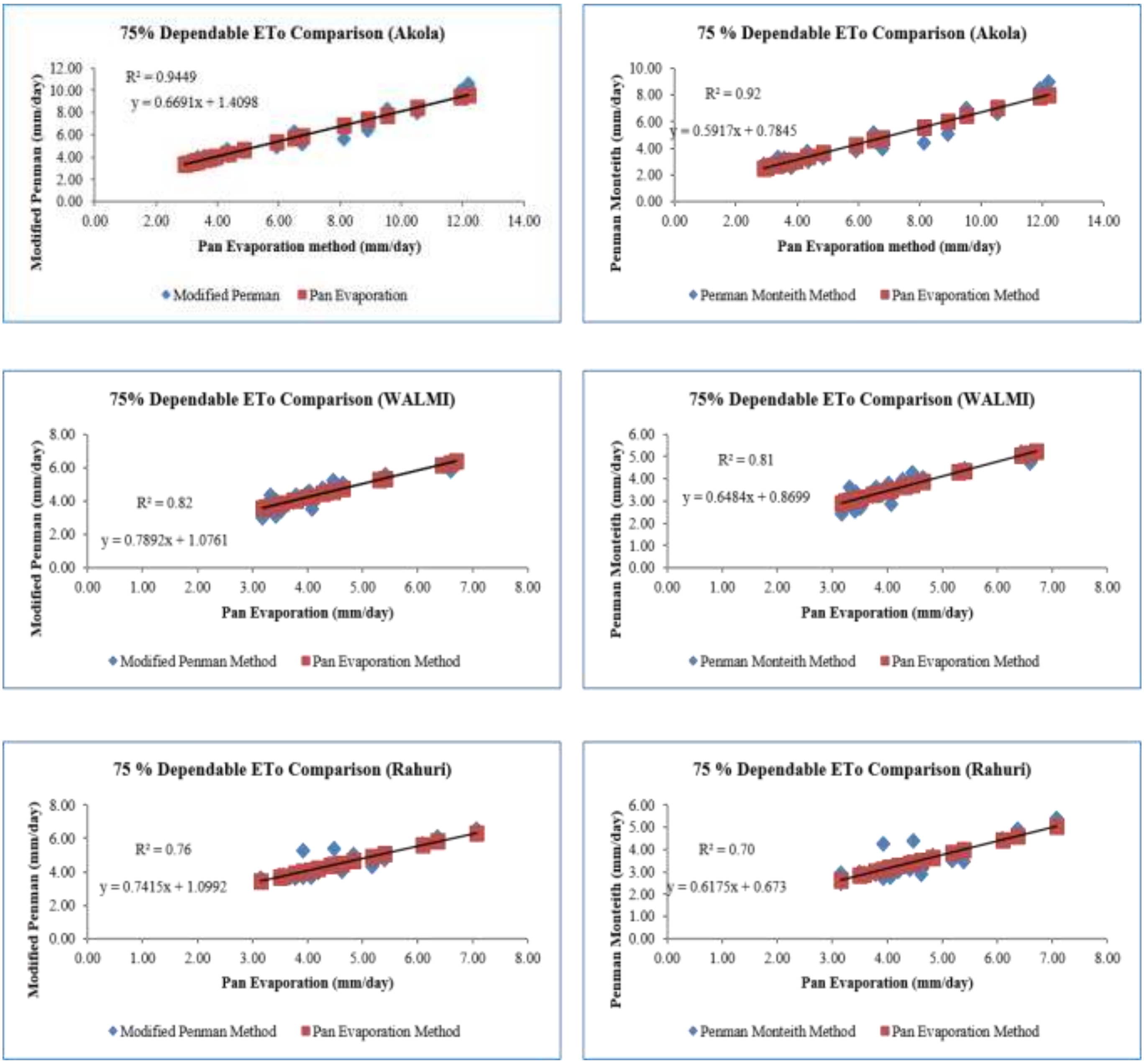

Fig 5: Regression analysis for 75% Dependable ETo estimates of Modified Penman and Penman Monteith Method with Pan Evaporation method for selected weather stations

Rahuri station

The MP and PM methods were compared with Pan Evaporation method to infer statistically in accuracy among them. The values of coefficient of determination are presented in Fig. 5. The coefficient of determination value is higher in MP method (R^2 = 0.82) as compared to PM method (R^2 = 0.67). The values of RMSE is higher PM as compared to MP method (1.75 and 2.15 respectively). This result shows that, the Modified Penman method points out a fairly consistent agreement, a fact that can be statistically confirmed by coefficients of determination and RMSE. The deviation of average ETo was observed up to 0.93 mm/day and PM method under predicted to the extent of -22.5 percent.

Owusu-Sekyere *et al.* (2017) [6] conducted the study in 2013 and repeated in 2014 and 2015 at the agro-meteorological station at University of Cape Coast, Ghana. This study was conducted to determine suitable simple ETo methods in Cape Coast by comparing estimated ETo values of three indirect-measurement methods: Hamon, Hargreaves, Blaney Criddle; and two direct-measurement methods: Class A pan and Piche-evaporimeter with the FAO Penman-Monteith equation (FAO56-PM) estimated ETo values. All the methods underestimated ETo values obtained by the FAO56-PM method.

However, the estimated ETo values by the indirect methods (Hamon, Hargreaves and Blaney-Criddle) are strongly correlated (R = 0.89, 0.87 and 0.81 respectively), while the direct measurement methods (Class A pan and Piche-evaporimeter methods) are weakly correlated (R= 0.37 and 0.31, respectively) with the FAO56-PM method. All but the Piche-evaporimeter methods appeared suitable for estimating ETo in the study area. The Class A pan, though weakly correlated with the FAO56-PM method, was also suitable because it had the least mean absolute error (MAE; 0.26 mm day^{-1}) and mean absolute percentage error (MAPE; 6.5%) among the other methods and its ETo curve was closer to the FAO56-PM's (Owusu-Sekyere *et al.*, 2017) [6]. The results of the present study are in line with the findings of these

Authors.

Regression statistics showed higher coefficient of determination and lower root mean square error for Modified Penman method as compared Penman Monteith method, which is vice versa. The statistical indicators, derived from Penman Monteith are closely associated with PM method. After analysis of regression statistics and compared with Pan evaporation data which is practically more appropriate hence, Modified Penman method is proposed for adoption in semi-arid regions of the country.

Singandhupe (2017) [8] tested five ETo models *viz*., Modified Penman -Monteith equation, Modified Penman method, Hargreaves method, Radiation method, Blaney-Criddle method along with Pan evaporation method and compared with FAO56- PM by using 22 years weekly weather data (1975 to 1996) in the command of Mula irrigation project (Ahmednagar District of Maharashtra), which falls in semi-arid belt of Maharashtra, India. The results revealed that the Modified Penman model of FAO24 is quite effective against the FAO56 PM model but the former model requires both radiation and aerodynamic parameters for estimating ETo.

The crop water requirement was calculated by FAO suggested method for all the three weather station data and expressed net irrigation requirement at root zone head in hamm for respective crop (Table 2). The Modified Penman method predicted higher values of NIR as compared Penman Monteith method for all the three weather stations data. The NIR values 23.9%, 25.5% and 16.4% was under predicted by Penman Monteith method respectively for Akola, Rahuri and Aurangabad Station. Among the kharif two seasonal crop LS cotton require higher water compared to other crops because its duration. Among the Rabi Crops Tomato and Wheat require higher water compared to other crops. Hot weather Groundnut NIR ranges from 412 ha mm to 624.8 ha mm for various locations and various methods.

Table 2: Comparison of difference in NIR Values calculated by Modified Penman and Penman Monteith methods for different weather station data

S.No.	Crops	Akola		Rahuri		Aurangabad	
		MP	PM	MP	PM	MP	PM
	Kharif						
1	LS Cotton	356.8	255.6	289.1	193.3	336.9	262.9
2	Hybrid Jowar	17.8	6.7	82.5	50.2	1.4	0.0
3	Groundnut	14.5	4.0	86.2	47.6	0.0	0.0
4	Onion (Kh. Veg)	64.7	36.9	41.7	12.2	28.8	14.2
	Rabi						
5	Wheat	411.9	317.1	406.1	318.9	459.9	395.9
6	Gram	334.4	262.5	317.9	255.9	368.2	318.5
7	Rabi Jowar	329.3	239.5	293.7	210.9	374.3	299.7
8	Tomato (Rabi vegetable)	416.0	321.1	403.7	317.4	467.6	401.4
	Hot Weather						
9	HW Groundnut	624.8	513.7	518.5	412.1	566.1	484.2
	Total	2570.2	1957.1	2439.4	1818.5	2603.2	2176.8
	Difference in NIR prediction by both the methods	613.1		620.9		426.4	
	% Under prediction by PM Method (Average21.9)	23.9		25.5		16.4	
	Mean	285.6	217.5	271.0	202.1	289.2	241.9
	Standard Error	69.86	57.13	55.58	46.71	73.38	63.07
	Standard Deviation	209.9	171.4	166.7	140.1	220.1	189.2

Conclusion

The Penman Monteith Method under predicted the ETo values to the extent of 18.2% to 22.3% for various regions and deviation in values of ET from 0.81 mm to 1.05 mm for various locations selected for the study as compared to Modified Penman method. Modified Penman model is proposed for adoption in semi - arid regions of the study area because it is predicted with higher coefficient of determination and least error when compared with E pan in the regression statistics. Among the various locations selected higher average ETo values are noticed for Akola (Vidharbha) region followed by Aurangabad (Marathwada) and Western Maharashtra (Rahuri-Ahmed Nagar) because of spatial and temporal variations observed in weather parameters. Kharif crops can be raised under rainfed conditions and Two Seasonal crops required supportive irrigations in Rabi season. However, Rabi and Hot weather crops require assured irrigation supply for crop production.

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