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Sensitivity Analysis of Reference Evapotranspiration (ETO) Models for Irrigation Requirement of Crops and Impact of Irrigation on Climate Changes in Semi-arid Region of India

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Estimation of simple reference ETo model is being received considerable attention over the globally accepted FAO56 Penman-Monteith model, because the data generated from the fitted sensors of weather stations are questionable. To solves this problem in research field of water management, we tested five ETo models and compared with FAO56- PM by using 22 years weekly weather data (1975 to 1996) of irrigation command (CCA 80,800 ha) of semi-arid area of Maharashtra, India(long. 74^0 18′, lat. 19^0 45′, alt. 435 m). 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 next temperature-based Hargreaves and Blaney Criddle model provided very significant effect as these models have expressed minimum RMSE, MBE, RE and high D-agreement. Development of water resources and irrigating seasonal field and horticultural crops in this semi-arid area has changed the physiological and physical attributes of vegetations. Due to more vegetation cover and cooling effect in irrigated area, the relative humidity has increased and evaporation rate, wind speed has decreased. When it was regressed with various weather parameters the temperature, wind speed, relative humidity and duration of bright sunshine have expressed positive effect and rainfall has shown negative effect on water loss from pan evaporimeter.

Keywords: Evapotranspiration; ETo model analysis; RMSE; D- agreement; MBE; RE; t-statistic; irrigation impact; climate change; lysimeter.

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1. INTRODUCTION

Evapotranspiratioin (ETo) is a continuous process of transfer of water from the plant through transpiration and from the soil through evaporation into the atmosphere in the land-plant- atmosphere continuum system. The weather parameter plays very significant role in regulating water supply to fulfill ETo demand of the crop. In most of the areas, the class A pan evaporimeter (Epan) data is easily accessible for computing reference ETo [1,2] however the pan coefficient (Kpan) is required to convert pan evaporation into pan reference ETo [3,4]. Hence the assessment of the impact of all meteorological parameters on water loss from open pan evaporimeter and the calibration of pan coefficient for a particular place is extremely essential for computation of pan ETo [4,5,6]. Besides pan reference ETo, numerous equations of reference ETo estimation models have been tested recently. But the performance of different models tested under different climatic situation fluctuates in a significant manner [7]. Under such weather aberrations, the sensitivity analysis of various ETo estimation models with globally accepted FAO56 PM model is essential in a special region and area of work. The lysimeter is the most desirable and common method for estimating actual evapotranspiration [4,7], yet due to limited in numbers and high installation cost, the micro level study on actual crop water demand and water budgeting has not been disseminated in remote areas where crop planning is necessary to bring the country under a suitable cropping system. In a lysimeter study, the selected crops are grown in a limited field area based on the size of lysimeter. The crop canopy during full growth stage is extended outside the lysimeter frame and does not contemplate the exact value for computing crop coefficient (actual crop ET divided by reference ETo). So, to avoid the computational error, the surrounding field area of lysimeter is kept identical to lysimeter cropped area to avoid any adverse outcome of various weather parameters on the measured lysimeter and computed ETo[8]. Estimation of reference ETo by FAO-56 Penman Monteith requires essentially several weather parameters viz. temperature, sunshine hours, wind speed, relative humidity, however in most of the ETo estimates models, only limited weather parameters are required which can be generated by cutting down a minimum amount within the small watershed area for estimation of reference ETo.

In irrigation command area, significant amount of water loss occurs (71% of the applied water) through conveyance in different segment viz. main canal (15%), distributary (7%) water courses (22%) and in field loss (27%) [9]. If the required amount of water to be applied to different crops is estimated by suitable ETo methods then the releasing water from the storage structure in to command area could be efficient. For estimation of ETo, several models have been proposed and tried in different places, especially in temperate regions of the earth, even though there is no universal consensus on the suitability of model for a given climate [10, 11]. Hence local calibration and validation is more important in semi – arid and arid region than the temperate climate as most of the models have been calibrated, validated in a temperate environment [12,4,10,13]. [14] computed lysimeter ETc and compared reference ETo by Modified Penman, Penman Monteith, Wright - Penman, Blaney Criddle, Radiation Balance and Hargreaves method for semi- arid (Iran) and sub-humid climate (Japan). For semi arid climate the Penman Monteith and for sub-humid climate the Penman model produced the best results. [15] described similar results when ETo of FAO-56PM was compared with the Hargreaves method in 48 locations in the USA. Recently FAO-56 equation of [4] has been globally accepted over FAO- 24 models by virtue of inclusion of physical parameters, i.e. surface resistance (70 s m^{-1}), plant stature (0.12 m) and albedo (0.23) which are essential for ETo estimation as Modified Penman method, though considered both aerodynamic and radiation term like FAO 56, the physical parameters are lacking which also plays a major role for ETo estimation.

Due to introduction of irrigation water in command area ,cultivation of high value cash crops, horticultural fruit crops , vegetable the macro and microclimate of the irrigated area has played a major role in changing the crop water demand scenario. In unirrigated and forest-land ecosystem, the physiological and physical attributes completely differ from the vegetation ecosystem. In irrigated ecosystem the vegetation and land cover improves availability of soil moisture, which further influences weather and climate resulting in the transfer of heat, evaporation of soil moisture into a water vapor form and transfer of water vapor from ground surface to the air [16]. Several researchers [17,18,19] have studied the impact of irrigation, land surface evapotranspiration and deforestation on climate changes and observed substantial fluctuations on climatic parameters when irrigation is provided to different crops or when forest grassland is converted in to the vegetation.

In the present study, the contribution of various weather parameters on water loss from class A pan evaporimeter was monitored through weekly meteorological data, viz. maximum and minimum temperature, relative humidity, wind speed, sunshine hour and rainfall as independent variables and water loss from class A pan evaporimeter as dependent variable. For this study the meteorological data for the period from 1975-1996 were collected from a nearby meteorological station and the data were used for multiple regression analysis and other statistical measures. Similarly, the reference ETo which was computed by different models (FAO56-Penman Monteith, ,Modified Penman, Hargreaves, Radiation Balance , Blaney Criddle, Pan evaporation) were compared with FAO 56 Penman Monteith model with statistical tools like RMSE, MBE, D-agreement , RE and t-statistics for their significance and adoption in semi- arid environment for agricultural water management in crops and cropping pattern, being adopted by the farmers.

2. MATERIALS AND METHODS

2.1 Study Area

For computation of reference ETo, the basic climatic data were collected at weekly intervals from the meteorological observatory of the Water Management Project, Mahatma Phule Agricultural University, Rahuri, Maharashtra, India (long. 74°18′, lat. 19^0 45′, alt. 435 m above mean sea level) for the period from 1975 to 1996. This earmarked meteorological station was set up at a distance of some 7 km downstream side of the major Mula Irrigation Project, which was brought into operation in the year 1971 however irrigation water in the command area was released as per designed cultural command area (CCA) in the year 1976. The catchment area is 2275.9 sq. km from where the rainwater is harvested and collected in the reservoir. The cultural command area (CCA) is 70,700 ha in right bank canal and 10,100 ha in left bank canal. The water resources created in this irrigation dam accommodate 736.23 million m^3 water, however the actual storage of water in the dam is considerably changing every year due to erratic distribution of rainfall in the catchment areas. For discharging harvested rain water in to a cultural command area for irrigation, 52 km and 18 km canals length with a discharge rate of 46.72 and 7.08 m^3 sec^{-1}, respectively, on both sides of the dam (right and left) have been constructed as per the design of the project.

2.2 Climate

The study area comes under the purview of semi – arid region with long term annual rainfall of 520 mm, distributed mainly in the rainy season (June to September). During rest of the period, rainfall amount is quite low and requires supplemental irrigation for growing crops. Before introduction of the irrigation project in this area, the farmers were growing rain-fed cereals and pulses with less productivity. Now in this command area, the irrigation water is being provided through the canal system (main canal, distributory, minor, field channel) to the field crops, particularly sugarcane, cotton, wheat and chickpea, groundnut from 1976 onwards and the cropping pattern has been changed towards high value cash crops besides food grain crops . Since then, the climatic variables have changed and resulted in significant improvement in crop yields. This may be due to cooling effect or some other unknown factors which needs in-depth study.

2.3 Soil Properties

The territory of a cultural command area is predominantly clay, clay loam and sandy clay loam in texture. The higher amount of clay in the command area, resulted in poor drainage and secondary salinization since the farmers were applying irrigation water at a greater depth each time due to uncertainty of next irrigation supply. To assess the impact of irrigation on soil attributes, in the year 2005, soil samples were collected from 0 to 60 cm at 20 cm depth interval from head, middle and tail reach of the command area and analyzed for physico-chemical properties. It was mentioned that the filth of the command area was developed into problematic soil due to waterlogged and secondary salinization with high intensity at head reach [20]. Before introduction of irrigation water in the command area, such problems was not visible as the whole command area was totally rain-fed.

2.4 Computation of Reference ETo

The reference evapotranspiration (ETo) was computed as per the standard procedure described in FAO56 and FAO 24 Irrigation and Drainage Paper of Food and Agricultural Organization, Rome Italy. The processes adopted in different methods are given here.

2.4.1 Reference evapotranspiration FAO56 PM

The modified Penman -Monteith equation described first by [21] has been accepted universally for daily as well as hourly estimation of reference ETo. The United Nations, Food and Agriculture Organization has recommended the following equation and it is being used by agronomists, hydrologist, irrigation engineers and other scientists in field exercises.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma\ (1 + 0.34U_2)} \quad (1)$$

Where,

- ET_0= reference evapotranspiration (mm day^{-1})
- Δ = slope of vapor pressure curve (kPa $^0C^{-1}$)
- R_n= net radiation ($MJm^{-2}\ day^{-1}$)
- G= soil heat flux density ($MJm^{-2}\ day^{-1}$)
- γ= psychrometric constant (0.0671 kPa $^0C^{-1}$)
- T= mean daily temperature at 2 m height
- U_2= wind speed at 2 m height (m s^{-1})
- e_s= saturation vapour pressure (kPa)
- e_a= actual vapour pressure (kPa)
- e_a-e_s= saturation vapour pressure deficit (kPa)

2.4.2 Modified Penman method

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 [22] 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 method have been accommodated in the modified formula with weather parameters. Several tables are prepared and mentioned in FAO- Irrigation and Drainage paper no. 24 for computation of certain parameters as mentioned in equation no.1.

$$ET_0 = c\{W.R_n + (1 - W).f(u).(e_a - e_d)\} \quad (2)$$

Where

- ETo = reference evapotranspiration (mm day^{-1})
- C= adjustment factor for day and night wind speed and different RH level
- W= weighing factor for altitude and temperature on radiation
- Rn= net radiation in equivalent evaporation (mm day^{-1})
- 1-W= weighing factor for altitude and temperature effect on wind and humidity
- f(u)= wind function or effect of wind on ETo and expressed in equivalent Evaporation (mm day^{-1})
- ea-ed= vapour pressure deficit (mbar)

2.4.3 Hargreaves method

Hargreaves method [23] is often used to compute ET_0 through temperature data for daily / weekly or longer period for use in regional planning, reservoir operation studies where other climatic data are not available or the available data are questionable.

$$ET_0 = 0.0023R_a(TC + 17.8)TR^{0.50} \quad (3)$$

Where,

- ETo= reference evapotranspiration (mm day^{-1})
- R_a= extra-terrestrial radiation (mm day^{-1})
- TR= Tmax.-Tmin. (°C)
- TC= mean temperature (°C);

mean temperature =(T max+Tmin)/2

2.4.4 Radiation method

The radiation method by [22] considers the radiation reaching to the earth surface as the major contributing factor for evapotranspiration. The data required for this method are air temperature and sunshine hours. In addition to these parameters, general levels of humidity and wind velocity are necessary. The equation is:

$$ET_0 = c(W \times R_s) \quad (4)$$

Where

ET_0 = Evapotranspiration (mm day^{-1})
Rs = Solar radiation in equivalent (mm day^{-1})
W = Weighing factor which depend on temperature and altitude.
C = adjustment factor which depends on mean RH and day time wind. The Rs value is estimated as
Rs = (0.25+0.50 n/N)* Ra. The details of n, N and Ra are given in Modified Penman model.

2.4.5 Blaney Criddle method

Blaney-Criddle [24] observed that the amount of water consumptively used by crops during the growing season was closely related to mean monthly temperatures and daylight hours. The equation for computing reference ETo is:

$$ET_0 = c\{p(0.46T + 8)\} \quad (5)$$

Where

T= mean daily temp. °C
p= mean daily percentage of total annual day time hours for a given month and latitude
c= adjustment factor which depends on minimum RH, sunshine hour and day time wind estimate

2.4.6 Pan evaporation method (Doorenboss and Pruitt, 1977) [22]

Evaporation pan provides a measurement of the integrated effect of radiation, wind, temperature and humidity on pan evaporation from a specific open water surface .In a similar fashion, plant also transpires water under the same environmental condition. But the magnitude of water loss from open water surface is higher than the plant surface. Reflection of energy from open water body is less (5- 8%) than plant parts (20-25%). During day time, evaporimeter retains more energy and water loss through evaporation during day and night time does not change significantly. But in plant, more water loss occurs during day and less during night. Hence the pan coefficient value is required, which can be calibrated for specific location instead of using the values given in FAO24.

$$ET_0 = E_{pan} \times K_p \quad (6)$$

Where,

ETo = Evapotranspiration (mm day^{-1})
E_{pan} = pan evaporation (mm day^{-1})
K_p = pan coefficient

The Kp value depends on wind speed, relative humidity and fetch distance. The pan coefficient was taken from FAO56 Irrigation and Drainage and pan ETo was estimated for the years 1975 to 1996.

2.5 Crop Coefficient (Kc)

The crop coefficient is basically the ratio of crop ETc to the reference ETo, and it represents the effect of four primary characteristics that differentiate the crop from reference grass.

$$Kc=ETc/ETo \quad (7)$$

Where

Kc= crop coefficient,
ETc= Crop evapotranspiration by lysimeter,
ETo= reference evapotranspiration by various models

The weekly crop coefficient values of two crops viz. soybean during rainy season of 1993 and mustard during winter season 1993-94 were estimated by FAO 56 PM model by considering actual ET crop of both crops grown in lysimeter as per equation no.7.

For monitoring actual crop evapotranspiration, two weighing type lysimeter (tank size 1.3 m x 1.3 m x 0.9 m) were installed in the field dimension of 78m x 45m. Near the same field weather station was also installed for recording all weather parameters. The soybean variety MACS 123 during kharif 1993 (June to November) and mustard variety Seeta were grown as test crop in lysimeter and in surrounding area to maintain same micro-climate. For irrigating soybean and mustard crop a border irrigation strip of 2.5 m width and 45 m length was prepared. Soybean was sown on 28.6.1993 and harvested on 13.10.1993 while mustard crop was sown on 3.11.1993 and harvested on 8.2.1994. In soybean crop three irrigations with total depth of 302.8 mm was provided besides 287.2 mm rainfall, received during crop growing period. In case of mustard total depth of irrigation water was 170.4 mm and rainfall received was 76.2 mm.

2.6 Data Analysis

2.6.1 Regression analysis

To measure the intensity of each weather parameter on water loss from pan evaporimeter, the multiple regression analysis was done by taking maximum and minimum temperature, relative humidity, sunshine hours, wind speed and rainfall as independent variables and pan evaporation as dependent variable . The coefficient of intercept and slope was compared. The calculated 't' value (coefficient divided with standard error) of the intercept and slope of different parameters for each year (calculated, but not mentioned in table) for 5-6 years mean was compared with table 't' value at 5% probability level at 51 degree of freedom (n=52) . Then the statistical significance of each parameter was derived based on the calculated t- value of the intercept and slope.

2.6.2 Statistical indicators

In agricultural modeling research, scientists generally evaluate model performance by regression line, correlation coefficient and occasionally by means of standard deviation. The four most widely used statistical methods are Root Mean Square Error (RMSE), Mean Bias Error (MBE), D-agreement and Relative Error. The index of D -agreement ranges between 0.0 to 1.0 where 1.0 value shows perfect agreement. Although the indicators provide a reasonable procedure for model comparison they do not indicate whether the model estimate is statistically significant or not and hence t - statistics test is required [25].

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (Pi-Oi)^2}{n}} \quad (8)$$

$$\text{MBE} = \frac{\sum_{i=1}^{n}(Pi-Oi)}{n} \quad (9)$$

$$D = 1-\frac{\sum_{i=1}^{n} (Pi-Oi)^2}{\sum_{i=1}(|\bar{O}i-Pi+|Oi-\bar{O}|)} \quad (10)$$

$$\text{RE (relative error)} = \frac{RMSE}{\bar{O}} \quad (11)$$

For interpretation of the results of D–agreement and RE value, the following criteria described by [26] was used:

D≥ 0.95 and RE ≤0.10 score : Very good
D≥ 0.95 and RE ≤0.15 RE ≥ 0.10: Good
D≥ 0.95 and RE≤ 0.20 RE ≥ 0.15: Acceptable
D≥ 0.95 and RE≤0.25 RE ≥ 0.20: Marginal

Other combinations of D-agreement and RE values are less important for comparison.

$$\text{t-statistic} = \frac{\bar{P}i - \bar{O}i}{\sqrt{\left(\frac{Pi^2}{n}+\frac{Oi^2}{n}\right)}} \quad (12)$$

$$R^2 = \frac{[\sum_{i=1}^{n} (Pi-\bar{P})(Pi-\bar{O})^2]}{\sum_{i=1}^{n} (Pi-\bar{P})^2 \sum_{i=1}^{n} (Oi-\bar{O})^2} \quad (13)$$

Where,

n= number of data pairs
$\bar{P}i$= average value of ETo estimated by various models(equation no. 2 to 6)
$\bar{O}i$= average value of ETo of FAO56 PM model (equation no.1)
Pi= weekly estimated ET_0 by various model (equation no. 2 to6)
O_i= weekly FAO 56 PM model (équation no.1)

3. RESULTS AND DISCUSSION

3.1 Regression Analysis

The multiple regression analysis was carried out with pan evaporation as dependent variable and seven weather parameters as independent variables, year-wise to assess the magnitude of different weather parameters on rate of water loss from pan evaporimeter. The magnitude of the weather parameters on water loss from pan evaporimeter is given in Table 1 in a block of 5-6 years (1976- 1980, 1981-1985, 1986-1990 and 1991-1996 as well as base year 1975) instead of each year depending upon the availability of weather data. In first year (1975), the wind speed made significant contribution to water loss out of seven weather parameters regressed on pan evaporation.

In the first year, the contributions of all weather parameters on water loss was quite low as expressed by R^2 value of 0.27. In a block year of 1976-1980, the contribution of all seven weather parameters towards water loss from pan evaporimeter was attributed to 78%. With regards to the contribution of individual weather parameters on water loss, the wind speed and duration of bright sunshine had a significant impact as evidenced by the calculated " t" value of 2.295 and 2.338 , respectively over table "t" of 2.006 at 5% probability level. The maximum temperature ranged during summer hot period (March 19 to June 3) was 36.4°C to 39.9°C. This high temperature enhanced the rate of water loss and the water vapor which subsequently moved from open water body and quickly displaced in another area attributing to more wind speed. This caused more vapour pressure deficit on open water body which was again recouped with continuous process of water loss from pan evaporimeter. The dry air from the surrounding area during this period (after harvest of winter crops) played a major role in increasing evaporation rate as evidenced by the calculated "t" value derived from multiple regression analysis (Table 1).

The duration of sunshine, on an average of five years was 7.6 hour day^{-1}, however the maximum value of 10.4 hour day^{-1} was recorded on 19 the

Table 1. Multiple regression analysis between pan evaporation (dependent variable) and seven weather parameters (independent variables)

Statistical parameters	Regression equation with coefficient	R2
	1975 as base year	
Y	= -1.094+0.087X_1 -0.046 X_2 +0.008 X_3 -0.093 X_4 +0.043X_5 +0.351 X_6 -0.017 X_7	0.27
SE	= + 32.10 + 1.113X_1 +0.662 X_2 +0.185 X_3 +0.226 X_4 +0.019X_5 +1.044 X_6 0.077 X_7	
t	= -0.034 + 0.078X_1 -0.070 X_2 +0.097 X_3 -0.350X_4 +2.216*X_5 +0.337 X_6 -0.216 X_7	
	1976-1980	
Y	= -8.244+ 0.157 X_1 +0.023 X_2 +0.003 X_3 -0.021 X_4 +0.062 X_5 +0.168X_6 -0.004X_7	0.78
SE	= -0.811 +0.081 X_1 +0.056 X_2 +0.013 X_3 +0.021X_4 + 0.027 X_5 +0.072 X_6 + 0.009X_7	
t	= --10.16 +1.933 X_1 + 0.412 X_2 + 0.261 X_3 -0.966X_4 + 2.295*X_5 +2.338* X_6 -0.409X_7	
	1981-1985	
Y	= -10.256+ 0.472 X_1 +0.052 X_2 -0.043 X_3 +0.008 X_4 +0.228 X5 + 0.318 X_6 -0.002 X_7	0.87
SE	= 1.77+0.054 X_1 +0.043 X_2 +0.011 X_3 +0.013X_4 + 0.024 X_5 +0.062 X_6 + 0.003X_7	
t	= --6.532* +8.801* X_1 +1.22 X_2 -3.841 X_3 -0.966X_4 + 2.295*X_5 +2.338* X_6 -0.409X_7	
	1986-1990	
Y	= -2.1+ 0.291 X_1 +0.155 X_2 -0.081 X_3 +0.001 X_4 +0.142 X_5 + 0.179 X_6 +0.001 X_7	0.84
SE	= 1.555+0.045 X_1 +0.038 X_2 +0.012 X_3 +0.013X_4 + 0.027 X_5 +0.051 X_6 + 0.003X_7	
t	=-1.351 +6.494* X_1+4.117* X_2 -6.901 X_3 + 0.093X_4 +5.233*X_5 +3.526* X_6 -0.423X_7	
	1991-1996	
Y	= -6.317+ 0.444 X_1 +0.063 X_2 -0.06 X_3 -0.005 X_4 +0.16 X_5 + 0.122 X_6 +0.004 X_7	0.91
SE	=1.32+0.037 X_1 +0.025 X_2 +0.009X_3 +0.009X_4 + 0.020 X_5 +0.039 X_6 + 0.002X_7	
t	=4.786* +11.941* X_1+2.496* X_2 -6.897* X_3 -0.496X_4 +8.014*X_5 +3.166* X_6 +1.909X_7	

*Note SE= Standard Error, * significant at 5 % probability level at 51 df (n=52) t= 2.006, Y= estimated evaporation, X_1= minimum temperature, X_2= maximum temperature, X_3= relative humidity (morning),X_4 = relative humidity (afternoon), X_5 wind speed , X_6 = sunshine hour , X_7= rainfall* standard meteorological week (7-13 May) which was considered as hot summer week. In 1981-1985, 1986-1990 and 1991-1996 block years, the water loss from pan evaporimeter was enhanced due to significant effect of all seven weather parameters and the contributions of these parameters to water loss, on an average was 87, 84 and 91% in respective block years. The major contribution of water loss from pan evaporimeter was observed through maximum and minimum temperature, wind speed and sunshine hours with positive trend and relative humidity during the morning period with negative trend in last two block years (1986-1990 and 1991-1996). In the block year of 1981-1985, however the effect of minimum temperature and relative humidity of afternoon hour was absent. The relative humidity during the afternoon period and rainfall did not show any significant impact on water loss from evaporimeter in all block years. The contributions of all the weather parameters when regressed with water loss from class A pan evaporimeter year- wise, was 85% to 94% during 1976-1980, 45% to 92% during 1981-1985, 73% to 89% during 1986 to 1990 and 92% to 95% during 1991-1996. Since the temperature, sunshine duration, wind speed and relative humidity played major role in enhancing water loss, it is quite essential to save significant amount of water loss due to evaporation. In various integrated water resources development programs, micro level watershed is constructed and maximum rain water is harvested, stored in farm pond without making any provision to control water loss. The growing of vegetation / trees in surrounding areas of the pond as well as field crops check air circulation and displacement of water vapor from pond to nearby areas. With the result, significant amount of water loss from evaporation is checked. Once irrigation resources are developed and irrigations are supplied to field crops throughout the year, the microclimate would also change substantially. [27] studied the evaporation reduction loss from the tank through the floating of foam and other material over the water surface for 8 years. The floating cover of the foamed wax block, cover with continuous wax and foamed rubber reduced evaporation loss to the extent of 36% –84%. The material cost and the cost of the water saved from the treatment with continuous wax cover proved economical, however the longevity, durability, efficiency of the material used for this work needs more research study.

Once a full command area or part of it, is brought under irrigation, the physiological and physical properties of vegetation / crops grown in the irrigated command area alter the net radiation (Rn) and this net radiation is further divided into sensible and latent heat flux with various magnitude [28]. The studies on impact of vegetation transformation from grassland eco-climatic region in the Canadian Prairies to annual field crop particularly spring wheat (50-60 % of grassland to cultivated area) has resulted a change on surface temperature. It was noticed that the seasonal pattern of heat flux has changed with introduction of wheat crop [29,30]. [31] reported from USA (great plain of USA) that due to changes in cropping pattern and the introduction of irrigation in five regions from dry land to irrigated land has brought a reduction in maximum temperature and mean temperature but increased the dew point temperature during the month of May to September where the atmospheric temperature was quite high.

3.2 Impact of Irrigation Development Project on Climatic Variables

After complete construction of irrigation projects, the introduction of high value cash and water demanding crops like sugarcane, cotton during rainy season and chickpea and wheat, vegetable crops (onion, tomato, brinjal) during the winter season in medium to heavy soils and perennial horticultural fruit crops like mango, chiku, guava in light soils have expanded the cultivable area by the farmers. In this command area, warabandhi system (rotational irrigation system) is being adopted wherein the irrigation department is releasing water for 15 days and keeping off for 21 days. During the 15 days on period, the dug wells in command areas are being recharged for irrigating field crops during canal off period. The farmers who are not receiving canal water particularly at tail reach locations, are also using dug well water but with lesser magnitude. So the impact of this cropping pattern as well as irrigation water which was provided in irrigation command has resulted a change on climatic variables.

The changes of different climatic variables after 21 years of continuous cropping with adequate water supply resulted in a marginal increase in maximum temperature of 0.4°C over the base year of 1975 in which the maximum temperature was 31.9°C. During individual block years, which started from 1976-1980 and continued up to 1991- 1996, the temperature was increased by 0.4, 0.5, 0.3 and 0.2°C in respective block years. Similar was the case with minimum temperature but the magnitude was less. With respect to water loss from open pan evaporimeter, it was reduced from 7.3 mm day^{-1} in 1975 to 6.9 mm day^{-1} (5.5 % less) after 21 years of study. The reduction in water loss from open water body was further squeezed in the block year of 1986-90 (6.6 mm day^{-1}) and 1991-96 (6.4mm day^{-1}). The water loss in one of the meteorological week i.e. in the hottest week period during 1975 was 16.4 mm day^{-1} and further reduced considerably to 13.1 mm day^{-1} (by 20.1%) after 21 years . The rainfall amount however reduced from 616.8 mm to 527.9mm over the base year of 1975 during the 21 year study period. A similar trend was noticed in different block years except in 1986-90, the rainfall received was slightly higher (625.4 mm) than the base year. Out of 21 years of study period, the total rainfall received in 1982 was very low (260.3 mm) as compared to average value of 532 mm. Due to receipt of very low rainfall in the year 1982, the amount of reference ETo increased by 3.6%, 3.7%, 0.5%, 1.32%, 1.2% and 7.0% in FAO 56 PM, Modified Penman, Hargreaves, Blaney Criddle, Radiation Balance and Pan evaporation models, respectively. This excess crop water demand was fulfilled by supplying an adequate amount of canal water supply as well as recharged well water. The relative humidity during the morning was increased with the passage of time, however in the afternoon hour the trend was reversed. In the year 1975 the relative humidity was 62.9 % and it increased to 73.4% after 21 years. In different block years, the RH value during morning was improved over base year and was found in the range of 72.2% to 75.4%. There is significant improvement in duration of bright sunshine over the base year. This increased duration of sunshine hours helped in more biomass production of different crops as there was no deficit of water in the command area to achieve higher productivity of improved or hybrid field and horticultural fruit crops. Regarding the intensity of the wind speed , it reduced from 8.5 km hr^{-1} in the year 1975 to 7.6 km hr^{-1} . In different block years also, the wind speed has reduced marginally over base year except in the block year 1981-85, wherein it has increased to 8.6 km hr^{-1}.

In the present situation, the increased temperature and RH have not deteriorated the crop performance in the command area and the farmers are still harvesting crop yield at a satisfactory level. [32] studied the general impact of climate after large scale transformation of vegetation to agriculture on global temperature in temperate latitudes. They found that conversion of grassland and forest land into cropland reduced temperature by 0.7°C in summer and 1.1°C in winter. In tropical and sub-tropical region, however conversion of vegetation by agriculture increased temperature of 0.8°C throughout the year. The impact of crop-land on cooling effect in temperate region was primarily due to (i) increased albedo (reduced net radiation) and (ii) increased latent heat for crops as compared to undisturbed vegetation. [33] studied the impact of deforestation for agriculture in North America's East of 100 ^{0} W longitude. He used General Circulation Model (GCM) and compared natural vegetation and deforestation independently considering 10 years meteorological data. Conversion of land from forest to cropland increased reflection coefficient of incoming radiation and decreased roughness length and stimulated resistance. These physiological changes reduced sensible heat flux, improved cooling effect and reduced the mean annual temperature by 0.6-1.0°C. However in tropical Savana of South America's Cerrado and Llanos; in Southern and Northern Africa, the GCM predicted that when the original mixture of grassland plus trees to cropland was changed, the surface temperature and wind speed increased in the cropland [34]. [35] reported that clearing of the Amazon forest area for cattle grazing also increased surface temperature in dry season.

Our present study on impact of irrigation and conversion of rainfed to the irrigated cropping system also provides similar trend on various climatic parameters after 21 years of irrigated cropping systems adopted in the Mula Irrigation Command area of Ahmednagar district in Maharashtra (India) as reflected in Table 2. Due to introduction of irrigation, the changes in physiological and physical properties of the vegetation and the land cover with various fields and horticultural fruit crops has provided cooling effect of the soil surface and above the soil surface due to sufficient amount of available soil moisture, potential transpiration rate occurred during both crop season. In the year 1975, the coefficient of variation with respect to all seven weather parameters were quite high as compared to the values recorded after introduction of irrigation water in canal command area . The heterogeneity of all climatic variables has been minimized after 21 years of irrigated cropping system adopted in the canal command areas.

Table 2. Temporal variations of weather parameters over time

Parameters	1976 – 80	1981 – 85	1986 – 90	1991 – 96	21 years average	1975
Maximum Temp (°C)						
Average	32.3	32.4	32.2	32.1	32.3	31.9
SD	3.5	3.6	3.2	3.6	3.5	3.8
CV %	10.9	11.12	10.1	11.2	10.8	12.0
Max.	39.9	39.8	39.2	39.3	39.5	40.2
Min.	27.6	27.4	26.8	26.4	27.1	26.9
Minimum Temp (°C)						
Average	18.3	18.1	17.8	17.2	17.8	17.7
SD	4.0	4.6	4.4	5.1	4.5	5.6
CV %	22.2	25.4	24.6	29.4	25.4	32.3
Max.	23.2	24.0	23.2	24.2	23.6	23.6
Min.	10.9	10.8	10.0	8.7	10.1	7.1
Pan Evaporation (mm day^{-1})						
Average	7.1	7.6	6.6	6.4	6.9	7.3
SD	2.7	2.8	2.3	2.6	2.6	3.4
CV %	38.3	37.0	35.4	41.6	38.0	45.7
Max.	13.1	14.1	12.2	12.5	13.1	16.4
Min.	3.8	4.4	4.0	3.6	3.9	4.1
Rainfall (mm)						
Average	10.5	8.1	12.0	10.3	10.2	11.9
(Total)	(530.8)	(418.6)	(625.4)	(537.0)	(527.9)	(616.8)
SD	13.3	17.7	16.4	14.2	15.4	23.4
CV %	1.3	2.2	1.4	1.4	1.6	2.0
Max.	51.0	104.2	61.6	53.0	67.5	94.8
Min.	0.0	0.0	0.0	0.0	0.0	0.0
RH (%) I (8.30 hrs)						
Average	72.2	72.7	73.2	75.4	73.4	62.9
SD	14.8	11.5	10.7	8.3	11.2	18.2
CV %	19.7	15.8	14.6	11.0	15.3	28.9
Max.	88.8	90.0	88.2	86.7	88.4	91.0
Min.	47.0	49.0	50.2	54.0	50.0	27.0
RH (%) II (14.30 hrs)						
Average	38.1	38.3	39.7	39.6	38.9	39.2
SD	16.4	14.6	14.9	14.7	15.1	19.2
CV %	43.1	38.1	37.5	37.0	38.9	49.0
Max.	69.6	67.8	69.8	67.7	68.7	80.0
Min.	16.4	18.4	19.0	21.5	18.8	10.0
Sunshine hours						
Average	7.6	7.8	7.9	7.8	7.8	6.0
SD	2.4	2.4	2.3	2.3	2.33	2.0
CV %	31.7	30.9	28.5	28.8	29.9	32.7
Max.	10.4	10.8	10.5	10.2	10.5	8.3
Min.	2.3	2.5	2.9	2.3	2.5	1.7
Wind speeds (km hr^{-1})						
Average	7.9	8.6	7.2	6.8	7.6	8.5
SD	3.9	4.2	2.8	3.1	3.5	4.6
CV %	48.7	42.0	39.1	45.5	45.6	54.3
Max.	17.1	17.5	12.0	15.2	15.5	18.9
Min.	3.1	4.1	3.3	2.5	3.3	3.1

Note : Figure in brackets are total rainfall

3.3 Application of Statistical Indicator

Simple regression analysis was carried out by considering FAO 56 Penman Monteith ETo estimation model as dependent variable and remaining five models as independent variables to assess the magnitude of relationship of five models with FAO56-PM model. The result presented in Tables 3 and 4 clearly indicates that the contribution of five models are highly significant as explained by 57 to 99% ((R^2 0.57 to 0.99) with the highest contribution observed in case of Modified Penman model (R^2 0.99) and lowest (R^2 0.076) in Blaney Criddle. So considering the magnitude of the contribution of each model, the Modified Penman model is proposed for adoption in semi - arid regions of the country. However this particular model needs radiation and aerodynamic parameters for estimation of evapotranspiration (ETo) and the components of these two parameters are not available in all meteorological observatory. For installation of automatic weather station to generate radiation and aerodynamic parameters, this model requires more expenditure. Thus an alternative model which is less expense is to be explored and assessed properly. In this case out of six models adopted, the Hargreaves model which has the second highest R^2 value (0.65) can be used for estimation of reference ETo since this model requires only temperature and extra-terrestrial radiation at a particular location. The statistical indicators, derived from various models are closely associated with FAO 56 PM model. Among five ETo models tested for comparison, the Modified Penman has the lowest RMSE (0.15 mm day^{-1}), MBE (0.01 mm day^{-1}) and Relative Error (0.032 mm day^{-1}) in comparison to other models. The Hargreaves model also expressed low RMSE (1.00 mm day^{-1}) and Relative Error (0.192 mm day^{-1}) but MBE and t statistics values are higher than Blaney Criddle and Pan evaporation model. The D-agreement (perfect agreement occurs between projected and observed value is 1.0) and RE values are quite comparable only in case of the Modified Penman model. Considering the statistical indicators of Modified Penman model with FAO56 PM, this model is highly acceptable for estimation of ETo in any semiarid region of the country [26] provided adequate budgetary provision is made to install automatic weather station in remote places, where the water harvesting structure is created. For instance, [36] made sensitivity analysis of different ETo estimate models and compared by using regression constant, correlation coefficient, MBE, RMSE , t-statistics. They concluded that the (i) bulk aerodynamic model performed best (ii) Penman's model overestimated PET, (iii) Penman's model and the Bowen ratio model gave satisfactory results. [37] developed decision support system for comparing different methods of ETo estimation under different climatic conditions. They computed ETo by Hargreaves, FAO24 Blaney Criddle, 1982-Kimberly Penman and compared with the Penman Monteith method. Sensitivity analysis for four weather stations (Davis –USA, Bellary, Kharagapur, Jagdalpur - India) were performed by them. Based on weighted average of the standard error of estimate (SEE), Hargreaves and Blarney Criddle method were ranked first for Davis (USA) and Jagdalpur (India) stations respectively. The 1982-Kimberly Penman method was ranked first for Kharagpur (India) station. [38] compared monthly data from six grassed lysimeter at Davis, University of California (USA) using Hargreaves model[23] (1985) and FAO 56 –PM model. They found that the standard error estimates (SEE) and R^2 value were 0.34 mm day^{-1} and 0.94 by Hargreaves model and 0.32 mm day $^{-1}$and 0.96 by FAO 56 –PM model , respectively. Based on the result [39, 40] have reported that Hargreaves model can be adopted under the semi - arid region of the country. In semi-arid region of Spain [41] compared hourly ETo estimates of FAO56- PM and ASCE –PM with lysimter ETo for 13 days (April-October, 2002) and for 16 days (April-October 2003) periods. They found that the average estimated FAO56-PM was also equal to the average measured value of lysimeter ETo. The ASCE –PM equation performed well but resulted a small overestimation with RMSE of 0.0878 mm h^{-1} and index of agreement of 0.97. Under similar climatic situation in Spain, [42] found that ASCE –PM underestimated lysimeter ETo by 2% with RMSE of 0.032mm h^{-1} and index of agreement 0.997, while FAO56- PM underestimated 3% with RMSE of 0.047 mm h^{-1} and index of agreement 0.993. [43] computed ETo by using 13 years meteorological data from humid region i.e. Rasht station of Northern Iran (37° 15' N, 49° 36' E, 6.9 m above mean see level) with 29 commonly used ETo equations and compared with FAO 56-PM model. The equations are based on four major groups: (1) pan evaporation based (2) temperature –based (3) radiation -based (4) mass transfer-based. The ETo estimates derived by these methods were compared with a FAO56 PM equation. Out of 8 equations used for comparison in pan evaporation method, the best performance was

Table 3. Simple regression analysis between ETo estimates of FAO 56 and ETo of various methods

Simulated parameter	Regression equation with coefficient	R2
	FAO 56 PM and Modified Penman	
Y	= 3.160+ 0.9960 X_1	0.99
SE	= 0.0159 +0.0033X_1	
t	=198* + 300.94*X_1	
	FAO 56 PM and Hargreaves	
Y	1.1750+0.752 X_1	0.65
SE	0.0804 +0.0167 X_1	
t	21.45*+ 44.91* X_1	
	FAO 56 PM and Blaney Criddle	
Y	4.1840+0.1749 X_1	0.08
SE	0.0865 +0.98 X_1	
t	48.37* +9.718* X_1	
	FAO 56 PM and Radiation Balance	
Y	1.9740 +0.7473 X_1	0.60
SE	0.0867 +0.0100 X_1	
t	22.14* +41.54* X_1	
	FAO 56 PM and Pan ETo	
Y	0.1912+ 1.0884 X_1	0.57
SE	0.1348+0.0281 X_1	
t	1.42+ 38.71* X_1	

*SE= Standard Error, * significant at 5 % probability level at 1143 df (n=1144) t=1.96*
Y= estimated ETo by FAO56 PM , X_1= calculated ETo by different models.

Table 4. Statistical Indicators

ETo model	RMSE mm day^{-1}	MBE mm day^{-1}	RE mm day^{-1}	D-agreement	t-statistics	ETo mm day^{-1}	Mean Annual ETo (mm)
FAO56 PM						4.62	1687
Modified Penman	0.15	0.01	0.032	0.997	0.18	4.63	1692
Hargreaves	1.00	0.58	0.192	0.839	8.45	5.20	1895
Blaney Criddle	1.40	0.38	0.281	0.381	6.75	4.99	1822
Radiation Balance	1.19	0.81	0.219	0.786	11.48	5.42	1977
Pan evaporation	1.39	0.60	0.266	0.796	5.04	5.22	1896

found to be of [44] equation (RMSE =0. 53mm day^{-1}, PE=4. 91%,). In case of temperature-based equation [24]Blaney Criddle (1950) model gave the best result (R^2=0. 99, RMSE=0. 33 mm day^{-1} and PE =1. 17 %). This was followed by (23) (R^2=0. 95, RMSE=0. 34 mm day^{-1} and PE=7. 87%). Satisfactory performance of the Blaney Criddle method in a humid region is that the adjective effect from surrounding areas is negligible as reported by several researchers [45,46]. Eight radiation based equations gave the best results as evidenced by the high coefficient of determination (R^2 0.93). In this case, however [45] model was the best since it resulted an overestimate of 0.22 % with an R^2 of 0.98 and RMSE of 0.18 mm day^{-1}. In case of ten mass transfer- based ETo models, all models as per MBE values, underestimated over FAO56

PM model and the R^2 values were 0.70 to 0.92, RMSE 0.66 to 1.73 mm day^{-1}, MBE -0.60 to +1.03 mm day^{-1}. These results confirm that the mass transfer models showed worse performance and are not acceptable in a humid region of Iran. With respect to the quantitative requirement of annual water demand (ETo), the Modified Penman model overestimated reference ETo by only 0.30% over FAO56- PM model while Hargreaves model overestimated by 12.6%, Pan evaporation by 12.4%, Blaney Criddle by 8.0% and Radiation balance by 17.2% as compared to FAO 56 -PM model wherein the annual crop water demand was 1687 mm.

3.4 Crop Coefficient

The crop coefficient values depend on several factors like height of plant, crop canopy, growth stages of different crop, irrigation methods, and initial soil moisture. In FAO Irrigation and Drainage Paper 56, the crop coefficient has been refereed as dual crop coefficient i.e. basal crop coefficient (Kcb) and soil evaporation coefficient (Ke), but in this paper the daily crop coefficient of two crops was estimated by considering single crop coefficient. The results revealed that in the case of soybean and mustard the crop coefficient values of the initial crop growth period were minimum and increased with advancing crop growth stages; towards crop maturity it was further decreased. The maximum Kc value of 1.47 was recorded in case of soybean during 27 August to 2nd September 1993 and Kc 1.71 in case of mustard during 24-31 Dec. 1993. A similar trend has been reported by [4,47] in their review paper on crop coefficient of all field crops, horticultural fruits and vegetable crops. With regards to the response of different time period to crop Kc value, second degree polynomial (Y=a+bx+cx2) was done considering weekly crop coefficient value as dependent variable and days after sowing as an independent variable and the data are presented in Figs. 1 and 2. The results of the second degree polynomial equation given in both figures revealed that the response was quite good as it has been explained by R^2 value of 0.7674 in case of soybean and R^2 0.8456 in case of mustard (Figs. 1,2).

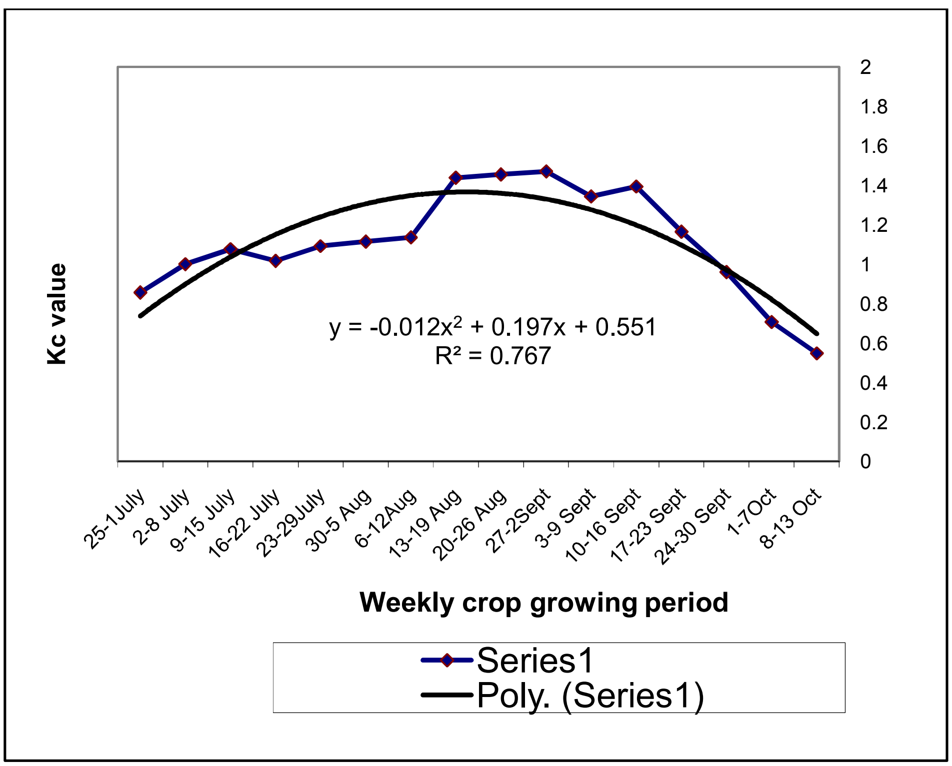

Fig. 1. Crop coefficient of soybean under FAO 56 PM model during 1993

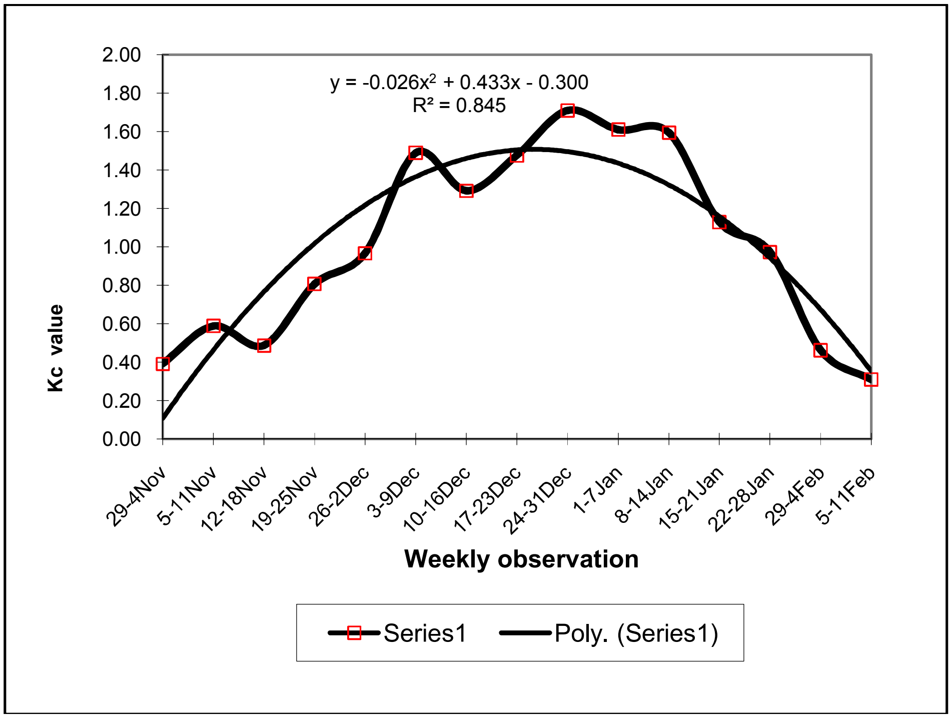

Fig. 2. Crop coefficient of mustard under FAO 56 PM model

4. CONCLUSION

The FAO-56 Penman Monteith equation for ETo includes many parameters like radiation and aerodynamic as well as crop height (0.12 m), surface resistance (70 m s^{-1}), albedo (0.23). It is considered as one of the most acceptable models under well-established weather station but much of the climatic data are deficient or inadequate due to prevalence of several constraints when the micro level study is taken up in irrigation command. In this paper, the comparison of reference ETo of five models with FAO56 PM have been elaborated. Under the semi arid climatic condition, Modified Penman model ranked first followed by temperature-based Blaney Criddle and Hargreaves model. In case of the Modified Penman model, both aerodynamic and radiation components are required to estimate ETo which needs significant amount of money to install and generate all meteorological parameters. However, in case of temperature based models i.e. Hargreaves and Blaney Criddle only temperature and extra-terrestrial radiation (Ra) data is required for ETo estimates. Based on the present experimental findings, these methods may be relatively considered for ETo estimation in semi-arid region of the country.

The introduction of irrigation in canal command area has changed physiological and physical properties of the land cover with green vegetation, horticultural and vegetable fruit crops. The influence of agricultural activities on weather parameter is clearly visible in terms of temperature, relative humidity, wind speed, pan evaporation rate after 21 years of field observations over the base year of 1975. The evaporation rate reduced by 5.5%, relative humidity (I) increased from 62.9% to 73.4%, maximum temperature and bright sunshine hours increased slightly over the base year. However the annual crop water demand (ETo) in case of FAO 56 - PM model increased from 1514 mm in 1975 to 1687 mm in 21years observation period. This 11.4% increase of crop water demand (ETo) would require a focused implementation of special irrigation management practice (pressurized irrigation system) in command area so that a substantial amount of water can be saved and the irrigated area can be increased in future.

CONFLICTING INTERESTS

Author has declared that no conflicting interests exist.

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