The Andhra Agric. J 65 (spl): 87-95, 2018

Development of GUI Based Software for Estimation of Evapotranspiration Using FAO-56 Penman-Monteith Method

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ABSTRACT

Estimation of reference evapotranspiration is a tedious exercise and needs a lot of climatological data. This study has been conducted to develop GUI based software for estimation of crop evapotranspiration using FAO-56 Penman-Monteith method.The software developed as Graphical User Interface (GUI) using visual basic 6.0 programming language for estimation of crop evapotranspiration. The developed software was able to estimate reference crop evapotranspiration rate (ET_o) quickly and with reliability. Developed software is capable of estimating crop evapotranspiration with hourly data, daily data, monthly data and even with missing data. The developed software can produce estimating output parameters such as net radiation of the crop surface, slope vapor pressure curve, saturation vapour pressure, psychrometric constant, extraterrestrial radiation along with reference evapotranspiration. Evapotranspiration of crop (ET_c)of wheat and summer groundnut at Junagadh, Gujrat, India were also estimated. Groundnut ET_c were estimated for initial, mid, and end stages as2.17, 7.36 and 4.06 mmd^{-1}, respectively. Whereas,ET_c for wheat for initial, mid, end stages were found to be 3.52, 5.12 and 1.81 mmd^{-1}, respectively.

Keywords: *Reference evapotranspiration,GUI-software, Penman-Monteith method*

Water is scare natural resources which need to be utilized efficiently and judiciously. Agriculture water management deals with utilization of the water by minimum lose and wastage. Supply of water as per the crop demand is majoris very important.The water demand of a crop in a particular region needs to be estimated to apply the correct amount of irrigation. The FAO-56 Penman-Monteith method is considered to be appropriate for estimation of reference crop evapotranspiration. It is the efficient method to estimate evapotranspiration of the crop using meteorological and crop parameters.

There are many methods more or less empirical have been developed over the last 50 years worldwide to estimate evapotranspiration from different climatic variables. Relationships are often subject to rigorous local calibrations to have global validity. The Testing for accuracy of the methods under a new set of conditions is laborious and time-consuming.Allen *et al.* (1998) reported that FAO-56 Penman-Monteith method is the standard method for the computation of the reference evapotranspiration. Allen (2000) worked on calculations of Evapotranspiration (ET) on a daily basis throughout 1988 for two locations near Men men, Turkey.Tyagi *et al.*, (2000) measureddaily, weekly, and seasonal crop evapotranspiration (ET_c) of wheat and sorghum directly from sensitive weighing type lysimeters at Karnal, India.Droogers *et al.*,(2002) comparedPenman-Monteith (PM) and Hargreaves (HG) methods and reported very reasonable agreement between the two methods.Gontia (2005) developed GUI based software for estimating crop evapotranspiration using FAO-56 Penman-Monteith method. He developed the excel sheet for estimation of reference evapotranspiration for hourly, daily, monthly and missing data. He has combined the remote sensing generated crop coefficient with reference evapotranspiration to estimate the crop evapotranspiration of wheat crop.Aftab *et al.*, (2008) reference evapotranspiration (ETo) computer software called REF_ET wasdeveloped for aiding improved irrigation planning and scheduling. The softwarerequires measured climatic data on a daily basis as its major input.

Keeping in view the above, there is need to develop a software for estimation of crop evapotranspiration considering the physical model Penman-Monteith in FAO 56. In this paper, the

development process of GUI based software was discussed in detail. It will help the researchers and planners to get quick and reliable evapotranspiration estimations.

MATERIAL AND METHODS

Data collection

The weather data recorded from the agro-meteorological observatory of Junagadh agricultural university.Junagadh is located at the foothills of mount Girnar. Geographically it is located at 21^0 31' latitude, 70^0 31' E longitudes at an altitude of 61m above mean sea level,85 km away from Arabian Sea at Somnath. The collected data were monthly, daily, hourly and missing data of temperature (max & min), relative humidity, and wind speed. These data were used to calculate reference and crop evapotranspiration by Penman-Monteith equation.

Reference Evapotranspiration (ET_o)

The Evapotranspiration rate from a reference surface, not short of water, is called the Reference Crop Evapotranspiration or Reference Evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics.The concept of the Reference Evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices.

Crop Evapotranspiration under standard condition (ET_c)

The crop evapotranspiration under standard conditions, denoted as ET_c, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.

Experimentally determined ratios of ET_c/ET_o, called crop coefficients (K_c), are used to relate ET_c to ET_o. The formula is as follows,$ET_c = K_c \times ET_o$.

FAO 56 Penman-Monteith method

The FAO 56 Penman-Monteithequation (Eq. 1) are as follows.

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

Where,
ET_o=reference evapotranspiration[mm d^{-1}], R_n=net radiation at the crop surface [MJ m^{-2} d^{-1}], G= soil heat flux density [MJ m^{-2} d^{-1}], T=air temperature at 2 m height [°C], u_2 wind speed at 2 m height [m s^{-1}], e_s=saturation vapour pressure [kPa], e_a=actual vapour pressure [kPa], e_s - e_a saturation vapour pressure deficit [kPa], Δ=slopevapour pressure curve [kPa °C^{-1}], γ=psychrometric constant [kPa°C^{-1}].The FAO Penman-Monteith equation determines the evapotranspiration from the hypothetical grass reference surface and provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which the evapotranspiration from other crops can be related.

The FAO Penman-Monteith equation for hourly time (Eq. 2) steps is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{37}{T_{hr}+273} u_2 (e^\circ(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{..... (2)}$$

Where, T_{hr}=mean hourly air temperature [°C], $e°(T_{hr})$=saturation vapour pressure at air temperature T_{hr} [kPa], e_a=average hourly actual vapour pressure [kPa], u_2=average hourly wind speed [ms^{-1}].
The actual vapour pressure (Eq. 3) is determined as:

$$e_a = e^\circ(T_{hr}) \frac{RH_{hr}}{100} \quad \text{..... (3)}$$

Where, e_a=average hourly actual vapour pressure [kPa], $e°(T_{hr})$=saturation vapour pressure at air temperature T_{hr} [kPa], RH_{hr} =average hourly relative humidity [%].

The net radiation is the difference between the net shortwave radiation (R_{ns}) and the net long wave radiation (R_{nl}) at the hourly time steps. If R_{ns} and R_{nl} need to be calculated, the extraterrestrial radiation value (R_a) for the hourly period should be used.

GUI software for estimation of evapotranspiration

The development of GUI software for estimation of monthly,daily,hourly & missing data for reference evapotranspiration and crop

evapotranspiration based on FAO-56 Penman-Monteithmethod was carried out. Software wasdeveloped in visual basic (6.0) programming language.

RESULTS AND DISCUSSION

The separate code for each subroutine was written in visual basic programming language to develop GUI based evapotranspiration software.

Development of Software for Estimation of Reference & Crop Evapotranspiration using Monthly data

General declaration of result command:

Dim a, b As Double

Dim j, tmax, tmaxk, tmink, tmin, ea, u2, N, tmonthi, tmonthi1, delta, gamma, rn, g, tmean, es, p, etmax, etmin, ld, lm, lat, dr, omegas, angledelta, ra, rs, rso, rns, rnl, yr As Double.

Private Sub Command1_Click()

Mean Temperature (T_{mean}):

Mean Temperature (T_{mean}) is estimated as average value of minimum and maximum temperature.

T (^oK)=T (^oC)+ 273.6

Dim tmaxk As Double

tmaxk = (Val(txtmax.Text) + 273.16) ^ 4

tmink = (Val(txtmin.Text) + 273.16) ^ 4

tmean = (Val(txtmax.Text) + Val(txtmin.Text)) / 2

Slope of saturation vapour pressure curve (Ä):

*delta = 4098 * (0.6108 * Exp((17.27 * tmean) / (tmean + 237.3)) / (tmean + 237.3) ^ 2)*

txtdelta.Text = delta

Atmospheric pressure (P):

Atmospheric pressure (P) is determined by subroutine given below

*p = 101.3 * ((293 - 0.0065 * 2) / 293) ^ 5.25*

Psychrometric constant (ã):

*gamma = 0.665 * 10 ^ -3 * p*

txtgamma.Text = gamma

Similarly, the sub routine for Actual vapour pressure (e_a), for other input parameters of month,day,year, inverse relative distance Earth-Sun as d_r, Solar Declination as ä,Sunset Hour Angle as $ù_s$, Extraterrestrial radiation for hourly or shorter periods (R_a),Daylight hours (N), Solar radiation (R_s), Net long wave radiation (R_{nl}), Net radiation (R_n), Soil heat flux (G), Reference Evapotranspiration Penman-Monteith Equation, Crop Evapotranspiration, Sub routine for clearing all input & output data was used at appropriate places.

Figure 1(a) shows the snapshot of Index of Crop Evapotranspiration Estimation software and Figure 1(b) shows the Title of developed Software.

Figure 2 shows the snapshot of the window with different meteorological data for estimation of monthly ETo. It also shows the output in the form of net radiation of the crop surface, slope vapor pressure curve, saturation vapour pressure, psychrometric constant, extraterrestrial radiation along with reference evapotranspiration.

method with mean monthly data

The Table 1 contains a list of input data along with its value for the estimation of mean monthly ETo. Table 2 shows the output parameters of estimated monthly ET_o

Development of Software for Estimation of Reference & Crop Evapotranspiration using Daily data

Subroutine for general declaration:

Dim a, b As Double

Dim j, tmax, tmin, ea, u2, N, tmonthi, tmonthi1, delta, gamma, rn, g, tmean, es, p, etmax, etmin, ld, lm, lat, dr, omegas, angledelta, ra, rs, rso, rns, rnl, yr As Double

Private Sub Command1_Click()

The subroutines for Actual vapour pressure (e_a) and Mean Saturation Vapour Pressure (e_s) have also been written.

Figure 3 shows windows for estimation of crop evapotranspiration with mean daily data. It also shows the output in the form of net radiation of the crop surface, slope vapor pressure curve, saturation vapour pressure, psychrometric constant, extraterrestrial radiation along with reference evapotranspiration.

Development of Software for Estimation of Reference & Crop Evapotranspiration using Hourly data

Subroutine for general declaration:

Dim j, ea, t, ta, tb, delta, gamma, es, p, ld, lm, lat, t1, dr, Lz, Lm1, w, w1, w2, angledelta, ra, rso, rn, rnl, b, ghr, Sc As Variant

Dim pi, yr As Variant

Private Sub command_click()

pi = 3.143

The subroutines for Mean saturation vapour pressure (e_s), For RH_{max}, the solar time angleat midpoint, Solar time angle at beginningof period [rad], Solar time angle at end of period [rad**],** Extraterrestrial radiation for hourly or shorter periods (R_a), For hourly or shorter periods soil heat flux were also used.

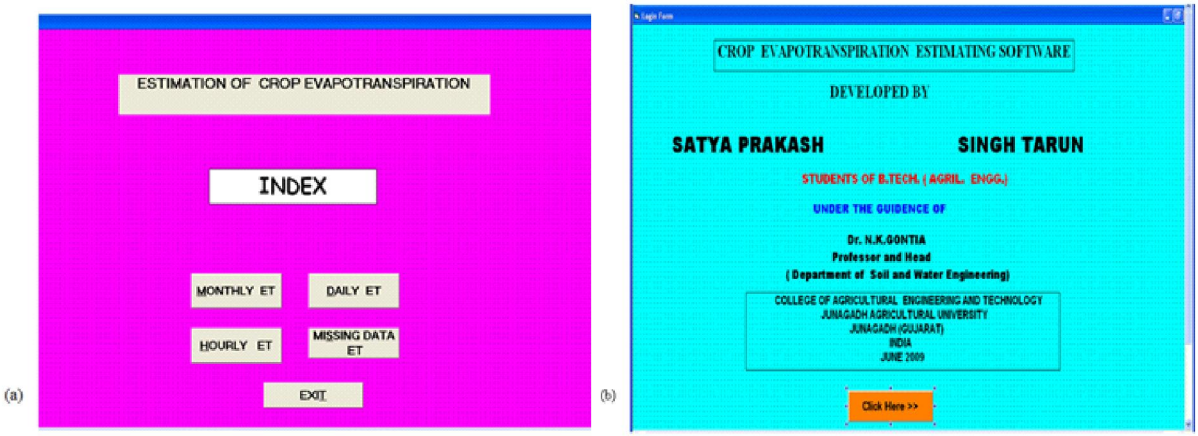

Fig. 1: (a) Index of Crop Evapotranspiration Estimation and (b) Title of developed Software

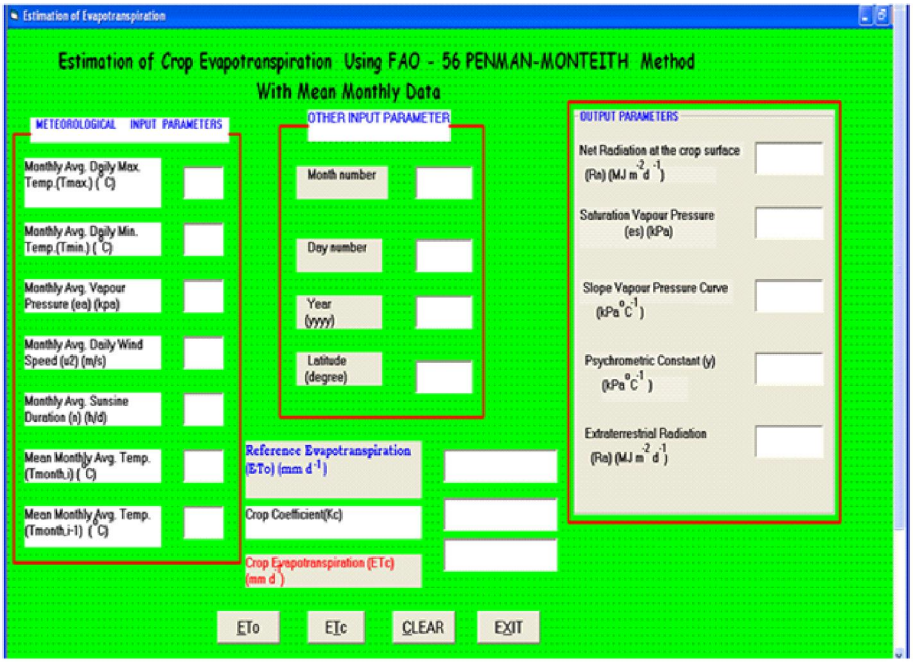

Fig. 2:Windows show estimation of crop evapotranspiration using FAO-56 Penman-Monteith method with mean monthly data

Table 1: Input meteorological data for estimation of monthly ETo

Parameter	Value
Monthly avg daily max temp (Tmax)	34.8^{0}C
Monthly avg daily min temp (Tmin)	25.6 ^{0}C
Monthly avg daily vapour pressure (ea)	2.85kPa
Monthly avg daily wind speed (u2)	2 m/s
Monthly avg sunshine duration (n)	8.5 hours/day
Mean monthly avg temp, for April (Tmonth,i)	30.2^{0}C
Mean monthly avg temp, for march (Tmonth,i-1)	29.2^{0}C
Crop coefficient (for groundnut) (K_c)	0.6

Table 2: Output parameters of estimated monthly ETo

Parameter			Value
Net radiation at the crop surface	(Rn)	[MJ m^{-2} d^{-1}]	14.340
Saturation vapour pressure	(es)	kPa	4.421
Slopevapour pressure curve	(Δ)	kPa^0C^{-1}	0.245
Psychrometric constant	(γ)	kPa^0C^{-1}	0.067
Extratrestial radiation	(Ra)	[MJ m^{-2} d^{-1}]	38.075
Reference Evapotranspiration	(ET_0)	mm d^{-1}	5.718
Cropevapotranspiration	(ET_c)	mm d^{-1}	3.431

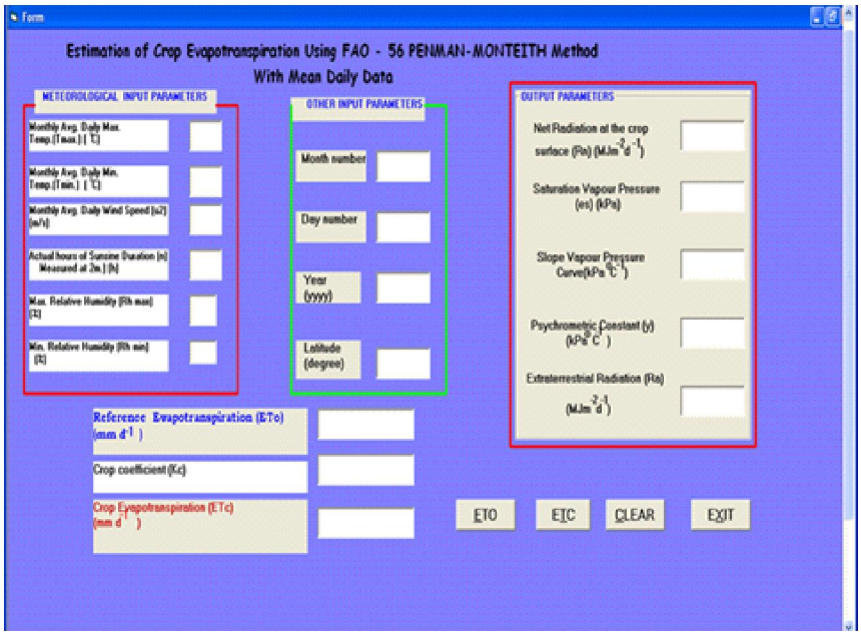

Fig.3:Window for estimation of crop evapotranspiration using FAO-56 Penman-Monteith method with mean daily data

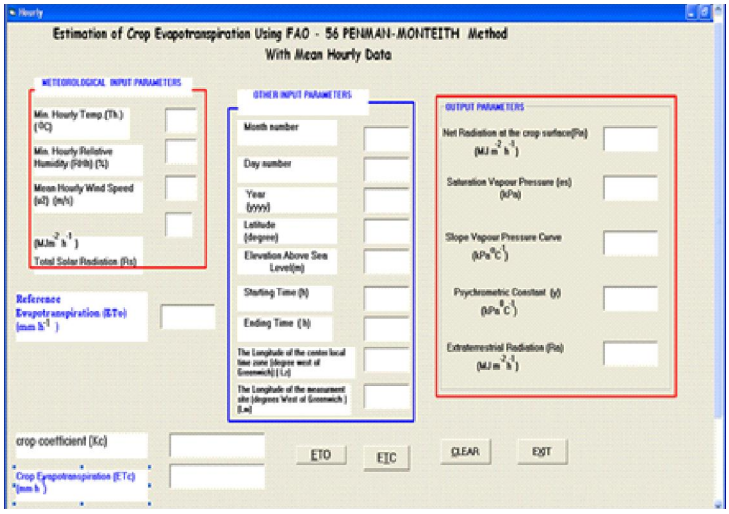

Fig. 4: Window shows hourly estimation of crop evapotranspiration using FAO-56 Penman-Monteith method

Table3: Input Meteorological Data for Estimation of Hourly ET_0

Parameter	Value
Mean hourly tempr(Thr)	38 ^{0}C
Mean hour relative humidity (RHhr)	52 %
Mean hourly wind speed (u2)	3.3 m/s
Total solar radiation (Rs)	2.45 $MJm^{-2}hour^{-1}$
Crop coefficient (for groundnut)(K_c)	0.6

Table 4: Output Parameters of Estimated Hourly ETo

Parameter	Value
Net radiation at the crop surface (Rn) [MJ m^{-2} d^{-1}]	1.750
Saturation vapour pressure (es) kPa	6.624
Slopevapour pressure curve (Δ) kPa^{0}C^{-1}	0.358
Psychrometric constant (γ) kPa^{0}C^{-1}	0.067
Extratrestial radiation (Ra) [MJ m^{-2} d^{-1}]	3.575
Reference Evapotranspiration (ET0) mm h^{-1}	0.625
Cropevapotranspiration(ET_c) mm h^{-1}	0.375

Table5: Input Meteorological Data for Estimation of Missing ET_0

Parameter	Value
Monthly avg daily max tempr (Tmax)	26.6 ^{0}C
Monthly avg daily min tempr(Tmin)	14.8 ^{0}C
Crop coefficient (for groundnut) (K_c)	0.6

Table 6: Output Parameters of Estimated Missing ETo

Parameter	Value
Net radiation at the crop surface (Rn) [MJ m^{-2} d^{-1}]	13.446
Saturation vapour pressure (es) kPa	2.583
Slopevapour pressure curve (Δ) kPa^{0}C^{-1}	0.150
Psychrometric constant (γ) kPa^{0}C^{-1}	0.067
Extratrestial radiation (Ra) [MJ m^{-2} d^{-1}]	40.468
Reference Evapotranspiration (ET_o) mm d^{-1}	4.539
Cropevapotranspiration (ET_c) mm d^{-1}	2.723

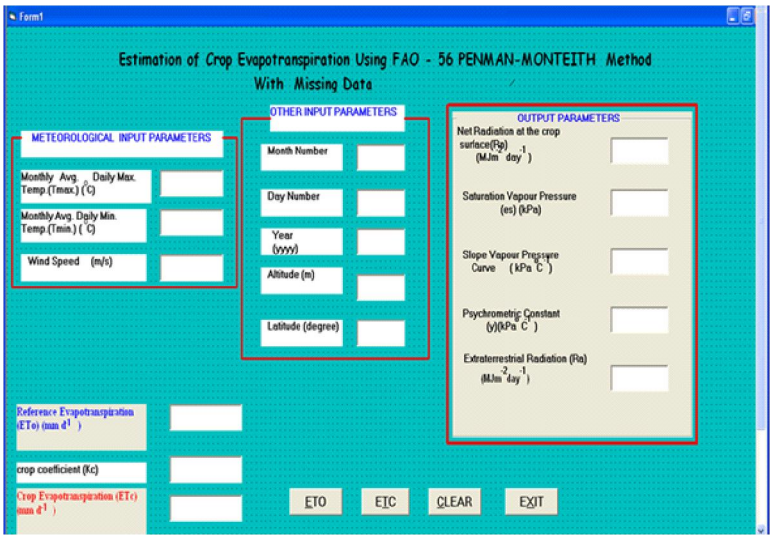

Fig. 5: Window shows estimation of crop evapotranspiration using FAO-56 Penman-Monteith method with Missing data

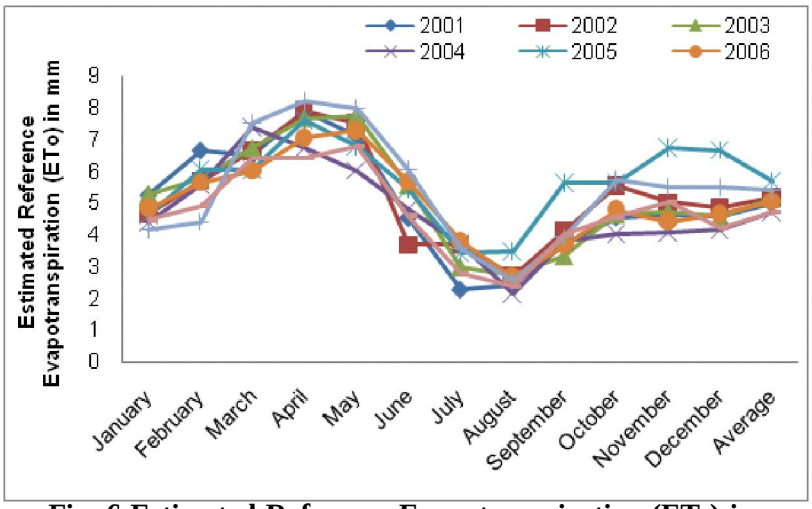

Fig. 6:Estimated Reference Evapotranspiration (ET_0) in mm

Stages of crop	ET_0(mmd^{-1})	K_c	Et_c(mmd^{-1})
Initial stage(Nov 1 to 21)	5.03	0.7	3.52
Mid stage(Nov22 to Jan 20)	4.46	1.15	5.12
End stage(Jan20 to Feb 10)	4.54	0.4	1.81

Table8: Crop Evapotranspiration of summer groundnut

Stages of crop	ET_o (mmd^{-1})	K_c	Et_c(mmd^{-1})
Initial stage (Feb 15 to Mar 5)	5.29	0.4	2.1
Mid stage (Mar 6 to May 5)	6.4	1.15	7.36
End stage (May 6 to 26)	6.77	0.6	4.06

Figure 4 shows windows shows hourly estimation of crop evapotranspiration using FAO-56 Penman-Monteith method. It also shows the output in the form of net radiation of the crop surface, slope vapor pressure curve, saturation vapour pressure, psychrometric constant, extraterrestrial radiation along with reference evapotranspiration.

Table 3 contains a list of input data along with its value for Estimation of Hourly ET_0. Table 4 shows the output parameters for Estimation of Hourly ET_0.

Development of Software for Estimation of Reference & Crop Evapotranspiration using Missing data

Sub-routine for general declaration:

Dim j, tmax, Tdew, tmin, ea, u2, N, tmonthi, tmonthi1, delta, gamma, rn, g, tmean, es, p, etmax, etmin, ld, lm, lat, dr, omegas, angledelta, ra, rs, rso, rns, rnl, yr As Double

Private Sub cmdresult_Click()

The sub-routine for Solar Radiation, clearing all input & output data were used at appropriate place.

Table 5 shows the Input Meteorological Data for Estimation of Missing ET_0. Table 6 contains the output parameters of Estimated Missing ET_o.

Whereas, Figure 5 presents windows showing estimation of crop evapotranspiration using FAO-56 Penman-Monteith method with Missing data.

Estimated Reference evapotranspiration (ET_0)of Junagadh region

Daily reference evapotranspiration and cumulative weekly crop evapotranspiration were estimated for 8 years in 2001-2008 and are presented through Figure 6. The reference evapotranspiration estimated values of the ET_o is varying with the atmospheric conditions. The average minimum value of ET_o is in year 2008 which is 4.71 mm d^{-1} and the average maximum ET_o is in year 2005 which is 5.69 mm d^{-1}. It can be seen from the figure that the ET_o is less in the month of June to October, because of the rainy days. It was foundto be high in the month of March to May because of high radiation of the sun. In 2008, the minimum ET_o is in August which is 2.39 mm d^{-1} and the maximum is in May which is 6.77 mm d^{-1}.

Estimation of crop evapotranspiration (ET_c) of wheat and summer Groundnut

The influence of various weather factors are incorporated in ET_c estimates. $ET_c$is an index of climatic demand. Crop coefficient K_c is influenced by crop type, climate, soil evaporation and crop growth stages, from which crop growth stages is the main factor that influence on K_c. From different stages of crop growth the $K_c$values of K_{cini}, K_{cmid}, and K_{cend}.

The crop evapotranspiration of different crops were estimated which is presented in Table 7 and 8. Crop evapotranspiration (ET_c) was obtained by multiplying reference evapotranspiration (ET_o) and crop coefficient (K_c) of respective month. Tables show that as the Kc values for the different crops were found varying the values of the ET_c were also found to vary.

The initial stage of the wheat is of 21 days according to that the $ET_c$for the initial period is 3.52 mm d^{-1} . At the mid stage the weighted value of $K_c$for the wheat was high which contains 60 days and the ET_c for the mid stage was 5.12mm d^{-1}. The end stage was of 20 days and for the end stage $ET_c$was of 1.81 mm d^{-1}.

Table 8 shows the estimated value of ET_c for summer groundnut for the initial, mid and end stages as 2.1, 7.36 and 4.06 mmd^{-1} respectively.

CONCLUSION

The software was found versatile and estimated crop evapotranspiration with hourly data, daily data, monthly data and missing data.The crop evapotranspiration of a crop can be estimated through the software by using crop coefficient as an input.The developed software was also estimated output parameters as net radiation of the crop, slope vapor pressure curve, saturation vapour pressure, psychrometric constant, extraterrestrial radiation and reference evapotranspiration.

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