Estimation of Hourly Reference Evapotranspiration

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Abstract: Evapotranspiration is one of the major components of the hydrologic cycle. Accurate estimation of evapotranspiration is essential in many studies such as hydrologic water balance, irrigation scheduling, and efficient water resource planning and management. The precise estimation of water requirement of crop is very important factor in the application of irrigation design and scheduling. Irrigation futures aim to identify an appropriate method for the calculation of reference crop evapotranspiration. The evapotranspiration rate from a reference surface, not short of water, is called reference crop evapotranspiration or reference evapotranspiration and it is denoted by ETo. The present study evaluates the use of FAO-56 Penman Monteith method for calculating ETo hourly, daily for twelve years from march 2000 to 2012, for Dowleswaram station in Andhra Pradesh, by collecting the climatic data from the department of Hydrology data centre, I and CAD project, Hyderabad. Average of monthly reference evapotranspiration was calculated for the study area and observed the trend line, this can be used to predict the ETo for the future years, this can be useful in the irrigation of crop pattern and amount of water to be supplied. It is found that Maximum reference evapotranspiration is observed on 11th may 2002, with a value of 14.1mm. Minimum reference evapotranspiration is observed on 31stoctober 2006, with a value of 1.46mm.

Keywords: Reference Evapotranspiration, Irrigation Scheduling, FAO-56 Penman Monteith method.

Introduction: Water cycle of the Earth's surface, showing the individual components of transpiration and Evaporation that make up evapotranspiration. Evapotranspiration is important parameters in hydrologic cycle because it has represented a considerable amount of moisture lost from a catchment. Accurate estimation of the reference crop evapotranspiration (ET_o) is investigated due to its critical role in affecting determination of crop water use efficiency in agricultural ecosystems. Reference evapotranspiration (ET_o) is defined as the rate at which readily available soil water is vaporized from specified vegetated surfaces. Appropriate methods needs to account for processes such as water uptake from soil water transport through plant and water loss. To schedule irrigation properly, an accurate and standard method is required to estimate crop water requirement. In order to use FAO-56 PM model in computing daily evapotranspiration, specific meteorological data are required such as daily maximum and minimum air temperature, solar radiation, wind speed, and relative humidity.

Study Area: For the analysis of the hourly ET_o and daily ET_o, Dowleswaram station is selected as study area. Dowleswaram station is located at 81°47' 34″ E longitude and 16° 56' 30″ N Latitude. Dowleswaram barrage is situated at a distance of 10 km from Rajahmundry which is built for irrigation purpose. Dowleswaram barrage is 15 feet high adn 3.5 km wide and having 175 crust gates. Dowleswaram is a town on the left bank of river Godavari.

Review of Literature: Evapotranspiration is the combination of soil evaporation and crop transpiration. Weather parameters, crop characteristics, management and environmental aspects affect Evapotranspiration. The evapotranspiration rate from a reference surface is called the reference evapotranspiration and is denoted as ET_o. 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. A large number of empirical or semi-empirical equations have been developed for assessing reference evapotranspiration from meteorological data. Numerous researchers have analysed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration ET_o. The Penman-Monteith equation was officially adapted as the FAO-recommended method with the publication of FAO-56 in 1998 (Allen et al. 1998). With the selection of Penman-Monteith as the ETo equation, it was necessary to choose the physical, physiological, and aerodynamic parameters for the reference grass. The FAO adopted a set of parameters for a hypothetical grass with a crop height of 0.12 m, an albedo of 0.23, and a fixed surface resistance value of 70 s m-1 (Allen et al. 1998). These parameters are very similar to the parameters of clipped Alta fescue grass that is found in the weighing lysimeters in Davis, California, a site that has been used in much ET research (Hargreaves and Allen 2003). The development of ET_o also allows simplified calculation of crop coefficients for different varieties of crops, which are used to adjust ET_o to a value specific to a particular crop at a certain time in the growth of the crop (Allen et al. 1998).

Methodology: Penman-Monteith as the primary method for computing ET_o. Penman-Monteith equation was officially adapted as the FAO-recommended method with the publication of FAO-56 in 1998 (Allen et al. 1998). The ET_o method that will be used as the reference standard for this study is the United Nations Food and Agriculture Organization's (FAO) Penman-Monteith method.

The step by step methodology used is as follows:

The equation used to calculate ET_o is FAO-56 Penman-Monteith equation, given as

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

Where

ET_o = daily reference ET [mm/d]

T = air temperature at 2 m high [°C]

VPD = vapour pressure deficit [kPa] that is (es-ea)

u_2 = wind speed at 2 m high [m/s]

Rn = Net radiation at the crop surface [MJ m-2 d-1]

Δ = slope vapour pressure curve [kPa °C-1]

γ = psychometric constant [kPa °C-1]

G = soil heat flux density [MJ m-2 d-1]

To calculate ET_o, some parameters like wind speed, relative humidity, temperature, sunshine hours, elevation, latitude and longitude of the study area are required. From these parameters all the other parameters were calculated. Daily readings of the required parameters were collected from the meteorological department.

The mean temperature was calculated by using the equation

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \qquad (2)$$

Atmospheric pressure P was calculated by using the equation

$$P = 101.3\left[\frac{293 - 0.0065z}{293}\right]^{5.26} \qquad (3)$$

In this equation the elevation z is known, so P was calculated by substituting z.

The psychometric constant, γ was calculated by using the equation

$$\gamma = 0.665 \times 10^{-3}\,P \qquad (4)$$

Slope vapour pressure curve Δ was calculated by using the equation

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27\times T_{mean}}{T_{mean}+237.3}\right)\right]}{(T_{mean}+237.3)^2} \quad (5)$$

Vapour pressure deficit VPD was calculated by using the equation

$$VPD = (e_s - e_a) \quad (6)$$

Saturated vapour pressure e_s was calculated by using the equation

$$e_s = \frac{e_{(Tmax)}+e_{(Tmin)}}{2} \quad (7)$$

Again e_{Tmax} and e_{Tmin} was calculated by using the equations

$$e_{(T_{max})} = 0.6108\exp\left[\frac{17.27T_{max}}{T_{max}+237.3}\right] \quad (8)$$

$$e_{(T_{min})} = 0.6108\exp\left[\frac{17.27T_{min}}{T_{min}+237.3}\right] \quad (9)$$

Actual pressure e_a was calculated by using the equation

$$e_a = \frac{RH_{mean}}{100}\left[\frac{e_{(T_{max})}+e_{(T_{min})}}{2}\right] \quad (10)$$

Here all the parameters are known: Net Radiation R_n was calculated by using the equation

$$R_n = R_{ns} - R_{nl} \quad (11)$$

Again R_{ns} & R_{nl} were calculated by using different equations

$$R_{ns} = (1-\alpha)R_s \quad (12)$$

$$R_{nl} = \sigma\left[\frac{(T_{max}+273.16)^4+(T_{min}+273.16)^4}{2}\right][034 - 0.14\sqrt{e_a}]\left[1.35\frac{R_s}{R_{so}} - 0.35\right] \quad (13)$$

To find R_{ns},that is Net solar radiation, R_s solar radiation should be calculated first

$$R_s = \left[0.25 + 0.50\left(\frac{n}{N}\right)\right]R_a \quad (14)$$

To find R_s, the parameters n, N, R_a were calculated by using the equation

$$N = \frac{24}{\pi}\omega_s$$

$$R_a = \frac{24\times 60}{\pi}G_{sc}d_r\left[(\omega_s\sin(\varphi)\sin(\delta)) + (\cos(\varphi)\cos(\delta)\sin(\omega_s))\right] \quad (15)$$

n is sunshine hours recorded

To calculate R_a that is extra terrestrial radiation,d_r, δ, ω_swere calculated By using the equations

$$d_r = 1 + 0.033\cos\left[\frac{2\pi}{365}J\right] \quad (16)$$

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)] \quad (17)$$

$$\delta = 0.409\sin\left[\frac{2\pi}{365}J - 1.39\right] \quad (18)$$

φ is Latitude and G_{sc} is a constant

To find R_{nl} that is Net long wave radiation, R_s and R_{so} were calculated first, but R_s was already calculated and R_{so} that is clear sky solar radiation was calculated by using the equation.

$$R_{so} = [0.75 + 2\times 10^{-5}z]R_a \quad (19)$$

Finally all the parameters were substituted in the ET_o equation and calculated the hourly, daily values of Reference Evapotranspiration for the study area.

Results and Discussions: From the above equations the various components such as estimation of reference evapotranspiration from the standard FAO-56 Penman method were analyzed and presented. During Evapotranspiration process the water molecules moves from the levels of higher moisture to lower moisture. The rate of this movement is governed by the difference of moisture content of the atmosphere air. Hence the temperature gradient is stronger than the rate of Evapotranspiration is also high. However it is important to note relative importance of individual meteorological parameters. Estimation of hourly Reference

Evapotranspiration was calculated by using FAO-56 Penman-Monteith Equation for the station Dowleswaram. The input data of daily meteorological parameters like Relative humidity, minimum and maximum temperatures, wind speed, sunshine hours have been collected from hydrology data center, I & CAD project, Hyderabad for 12 years, from January 2000 to March 2012. Using the standard FAO-56 Penman-Monteith equation, the hourly, daily Reference Evapotranspiration were calculated for 12 years from January 2000 to march 2012. Average monthly ET_o was also calculated. Table 1 and 2 shows the yearly average values of study area

Conclusions: From the study area using FAO-56 penman method, Meteorological parameters like relative humidity, wind speed, sunshine hours; maximum and minimum temperatures were studied at Dowleswaram basin. For 12 years, Maximum Reference Evapotranspiration was observed on 11th May 2002, with a value of 14.1mm, Minimum Reference Evapotranspiration was observed on 31st October, 2006, with a value of 1.46mm. The trend line from January 2000 to January 2012 for 12 years is observed to be in decreasing trend. By finding the trend of Reference Evapotranspiration, the amount of water to be supplied of the irrigation purpose shall be calculated. From the calculations it is known that as the temperature reaches the maximum, the reference evapotranspiration also reaches high. This knowledge is used to suggest alternative cropping pattern.

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Table 1: Yearly Averages of the Study area

Year	(N) hrs	(d_r)	(R_a) MJm^{-2} d^{-1}	(R_s) MJm^{-2} d^{-1}	(R_{ns}) MJm^{-2} d^{-1}	(R_{so}) MJm^{-2} d^{-1}	(R_{nl}) MJm^{-2} d^{-1}	(R_n) MJm^{-2} d^{-1}	(ET_o) mm
2000	12.0	1	34.4	18.13	13.96	25.88	2.55	11.4	4.75
2001	12.0	1	34.5	17.15	13.2	25.89	2.28	10.93	4.97
2002	12.0	1	34.5	17.72	13.65	25.89	2.49	11.16	5.22
2003	12.0	1	34.5	17.36	13.37	25.89	2.26	11.1	4.78
2004	12.0	1	34.4	18.24	14.04	25.88	2.39	11.65	4.38
2005	12.0	1	34.5	16.5	12.71	25.89	1.77	10.94	4.39
2006	12.0	1	34.5	16.96	13.06	25.89	1.75	11.31	4.21
2007	12.0	1	34.5	16.93	13.04	25.89	1.55	11.48	4.07
2008	12.0	1	34.4	17.26	13.29	25.88	1.7	11.59	4.2
2009	12.0	1	34.5	16.81	12.94	25.89	1.43	11.51	4.1
2010	12.0	1	34.5	16.34	12.58	25.89	1.42	11.16	3.91
2011	12.0	1	34.5	17.04	13.12	25.89	1.65	11.47	4.05
2012	11.5	1	32.0	16.96	13.06	24.04	2.01	11.05	3.91

Table 2: Yearly Averages of the Study area

Year	T_{mean} ^0c	eT_{min} ^0c	e_{Tmax} ^0c	(e_s) Kpa	(e_a) Kpa	(Δ) Kpa^0c^{-1}	(δ) rad	(ω_s) rad
2000	29.33	3.25	5.23	4.24	2.98	0.24	-0.0013	1.57
2001	29.22	3.24	5.19	4.21	3	0.24	-0.0008	1.57
2002	29.57	3.24	5.41	4.33	2.93	0.24	-0.0008	1.57
2003	29.41	3.27	5.32	4.3	3.07	0.24	-0.0008	1.57
2004	29.48	3.15	5.49	4.32	3.13	0.24	-0.0013	1.57
2005	29.84	3.22	5.64	4.43	3.38	0.24	-0.0008	1.57
2006	29.84	3.21	5.61	4.41	3.48	0.24	-0.0008	1.57
2007	29.8	3.21	5.61	4.41	3.71	0.24	-0.0008	1.57
2008	29.67	3.15	5.62	4.39	3.59	0.24	-0.0013	1.57
2009	30.21	3.18	5.9	4.54	3.83	0.25	-0.0008	1.57
2010	29.41	3.13	5.52	4.33	3.68	0.24	-0.0008	1.57
2011	29.14	2.98	5.54	4.26	3.59	0.24	-0.0008	1.57
2012	27.76	2.54	5.47	4.01	3.37	0.22	-0.2082	1.50

Figure 1: Trend Line for ET_o for 12 years (average monthly data)