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COMPARATIVE STUDY ON ESTIMATION OF VARIOUS EVAPOTRANSPIRATION TECHNIQUES WITH PENMAN-MONTEITH METHOD

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ABSTRACT

Evapotranspiration (ET) is one of the important parameter in hydrology and development of watershed. Concept of ET is crucial mainly in water requirements to crops and planning of any water resources structures. ET is the combined processes of evaporation from soil and plant surfaces and transpiration from plant tissues. Several methods are described by Food and Agricultural Organisation (FAO) and The International Commission for Irrigation and Drainage (ICID): of which Penman – Monteith Method (PMM) was considered as a standard method to evaluate Potential Evapotranspiration (PET). Various methods were adopted in this paper to estimate PET based on temperature, radiation and physical methods. Thus, values of PET for the study area were estimated from all the above said methods. It is a clear known fact that all the metrological parameters may not be obtained from all the corresponding metrological stations and thus some empherical formulas which are described on above classification quite difficult in order to estimate PET and there by based on the obtained PET values are thus validated and compared with R^2 *value. Finally, the suitable method on par with standard Penman – Monteith method for the selected watershed is Turc method as value of* $R^2 = 0.813$ *(81.3 %) which yields better when compared to that of methods.*

Key words: Metrological parameters, Potential Evapotranspiration (PET), Penman Monteith Method, vegetation transpiration, rain-fed regions..

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1. INTRODUCTION

In India watershed-based development has been the strategy for growth and sustainability of agriculture in the vast semi-arid and dry sub-humid regions popularly called rain-fed regions. The global water consumption is doubling every 20 years and projected increase in food demand will have to be met by irrigation. Watershed Development projects have been undertaken to enhance agricultural production, conserve natural resources base and ensure rural livelihood since 1980s [9 & 11]. Initially soil and water conservation was the primary objective of the program which attracted large public investments in the last 25 years. Participatory integrated watershed management covering an area from the highest point (ridge line) to the outlet is, therefore, the process of formulating, implementing and managing a course of actions involving natural and human resources in a watershed, taking into account all the factors operating within the watershed. Evapotranspiration is a major component of the hydrologic cycle, as such, its quantity is of major concern to water resource planners around the world. ET describes the water transported from the land's surface to the atmosphere [6]. It includes direct evaporation from soil surface, small water surface and wet canopy surface, as well as vegetation transpiration [2&8]. A. F. Meyer, stated that temperature indirectly affects the water table by causing fluctuations in barometric pressure, but temperature can also have a direct effect on water levels determined through observation and experimentation that migration of water can be induced by changes in soil and water temperature.

Evapotranspiration is an important variable in the water and energy balance on the Earth's surface and a key process in the climate system. Evaporation demand or potential evaporation is projected to increase almost everywhere in the world in future climate scenarios (IPCC, 2008). This is because the water holding capacity of the atmosphere increases with higher temperatures, but relative humidity is not projected to change markedly. The FAO radiation method was the best of the non-combination equation methods. The FAO-Penman method was poorly ranked due to its chronic over estimation. Several limitations are there in data availability for the Indian conditions. Nevertheless, the PET needs to be estimated to determine the crop water requirements using crop specific coefficients. [3]

The primary force driving evaporation and transpiration is energy input from the sun. Transpiration is a special case of evaporation. Evaporation occurs at the surface of moist cells within the plant tissues, and the water vapor then diffuses into intercellular leaf spaces and diffuses through stomates to the atmosphere. Other factors that affect evaporation from free water surfaces and transpiration from vegetated surfaces involve differences in reflectance of radiation, which affects radiant energy input, differences in heat storage capacities and the aerodynamic roughness of water and vegetation which affects the transfer of sensible and latent heat.

The classic work of Penman laid the foundation for relating evapotranspiration to metrological variables. Penman combined the energy balance component required to sustain evaporation with a mechanism to remove water vapor. Many investigators, including Penman, continued to expand the theory of the combination equation since 1950 with special emphasis on the aerodynamic aspects. A detailed summary of the work in 1950's and early 1960's was presented by Rijtema (1965) and Monteith (1965). Today, the most basic and practical equation for estimating evapotranspiration is commonly known as "Penman – Monteith" method [10]. Food and Agricultural Organization (FAO) in May 1990, in collaboration with the International Commission for Irrigation & Drainage and with the World Meteorological Organization (WMO), recommended the adoption of the Penman-Monteith combination method as a standard method for estimating reference evapotranspiration. This method overcomes the previous Penman-Monteith and provides values more consistent with actual crop water use data worldwide. The objectives of the present study are to estimate daily, monthly reference evapotranspiration and to estimate daily reference evapotranspiration values with limited data.

On the other hand, estimation of ET is quite difficult and becomes more complex due to unavailability of all metrological parameters at all stations [12]. Hence, estimation of Potential Evapotranspiration (PET) becomes necessary for most of the watersheds. It is defined as “the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water”. Reference Evapotranspiration (RET) also plays a key role in developing a crop co-efficient based on ET for other crops [6 & 16]. The use of RET – crop coefficient approach has been largely successful in obviating the need to calibrate a separate ET equation for crop and stage of growth [1]. A large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate Evapotranspiration from different climatic variables. The availability of worldwide climatic databases further facilitates the adoption of values from nearby stations. Such procedures have proven to perform better than any of the alternative empirical formulas; and will largely improve transparency of calculated evapotranspiration values [17 & 18]. Owing to the difficulty of obtaining accurate field measurement, ET is commonly computed from weather data. However, no single existing method using meteorological details universally adaptable under all climatic regimes. Therefore, use of specific method is limited by the conditions in which they have been developed [3]. In general six different methods for the calculation of PET at three sites in eastern North Carolina. Namely: Penman – Monteith method, Makkink method, Priestly – Taylor method, Turc Method, Hargreaves – Samani method and Thronthwaite method [3, 7, 15 & 19]. The Penman – Monteith was used as the standard and compared RET estimates by other methods [13].Several researchers have studied the influence of the various climatological parameters on the ET and developed a number of formulae for determining the Potential Evapotranspiration (PET) [4 & 14]. The modified Penman method was considered to offer the best results with minimum possible error in relation to a living grass reference crop and hence it is a good predictor of potential evapotranspiration compared to all other methods. Other factors that affect evaporation from free water surfaces and transpiration from vegetated surfaces involve differences in reflectance of radiation, which affects radiant energy input, differences in heat storage capacities and the aerodynamic roughness of water and vegetation which affects the transfer of sensible and latent heat. Historical and recent studies of evapotranspiration and evaporation clearly show, where soil water is not limiting, that the primary variable controlling the rate of E and ET is solar radiation impinging on the evaporating surfaces.

The values thus obtained using various relations which were shown in detail in further sections were cross examined by using R^2 value to measure the goodness of fit between both the values on X and Y axes. R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determinations for multiple regressions. It can be defined as the percentage of the response variable variation that is explained by a linear model [21]. In this paper, authors were mainly concentrated on simple linear regression analysis rather than multiple regression analysis or any other type of regression analysis, due to the fact that only one independent variable (i.e.,) values obtained by PMM was considered to compare the values of PET obtained by various methods. In general, multiple regression analysis two or more independent variables are used to predict the value of a dependent variable [22]. Multiple regressions, on the other hand, are a broader class of regressions that encompasses linear and nonlinear regressions with multiple explanatory variables. It is also a broader class of regressions that includes linear and nonlinear regressions with multiple explanatory variables. Therefore, in this analysis as only one independent variable is chosen only simple linear regression analysis was carried to estimate value of R^2. As it measures the dependency, greater the value of R^2, more the dependency.

1.1. Objectives of the Study

The main objective of this paper is to estimate pet for the study area using various empirical formulae, from the available metrological parameters. As mentioned that, all the metrological parameters may not be available to find values of pet for a particular water shed, the values obtained which are compared with the standard penman – monteith method (pmm) and their behavior and movements are observed. Finally, with the help of trend analysis using ms – excel the most suitable method is recommended for the study area with the available metrological parameters

2. STUDY AREA

The present study area Dharmaram watershed lies in Dharmaram village of Mannevari Turkapally (M. Turkapally) mandal in Nalgonda a district of Telangana, India.The geographical extends of study area are 17^0 35’ 30” to 17^0 39’ 0” N and 78^0 49’ 30” to 78^0 47’ 0” E. This study area lies in two topo sheet numbered 56 K / 14 / NW and 56 K / 14 / SW as per Survey of India (SOI). Dharmaram is surrounded by Jagdevpur Mandal towards North, Rajapet Mandal towards East, Bommala Ramaram Mandal towards South, Yadagirigutta Mandal towards West. Bhongir, Jangaon, Hyderabad, Siddipet are the nearby Cities to Dharmaram. The location of study area is shown in the Fig.1. The climate of this study area will be very hot during the months of April and May and whose average maximum and minimum temperatures are recorded as 32.29^0C and 21.79^0C.The annual normal rainfall in this Mandal is 711 millimeters. The bulk of the rainfall is received through the south-west monsoon during June to September, while some rainfall is also received through the north-east monsoon between October and December. The soils occurring in the study area are mostly black cotton, alkaline and alluvial soils, of which red soils constitute 85 % of the area which can be seen in Fig. 2. Paddy is the staple food crop, which is mostly cultivated along with the other principal crops like Jowar, Bajra, maiz, chillies groundnut and cotton are also grown as well. Nalgonda district covers an area of 14,22,000 ha of which only 5.6% of the area is under forests, 7.8% is put to non-agricultural uses, 4.3% under pasture and 21.2% under current fallows. Net sown area accounts for 33.6% of the geographical area and the cropping intensity is 117%.The major geological formations that are observed in the study area are, the peninsular granite-gneisses. The granites are medium to coarse grained, grayish to pink, highly fractured and jointed; and intruded at places by quartz reefs. The gneisses are highly foliated whereas the granites are massive. Also in some portions of the Mandal is covered by limestone, quartzite, chists. The main livelihood in the study area is of agriculture and some other some commercial crops. Paddy is the staple food crop, which is mostly cultivated along with the other principal crops like Jowar, Bajra, maiz, chillies groundnut and cotton are also grown as well. The district divided into 64 micro-basins. The major river Krishnais perennial and all other rivers are seasonal and ephemeral. The overall drainage pattern in the districts is dendritic to sub - dendritic and rectangular. Ground water plays a predominant role in the net irrigated area by constituting to57.20%, whereas surface water irrigation accounts for 38.63% of the whole district. Majorly there are seven surface irrigation projects in the district viz; Nagarjunasagar, Musi, Dindi, Asifnagar, Pendlipalkala, Shaligowraram and Bheemanpally projects. Two number of check dams were constructed in the study area with the following dimensions of 6.00 m length, 1.00 m width and 0.50 m depth. Water Absorption Trenches (WAT) are constructed in some areas of the study area along the down of ridges with the following dimensions 6.00m length, 1.00m width, 1.00m depth. Stone Gully plugs (SGP) and Sunken Pits (SP) are constructed nearer to check dams with different lengths for the sake of infiltration process into the earth [5].

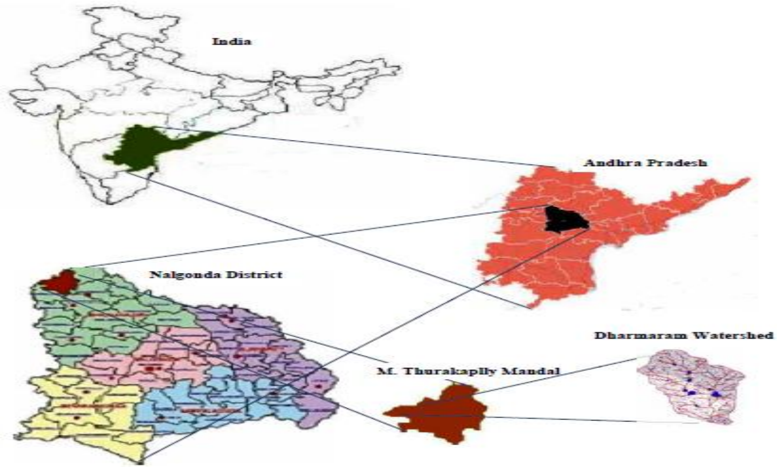

Figure 1 Location of Study Area

Figure 2 Characteristics of Soil in Study Area

3. METHODOLOGY AND DATA COLLECTION

Sensitivity analysis is a useful and common way to study on regional and seasonal behavior of ET0 in response to changes in climatic variables. Bakhtiari and Liaghat (2011) analyzed the sensitivity of the ASCE-Penman-Monteith equation for four climatic variables in the semi-arid climates. They showed that the change in ET was linearly related to the climatic variables. Their results also indicated that computed ET was most sensitive to vapor pressure deficit (VPD) followed by wind speed at 2 meter height (U2). Short wave solar radiation (Rs) and mean air. [5]

The modified Penman method was considered to offer the best results with minimum possible error in relation to a living grass reference crop. It was expected that the pan method would give acceptable estimates, depending on the location of the pan. The radiation method was suggested for areas where available climatic data include measured air temperature and sunshine, cloudiness or radiation, but not measured wind speed and air humidity. The measurement of PET from a grass surface is very difficult and time consuming process. However, different approaches to measure the same can be listed as:

1. Water budgeting technique.
2. Direct soil water measurement (Gravimetric, neutron probe, TDR etc).
3. Hydrologic budget (mass balance) method.
4. Lysimetric (Weighing, non-weighing, drainage lysimeters) measurement.
5. Indirect meteorological (Bowen ratio and eddy correlation) methods.
6. Chamber techniques.
7. Biological (Sap flow technique, Porometer, photometer) methods.
8. Passive (Pan Evaporation) methods.
9. Indirect methods (Empherical relations)

To estimate the Potential Evapotranspiration (PET) by using various methods as mentioned in earlier sections for the study area Dharmaram watershed various metrological parameters like precipitation, maximum and minimum temperatures, humidity (low and high), wind velocity and evaporation are obtained from Indian Metrological Department (IMD) at Begumpet, Hyderabad from 2006 to 2015 [17]. Annual values of some parameters were presented in Table 1. On the other hand, other basic parameters like Extra-terrestrial radiation(Ra), solar radiation, Julian calendar, actual hours of bright sunshine hours, Maximum possible hours of sunshine hours, saturation vapor pressure, Daylight duration, percentage day light hours, Psychometric constants, Wind speed at 2 m elevations were also obtained. Following are some of the assumptions were made for ease of calculations [20].

- Distribution of precipitation was uniform all over the watershed; hence point rainfall data was applied uniformly over the entire study area.
- All the precipitation occurred over the soil infiltrates into soil unless the soil is either impervious or it has reached saturation.
- Also it is assumed that soil moisture is depleted by the actual Evapotranspiration only.

Table 1 Annual values for metrological parameters from 2006 – 2015

Year	Name of the metrological parameter						
	Maximum temperature (^{0}C)	**Minimum temperature (^{0}C)**	**Relative humidity (high) (%)**	**Relative humidity (low) (%)**	**Pan evaporation (mm)**	**Wind Velocity (m/s)**	**Precipitation (mm)**
2006	32.00	22.36	81.60	42.12	4.86	2.44	477.32
2007	31.68	21.44	84.66	41.76	4.66	2.29	494.21
2008	32.15	21.84	83.72	41.42	5.05	2.29	616.25
2009	32.21	21.79	83.58	41.06	5.06	2.18	565.65
2010	32.64	22.31	80.27	37.22	5.85	2.13	464.33
2011	32.16	21.75	81.05	37.93	5.85	2.35	364.28
2012	32.89	21.67	78.97	32.82	6.98	2.34	351.96
2013	32.13	22.01	83.1	37.69	4.69	2.02	678.78
2014	32.09	20.87	81.61	31.95	5.12	2.24	349.00
2015	33.02	21.90	79.50	35.95	5.23	2.25	369.37

Table 1 represents annual values of various metrological parameters for the study area from 2006 to 2015. The above values were used in order to estimate PET values during those years by using various empirical relations which are shown discussed in further. In the similar lines, other parameters which were stated above were estimated using various empirical relations and further used in calculation of PET. The most common method is that direct soil measurement technique is widely used to measure ET. Similarly, other methods based on various parameters like temperature based methods, radiation based methods, physical methods and combination methods were also widely in use to measure PET and shown in Table 2.

Table 2 Various empirical relations based on different parameters

S. No.	Basis parameter	Name of the method	Formula
1	Temperature	Thronthwaite method	$1.6\ Xl\ X \left(\frac{10\ X\ T_m}{I}\right)^a$
		Jensen – Haise method	$R_s(0.025\ X\ T_m + 0.08)$
		Hargreaves method	$0.023\ X\ R_a\ X\ {T_D}^{0.5}\ X\ (T_m\ + 17.8)$
2	Radiation	Turc Method	$0.40\ X\ T_m\ X\ \left(\frac{R_s + 50}{T_m + 15}\right)$
		Makkink method	$0.65\ X\ \left(\frac{\Delta}{\Delta + \gamma}\right)\ X\ R_s$
		Priestly – Tailor method	$1.26\ X\ \left(\frac{\Delta}{\Delta + \gamma}\right)\ X\ (R_n\ - G)$
3	Physical	Christiansen method	$0.755\ X\ E_0\ X\ C_{T2}\ X\ C_{W2}\ X\ C_{H2}\ X\ C_{s2}$
4	Combined method	Penman – Monteith method	$\frac{0.408\ X\ \Delta\ X\ (R_n - G)\ X\ \gamma\ \frac{900}{T+273} U_2(e_a -\ e_d)}{\Delta +\ \gamma(1 + 0.34\ U_2)}$

Table 2 represents various empirical formulas based on various parameters to estimate PET. Values of PET were estimated using above relations from 2006 to 2015. Thus, by the use of Ms – Excel and with the help of trend analysis and by linear interpolation value of R^2 (or) coefficient of determination was estimated to find the most accurate method on par with standard method called as Penman – Monteith Method (PMM), which were presented in further sections.

4. RESULTS AND DISCUSSIONS

Calculation of PET was performed using above said empirical relations with the help of Ms – Excel and also value of R^2 value was determined which were shown in Table - 3

Table 3 Estimated annual values of PET in mm using various formulas

Year	Name of the method							
	Thronthwaite	**Jensen - haise**	**Hargreaves**	**Turc**	**Makkink**	**Priestly - Taylor**	**Christiansen**	**Penman – Monteith**
2006	10.92	6.25	4.55	21.86	1.47	2.20	3.34	7.30
2007	9.58	6.11	4.61	21.70	1.48	2.11	3.34	6.67
2008	10.42	6.20	4.65	21.80	1.48	2.10	3.61	6.93
2009	10.03	6.19	4.70	21.83	1.48	2.10	3.75	6.53
2010	11.38	6.30	4.73	21.95	1.47	2.09	4.23	6.81
2011	10.15	6.18	4.70	21.81	1.47	2.10	4.13	6.98
2012	10.71	6.25	4.93	21.90	1.48	2.09	4.83	7.1
2013	10.85	6.23	4.66	21.82	1.48	2.09	3.41	6.44
2014	4.83	6.09	4.78	21.66	1.48	2.10	3.52	6.56
2015	11.29	6.30	4.89	21.95	1.47	2.09	3.67	6.93
Mean	10.02	6.21	4.72	21.83	1.48	2.11	3.78	6.83

Table 3 indicates the calculated values of PET in mm, using various formulae based on different parameters namely: temperature, radiation, Physical and combined methods. It can be seen clearly that values obtained from Turc method shows highest mean with an intensity of 21.83 mm, whereas Makkink method shows the least value of PET whose mean is only 1.48 mm for the study area. Thronthwaite method with a mean value of 10.02 mm stood next to Turc method and follows in the order of Jensen – haise method, Hargreaves method, Christiansen method and Priestly – Taylor method with corresponding intensities as 6.21 mm, 4.72 mm, 3.78 mm and 2.11 mm respectively.

The values thus obtained from the above calculations were performed with trend analysis using Ms – Excel and value of R^2 was estimated which can be seen from Table – IV. During trend analysis, Penman – Monteith Method was taken as standard method and also as an independent term, with a main reason that PMM was considered to be as a reference method to estimate PET by FAO. Hence, values of R^2 were estimated by comparing between PMM and other remaining methods.

Table 4 Values of R^2 and linear equations between PMM and other methods

S. No.	Comparison between	Equation	R^2
1	PMM and Thronthwaite	y = 4.1514x - 18.221	0.7188
2	PMM and Jensen – haise	y = 0.2744x + 4.3372	0.7073
3	PMM and Hargreaves	y = 0.269x + 2.9071	0.7682
4	PMM and Turc	y = 0.2298x + 20.282	0.8137
5	PMM and Makkink	y = 0.0008x + 1.471	0.6686
6	PMM and Priestly - Taylor	y = 0.1322x + 1.2003	0.7553
7	PMM and Christiansens	y = 1.9636x - 9.6339	0.7335

Standard method prescribed by FAO (i.e.,) PMM was taken on X – axis and other remaining methods were considered on Y- axis. Thus the obtained values of R^2 and corresponding linear equations were presented in Table 4. It was observed that value of R^2 is high for Turc method and least with Makkink method whose intensities are 0.8137 (81.37 %) and 0.6686 (66.86 %) respectively. Also, it can be seen that, there was no downfall in slopes for any of the equation.

5. CONCLUSIONS

PET values obtained from various relations based on different parameters.

- Performance of PET on annual basis was indicated by the linear regression analysis, whose R^2 values for all the models seems to be similar ranging from 0.66 – 0.81 only.
- Turc method shows that the intercept higher value.
- R^2 value is high for Turc method which is 0.81 and the least value is observed for Makkink method with a value of 0.66.
- Finally, it can be concluded that Turc method is best suitable for the better yield of PET of next to standard PMM for study area.

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