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**Research Article**

# IDENTIFICATION OF SUITABLE METHOD FOR CROP WATER ASSESSMENT BY ESTIMATING EVAPOTRANSPIRATION - A CASE STUDY

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**Abstract-** This paper presents identification of suitable method for assessment of crop water requirements in the agriculture lands at Malaprabha Riverbed, Bagalkot, India (15.8N-75.5E). Climatic data required for assessment are collected for the selected site. In the present investigation, Blaney-Criddle, Christiansen, Hargreaves, Turc and Thornthwaite methods are employed to estimate evapotranspiration and resultant values are compared with standard reference Penman-Monteith estimated values for the said region. The evapotranspiration is obtained for four different seasons and comparative analysis is carried. Turc and Thornthwaite methods resulted in more deviation from reference and Blaney- Criddle, Hargreaves and Christiansen pan evaporation methods derived the results much closer to each other and standard reference. However, Blaney-Criddle method requires only air temperature data for analysis and yields optimum results. In view of this, Blaney-Criddle method is selected as most suitable method for the said location. Further, water requirement of various crops grown in North Karnataka region are assessed by using crop factors.

**Keywords**- Irrigation Systems, Evapotranspiration, Crop Water, Extra Terrestrial Radiation, Temperature and Humidity

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## Introduction

India is a country of 638,000 villages and more than 70% percent of India's population is involved in agriculture and allied businesses. Agriculture is the backbone of Indian economy and contributes a major part in GDP. Farmers entirely dependent on variable rainfall and groundwater to fulfill irrigation need of the crops. Electricity consumption by irrigation pump sets alone accounts approximately 20% of India's total electricity consumption, which has become burden on grid. Building further generating units and grid system, is too expensive. This issue can be resolved by identifying the excessive installations and re-sizing them optimally [1]. Optimization of irrigation system size depends on water requirement of the crops grown in the respective fields. Thus, it necessitates the assessment of exact irrigation water need of the agriculture land. Evapotranspiration (ET) of the location is required for assessment of crop water requirement.

Literatures presented number of empirical approaches for determination of evapotranspiration. Availability of meteorological data and converting that to water requirement is very difficult. Deciding the accuracy of different methods is a difficult task. Each method has its own limitation. However, no single method is universally acceptable under varying conditions. Large number of data requirement also limits the application of many of the techniques for crop water assessment. Jensen, evaluated about 20 equations, 9 of which are combination equations, against measured evapotranspiration (ET) values. Study showed that Penman-Monteith and Kimberly Penman were the two best relations in terms of accuracy of estimation. The radiation method was the best of the non-combination equation methods. The FAO-Penman method was poorly ranked due to over estimation. Several limitations are there in data availability for the Indian conditions. Nevertheless, the evapotranspiration needs to be estimated to determine the crop water requirements using crop factors [2].

D. Soundar Rajan, proposed two ways of deriving evapotranspiration by temperature and radiation methods. Comparison is carried amongst the various methods for a site in Tamil Nadu and concluded that Penman Monteith method which employs combined effect of temperature and aerodynamic variations is more promising method [3].

Swati Pandey, presented comparison of various universally accepted methods of evapotranspiration estimation with Penman method as a reference. Comparative analysis indicated the suitability of Hargreaves method, Christiansen method and Pan Evaporation method. The improvement in estimation was carried out through transformation of standard equations. The models indicated that during estimation of ET morning time relative humidity play the dominant role [4].

Selecting a suitable methodology for ET estimation for agriculture lands in Malaprabha Riverbed, Bagalkot, India (15.8351N-75.5394E) is the main focus of this paper. In this paper, five different methods are used. The FAO Penman-Monteith method is considered as a standard reference for ET estimation. The results will be employed for the assessment of optimal irrigation pump capacity for agriculture fields to achieve energy conservation.

## Evapotranspiration and Crop Water Need [5]

### A. Evaporation and Transpiration

In agricultural lands, water gets lost from the soil surface through evaporation. The other way of water loss is transpiration, where water contained in plant tissues vaporizes into the atmosphere through stomata of plant leaf. The combination of these processes is refereed as evapotranspiration (ET). Evaporation and transpiration occur simultaneously. At initial stages of crop growth evaporation is dominating, but once crop is fully-grown and covers the ground transpiration becomes the dominant. It is estimated that, with growth of crops from initial to mid-season stage, evaporation reduce to 10% from 100% and transpiration reaches to 90%.

### B. Factors affecting crop evapotranspiration

Evapotranspiration is affected by climatological factors such as solar radiation, air temperature, air humidity and wind speed. The soil water content and the ability of the soil to conduct water to the roots, Crop characteristics and cultivation practices also have significant influence on transpiration. The crop type, variety and development stages affect evapotranspiration. Differences in crop resistance to transpiration, crop height, crop roughness, reflection, canopy cover and crop rooting characteristics result in different evapotranspiration levels in different types of crops under identical environmental conditions.

### C. Reference crop evapotranspiration

The evapotranspiration from a reference surface not short of water is referred as reference crop evapotranspiration ($ET_o$). The concept of $ET_o$ yield evaporative demand of the atmosphere irrespective of type of crop, development stage of crop and other aspects. The crop evapotranspiration at standard conditions ($ET_c$), is the evapotranspiration from disease-free, healthy crops, grown in large fields. The values of $ET_c$ and Crop Water Requirements are identical, where they indicate amount of water lost through evapotranspiration and amount of water that is needed to compensate for the loss. $ET_c$ can be calculated from climatic data by directly combining the effect of crop characteristics with $ET_o$. Experimentally determined ratios of $ET_c/ET_o$, called crop factor ($K_c$), are used to assess crop water need by [Eq-1]:

$$ET_C = K_c \times ET_o \quad [1]$$

Where,
$ET_{crop}$ = crop evapotranspiration or crop water requirement (mm/day)
$K_c$ = crop factor
$ET_o$ = reference evapotranspiration (mm/day)

The crop factor, $K_c$, mainly depends on the crop type, growth stage and climate. Thus, to determine the crop factor, it is necessary to know the total length of the growing season and lengths of various growth stages. The total growing period is divided into 4 growth stages. The initial stage- the period from sowing or transplanting until the crop covers about 10% of the ground. Crop development stage- initial stage to until full ground cover has been reached. The mid - season stage- end of development stage to until maturity, it includes flowering and grain-setting. The late season stage starts at the end of the mid season stage and lasts until the last day of the harvest. For each session the crop factor will be different, i.e water need will be different.

### Meteorological Data for Selected Site

The local climatic data required for analysis in five different methods are collected and various data requirement for all methods are listed in [Table-1]. Temperature, humidity and wind speed data of the selected site are presented in [Table-2].

**Table-1** *Climatic data requirement for different methods*

| Method | Data Required |
|---|---|
| Hargreaves | mean temperature, difference between maximum and minimum temperature, extra-terrestrial radiation |
| Turc | solar radiation in langleys, maximum possible hours of sunshine, mean temperature |
| Thornthwaite | mean temperature, average day length (hours) of the month |
| Blaney-Criddle | mean temperature, maximum possible hours of sunshine |
| Christiansen | mean temperature, wind speed 2 m above ground level, mean relative humidity, percentage of possible sunshine |

**Table-2** *Climatic data for selected site*

| Month | Avrg. Temperature Data (°C) | | Relative Humidity Data | | Avrg. Wind Speed |
|---|---|---|---|---|---|
| | Max | Min | Max | Min | V(m/s) |
| Jan | 31.3 | 14.0 | 66 | 30 | 3.4 |
| Feb | 33.5 | 15.2 | 61 | 31 | 3.7 |
| March | 35.3 | 18.0 | 62 | 32 | 2.9 |
| April | 38.5 | 21.7 | 72 | 46 | 3.8 |
| May | 37.0 | 19.6 | 78 | 58 | 5.6 |
| June | 28.5 | 20.8 | 84 | 76 | 7.4 |
| July | 25.2 | 19.8 | 90 | 92 | 6.9 |
| August | 26.3 | 19.5 | 92 | 87 | 5.8 |
| Sept | 25.2 | 19.0 | 89 | 81 | 5.6 |
| Oct | 30.1 | 18.2 | 71 | 64 | 5.9 |
| Nov | 29.6 | 17.1 | 70 | 47 | 4.1 |
| Dec | 29.8 | 13.4 | 62 | 33 | 3.6 |

### Methods for Assessment of Evapotranspiration [2]

### A. Thornthwaite Method:

Thornthwaite introduced the concept of potential evapotranspiration and defined $ET_o$ as the maximal water quantity given out to atmosphere, from a vegetation cover with perfect physiological activity and sufficient water and nutrient conditions. Thornthwaite method developed in 1948 is an empirical study, between mean air temperature and Evapotranspiration. It is originally developed for the eastern US and is known for the under-estimation in the arid and overestimation in the humid areas, requiring only sunshine hours besides the temperature for computation. The equation is given by:

$$ET_o = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(10\,\frac{T_a}{I}\right)^{\alpha} \quad [2]$$

Where,
$ET_o$ is the estimated potential evaporation (mm/month)
$T_a$ is the average daily temperature of the month being calculated in degrees Celsius
N is the number of days in the month
L is the average day length (hours) of the month
α, an empirical exponent,

$$\alpha = (6.75 \times 10^{-7})I^3 - (7.71 \times 10^{-5})I^2 + (1.792 \times 10^{-2})I + 0.4923 \quad [3]$$

I is a heat index which depends on the 12 monthly mean temperatures,

$$I = \sum_{i=0}^{12}\left(\frac{T_a}{5}\right)^{1.514} \quad [4]$$

### B. Hargreaves Method:

Hargreaves evapotranspiration assessment method developed in 1985 is an empirical relation based on air temperature and radiation. The Hargreaves method is given by:

$$ET_o = 0.0023 R_A T_d^{\,0.5}(T_m + 17.8) \quad [5]$$

Where,
$R_A$ is extra-terrestrial radiation (mm/ day)
$T_D$ is difference between maximum and minimum temperature (°C)
$T_m$ is mean temperature (°C)

### C. Turc Method:

An empirical method was developed by Turc to estimate evapotranspiration on a regional scale. Equations were developed for annual and monthly assessments. Turc method estimates monthly $ET_o$ based on measurements of maximum and minimum air temperature and solar radiation. The method is given by equation:

$$ET_o = 0.40\, T_m \frac{(R_s+50)}{(T+15)} \quad [6]$$

Where,
$T_m$ is mean air temperature (°C)
$R_s$ is solar radiation in langleys
The solar radiation ($R_s$) is in turn computed from the following expression,

$$R_s = \left[0.25 + 0.5\left(\frac{n}{N}\right)\right] R_A \quad [7]$$

Where,
$R_A$ is extra-terrestrial radiation (MJ $m^{-2}$ $day^{-1}$)
n is actual hours of bright sunshine (hrs)
N is maximum possible hours of sunshine (hrs)

### D. Christiansen Pan Evaporation Method:

Christiansen method is a simple method to estimate pan evaporation and crop evapotranspiration. This method is purely empirical as it is not based on any physical equation. This method can somehow accurately estimate ET on a monthly basis. However, this method cannot be used to calculate crop water on a daily basis or for shorter time steps. The mathematical model of the method is given by:

$$ET_o = 0.755\ E_o C_{T2}\, C_{W2}\, C_{H2}\, C_{S2} \quad [8]$$

Where,

$$E_o = 0.862 + 0.179\left(\frac{T_m}{20}\right) - 0.041\left(\frac{T_m}{20}\right)^2$$

$$C_{W2} = 1.189 - 0.240\left(\frac{W}{6.7}\right) + 0.051\left(\frac{W}{6.7}\right)^2$$

$$C_{H2} = 0.499 + 0.620\left(\frac{H_m}{0.60}\right) - 0.119\left(\frac{H_m}{0.60}\right)^2$$

$$C_{S2} = 0.904 + 0.0080\left(\frac{S}{0.8}\right) + 0.088\left(\frac{S}{0.8}\right)^2$$

$E_o$ is open pan evaporation (mm)
$T_m$ is the mean temperature in °C
W is mean wind speed 2 m above ground level in km per hour
$H_m$ is mean relative humidity, expressed decimally
S is the percentage of possible sunshine, expressed decimally.
C terms are dimensionless coefficients for temperature (T), mean wind speed (W), mean relative humidity (H) and percent of bright sunshine hours (S).

### E. Blaney-Criddle Method:

Blaney-Criddle method was developed to estimate evapotranspiration necessary to determine supplemental irrigation. The Blaney-Criddle method is simple, using measured data on temperature only. Under "extreme" climatic conditions the method is inaccurate. In windy, dry, sunny areas, the reference evapotranspiration was underestimated. The Blaney-Criddle method is given by:

$$ET_o = p(0.46T_{mean} + 8) \quad [9]$$

Where,
$T_{mean}$is Mean daily temperature (°C)
p is Mean daily percentage of annual daytime hours

## Results and Discussions

Reference Evapotranspiration for the agriculture lands at Malaprabha Riverbed is derived using five methods. The seasonal evapotranspiration values from different methods are presented in [Table-3].

**Table-3** *Estimated values of evapotranspiration from diferent methods*

| Method | June–Sept | Oct-Dec | Mar-May | Jan-Feb |
|---|---|---|---|---|
| Penman | 5.19 | 3.86 | 7.10 | 4.47 |
| Hargreaves | 4.87 | 4.30 | 7.01 | 4.79 |
| Turc | 12.76 | 12.12 | 13.32 | 12.13 |
| Thornthwaite | 10.96 | 9.61 | 12.52 | 8.73 |
| Blaney-Criddle | 4.31 | 4.69 | 6.28 | 5.12 |
| Christiansen | 4.21 | 4.14 | 6.69 | 4.61 |

Comparison of the evapotranspiration results from different methods indicate that Hargeaves, Blaney-Criddle and Christiansen methods evapotranspiration values closely match with each other. On other hand Thornthwaite and Turc methods results in overestimation. The results of Penmon method is taken as reference for comparison. The comparison is presented in [Fig-1] and [Fig-2].

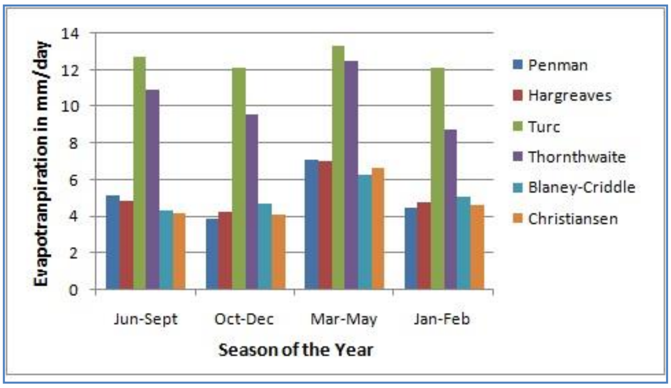


**Fig-1 Evapotranspiration in mm/day, Comparison of five methods with reference Penman method**

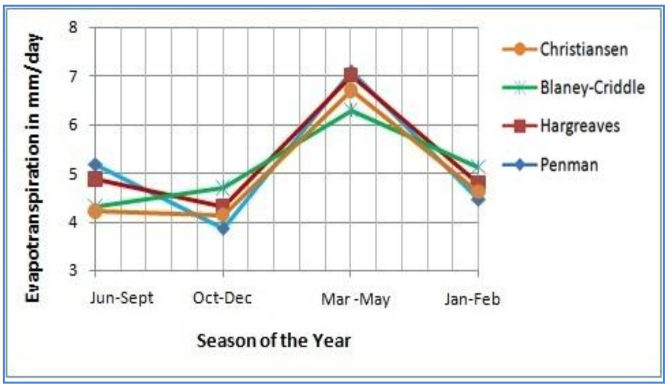


**Fig-2 Evapotranspiration in mm/day, Close comparison of selected methods with reference method**

Thus, comparison shows that, for selected location Blaney-Criddle, Hargreaves and Christiansen methods provide results in-line with reference method. Amongst the methods described, BalnneyCriddle method requires lesser amount of local data, and evapotranspiration for any site can be assessed with only the temperature data. Thus the Blaney-Criddle method is employed in the present work. Crop water requirement depends on cultivation area, type of the soil and its percolation properties, season of the year and type of the crops grown. Thus, total crop water is assessed by evapotranspiration, which will yield optimum water need in mm/day with approximating climatic factors. With known values of crop factors and growth period of the crops, water requirements can be calculated for various crops. In the present methodology, sizing of the pumps is carried for maximum water requirement conditions i.e for the mid-season stage of any crop. Thus, the resulting pump will fit for all seasons and worst conditions. For the site at reference crop evapotranspiration were assessed for different months. It is observed that maximum value of $ET_0$ is 6.20 mm/day. Further, crop water requirements for various crops for the selected site are evaluated. [Table-4] presents the crops and water requirements of major crops grown in selected site.

**Table-4** *Crop water requirement of different crops*

| Crop | Mid Season (Days) | Crop Factor (Kc) | Crop Water (mm/day) | Crop Water (m3/Acre/day) | Crop Water (lit/Hect/day) |
|---|---|---|---|---|---|
| Sugarcane | 136 | 1.15 | 7.13 | 28.8 | 71300 |
| Cotton | 72 | 1.15 | 7.13 | 28.8 | 71300 |
| Sorghum | 48 | 1.10 | 6.82 | 27.59 | 68200 |
| Tomato | 56 | 1.15 | 7.13 | 28.8 | 71300 |
| Onion | 36 | 1.00 | 6.20 | 25.08 | 62000 |
| Maize | 60 | 1.15 | 7.13 | 28.8 | 71300 |
| Sunflower | 50 | 1.10 | 6.82 | 27.59 | 68200 |
| Groundnut | 52 | 1.00 | 6.20 | 25.08 | 62000 |

In similar, using reference crop evapotranspiration, crop water requirements of any crop can be calculated for the respective growth period.

## Conclusion

Identification of suitable method for assessment of crop water requirements in the agriculture lands at Malaprabha Riverbed is presented in the paper. Five different methods are employed for assessment of evapotranspiration. The climatic data required for each method are listed. The results are compared with standard reference Penman-Monteith estimated values. The comparison revealed that, Turc and Thornthwaite methods yield excessive values of evapotranspiration and Blaney- Criddle, Hargreaves and Christiansen methods give optimum results. Amongst said methods, Blaney-Criddle requires lesser amount of data and hence it is concluded that, Blaney-Criddle method is most suitable method for the selected site. Further, actual crop water requirement of various crops are assessed.

This study is carried for optimally sizing the irrigation pumps based on exact crop water requirements, without affecting the water supply reliability.

**Conflict of Interest: None declared**

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