Comparison of methods for estimation of reference evapotranspiration in North-Central Plateau zone of Odisha

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ABSTRACT

Estimation of Evapotranspiration is vital role for proper water management and efficient farming activities. A decision support system (DSS_ET) was developed which supports 22 ET₀ estimation methods with varied options for calculation of various intermediate parameters. The objective of the study is to estimate ET₀ in the North central Plateau zone of Odisha, using weather data of the respective locality and screening of methods to estimate ET₀ close to FAO-56 Penman Monteith method. The FAO-24 Penman(c=1) and Turc methods yielded the highest (5.605 mm/day) and the lowest mean ET₀ (4.201 mm/day) respectively. For this zone, the highest ET₀ values was found to be 10.32 mm/d for FAO-24 Penman (c=1) method followed by Businger-van Bavel (9.73 mm/d) and FAO-PPP-17-Penman (9.68 mm/d) in the month of May, whereas, lowest ET₀ value was found in the month of December (2.54 mm/d) for the Priestly-Taylor method followed by 1982 Kimberly-Penman method (3.07 mm/d). Among all the methods, Penman-Monteith and Priestley-Taylor methods were ranked first and tenth respectively. For this zone, correction factor for Penman-Monteith and 1982 Kimberly-Penman methods approaches to one. The FAO-24 Penman (c=1) and Businger-van Bavel methods give more diversion from FAO-56 Penman-Monteith method.

Key words: BvB, FAO-56 PM, PM, PT, Reference Evapotranspiration(ET₀), Turc.

INTRODUCTION

Water plays a vital role for every living being. Water is and will become scarce natural resource in the near future. A clear understanding of the water balance is essential for exploring water saving measures. Due to economic and environmental constraints on new water resources developments, and increasing municipal and industrial needs, agriculture’s share of water use is likely to go down day by day. In agriculture, most of the water is lost due to evapotranspiration by the canopy cover of the plant and surface evaporation. It is the combination of soil evaporation and crop transpiration process. About 70% of the water loss from the earth’s surface occurs as evaporation (Almhab and Busu, 2008). Thus, accurate estimation of evapotranspiration is very important for studies, such as hydrologic water balance, irrigation system design and management, water resources planning and management, etc. The rate of evapotranspiration from an extensive surface of 8-15 cm tall, green grass cover of uniform height actively growing, completely shading the ground and with adequate water is called as the reference evapotranspiration (Doorenbos and Pruitt, 1977). Allen et al., (1998) defined ET₀ as “the evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm-1 and albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water”. The evapotranspiration rate is normally expressed in millimetres per unit time (mm/ day). Estimation of evapotranspiration requires number of parameters. Therefore, it becomes impractical for many users to select the best ET₀ estimation method for the available data and climatic condition. To overcome this problem, Reddy (1999) developed a decision support system consisting of nine widely used ET₀ estimation methods. This decision support system was further modified to include more ET₀ estimation methods (Swarnakar and Raghuwanshi, 2000) and named as DSS_ET model.

This model was further improved by Bandopadhyay et al.(2008). The DSS_ET model can be used to identify the best ET₀ method for different climatic conditions. It is developed in Microsoft Visual Basic 6.0. It consists of a model base for estimating ET₀ by twenty-two different methods and ranking them and a user-friendly graphical interface. These available methods can be used for estimating daily and monthly ET₀ values for the time interval considered in this study. The aim of present study is to estimate the reference evapotranspiration by using the available methods and ranked them to find the best suited method.
MATERIALS AND METHODS

Odisha lies at north latitude 17° 78' and 22° 73' and east longitude 81° 37' and 87° 53' with average elevation of 45 meters above MSL and a coast line of 480 km. It has a geographical area of 1,55,707 sq. km (4.87% of total area of India). Odisha is differentiated into ten different agro-climatic zones. The analysis was carried out on the basis of climatic data available at different agro-climatic stations. Thirty-three years (1981-2013) daily climatic data of minimum and maximum air temperature, mean relative humidity, average wind speed, solar radiation, and rainfall were collected from the website http://global.weather.tamu.edu/home/view/13292. The North Central Plateau have one research station Keonjhar lies at Latitude (°N) 21.63 and Longitude (°E) 85.58 with Hot and Moist climate and the mean annual rainfall is 1535 mm.

Estimation of Reference Evapotranspiration: The methods given below are taken for estimation for ET₀ for present study estimated by using following methods, a) Standardized form of FAO-56 Penman-Monteith by ASCE 2005 b) Penman Monteith Method (Monteith (1965), Allen (1986), Allen et al. 1989) c) Hargreaves Temperature Method d) Priestly-Taylor Radiation & Temperature Method e) Ture Radiation and Temperature Method f) 1972 Kimberly-Penman Method g) 1982 Kimberly-Penman Method h) CIMIS Penman method i) FAO-PPP-17 Penman (ET₀) method j) FAO-24 Penman (c=1) (ET₀) method [Doorenbos and Pruitt (1975, 1977)] k) Businger-van Bavel (ET₀) method

Estimation of daily evapotranspiration using DSS_ET: DSS_ET is a Decision Support System developed at IIT Kharagpur for estimation of crop evapotranspiration. The DSS ET model (Reddy, 1999) developed in Microsoft Visual Basic 6.0 is used in this present study to estimate reference evapotranspiration. The DSS_ET developed for ET₀ estimation includes a model base with decision-making capabilities, a graphical user interface and a database management system. This model is used to identify the best ET₀ estimation method for a given climatic condition. It identifies the data requirement of a method and if the available method satisfies the data requirement of the first-rank method (Penman-Monteith) as given in ASCE ranking. The system estimates the ET with that method: otherwise, it searches for the next suitable method. Same procedure is repeated until a suitable method is identified for given location and data conditions. By using the available daily climatological data, the daily reference evapotranspiration (ET₀) values were estimated for 33 years duration, using ten available methods.

Statistical analysis: ET₀ estimates from all methods were compared by using simple error analysis and linear regression. For each location, the following parameters were calculated
• Standard Error Estimate (SEE)
• Root Mean Square Error (RMSE)
• Percentage Error Estimate (PE)
• Mean Bias Error (MBE)
• Coefficient of Determination (R²)
• Regression Coefficient (b)
• Monthly Mean (mm/d)

The performance of a model is good when regression coefficient (b) is close to 1.0, R² > 0.6, RMSE < 0.6 mm d⁻¹ and PE < 20%.

RESULTS AND DISCUSSION

Reference Evapotranspiration ET₀ Comparison for North Central Plateau: The mean monthly ET₀ was estimated using all the methods and compared with the FAO-56 Penman-Monteith estimates. Out of all the 10 methods, the FAO-24 Penman(c=1) method yielded the highest mean ET₀ (5.605 mm/day). The Turc method estimated the lowest mean ET₀ of 4.201 mm/day. The Penman-Monteith and Priestley-Taylor methods resulted in the minimum and maximum SEE and RMSE values respectively. Similarly the percentage error (PE) was found minimum and maximum for 1982 Kimberly-Penman method and FAO-24 Penman (c=1) method respectively. Priestley-Taylor and FAO-24 Penman(c=1) methods resulted the minimum and maximum mean bias error (MBE) values respectively. For this zone, the highest ET₀ values was found to be 8.70 mm/d for FAO-24 Penman(c=1) method followed by Businger-van Bavel (8.46 mm/d) and CIMIS-PPP-17-Penman (8.03 mm/d) in the

Table 1: Statistical summary of monthly ET₀ estimates for north central plateau

| Statistical Parameters | PM | KP-82 | KP-72 | FAO-PPP-17-P | FAO-24-P(c=1) | HG | BvB | Ture | PT | CIMIS-Penman |
|------------------------|----|-------|-------|--------------|--------------|----|-----|------|-----|---------------|
| Mean (mm/d)            | 4.355 | 4.373 | 4.831 | 5.103        | 5.605        | 4.808 | 5.425 | 4.201 | 4.054 | 4.995          |
| R²                     | 0.994 | 0.929 | 0.986 | 0.987        | 0.985        | 0.775 | 0.975 | 0.764 | 0.561 | 0.994          |
| SEE(mm/mm/d)           | 0.175 | 0.495 | 0.465 | 0.746        | 1.253        | 0.953 | 1.116 | 0.919 | 1.272 | 0.559          |
| b                      | 0.976 | 0.979 | 1.083 | 1.147        | 1.254        | 1.049 | 1.219 | 0.917 | 0.860 | 1.108          |
| PE                     | 2.31  | 1.89  | 8.37  | 14.48        | 25.73        | 7.86  | 21.70 | 5.76  | 9.06  | 12.02          |
| MBE                    | -0.103 | -0.084 | 0.373 | 0.646        | 1.147        | 0.350 | 0.967 | -0.257 | -0.404 | 0.536          |
| RMSE(mm/mm/d)          | 0.175 | 0.489 | 0.432 | 1.112        | 3.141        | 1.815 | 2.491 | 1.691 | 3.233 | 0.625          |
Table 2: Ranking of different methods for this zone with respect to FAO-56 Penman method

| Station Name              | PM  | KP-82 | KP-72 | FAO-PP-17-P | FAO-24 P (c=1) | HG  | BvB | Turc | PT  | CIMIS-Penman |
|---------------------------|-----|-------|-------|-------------|---------------|-----|-----|------|-----|---------------|
| North Central Plateau     | 1   | 4     | 2     | 5           | 7             | 8   | 6   | 9    | 10  | 3             |

Month of May, whereas, lowest ET<sub>0</sub> value was found in the month of December (2.63 mm/d) for the Priestly-Taylor method followed by 1982 Kimberly-Penman method (3.07 mm/d). All these details have been depicted in Table 1 below.

**Ranking of ET<sub>0</sub> Estimation Methods:** The PM method performed very well throughout for this the zone; hence it was ranked as first form the zone. The PM equation includes vegetation leaf area effects on canopy resistance and vegetation height effects on the surface roughness parameter which appears to significantly improve the accuracy of this method for estimating ET<sub>0</sub> over a wide range of climates and locations. From the above study in the North central Plateau zone of Odisha, we arrived at the following ranking of different methods. Penman Monteith was ranked first among all the methods whereas Priestley-Taylor was ranked as the least convincing method.

**Correction Factor for North Central Plateau:** For this zone, correction factor for Penman-Monteith and 1982 Kimberly-Penman methods approaches to one. The FAO-24 Penman (c=1) and Businger-van Bavel methods give more diversion from FAO-56 Penman-Monteith method. The correction factor for north central plateau is shown in Fig 1.

In the present investigation, the FAO-24 Penman (c=1) method yielded the highest mean ET<sub>0</sub> and the Turc method estimated the lowest mean ET<sub>0</sub> (Table 2). The results were similar to the findings of Martinez and Thepadia (2010) in Florida, where Turc equation was recommended for estimating reference evapotranspiration in the absence of complete data sets to calculate ET<sub>0</sub> using the FAO 56 PM equation. Tabari (2011) also found the Turc method useful in estimating Reference Evapotranspiration. Penman Monteith was ranked first among all the methods whereas Priestley-Taylor was ranked as the least convincing method.

**CONCLUSION**

In this study, the ET<sub>0</sub> was estimated from the available climatic data for North Central Plateau agro-climatic zone of Odisha, India by all 11 applicable methods using DSS_ET software. The long term daily climatic data of minimum and maximum air temperature, mean relative humidity, wind speed, solar radiation and sun shine hours obtained from website were used to estimate reference evapotranspiration. By taking the standard FAO-56 Penman-Monteith method, other methods are statistically analyzed with different parameters of SEE, MBE, PE, RMSE, coefficient of determination and regression coefficient. Ranking of the 10 methods was done on the basis of SEE with respect to FAO-56 PM ET<sub>0</sub> to decide the best ET<sub>0</sub> estimation method. In addition, a correction factor to convert ET<sub>0</sub> estimates of different methods to the equivalent of the FAO-56 PM method was also determined for each method for the North Central Plateau zone of Odisha. Among the combination based methods, PM method gave ET<sub>0</sub> estimates closer to the standard FAO-56 PM method than other methods. After Penman-Monteith method, Kimberly-Penman method and CIMIS Penman results better in the zone and FAO-24 Penman (c=1) and Priestly Taylor methods performed poorly for most of the agro-climatic zones. May month was found as the peak ET<sub>0</sub> month whereas the minimum ET<sub>0</sub> occurred during December and January for this zone. The FAO-24 Penman (c=1) and Businger-van Bavel methods give more diversion from FAO-56 Penman-Monteith method.
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