

Comparison of Different Methods in Estimating Reference Evapotranspiration at Gaya District of Bihar, India

Abstract

Evapotranspiration (ET), a complex mechanism in the hydrological cycle, influences runoff, which in turn influences how much water is required for irrigation. There are many techniques available to calculate of the reference evapotranspiration (ET_o). Unfortunately, most efficient reference evapotranspiration approaches are parameter-rich models, making them unsuitable for use in data-scarce locations. On the other hand, accuracy and reliability of simple ET_o models vary widely according to regional climate conditions. The purpose of this study was to assess the effectiveness of two temperature-based and three radiation-based simple ET methods in estimating ET algorithms used to forecast the wheat crop for the years 2017–2018 in Gaya District, Bihar. The performance was measured by comparing the temperature and radiation-based method with the parameter intensive Penman-Monteith method. Comparative evaluation of two method (radiation and temperature) was performed through statistical tests, and it was found that the ($R^2 = 1$ and $R^2 = 0.98$) and $RMSE = 0.84$. The study found that ET_o values calculated from the six methods were highly correlated (Pearson correlation coefficient 0.84 to 0.99). Through data analysis for model comparison, it was found that the Radiation method performed satisfactorily when compared to the standard Penman-Monteith model estimate ($R^2 = 0.94$). However, multivariate statistical testing revealed that the ET_o readings obtained using various techniques differed significantly from one another. In comparison to radiation-based ET_o approaches, temperature-based ET_o techniques showed greater disparities. The Priestley-Taylor, Turc, and Jensen-Haise methods all outperformed the other ET_o methods in general. When estimating ET_o in this study region, it was discovered that radiation-based approaches performed better than temperature-based methods.

Keywords: Priestley-Taylor; Jensen-Haise; Hargreaves; Turc; Hargreaves-Samani; Penman-Monteith.

1. INTRODUCTION

“Evapotranspiration (ET) is a key component in defining the hydrological cycle in ecological systems, estimating water balance, and scheduling irrigation (Berti et al., 2014).

Evapotranspiration is the process by which water is moved from the earth's surface (i.e., the plant-soil system) to the atmosphere by transpiration (T) from plants through stomata found in plant leaves as well as by evaporation (E) from surfaces (soils and moist vegetation)” (Rawat et al.,2019). A precise estimation of ET is required in order to plan and budget for water. Evapotranspiration is expected to have the biggest direct impact on water supplies due to climate change. Hydrological changes in tropical regions have the potential to have one of the most important effects on global climate change (IPCC, 2007). Rising temperatures and changed rainfall patterns are now indisputable signs of climate change. More evapotranspiration will come from a warmer atmosphere, which will affect the hydrological system and water supplies (Shahid, 2011). For the management of long-term water supplies, it is crucial to quantify the variations in ET caused by climate change. Measuring potential changes in ET and the likelihood of water losses as a result of climate change is crucial, especially in cropland areas. Due to its importance, hydrologists have developed several ways for determining ET. Each approach has its own viewpoint and conceptual underpinnings and was created for a particular climatic setting. “Increases in ET were also found for warm conditions that often coincide with drought over most of Europe” (Stegehuis et al., 2013).

“The concept of reference evapotranspiration provides a convenient index to represent or estimate the maximum water loss to the atmosphere. Reference evapotranspiration estimates are required in many rainfall-runoff and ecological models used in global change research” (Hay and McCabe, 2002). In many regions of the world, water is a scarce resource. The need for domestic, industrial, and agricultural water use is rising daily as a result of the world population's rapid growth. As a result, the agricultural sector uses less water, but despite the limited water supply, crop production must be enhanced. “In the Gaya district, agriculture dominates. Every one of the three crop seasons involves cultivation. Paddy, wheat, potatoes, lentils, sorghum, millet, cowpea, and ground nuts are the principal crops grown in the Gaya area. Groundwater, which accounts for 38.5% of the country's total water resources, is crucial for irrigation, rural and urban drinking water supply, and industrial growth. Groundwater meets nearly 55 % irrigation, 85 % of rural and 50 % of urban and industrial needs” (Government of India, 2007).

There are about 50 approaches or models available to estimate reference evapotranspiration, however they often produce inconsistent results because of their various input data requirements and assumptions, or because they were frequently created for climatic zones (Grismer *et al.*,

2002). “Accurate estimation of ET_o and its possible variations due to climate change are very crucial for water resources planning and management in the scheme. The Penman-Monteith method, one of the most dependable techniques that fully consider atmospheric fluctuations, offers the most realistic estimate of ET_o ” (Allen *et al.*, 2006; Sentelhas *et al.*, 2010; Ravazzani *et al.*, 2011; Lee & Cho, 2012). The purpose of this research is to examine the performance of six widely used simple ET_o approaches in estimating ET_o in Gaya District, Bihar, namely Hargreaves Samani, Hargreaves, Jensen-Haise, Priestley-Taylor, Turc and Penman-Monteith. The performance of these simple ET_o approaches is examined in the current study by comparing them.

2. Materials and Methods

2.1 Study Area

The research region in the Gaya District, which is 111 m above mean sea level on average, is situated between latitudes 24°-46'-48.0360" N and 84°-58' 54.5772" E. (Fig. 1). The district is bounded in the north by Arwal, Jahanabad and Nalanda districts, in the east by Nawada and west by Aurangabad district. The southern part is bounded by Jharkhand state. The weather is mostly dry, described as tropical steppe, semi-arid, and hot, with sweltering summers and very cold winters. Black soils make up 42% of the area's soils, Sandy Loam soils make up 14%, and Sandy soils make up 22%. The water table in the region, according to Borana (2012), is saline, with only a few minuscule pockets of fresh water in the southwest. Seasonal temperature changes that are incredibly large (20^o C in winter to 45^o C in summer). The average annual rainfall is 961.83 mm, of which 847.4 mm fall during the monsoon and 114.43 mm during the dry season. Agricultural activity in the area is by and large confined to the traditional *kharif* cultivation depending primarily on monsoon rainfall and *rabi* cultivation in localized patches where irrigation facilities are available. Gaya is the second largest contributor to the economy of Bihar, after Patna.

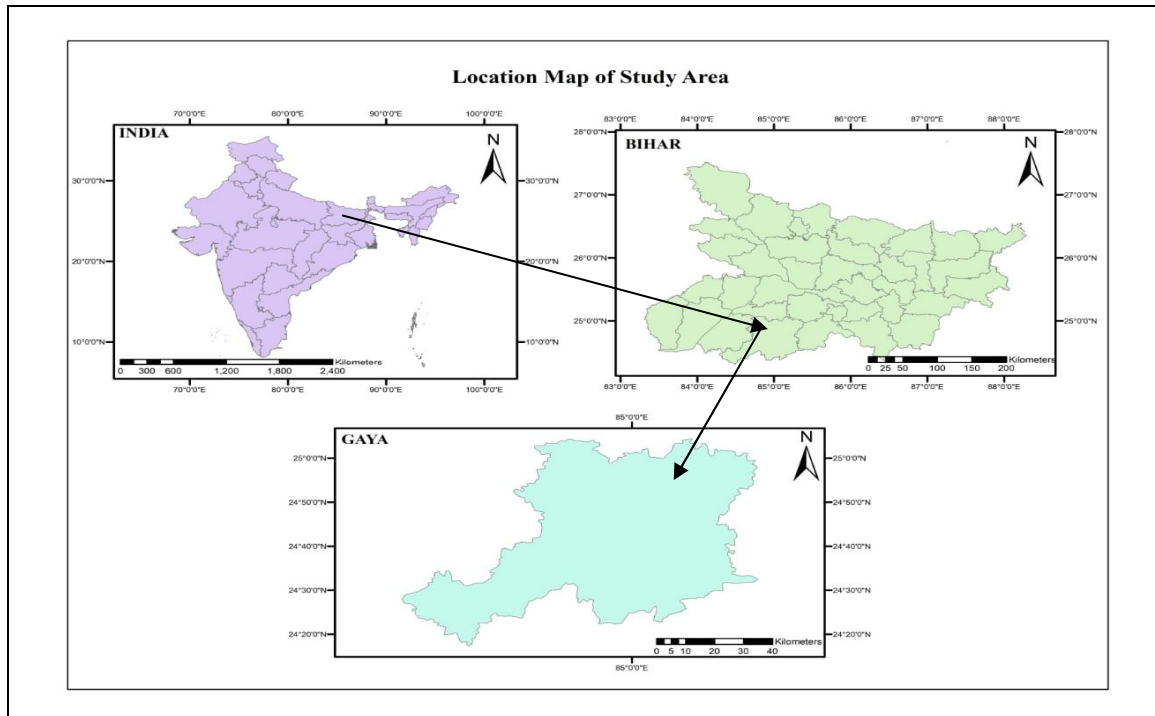


Fig 1: Study area

2.2 Data

The following weather data are recommended for estimating reference evapotranspiration.

- Wind speed (required, hourly data is preferred)
- Precipitation (daily data are recommended)
- Humidity (hourly data such as vapor pressure or dew point temperature)
- Solar radiation (hourly is preferred)
- Maximum and minimum Temperature (hourly is preferred)

2.3 Estimation of Reference Evapotranspiration

The method of Priestley-Taylor, Jensen-Haise, Turc, Hargreaves-Samani, and Hargreaves were used for estimation of reference evapotranspiration (ET_o) and compared with Penman-Monteith method. “These methods were divided into two broad groups viz., radiation-based methods (Priestley-Taylor, Jensen-Haise and Turc) and temperature-based methods (Hargreaves-Samani and Hargreaves). Such methods were selected by considering the availability of meteorological data required by those models” [24].

2.2.1 Turc Method

Turc (1961) proposed a simple equation for computing ET by using only mean temperature, solar radiation, and relative humidity. Jensen *et.al.* (1990) reported that the Turc method is reliable under humid conditions similar to present study area. The Turc equation is as follows:

When $RH < 50\%$

$$ET_o = 0.0133 \frac{T_m}{T_m + 15} (Rs + 50) \left(1 + \frac{50 - RH}{70}\right) \quad (1)$$

When $RH > 50\%$

$$ET_o = 0.0133 \frac{T_m}{T_m + 15} (Rs + 50) \quad (2)$$

Where, T_m is mean of temperature ($^{\circ}C$), Rs is the solar radiation of the crop surface ($MJ m^{-2} day^{-1}$), and RH is the relative humidity (%).

2.2.2 Hargreaves-Samani Method

The Hargreaves-Samani equation (Hargreaves & Samani, 1982) is derived through regression of temperature reduction coefficient and relative humidity factor. The equation is expressed below:

$$ET_o = 0.0023(T_{max} - T_{min}) 0.5 (T_m + 17.8) Ra \quad (3)$$

Where, T_m , T_{max} and T_{min} refer to mean, maximum and minimum temperatures ($^{\circ}C$), and R_a is the extraterrestrial radiation of the crop surface ($MJ m^{-2} day^{-1}$).

2.2.3 Hargreaves method

The Hargreaves and Samani (1985) proposed equation for calculating potential evapotranspiration ($mm day^{-1}$).

$$ET_o = 0.0135 \times Rs \times (T_{mean} + 17.8) \quad (4)$$

Where, T_{mean} is mean air temperature, Rs is solar radiation ($MJ m^{-2} day^{-1}$).

2.2.4 Priestley-Taylor method

Priestley & Taylor (1972) found that “the actual evaporation is 1.26 times greater than the potential evaporation and hence they replaced the aerodynamic terms with a constant value of 1.26. Consequently, Priestley-Taylor method needs only long-wave radiation and temperature to estimate ET”. Priestley-Taylor equation for computing ET is given below:

$$ET_o = 1.26 \frac{\Delta}{\Delta + \gamma} (Rn - G) \frac{1}{\lambda} \quad (5)$$

Where, Δ is the slope vapor curve ($\text{kPa } ^\circ\text{C}^{-1}$), γ is the psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), Rn is the net radiation of the crop surface ($\text{MJm}^{-2} \text{ day}^{-1}$), G is the soil heat flux density ($\text{MJ m}^{-2} \text{ day}^{-1}$), and λ is the latent heat of vapor (MJ kg^{-1}).

2.2.5 Jensen–Haise Model

The Jensen and Haise (1963) developed “empirical model which can be applied for arid and semiarid regions” (Pereira and Pruitt, 2004). “It estimates potential evapotranspiration based on radiation” (Jensen et al., 1990). The model requires daily mean temperature ($^\circ\text{C}$) and global radiation data (mm day^{-1}) as input to calculate the potential evapotranspiration (mm day^{-1}) expressed by

$$ET_o = (0.0252 \times T_{\text{mean}} + 0.078) \times R_s \quad (6)$$

Where, T_{mean} is mean air temperature, R_s is solar radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$)

2.2.6 Penman-Monteith equation

The Penman-Monteith method (Monteith, 1965) combines “the fixed bulk surface resistance and vapor aerodynamic. It has a strong theoretical basis and can be expressed as below:

$$ET_o = 0.408 \frac{(Rn - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (7)$$

Where, ET_o is the reference evapotranspiration (mm day^{-1}), Δ is the slope vapor curve ($\text{kPa } ^\circ\text{C}^{-1}$), R_n is the net radiation of the crop surface ($\text{MJm}^{-2} \text{ day}^{-1}$), G is the soil heat flux density ($\text{MJm}^{-2} \text{ day}^{-1}$), T is the air temperature at 2m height ($^\circ\text{C}$), u_2 is the wind speed at 2m height (m s^{-1}), e_s is the saturation vapor (kPa), e_a is the actual vapor pressure (kPa), and γ is the psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$)” [24].

2.3 Statistical Indicators

2.3.1 Correlation Coefficient(r)

The correlation coefficient is a statistical measure of the strength of a linear relationship between two variables. Its values can range from -1 to 1.

2.3.2 Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) is the standard deviation of the residuals (prediction errors). This produces a value between 0 and 1.

3 Results

The Pearson correlation coefficients were calculated among the five methods **in comparison to the Penman-Monteith method with values ranged from 0.84 to 0.99 (Table.1)**. Under the radiation-based method, the Turc has correlate with the Penman-Monteith (with a $R = 0.94$), while the Jensen-Haise method was correlate with Penman-Monteith with a value ($R = 0.85$). **Under the temperature-based method, the correlation coefficients were 0.99 and 0.95, respectively between Penman-Monteith and Hargreaves-Samani and Penman-Monteith and Hargreaves. while the Hargreaves method ($R=0.95$)**. Multivariate statistical tests indicated that each radiation and temperature-based method of ET_o was significantly different from all the others at a 0.14 and 0.04 significance level.

The Turc method yielded the lowest long term averaged annual ET_o while the Hargreaves-Samani method predicted the highest values are shown in Figure 2. The ET_o estimated by the Hargreaves- Samani method was even slightly lower than Penmen-Monteith method as discussed in the next paragraph. Across the 36 sites, greater differences were found among the temperature based ET_o methods and radiation based ET_o methods represent in Figures 2, 3, and 4. The ET_o values predicted by the three radiation-based methods were found to be higher value of Jensen-Haise method and lowest value of Turc method in magnitude, especially for the Jensen-Haise method and Turc methods, which had a correlation coefficient of 0.96. The peak values are found in February-April as the temperature is high during this period. On the other hand, the least ET_o values are observed in the months of November, December, and January. The monthly pattern produced by different methods is not similar. The Jesensen-Haise method and Hargreaves method showed almost equal ET_o for all months. The Hargreaves-Samani method, Hargreaves method and Jensen- Haise method (November, December, February, and March) showed similar pattern like the Penman- Monteith method. The ET_o estimated by Hargreaves-Samani Method was slightly higher (3.4 mm day^{-1} in November and 7.0 mm day^{-1} in April) than Penmen-Monteith method.

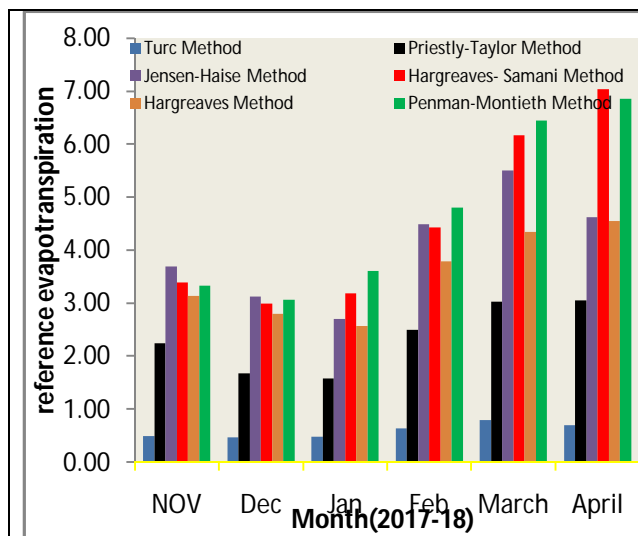


Fig 2: A comparison of six potential evapotranspiration methods for regional use in the Gaya, Bihar

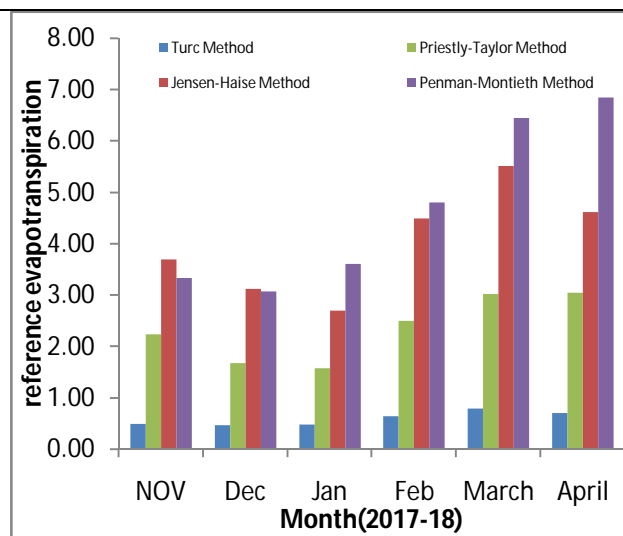


Fig 3: Comparison of Penman-Monteith ET₀ Simulated by the three Radiation Based Methods

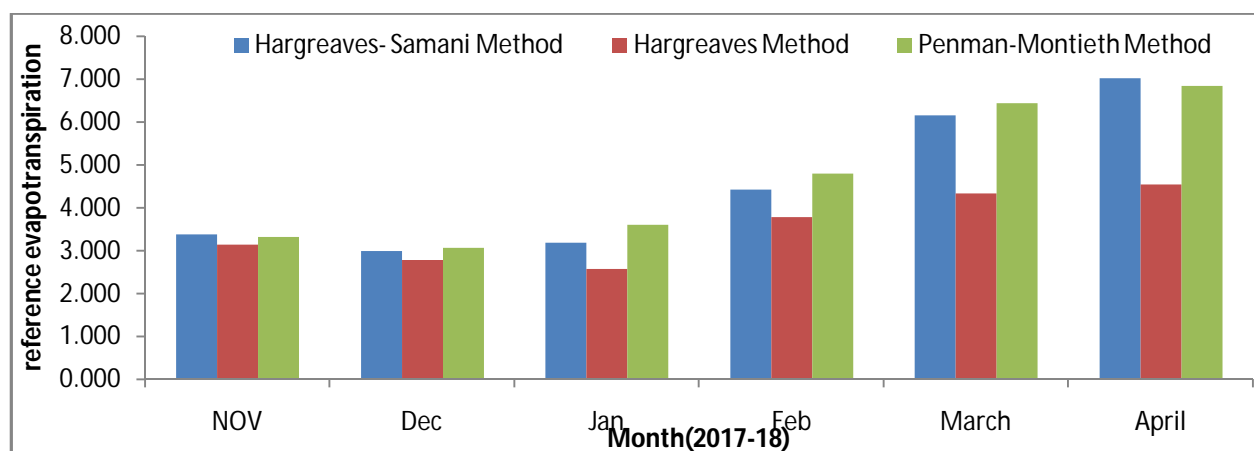


Fig 4: Comparison of Penman-Monteith reference evapotranspiration Simulated by the Two Temperature Based Methods

Table 1.: Pearson correlation between reference evapotranspiration (ET₀) methods for regional use in the Gaya, Bihar (n = 36)

Reference evapotranspiration Method	Penman-Monteith Method	Hargreaves-Samani Method	Hargreaves Method	Jensen-Haise Method	Priestly-Taylor method	Turc Method
Penman-Monteith Method	---	0.990	0.954	0.852	0.919	0.944
Hargreaves-Samani Method	0.99	---	0.963	0.835	0.932	0.911
Hargreaves Method	0.954	0.963	---	0.931	0.985	0.940
Jensen-Haise Method	0.852	0.835	0.931	---	0.948	0.959
Priestly-Taylor method	0.919	0.932	0.985	0.948	---	0.928
Turc Method	0.944	0.911	0.940	0.959	0.928	---

The relations of Penman-Monteith method with five others methods are shown in Figure 5-9. The relationships can be well expressed in the polynomial form $aX^2 + bX + c$. The square root of correlation coefficient (R^2) was used to measure the strength of correlation. The results showed higher correlation coefficients for the temperature-based methods and lower correlation coefficients for the radiation-based methods for study area. The Turc Method yielded the highest correlation coefficient (0.919) among the radiation-based methods. The Hargreaves-Haise Method yielded the highest correlation coefficient (0.991) among the temperature-based methods. The Turc method and Hargreaves method showed slightly similar correlation coefficients compared to temperature and radiation-based methods. Priestly-Taylor and Jensen-Haise method showed lower correlation coefficients compared to temperature –based method. Temperature-based methods yielded correlation coefficients in the range of 0.910 to 0.991. This means that the reference evapotranspiration methods based on temperature have a best relationship with the Penman-Monteith method. The Hargreaves-Samani method produced high correlation coefficient compared to other radiation-based methods for study area represent in table 2.

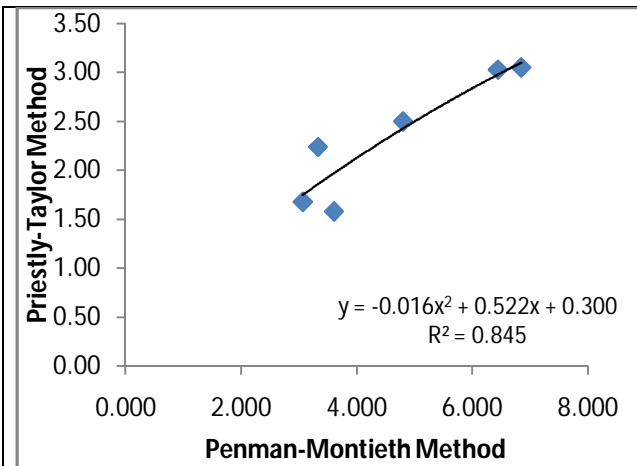


Fig 5: Relationship between Penman-Monteith & Priestly-Taylor Method

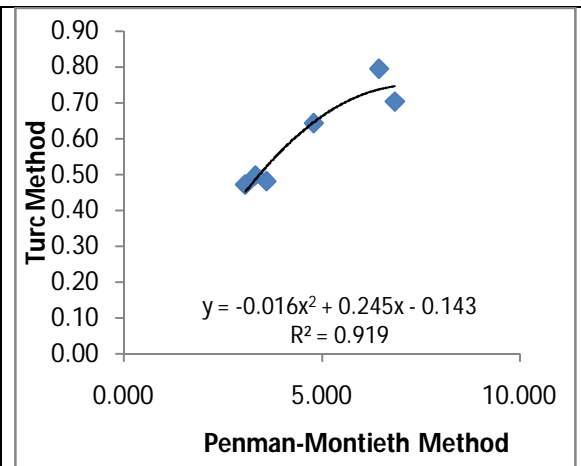


Fig 6: Relationship between Penman-Monteith & Turc Method

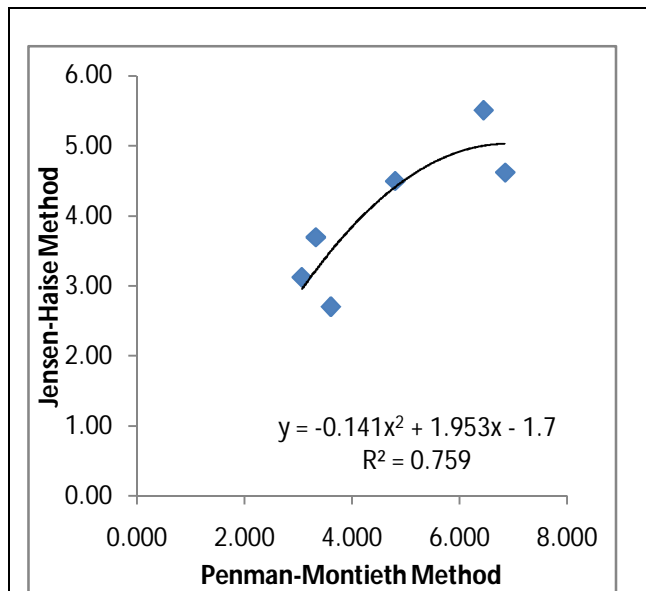


Fig 7: Relationship between Penman-Monteith & Jensen-Haise Method

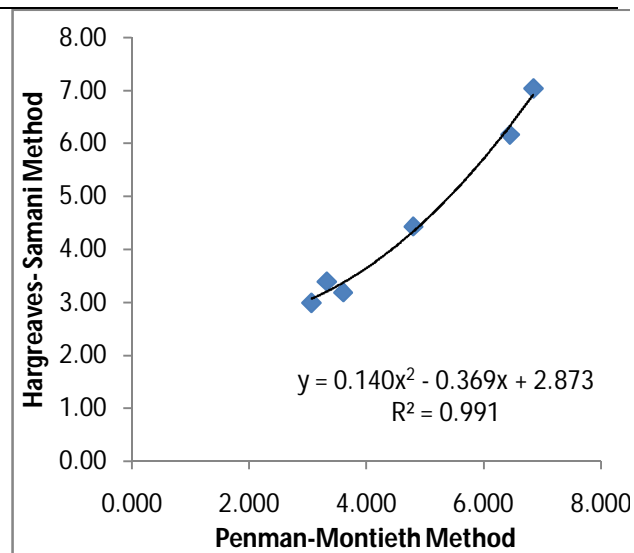


Fig 8: Relationship between Penman-Monteith & Hargreaves-Samani Method

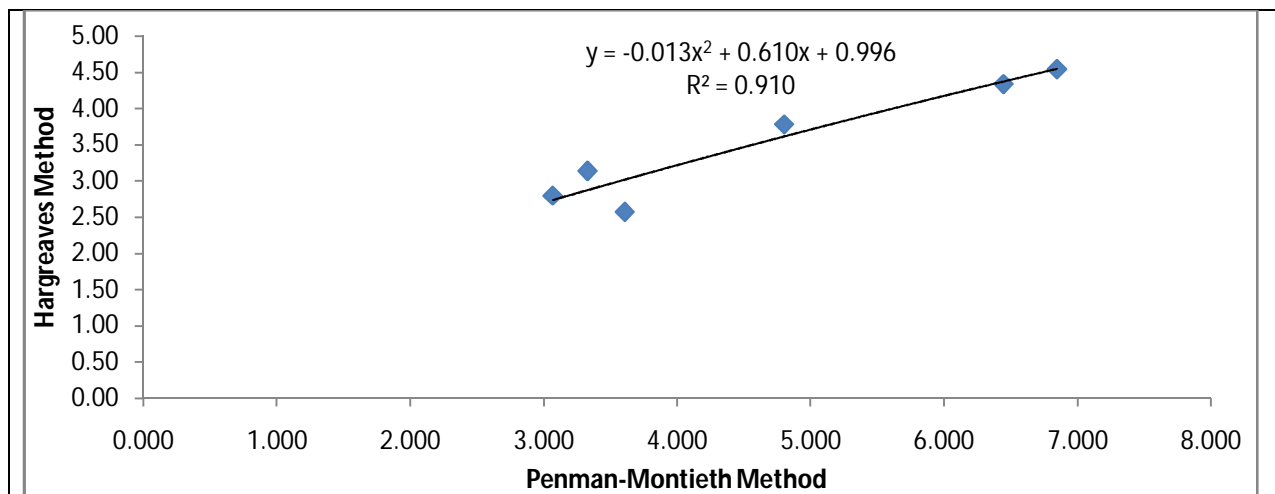


Fig 9: Relationship between Penman-Monteith & Hargreaves Method

Table 2: Average reference evapotranspiration of Rabi Season Among different Methods.

Average reference evapotranspiration of Rabi Season (2017-18)					
Penman-Monteith Method	Hargreaves Method	Hargreaves- Samani Method	Jensen-Haise Method	Priestly-Taylor Method	Turc Method
3.329	3.142	3.392	3.691	2.240	0.498
3.068	2.798	2.993	3.120	1.679	0.473
3.608	2.575	3.189	2.700	1.582	0.482
4.803	3.787	4.432	4.494	2.501	0.643
6.448	4.344	6.160	5.506	3.029	0.794
6.848	4.551	7.032	4.616	3.051	0.703

4. Discussion and Conclusions

This study provided evidence that ET_o is challenging to estimate precisely and should be utilised cautiously when calculating actual water loss from natural systems. The commonly used ET_o methods for this comparison study gave a wide range of values, showing differences in ET_o across the study area among five methods. Evapotranspiration is a major controlling factor of hydrological processes. Climate change will affect the hydrological processes mainly through Evapotranspiration. Assessment of ET_o especially in the context of climate change is therefore very important. The study showed that different five method of ET_o in the region ranges from 0.60 mm day^{-1} to 4.53 mm day^{-1} (Nov 2017 to April 2018) for wheat crop. Among the five ET_o methods, radiation-based methods were found to perform lesser in term of producing similar pattern as produced by the Penman-Monteith method. However, as the temperature-based methods were found to produce similar ET_o pattern with reasonable errors, it can be concluded that the temperature-based methods are suitable for estimating ET_o in the study area. Among the temperature-based method, Hargreaves-Samani method was found to perform best followed by the other method. The temperature-based approaches utilised in the current study's Hargreaves-Samani method demonstrated the lowest errors and the highest correlation of all the methods. The Hargreaves-Samani approach likewise displayed the best correlation when fitting a polynomial regression line with the Penman-Monteith estimations, followed by the other four methods. Capability of Hargreaves and Jensen-Haise methods in estimating ET_o is similar. Therefore, Turc method can be used more easily compared to Priestley-Taylor method in estimating ET_o in the study area.

Reference

1. Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations.
2. Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. (1998). Crop Evapotranspiration-Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO Corporate Document Repository.
3. Allen, R.G., Clemmens, A.J., Burt, C.M., Solomon, K., O'Halloran, T., 2005. Prediction accuracy for projectwide evapotranspiration using crop coefficients and reference evapotranspiration. *J. Irrig. Drain. Eng.* 131 (1), 24–36.
4. Allen, R. G., Pruitt, W. O., Wright, J. L., Howell, T. A., Ventura, F., Snyder, R., Itenfisu, D., Steduto, P., Berengena, J., Yrisarry, J. B., Smith, M., Pereira, L. S., Raes, D., Perrier, A., Alves, I., Walter, I. & Elliott, R. (2006). A recommendation on standardized surface

- resistance for hourly calculation of reference ETo by the FAO56 Penman-Monteith method. *Agricultural Water Management*, 81, 1–22.
5. Band, L.E., D.S. Mackay, and I.F. Creed, 1996. Ecosystem Processes at the Watershed Sale: Sensitivity to Potential Climate Change. *Limnol. Oceanogr.* 41(5):928-938.
 6. Berti, A., Tardivo, G., Chiaudani, A., Rech, F., Borin, M., 2014. Assessing reference evapotranspiration by the Hargreaves method in north-eastern Italy. *Agric. Water Manag.* 140, 20–25. <https://doi.org/10.1016/j.agwat.2014.03.015>.
 7. Burnash, R. J. C. (1995). The NWS River forecast system- catchment modeling. In V. P. Singh (Ed.), *Computer Models of Watershed Hydrology* (pp. 311–366). Water Resources Publications, Highlands Ranch, CO.
 8. Currie, D.J., 1991. Energy and Large-Scale Patterns of Animal- and Plant-Species Richness, *The American Naturalist* 137(1):27-49.
 9. Grismer, M.E., M. Orang, R. Snyder, and R. Matyac, 2002. Pan Evaporation to Reference Evapotranspiration Conversion Methods. *J. Irrigation and Drainage Engineering* 128(3):180-184.
 10. Hargreaves, G.H., Samani, Z.A., 1985. Reference crop evapotranspiration from temperature. *Appl. Eng. Agric.* 1 (2), 96–99.
 11. Hargreaves, G.H., Samani, Z.A., 1982. Estimating potential evapotranspiration. *J. Irrig. Drain. Div.* 108 (3), 225–230.
 12. Hargreaves, G.H., Allen, R.G., 2003. History and evaluation of Hargreaves evapotranspiration equation. *J. Irrig. Drain. Eng.* 129 (1), 53–63.
 13. Hay, L.E. and G.J. McCabe, 2002. Spatial Variability in Water Balance Model Performance in the Conterminous United States. *Journal of the American Water Resources Association (JAWRA)* 38(3):847-860.
 14. IPCC (2007). Summary for Policymakers. In M. L. Parry, O. F. Canziani, J. P. Palutik of, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
 15. Jensen, M.E., Haise, H.R., 1963. Estimating evapotranspiration from solar radiation. *Proc. J. Irrig. Drain. Div. Am. Soc. Civ. Eng* 89 (IR4), 15–41 Closure, 91(IR1): 203–205.
 15. Jensen, M.E., Burman, R.D., Allen, R.G., 1990. Evapotranspiration and Water Irrigation Requirements. Committee on Irrigation Water Requirements. Irrigation and Drainage Division of ASCE, Manual No. 70, ASCE, New York pp 329.
 16. Lee, K. H. & Cho, H. Y. (2012). Simple method for estimating pan coefficient: Conversion of pan evaporation to reference evapotranspiration. *Journal of irrigation and drainage engineering*, 137 (1), 98–103.
 17. Martinez, C.J., Thepadia, M., 2010. Estimating reference evapotranspiration with minimum data in Florida, USA. *J. Irrig. Drain. Eng.* 136 (7), 494–501. [https://doi.org/10.1061/\(ASCE\)IR.1943-4774.0000214](https://doi.org/10.1061/(ASCE)IR.1943-4774.0000214).

18. Priestley, C.H.B., Taylor, R.J., 1972. On the assessment of surface heat flux and evaporation using large scale parameters. *Mon. Weather. Rev.* 100, 81–92.
19. Ravazzani, G., Corbari, C., Morella, S., Gianoli, P. & Mancini, M. (2011). Modified Hargreaves-Samani equation for the assessment reference evapotranspiration in Alpine River basin. *Journal of irrigation and drainage engineering*, 138 (7), 592–599.
20. Rawat, K. S., Singh, S. K., Bala, A., Sazabo, S. (2019). Estimation of crop evapotranspiration through spatial distributed crop coefficient in a semi-arid environment. *Agricultural Water Management*, 213 (922-933).
21. Sentelhas, P. C., Gillespie, T. J. & Santos, E. A. (2010). Evaluation of FAO Penman–Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. *Agricultural Water Management*, 97 (5), 635–644.
22. Shahid, S. (2011). Impacts of Climate Change on Irrigation Water Demand in Northwestern Bangladesh. *Climatic Change*, 105 (3-4), 433–453.
23. Turc, L., 1961. Estimation of irrigation water requirements, potential evapotranspiration: a simple climate formula evolved up to date. *Ann. Argon.* 12, 13–49.
24. Tukimat NN, Harun S, Shahid S. Comparison of different methods in estimating potential evapotranspiration at Muda Irrigation Scheme of Malaysia. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*. 2012 Sep 19;113(1):77-85.