__Original Research Article__

Comparison of different methods in estimating potential evapotranspiration at Gaya District of Bihar

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 potential evapotranspiration (PET).Unfortunately, most efficient PET approaches are parameter-rich models, making them unsuitable for use in data-scarce locations. On the other hand, accuracy and reliability of simple PET 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 those methods with theparameter intensive Penman-Monteith Method. Comparative evaluation of two method (radiation & temperature) was performed through statistical tests, and it was found that the (R^2=1 and R^2=0.98) and RMSE = 0.838. The study found that PET 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 PET readings obtained using various techniques differed significantly from one another.In comparison to radiation-based PET approaches, temperature-based PET techniques showed greater disparities. The Priestley-Taylor, Turc, and Jensen-Haise methods all outperformed the other PET methods in general. When estimating PET in this study region, it was discovered that radiation-based approaches performed better than temperature-based methods.The findings of this investigation show that having access to water and receiving a sufficient amount of rainfall results in higher wheat yields.

Keywords:*Potential evapotranspiration, Priestley-Taylor Model, Jensen-Haise Model, Hargreaves Model, Turc Model, Hargreaves-Samani Model & Penman-Monteith Method.*

Introduction

The water lost due to the atmosphere through two processes evaporation and transpiration is known as evapotranspiration. Evaporation is the loss from exposed surfaces of open water, such as lakes, reservoirs, wetlands, bare soil, and snow cover, while transpiration is the loss from live plant surfaces. The word "evapotranspiration" (ET) is used to refer to the total amount of water vapour and plant transpiration that leaves the Earth's surface and enters the atmosphere. It controls runoff volume or river flow, irrigation water requirements, and soil moisture contents, making it the second-most significant element in the hydrological cycle after rainfall (Mohan &Arumugam, 1996). 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 a number of ways for determining ET. Each approach has its own viewpoint and conceptual underpinnings and was created for a particular climatic setting. Some of these techniques are just modified versions of other techniques. However, the main issue with ET estimation is the validity and precision of the approaches (Burnash, 1995). The concept of PET provides a convenient index to represent or estimate the maximum water loss to the atmosphere. PET estimates are required in many rainfall-runoff and ecological models used in global change research (Band *et al.*, 1996; Hay and McCabe, 2002). Potential evapotranspiration is also used as an index to represent the available environmental energies and ecosystem productivity (Currie, 1991). For example, in the four vertebrate classes studied, Currie (1991) found that 80 to 93 percent of the variability in species richness could be statistically explained by ecosystem PET.There are about 50 approaches or models available to estimate PET, however they often produce inconsistent results because of their various input data requirements and assumptions, or because they were frequently created for particular climatic zones (Grismer*et al.*, 2002). Accurate estimation of ET and its possible variations due to climate change are very crucial for water resources planning and management in the scheme. The purpose of this research is to examine the performance of six widely used simple ET approaches in estimating ET in Gaya District, Bihar, namely the Hargreaves Samani Method, the Hargreaves Method, the Jensen-Haise Method, the Priestley-Taylor Method, the Turc Method, and the Penman-Monteith Method.The performance of these simple ET approaches is examined in the current study by comparing them. The Penman-Monteith method, one of the most dependable techniques that fully takes into account atmospheric fluctuations, offers the most realistic estimate of ET (Allen *et al.*, 1998, 2006; Sentelhas*et al.*, 2010; Ravazzani*et al.*, 2011; Lee & Cho, 2012).xxx

Materials and Methods

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 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 (2^{0}C in winter to 45^{0}C in summer). The average annual rainfall in the Gaya district is 961.83 mm, of which 847.4 mm fall during the monsoon and 114.43 mm during the dry season. 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).

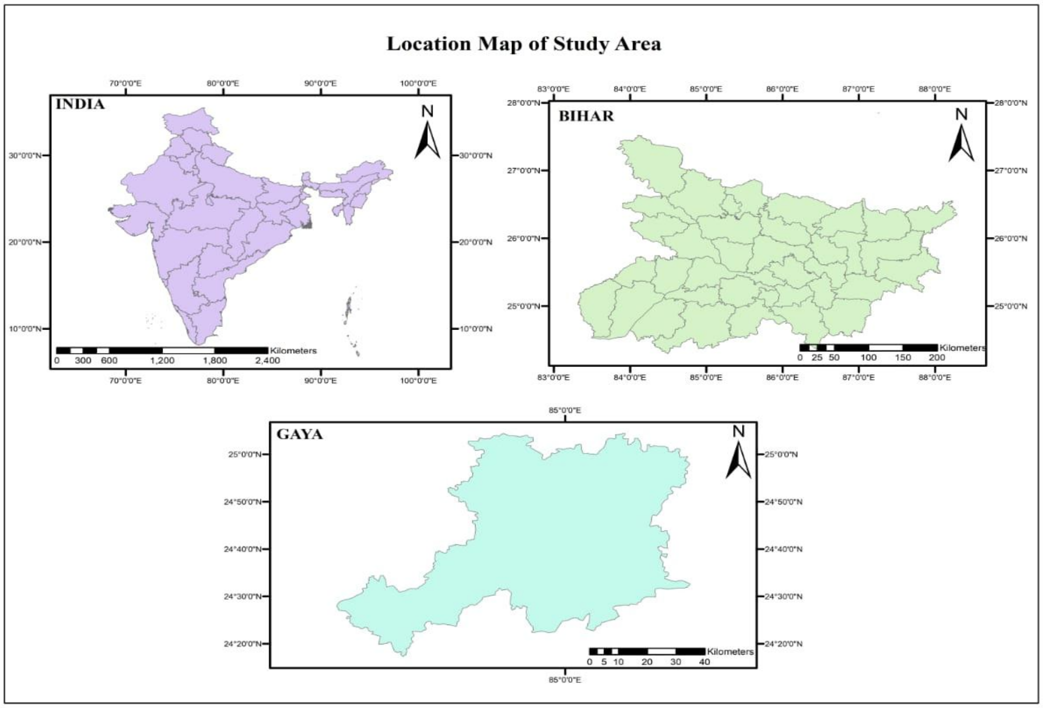

Fig1:Location Map of Study Area

Potential Evapotranspiration

Priestley-Taylor Method, Jensen-Haise Method, Turc Method, Hargreaves-Samani Method, and Hargreaves Method are five straightforward approaches that were chosen to estimate PET of the research region in order to compare their performance. These methods are compared with Penman-Monteith Method.These methods can be divided into two broad groups viz., radiation-based methods (Priestley-Taylor Method, Priestley-Taylor Method, Turc Method) and temperature-based methods (Hargreaves-Samani Method, Hargreaves Method. The PET techniques were selected by considering the availability of meteorological data required by those models. Performance of the PET techniques was measured by comparing them.

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%

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

When RH > 50%

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

Where, Tm is mean of temperature (°C),Rs is the solar radiation of the crop surface (MJm^{-2} day^{-1}), and RH is the relative humidity (%).

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:

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

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

Hargreaves method

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

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

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

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:

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

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

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 estimate potential evapotranspiration based on radiation (Jensen et al., 1990). The model requires daily mean temperature (°C) and global radiation data (mm day^{-1}) as input to calculate the potential evapotranspiration (mm day^{-1}) expressed by

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

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

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:

$$\mathbf{ET_o = 0.408 \frac{(Rn-G)+\gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma(1+0.34u2)}} \quad (7)$$

Where, ET_o is the reference evapotranspiration (mm day^{-1}),Δ is the slope vapor curve (kPa °C^{-1}),R_n is the net radiation of the crop surface (MJm^{-2} day^{-1}),G is the soil heat flux density (MJm^{-2} day^{-1}),T is the air temperature at 2m height (°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 psychometric constant (kPa °C^{-1}).

Resultsand Discussion

Comparison of PET methods

The Pearson correlation coefficients were calculated among the five methods and the values ranged from 0.84 to 0.99. These correlation coefficients compared radiation and temperature based method with Penman-Monteith method. Under the radiation based method, theTurc method has correlate with the Penman-Monteith and correlation coefficients value is (R=0.94), while the Penman-Monteith is correlate withthe Jensen-Haise method and correlation coefficients value is(R=0.85). Under the temperature based method, the correlation coefficients, between the Penman-Monteith and Hargreaves-Samani method had (R=0.99), while the Hargreaves method (R=0.95) are shown in Table.1. Multivariate statistical tests indicated that each radiation and temperature based method of PET 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 PET while the Hargreaves-Samani method predicted the highest values are shown in Figure 2. ThePET estimated by the Hargreaves- Samani method was evenslightly lower than Penmen-Monteith method as discussedin the next paragraph. Across the 36sites, greater differences were found among the temperaturebased PET methods and radiation basedPET methods represent in Figures 2, 3, and 4. The PET 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 PET 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 Hargreves method showed almost equal PET for all months. The Hargreves-Samani method, Hargreves method and Jensen- Haisemethod (November, December, February and March) showed similar pattern like the Penman- Monteith method. The PET estimated by Hargreves-SamaniMethod was slightly higher (3.4 mm/day in November and 7.0 mm/day in April) than Penmen-Monteith method.

Table 1: Pearson Correlation Coefficients Among Six PET Methods (n = 36).

PET Method	**Penman-Monteith Method**	**Hargreves-Samani Method**	**Hargreves Method**	**Jensen-Haise Method**	**Priestly-Taylor method**	**Turc Method**
Penman- Monteith Method	---	0.990	0.954	0.852	0.919	0.944
Hargreves-Samani Method	0.99	---	0.963	0.835	0.932	0.911
Hargreves 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	---

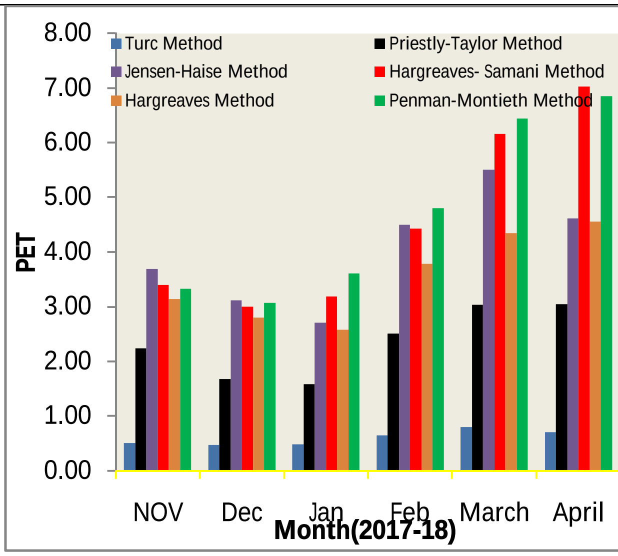

Fig 2: A comparison of six potential evapotranspiration methods for regional use in the Gaya ,Bihar

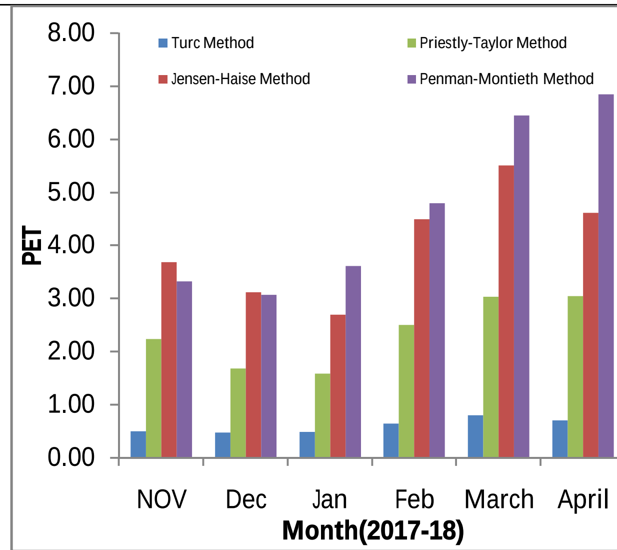

Fig3: Comparison of Penmen-Monteith PET Simulated by the Three Radiation Based Methods

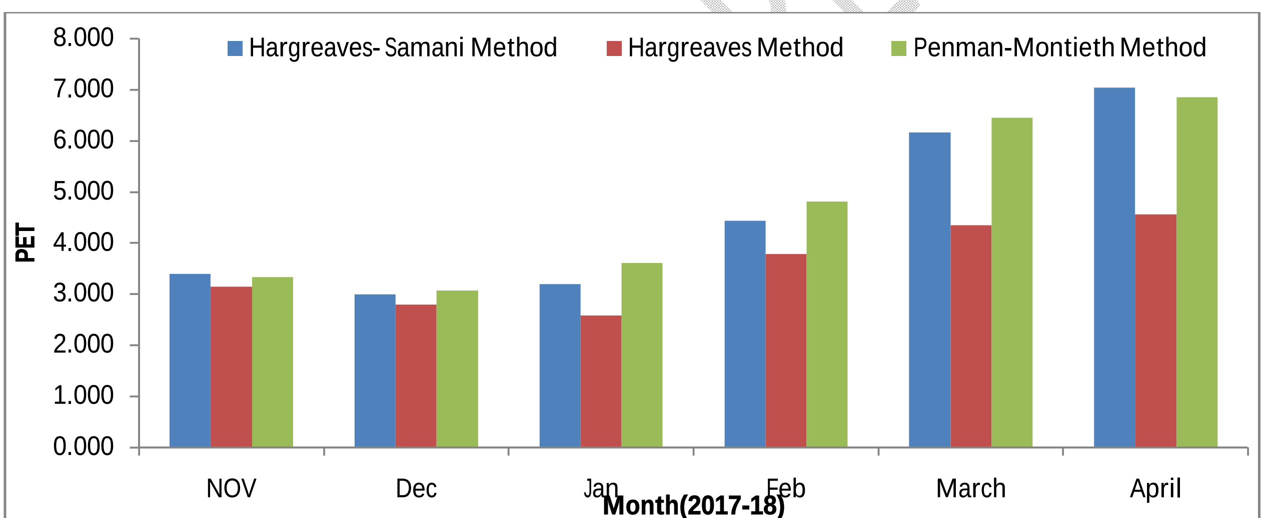

Fig 4: Comparison of Penmen-Monteith PET Simulated by the Two Temperature Based Methods

Table 2: Average PET of Rabi Season Among different Methods.

Average PET of Rabi Season (2017-18)					
Penman-Montieth 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

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 PET 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.

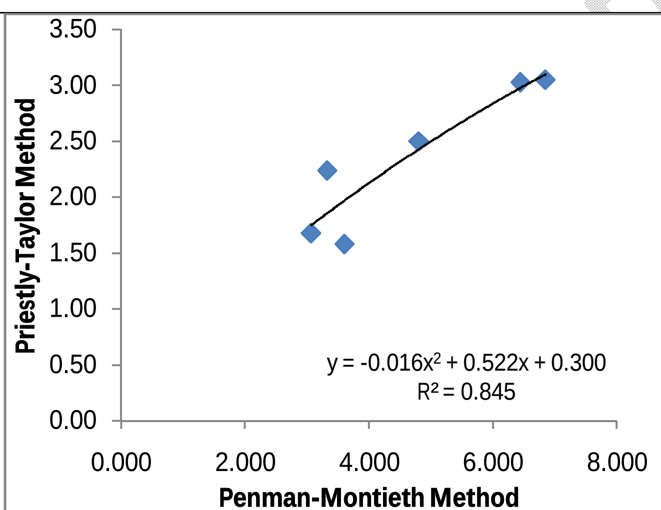

Fig 5: Relationship between Penman-Montieth & Priestly-Taylor Method

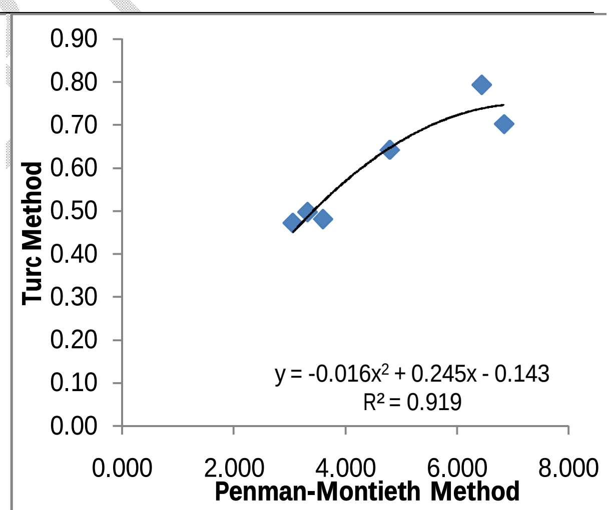

Fig 6: Relationship between Penman-Montieth &Turc Method

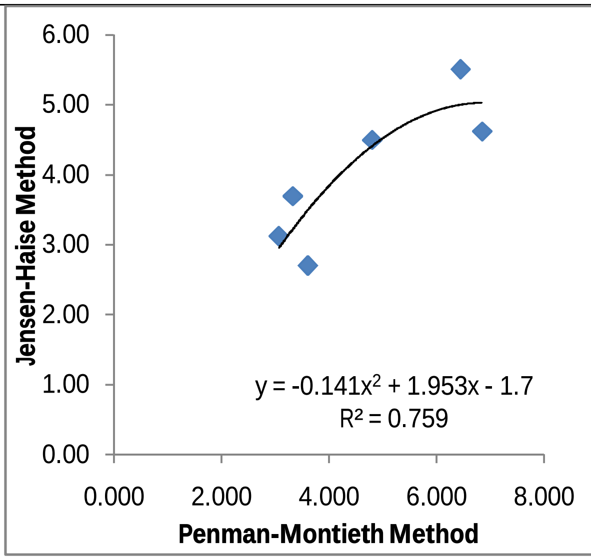

Fig 7: Relationship between Penman-Montieth &Jensen-Haise Method

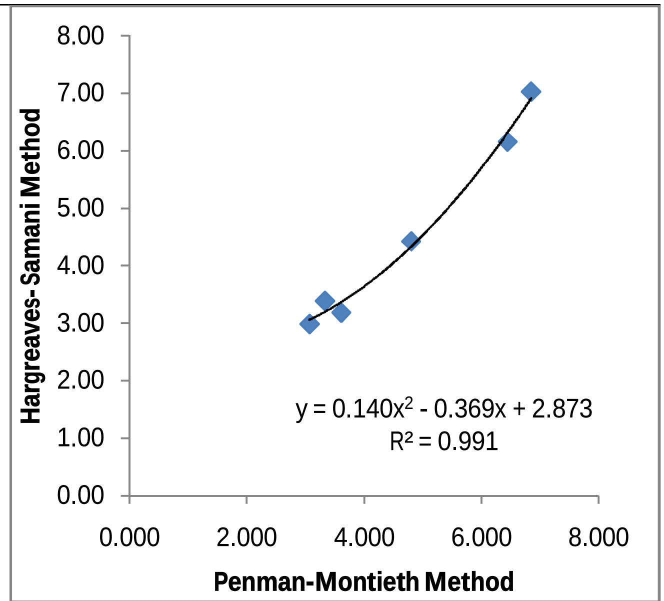

Fig 8: Relationship between Penman-Montieth &Hargreaves-Samani Method

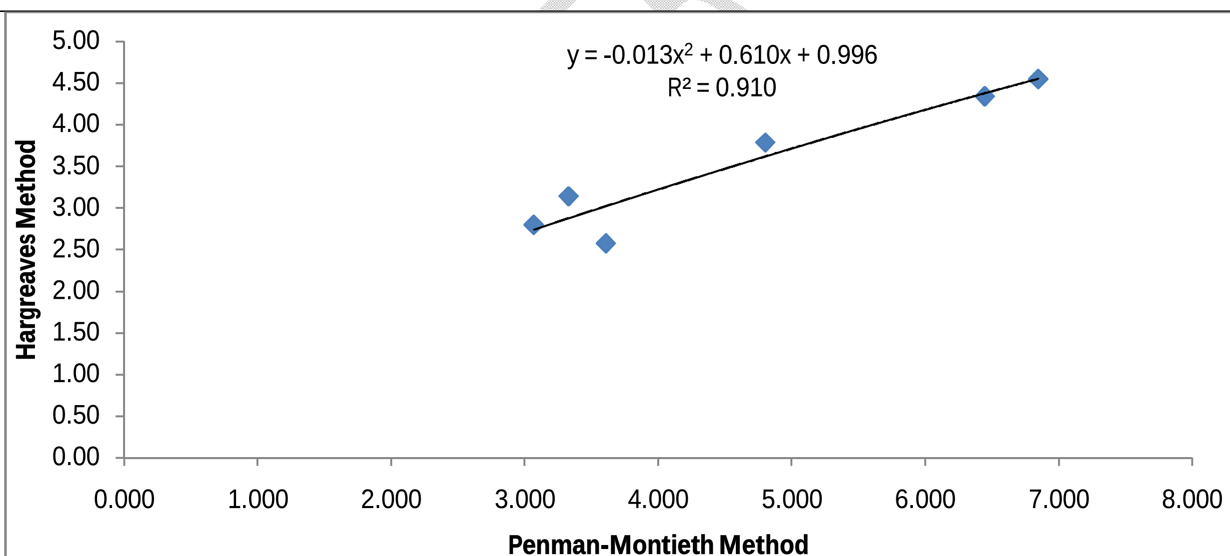

Fig 9: Relationship between Penman-Montieth &Hargreaves Method

Discussion and Conclusion

This study suggested that PET is difficult to estimate accurately and should be used with caution for estimating actual water loss from natural systems. The commonly used PET methods for this comparison study gave a wide range of values, showing differences in PET 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 PET especially in the context of climate change is therefore very important. The study showed that different five method of PET in the region ranges from 0.60mm/day to 4.53mm/day(Nov 2017 to April 2018)for wheat crop. Among the five PET 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 PET pattern with reasonable errors, it can be concluded that the temperature based methods are suitable for estimating PET in the study area. Among the temperature-based method, Hargreves-Samani method was found to perform best followed by the other method. Hargreves-Samani method showed the highest correlation among all the methods and less errors among the temperature based methods used in the present study. During fitting polynomial regression line with the Penman-Monteith estimates, Hargreves-Samani method also showed the highest correlation followed by other four methods. Capability of Hargreves and Jensen-Haise methods in estimating PET is more or less similar. Therefore, Turc method can be used more easily compared to Priestley-Taylor method in estimating PET in the study area.

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