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**Research Article**

# Comparative Assessment of Empirically Estimated Reference Evapotranspiration with CROPWAT 8.0 Outcome in Indian Punjab

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## ABSTRACT

As opposed to rapid climate variability affecting agriculture and farm operations, location specific implementation of crop simulation model becomes a necessary mitigation option to forewarn a decision well in advance. To address this issue, present study was framed to decide upon the reliability of popular irrigation simulation model namely CROPWAT (v.8.0) outcome along with suitability of different empirical methods in reference evapotranspiration computation at two different districts (viz. Ludhiana & Gurdaspur) of semi-arid environment of Indian Punjab .Correlation study reported FAO-24 Pan method as the superior one in Ludhiana while Jensen-Haise method seemed to be the optimal in reference ET estimation in Gurdaspur. Total mean monthly ETo recorded to be highest in April month followed by October and lowest was observed in January for both districts regardless of the empirical approaches. The agreement between model output and empirically deduced results reported FAO 24 Pan method and Jensen Haise method much in accordance with model outcome for both the districts. However, Papadakis method, Hamon and Blaney-Criddle method performed more or less poorly (overestimation) irrespective of different agro-climatic regions of Punjab. The foresaid findings were also supported by the standard error of estimate data. Thus, it can be inferred from the result of different statistical indicators, that apart from sole standard method of FAO Penman-Monteith, FAO-24 Pan method and Jensen-Haise method may be recommended for reference ET estimation particularly under data scarce conditions to bring more climate resiliency.

**Key words:** Crop simulation model, Mitigation, CROPWAT 8.0, Reference evapotranspiration, Climate resiliency

## Introduction

Climate change signals have been receiving by the whole world and the state of Punjab is also not an exception to it. Kaur *et al*. (2011) reported that more than 80 per cent of the state area will fall under critical water level of >10 m depth by 2020. At the outset of such crisis scenario, proper management of water resources in field crop is of utmost importance to increase crop productivity. Evapotranspiration (ET) is considered to be an indispensable parameter in hydrologic studies, such as irrigation scheduling and management, crop water demand, and environmental impact assessment (Tamesgen *et al.*, 2005). Different empirical methods for

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reference ET estimation developed over last few decades mainly classified under four heads (Jensen, 1990) viz. Temperature based (Hargreaves, Thornthwaite etc.), Pan methods (FAO 24 Pan, Christiansen Pan), Radiation based (Jensen and Haise, Turc etc.) and Energy balance or Combination methods (FAO Penman-Monteith, FAO-24 corrected Penman etc.). Amongst them, Penman-Monteith (PM) method released by the Food and Agriculture Organization (FAO) is most internationally used (Sentelhas *et al.*, 2010). Various researchers have also computed evapotranspiration by different empirical methods and compared the outcome with Penman-Monteith method to adjudge the reliability of model (Rahman *et al.*, 2008; Kingra and Mahey, 2009). Simulation results also showed the effect of rising temperature on evapotranspiration demand which is also moderated by availability of water resources (Islam *et al.,* 2015). However, lack of several meteorological data in spatial and temporal scale hindered the direct implication of FAO Penman Monteith method. Thus, several water balance model has been developed by international organisations using FAO PM method as administrator for calculation of location specific PET of crops using available meteorological data.

One such windows based decision support system namely CROPWAT using FAO Penman-Monteith method require simple climatic data (temperature, humidity, wind etc.), soil data and crop characteristics of a particular location as inputs to estimate the crop water requirement through measurement of reference evapotranspiration. Islam *et al*. (2015) Simulation results also showed the effect of rising temperature on evapotranspiration demand is moderated by availability of water resources. Hence, in the present study, an attempt has been made to compare the ETo derived from CROPWAT (version: 8.0) with that of different empirical methods at two selected districts of Punjab i.e. Ludhiana and Gurdaspur; to check the multi-locational reliability of the model output vis-à-vis suitability of empirical methods in estimation of Crop ETc.

## Materials and Methods

### *Experimental site*

The present research work was carried out at two selected locations of Punjab *viz.* Ludhiana, representing mainly the central core alluvial plain region (30°55′ N, 75°54′ E and 247 above mean sea level) and Gurdaspur, representing mainly hilly undulating tracts and flood plains in some places (31°94′ N, 75°25′ E and 241 m above mean sea level) agro-climatic zone of Punjab. The average annual rainfall is 733 mm for Ludhiana whereas for Gurdaspur, it is 875.4 mm; and 75-80 percent of this rainfall occurs during south-west monsoon period.

### *Estimation of ETo*

Detailed calculation procedures for computing reference ETo using CROPWAT 8.0 were archived in two FAO publications of the Irrigation and Drainage series, namely, NO. 33 "Yield response to water" (Doorenboss and Kassam, 1979) and No. 56 "Crop Evapotranspiration-Guidelines for computing crop water requirements". Daily data on weather elements (from Oct. 1, 2016 to April 30, 2017) were collected from Agrometeorological Observatory of Punjab Agricultural University, Ludhiana and Regional Research Station, Gurdaspur, Punjab (Fig.1 A & B) to estimate reference evapotranspiration using different empirical methods such as

1. Pan method (ETo = Kp*Epan),
2. Blaney Criddle method ($ET_o = p(0.457T_{mean} + 8.128)$,
3. Papadakis method (ETo = $0.5625(e_d Tmax - e_d)$),
4. Jensen and Haise method (PET = Rs (0.025 * T + 0.08),
5. Modified Jensen and Haise method (PET= 0.012(T-15.4)Rs),
6. Hamon method ($PET_{Ham} = 0.0055(DL/12)^2$ (AH X 2.88) 25.4),
7. Modified Hargreaves and Samani method (ETo = $0.0023(Tmax - Tmin)^b$ (Tmax+Tmin/ 2 + 17.8)Ra

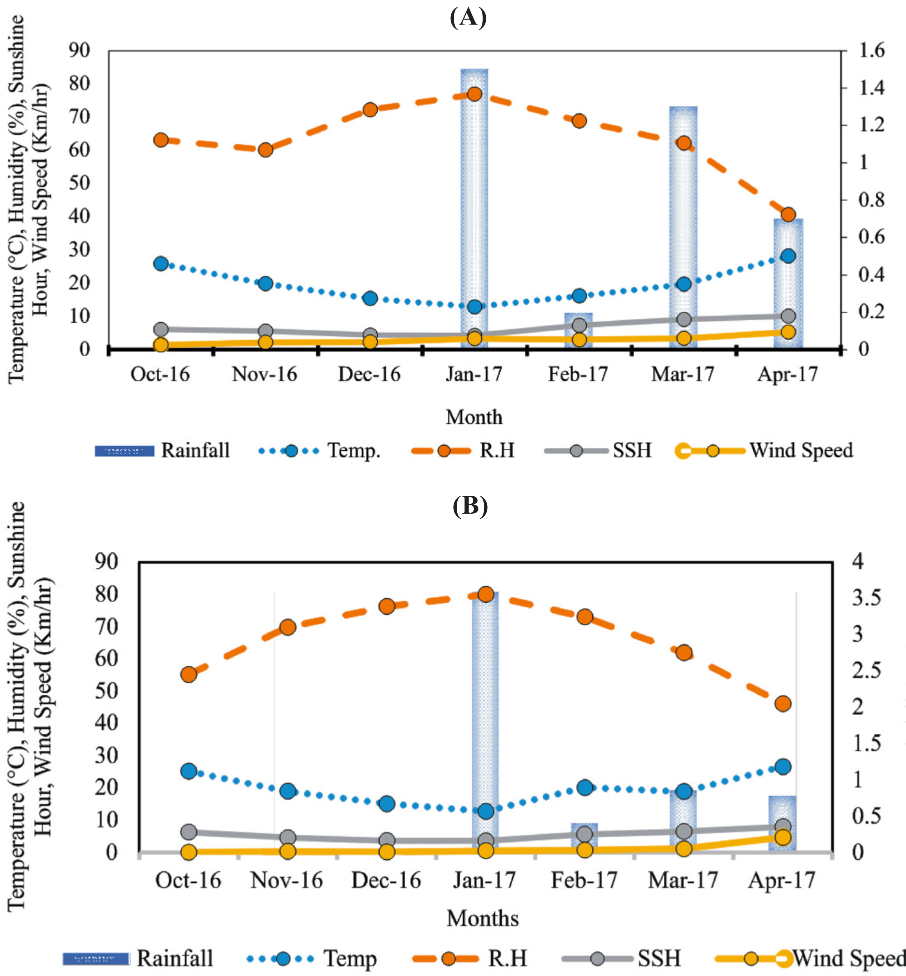


**Fig. 1.** Meteorological conditions prevailing during *rabi* season of 2016-17 at Ludhiana (A) and Gurdaspur (B) districts of Punjab

8. FAO Penman-Monteith method: ETo = $\frac{0.408\Delta(Rn-G)+\gamma\left(\frac{900}{T+273}\right)u_2(es-ea)}{\Delta+\gamma(1+0.34u_2)}$, Where, Standard alphabets are used to indicate different parameters as mentioned in FAO (Allen *et al.*, 1998). Besides, Regression analysis were performed to find out the association and standard error of estimates between different methods and software computed ETo.

### *Model Performance measures*

Performance of CROPWAT 8.0 in estimation of reference ETo in both Ludhiana and Gurdaspur districts was evaluated using statistical indicators also namely, mean bias error (MBE), mean Absolute Error (MAE), Root mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and finally with Nash-Sutcliffe Efficiency (NSE). These parameters are most commonly used to compare the model output value with the observed value (Banerjee *et al.*, 2016).

## Results and Discussion

### *Variability in model performance at two districts*

#### *Ludhiana*

In case of Ludhiana region, among different employed empirical approaches, Pan evaporation method, Jensen and Haise method, and Blaney-

Criddle method underestimate the CROPWAT 8.0 determined mean reference evapo-transpiration for the crop (Table 1). Meanwhile, average seasonal reference ETo were overestimated by Papadakis, modified Jensen and Haise, Hamon and finally the Modified Hargreaves and Samani method. Considering the Standard error of estimates and Correlation coefficient values obtained between different methods and CROPWAT 8.0 computed ETo data, it can be suggested that the pan evaporation and modified Jensen and Haise method estimated ETo will be much in continuity or on line followed by Jensen and Haise method and Modified Hargreaves and Samani method with that of the CROPWAT 8.0 determined results which used the FAO Penman-Monteith equation for calculation. This was mainly due to highest correlation coefficient values and lowest standard error of estimate recorded by the above said methods as compared to FAO PM method. However, contrary to this finding, Mohan (1991) has recommended the FAO-24 radiation method in per-humid climates, the Hargreaves and Samani temperature-based method in humid climates, and the FAO-24 Blaney–Criddle temperature-based method in subhumid and semiarid climates of Tamil Nadu, India. Kingra *et al.* (2004) estimated PET by various methods for Ludhiana and concluded that pan evaporation correlated well with Papadakis method ($R^2$=0.84) followed by Jensen and Haise and Modified Jensen and Haise ($R^2$=0.79) and least for Thornthwaite method ($R^2$=0.65).

*Gurdaspur*

For Gurdaspur region, the results showed that the potential evapo-transpiration during *rabi* season was relatively on higher side in case of all empirical methods as compared to software derived ETo data (Table 1). The trend of reference ETo remained similar with that of Ludhiana region as winter prevailed in North India mainly during December-January. However, the total estimated reference ETo regardless of the empirical and model approach was quite higher in case of Ludhiana district than Gurdaspur both in terms of lowest and highest value. For Gurdaspur region, pan evaporation and hamon

**Table 1.** Monthly mean of daily ETo values (mm/day) determined using seven empirical methods vis-à-vis CROPWAT 8.0 and Statistical analysis performed between the methods at Ludhiana (Ldh.) and Gurdaspur (Gsp.) district of Punjab

| Month | Epan | | Blaney-Criddle method | | Papadakis method | | Jensen and Haise method | | Modified Jensen and haise | | Hamon method | | Modified Hargreaves and Samani method | | CROPWAT 8.0 derived ETo | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ldh. | Gsp. | Ldh. | Gsp. | Ldh. | Gsp. | Ldh | Gsp. | Ldh. | Gsp. | Ldh | Gsp | Ldh | Gsp | Ldh. | Gsp. |
| October-2016 | 3.5 | 3.1 | 4.58 | 4.43 | 5.41 | 2.72 | 2.37 | 4.10 | 4.37 | 4.26 | 5.73 | 5.97 | 4.26 | 4.07 | 2.72 | 2.37 |
| November-2016 | 2.5 | 2.9 | 2.99 | 2.83 | 4.65 | 1.95 | 1.38 | 2.30 | 2.88 | 2.51 | 3.26 | 3.61 | 3.27 | 2.92 | 1.95 | 1.38 |
| December-2016 | 1.2 | 2.7 | 2.12 | 2.09 | 3.09 | 1.33 | 0.98 | 1.53 | 1.97 | 1.74 | 2.76 | 2.88 | 2.31 | 2.14 | 1.33 | 0.98 |
| January-2017 | 1.3 | 1.9 | 1.80 | 1.78 | 2.17 | 1.36 | 1.01 | 1.42 | 1.87 | 1.68 | 2.63 | 2.74 | 1.99 | 1.81 | 1.36 | 1.01 |
| February-2017 | 2.3 | 2.2 | 2.46 | 2.42 | 3.63 | 2.33 | 1.67 | 2.50 | 3.34 | 2.83 | 3.28 | 3.41 | 3.08 | 2.79 | 2.33 | 1.67 |
| March-2017 | 4.0 | 3.4 | 3.40 | 3.24 | 4.29 | 3.58 | 2.66 | 3.75 | 5.15 | 4.08 | 4.3 | 4.13 | 4.25 | 4.09 | 3.58 | 2.66 |
| April-2017 | 7.6 | 4.7 | 6.04 | 5.38 | 7.84 | 5.9 | 5.15 | 6.35 | 7.84 | 6.54 | 5.33 | 5.38 | 6.63 | 6.36 | 5.9 | 5.15 |
| SEE | 0.23 | 0.61 | 0.76 | 0.67 | 0.78 | 0.64 | 0.46 | 0.33 | 0.21 | 0.32 | 1.16 | 1.08 | 0.38 | 0.30 | | |
| Correlationcoefficient | 0.99 | 0.92 | 0.90 | 0.91 | 0.90 | 0.92 | 0.97 | 0.98 | 0.99 | 0.98 | 0.75 | 0.74 | 0.97 | 0.98 | | |

method data indicated a slight underestimation of reference ETo than the FAO Penman-Monteith data (model derived) towards *rabi* crop harvesting period (March-April). Jensen-Haise, Modified Jensen-Haise and Hargreaves-Samani method gave highest correlation coefficient (0.98) with FAO Penman Monteith ETo followed by Pan Evaporation, Papadakis and Blaney-criddle method. Amongst different approaches, Hamon method showed highest standard error of estimates (1.08) with minimum correlation coefficient (0.74). Thus, Hamon method was found most distant to CROPWAT 8.0 estimated reference ETo. Both Blaney-Criddle and Papadakis method also performed poor in Gurdaspur as they recorded standard error significantly on higher side. On the other hand, Jensen-haise, modified Jensen-Haise and Hargreaves-Samani method recorded higher correlation coefficient followed by Pan evaporation method in concordance with CROPWAT 8.0 derived ETo. Therefore, they are in close proximity with the FAO Penman Monteith method obtained reference ETo data thus, suits well in PET determination of *rabi* crops for Gurdaspur district. Hari *et al*. (2016) estimated ET using four different methods for the Bapatla region in India and reported no significant differences and similar trend between the FAO-56 Penman-Monteith and Blaney-Criddle method. Barman *et al*. (2012) determined the number of life-saving irrigation through simulation which was later used to extrapolate the computed ETc for irrigation planning at regional scale.

### *Statistical evaluation of model performance*

Computation of bias, RMSE, MAPE and NSE value denotes the accuracy of CROPWAT 8.0 determined reference ET with empirically estimated PET. Evaluation of the software outcome at different locations (Ludhiana and Gurdaspur) of Indian Punjab through these statistical tools were presented in Table 2 and Table 3, respectively. Considering the criterion of above said indicators, it was observed that FAO-24 Pan method, Jensen & Haise method, Blaney-Criddle method and Modified Hargreaves

**Table 2.** Statistical test of different empirical approaches with CROPWAT 8.0 estimated ETo through different indicators for Ludhiana region

| DifferentApproaches | MBE | RMSE | MAPE | NSE |
|---|---|---|---|---|
| FAO 24 Pan method | -0.46 | 0.49 | 13.41 | 0.64 |
| Papdakis method | -1.70 | 1.86 | 39.88 | -0.19 |
| Jensen (J) &Haise (H) method | -1.11 | 1.25 | 28.95 | 0.53 |
| Modified J & H method | -1.17 | 1.28 | 30.75 | 0.56 |
| Blaney-Criddle method | -0.60 | 0.88 | 21.42 | 0.60 |
| Hamon method | -1.16 | 1.52 | 35.60 | -0.74 |
| Modified Hargreaves & Samanimethod | -0.94 | 1.00 | 28.81 | 0.52 |

**Table 3.** Statistical test of different empirical approaches with CROPWAT 8.0 estimated ETo through different indicators for Gurdaspur region

| DifferentApproaches | MBE | RMSE | MAPE | NSE |
|---|---|---|---|---|
| FAO 24 Pan method | -0.81 | 1.04 | 34.56 | -0.52 |
| Papadakis method | -1.33 | 2.09 | 50.62 | -0.75 |
| Jensen (J) &Haise (H) method | -0.96 | 1.04 | 35.59 | 0.58 |
| Modified J & H method | -1.20 | 1.26 | 38.57 | 0.37 |
| Blaney-Criddle method | -0.99 | 1.14 | 35.32 | 0.11 |
| Hamon method | -1.84 | 2.06 | 48.86 | -1.25 |
| Modified Hargreaves & Samanimethod | -1.28 | 1.30 | 40.75 | 0.16 |

and Samani method performed significantly well with CROPWAT 8.0 estimated reference ET data in case of Ludhiana region; whereas, Papadakis and Hamon method were simply outperformed with respect to simulation model. Thus, FAO-24 Pan method and Jensen & Haise method were fitted aptly with the model outcomes for Ludhiana. On the other Hand, for Gurdaspur region, all the statistical tools supported Jensen & Haise, Modified Jensen and Haise, Modified Hargreaves and Samani and finally Blaney-Criddle method (some extent) on line with model estimated data in estimation of crop evapotranspiration in Gurdaspur region. Here, FAO-24 Pan, Papadakis method and Hamon method tremendously underestimate the software derive ET data. Hence, these two methods should be discarded in ET determination for Gurdaspur district. Therefore, Jensen-Haise, Modified Hargreaves and Samani method provided better results compared to other empirical approaches and should be followed in ET estimation of *rabi* crops in Gurdaspur district.

## Conclusions

Observing the standard error of estimates and correlation coefficient values, it was found that Pan evaporation method and Jensen and Haise method supported the model output in case of Ludhiana district whereas, Jensen-haise, modified Jensen-Haise and Hargreaves-Samani method fitted well with the software estimated reference ET in Gurdaspur region. Furthermore, FAO-24 Pan evaporation method and Jensen Haise method were backed up by different statistical indicators in terms of accuracy. Combining the results of different statistical tools, it was also found that Hamon method, Papadakis method and Blaney-Criddle method performed more or less poorly irrespective of the locations.

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