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Short Communication

Evaluation of pan-coefficient estimation methods for reference evapotranspiration (ETo) under humid environment of UBV zone of Assam

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Under the future climatic scenarios as depicted by the Inter Governmental Panel on Climate Change (IPCC, 2018), the evaporation demand is projected to increase globally and in response to this, the water demand of the crops is very likely to accelerate due to the possible increase in the vapour pressure deficit resulting out of increase in the temperature. The Actual Evapotranspiration of both rice and wheat has already shown increasing trends in some of the sub-humid regions of the India (Kingra *et al.,* 2019). Owing to the present circumstances of ever depleting fresh water there is need to optimize the use of the available water resources by minimizing the conveyance losses occurred during irrigation given to meet evapotranspiration (ET) demand of the crops. Reference Crop Evapotranspiration (ET_o) is an essential component for use in water supply planning & irrigation scheduling (Snyder, 1992), since crop evapotranspiration (ET_c) is an estimated product of ET_o and Crop-Coefficient (K_c) and this method is also very important due its ease of adjustment and application. In recent years, the FAO 56 Penman-Monteith equation is the most widely accepted and authenticated methodology in agricultural studies. However, besides the need of good computational skill, one of the major setbacks of this method is that, it accounts for the use of many climatic parameters, some of which are scarce or are not reliable in developing countries. ET_o estimated by pan evaporation method using K_p, with proper regional calibration and validation, is a simple method and does not account major weather parameters which affect the value of ET_o. Researchers like Rao *et al.* (2013) and Pradhan *et al.* (2013) had studied on estimation of ET_o in relation to Epan in different parts of India, however, such type of work is scanty in Assam and therefore, keeping this in view, the present study was conducted to evaluate the best K_p estimation method among different empirical methods under the climatic condition of Upper Brahmaputra Valley (UBV) Zone of Assam.

Based on availability of quality long term daily meteorological data (from 1997 to 2019), Jorhat district (Lat: 26º47´N; Long: 94º12´E and Alt: 87 m) of Assam was selected for the study as a representative of the UBV zone. The Class-A Open Pan Evaporimeter (USWB) used in the study was situated on a short green grass cover. The value of upwind fetch distance (F) used for the computation of K_p was 10 m. Based on the strong correlation between E_{pan} and ET_o, the following functional relationship between ET_o, E_{pan} and K_p was used in the study;

$$ET_o = E_{pan} \times K_p \qquad \text{…………(Eq. 1)}$$

The K_p values were found out daily using five approaches *viz*., Snyder (1992), Cuenca (1989), Orang (1998), Allen and Pruit (1991) and Pereira et al. (1995) and then averaged for monthly values. To check the accuracy and reliability, the K_p values obtained were compared with that of K_p_PM which was obtained from the ratio of reference crop evapotranspiration estimated by FAO 56 PM method (ET_o _PM) to E_{pan}. The accuracy of the different K_p estimated by empirical methods were performed by the statistical approaches viz., Root mean square error (RMSE), Mean Absolute Deviation (MAD), Per cent Error (PE) and Index of Agreement (d). In order to estimate ET_o from K_p calculated using the aforementioned empirical methods and E_{pan}, the Eq. 1 was used. Depending on the performance measures, a best pan coefficient estimation method out of the five empirical methods, for estimating ET_o in the region was found out and daily ET_o (best) values were computed. In order to trim down the difference in the values of ET_o calculated using FAO 56 PM method and ET_o (best), linear regression techniques were used to develop the coefficients and was represented in the form of an equation.

The daily mean pan evaporation (E_{pan}) and mean evapotranspiration estimated using Penman-Monteith (ET_o_PM)

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Table 1: Monthly observed K_p (K_{p}_PM) and K_p values of different empirical methods

Month	K_p_PM (ET_o/E_{pan})	K_p_Snyder	K_p_Cuenca	K_p_Orang	K_p_Allen & Pruit	K_p_Pereira
January	1.38	0.97	0.81	0.86	0.84	0.81
February	1.30	0.95	0.78	0.85	0.83	0.80
March	1.17	0.94	0.76	0.85	0.83	0.79
April	1.19	0.95	0.75	0.85	0.83	0.79
May	1.24	0.94	0.76	0.85	0.83	0.79
June	1.25	0.95	0.76	0.85	0.83	0.80
July	1.26	0.95	0.76	0.85	0.83	0.80
August	1.33	0.95	0.77	0.85	0.83	0.81
September	1.28	0.95	0.78	0.85	0.83	0.81
October	1.32	0.95	0.79	0.85	0.83	0.82
November	1.29	0.96	0.80	0.86	0.84	0.82
December	1.33	0.97	0.81	0.86	0.84	0.82
Annual	1.28	0.96	0.78	0.85	0.83	0.81

Table 2: Comparison of K_p_PM with K_p_Syder, K_p_Cuenca, K_p_Orang, K_p_Allen and Pruit and K_p_Pereira using statistical measures

Method	**RMSE**	**d**	**MAD**	**PE**
K_p_Snyder	0.34	0.30	0.32	24.73
K_p_Cuenca	0.51	0.23	0.50	38.56
K_p_Orang	0.43	0.26	0.42	32.52
K_p_Allen and Pruit	0.45	0.25	0.44	34.18
K_p_Pereira	0.48	0.25	0.47	36.28

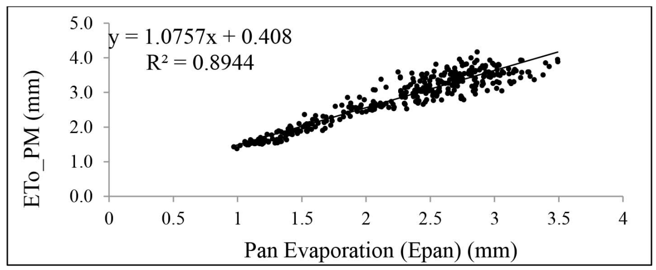

Fig. 1: Comparison of daily ET_o_PM method with E_{pan}

Table 3: Monthly observed ET_o (mm) estimated using PM method and estimated from K_p values obtained from different empirical methods

Month	ET_o_PM	ET_o_Snyder	ET_o_Cuenca	ET_o_Orang	ET_o_Allen & Pruit	ET_o_Pereira
January	48.48	34.11	28.31	30.46	29.58	28.74
February	67.48	49.48	40.76	44.38	43.32	41.80
March	86.03	69.80	56.64	62.78	61.47	58.74
April	96.95	77.27	61.60	69.40	67.84	64.27
May	108.90	83.39	67.17	74.92	73.27	70.43
June	104.24	79.79	64.31	71.64	70.00	67.62
July	106.51	82.34	65.63	73.86	72.10	69.22
August	106.65	76.56	61.92	68.66	67.00	64.97
September	95.12	71.31	58.54	63.94	62.39	61.07
October	82.94	60.17	50.05	53.93	52.59	51.83
November	63.36	47.29	39.41	42.29	41.14	40.40
December	48.59	35.86	29.91	32.00	31.05	30.41
Annual	**84.60**	**63.95**	**52.02**	**57.36**	**55.98**	**54.12**

method quantifies a strong relation between the two variables with high coefficient of determination ($R^2 = 0.89$) which suggests that with a suitable pan coefficient (K_p), E_{pan} can be used successfully for the estimation of ET_o. (Fig. 1)

Estimation of K_p

The mean K_p values on annual basis for Penman Monteith, Snyder, Cuenca, Orang, Allen & Pruit, and Pereira methods were found as 1.28, 0.96, 0.78, 0.85, 0.83 and 0.81 respectively (Table 1). The value of K_p for Snyder method (0.96) was closer to the value of PM method (1.28). Irmark *et al.* (2002) also obtained average K_p values of 0.93 by the Snyder equation at humid region of Florida, USA. It was seen that variation of mean monthly observed pan coefficient value (K_p_PM) was greater than 1 on all months. It may be due to the fact that ET_o (1.62 and 3.63 mm day^{-1} in January and May respectively) is overestimated E_{pan} (1 mm in January and 2.9 mm in May months) in this region. Similar conclusion was drawn by Gogoi Khanikar and Nath (1997) where they found that E_{pan} did not represent the upper limit of ET_o in this region, during the period

Table 4: Comparison of ET_o_PM with ET_o_Syder, ET_o_Cuenca, ET_o_Orang, ET_o_Allen and Pruit and ET_o_Pereira using statistical measures

Method	RMSE	d	MAD	PE
ET_o Snyder	0.71	0.33	0.69	24.72
ET_o_Cuenca	1.10	0.23	1.09	38.55
ET_o_Orang	0.93	0.27	0.91	32.51
ET_o_Allen & Pruit	0.97	0.26	0.95	34.17
ET_o_Pereira	1.03	0.26	1.02	36.27
ET_o Snyder (Pooled data 2017-19)	0.67	0.56	0.57	19.70
ET_o* (Pooled data 2017-19)	0.49	0.65	0.39	14.98

of 1985-94. Similar conclusions were drawn by Narda *et. al* (1992) for Punjab**.** Stan and Neculau (2015) in their study on relation of ET_o and E_{pan} in different locations of Romania found that ET_o (by PM method) was greater than E_{pan} during spring, as such K_p values were found between 1.14 to 1.47 in that season in those locations. In our study region since, relative humidity is high (Mean RH 77% in winter and 83% in monsoon), it may cause lower evaporation as evaporation is inversely proportional to RH. On the other hand in this region wind is lighter (1.0 km/hr in December and 2.9 km/hr in July), hence it does not contribute much to the rate of evaporation.

The statistical evaluation techniques used to compare the mean K_p values calculated using empirical methods with the observed values calculated using the FAO PM method (*i.e.,* K_p_PM) over a period of 20 years revealed poor insignificant relations with low Index of Agreement (< 0.50) on annual basis (Table 2). The RMSE was found to be lowest in case of K_p_Snyder as compared to the other empirical methods. Similarly, among the five methods the annual MAD and PE values were found to be lowest (0.32 and 24.73 respectively) for K_p_Snyder when associated with K_p_PM.

Estimation of ET_o

The mean monthly ET_o values on annual basis for Penman Monteith and ET_o estimated from the K_p values obtained from empirical methods viz., Snyder, Cuenca, Orang, Allen & Pruit, and Pereira using Eq. 1 were found as 84.60, 63.95, 52.02, 57.36, 55.98 and 54.12 mm month^{-1} respectively (Table 3).

The daily mean ET_o for the whole year was also estimated and statistical evaluation techniques were used to compare the performance of the aforementioned methods. It was revealed that, ET_o_Snyder had a superior association (Table 4) with ET_o_PM with lowest annual RMSE (0.71), MAD (0.69) and PE (24.72) and higher index of agreement (0.33) compared to the other empirical methods.

In order to strengthen the association between ET_o_PM and ET_o_Snyder, an equation was developed (Eq. 2) using linear regression technique over 20 years average daily data, with coefficient of determination (R^2) value of 0.93 (Fig. 2).

$ET_o* = 0.38611+1.11930*ET_o\_Snyder$ ……..Eq. 2

Where, ET_o* refers to the estimated reference evapotranspiration

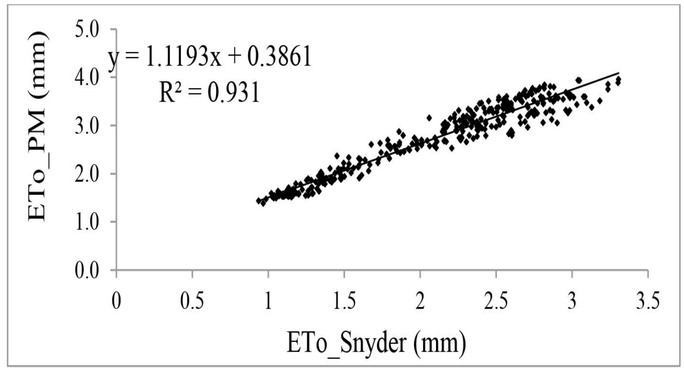

Fig. 2: Comparison of daily ET_o_PM method with ET_o_Snyder

To know the accuracy of the ET_o* over that of the ET_o_Snyder, three years (2017, 2018 and 2019) daily data was used for validation and compared with that of ET_o_PM. The pooled data analysis revealed that, estimation of ET_o can be done comparatively with greater accuracy (Table 4) by using the modified linear regression line (Eq. 2) than the direct values of ET_o_Snyder. It was observed that, RMSE, MAD and PE can be respectively reduced from 0.67, 0.56 and 19.70 to 0.49, 0.39 and 14.98 and the 'd' value increased from 0.56 to 0.65 which consequently narrowed down the errors for better acceptability of estimated results.

Conflict of Interest Statement: The author (s) declares (s) that there is no conflict of interest.

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