Journal of Agrometeorology 15 (2) : 108-114 (December 2013)

Reference crop evapotranspiration over India: A comparison of estimates from open pan with Penman-Monteith method*

B. BAPUJI RAO, V.M. SANDEEP, P. SHANTIBHUSHAN CHOWDARY, V.P. PRAMOD and V.U.M. RAO

Central Research Institute for Dryland Agriculture, Hyderabad - 500 059

E-mail: vmsandeep@gmail.com

ABSTRACT

In the present study the daily reference crop evapotranspiration (ET_0) estimated from open pan evaporation data for 52 widely distributed locations across India are compared with P-M estimated ET_0. The annual and intra-seasonal variability of ET_0 and the inter comparison of these two methodologies has been carried out. Results showed that estimates of ET_0 from open pan were always lower than those of P-M and error range was d" 29% across locations. Calibration coefficients evolved from the present study were found to reduce the errors considerably in ET_o estimates.

Keywords: Reference crop ET, Penman-Monteith, open pan evaporation, calibration coefficients.

Efficient use of water resources in agro-ecosystems of the World has become increasingly important because of rapid depletion of water resources, industrial development and population increase, drought conditions, and degradation of ground and surface water quality in many regions. In many cases, evapotranspiration (ET), which is the sum of transpiration through plant canopy and evaporation from soil, plant, and open water surface, can be the largest component of the hydrologic cycle. Improved techniques are needed for accurate quantification of ET on a field, watershed and regional scale to enhance efficient use of water resources and sustainability of agro-ecosystem productivity and protect the environment and water quality. Accurate quantification of ET is crucial in water allocation, irrigation management, evaluating the effects of changing land use on water yield, environmental assessment, and development of best management practices to protect surface and ground water quantity and quality.

Evaporation demand or potential evaporation is projected to increase almost everywhere in the world in future climate scenarios (IPCC, 2008). This is because the water holding capacity of the atmosphere increases with higher temperatures, but relative humidity is not projected to change markedly. As a result water vapor deficit increases in the atmosphere as does the evaporation rate. Thus, the process of evapotranspiration (ET) is of great importance in present and future climates. The measurement of ET from a crop surface is a very difficult and time consuming task.

In spite of the efforts of numerous scientists, reliable estimates of regional ET are extremely difficult to obtain mainly because of its dependence on soil conditions and plant physiology, so that advances in the knowledge of the underlined interactions and its all round influence have been few and far between. Because of its complexity, the concept of potentialevapotranspiration (PET) has been introduced, which is largely independent of soil and plant factors but has shown dependent on climatic factors. Temporal variations of PET and quantification of its trend can serve as a valuable reference data for the regional studies of hydrological modeling, agricultural water management, irrigation planning and water resource management as demonstrated by Liang *et al.* (2010).

Potential evapotranspiration is defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (Doorenbos and Pruitt, 1977). As the definition suggests that the PET is for a grass reference ET_0. The concept of reference ET is being used to avoid ambiguities associated in the definition of PET (Jensen, 1974 and Perrier, 1982). Reference ET_0 refers to ET from a vegetative surface over

* Paper presented in national seminar on "Climate change and Indian Agriculture : Slicing down the Uncertainty" held at CRIDA, Hyderabad during 22-23 January-2013 and reviewed for special issue of the Journal.

which weather data are recorded and allows to develop a set of crop coefficients to be used to determine ET for other crops. By adopting reference ET_0, it has become easier to select crop coefficients and to make reliable ET estimates in new areas. The use of ET_0 – crop coefficient approach has been largely successful in obviating the need to calibrate a separate ET equation for crop and stage of growth (Jensen *et al.*, 1990). The reference ET_0 estimated by FAO open pan method was validated against the FAO Penman-Montieth method for 52 locations spread across India.

MATERIALS AND METHODS

Weather data utilized in the present study were collected from the Meteorological observatories maintained by 25 All India Coordinated Research Project on Agrometeorology (AICRPAM) and 25 All India Coordinated Research Project on Dryland Agriculture (AICRPDA) centers located across the country. Both the research projects have 12 centers in common, thus making the total number of locations to 37. Data from 15 more observatories maintained by India Meteorological Department (IMD) were also collected and the geographical location of these 52 centers are depicted in Fig. 1. It could be noted from the figure that these locations fairly represent the entire country. The reference crop evapotranspiration (ET_0) has been estimated using two approaches detailed below:

FAO-24 Open pan (1977) method

Fig. 1: Locations selected for present study

$$PET = K_p E_p$$

Where,

K_p = pan coefficient

E_p = measured Open pan evaporation (mm)

Pan coefficient as computed by Allen and Pruitt (1989) for green and dry fetch is adopted in this study which is:

Green Fetch

$$K_p = 0.108 - 0.000331 U_2 + 0.0422 \ln(\text{Fetch}) + 0.1434 \ln(RH_{mean}) - 0.000631 [\ln(\text{Fetch})]^2 [\ln(RH_{mean})]$$

Dry Fetch

$$K_p = 0.61 + 0.00341\, RH_{mean} - 0.00000187\, U_2 RH_{mean}\ 0.000000111\, U_2 (\text{Fetch}) + 0.0000378\, U_2 \ln(\text{Fetch}) - 0.0000332\, U_2 \ln(U_2) - 0.0106 [\ln(U_2)][\ln(\text{Fetch})] + 0.00063 [\ln(\text{Fetch})]^2 [\ln(U_2)]$$

Where U_2 is the wind speed at 2 m.

In the present study, green fetch coefficients were used during *kharif* and *rabi* seasons and dry fetch coefficients during winter and summer periods. A fetch of 10 m during *kharif* and *rabi* periods and 100 m during winter and summer periods were assumed. Once the PET is estimated on a daily basis, average values were derived on annual and for the periods of *kharif* (June-September), *rabi* (October - December), Winter (January -February) and summer (March -May). Inverse distance weighted method is used to prepare the spatial distribution of ET_0 utilizing the data from the 52 locations.

The accuracy of open pan estimated ET_0 ($OPET_0$) in relation to P-M method ($PMET_0$) was determined using statistical tools like root mean square (RMSE), mean bias (MBE), mean percentage (MPE) errors and Index of agreement (D-index) as

$$RMSE = [\Sigma(PMET_0 - OPET_0)^2/n]^{0.5}$$

$$MBE = [\Sigma (PMET_0 - OPET_0)]/n$$

$$MPE = \{\Sigma(PMET_0 - OPET_0)/PMET_0]100\}/n$$

$$\text{D-index} = 1 - \left(\sum_{i=1}^{n} (OPET_0 - PMET_0)^2 \Big/ \sum_{i=1}^{n} (|OPET_0 - PMET_0 avg| + |PMET_0 - PMET_0 avg|)^2 \right)$$

Where, n = number of observations, $PMET_0 = ET_0$ as estimated by Penman-Monteith method, $OPET_0 = ET_0$ as estimated by Open pan. While determining MPE value, the sign of the errors were neglected and the percentage errors were added to calculate the mean.

Calibration / adjustment coefficients

Majority of the Indian locations have only rainfall and air temperature data. This necessitates for the application of temperature based or other simple methods like Open pan in the PET estimation. However, these simple methods do not account major weather parameters which affect the value of PET hence, local calibration is necessary. The FAO also recommended that empirical methods be calibrated or validated for new locations using the standard FAO Penman-Monteith method (Smith *et.al.*, 1991).

Allen *et.al.* (1994) suggested the use of following relation at locations with limited data to marginalized errors as:

$PET_{pm} = b\ PET_e$ or $PET_{pm} = a + b\ PET_e$

Where,

PET_{pm} is Penman Monteith estimated PET

PET_e is PET estimated by temperature or any simple method

The utility of this method in narrowing down the errors in PET estimation by different approaches for a coastal location of Andhra Pradesh was demonstrated in an earlier study by Rambabu and Rao (1999).

In order to improve the predictability of Open pan estimates, calibration/ adjustment coefficients were evolved by linear regression technique with Penman-Monteith estimate as dependent variable. The coefficient "a" values indicate whether Open pan method is underestimating or overestimating and coefficient "b" values (slope values) indicate whether the PET estimate by Open pan is nearer to Penman-Monteith estimates or not. The Open pan adjusted PET values were again subjected to statistical analysis using the approaches indicated above.

RESULTS AND DISCUSSION

Spatial distribution of average ET_0 (mm day^{-1}) on annual basis as estimated by P-M method and Open pan method are presented in Fig. 2 (a) and (b), respectively. It could be seen from the figure that Open pan ($OPET_0$) values are lower than $PMET_0$ for majority of the locations. Highest ET_0 values (6.5 to 8.5 mm day^{-1}) are noticed over Central Rajasthan and lowest (2.5 to 3.5 mm day^{-1}) over Jammu & Kashmir, Himachal Pradesh and Eastern parts of Assam and Arunachal Pradesh. PET estimated by both the methods are in tandem over Uttar Pradesh, Bihar, Jharkhand and Haryana states.

During southwest monsoon season, $OPET_0$ values (2 to 3 mm day^{-1}) are lowest for Northeastern region, West Bengal and eastern parts of Orissa and Bihar (Fig. 3 b). Highest values are noticed once again over Central and Western parts of Rajasthan. Southern parts of Tamil Nadu, Andhra Pradesh and Western parts of Karnataka experiences high ET_0 values (5 to 6 mm day^{-1}). The reason being that these areas receive most of annual rainfall from northeast monsoon. The $PMET_0$ values during the northeast monsoon season were found to be highest (4 to 7 mm day^{-1}) over Central Rajasthan (Fig. 4 a). Compared to southwest monsoon season, ET_0 values estimated by both the methods were lower during northeast monsoon. Among all the seasons, summer season ET_0 values were found to be highest over all regions of the country (Fig. 5). Estimates from $OPET_0$ during summer were lowest (2 to 3 mm day^{-1}) over parts of Northeastern region and highest (7 to 13 mm day^{-1}) over Kutch, Southern parts of Rajasthan, Deccan Plateau covering parts of Andhra Pradesh, Maharashtra and Karnataka (Fig. 5 b). The estimates from $PMET_0$ were highest (7 to 13 mm day^{-1}) over Western parts of Gujarat, Rajasthan and Southern end of Deccan Plateau (Fig. 5 a).

Winter season ET_0 rates were found to be lowest among all the seasons (Fig. 6). $OPET_0$ estimates were lowest (1 to 2 mm day^{-1}) for Northern parts of the country, Indo-Gangetic Plains and parts of Northeastern states (Fig. 6 b). There is a general progressive increase in ET_0 rates estimated by both the methods in the north to south direction. The $PMET_0$ rates were highest (4 to 5 mm day^{-1}) over Southern states of Karnataka, Kerala, Tamil Nadu and Andhra Pradesh.

In general, $OPET_0$ estimates were found to lower than $PMET_0$ irrespective of seasons and regions. The per cent deviation of $OPET_0$ estimates from $PMET_0$ were worked out and the spatial distribution of this are presented in Fig. 7. It could be noted from Fig. 7 that the deviations are minimum over Western Gujarat, North interior Karnataka and South central of Maharashtra. Deviations were at their maximum over Eastern parts of the country, West Bengal, Eastern parts of Bihar and over Thar desert.

Estimates of $OPET_0$ were compared with $PMET_0$ using statistical tools like MBE, MPE, RMSE, Pearson's correlation coefficient and Index of agreement and the resultant comparison presented in Table 1. The negative values of the MBE indicated that $OPET_0$ estimates were lower than $PMET_0$

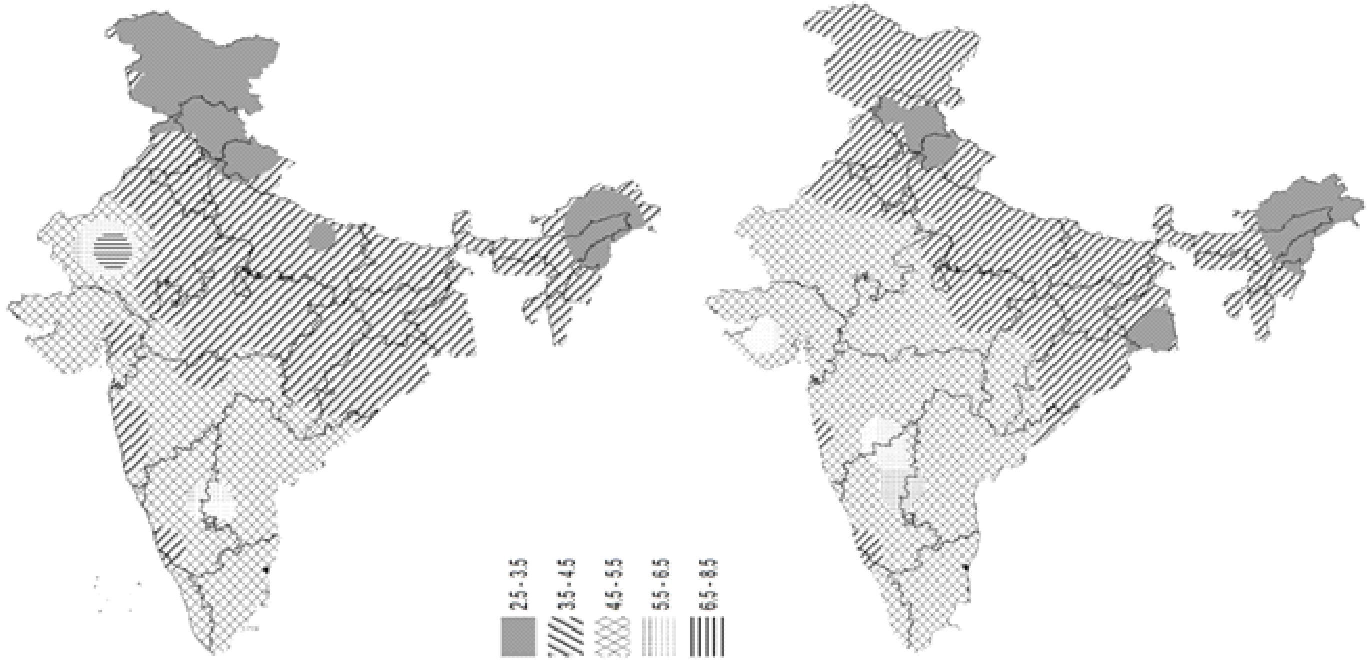

Fig. 2: Annual ETo (mm day^{-1}) as estimated by (a) P-M method and (b) Open pan method

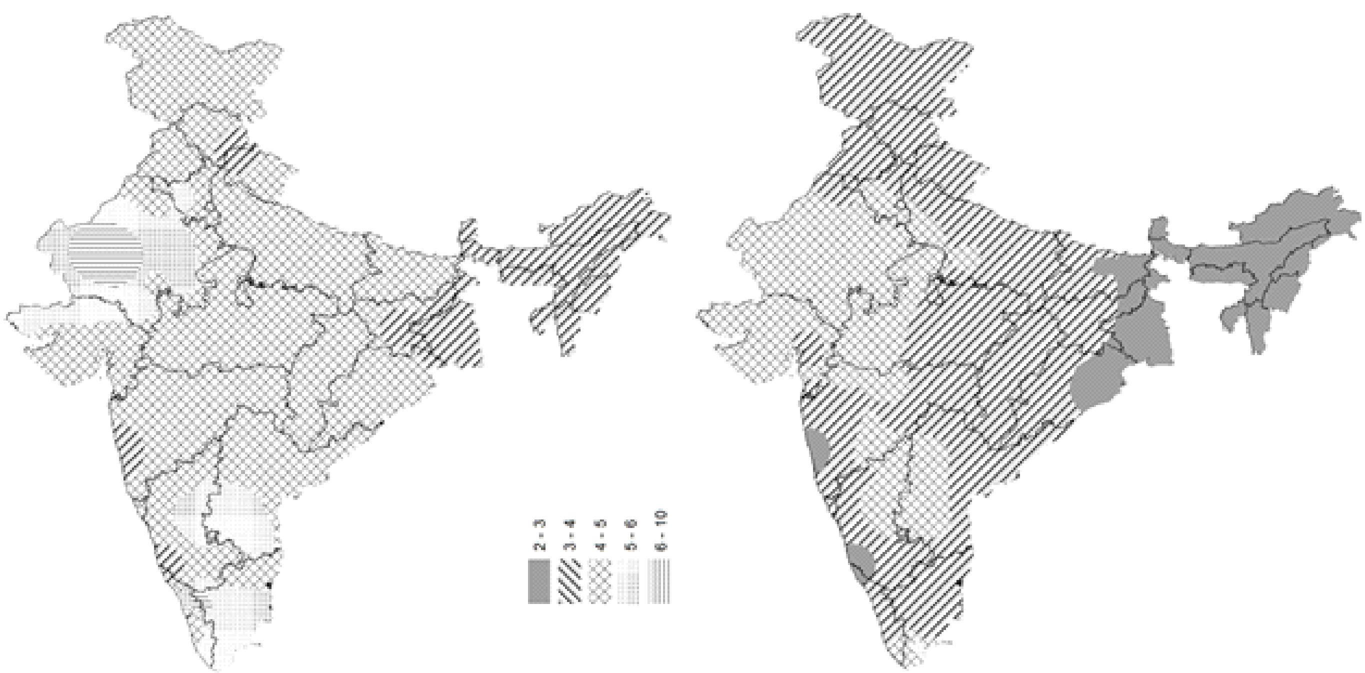

Fig. 3: ETo (mm day^{-1}) during southwest monsoon season as estimated by (a) P-M method and (b) Open pan method

Fig. 4: ETo (mm day^{-1}) during northeast monsoon season as estimated by (a) P-M method and (b) Open pan method

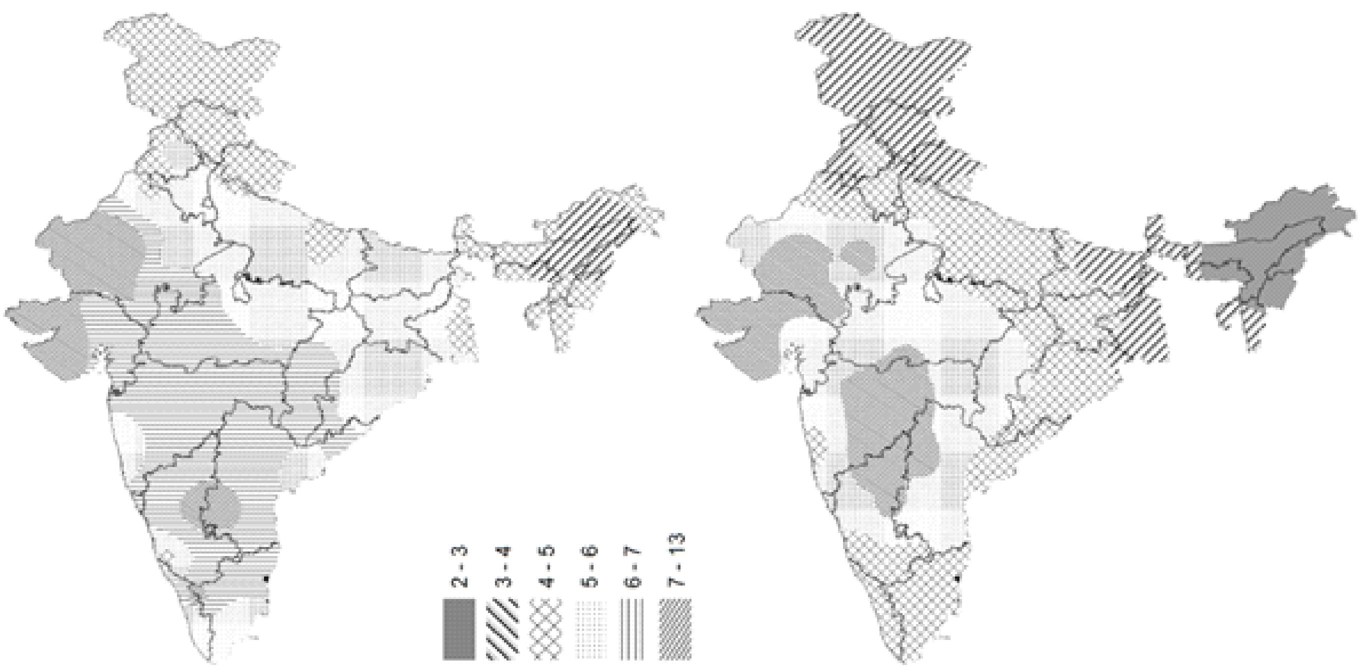

Fig. 5: ETo (mm day^{-1}) during summer season as estimated by (a) P-M method and (b) Open pan method

Fig. 6: ETo (mm day^{-1}) during winter season as estimated by (a) P-M method and (b) Open pan method

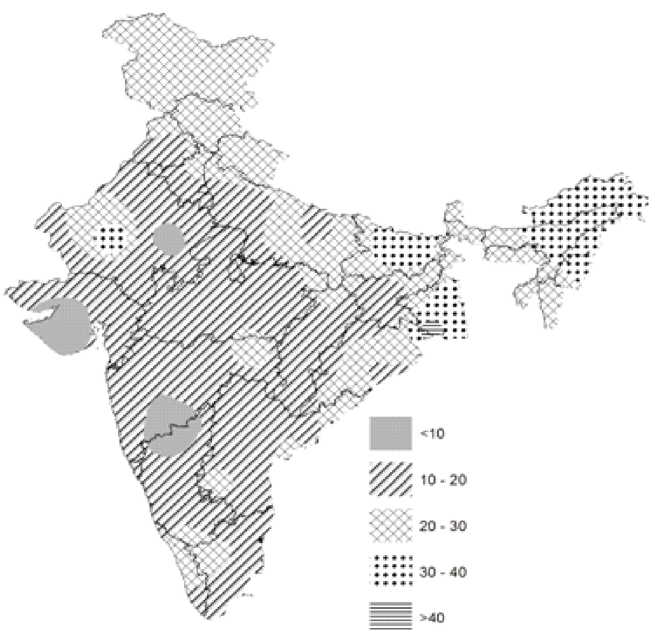

Fig. 7: Mean per cent deviation (%) of Open pan from P-M

Table 1: Performance of Open pan estimates *vis-a-vis* Penman Monteith estimates.

Season	MBE	RMSE	MPE	D -Index	r
Annual	-0.76	1.46	28.45	0.84	0.71
Winter	-0.52	0.95	27.28	0.86	0.67
Summer	-0.92	1.72	24.35	0.81	0.69
Monsoon	-0.86	1.62	30.85	0.80	0.67
Post Monsoon	-0.37	0.98	26.41	0.83	0.74

in all the seasons. Among different seasons, the difference narrowed-down to some extent during post-monsoon season as indicated low MBE value (-0.37). High RMSE and MBE values for summer season indicate the disagreement between the two methods during summer season. The MPE indicate that, the errors could be in the range of 26 to 31% in using Open pan method to estimate ET_0. Low correlation coefficients and D-index values indicate that adopting Open pan method may not give accurate estimates of ET_0 for Indian conditions.

Adjustment with calibration coefficients

Calibration coefficients were evolved by regressing annual $OPET_0$ estimates for different locations on the corresponding $PMET_0$ and the resultants values are plotted to depict the spatial variability across locations in Fig 8 a and b. It can be noticed from the Fig 8 that there is a large spatial variability. Then using these coefficient values the annual $OPET_0$ estimates were adjusted and the resultant adjusted values were subjected to statistical analysis. The results of the analysis showed that the mean MBE values from +0.66 to -0.13, RMSE from 1.82 to 0.83 and MPE from 44.26 to 12.84. Thus, there is considerable reduction in the errors associated with original (pre-adjusted) $OPET_0$ estimates. It is suggested that employing calibration coefficients may be resorted to have ET_0 estimates from Open pan to as much closer to $PMET_0$ as possible for different locations and time periods.

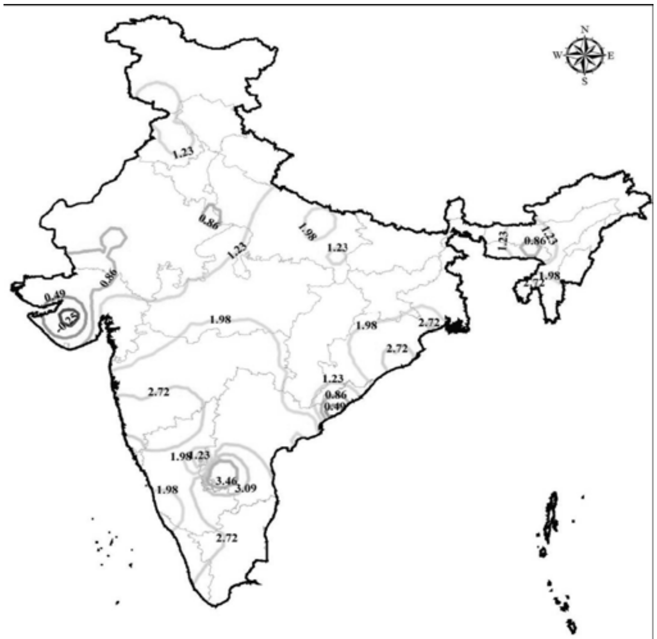

Fig 8a : Spatial distribution of calibration coefficient 'a'

Fig 8b : Spatial distribution of calibration coefficient 'b'

CONCLUSIONS

Reference crop evapotranspiration (ET_0) estimated by Open pan method are lower than Penman Monteith method irrespective of locations and seasons. On an average, $OPET_0$ estimates have around 29% error compared to $PMET_0$. Spatial variations in deviations in $OPET_0$ from $PMET_0$ are noticed. They are minimum over Western Gujarat, North interior Karnataka and South central of Maharashtra. Deviations were at their maximum over Eastern parts of the country, West Bengal, Eastern parts of Bihar and over Thar desert. Based on different statistical tools used, it can be concluded that Open pan method may not give accurate estimates of ET_0 for Indian conditions without a proper calibration. Calibration coefficients proposed in the present study were found to narrow down the errors considerable and this method may be employed to estimate ET_o from Open pan with reasonable accuracy.

REFERENCES

Allen, R. G. and Pruitt, W. O. (1991). FAO-24 reference evapotranspiration factors. *J. Irrig. Drain. Engg.*, ASCE, 117 (5): 758-773.

Allen, R. G., Periera, L. S., Raes, D. and Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirement, FAO Irrigation and Drainage Paper No 56, FAO, Rome, Italy, 300p.

Doorenboss, J. and W.O. Pruitt. (1977). Guidelines for predicting crop water requirements. irrigation and drainage paper No 24, Second edition, Food and Agriculture Organization, Rome, 156p.

IPCC. (2008). Special report on managing the risks of extreme events and disasters to advance climate change adaptation. http://www.ipcc-wg2. gov/SREX/images/uploads/SREX-All_FINAL.pdf.

Jensen, M. E. (1974). (Ed) Consumptive use of water and irrigation water requirements. Rep. Tech. Com. on Irrig. Water requirements, *Irrig. Drain. Div.*, ASCE, 227p.25.

Jensen, M.E., Burman, R.D. and Allen, R.G. (ed). (1990). Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practices No. 70., *Am. Soc. Civil Engrs.*, New York, 360p.

Liang, L., L. Li. and Liu, Q. (2010). Temporal variation of reference evapotranspiration during 1961-2005 in the Taoer river basin of Northeast China. *Agril. For. Meteorol.*, 150 : 298-306.

Rambabu, A. and B. Bapuji Rao. (1999). Evaluation and calibration of some potential evapo- transpiration estimating methods. *J. Agrometeorol*, 1(2) : 155-162.

Smith, M., Allen, R.G., Monteith, J.L., Pereira, L. and Segeren, A. (1991). Report of the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements. UN-FAO, Rome, Italy, 54p.