Estimation of Potential Evapotranspiration using Empirical Models for Imphal

Nganthoi Naorem, Th. Kiranbala Devi

Abstract *– Estimation of evapotranspiration of an area is highly essential for irrigation scheduling and design of irrigation project. It is the basic parameter for estimating the crop water requirements. In this study, Potential evapotranspiration (PET) were computed using 10 empirical models viz. Blaney-Criddle, Thornthwaite, Hargreaves, Penman, Penman-Monteith, Jensen-Haise, Turc, Priestley-Taylor, Makkink and Open pan method with the help of climatological data for the year 2012 for Imphal, Manipur. The missing climatic data to be used in the empirical models are computed according to the guidelines given in FAO Irrigation and Drainage paper, 56.FAO Rome, Italy. The empirically estimated PET from all these models were validated with the actual measured mesh covered pan evaporation value using calibration co-efficients. From the study, Hargreaves method was found to be the most suitable method for the region with least biasness and minimum error. The calibration co-efficients developed in this study can be used for reducing the error of estimating evapotranspiration by these empirical models for the area under study.*

Keywords - Calibration co-efficients, Error analysis, Missing Climatic data, Pan evaporation, Potential Evapotranspiration.

I. INTRODUCTION

Evapotranspiration (ET) or consumptive use of water is the total quantity of water removed from the soil by evaporation and transpiration. Evaporation is the loss of water in the form of vapour from soil, water surfaces, or from plant leaf surfaces holding water droplets from rain, irrigation, or dew formation and Transpiration is the loss of water through the leaves of the plant into the atmosphere during the process of photosynthesis. Planning of irrigation scheme, irrigation scheduling, effective design and management of irrigation system requires knowledge of exact amount of water needed by different crop in a given set of climatological condition of the region. In addition, yields of the crops are adversely affected with excess or inadequate water supply. To meet the demand of food production with limited cultivation area due to urbanization is the big question right at this moment. For better crop production, water should be supplied in proper quantities and at specific intervals. Therefore, the estimation of water requirements of crop is very much essential for agricultural planning and design of irrigation projects. For estimating the water requirements of crop, the main parameter which is required to be determined is evapotranspiration. ET or consumptive use of water depends on various factors like climatic factors, crop factors, soil factors, management factors etc.

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Nganthoi Naorem, Faculty of Civil Engineering Department, Manipur Institute of Technology, Takyelpat Imphal.

Dr. Th. Kiranbala Devi, Faculty, Manipur Institute of Technology, Takyelpat, Imphal.

Climatic factors which impact ET include air temperature, wind speed, humidity, solar radiation etc. Doorenbos and Pruitt (1977) stated that the climate was the most important factor to be taken into account while estimating crop water requirements. Potential Evapotranspiration (PET) is the upper limit of ET for a crop in a given climate which is defined as the evapotranspiration which would occur if there was always an adequate water supply available to a fully vegetated surface [8]. There are various methods for estimating PET viz. Water Budget method, Field Experimental Plots, Lysimeter method, Empirical methods etc. As a latest technology estimating ET using remote sensing & GIS is in the latest trend. However in cases where direct field measurement and remote sensing & GIS facility is inconvenient, estimation of PET using empirical models is preferred. There are various empirical models to estimate potential evapotranspiration (PET) which are developed using climatological data for use in specific areas. So, estimation of PET with these empirical models produce inconsistent result in different agro-climatic region. In order to get higher accuracy of estimate and to select the best method for estimating PET in any particular region, a comparative study and hence, local calibration is required. Calibration or validation of one empirical equation using another standard equation is used by many researchers. The standard FAO Penman-Monteith method is recommended to be used to calibrate or validate other empirical equations for new locations [27]. B.Rao et.al. (2012) used the standard FAO Penman-Monteith method to develop calibration co-efficients[24]. In this study, PET for Imphal, Manipur is estimated using 10 empirical models namely Blaney-Criddle, Thornthwaite, Hargreaves, Penman, Penman-Monteith, Jensen-Haise, Turc, Priestley-Taylor, Makkink and Open pan method. These empirical equations relate the evapotranspiration with readily available climatological data like temperature, humidity, wind speed, sunshine hours, solar radiations etc thereby simplifying the difficulties in obtaining accurate field measurements for predicting ET. Calibration is done using the actual mesh covered pan evaporation value of the region. To select the best empirical method for estimatimg PET in the region statistical analysis is performed.

II. STUDY AREA

Manipur state lies at a latitude of 23°83’N – 25°68’N and a longitude of 93°03’E – 94°78’E. The state occupies a geographical area of about 22,347 sq.km. The state capital Imphal is an oval-shaped valley which covers an area of about 700 square miles and is surrounded by beautiful blue mountains. It lies at an altitude of 790 meters above the sea level. The valley slopes from North to South. Manipur state consists of four major river basins - they are Yu River Basin in the East, Barak River Basin in the West, Manipur River Basin in the central part of Manipur and a part of Lanye River Basin lies in the North (4).

Lying in the north eastern corner of India, the area experiences a normal cordial climate though the winter is a bit chilly. The maximum temperature is around 32 degree C during summer and the temperature often falls below zero in winter. The Coldest month is January and the warmest month is July. The rainy season begins from the month of May and last till the mid of October. The area receives an annual rainfall of about 1467.5mm. The map showing the wetlands of Manipur basin is shown in figure 1.

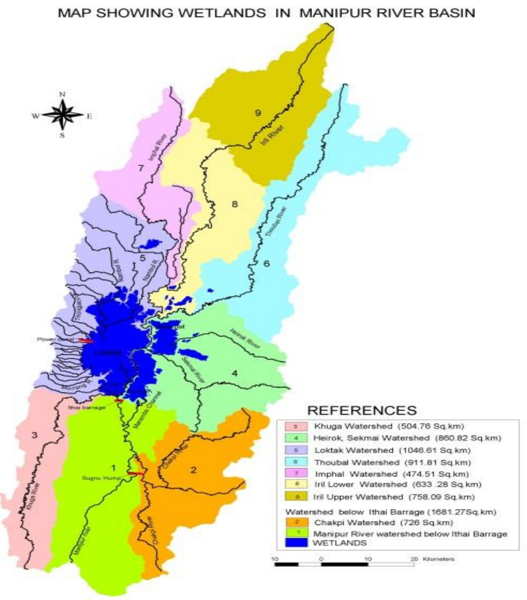


Fig. 1: Map showing wetlands in Manipur river basin

Source: Loktak Development Authority, Manipur.

III. MATERIALS AND METHODS

The meteorological data utilized in the present study is collected from the Indian Meteorological Department,the Regional Meteorological Centre, LGBI Airport, Guwahati. The monthly climatological data for the year 2012 were collected from the Indian Meteorological Department, Regional Meteorological Centre, LGBI Airport, Guwahati for Imphal station (24° 45'N latitude and 93° 53'E longitude and altitude of 779 m above msl), Manipur. Monthly rainfall in mm, monthly mean maximum & minimum temperature in °C, monthly mean wind speed at 2m above ground in kmph, monthly mean relative humidity at 1430 hrs IST in %, monthly mean evaporation in mm and actual sunshine hours for the year 2012 are collected. The collected data is not sufficient for estimating PET by the 10 empirical models and those missing climatic data are computed according to the guidelines given in FAO Irrigation and Drainage paper, 56.FAO Rome, Italy. Solar radiation, vapour pressure, atmospheric pressure, psychromatic constant and soil heat flux are computed using the available data. Using these data in excel sheet, monthly PET were computed by 10 empirical models namely Blaney-Criddle method (1977), Thornthwaite method (1948), Hargreaves method (1985), Penman method (1977), Penman-Monteith method (1991), Jensen-Haise method (1963), Turc method (1961), Priestley-Taylor method (1972), Makkink method (1957) and Open pan method (1977).

Statistical analysis is performed using root mean square error (RMSE) and mean bias error (MBE) between the actual mesh covered pan evaporation as standard value and PET by the other 10 empirical models to quantify the magnitude and nature of variation of these empirical models compared to the mesh covered pan evaporation. The expression for these statistical parameters were as follows :

$$RMSE = \sqrt{[(1/n)\Sigma (PET_e - PE)^2]} \quad (1)$$

$$MBE = [\Sigma (PET_e - PE)]/n \quad (2)$$

Where,

n = number of observations

PE = mesh covered pan evaporation value

PET_e = estimated potential evapotranspiration

Calibration co-efficients were evolved by performing linear regression analysis considering the mesh covered pan evaporation as the independent variable and PET by the 10 empirical models as dependent variable. These regression co-efficients were used to get the calibrated PET by multiplying the estimated PET with co-efficient "m" (i,e slope value) and then adjusting the product by intercept i,e "c" value [suggested by Allen et.al. (1994)]. Then, the resultant calibrated PET were again subjected to statistical analysis to check the applicability of these co-efficients in reducing the errors.

IV. RESULTS AND DISCUSSIONS

The monthly PET estimated using the meteorological data at Imphal station, Manipur for the year 2012 by 10 empirical models and the monthly value of actual pan evaporation (PE) are shown in Table 1 & Fig.2. It is shown that some of the estimated PET are in close proximity to the actual pan evaporation value whereas the remaining estimated PET are either overestimated or underestimated in comparision with the actual pan evaporation value. From the correlation study between PET_e (y) and PE (x), the co-efficients of regression (r^2) obtained for Blaney-Criddle, Thornthwaite, Hargreaves, Penman, Penman-Monteith, Jensen-Haise, Turc, Priestley-Taylor, Makkink and Open pan method are 0.631, 0.512, 0.939, 0.893, 0.698, 0.875, 0.813, 0.672, 0.721 and 0.741 respectively as shown in Fig.3. This showed that the empirical models were highly correlated with the actual pan evaporation as r^2 were more than 0.50. The accuracy of these empirical models compared to actual pan evaporation were analyzed using statistical parameters namely root mean square error (RMSE) and mean bias error (MBE). The RMSE values between the actual pan evaporation and estimated PET were 4.209, 1.178, 1.312, 1.659, 0.909, 0.719, 0.657, 1.058, 0.500 and 0.968 mm/d for Blaney-Criddle, Thornthwaite, Hargreaves, Penman, Penman-Monteith, Jensen-Haise, Turc, Priestley-Taylor, Makkink and Open pan method respectively. Similarly, the MBE values were 3.79, 0.17, 1.30, 1.57, 0.45, 0.59, 0.47, 0.61, -0.18 and -0.90 mm/d for Blaney-Criddle, Thornthwaite, Hargreaves, Penman, Penman-Monteith, Jensen-Haise, Turc, Priestley-Taylor, Makkink and Open pan method respectively.

It can be concluded that the estimated PET using these empirical models showed deviation from the actual pan evaporation to a great extent thereby necessitating validation of the result with calibration. The calibration co-efficients evolved by simple linear regression technique are presented in Table 2. A comparative study of RMSE and MBE before and after applying calibration co-efficients were presented in Fig.4 and Fig.5 respectively. It is revealed that the errors (RMSE & MBE) were minimized to a great extent after applying the calibration co-efficients.

Table 1: Monthly PET estimated by the 10 empirical models & the actual mesh covered pan evaporation value for the year 2012

PET in mm/d	ActualPan Evaporation	Blaney-Criddle	Thornthwaite	Hargreaves	Penman	Jensen-Haise	Penman-Monteith	Turc	Priestley-Taylor	Makkink	Open pan method
Jan	1.7	3.45	0.78	2.92	3.01	1.59	2.11	1.90	1.73	1.54	1.04
Feb	3.0	4.22	1.34	4.04	4.72	2.05	3.29	2.88	2.18	1.89	1.65
Mar	3.4	6.47	2.30	4.83	5.59	3.56	4.06	4.11	3.52	3.05	1.91
April	3.1	7.67	3.02	4.91	5.16	4.08	4.09	3.98	4.43	3.40	2.03
May	4.1	8.84	4.36	5.55	6.05	4.71	4.73	4.33	4.88	3.67	2.57
June	3.2	9.62	4.87	4.58	5.26	4.79	4.40	4.37	5.12	3.70	2.50
July	3.3	9.92	5.01	4.44	5.35	4.86	4.45	4.38	5.10	3.71	2.56
Aug	3.2	9.17	4.78	4.55	5.20	4.76	4.33	4.29	4.93	3.62	2.44
Sept	2.9	7.19	4.44	4.12	4.04	3.38	3.32	3.20	3.59	2.57	2.21
Oct	2.7	5.70	3.11	4.00	3.49	2.74	2.78	2.75	2.83	2.17	2.04
Nov	2.4	4.56	1.89	3.35	3.04	2.03	2.32	2.24	2.05	1.74	1.78
Dec	1.7	3.30	0.82	2.91	2.56	1.51	1.87	1.82	1.59	1.45	1.09

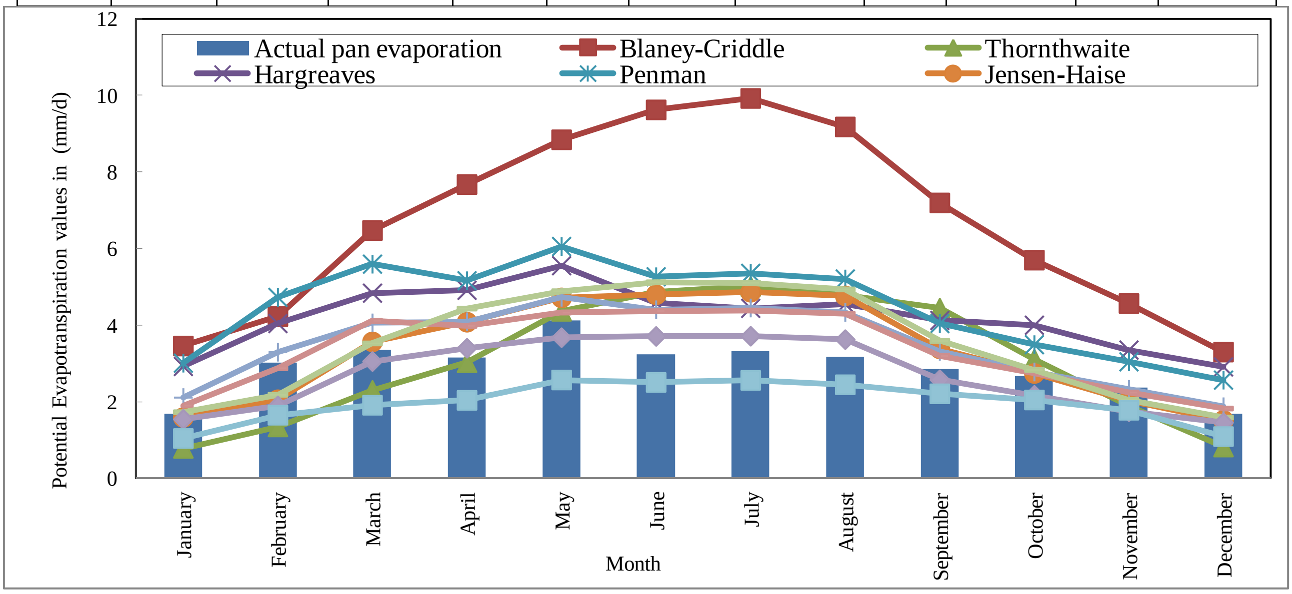
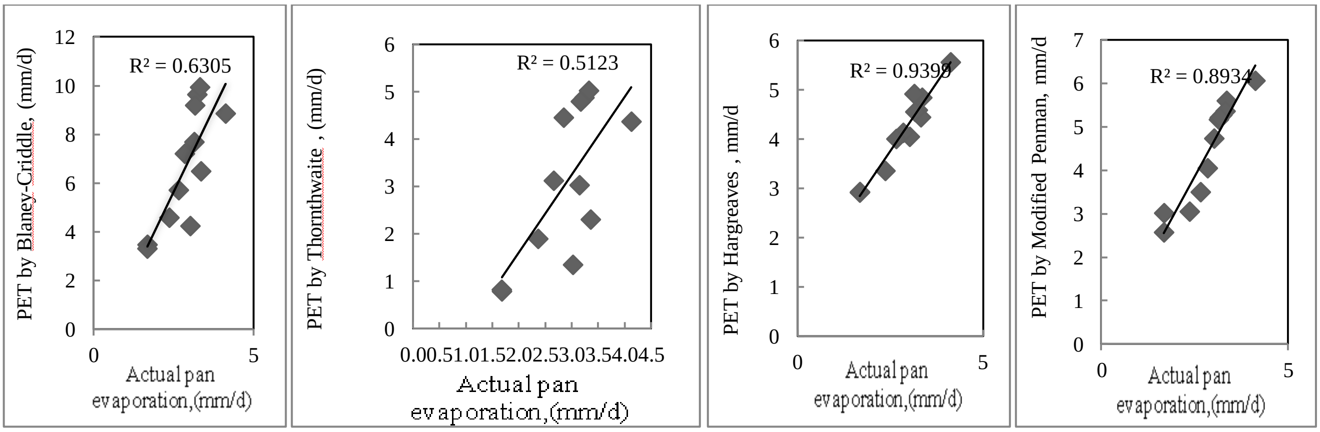


Fig. 2 : Comparision of estimated PET with actual pan evaporation value for the year 2012



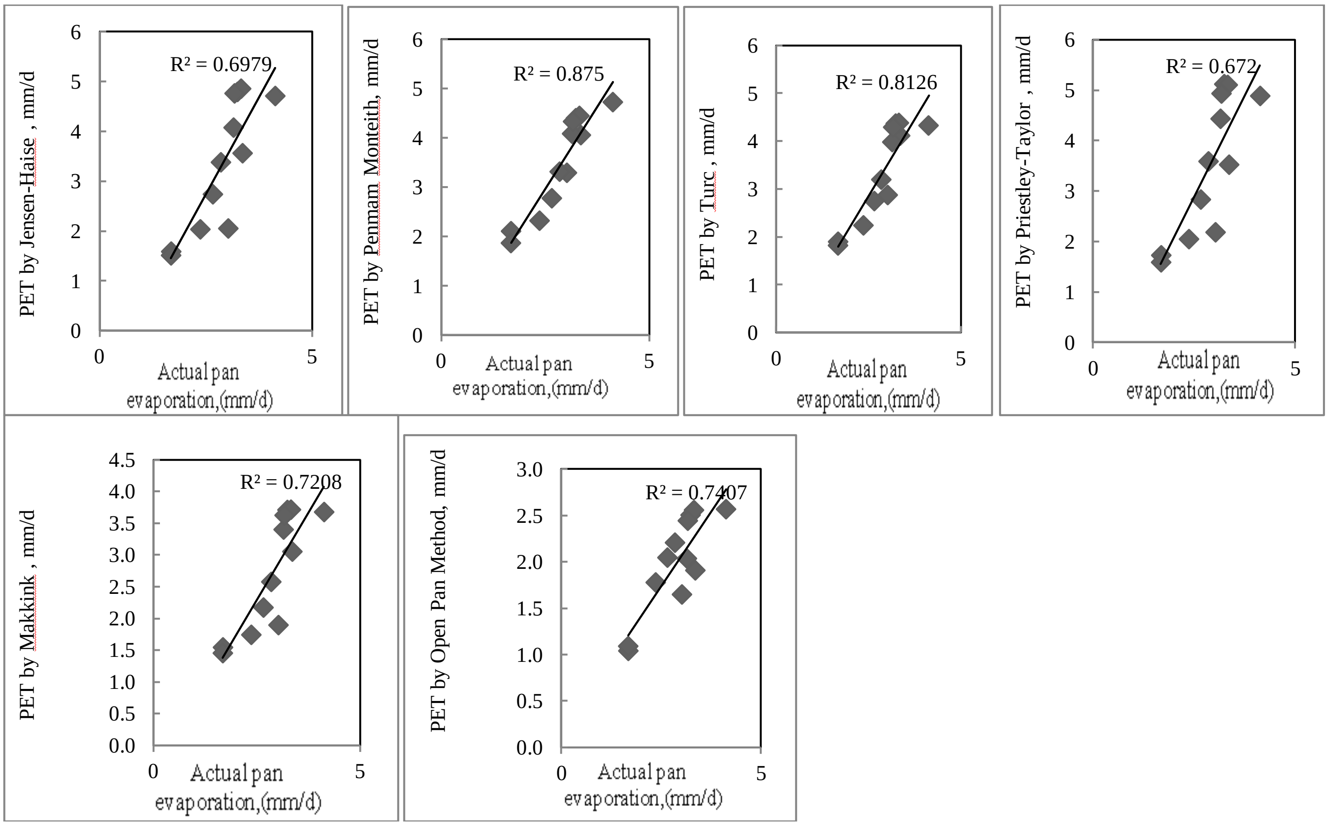


Fig. 3: Scatter plot between actual pan evaporation vs empirically derived PET

Table 2: Calibration co-efficients to be employed to minimize errors in the calculation

x	Blaney-Criddle	Thornthwaite	Hargreaves	Penman	Jensen-Haise	Penman-Monteith	Turc	Priestley-Taylor	Makkink	Open pan method
m	0.231	0.313	0.849	0.568	0.449	0.657	0.631	0.418	0.655	1.153
c	1.341	1.930	-0.667	0.355	1.389	0.603	0.769	1.425	1.111	0.597

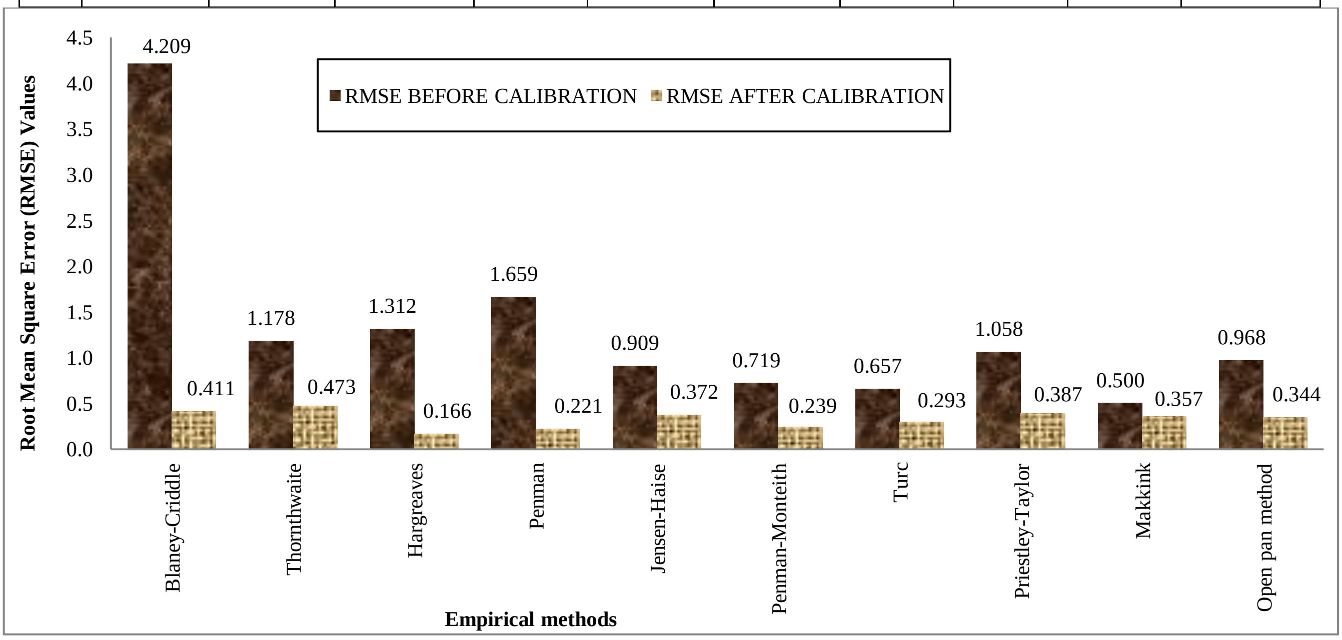


Fig. 4: Bar representation showing RMSE values of estimation before and after applying calibration coefficients

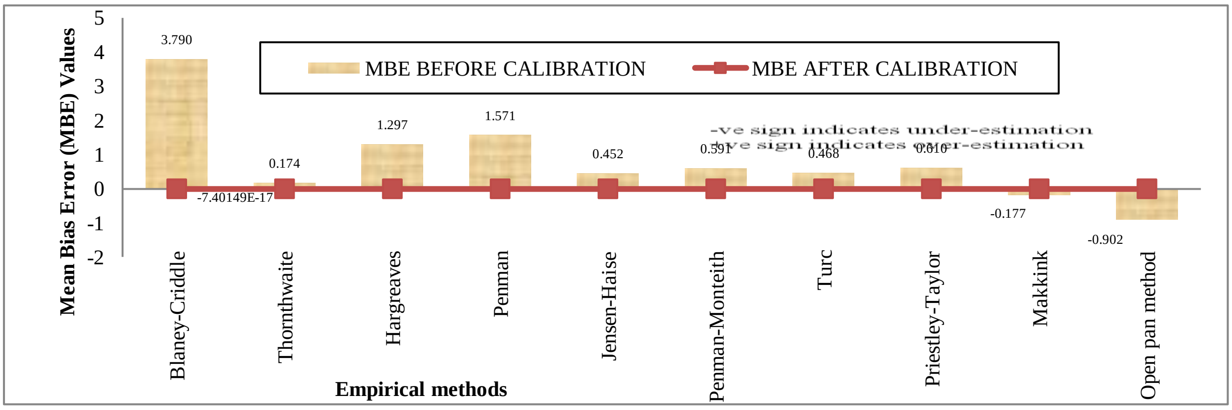


Fig. 5 : Bar representation showing MBE values of estimation before and after applying calibration coefficients

V. CONCLUSION

Hargreaves method (1985) was found to be the most suitable method for estimating PET for Imphal, Manipur with the lowest RMSE value (0.166) and high correlation co-efficient (0.939). Before applying calibration co-efficients, Makkink method (1957) has got the lowest RMSE value (0.500) with reasonably good correlation co-efficient (0.721). It can also be concluded that the calibration co-efficient (Table 2) developed in this study can be used for estimating PET accurately by these 10 empirical models for this region.

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