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Original Research Article

Evaluation of reference evapotranspiration methods for the northeastern region of India

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ABSTRACT

The study planed to identify a suitable alternative to the FAO-56 Penman-Monteith (FAO56PM) equation for calculating reference evapotranspiration (ET_0) from chosen temperature and radiation based models utilizing monthly meteorological data from 30 destinations in diverse agro-ecological regions of the Northeast (NE) India i.e., Assam Bengal Plain (ABP), eastern Himalaya (EH), and the northeastern hilly (NEH) region. Radiation-based IRMAK3 most appropriate in the ABP (weighted root mean square deviation, WRMSD=0.17 mm d^{-1}, r^2=0.98, for Nagrakata), and TURC model being in the first three rank of most of the sites, with the lowest error and highest correlation in NEH (WRMSD=0.10 mm d^{-1}, r^2=0.92, for Shillong), and EH (WRMSD=0.23 mm d^{-1}, r^2=0.95, for Gangtok). Findings reveal that IRMAK3 and TURC models performed equally well and were observed to be the best among selected models for the majority of stations followed by FAO24 Blaney-Criddle (FAO24BC), and 1957MAKK. Pair-wise regression equations were developed for preferred FAO56PM ET_0 estimates to ET_0 estimates by alternative methods. Cross-correlation of eighteen chose methods demonstrated that the five equations (i.e. four radiation- and one temperature-based) performed exceptionally well when contrasted with the FAO56PM model, thus being advised for assessing ET_0 under limiting data conditions as have yielded a better estimate of ET_0 with a small error.

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1. Introduction

Evapotranspiration is the integrated process of evaporation and transpiration and is affected by meteorological variables, crop characteristics, and management practices, as well as environmental characteristics. ET_0 is the water evaporated from a reference surface, and was presented to quantify evaporative demand of the atmosphere, independent of the crop growth parameters and management practices (Allen, Pereira, Raes, & Smith, 1998; Zotarelli, Dukes, Romero, Migliaccio, & Morgan, 2010).

ET_0 is a highly nonlinear variable controlling varieties of issues in water management, hydrology, agriculture, irrigation scheduling, and proper planning of available fresh water resources. Among the different components of the hydrological cycle, a precise approximation of evapotranspiration is perhaps most difficult due to its complex interactions with the soil–plant–atmosphere system.

The reliable estimation of ET_0 is essential to estimate the net irrigation requirement, regional water resources planning, and management and to model the climate change effect. The direct approach to quantify ET_0 is using lysimeter measurement, or it could be indirectly calculated using the energy balance approach (or empirical models). However, the lysimetric approach is time-consuming and requires precise instrumentation. The indirect approach (methods) is based on site specific meteorological data, altitude, and latitude. The FAO56PM method is the most suitable indirect approach for accurate estimation of ET_0 and evaluation of other empirical models (Allen et al., 1998; Berti, Tardivo, Chiaudani, Rech, & Borin, 2014; Djaman et al., 2015; Lima et al., 2013; Pandey, Pandey, & Mahanta, 2014; Pereira, Allen, Smith, & Raes, 2015; Tabari et al., 2013; Widmoser, 2009).

The FAO Irrigation & Drainage Paper No. 56, (Allen et al., 1998), and ASCE Task Committee on Standardized Evapotranspiration Calculations (ASCE-EWRI, 2005) recommended that the FAO56PM method could be used as a standard equation to calculate ET_0. The FAO56PM method was validated against lysimeter measured data in diverse climatic conditions worldwide and reported the best method for ET_0 estimation (Allen et al., 2005; ASCE-EWRI, 2005; DehghaniSanij, Yamamoto, & Rasiah, 2004; Ghamarnia, Mousabeyg, Amiri, & Amirkhani, 2015; Itenfisu, Elliott, Allen, & Walter, 2003; Jain, Nayak, & Sudheer, 2008; Mohan & Arumugam, 1996; Xu, Peng, Ding, Wei, & Yu, 2013). Additionally, the FAO56PM now widely used as reference methods in the field of agronomy, irrigation water management, and other related fields for research purpose (Alexandris, Kerkides, & Liakatas, 2006).

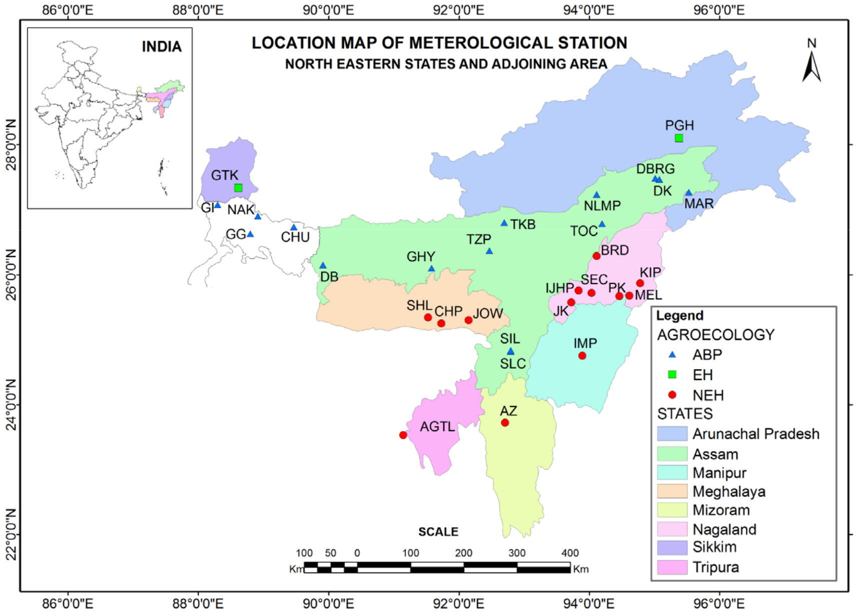
The FAO56PM accounts for aerodynamic as well as physiological parameters, which requires several meteorological parameters such as air temperature, relative humidity, solar radiation or sunshine hour and mean wind speed at 2 m height. The accessibility of required information to utilize FAO56PM is poor under Indian conditions, particularly in NE, India because at most meteorological stations, the necessary information to utilize FAO56PM is not accessible, or if accessible then they have missing records this may be because of defective sensors or low upkeep.

The ET_0 estimation equations can be grouped in view of their data necessities as temperature based, radiation based, mass exchange based, and combination based. The execution of the particular ET_0 estimation method varies with climatic conditions and accessibility of meteorological information, and the data prerequisites change from method to method (Jensen et al., 1990).

To overcome data inadequacy issue, The FAO Revised and Improved Procedure for Crop Water Requirements (Smith et al., 1991) suggested that empirical methods be standardized for new destinations utilizing the FAO56PM model. Performance Assessment of the different ET_0 estimation methods is a challenging task. Jensen, Burman, and Allen (1990) ranked FAO56PM the best, followed by Kimberly Penman (Wright, 1982), and FAO24 Radiation (FAO24RD) (Doorenbos & Pruitt, 1977) regarding predictive power, in comparison with lysimeter based study. Steiner, Howell, and Schneider (1991) assessed Penman (Penman, 1963), FAO56PM, Jensen–Haise (JH) (Jensen et al., 1990), and Priestley–Taylor (PT) (Priestley & Taylor, 1972) models against lysimeter measured ET_0 under the climate of Southern Great Plains. Findings showed that the FAO56PM was the best to an approximation of ET_0, and well over the whole range of measured values. Yoder, Odhiambo, and Wright (2005) evaluated eight different ET_0 equations under climatic conditions of southern United States and concluded that TURC (Turc, 1961) may be an attractive alternative to FAO56PM model while Hargreaves (HAR) (Hargreaves & Samani, 1985) is not suitable for selected sites. Nandagiri and Kovoor (2006) assessed the performance of seven different ET_0 methods across the climatic conditions of India and reported the TURC is the best option under humid conditions. Suleiman and Hoogenboom (2007) compared the PT and FAO56PM under humid climate. Their outcomes demonstrated that the utilization of FAO56PM for calculating ET_0 would enhance the irrigation efficiency in Georgia, particularly in the mountainous and coastal areas. Fooladmand, Zandilak, and Ravanan (2008) compared different types of Hargreaves equations for 14 weather stations in the south of Iran taking FAO56PM as standard. The results support HAR equation is a better option under humid climate and low wind conditions. Tabari, Grismer, and Trajkovic (2013) compared 31 different ET_0 equations including developing two new radiation based equation (similar to that of Irmak et al. (2003)) in the northern, Iran (humid environment) considering FAO56PM as standard. Results revealed that developed equation performed better than other selected equations hence radiation-based model were the suitable option to estimate ET_0.

George and Raghuwanshi (2012) evaluated six different ET_0 models for four sites in India to identify the best and the worst performing methods at each location. The FAO24RD method identified as close agreement with FAO56PM for the humid site. Xu et al. (2013) evaluated PT, HAR, and TURC models for humid East China and reported TURC is a suitable choice for the region. Djaman et al. (2015) evaluated sixteen ET_0 methods against FAO56PM under Sahelian conditions in the Senegal River Valley and reported temperature–humidity based (Valiantzas1, Valiantzas, 2013), and solar radiation based (Valiantzas2, Valiantzas, 2013) over performed other selected methods are the suitable alternative of FAO56PM. Zhao et al. (2014) developed linear regression between two temperature-based models and standard FAO56PM. Good agreements were observed between the developed models and standard FAO56PM.

In spite of the advancement in studies identified with assessments of generally utilized ET_0 methods under humid conditions (Bogawski & Bednorz, 2014; Chen, Gao, Xu, Guo, & Ren, 2005;



Meteorological Stations (abbreviations): Agartala (AGTL), Aizwal(AZ), Bhandari(BRD), Cheerapunji(CHP), Chupara (CHU), Dibrugarh (DBRG), Dikom (DK), Dhubri (DB), Gangtok (GTK), Ging (GI), Gungaram (GG), Guwahati (GHY), ICAR Jharanpani (IJHP), Imphal (IMP), Jalukie(JK), Jowai (JOW), Kiphiri(KIP), Margherita (MAR), Meluri (MEL), N Lakhimpur (NLMP), Nagrakata (NAK), Pasighat (PGH), Pheck (PK), Sechu (SEC), Shillong (SHL), Silchar(SIL), Silcoorie (SLC), Tezpur (TZP), Thakurbari (TKB), Tocklai (TOC)

Fig. 1. Location map of North Eastern region of India, showing different states, agro-ecological regions and selected meteorological stations.

Jensen et al., 1990; Pandey et al., 2014; Sentelhas, Gillespie, & Santos, 2010; Trajkovic, 2007), a generalization of the particular model has restricted worldwide pertinence because of their regional climatic reliance. Numerous studies under different climate conditions proposed that regional calibration of temperature and radiation based models can improve their performance (Irmak, Irmak, Allen, & Jones, 2003; Trajkovic, 2005; Xu & Singh, 2001, 2002).

Various limits exist in the accessibility of climate information under the NE, India conditions, for example, scarce data recording stations, missing information. The present examination has been doing to figure out a suitable alternative to the FAO56PM model for the main stations of the region and after that to determine most appropriate according to the agro-ecological region of NE India (Fig. 1). Past studies completed in the study region (for two destinations) was centered on assessing different ET_0 models against the FAO56PM, for example, with pan evaporation based model (Jhajharia, DebBarma, & Agrawal, 2004a), with TURC, JH, and PT (radiation-based models) (Jhajharia, DebBarma, & Agrawal, 2004b), and with HAR (temperature models) (Pandey, Radheshyam, & Hibu, 2009). Pandey et al. (2014) carried out parametric adjustment of temperature based Hargreaves' model to enhance its execution. In any case, none of those above studies gives a general outline of the area. So in the present study, an exertion was made to judge ordinarily utilized ET_0 methods and to recognize a suitable method that can be used for a point scale estimation of ET_0 over NE locale. The findings, are likely to help in diminishing the error associated with ET_0 estimation, and the recognized models in this study could be utilized as part of further examinations in the related field, for example, irrigation planning and management, climate change studies, and water resource planning.

2. Materials and methods

2.1. About study area

NE, India falls under the humid subtropical ecosystem, characterized by a significant amount of rainfall throughout the year, with humid summers, severe monsoons, and mild winters. NE physio graphically may classify into three agro-ecological regions, namely ABP, EH, and NEH (Purvachal) as per Sehgal, Mondal, Mondal, and Vadivelu (1990). Selected meteorological stations along with abbreviation for present investigation according to agroecological regions are depicted in Fig. 1.

2.2. Data availability

In applying various evapotranspiration equations, data (1980–2010 for most of the stations) were collected from different India meteorological stations, Tea Research Association, and an Indian council of agricultural research stations situated in various locations in eight states of in NE region of India (Fig. 1). Some of the stations having a limitation of either sunshine or wind speed data, in this condition missing values were estimated by developing regression equations among the observed values and the global data set(1° latitude by 1° longitude grid) obtained from the climatology resource for agro-climatology (http://power.larc.nasa.gov/). The quality check and integrity of different data was performed as recommended by Allen (1996).

3. Methodology

3.1. Selection of ET_0 methods

Various ET_0 estimation techniques taking into account

Table 1
Details of selected methods for evaluation and input parameters in each method including their references.

Equations (abbreviation)	Reference(s)	Formula	Parameters
		Radiation-based	
Caprio (CP)	Caprio (1974)	$ET_0 = (0.01092708T + 0.0060706)R_s$	R_s, T
Irmak (IRMAK1, IRMAK2, IRMAK3)	Irmak et al. (2003) Tabari et al. (2011)	$ET_0 = -0.611 + 0.149 \times R_s + 0.079 \times T \quad (IRMAK1)$ $ET_0 = -0.642 + 0.174 \times R_s + 0.0353T \quad (IRMAK2)$ $ET_0 = -0.478 + 0.156 \times R_s - 0.0112 \times T_{\max} + 0.0733 \times T_{\min}(IRMAK3)$	R_s, T, $T_{\max}$, $T_{\min}$,
McGuinness–Bordne (MGB)	McGuinness and Bordne (1972)	$ET_0 = (0.005T - 0.0838)R_s$	R_s, T
Ritchie (RT)	Jones and Ritchie (1990), Valipour (2015)	$ET_0 = R_s\alpha[(0.002322T_{\max} + 0.001548T_{\min} + 0.11223)]$	R_s, $T_{\max}$, $T_{\min}$
Jensen–Haise (JH)	Jensen et al. (1990)	$ET_0 = 0.408 \times C_T \times (T - T_X) \times K_T \times R_a \times TD^{0.5}$	
Turc (TURC)	Turc (1961), Xu, Singh, Chen, and Chen (2008)	$ET_0 = a_T 0.013\frac{T}{T+15}\left(\frac{23.8856R_S + 50}{\lambda}\right)$	R_s, T
Modified Turc (MODTURC)	Trajkovic and Kolakovic (2009b)	$ET_0 = \mathrm{C_u} \times 0.013 \times (23.\ 88 \times \mathrm{R_s} + 50) \times \mathrm{T} \times (\mathrm{T} + 15)^{-1}$ $\mathrm{Where C_u} = -0.0211 \times \mathrm{U_2}^2 + 0.\ 1109 \times \mathrm{U_2} + 0.\ 9004$	R_s, T, U_2
Makkink (1957MAKK)	Makkink (1957)	$ET_0 = 0.61\frac{\Delta}{\Delta+\gamma}\frac{R_S}{2.45} - 0.12$	R_s, T
Priestley–Taylor (PT)	Priestley and Taylor (1972)	$ET_0 = 1.26\frac{\Delta}{\Delta+\gamma} \times \frac{Rn - G}{\lambda}$	T, $T_{\max}$, $T_{\min}$, n, RH, φ, E
FAO24-Radiation (FAO24RD)	Doorenbos and Pruitt (1977)	$ET_0 = a + b\left[\frac{\Delta}{\Delta+\gamma} \times R_s\right]$	R_s, T
		Temperature based	
Hargreaves (HAR)	Hargreaves, and Samani (1985)	$ET_0 = 0.0023(TD)^{0.5}(T + 17.8)R_a$	R_a, T, $T_{\max}$, $T_{\min}$
Hargreaves1 (HAR1)	Droogers and Allen (2002)	$ET_0 = 0.408 \times 0.0030(T + 20)(TD)^{0.4}R_a$	R_a, T, $T_{\max}$, $T_{\min}$
Hargreaves2 (HAR2)	Droogers and Allen (2002)	$ET_0 = 0.408 \times 0.0025(T + 16.8)(TD)^{0.5}R_a$	R_a, T, $T_{\max}$, $T_{\min}$
FAO24-Blaney-Criddle (FAO24BC)	Allen and Pruitt (1986)	$ET_0 = a + bP(0.46T + 8.13)(1 + 0.0001E)$	T, n, $RH_{\min}$, φ, u_2, E
Thornthwaite (TH)	Thornthwaite (1948)	$ET_0 = 16\left(10\frac{T}{I}\right)^i$	T, φ
Baier-Robertson (BR)	Baier and Robertson (1965)	$ET_0 = 0.157T_{\max} + 0.158(TD) + 0.109R_a - 5.39$	R_a, $T_{\max}$, $T_{\min}$

Note: ET_0, R_n, R_s, G, Δ, γ, u_2, T are same those defined in the FAO56PM, $T_{\max}$=maximum air temperature(°C), $T_{\min}$=minimum air temperature (°C), TD=$T_{\max}-T_{\min}$ (°C), E=elevation (m), RH=mean relative humidity(%), n=actual duration of sunshine hour(h), $RH_{\min}$=minimum relative humidity(%), φ=latitude(rad), R_a=extra-terrestrial radiation(MJ m^{-2} d^{-1}), λ=latent heat transfer=2.45(MJ kg^{-1}), U_2=long-term mean annual wind speed at 2 m (m s^{-1}), C_T, C_u, T_X, K_T, α, a, b, a_T, P, i, I are the empirical coefficients.

distinctive data prerequisites are available in the literature. The point of interest interpretation of frequently utilized methods can be found as a part of Jensen et al. (1990), Allen et al. (1998), and in the manual of "REF-*ET* for Windows" (Reference Evapotranspiration Calculator programming) (Allen, 2000). As to avoid recurrence of already available literature on ET_0 estimation, simply the name and abbreviations of the particular method, references, formula, and data prerequisites have been said in Table 1. For this study, 18 methods were shortlisted keeping in perspective their data prerequisites and performance under humid environment. All the shortlisted methods alongside references and other details appear in Table 1.

3.2. Standardized ET_0 estimation

The reference ET_0 values were estimated using FAO56PM for each of the stations. The FAO56PM is a hypothetical grass reference based model that have following characteristics: mean height of vegetation (h)=0.12 m, measurement of temperature, humidity, and wind at the height of 2 m, latent heat transfer (λ)=2.45(MJ kg^{-1}), bulk surface resistance of 70 s m^{-1}, and albedo=0.23. The final form of the FAO56PM equation for daily or monthly time step is defined as (Allen et al., 1998)

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_S - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

where ET_0=reference evapotranspiration (mm d^{-1}), R_n=net radiation (MJ m^{-2} d^{-1}), (e_S-e_a)=difference between the saturation vapor pressure e_S (kPa) and the actual vapor pressure e_a (kPa), Δ=slope of the saturation vapor pressure–temperature curve (kPa °C^{-1}), γ=psychrometric constant(kPa °C^{-1}), u_2=wind speed at 2 m height(m s^{-1}), T=mean daily air temperature (°C), G=monthly soil heat flux density(MJ m^{-2} d^{-1}). All the intermediate parameters were computed following Allen et al. (1998).

Month to month ET_0 was ascertained utilizing "REF-ET for Windows" Version 3.1.16 software (Allen, 2000). For other applicable methods (not recorded in "REF-ET for Windows") Microsoft Excel software was utilized.

The values estimated from different equations were compared with the reference value obtained from FAO56PM at the respective station. The performance of equations was evaluated by utilizing several statistical measures.

3.3. Comparison of the performance of different ET_0 methods

The performances of different selected methods were evaluated against standard FAO56PM. The various error indices used for evaluation of performance are mentioned below:

3.3.1. Index of agreement (d)

$$d = 1 - \frac{\sum_{i=1}^{N}\left(ET_{Eq,i} - ET_{FAO56PM,i}\right)^2}{\sum_{i=1}^{N}\left(\left|ET_{Eq,i} - \overline{ET_{FAO56PM,i}}\right| + \left|ET_{FAO56PM,i} - \overline{ET_{FAO56PM,i}}\right|\right)^2} \tag{2}$$

where $ET_{FAO56PM}$=ET_0 estimated using FAO56 PM (mm d^{-1});

$ET_{Eq}=ET_0$ values utilizing other selected equation (mm d^{-1}) and N=the total number of observations.

3.3.2. Mean absolute error (MAE)

$$MAE = \frac{\sum_{i=1}^{N} \left| ET_{FAO56PM,i} - ET_{Eq,i} \right|}{N} \tag{3}$$

3.3.3. Standard error of estimate (SEE)

The *SEE* is computed following the equation suggested by Irmak, Allen, and Whitty (2003) as

$$SEE = \sqrt{\frac{1}{N(N-2)}} \left[N \sum_{i=1}^{N} ET_{Eq,i}^{2} - \left(\sum_{i=1}^{N} ET_{Eq,i} \right)^{2} - \left[\frac{\left[N \sum_{i=1}^{N} ET_{FAO56PM,i} \times ET_{Eq,i} - \left(\sum_{i=1}^{N} ET_{FAO56PM,i} \right) \left(\sum_{i=1}^{N} ET_{Eq,i} \right) \right]^{2}}{\sum_{i=1}^{N} ET_{FAO56PM,i}^{2} - \left(\sum_{i=1}^{N} ET_{FAO56PM,i} \right)^{2}} \right] \right] \tag{4}$$

3.3.4. The root mean square difference (RMSD)

$$RMSD = \sqrt{\left[\frac{\left[\sum_{i=1}^{N} ET_{FAO56PM,i} - ET_{Eq,i} \right]^{2}}{N} \right]} \tag{5}$$

Linear regression fitting between the ET_0 estimates by the FAO56PM and comparison equation ($ET_{Eq.}$) as follows;

$$ET_{FAO56PM} = s * ET_{Eq.} \tag{6}$$

where *s* is regression line slope. The measurement unit of *MAE*, *SEE*, and *RMSD* is mm d^{-1} while *d* is dimensionless.

The fitting regression line through the origin is based on an assumption of zero mean residual, is advantageous in comparing equations as both theoretical approaches origin simultaneously when actual values of ET_0 is zero (Trajkovic & Kolakovic, 2009a).

This approach was utilized to an examination of the reliability of fit between ET_0 estimates, by comparison, equation, and the FAO56PM. The regression coefficients were utilized to correct ET_0 estimates. Afterward, adjusted root mean square deviation (*ARMSD*) was calculated as follows;

$$ARMSD = \sqrt{\left[\frac{\left[\sum_{i=1}^{N} ET_{FAO56PM,i} - s \times ET_{Eq,i} \right]^{2}}{N} \right]} \tag{7}$$

where *ARMSD* is adjusted, root mean square deviation in mm d^{-1}. The *ARMSD* indicates precision in assessing ET_0 without a consistent predisposition. Utilizing both *RMSD* and *ARMSD* are the effective methodology to evaluate the predictive power of unadjusted ET_0, and ease of revising the coefficients of the specific comparison equation to a reference value to improve statistical fitness. Based on indices mentioned above, weighted RMSD (*WRMSD*) may be formulated as follows (Jensen et al., 1990):

$$WRMSD = 0.67 \times RMSD + 0.33 \times ARMSD \tag{8}$$

Table 2

Station wise ranking measures of first three selected equations against FAO56PM (reference equation) in the ABP region.

St.	ET_0 equations (in order of ranking)	Variability measures (mm d^{-1})		Ranking measure (mm d^{-1})		St.	ET_0 equations (in order of ranking)	Variability measures (mm d^{-1})		Ranking measure (mm d^{-1})	
		Mean	SD	WRMSD	MAE			Mean	SD	WRMSD	MAE
CHU	**FAO56PM**	3.00	0.69			**NLMP**	**FAO56PM**	2.99	0.74		
	IRMAK3	3.20	0.62	0.34	0.24		IRMAK3	3.05	0.59	0.30	0.22
	MODTURC	3.21	0.57	0.34	0.24		MODTURC	3.15	0.57	0.39	0.28
	1957MAKK	2.74	0.52	0.45	0.32		FAO24BC	2.96	0.60	0.43	0.37
DBRG	**FAO56PM**	3.00	0.65			**NAK**	**FAO56PM**	3.00	0.72		
	IRMAK3	2.94	0.57	0.24	0.18		IRMAK3	3.01	0.58	0.17	0.14
	MODTURC	3.08	0.53	0.30	0.24		IRMAK2	2.92	0.47	0.45	0.38
	FAO24RD	3.25	0.59	0.41	0.28		1957MAKK	2.70	0.47	0.52	0.37
DK	**FAO56PM**	2.67	0.69			**SIL**	**FAO56PM**	3.45	0.64		
	FAO24BC	2.70	0.59	0.40	0.33		TURC	3.60	0.56	0.31	0.17
	1957MAKK	2.46	0.48	0.43	0.32		IRMAK3	3.21	0.53	0.40	0.28
	IRMAK3	2.96	0.71	0.45	0.35		FAO24RD	3.71	0.69	0.44	0.27
DB	**FAO56PM**	2.95	0.69			**SLC**	**FAO56PM**	3.26	0.70		
	IRMAK3	2.97	0.54	0.21	0.17		IRMAK3	3.22	0.56	0.30	0.23
	FAO24RD	3.22	0.59	0.45	0.31		MODTURC	3.37	0.55	0.38	0.30
	TURC	3.26	0.50	0.49	0.31		1957MAKK	2.93	0.48	0.57	0.39
GI	**FAO56PM**	2.55	0.61			**TZP**	**FAO56PM**	3.00	0.73		
	IRMAK3	2.52	0.63	0.23	0.18		IRMAK3	3.04	0.59	0.21	0.16
	IRMAK2	2.42	0.57	0.23	0.20		IRMAK2	2.90	0.53	0.40	0.34
	1957MAKK	2.36	0.48	0.14	0.24		FAO24RD	3.30	0.71	0.51	0.34
GG	**FAO56PM**	3.18	0.68			**TKB**	**FAO56PM**	2.94	0.76		
	IRMAK3	3.20	0.66	0.43	0.35		FAO24BC	2.98	0.57	0.38	0.34
	1957MAKK	2.99	0.75	0.45	0.34		IRMAK3	3.15	0.65	0.40	0.31
	FAO24BC	3.27	0.84	0.45	0.38		1957MAKK	2.74	0.48	0.45	0.34
GHY	**FAO56PM**	3.12	0.77			**TOC**	**FAO56PM**	2.88	0.27		
	IRMAK3	3.09	0.59	0.30	0.22		IRMAK3	2.95	0.59	0.29	0.24
	FAO24BC	2.86	0.71	0.46	0.34		FAO24BC	2.86	0.62	0.34	0.26
	1957MAKK	2.86	0.52	0.53	0.37		1957MAKK	2.67	0.55	0.44	0.32
MAR	**FAO56PM**	2.80	0.73								
	FAO24BC	2.72	0.62	0.30	0.24						
	IRMAK3	3.02	0.67	0.38	0.28						
	IRMAK2	2.98	0.55	0.44	0.33						

Note: St.=stations, SD=standard deviation.

Table 3
Station wise ranking measures of first three selected equations against FAO56PM (reference equation) in the NEH region.

St.	ET_0 equations (in order of ranking)	Variability measures (mm d^{-1})		Ranking measure (mm d^{-1})	
		Mean	SD	WRMSD	MAE
AGTL	**FAO56PM**	3.85	0.68		
	FAO24RD	4.01	0.76	0.40	0.29
	TURC	3.68	0.58	0.42	0.27
	FAO24BC	4.12	0.71	0.43	0.30
AZ	**FAO56PM**	3.55	0.69		
	TURC	3.47	0.61	0.24	0.15
	IRMAK2	3.00	0.53	0.28	0.22
	RT	3.71	0.72	0.28	0.18
BRD	**FAO56PM**	2.97	0.86		
	FAO24BC	2.97	0.91	0.24	0.20
	MODTURC	2.87	0.68	0.30	0.20
	TURC	3.14	0.75	0.32	0.21
CHP	**FAO56PM**	2.52	0.41		
	IRMAK3	2.44	0.46	0.23	0.17
	TURC	2.63	0.47	0.25	0.18
	IRMAK2	2.37	0.40	0.26	0.19
IJHP	**FAO56PM**	2.85	0.92		
	FAO24BC	2.93	1.03	0.26	0.19
	TURC	2.98	0.79	0.31	0.24
	FAO24RD	2.99	1.12	0.39	0.27
IMP	**FAO56PM**	3.12	0.71		
	IRMAK3	3.08	0.60	0.27	0.20
	TURC	3.37	0.58	0.39	0.25
	MODTURC	3.39	0.61	0.43	0.32
JK	**FAO56PM**	3.15	0.79		
	FAO24BC	3.24	0.85	0.23	0.16
	TURC	3.23	0.70	0.30	0.18
	RT	3.41	0.82	0.40	0.27
JOW	**FAO56PM**	2.72	0.74		
	TURC	2.87	0.70	0.23	0.14
	RT	2.89	0.80	0.24	0.16
	FAO24BC	2.56	0.80	0.29	0.23
KIP	**FAO56PM**	3.48	0.85		
	IRMAK1	3.52	0.73	0.17	0.14
	FAO24BC	3.53	0.88	0.20	0.15
	TURC	3.41	0.80	0.23	0.12
MEL	**FAO56PM**	3.50	0.83		
	FAO24BC	3.56	0.87	0.21	0.16
	IRMAK1	3.55	0.71	0.21	0.17
	TURC	3.45	0.79	0.23	0.11
PK	**FAO56PM**	3.28	0.73		
	FAO24BC	3.23	0.75	0.15	0.11
	IRMAK1	3.34	0.64	0.20	0.17
	TURC	3.22	0.70	0.24	0.16
SEC	**FAO56PM**	3.33	0.80		
	FAO24BC	3.28	0.81	0.20	0.15
	IRMAK1	3.39	0.69	0.26	0.19
	TURC	3.27	0.73	0.28	0.18
SHL	**FAO56PM**	2.66	0.63		
	TURC	2.69	0.61	0.10	0.07
	1957MAKK	2.52	0.48	0.33	0.26
	IRMAK3	2.51	0.59	0.34	0.24

Note: St.=stations, SD=standard deviation.

Table 4
Station wise ranking measures of first three selected equations against FAO56PM (reference equation) in the EH region.

St.	ET_0 equations (in order of ranking)	Variability measures (mm d^{-1})		Ranking measure (mm d^{-1})	
		Mean	SD	WRMSD	MAE
GTK	**FAO56PM**	2.85	0.61		
	TURC	2.63	0.66	0.32	0.23
	FAO24RD	2.98	0.80	0.34	0.24
	IRMAK3	2.68	0.70	0.35	0.28
PGH	**FAO56PM**	3.05	0.66		
	TURC	3.18	0.66	0.23	0.15
	IRMAK3	2.89	0.63	0.26	0.18
	FAO24RD	3.23	0.73	0.32	0.21

Note: St.=stations, SD=standard deviation.

The weighted RMSD speaks to the capacity of different models with anticipating ET_0 unequivocally amid every one of the months. Additionally, it likewise shows the limit of adjustment using a linear multiplier.

3.4. Ranking of alternative ET_0 equations

The ranking of the equation depended on *WRMSD* and *MAE*. The *WRMSD* was chosen as the useful ranking measure in light of the fact that this demonstrates the ability of the specific equation to estimate ET_0 during all months. *MAE* is a suitable index to quantify normal error extent (Willmott & Matsuura, 2005). Both chosen error measurements, particularly prescribed for climatic variables adequacy assessment (Chai & Draxler, 2014). The final ranking was figured utilizing an average of *WRMSD* and *MAE* i.e. the best model is the one that has the most minimal value acquired by the mean of *WRMSD* and *MAE*.

4. Results

Month to month ET_0 values was estimated for every single chose station as portrayed in Fig. 1. For every site, every tested model was compared with the FAO56PM model utilizing WRMSD, and MAE. The initial three positioned model for every station was chosen initially taking into account the most minimal of the average of WRMSD and MAE and after that the highest r^2 value. Tables 2–4 present the ranking measures values of *WRMSD MAE* . Tables 5–7 depict regression equations and performance measures values of *d*, r^2, *SEE*, for first three selected equations for each station.

4.1. Composite regional results

For each of the three regions, recognized methods had MAE values less than 1.0 mm d^{-1}, recommending that all shortlisted equations give a good estimate of FAO56PM. Over the region, IRMAK3 was distinguished as a most suitable option of FAO56PM with performance indices ($SEE = 0.07$ mm d^{-1}, $d = 0.98$, and $r^2 = 0.98$). The TURC was another reasonable decision for NE, India with performance indices ($SEE = 0.08$ mm d^{-1}, $d = 0.99$, and $r^2 = 0.92$). Detail region specific insightful analysis as takes after.

4.1.1. ABP Region

The mean monthly ET_0 values estimated by first five judged methods and standard FAO56PM are depicted in Fig. 2. Statistical indices of mean monthly ET_0 estimated by first three ranked methods (only top three ranked models discussed herewith) against PMFAO56 summarized in Table 2 for all the selected locations. According to Table 2, all the first three ranked equations showed the values of different error measures lower than 1.0 mm d^{-1} it means all first three methods could be used for reliable ET_0 estimation. Within the region station-wise analysis (Tables 2, 5, and Fig. 2), suggesting that the

Table 5
Station wise performance measures of developed models for first three ranked equations against FAO56PM (reference equation) in the ABP region.

St.	Equation calibrated (X)	Developed regression equation $ET_0=aX+b$	Performance measures			St.	Equation calibrated (X)	Developed regression equation $ET_0=aX+b$	Performance measures		
			SEE (mm d^{-1})	d	r^2				SEE (mm d^{-1})	d	r^2
CHU	IRMAK3	$0.839X+0.67$	0.19	0.95	0.90	**NLMP**	IRMAK3	$0.743X+0.81$	0.23	0.95	0.85
	MODTURC	$0.787X+0.84$	0.17	0.94	0.91		MODTURC	$0.695X+1.07$	0.25	0.91	0.80
	1957MAKK	$0.708X+0.60$	0.10	0.91	0.90		FAO24BC	$0.66X+0.97$	0.35	0.89	0.66
DBRG	IRMAK3	$0.774X+0.61$	0.15	0.96	0.93	**NAK**	IRMAK3	$0.795X+0.62$	0.07	0.98	0.98
	MODTURC	$0.69X+1.0$	0.19	0.94	0.87		IRMAK2	$0.546X+1.2$	0.26	0.86	0.69
	FAO24RD	$0.776X+0.91$	0.21	0.92	0.88		1957MAKK	$0.62X+0.84$	0.15	0.88	0.90
DK	FAO24BC	$0.638X+1.01$	0.13	0.88	0.66	**SIL**	TURC	$0.793X+0.85$	0.21	0.94	0.84
	1957MAKK	$0.581X+0.93$	0.14	0.89	0.88		IRMAK3	$0.777X+0.52$	0.18	0.92	0.88
	IRMAK3	$0.88X+0.63$	0.28	0.90	0.82		FAO24RD	$0.996X+0.26$	0.26	0.93	0.85
DB	IRMAK3	$0.764X+0.71$	0.13	0.97	0.94	**SLC**	IRMAK3	$0.734X+0.81$	0.21	0.94	0.85
	FAO24RD	$0.783X+0.88$	0.23	0.91	0.85		MODTURC	$0.675X+1.15$	0.27	0.91	0.75
	TURC	$0.683X+1.24$	0.19	0.88	0.86		1957MAKK	$0.625X+0.88$	0.19	0.85	0.84
GI	IRMAK3	$0.948X+0.09$	0.23	0.96	0.86	**TZP**	IRMAK3	$0.781X+0.69$	0.13	0.97	0.95
	IRMAK2	$0.844X+0.26$	0.23	0.94	0.83		IRMAK2	$0.641X+0.96$	0.25	0.90	0.77
	1957MAKK	$0.744X+0.45$	0.14	0.93	0.91		FAO24RD	$0.878X+0.65$	0.31	0.91	0.81
GG	IRMAK3	$0.63X+1.18$	0.22	0.93	0.88	**TKB**	FAO24BC	$0.653X+1.05$	0.28	0.91	0.76
	1957MAKK	$0.742X+0.61$	0.19	0.95	0.93		IRMAK3	$0.789X+0.83$	0.25	0.93	0.85
	FAO24BC	$0.758X+0.84$	0.38	0.93	0.79		1957MAKK	$0.608X+0.95$	0.15	0.90	0.91
GHY	IRMAK3	$0.72X+0.82$	0.18	0.95	0.90	**TOC**	IRMAK3	$0.712X+0.89$	0.16	0.95	0.92
	FAO24BC	$0.84X+0.23$	0.28	0.93	0.84		FAO24BC	$0.726X+0.76$	0.21	0.95	0.88
	1957MAKK	$0.64X+0.77$	0.13	0.89	0.93		1957MAKK	$0.667X+0.74$	0.15	0.92	0.92
MAR	FAO24BC	$0.789X+0.5$	0.22	0.95	0.87						
	IRMAK3	$0.861X+0.60$	0.23	0.94	0.88						
	IRMAK2	$0.651X+1.15$	0.29	0.89	0.73						

Note: St.=stations, ET_0 (mm d^{-1}), X=regressed ET_0 Eq. (calibrated method).

IRMAK3 model had the lowest error measures at 11 sites out of 15 selected sites. The lowest values of different statistical measures were observed at NAK ($WRMSD=0.17$ mm d^{-1}, $MAE=0.14$ mm d^{-1}, $SEE=0.07$ mm d^{-1}, $d=0.98$, and $r^2=0.98$), while highest at GG ($WRMSD=0.43$ mm d^{-1}, $MAE=0.35$ mm d^{-1}, $SEE=0.22$ mm d^{-1}, $d=0.93$, and $r^2=0.88$).

The FAO24BC model followed as it is ranked first in MAR ($WRMSD=0.30$ mm d^{-1}, $MAE=0.24$ mm d^{-1}, $SEE=0.22$ mm d^{-1}, $d=0.95$, and $r^2=0.87$) and TKB ($WRMSD=0.38$ mm d^{-1}, $MAE=0.34$ mm d^{-1}, $SEE=0.28$ mm d^{-1}, $d=0.91$, and $r^2=0.76$). It was ranked second at TOC (Table 2).

The MODTURC ranked second at four sites. The different assessment measures are ($WRMSD=0.34$ mm d^{-1}, $MAE=0.24$ mm d^{-1}, $SEE=0.17$ mm d^{-1}, $d=0.94$, and $r^2=0.91$ for CHU), ($WRMSD=0.30$ mm d^{-1}, $MAE=0.24$ mm d^{-1}, $SEE=0.25$ mm d^{-1}, $d=0.91$, and $r^2=0.85$ for NLMP), and ($WRMSD=0.38$ mm d^{-1}, $MAE=0.30$ mm d^{-1}, $SEE=0.27$ mm d^{-1}, $d=0.91$, and $r^2=0.75$ for SLC).

Another promising equation in the region is 1957MAKK it secured the third rank at 6 sites (Table 2).The lowest values of different goodness of fit measures ($WRMSD=0.24$ mm d^{-1}, $MAE=0.24$ mm d^{-1}, $SEE=0.24$ mm d^{-1}, $d=0.93$, and $r^2=0.91$ for GI), and highest at SLC ($WRMSD=0.57$ mm d^{-1}, $MAE=$

Table 6
Station wise performance measures of developed models for first three ranked equations against FAO56PM (reference equation) in the NEH region.

St.	Equation calibrated (X)	Developed regression equation $ET_0=aX+b$	Performance measures			St.	Equation Calibrated (X)	Developed regression equation $ET_0=aX+b$	Performance measures		
			SEE (mm d^{-1})	d	r^2				SEE (mm d^{-1})	d	r^2
AGTL	FAO24RD	$1.001X+0.16$	0.22	0.93	0.81	**JOW**	TURC	$0.847X+0.61$	0.17	0.94	0.95
	TURC	$0.737X+0.84$	0.29	0.90	0.74		RT	$1.066X-0.021$	0.19	0.98	0.98
	FAO24BC	$0.99X+0.31$	0.33	0.93	0.90		FAO24BC	$1.036X-0.027$	0.19	0.97	0.94
AZ	TURC	$0.835X+0.50$	0.18	0.97	0.91	**KIP**	IRMAK1	$0.849X+0.56$	0.11	0.99	0.98
	IRMAK2	$0.729X+0.54$	0.11	0.95	0.96		FAO24BC	$1.06X+0.001$	0.18	0.99	0.95
	RT	$1.018X+0.09$	0.16	0.97	0.95		TURC	$0.913X+0.23$	0.19	0.98	0.94
BRD	FAO24BC	$1.02X-0.064$	0.24	0.98	0.93	**MEL**	FAO24BC	$1.014X+0.01$	0.19	0.98	0.95
	MODTURC	$0.778X+0.56$	0.15	0.97	0.95		IRMAK1	$0.829X+0.65$	0.14	0.98	0.96
	TURC	$0.835X+0.65$	0.20	0.96	0.93		TURC	$0.916X+0.25$	0.21	0.98	0.93
CHP	IRMAK3	$0.994X-0.070$	0.20	0.93	0.81	**PK**	FAO24BC	$1.051X-0.12$	0.13	0.99	0.97
	TURC	$1.038X+0.018$	0.19	0.93	0.83		IRMAK1	$0.853X+0.53$	0.16	0.98	0.93
	IRMAK2	$0.887X+0.130$	0.16	0.92	0.82		TURC	$0.911X+0.23$	0.22	0.97	0.90
IJHP	FAO24BC	$1.086X-0.17$	0.22	0.98	0.95	**SEC**	FAO24BC	$0.977X+0.02$	0.19	0.98	0.94
	TURC	$0.816X+0.651$	0.22	0.97	0.92		IRMAK1	$0.821X+0.66$	0.20	0.97	0.91
	FAO24RD	$1.61X-0.321$	0.28	0.97	0.93		TURC	$0.865X+0.38$	0.24	0.96	0.89
IMP	IRMAK3	$0.780X+0.64$	0.21	0.96	0.88	**SHL**	TURC	$0.933X+0.20$	0.08	0.95	0.92
	TURC	$0.771X+0.953$	0.17	0.93	0.91		1957MAKK	$0.713X+0.62$	0.17	0.93	0.87
	MODTURC	$0.794X+0.903$	0.22	0.92	0.87		IRMAK3	$0.852X+0.23$	0.25	0.93	0.82
JK	FAO24BC	$1.034X-0.024$	0.19	0.98	0.95						
	TURC	$0.819X+0.64$	0.25	0.96	0.87						
	RT	$0.995X+0.27$	0.20	0.96	0.94						

Note: St.=stations, ET_0 in (mm d^{-1}), X=regressed ET_0 Eq. (calibrated methods).

Table 7
Station wise performance measures of developed models for first three ranked equations against FAO56PM (reference equation) in the EH region.

St.	Equation calibrated (*X*)	Developed regression equation $ET_0 = aX + b$	Performance measures		
			SEE (mm d^{-1})	*d*	r^2
GTK	TURC	1.04X − 0.34	0.14	0.96	0.95
	FAO24RD	1.23X − 0.55	0.24	0.95	0.91
	IRMAK3	1.05X − 0.31	0.27	0.94	0.85
PGH	TURC	0.962X + 0.24	0.16	0.97	0.94
	IRMAK3	0.939X + 0.02	0.13	0.97	0.96
	FAO24RD	1.065X − 0.061	0.18	0.96	0.93

Note: St. = stations, ET_0 in (mm d^{-1}), *X* = regressed ET_0 Eq. (calibrated methods).

0.39 mm d^{-1}, $SEE = 0.19$ mm d^{-1}, $d = 0.85$, and $r^2 = 0.84$).

All in all, the IRMAK3 equation was closest to FAO56PM with mean deviation ranged from 0.3% to 0.6% of FAO56PM, which is well within the suggested limit of 15% by Hargreaves and Allen (2003) and Allen (1996). The IRMAK3 is the multilinear regression model, which assumes that each input variable has an independent impact on output irrespective the other inputs. The superior performance of IRMAK3 model confirms that radiation and temperature extreme is the dominant factors to drive the ET_0 process while wind speed has a very less impact. Findings of the present investigation are similar to Allen et al. (1998) suggestions that under humid environment wind speed, only reduce the saturation level of the air slightly consequently, wind speed has very less impact on ET_0. Another interesting model for the region is

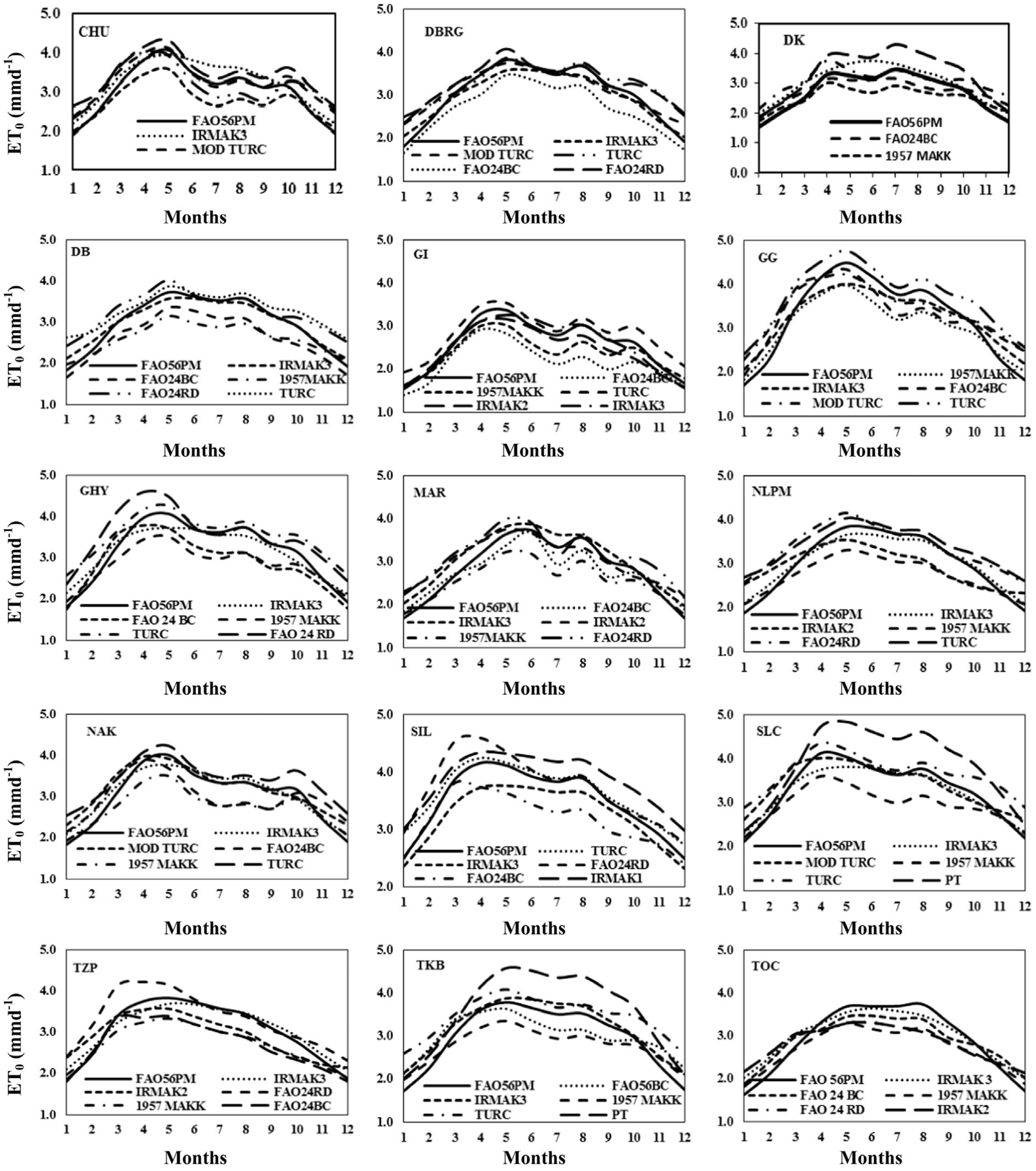


Fig. 2. Station wise intercomparisons of top five ranked methods with FAO56PM for ABP region.

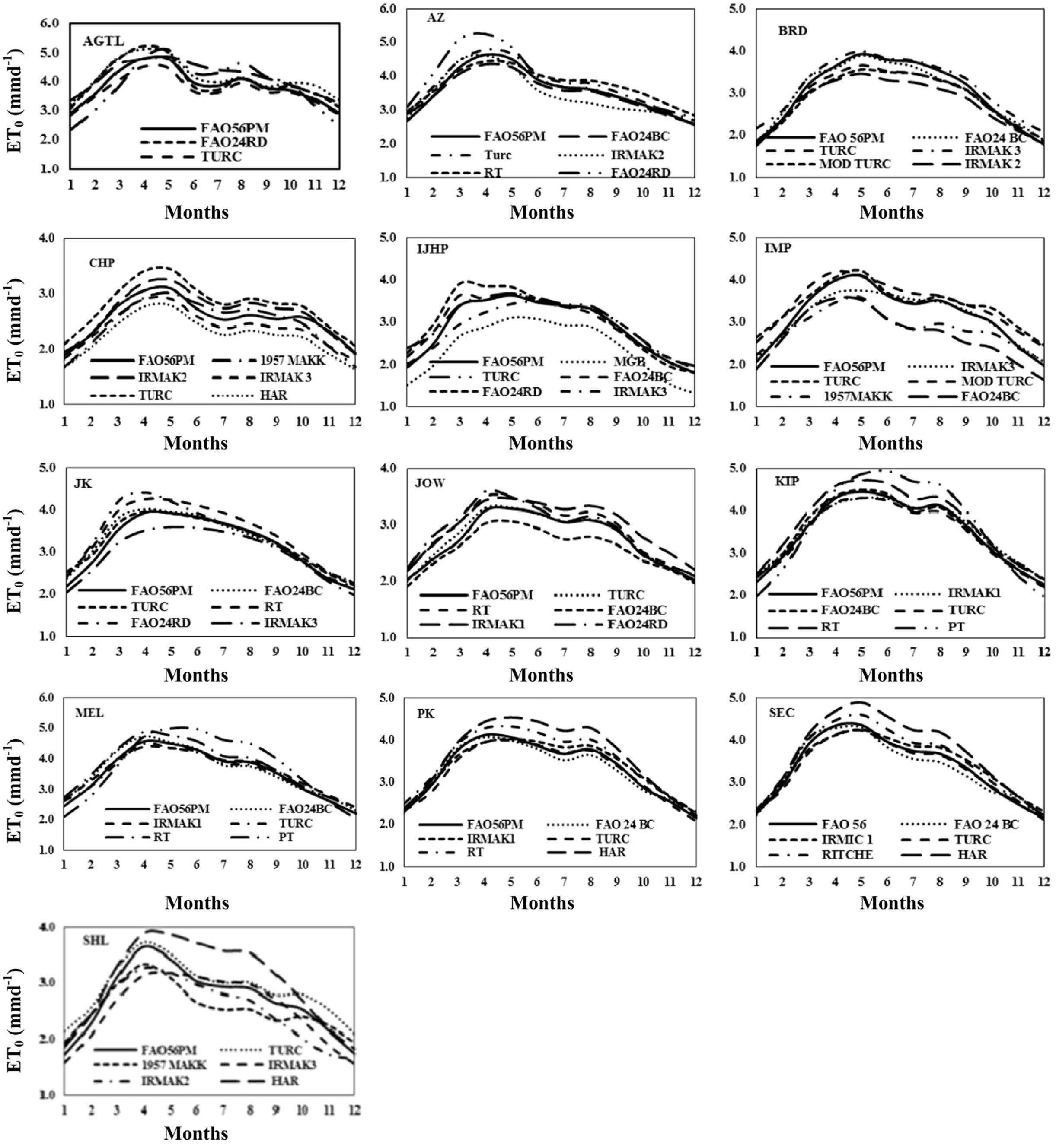


Fig. 3. Station wise intercomparisons of top five ranked methods with FAO56PM for NEH region.

MODTURC showed the potential to quantify ET_0 accurately. In contrast, to IRMAK3, it requires an addition parameter of long-term, average annual wind speed data. It may be due to terrain influence on the wind speed of those particular stations.

The highest underestimation was observed in the case of 1957MAKK model, is another closely following equation to IRMAK3 for the study region. It tended to underestimate consistently reference ET_0, although the largest underestimation (10.12%) is well within the recommended limit of 15%.

4.1.2. NEH region

The ET_0 assessed in the present study through radiation-based methods are closely associated with FAO56PM (Table 6, and Fig. 3). The different statistical indices of radiation-based methods were superior to of temperature-based methods. Among the radiation-based methods the TURC model was observed to be the best suitable option at different stations such as AZ (*WRMSD*=0.24 mm d^{-1}, *MAE*=0.15 mm d^{-1}, *SEE*=0.18 mm d^{-1}, *d*=0.97, r^2=0.91), JOW (*WRMSD*=0.32 mm d^{-1}, *MAE*=0.07 mm d^{-1},*SEE*=0.08 mm d^{-1}, *d*= 0.99, and r^2=0.95), SHL (*WRMSD*=0.10 mm d^{-1}, *MAE*=0.07 mm d^{-1}, *SEE*=0.08 mm d^{-1}, *d*=0.99, and r^2=0.92).

The station wise analysis (Table 3), suggesting that the TURC model ranked second best at (AGTL,CHP,IJHP,IMP, JK).The lowest values of different statistical measures was observed at JK (*WRMSD*=0.30 mm d^{-1}, *MAE*=0.25 mm d^{-1}, *SEE*=0.22 mm d^{-1}, *d*=0.96, and r^2=0.87), while highest at AGTL (*WRMSD*= 0.42 mm d^{-1}, *MAE*=0.27 mm d^{-1}, *SEE*=0.29 mm d^{-1}, *d*=0.90, and r^2=0.84).

The TURC method ranked third at BRD, KIP, MEL, PK, and SEC (Table 3). The values of different error measures (*WRMSD*=0.32 mm d^{-1}, *MAE*=0.21 mm d^{-1}, *d*=0.96, *SEE*=0.20 mm d^{-1}, and r^2=0.93 for BRD), and for KIP (*WRMSD*=0.23 mm d^{-1}, *MAE*=0.12 mm d^{-1},

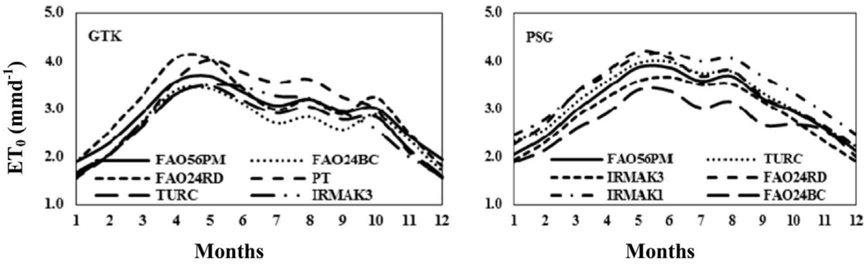


Fig. 4. Station wise intercomparisons of top five ranked methods with FAO56PM for EH region.

d=0.98, SEE=0.19 mm d^{-1}, and r^2=0.95). At MEL, PK error statistics ($WRMSD$=0.23 mm d^{-1}, and 0.24, MAE=0.11 mm d^{-1}, 0.16 mm d^{-1}, d=0.98, and 0.97, SEE=0.21 mm d^{-1}, and 0.22 mm d^{-1}, r^2=0.95, and 0.97, respectively). For SEC site error indices ($WRMSD$=0.28 mm d^{-1}, MAE=0.18 mm d^{-1}, d=0.96, SEE=0.24 mm d^{-1}, and r^2=0.94).

Another promising equation for the region is FAO24BC, which ranked, first at the stations (BRD, IJHP, JK, MEL, PK, and SEC). Station wise analysis (Tables 3, 6, and Fig. 3), suggesting that the FAO24BC model had the lowest error measures at 6 sites out of 13 selected sites. The lowest values of different statistical measures was observed at PK ($WRMSD$=0.15 mm d^{-1}, MAE=0.11 mm d^{-1}, SEE=0.07 mm d^{-1}, d=0.99, and r^2=0.97), while highest at BRD ($WRMSD$=0.24 mm d^{-1}, MAE=0.20 mm d^{-1}, SEE=0.24 mm d^{-1}, d=0.98, and r^2=0.93). It ranked second at KIP ($WRMSD$= 0.20 mm d^{-1}, MAE=0.15 mm d^{-1}, SEE=0.18 mm d^{-1}, d=0.99, and r^2=0.95) and third at AGTL, and JOW (Table 3).

The mean monthly ET_0 values estimated by first five ranked methods stated in Fig. 3. The study showed that the monthly pattern of different methods is not similar. However, TURC method and FAO24BC method showed a similar trend to that of the FAO56PM method. The TURC method slightly underestimates ET_0, while FAO24BC slightly overestimate the ET_0 values at most of the stations.

Hence, in the NEH region, TURC performed very well, being in the first three ranks at around 90% stations of the region, followed by FAO24BC.

Taking into account our findings, it might construe that the performance of the particular model is by all accounts more subject to the individual model structure instead of model sort (i.e., radiation- or temperature-based). In particular, FAO24BC (a temperature model) and TURC (a radiation model) both performed well and 1957MAKK (radiation based) indicated less encouraging fits. One reason of this may be in a humid climate, radiation and temperature are the primary controlling component of evapotranspiration process.

4.1.3. EH region

Two Stations fall under EH, region i.e. GTK and PSG. TURC was ranked first at both the stations ($WRMSD$=0.32 mm d^{-1} and 0.23 mm d^{-1}, MAE=0.23 mm d^{-1} and 0.15 mm d^{-1}, d=0.96, and 0.97, and SEE=0.14 mm d^{-1}, and 0.16 mm d^{-1}, respectively). Analysis of results revealed that the other suitable choice for the region is FAO24RD and IRMAK3 in order of ranking (Table 4). Different error statistics for both equations at GTK ($WRMSD$=0.34 mm d^{-1} and 0.35 mm d^{-1}; MAE=0.24 mm d^{-1}, and 0.28 mm d^{-1}; d=0.95 and 0.94, SEE=0.24 mm d^{-1}, and 0.27 mm d^{-1}, respectively). At PSG site, IRMAK3, was ranked second, and FAO24 RD as third with values of error statistics ($WRMSD$=0.26 mm d^{-1} and 0.32 mm d^{-1}, MAE=0.18 mm d^{-1}, and 0.21 mm d^{-1}, d=0.97 and 0.96, SEE=0.13 mm d^{-1},and 0.18 mm d^{-1}, r^2=0.96 and 0.93, respectively) (Table 4). Hence in EH region, TURC is the best choice followed by FAO24RD and IRMAK3.

Overall, based on present investigation the TURC models is the suitable choice in NEH, and EH regions, and well correlated with the findings of (Yoder et al., 2005; Irmak et al., 2008; Martinez & Thepadia, 2010), they advocated TURC under limiting data condition when wind speed data is missing.

4.2. Regression equations

Simple regression models developed for top three ranked equations based on WRMSD and MAE for all the sites. The execution of the created regression models assessed in regards to the standard error of estimate (SEE) and r^2 values obtained in the validation phase through the comparison with FAO56PM. The established regression equations and their associated validation performance statistics are depicted in Table 5 (for ABP region), in Table 6 (for NEH region), and Table 7 (for EH region). As can be seen from Tables 5–7 that the developed regression model performed better than the original form in yielding ET_0 values similar to the FAO56PM. As can be seen from Fig. 2 (for ABP region), Fig. 3 (for NEH region), and Fig. 4 (for EH region), that the month to month intercomparison of region specific stations insightful main five ranked methods with FAO56PM. Findings additionally support that the identified equations can be utilized to foresee the ET_0 values with reasonable precision.

5. Discussion

Evapotranspiration is an imperative controlling component in hydrological processes. As of late, McVicar et al. (2012) uncovered that diminishing evaporative demand was globally widespread, and climate change will disturb the hydrological cycle mainly through evapotranspiration. Accurate accounting of ET_0, particularly in the context of climate change, is, crucial. The execution of 18 different ET_0 methods was tried to recognize a suitable method for assessing and anticipating ET_0 over the considered area.

Among the selected methods, radiation-based methods performed superior regarding producing a similar pattern as generated by the FAO56PM. The IRMAK3, TURC, FAO24BC, and 1957MKK, methods showed higher accuracy. Moreover, FAO24BC (temperature-based) demonstrated the capability to estimate ET_0 with reasonable accuracy. The performance of IRMAK3 found best, in the ABP region at 11 stations out of fifteen stations, followed by FAO24BC and 1957MAKK. The TURC ranked among first three methods for NEH Region, trailed by FAO24BC and IRMAK3. In EH region, TURC ranked first, followed by FAO24RD. The IRMAK3 and TURC methods yielded the highest association based on $WRMSD$, MAE, SEE, d, and r^2 among the radiation-based Equations. However, the predictive ability of these two methods is almost similar, as both also secured top ranks at limiting data sites. Among the temperature-based methods, FAO24BC performed the best. However, the HAR equations performed poorly (secured fifth rank only at two locations in the NEH region). All the selected methods showed variability in performance in the selected study region. Findings of results, support that the selected method is more relevant to ET_0 estimation compared to available data, because simpler methods over performed with sophisticated methods.

The superior execution of the radiation based methods acquired in this study is in good concurrence with the findings in another humid environment, for example, George and Raghuwanshi (2012), Jensen et al. (1990), Tabari et al. (2011) and Yoder et al. (2005). Findings recommend presuming that the radiation-based models are a reasonable decision for ascertaining ET_0 in the study range. The unsuitable execution of the other chose methods, for example, JH found in the present examination corresponding great with the outcomes found in other humid atmospheres as reported (Irmak et al., 2003; Irmak, Irmak, Allen, & Jones, 2003; Trajkovic & Kolakovic 2009a).

The developed regression equations for top three ranked methods can be used for estimates ET_0 with higher accuracy compare to the original equation. Therefore, these equations can aid as a beneficial tool for a reliable estimate.

6. Conclusions

This study evaluated the performance of 18 ET_0 equations against the FAO56PM equation under the climatic conditions in the NE, India.

Radiation-based equations of IRMAK3, TURC, 1957MAKK, and MODTURC had superior and consistent performance in all the three regions, hence recommended under limiting data conditions in the North East India.

Among the temperature-based equations, the FAO24BC performed satisfactorily, and secured third rank across the category. However, all other selected methods in this category performed poorly.

All in all, the best five equations (i.e. four radiations-one temperature-based) that could be utilized as a suitable option for FAO56PM are ranked as follows: IRMAK3, TURC, FAO24BC,1957-MAKK, and MODTRUC. However, these equations may need calibrations in the comparative new region to signify changes in climatic variables.

In general, the superior performance of radiation based models confirms that the temperature extreme and radiation are the dominant factors to drive ET_0 process in the region while wind speed has a very less impact.

The result in of this study gives helpful data and documentation to choose more exact ET_0 estimations in the region under limiting data conditions. The developed regression models are useful to the precise agricultural water management, regional water resources planning, and other hydrological modeling related studies that can aid in more proficient and viable water resources management.

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