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Calibration, Validation and Evaluation of Temperature- and Radiation-based and Valiantzas' ET_0 Equations at Humid Dehradun District of Uttarakhand

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Abstract: The present study was undertaken to calibrate, validate and evaluate the performance of some temperature- & radiation-based and Valiantzas' ET_0 equations in comparison to standard FAO56-PM model in humid climatic conditions prevailing at Dehradun district of Uttarakhand (India). Prior to analysis, quality control of 31 years (1989-2019) daily meteorological dataset was ensured by omitting days with missing data and neglecting outliers. For calibration, 65% dataset (20 years, 1989-2008) was considered while, remaining 35% dataset (11 years, 2009-2019) was utilized for validation. The analysis showed that almost all calibrated equations performed well with higher value of Agreement index (D), reduced errors (RMSE, MAXE, PE) and nearby optimum value of ratio (R) of $ET_{0method}$ to $ET_{0FAO56\text{-}PM}$. The global performance indicator (GPI) analysis revealed that Valiantzas' V3 equation performed best among all considered equations.

Keywords: Calibration, Temperature-based, Radiation-based, Valiantzas', Reference evapotranspiration

Water is becoming a scarce commodity day-by-day due to increasing human population, urbanization, industrial development, severe negligence, and over-exploitation. It is estimated that per capita availability of water on annual basis in Indian conditions has been reduced from 1816 m^3 in 2001 to 1544 m^3 in 2011 (CWC 2015) which is expected to further drop down to 1140 m^3 in 2050 (Lal and Stewart 2012). Evapotranspiration (ET) being one of the basic elements of hydrological cycle is a very important and essential parameter for a large number of scientific and management studies including that of agriculture, crop simulation models, crop water requirement, environmental assessment, hydrology, irrigated areas, irrigation scheduling, watershed etc. (Bautista et al 2009, Sentelhas et al 2010, Vazquez and Hampel 2014). The most weather elements affecting evapotranspiration are air temperature, humidity, radiation, and wind speed (Nassif et al 2021). The calculated values of ET help in determining reference evapotranspiration (ET_0), which can be estimated either using lysimeters or meteorological data (Lopez-Urrea et al 2006) but as lysimeters are very expensive, takes more time to install and requires more maintenance, several equations were developed to indirectly estimate ET_0 from meteorological data causing confusion to select any specific equation as "standard". The Food and Agricultural Organization (FAO) of the United Nations proposed Penman-Monteith model in its Irrigation and Drainage Paper No. 56 (referred to as FAO56-PM model as "standard" and researchers have confirmed its superior performance over other ET_0 equations in different climatic conditions across the globe. A number of researchers recommended local calibration of existing empirical ET_0 equations before utilizing them due to their widely non-consistent performance as they optimally perform only under specific climatic conditions for which they were originally being developed. In order to use them at other places having less meteorological parameters and/or at different climatic condition, their local calibration is essentially required (Pereira et al 2006, Bautista et al 2009). The standard FAO56-PM model can be used to calibrate and validate empirical equations for new regions as per the recommendation of FAO Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements. Some of existing ET_0 equations were calibrated, validated and evaluated by various researchers (Criestia et al 2013, Heydari and Heydari 2014, Tomar 2016) throughout the globe for different climatic conditions against standard FAO56-PM model. From above, it is evident that no information on calibration, validation, and evaluation of ET_0 equations for Indian humid locations is available. Therefore, an attempt has been made in the present study to calibrate, validate, and evaluate the performance of some existing ET_0 equations for humid Dehradun district of Uttarakhand considering standard FAO56-PM model as an index.

MATERIAL AND METHODS

The study was carried out for humid Dehradun district

(78°04'E longitude, 32°19'N latitude and 516.5 m above m.s.l.) of Uttarakhand state using 31 years (1989-2019) of daily dataset consisting of all required meteorological parameters. Prior to analysis, quality control of dataset was ensured by removing days with missing data and avoiding outliers. For calibration, 65% dataset (20 years, 199-2008) was utilized while remaining 35% dataset of 11 years (2009-2019) was used for validation.

Reference Evapotranspiration Estimation

FAO-56 PM model: The recommended form of FAO56-PM model consisting of aerodynamic and surface resistance terms (Allen et al. 1998) is presented as Equation 1:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad (1)$$

Where ET_0 = reference evapotranspiration (mm/day), Δ = slope of vapour pressure curve (kPa/°C), R_n = net radiation at crop surface (MJ/m^2/day), G = soil heat influx density (MJ/m^2/day), γ = psychrometric constant (kPa/°C), T = mean daily air temperature (°C), U_2 = wind speed at 2 m height (m/sec), e_s = saturation vapour pressure (kPa), e_a = actual vapour pressure (kPa). The nature of climate system allows soil heat flux density (G) on daily timescale to be ignored as on daily basis, its value is nearly zero (Allen et al. 1998).

ET_0 equations considered: Pertinent details of ET_0 equations considered in this study are presented in Table 1.

Calibration coefficient determination: In this study, the procedure outlined in Tabari and Talaee (2011) for calculating calibration coefficient was adopted and its simplified procedure consists of two-steps as, (i) calculating ratio (R) as $ET_{0method}/ET_{0FAO56\text{-}PM}$, and (ii) multiplying inverse of this ratio (1/R) with original coefficient to get calibrated coefficient.

Statistical analysis and ranking: For comparing the performance of all considered ET_0 equations against standard FAO56-PM model, statistical analysis in terms of Agreement index (D), Root mean square error (RMSE), Maximum absolute error (MAXE), and Percent error of estimate (PE) was conducted while, Global performance indicator (GPI) was used for ranking purpose (Table 2) which extends combined normalized effect of all considered statistical indices between their minimum and maximum values of "0.00" and "1.00", respectively (Despotovic et al 2015).

RESULTS AND DISCUSSION

The performance of considered ET_0 equations against standard FAO56-PM model in terms of calibration coefficient and percent deviation from their corresponding original values, statistical indices (D, RMSE, MAXE, PE) and ratio (R) of $ET_{0method}$ to $ET_{0FAO56\text{-}PM}$ are presented in Table 3 and Table 4, respectively while, their overall ranking is presented in Table 5.

Calibration Coefficient

Temperature-based equations: The calibration coefficient of ALN and BR equations as 0.00186 and 0.09227 was lowered to 37.78 and 41.23% in comparison to their respective original values of 0.0030 and 0.157, respectively. At the study area, calibration coefficient of DA equation with 38.00% lower deviation in comparison to its original coefficient (0.0025) was obtained as 0.00155. Likewise, calibration coefficient for HAR and HH equations as 0.00151 and 0.00144, respectively was 34.35 and 37.39% lesser in comparison to their original coefficient of 0.0023. For KHA and SAM equations, calibration coefficient of 0.00780 was found lowered by 42.22% in comparison of its original coefficient of 0.0135. The calibration coefficient of TRA equation (0.00184) was f20.00% decreased in comparison to its original counterpart (0.0023). The calibrated temperature-based ET_0 equations extended decrement in value of calibration coefficient in between 20.00% (TRA) and 42.22% (SAM).

Radiation-based equations: The calibration coefficient of radiation-based equations was decreased in the range from 8.05% (MPT) to 42.62% (MB) while, 4.83% increment in its value was observed with SS equation (Table 3). For BG and CAP equations, calibration coefficient was obtained as 1.08490 and 4.23329 which was lower to the tune of 34.25% and 30.60% in comparison to their original coefficients of 1.65 and 6.1, respectively. At humid Dehradun district, calibration coefficient of HAN equation was found 18.09% lesser, yielding its value as 0.57334 in comparison to original coefficient of 0.70. Similarly, calibration coefficient of IRS and MB equations as 0.12627 and 0.00844 was 15.26 and 42.62% lower in comparison to their respective original coefficients of 0.149 and 0.01471. In comparison to original coefficient (1.18), calibrated MPT equation produced 8.05% lower value of coefficient as 1.08502 while, its value for SS equation (0.07338) was found 4.83% higher in comparison to its original coefficient of 0.07.

Valiantzas' equations: The calibrated Valiantzas' equations produced lower correlation coefficients in the range from 3.23% (V3) to 26.64% (V6). For V1 and V2 equations, calibration coefficients as 0.04673 and 0.04358 were found lower to the tune of 8.37 and 14.55%, respectively in comparison to their original coefficient (0.051) while, for V3, V4, V5 and V6 equations, in comparison to their original coefficient of 0.0393, lower values of calibration coefficients as 0.03803, 0.03006, 0.02976 and 0.02883 were obtained. Likewise, calibration coefficient for V7 equation as 0.01618 was found 24.39% lower in comparison to its original coefficient of 2.4.

Performance of calibrated ET_0 equations vs standard

FAO56-PM model: In almost all cases, calibrated equations produced higher D values, lower errors (RMSE, MAXE, PE) with value of ratio (R) near to 1.00 indicating closer ET_0 estimates to that of standard FAO56-PM model (Table 4). The pertinent details are discussed hereunder as:

Temperature-based equations: Except SAM equation, all calibrated ET_0 equations produced higher values of D (>0.95) and its highest value (0.9845) was obtained with TRA equation. The increment in D value was in the range from 11.67% (TRA) to 65.51% (SAM). The values of RMSE, MAXE, and PE with calibrated equations showed decrement ranging from 68.32% (SAM) to 85.79% (ALN), 62.71% (TRA) to 81.95% (DA), and 80.64% (TRA) to 91.21% (ALN), respectively. The TRA equation produced best ratio (R) of 1.1155 while, SAM equation produced worst result.

Radiation-based equations: For calibrated radiation-based

Table 1. Different ET_0 equations considered in the study

Equation (Notation)	Representative mathematical form	Reference	Eq. No.
Temperature-based equations			
Allen (ALN)	$ET_0 = 0.408 \times 0.0030R_a(T + 20.0)(T_{max} - T_{min})^{0.40}$	Allen (1993)	(3)
Baier-Robertson (BR)	$ET_0 = 0.157T_{max} + 0.158(T_{max} - T_{min}) + 0.109R_a - 5.39$	Baier and Robertson (1965)	(4)
Droogers-Allen (DA)	$ET_0 = 0.408 \times 0.0025R_a(T + 16.8)(T_{max} - T_{min})^{0.50}$	Droogers and Allen (2002)	(5)
Hargreaves (HAR)	$ET_0 = 0.408 \times 0.0023R_a(T + 17.8)(T_{max} - T_{min})^{0.50}$	Hargreaves (1994)	(6)
Heydari-Heydari (HH)	$ET_0 = 0.408 \times 0.0023R_a(T + 5.9519)(T_{max} - T_{min})^{0.611}$	Heydari and Heydari (2014)	(7)
Samani (SAM)	$ET_0 = 0.408 \times 0.0135R_a(T + 17.8)(T_{max} - T_{min})^{0.50}[0.00185(T_{max} - T_{min})^2 - 0.0433(T_{max} - T_{min}) + 0.4023]$	Samani (2004)	(8)
Trajkovic (TRA)	$ET_0 = 0.0023R_a(T + 17.8)(T_{max} - T_{min})^{0.424}$	Trajkovic (2005)	(9)
Radiation-based equations			
Berengena-Gavilan(BG)	$ET_0 = 0.408 \times 1.65\left(\frac{\Delta}{\Delta + \gamma}\right)(R_n - G)$	Berengena and Gavilan (2005)	(10)
Caprio (CAP)	$ET_0 = 6.1 \times 10^{-6}R_s(1.8\,T + 1.0)$	Caprio (1974)	(11)
Hansen (HAN)	$ET_0 = 0.408 \times 0.70\left(\frac{\Delta}{\Delta + \gamma}\right)R_s$	Hansen (1984)	(12)
Irmak-R_s (IRS)	$ET_0 = 0.149R_s + 0.079T - 0.611$	Irmak et al. (2003)	(13)
McGuinness-Bordne (MB)	$ET_0 = \left\{(0.0082T - 0.19)\left(\frac{R_s}{1500}\right)\right\} \times 2.54$	McGuinness and Bordne(1972)	(14)
Modified Priestley-Taylor (MPT)	$ET_0 = 0.408 \times 1.18\left(\frac{\Delta}{\Delta + \gamma}\right)(R_n - G)$	Abtew (1996)	(15)
Stephens-Stewart (SS)	$ET_0 = 0.408 \times (0.0148\,T + 0.07)R_s$	Stephens and Stewart (1963)	(16)
Valiantzas' equations			
Valiantzas 1 (V1)	$ET_0 = 0.051(1 - \alpha)R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + 0.052(T + 20)(1 - 0.01RH)(a_u - 0.38 + 0.54U_2)$	Valiantzas (2006)	(17)
Valiantzas 2 (V2)	$ET_0 = 0.051(1 - \alpha)R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + 0.048(T + 20)(1 - 0.01RH)(0.50 + 0.536U_2)$	Valiantzas (2006)	(18)
Valiantzas 3 (V3)	$ET_0 = 0.0393R_S\sqrt{T + 9.5} - 2.4\left(\frac{R_S}{R_a}\right)^2 - 0.024(T + 20)(1 - 0.01RH) + 0.066W_{aero}(T + 20)(1 - 0.01RH){U_2}^{0.6}$ W_{aero} = 0.78, when RH > 65%; and W_{aero} = 1.067, when RH ≤ 65%.	Valiantzas (2013c)	(19)
Valiantzas 4 (V4)	$ET_0 = 0.0393R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + C_u(T + 20)(1 - 0.01RH)$ C_u = 0.054 when RH > 65%; and C_u = 0.083 when RH ≤ 65%	Valiantzas (2015)	(20)
Valiantzas 5 (V5)	$ET_0 = 0.0393R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + C_u(T + 20)(1 - 0.01RH)$ $C_u = 0.076–0.0119\,(RH-50)^{0.2}$, when RH >50%, and $C_u = 0.076+0.0084\,(50-RH)^{0.2}$, when RH ≤50%	Valiantzas (2015)	(21)
Valiantzas 6 (V6)	$ET_0 = 0.0393R_s\sqrt{T + 9.5} - 0.19{R_s}^{0.6}\varphi^{0.15} + 0.0061(T + 20)(1.12T - T_{min} - 2)^{0.7}$	Valiantzas (2013a)	(22)
Valiantzas 7 (V7)	$ET_0 = 0.051(1 - \alpha)R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + 0.075(T + 20)(1 - 0.01RH)$	Valiantzas (2013b)	(23)

ET_0 = reference evapotranspiration (mm/day), R_s= solar radiation (MJ/m^2/day),R_a= extra-terrestrial radiation (MJ/m^2/day), T = mean air temperature (°C), RH = relative humidity (%), U_2= wind speed at 2 m height (m/sec), TR = temperature difference (°C), T_{dew}= dew point temperature (°C), T_{max}= maximum air temperature (°C), T_{min}= minimum air temperature (°C), equations, value of D was vary in between 0.9364 (HAN) and 0.9934 (CAP). The increment in D value was observed in between 0.58% (MPT) and 64.43% (MB) while, with HAN equation, its value was decreased to the tune of 2.76%. The values of RMSE, MAXE, and PE with calibrated equations varied in the range from 0.1961 mm/day (CAP) to 0.6312 mm/day (MB), 0.2700 mm/day (BG) to 1.8400 mm/day (MB), and 1.4769% (MPT) to 9.7139% (MB), respectively. The values of RMSE, MAXE, and PE were decreased in the range from 26.39 (MPT) to 85.49% (BG), 30.09 (IRS) to 89.16% (BG), and 13.52 (HAN) to 92.02% (BG), respectively while, highest increment in RMSE and PE were obtained with HAN and SS equations to the tune of 20.60 and 75.00%, respectively. The calibrated BG and MPT equations both yielded best result in terms of ratio (R) as 0.9851 with respective decrement of 34.24 and 8.05% while, IRS equation was adjudged worst with R value of 1.1129.

Valiantzas' equations: The calibrated Valiantzas equations produced higher D values [0.9489 (V6) to 0.9974 (V3)], lower RMSE values [0.1241 mm/day (V3) to 0.4682 mm/day (V6)], lower MAXE values [0.1600 mm/day (V1) to 0.6379 mm/day (V6)], and lower PE values [1.8982% (V3) to 5.6618% (V6)]. Except V1, all other equations produced higher D values in the range from 0.04% (V3) to 8.93% (V4) while, RMSE, MAXE, and PE values were lowered in the range from 8.07 (V3) to 65.39% (V4), 43.59 (V3) to 75.27% (V4), and 3.49 (V3) to 91.65% (V4), respectively. The calibrated V2 equation yielded best value of R as 0.9992.

Ranking of considered ET_0 equations: The normalized values of statistical indices and overall ranking of calibrated equations revealed that no temperature-based equation could make its place among top three positions, however, Valiantzas' V3 equation performed best, followed by two radiation-based (BG and MT) equations with corresponding GPI values of 0.3439, 0.2940, and 0.2916 while, temperature-based SAM equation with least GPI value of -

Table 3. Original and calibration coefficients of ET_0 equations

Equation (s)	Coefficient (s)		
	Original	Calibration	
Temperature-based equations			
ALN	0.0030	0.00186	(-37.78%)
BR	0.157	0.09227	(-41.23%)
DA	0.0025	0.00155	(-38.00%)
HAR	0.0023	0.00151	(-34.35%)
HH	0.0023	0.00144	(- 37.39%)
SAM	0.0135	0.00780	(-42.22%)
TRA	0.0023	0.00184	(- 20.00%)
Radiation-based equations			
BG	1.65	1.08490	(- 34.25%)
CAP	6.1	4.23329	(- 30.60%)
HAN	0.70	0.57334	(- 18.09%)
IRS	0.149	0.12627	(- 15.26%)
MB	0.01471	0.00844	(- 42.62%)
MPT	1.18	1.08502	(- 8.05%)
SS	0.07	0.07338	(+ 4.83%)
Valiantzas' equations			
V1	0.051	0.04673	(- 8.37%)
V2	0.051	0.04358	(- 14.55%)
V3	0.0393	0.03803	(- 3.23%)
V4	0.0393	0.03006	(- 23.51%)
V5	0.0393	0.02976	(- 24.27%)
V6	0.0393	0.02883	(- 26.64%)
V7	2.4	1.81469	(- 24.39%)

ALN = Allen, BR = Baier and Robertson, DA = Droogers and Allen, HAR = Hargreaves, HH = Heydari and Heydari, SAM = Samani, TRA = Trajkovic, BG = Berengen aand Gavilan, CAP = Caprio, HAN = Hansen, IRS = Irmak-R_s, MB = McGuinness and Bordne, MPT = Modified Priestley and Taylor, SS = Stephens and Stewart, V1 = Valiantzas 1, V2 = Valiantz as 2, V3 = Valiantz as 3, V4 = Valiantz as 4, V5 = Valiantz as 5, V6 = Valiantz as 6, V7 = Valiantz as 7.
Figures in parenthesis show percent deviation in comparison to original coefficient, (+) represents increment, and (-) shows decrement w.r.t. original coefficient.

Table 2. Computational form of considered statistical indices

Statistical index	Notation	Computational form	Eq. No.
Agreement index	D	$1-\frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(\lvert P_i-\bar{O}\rvert+\lvert O_i-\bar{O}\rvert)^2}$	(24)
Root mean square error	RMSE	$\sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{n}}$	(25)
Maximum absolute error	MAXE	$MAX[\lvert O_i-P_i\rvert]_{i=1}^{n}$	(26)
Percent error of estimate	PE	$\left\lvert\frac{\bar{P}-\bar{O}}{\bar{O}}\right\rvert\times 100$	(27)
Global performance index	GPI	$\sum_{i=1}^{n}(\bar{X}_i-X_{ij})\times a_i$	(28)

$\bar{O}$ = mean of FAO56-PM ET_0 (mm/day), $\bar{P}$ = mean of ET_0 (mm/day) obtained with equations, O_i = FAO56-PM ET_0 (mm/day) value, P_i = predicted value of ET_0 (mm/day) obtained with equations, $\bar{X}_i$= median value of scaled indicator "i", X_{ij}= median value of indicator "i" for method "j", n = total number of observations, a_i is (-)1 for R^2 and (+)1 for all other individual statistical indices.

Table 4. Comparative performance of original and calibrated ET_0 equations vs FAO56-PM model along with their ratio during validation period (2009-2019)

Equation(s)	Features	Statistical indices				R
		D	RMSE	MAXE	PE	
Temperature-based equations						
ALN	Original	0.6794	2.0543	3.4546	71.4205	1.8034
	Calibrated	0.9840	0.2919	0.6374	6.2807	1.1181
	% variation	+44.83	-85.79	-81.55	-91.21	-38.00
BR	Original	0.6199	2.3722	3.6649	82.9789	1.9788
	Calibrated	0.9581	0.4513	1.0994	7.5380	1.1630
	% variation	+54.56	-80.98	-70.00	-90.92	-41.23
DA	Original	0.6743	2.1279	3.8217	72.8723	1.8118
	Calibrated	0.9811	0.3254	0.6899	7.1809	1.1233
	% variation	+45.50	-84.71	-81.95	-90.15	-38.00
HAR	Original	0.7196	1.8370	3.3288	63.0335	1.7119
	Calibrated	0.9808	0.3263	0.6709	7.0363	1.1239
	% variation	+36.30	-82.24	-79.85	-88.84	-34.35
HH	Original	0.6653	2.2718	4.4300	75.1687	1.8074
	Calibrated	0.9715	0.4237	1.1200	9.6821	1.1317
	% variation	+46.02	-81.35	-74.72	-87.12	-37.39
SAM	Original	0.5109	3.6425	10.6500	106.1499	2.1251
	Calibrated	0.8456	1.1539	3.9500	19.1117	1.2279
	% variation	+65.51	-68.32	-62.91	-82.00	-42.22
TRA	Original	0.8816	0.9534	1.7689	32.9825	1.3944
	Calibrated	0.9845	0.2904	0.6597	6.3860	1.1155
	% variation	+11.67	-69.54	-62.71	-80.64	-20.00
Radiation-based equations						
BG	Original	0.7933	1.4986	2.4900	49.8256	1.4981
	Calibrated	0.9916	0.2174	0.2700	1.4838	0.9851
	% variation	+25.00	-85.49	-89.16	-97.02	-34.24
CAP	Original	0.8537	1.2013	2.4900	38.9032	1.3813
	Calibrated	0.9934	0.1961	0.3200	3.6077	0.9585
	% variation	+16.36	-83.67	-87.15	-90.73	-30.61
HAN	Original	0.9630	0.4279	1.0793	10.7459	1.1927
	Calibrated	0.9364	0.5161	0.6778	9.2928	0.9769
	% variation	-2.76	+20.60	-37.21	-13.52	-18.09
IRS	Original	0.9183	0.6489	1.1300	20.6820	1.3133
	Calibrated	0.9541	0.4364	0.7900	2.2749	1.1129
	% variation	+3.90	-32.76	-30.09	-89.00	-15.26
MB	Original	0.5705	2.8577	5.2300	91.2124	1.9176
	Calibrated	0.9381	0.6312	1.8400	9.7139	1.1004
	% variation	+64.43	-77.91	-64.82	-89.35	-42.62
MPT	Original	0.9858	0.2954	0.6000	7.1497	1.0714
	Calibrated	0.9916	0.2174	0.2800	1.4769	0.9851
	% variation	+0.58	-26.39	-53.33	-79.34	-8.05
SS	Original	0.9750	0.3596	0.1600	10.0965	0.9116
	Calibrated	0.9882	0.2510	0.2800	5.7554	0.9556
	% variation	+1.36	-30.20	+75.00	-43.00	+4.83
Valiantzas' equations						
V1	Original	0.9945	0.1784	0.3300	5.5437	1.0809
	Calibrated	0.9940	0.1787	0.1600	3.2886	0.9905
	% variation	-0.05	+0.17	-51.52	-40.68	-8.36

Cont...

Table 4. Comparative performance of original and calibrated ET_0 equations vs FAO56-PM model along with their ratio during validation period (2009-2019)

Equation(s)	Features	Statistical indices				R
		D	RMSE	MAXE	PE	
V2	Original	0.9753	0.3915	0.7200	13.1188	1.1694
	Calibrated	0.9904	0.2243	0.2400	3.3453	0.9992
	% variation	+1.55	-42.71	-66.67	-74.50	-14.55
V3	Original	0.9970	0.1350	0.3900	1.9668	1.0207
	Calibrated	0.9974	0.1241	0.2200	1.8982	0.9791
	% variation	+0.04	-8.07	-43.59	-3.49	-4.08
V4	Original	0.9028	0.8757	1.8714	27.7146	1.3206
	Calibrated	0.9834	0.3031	0.4628	2.313	1.0101
	% variation	+8.93	-65.39	-75.27	-91.65	-23.51
V5	Original	0.9071	0.8272	1.9754	27.167	1.3314
	Calibrated	0.9794	0.3259	0.4957	3.7026	1.0082
	% variation	+7.97	-60.60	-74.91	-86.37	-24.28
V6	Original	0.8886	0.8397	1.4283	28.5984	1.3921
	Calibrated	0.9489	0.4682	0.6379	5.6618	1.0212
	% variation	+6.79	-44.24	-55.34	-80.20	-26.64
V7	Original	0.9033	0.8285	1.5234	27.9789	1.3536
	Calibrated	0.9772	0.3358	0.4455	3.2325	1.0235
	% variation	+8.18	-59.47	-70.76	-88.45	-24.39

See Table 3 for details

Table 5. Normalized value of statistical indices and overall ranking of calibrated ET_0 equations

Equation(s)	Statistical indices				GPI	Rank
	D	RMSE	MAXE	PE		
Temperature-based equations						
ALN	0.9117	0.1629	0.1260	0.1813	-0.0063	12
BR	0.7411	0.3177	0.2479	0.2287	-0.1598	17
DA	0.8926	0.1955	0.1398	0.2152	-0.0675	16
HAR	0.8906	0.1963	0.1348	0.2098	-0.0559	15
HH	0.8294	0.2909	0.2533	0.3096	-0.3076	18
SAM	0.0000	1.0000	1.0000	0.6654	-1.2898	21
TRA	0.9150	0.1615	0.1318	0.1852	-0.0180	13
Radiation-based equations						
BG	0.9618	0.0906	0.0290	0.0003	0.2940	2
CAP	0.9736	0.0699	0.0422	0.0804	0.2094	6
HAN	0.5982	0.3807	0.1366	0.2949	-0.0347	14
IRS	0.7148	0.3033	0.1662	0.0301	0.1613	8
MB	0.6094	0.4924	0.4433	0.3108	-0.4802	19
MPT	0.9618	0.0906	0.0317	0.0000	0.2916	3
SS	0.9394	0.1232	0.0317	0.1614	0.1199	10
Valiantzas' equations						
V1	0.9776	0.0530	0.0000	0.0684	0.2766	4
V2	0.9539	0.0973	0.0211	0.0705	0.2328	5
V3	1.0000	0.0000	0.0158	0.0159	0.3439	1
V4	0.9078	0.1738	0.0799	0.0315	0.1826	7
V5	0.8814	0.1960	0.0886	0.0840	0.1257	9
V6	0.6805	0.3341	0.1261	0.1579	0.0770	11
V7	0.3801	0.6840	0.3597	1.0000	-1.0482	20

See Table 3 for details

1.2898 was adjudged worst among all considered ET_0 equations (Table 5).

CONCLUSIONS

The present study revealed that except radiation-based HAN equation, all other calibrated equations produced higher values of D while, values of RMSE with calibrated temperature-based, radiation-based, and Valiantzas' equations decreased considerably and these equations yielded lowered values of MAXE and PE as well. The best value of ratio (R) of $ET_{0method}$ to $ET_{0FAO56M}$ was obtained with temperature-based TRA, radiation-based BG & MPT and Valiantzas' V2 equations. The overall ranking revealed that among all considered ET_0 equations, Valiantzas' V3 equation performed best, followed by two radiation-based equations (BG and MPT) while, temperature-based SAM equation showed worst performance.

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