Estimation of Reference Evapotranspiration using Regionally Calibrated Hargreaves-Samani Equation

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Evapotranspiration (ET_O) is a significant module in water-balance, irrigation scheduling and estimation of crop water requirement models. ET_O can be adequately assessed when meteorological data are accessible to implement robust and strong models such as FAO-56 Penman-Monteith (PM). However, due to data insufficiency, substitute methodologies are essential. In this context, this study aims to calculate ET_O from regionally calibrated Hargreaves-Samani (HS_{CAL}), Hargreaves-Samani (HS) and Hargreaves methods which base on Land Surface Temperature (LST) and Solar Radiation (SR). SR was calculated from empirical formulas and Shuttle Radar Topography Mission (SRTM) 30m Digital Elevation Model (DEM). HS_{CAL} uses SR which calculated from empirical formulas as an input, whereas HS and Hargreaves uses SR which calculated from the SRTM 30m DEM. LST was calculated from Landsat8 (LS8) thermal band for all three methods. Furthermore, ET_O obtained from the HS_{CAL} ($ET_{O,HSCAL}$) was compared with standard FAO-ET_O values and after verification HS_{CAL} treated as standard for the verification of the remaining two methods on various Land Use Land Cover (LULC) types. Results of comparison between $ET_{O,HSCAL}$ and standard FAO-ET_O shows that mostly values are within the range but lower side. Comparison also disclose that vegetation and built-up LULC are the best and worst case respectively. Further, $ET_{O,HSCAL}$ values are mostly fall within lower class of the ranges during the monsoon season (August-September). Further, the performance of the HS and Hargreaves are evaluated based on statistical indicators; Root Mean Square Error (RMSE), Mean Bias Error (MBE), Mean Absolute Error (MAE) and Correlation Coefficient (R_2). ET_O values of HS ($ET_{O,HS}$) and Hargreaves ($ET_{O,H}$) are underestimated in the sami-arid climate zone. The mean values of all statistical indicators are lower for $ET_{O,HS}$ in comparison to $ET_{O,H}$ when $ET_{O,HSCAL}$ is used to compare $ET_{O,H}$ with $ET_{O,HS}$. It indicates that, in comparison to $ET_{O,H}$, $ET_{O,HS}$ is close to $ET_{O,HSCAL}$.

Keywords: Reference Evapotranspiration (ETO); Hargreaves-Samani; Hargreaves; Shuttle Radar Topography Mission (SRTM) and Landsat 8

Introduction

Evapotranspiration is a critical input of the water rotation programs. It accompanies a fundamental and essential part in the hydrological sequence, which has countless significance in climatic, cultivation, environmental, and hydrological. It also encompasses both evaporation and transpiration from soil and plant respectively and reason for heavy rainfall (90%) in semi-arid areas [1], [2]. Therefore, its precise assessment is not simply critical for the learning of weather variation and valuation of aquatic assets but also has a rich presentation / application in the administration of crop water requirements, calculation, and watching of drought, operative and actual expansion of water resources, etc. [3]. However, due to the lack of estimated evapotranspiration values, ETo is regularly involved to evaluate authentic evapotranspiration.

Throughout the last couple eras, several approaches have been established and suggested to evaluate ETo for multiple forms of environmental circumstances. Amongst these, the PM equation has been considered as the primary and standard way. Moreover, it is also considered as the standard technique and consumed by many scientists to authenticate various formulas [4]–[7] used PM equation to approximate ETo and scrutinize the consequence of urban sprawl, geographical, environmental and landscape disorders on evapotranspiration. Accordingly, [8] monitors the PM process to closely examine the values of ETo in relation to the variance of climatic input variables, and [9]–[18] evaluates the PM process' accuracy for the estimation of ETo using a variety of incomplete climate-related datasets from PMO landscapes in the southern Ecuadorian high Andes.

The PM equation demands an extensive array of weather-related data like Moisture (Hum), Temperature (Temp) Solar Radiation (SR), Vapor Stress (VP), Wind Speed (WS), and Soil Heat Flux (SHF). However, it's unlikely that most weather stations will have access to all of this meteorological data. Further, PM equation is inappropriate when climate data are only partially available [5], [19], [20].

To overwhelmed the subjected matter that is availability of climatic factors, numerous methods for instance Hargreaves, Trabert (Tr), Blaney-Criddle (BC), Hargreaves-Samani (HS), Thornthwaite (Th), Abtew (Ab), Jensen-Haise (JH), Makkink (Mk), PriestlyTaylor(PT), Turc (Tu), and Ivanov(Iv) are explored to estimate ETo with inadequate weather-related data [3]–[5], [21], [22].

Subsequently, [4] matched numerous globally acknowledged ETo estimation ways, e.g., MK, Iv , PT, BC and HS model by considering the PM as a regular routine. Among these five models, MK Model was considered to be the best suitable model. Based on previous research for estimating the ETo, [23] plays with various models to determine which model would perform better in various climates, chose five models constructed on the basis of temperature, five was relied on radiation, and five established on mass transfer. They came to the conclusion that models based on radiation performed better and were more suited to climate change than models based on temperature or, more precisely, models based on mass transfer.

Among the approaches stated above, maximum attention has been received to the HS equation from the investigation groups as it only desires temperature and SR for calculation. Although HS equation is simplified but it brings incorrectness and produce inconsistence results to ETo calculation [5], [24]–[27] assessed HS and BC methods' accuracy with regard to the regular PM method for calculating ETo in arid coastal areas of Baluchistan and Sindh. The study consequences recommended that the HS and BS methods underestimated and overestimated respectively over the standard PM routine at all the weather calculation locations of coastal environment. Likewise, [17] assesses the HS equation for calculating value of ETo. Results showed that at inland sites over Tunisian locations showed an organized overestimation when comparing ET_O daily values estimates by the HS equation and PM method.

Therefore, further investigation is required to fine-tune the HS coefficients to regional situations to achieve better accuracy in values. The calibration of HS constant for numerous climatic circumstances can be a satisfactory method to guesstimate the ET_O with better precision. Many scientists have prospered the calibration of these coefficients under various weather situations.[28]–[30]. Further, [31] make the comparison of the calibrated dataset of the HS calculation method by involving the Solver tool from Microsoft Excel, the nonlinear optimization algorithm is used in this program. This study used daily data from six weather points which positioned in the state of Minas Gerais, from 1997 to 2016. Correspondingly, fuzzy logic also plays an important role in data calibration. [5] calibrated only two constants of HS equation for numerous weather estimation points of India like Bikaner, Calcutta, Kakinada, Coimbatore, Panjim-Goa, Kota, Deharadun, and Srinagar. Results depict that Modified Hargreaves and Samani (MHS) equation improved the values of the output by minimizing the error in ET_O estimation.

Although multiple researches has been done for the calibration of HS formula which were used for the calculation of ETo but there were still discrepancies in the credibility of the calibration of the HS equation particularly for Pakistani area. As a result, [6] conducted a research and calibrated the all four constants (ah, bh, ch and dh), using fuzzy logic, of the HS equation for multiple weather calculation points of Pakistan and found incredible results in comparison with results produced by PM equation.

In this study, four parameters base regionally calibrated HS_{CAL} equation [6] will be used to estimate the ET_O and these ET_O values will compare with standard FAO-ET_O values. Furthermore, estimated values through HS_{CAL} will become standard for the verification of ET_O values calculated by HS and Hargreaves on various LULC through statistical indicators; Root Mean Square Error (RMSE), Mean Bias Error (MBE), Mean Absolute Error (MAE) and Correlation Coefficient (R_2).

Objectives

The main objective of this study is to estimate and verify ET_O values, on multiple LULC types, using three different versions of Hargreaves equation. The second objective is to calculate the LST and SR through satellite data and empirical formula. SR calculated by Empirical formula used in one algorithm (HS_{CAL}) whereas remaining two algorithms (HS and Hargreaves) will use SR which calculated by satellite dataset.

MATERIAL AND METHODS Investigation site

In this research, four Canal Commands (Figure 1), Central Bari Doab Canal, Marala Ravi Canal, Raya Canal and Upper Chenab Canal, of three main canals M.L.L (U.C.C), Badian Ravi B Dipalpur (BRBD Link Canal) and Marla Ravi Canal has been taken to compute reference Evapotranspiration (ET_O). These canals and their command areas belong to Punjab Rice Wheat Agroclimatic Zone (PRW-ACZ). The overall size of the study area is 1121501 hectare.

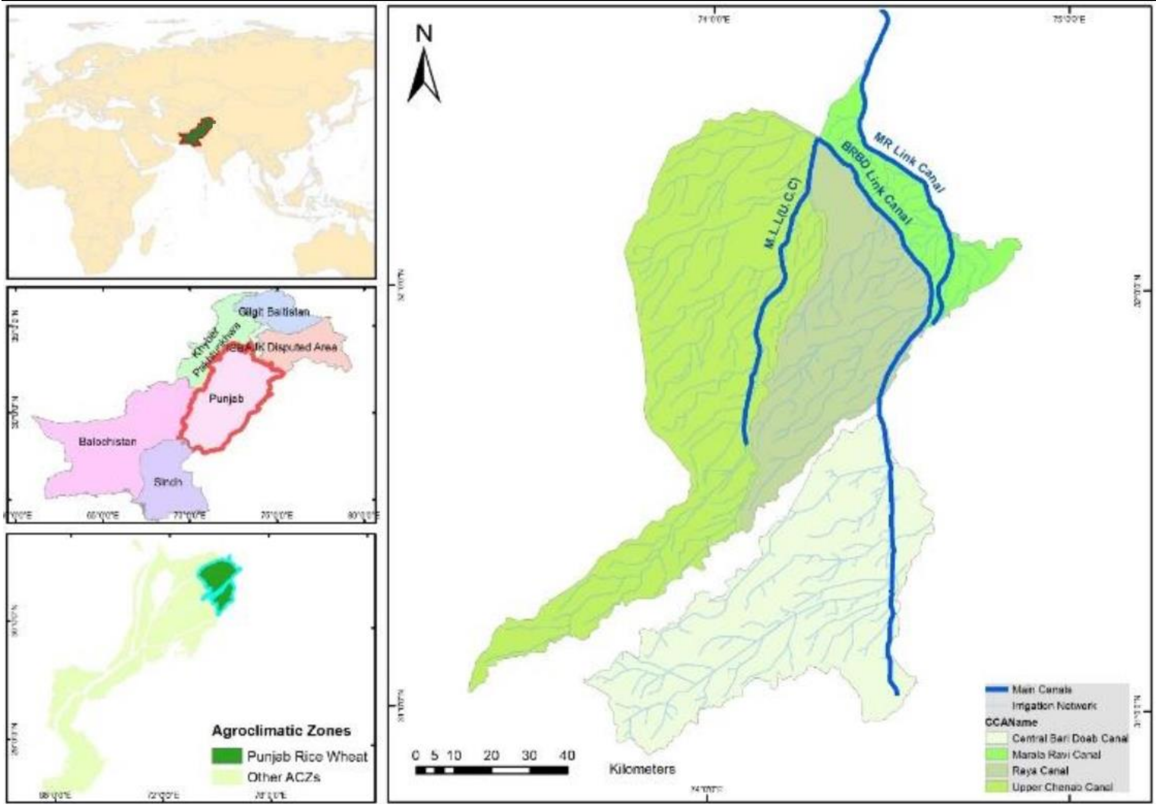

Figure 1: Study Area (Four canal command areas from Punjab Rice Wheat (PRW) Agroclimatic Zone)

The study area base on rice and wheat cropping system. The scheme covers 1.1 million acres of agronomic area grown through canal water in six districts; Gujranwala, Kasur, Lahore, Nankana sahib, Sheikhupura and Sialkot. A hefty portion / area of the sowing is based on annual rice-wheat cropping plan, with rice sown primarily before wheat. Other significant crops are cotton, sugarcane, pearl millet, maize, barley and fruit. The designated examination area includes barren land, biomass cover and built-up area. The study area found high temperature in the summer, monsoon season is rainy, and freezing in the winter season. Good summer season precipitation with the late season extraction of monsoon supports to sustain water basins at full volume to accommodate the sowing necessities of Rabi crops from October to December. At this time insignificant precipitation occurs in Pakistan [32]. Furthermore, during growing period of rice crop, the mean maximum and minimum temperature ranges from 34-38 and 22-26.5 degrees Celsius. Further, the rainfall for the duration of monsoon season ranged from 200-800mm, with a north to south incline, [32].

MATERIAL AND METHODS Acquisition of LULC Map

Dynamic Land Cover map (DLCM) from portfolio of the Copernicus Global Land Service (CGLS) was acquired using Google Earth Engine (GEE) platform for study area. This global map is classified into multiple major and sub classes. Water, Trees, Crops, Builtup and Rangeland classes were selected than obtained and marked random points on each class for cross validation of $ET_{O,H}$ and $ET_{O,HS}$ in comparison with $ET_{O,HSCAL}$.

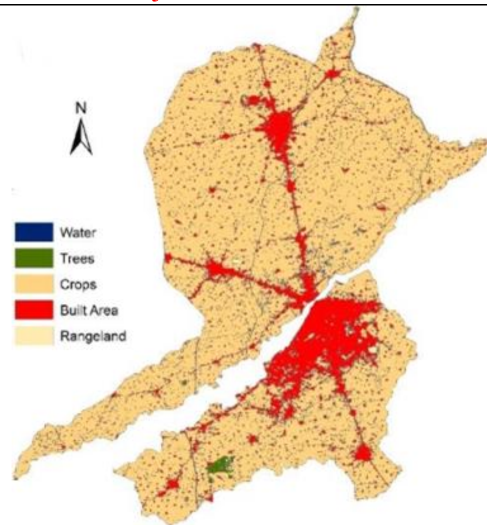

Figure 2: Major Classes in Study Site

Hargreaves Equation

As mentioned earlier, the central hindrance to involve the PM equation, for the calculation of ET_O, is that it involves multiple weather parameters which are frequently not obtainable. The first alternative could be the empirical equation which base on few inputs. Due to minimum inputs parameters, preference have been given to the HS equation / model. HS is also called temperature-based ET_O formulation because it base on temperature and solar radiation. Eq (1)**Error! Reference source not found.**, by [33], is initial and simplest form of the Hargreaves equation which later updated and called HS equation for estimation of ET_O.

$$ET_0 = 0.0135 \, . \, R_S \, (T_{mean} + 17.8) \qquad (1)$$

Where ET_O and R_S is the same unit of water evaporation. T_{mean} is depicted daily mean air temperature.

Hargreaves-Samani

The Hargreaves–Samani (1982, 1985) modified the Hargreaves equation (HS) and it's also called temperature-based ET_O formulation because it requires minimum and maximum temperature only. The method is elaborated by the Eq. (2)

$$ET_o = (0.408) * 0.0023 * R_S * (T_{mean} + 17.8)(TD)^{0.5} \qquad (2)$$

Where R_S is extraterrestrial radiation ($MJ \, . \, m^{-2} \, day^{-1}$); and the daily mean, difference between maximum and minimum air temperature are represented as T_{mean}, TD respectively. Factor of the 0.408 was used to renovate the unit of the values from $MJ \, m^{-2} \, day^{-1}$ to $mm \, day^{-1}$.

Hargreaves-Samani Calibrated

HS model is built on the equation which is not considering the significances of humidity and wind speed while calculating the ET_O values. With the uses of less data, [5] find out that the HS equation are not able to provide accurate results of ET_O under extreme meteorological / weather environments. Therefore, [6] applied Fuzzy logic to find out the improved values of constants of HS method at various metrological stations of Pakistan (Table 1) and called as HS_{CAL} (Eq. (3)).

$$ET_0 = a_h * R_S * (T_{max} - T_{min})^{b_h}(T_{eff} + c_h) \qquad (3)$$

Table 1: Values of four (04) parameters at various weather stations use to calibrate Hargreaves-Samani Equation

Bahawalnagar	0.0012	0.55	22.8	0.63
Kotli	0.0021	0.46	13.6	0.57
Jhelum	0.00118	0.65	17.2	0.64
Lahore	0.0010	0.57	22.9	0.67
Muzaffarabad	0.0013	0.62	15.6	0.48
Sialkot	0.0019	0.51	16.2	0.6
Islamabad	0.0020	0.45	11.9	0.61
Skardu	0.0011	0.47	15.3	0.74
DIK	0.0013	0.62	13.8	0.67
Gilgit	0.0010	0.69	12.8	0.55

The Eq. (3) shows the maximum and minimum temperature which depicted as T_{min} and T_{max} respectively, T_{eff} is estimated with Eq. (4) and R_S is the extra-terrestrial solar radiation (SR) which can be obtained using Eq. (5). Further, in this equation four variables (ah, bh, ch and dh) were under consideration. Variable dh was calibrated because this study did not use mean temperature as a substitute of effective temperature and remaining three parameters were also calibrated with combination of dh constant.

$$T_{eff} = dh\,((3 * T_{max}) - T_{min})/2 \qquad (4)$$

Where dh, T_{max} and T_{min} are the coefficient, daily maximum and daily minimum temperature respectively.

$$R_S = a\,(\Delta T)^{0.5} R_a \qquad (5)$$

Where a is the coefficient which keeps the value Inland =0.16 & costal area= 0.19; and delta T is the difference between maximum and minimum temperature. Ra = extraterrestrial radiation (MJ·m–2·day–2), is assessed by Eq (6), with the involvement of location's latitude and year's calendar day.

$$R_a = 37.6\, G_{SC} d_r(\omega_S \,.\, sin\varphi \,.\, sin\delta cos\varphi \,.\, cos\delta \,.\, sin\omega_S) \qquad (6)$$

where G_{SC} = solar constant (0.0820 $MJ\cdot m^{-2}\cdot min^{-1}$), f = latitude (radians), converted from degrees latitude to radians (radians = degrees(p/180)), and a single multiplication of two constant numbers 24(60) is a input factor used to convert min-hours and then hours-day. Based on the year's calendar day, remaining other input factors are computed by Eq. (7)

$$d_r = 1 + 0.33\,cos(\frac{2\pi}{365}J) \qquad (7)$$

where d_r = opposite relative space from earth to sun, and J = year's calendar day.

$$\delta = 0.4093\,.\,sin(\frac{2\pi}{365}J) \qquad (8)$$

where $\boldsymbol{\delta}$ = solar declination (radians), and J = year's calendar day.

$$\omega_S = arccos(-tan\varphi\,.\,tan\delta) \qquad (9)$$

where $\boldsymbol{\omega_S}$ = sunset hour angle (radians), and J = year's calendar day.

Land Surface Temperature and Solar Radiation Calculation Method

Land Surface Temperature (LST) is calculated using thermal band of the LS8 satellite, whilst Solar Radiation is computed using two different methods; from satellite base data and Empirical formulas using Digital Elevation Model (DEM) of SRTM 30m data and Eq. ((5)-(9)) respectively. Hargreaves, HS and HS_{CAL} used the LST which were computed from LS8 dataset whereas SR computed from DEM used in Hargreas and HS. HS_{CAL} used solar radiation which was computed from empirical formulas using Eq. (4)-(9).

Evaluation Criteria

To accomplish the assessment of the substitute ETo techniques, the three (03) procedures were encoded into excel spreadsheet and then involved to geo-statistically investigate the datasets. Miscalculation in ETo values computed from the different procedures associated with those from the HS_{CAL} equation was measured with the involvement of various geostatistical equations; Mean Bias Error (MBE) Eq. (10), Mean Absolute Error (MAE) Eq. (11), Root Mean Square Error (RMSE) Eq.(12). MBE is demarcated as

$$MBE = 1\ n \sum (ET_{(i)\ method} - ET_{(i)\ 0,HSCAL})\ 1\ i=1 \quad (10)$$

Where MBE shows errors in mm, ET_{method} is daily ETo assessment from other ETo estimations methods (mm), HS_{CAL} is daily ETo from result of the study [6], and n is number of samples points which taken at different dates and LULC types. By taking into account both under- and overestimations of ETo, MBE delivers an overall average of the errors. (negative representing that $ET_{method} < HS_{CAL}$, and positive sign (+) with magnitude demonstrating that $ET_{method} > HS_{CAL}$). MAD (Eq. (11)) is suggested to measure the average magnitude of the error. MAE sign is removed by taking the absolute value of the error, and is defined as

$$MAD = \frac{1}{n}\sum_{i=1}^{1} |ET_{(i)\ method} - ET_{(i)\ O\cdot HS_{CAL}}| \quad (11)$$

where MAE is mean absolute error (mm).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{1} \left(ET_{(i)\ method} - ET_{(i)\ O\cdot HS_{CAL}}\right)^2} \quad (12)$$

The evaluation and performance of various other methods, and subsequently the resultant differences, were assessed for the growing season, during the months of June through October.

Ranges of Reference Evapotranspiration

As per FAO [34], Table 2 provides typical ETo value ranges for various agroclimatic areas.

Table 2. Average ETo for different agroclimatic regions in mm/day

Regions	Mean daily temperature (°C)		
	Cool ~10°C	Moderate 20°C	Warm > 30°C
humid and sub-humid	1-2	2-4	4-7
arid and semi-arid	1-3	4-7	6-9

Satellite Data Preprocessing and Vegetation Index

The optical remote sensing images of LS8 satellite for rice season of the year 2021 was used in this study. According to Table 3, seven (07) images of the study area were downloaded with less than 5 percent of cloud cover. The combination of multispectral bands along with TIR bands makes an ideal choice of LS8 images to derive LST. Moreover, [35] study shows that Landsat-derived LSTs are closer in magnitude than MODIS-derived LSTs. Further, SRTM 30m was used to calculate the solar radiation using ArcMap tool. All acquired dataset having UTM coordinate system and Study area lies within zone 43N

Table 3: Satellite data detail

Sr.No	Satellite	Date	Time	Path/Row
1	LANDSAT-8	06-06-2021	10:00 a.m	149/38
2	LANDSAT-8	25-06-2021	10:00 a.m	149/38
3	LANDSAT-8	28-08-2021	10:00 a.m	149/38
4	LANDSAT-8	13-09-2021	10:00 a.m	149/38
5	LANDSAT-8	29-09-2021	10:00 a.m	149/38
6	LANDSAT-8	15-10-2021	10:00 a.m	149/38
7	LANDSAT-8	31-10-2021	10:00 a.m	149/38

Work flow of Study

Reference Evapotranspiration (ET_O) has been estimated through one empirical and two satellite base methods. All three methods require LST, SR and constants values. LST and SR are calculated using LS8 thermal band and SRTM 30m DEM respectively for Hargreaves and HS equations whereas for HS_{CAL} method, SR are estimated using empirical formulas (Eq. (4)-(9)) and LST is calculated same as for Hargreaves and HS equations. As per Table 1, coefficient values of the Lahore metrological station were used to estimate the $ET_{O,HSCAL}$ as Lahore station falls within study area. Finally, $ET_{O,HSCAL}$ were verified with ranges of ET_O values (Table 2) published by FAO whereas $ET_{O,H}$ and $ET_{O,HS}$ are verified through $ET_{O,HSCAL}$. (See Figure 3)

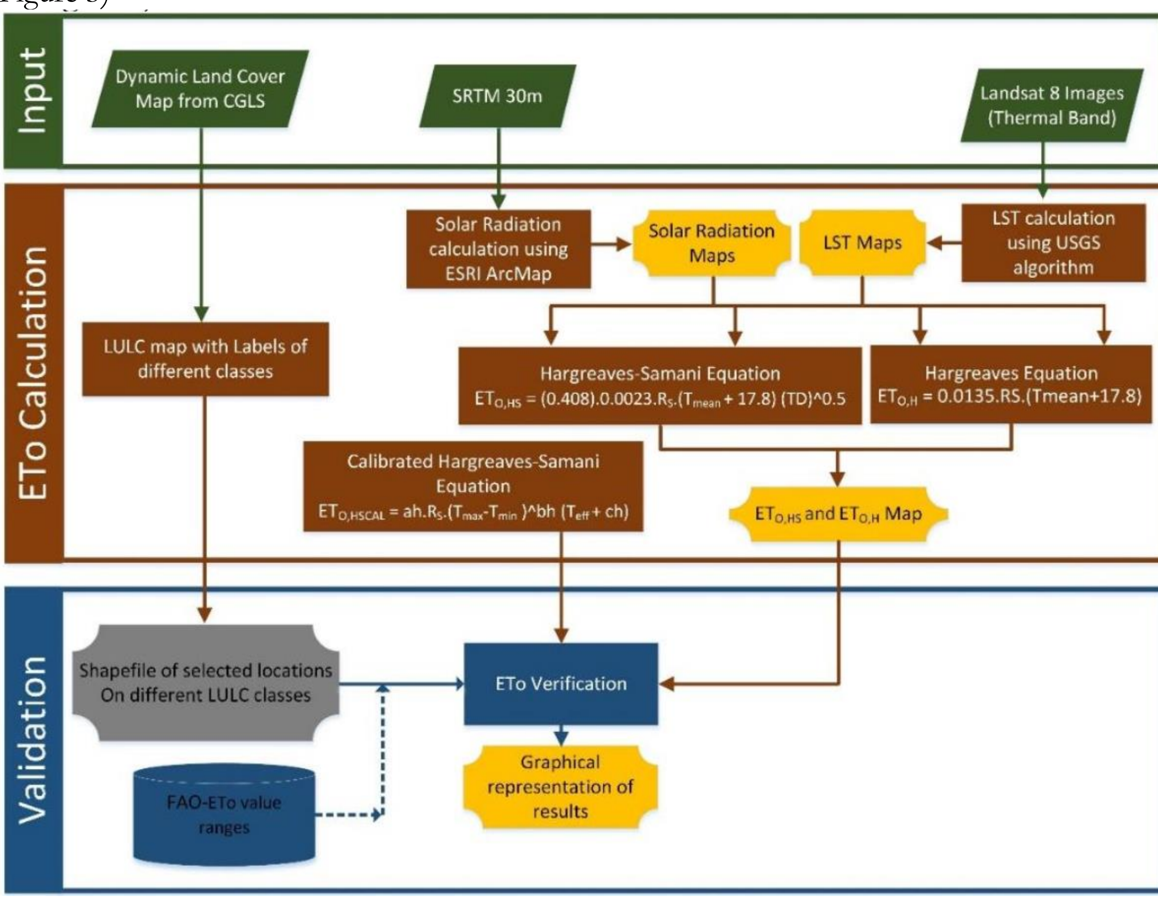

Figure 3: Flow diagram for ET_O retrieval through Hargreaves, Hargreaves-Sammani (HS) and Hargreaves-Samani Calibrated (HS_{CAL}) equations and their verification processes.

Land surface temperature (LST) is a vital parameter in the science of land–surface procedures locally and worldwide; LST has been used in ecological, soil moisture calculation [36]–[38], climatic, biogeochemical and hydrological studies. Currently, LST can only be attained over hefty spatial and temporal scales through satellite data, which have fascinated to researchers in the last three decades [39], [40]. For current study, LST is estimated through LS8. The LST values ranges between 8.68-51°C over the growing season (JuneSeptember). Highest temperature is observed during the month of June (06 and 25) and gradually decreasing till end of September. In October, LST again elevated in magnitude in comparison with LST recorded during the months of August and September (see Figure 4).

RESULT AND DISCUSSION

Solar Radiation Maps

Solar radiation (SR) values are extracted through 30m Digital Elevation Model (DEM) which was developed from Shuttle Radar Topography Mission (SRTM) and used into Hargreaves and HS equation for the calculation of ET_O values. For current study, SR values ranges between 2000-6500 Wh/m_2 over the growing season (June-September). Highest value of SR is observed during the month of June and gradually decreasing till end of October (see Figure 5.

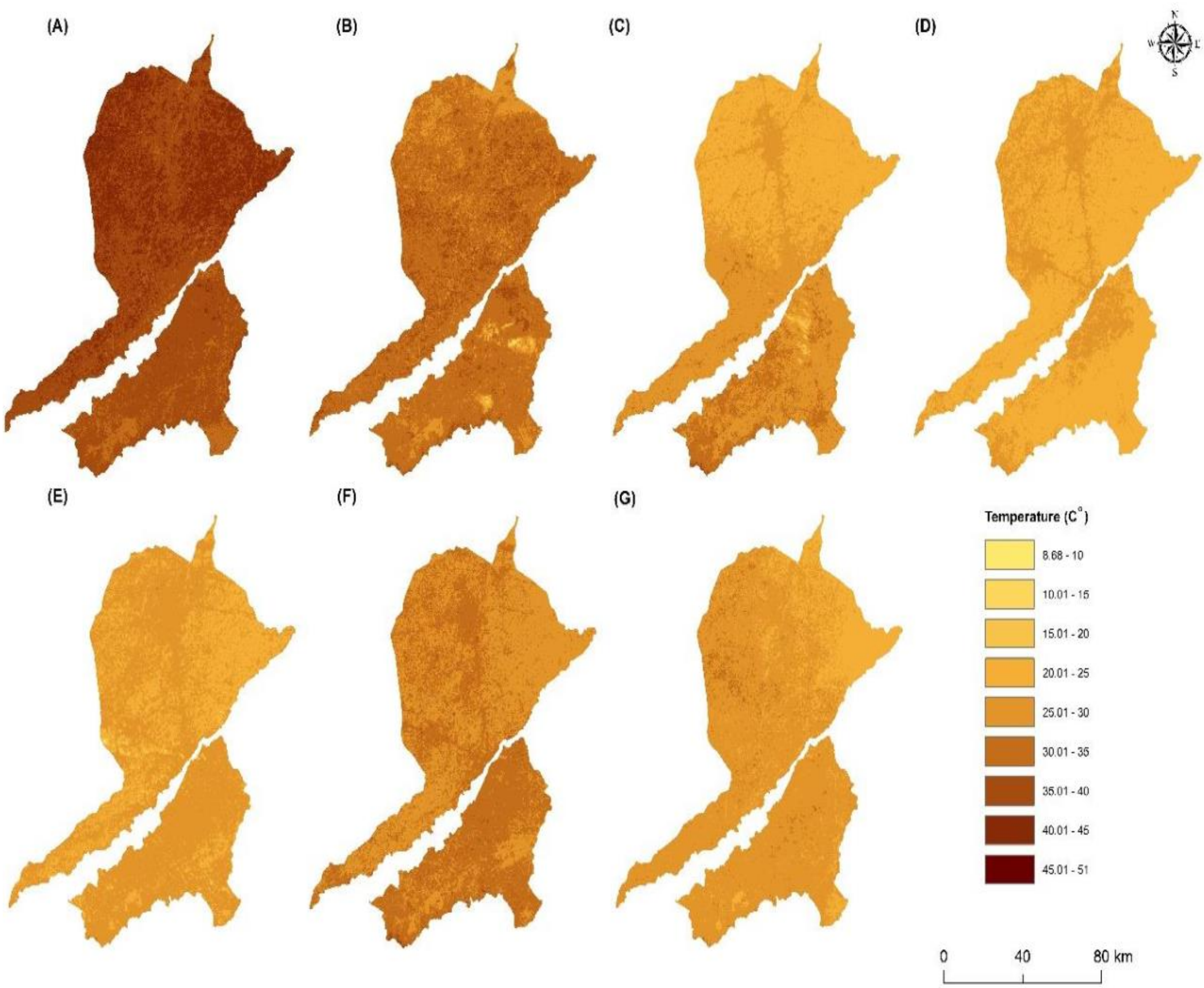

Figure 4: LST maps derived through LS8 on A) 06 Jun, 2021 B) 25 Jun, 2021 C) 28 Aug, 2021 D) 13 Sep, 2019 E) 29 Sep, 2021 F) 15 Oct, 2021 G) 31 Oct, 2021

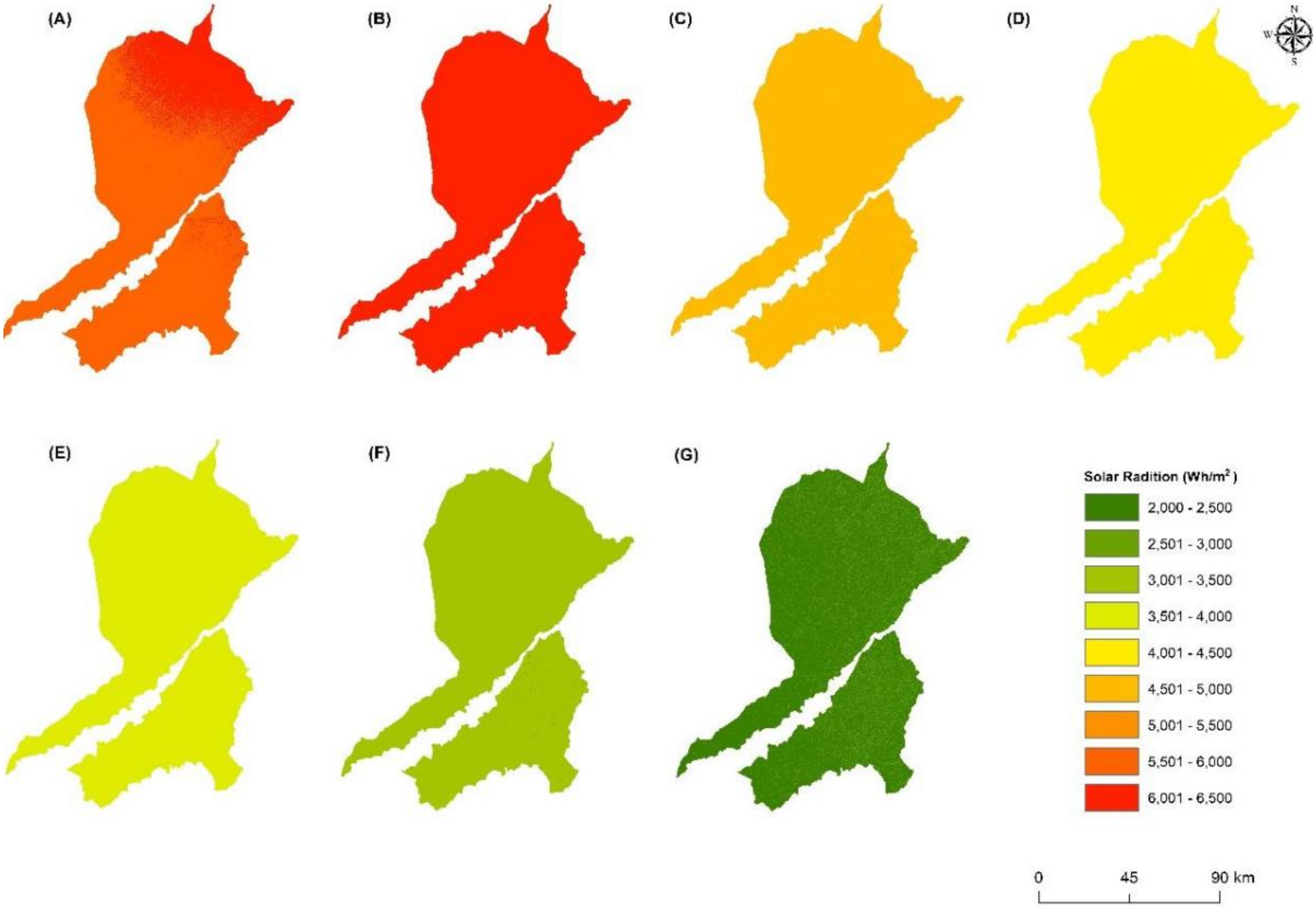

Figure 5: Solar Radiation maps derived through SRTM on A) 06 Jun, 2021 B) 25 Jun, 2021 C) 28 Aug, 2021 D) 13 Sep, 2019 E) 29 Sep, 2021 F) 15 Oct, 2021 G) 31 Oct, 2021

Reference Evapotranspiration (ET_O) map

Reference evapotranspiration (ET_0) plays vital role for planning of irrigation scheme and organization of water resources at small or low level. It is not permanently conceivable to estimate ET_0 directly through lysimeter. Thus, various methods / equations have been formalized and tested for the estimation of the ET_O [2], [10], [15], [16], [26], [41]–[45]. In this study, ET_O maps at various dates during growing season (June-October) has been calculated by the HS and Hargreaves equations. Sample ET_O maps on different dates are shown in Figure 6 which were estimated by Hargreaves equation (Eq. (1)). Highest value of $ET_{O,H}$ is observed during the month of June and gradually decreasing till end of October.

Evaluation of $ET_{O,CAL}$ with respect to FAO-ET_O ranges

Using Eq ((3)-(9)), $ET_{O,CAL}$ was computed and compare the values on various LULC classes with ranges, mentioned in Table 2, provided by FAO. Table 4, depicts the value of $ET_{O,CAL}$ and their respected temperature values. Mostly values are within range of the lower side. The Vegetation LULC is the best case where $ET_{O,CAL}$ values fall within the range during the growing season i.e June-October. Whereas $ET_{O,CAL}$ values shows great scatter over Builtup LULC in comparison with temperature and mostly values are out of the range. Further, it was analyzed that in monsoon season (July-August), values are not shown with in their respective ranges and mostly fall into lower class of the ranges (e.g Moderate to cool).

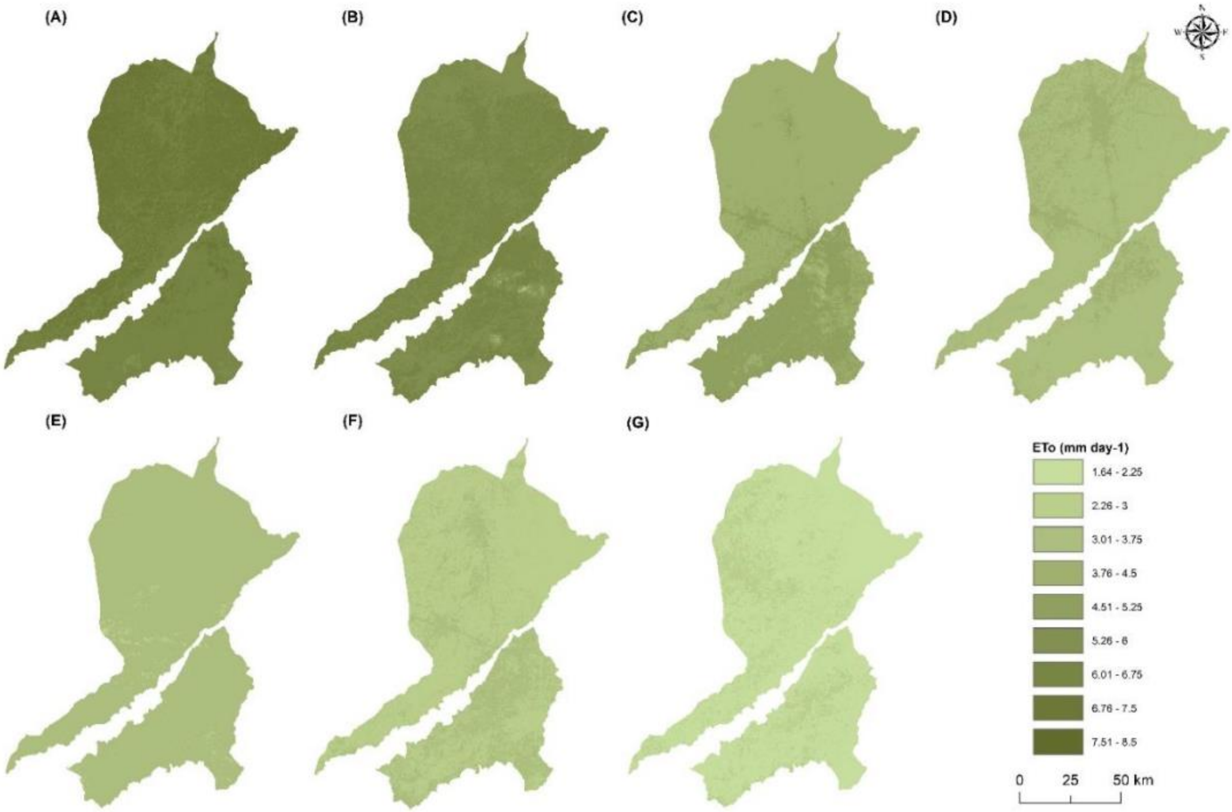

Figure 6: Sample ETo maps estimated through HS equation on A) 06 Jun, 2021 B) 25 Jun, 2021 C) 28 Aug, 2021 D) 13 Sep, 2019 E) 29 Sep, 2021 F) 15 Oct, 2021 G) 31 Oct, 2021

Table 4: Comparison of $ET_{O,HSCAL}$ and Temperature values on various LULC types

Dates		**2021**						
		06-Jun	**25-Jun**	**28-Aug**	**13-Sep**	**29-Sep**	**15-Oct**	**31-Oct**
Water	**ETo (mm d^{-1})**	6.43	6.22	3.59	3.36	3.85	4.08	4.18
	Temp (°C)	40.11	34.15	26.15	25.28	26.14	29.69	25.38
Trees	**ETo (mm d^{-1})**	5.92	5.78	4.55	3.70	5.02	6.03	5.08
	Temp (°C)	37.95	32.78	27.05	25.63	26.07	30.58	25.44
Vegetation	**ETo (mm d^{-1})**	7.71	5.73	4.72	5.22	5.98	6.15	6.51
	Temp (°C)	36.74	31.80	27.85	24.48	25.85	30.11	26.37
BuiltUp	**ETo (mm d^{-1})**	8.49	9.25	8.90	6.12	8.07	8.12	9.02
	Temp (°C)	39.34	30.72	24.01	24.48	24.51	29.10	26.30
Rangeland	**ETo (mm d^{-1})**	5.49	6.26	5.89	3.12	5.06	5.10	6.00
	Temp (°C)	38.15	33.16	27.39	24.91	25.69	30.48	26.82

Comparison of ETo methods

In this study, HS_{CAL} (empirical equation to calculate the ETo) values are the standard to compare the results with other two equations (Hargreaves and HS) which uses the satellite data . Overall, the Hargreaves and HS equations inclined to underestimate ETo, The Hargreaves equation formed a bigger scatter of assessments in comparison to other calculation using other equations. The RMSE, MBE and MAD of all temperature-based assessment of ETo to the HS_{CAL} evaluation are depicted in Table 5 for various dates which lies with in growing season.

The Hargreaves equation showed the highest values of RMSE which ranged from 1.31–6.10 (mm d^{-1}) on various LULC types. Values of RMSE are 1.31, 1.38, 2.41, 6.10 and 3.98 for water, trees, vegetation, builtup, and rangeland respectively with a mean 3.04 mm d^{-1}. Hargreaves equation is dependent on LST and in case of Builtup, higher the LST higher the ETo. Further, Values of MBE fluctuated from -0.62–3.90 mm d^{-1} and particular values for all classified LULC (water, trees, vegetation, builtup, and rangeland) are -0.62, 0.09, 0.71, 2.98 and 3.90 respectively. Moreover, values of MAD ranges from 0.92-3.90 and estimated values for water, trees, vegetation, builtup, and rangeland are 0.93, 0.95, 0.92, 2.98 and 3.90.

The minimum value of RMSE, MAE are seen in water whereas MAD are observed in vegetation LULC type. The maximum value of RMSE is seen in builtup whereas MAE and MAD are observed in rangeland that is 3.90 mm d^{-1}.

The HS equation exhibited less error as compare to Hargreaves equation in comparison with HS_{CAL}. Values of RMSE ranged from 1.30 to 4.97 mm d^{-1} with mean 2.60 mm d^{-1}. The mean value of RMSE are smaller than those found from Hargreaves equation i.e 2.60 mm d^{-1}. Values of RMSE for water, trees, vegetation, builtup, and rangeland LULC types are 1.54, 1.30, 2.89, 4.97 and 2.34 mm d^{-1} respectively. The HS equation showed positive bias at all LULC types and MBE extended from 0.03–1.89 mm d^{-1} with a average of 1.16 mm d^{-1}. Generally, the HS equation estimated the ETo values which are closer to ETo values calculated by HS_{CAL} as compare to values of ETo calculated by Hargreaves equation.

Table 5: Statistical Coefficients values in comparison between HS_{CAL} to HS and Hargreaves.

Sr. No.	Statistical Coefficient	Method name	Land Use Land Cover Types					
			Water	**Trees**	**Vegetation**	**Built-Up**	**RangeLand**	**Mean**
1	MBE	HS	0.03	0.73	1.38	1.81	1.89	1.17
		Hargreaves	-0.62	0.09	0.71	2.98	3.90	1.41
2	MAD	HS	0.75	0.92	1.38	1.81	1.90	1.35
		Hargreaves	0.93	0.95	0.92	2.98	3.90	1.94
3	MaxAE	HS	6.43	5.92	2.58	4.11	6.24	5.06
		Hargreaves	6.43	5.92	2.43	4.34	4.84	4.79
4	MinAE	HS	0.11	0.26	0.37	0.03	0.03	0.16
		Hargreaves	0.00	0.08	0.26	0.42	2.41	0.63
5	RMSE	HS	1.54	1.30	2.89	4.97	2.34	2.61
		Hargreaves	1.31	1.38	2.41	6.10	3.98	3.04
6	SD	HS	1.48	1.00	1.36	1.36	1.45	1.33
		Hargreaves	1.70	1.27	1.54	0.42	0.38	1.06
7	Correlation	HS	0.75	0.37	0.28	0.46	0.41	0.45
		Hargreaves	0.71	0.28	0.30	-0.44	0.64	0.30

Inaccuracy in Estimated ETo- Daily throughout the Growing Period

To gauge the routine of the substitute ETo methods, for study, planning and completion of daily routine work regarding irrigation scheduling, within time period of the whole growing period in the study region from June-October, values of daily data were estimated and finally error statistics were also recorded (See Table 5)

The Hargreaves equation consistently estimated ET_O values very near to ET_O values which were calculated by HS_{CAL} from June to September for Water, Trees and Vegetation LULC type but for the month of October it estimated substantial low values (underestimated) of ET_O almost half of the ET_O values calculated from HS_{CAL}. Whereas for Builtup and rangeland, Hargreaves methods estimated pretty low (less than half) ET_O values throughout the whole growing season Figure 7.

The HS method exhibited consistency in estimation of ET_O values near to ET_O values which were calculated by HS_{CAL} for all LULC types, which mentioned in Figure 2, from June to mid of September. From Second half of September to end of October, pretty low (less than half) ET_O values were computed through satellite data throughout the whole growing season same as Hargreaves method Figure 7. It clearly reveal that both alternate methods underestimate the ET_O values as compare to HS_{CAL} ET_O values for entire growing season at all LULC type (see Figure 2).

CONCLUSION

The FAO56 PM equation is the utmost looked-for technique of approximating ETo since it is a worldwide authentic, recognized standard. However, at sites where compulsory data are of uncertain in magnitude, inadequate, or inaccessible methods that require temperature only may be preferred.

For current study, $ET_{O,HSCAL}$ were calculated on various LULC using HS_{CAL} method (which is totally base on empirical formulas) as recommended by [6] an alternate method of FAO56 PM equation. In HS_{CAL} method, four parameters (ah, bh, ch and dh) of HS are calibrated regionally. $ET_{O,CAL}$ were further compared with FAO average ETO values mentioned in Table 2. Mostly values are within the range but lower side. Furthermore, vegetation and buitup LULC are the best and worst case respectively with respect to comparison between $ET_{O,CAL}$ and FAO ET_O values. During the monsoon season values are mostly fall within lower class of the ranges.

For current study area, $ET_{O, HSCAL}$ data set is considered as the standard for comparison of Hargreaves and HS methods, these methods are using satellite-derived calculated maximum and minimum temperature and SR from LS8 and 30m DEM from SRTM respectively. The Hargreaves and HS equation underestimate ETo in the sami-arid climate of ACZ-PRW. When comparing $ET_{O,H}$ and $ET_{O,HS}$ with $ET_{O,HSCAL}$, the mean values of RMSE, MBE, MAD and Correlation are lower in $ET_{O,HS}$ in compare to $ET_{O,H}$. It reveals that $ET_{O,H}$ is near to $ET_{O,HSCAL}$ as compare to $ET_{O,H}$.

In the absence of comprehensive data sets, the PM equation cannot be used to calculate ETO. HS_{CAL} regionally calibrated method is recommended for estimating ET_O in ACZPRW. The empirical based ETo data set permissible for the assessment of satellite based ET_O data set at more localities and situations than would previously been possible.

Author's Contribution

In this manuscript, Mamoon Ur Rasheed provided the main ideas, chose the algorithms, evaluated the algorithm sensitivity and also wrote the whole manuscript. Syed Amer Mahmood review the results and supervise the whole activity. Rao Mansor Ali Khan helped much on processing Landsat 8 data and involve in discussions. Muhammad Abdullah Sohl contributed to generate some graphs and involve in discussions.

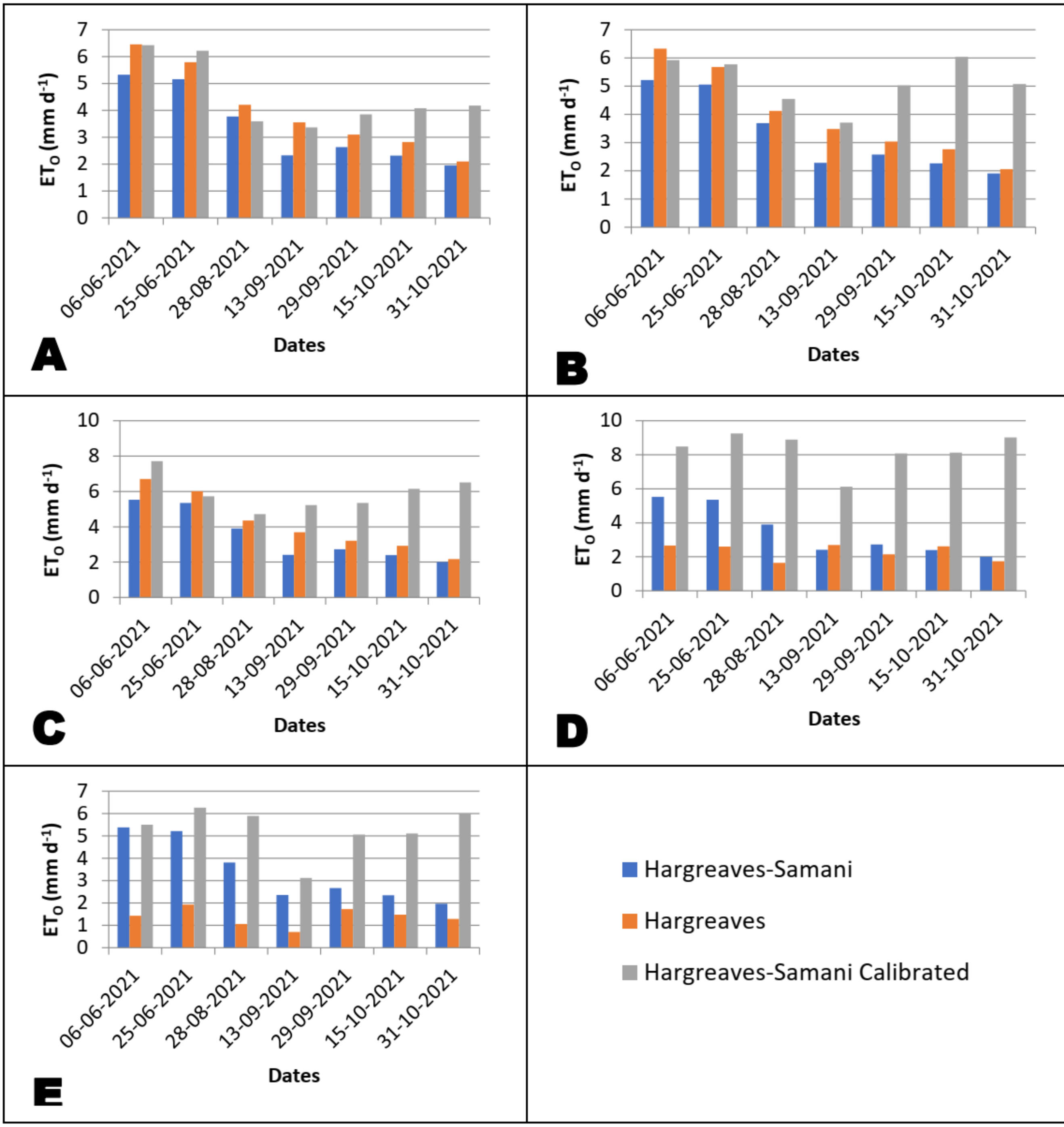

Figure 7: Date wise comparison of ET_O values estimated through HS, Hargreaves and HS_{CAL} A) Water B) Trees C) Vegetation D) BuiltUp E) Rangeland

Conflict of interest

Authors declare there is no conflict of interest for publishing this manuscript in IJIST.

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