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Determination of Wheat Evapotranspiration using the Earth Engine Evapotranspiration Flux (EEFLUX)

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***Abstract*— *In this study an automated Earth Engine Evapotranspiration Flux (EEFlux) was used to produce actual evapotranspiration (ETa) estimates for rabi wheat, compared against the FAO-56 approach using ground-measured weather data. Eight cloud-free Landsat images from the 2020-2021 rabi season were processed in METRIC-EEFlux, producing ETa values ranging from 0.95 mm to 4.07 mm, with an average of 2.41 mm. Conversely, the FAO-56 method estimated ETa values between 0.64 mm and 4.80 mm, averaging 2.58 mm. Cumulative ETa for wheat was 290 mm (EEFlux) and 336 mm (FAO-56). The comparison showed moderate agreement (IA = 0.67), with EEFlux underestimating by 13.69% relative to FAO-56. EEFlux-ETa had an RMSE of 0.93 mm/day and NRMSE of 0.33. The findings suggest that EEFlux can achieve more accurate ET estimates with frequent satellite imagery, improved weather data, and automated ETrF adjustments, necessitating further validation across multiple years to confirm its general applicability.*

***Keywords*— Actual evapotranspiration; EEFlux; FAO-56; Landsat; Wheat**

I. INTRODUCTION

Accurate estimation of actual crop evapotranspiration (ETa) holds great significance in both irrigated and dryland agricultural practices. Traditionally, various experimental methods have been employed to gauge ETa, such as lysimeters, the Bowen ratio, eddy covariance (EC), scintillometer (SC), and the soil water balance method. Empirical approaches, like the FAO-56 and ASCE methods, are also utilized. Nonetheless, these techniques exhibit limitations when applied to broader regions characterized by diverse land surfaces. To address this issue, innovative methods relying on surface energy balance and remote sensing data have been developed.

Several remote sensing-based models and algorithms, including Two-Source Energy Balance (TSEB) (Kustas & Norman, 1996), Atmosphere-Land Exchange Inverse (ALEXI) (Anderson et al., 1997), Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen et al., 2005; Bastiaanssen W.G.M. et al., 1998), Simplified Surface Energy Balance Index (S-SEBI) (Roerink et al., 2000), Surface Energy Balance System (SEBS) (Su, 2002), North American Land and Data Assimilation System (NLDAS) (Cosgrove et al., 2003), disaggregated ALEXI model (DisALEXI) (Norman et al., 2003), and Mapping Evapotranspiration at High Spatial Resolution with Internalized Calibration (METRIC) (Allen et al., 2007), have been harnessed for regional ETa estimation. Among these, METRIC is widely used, albeit it demands substantial data preprocessing and manual calibration.

To streamline this process, the Google Earth Engine Evapotranspiration Flux (EEFlux) platform was conceived to automate the application of the METRIC algorithm, simplifying data entry and calibration. EEFlux leverages Landsat imagery and gridded weather data to estimate ETa at the field scale, generating intermediate product maps like surface temperature, albedo, reference evapotranspiration, and crop coefficient maps.

Nonetheless, the automated nature of ETa estimation through EEFlux justifies a thorough assessment, particularly for specific regions and crops. Prior research indicates that while EEFlux generally provides reasonably accurate results, it may occasionally overestimate or underestimate ETa due to the automation processes, utilization of spatial weather data, and factors such as elevated wind speeds and residual soil evaporation. Overestimation can occur during the crop's maturity stage when the majority of energy is dedicated to heating the atmosphere rather than transpiration. Furthermore, EEFlux's performance has not been extensively scrutinized in Indian conditions or with non-irrigated crops.

This study seeks to evaluate the efficacy of METRIC-EEFlux in estimating ETa in India, taking into account the unique challenges and environmental conditions specific to the region.

II. MATERIALS AND METHODS

Study Sites

The research study was carried out in the Climate Smart Block established within the Centre for Advanced Agriculture Science and Technology focused on Climate Smart Agriculture Water Management, Mahatma Phule Krishi Vidyapeeth, Rahuri, during the rabi season. The study area is located at 19° 19' 19.70" N latitude and 74° 39' 27.27" E longitude, with an elevation of 527 meters.

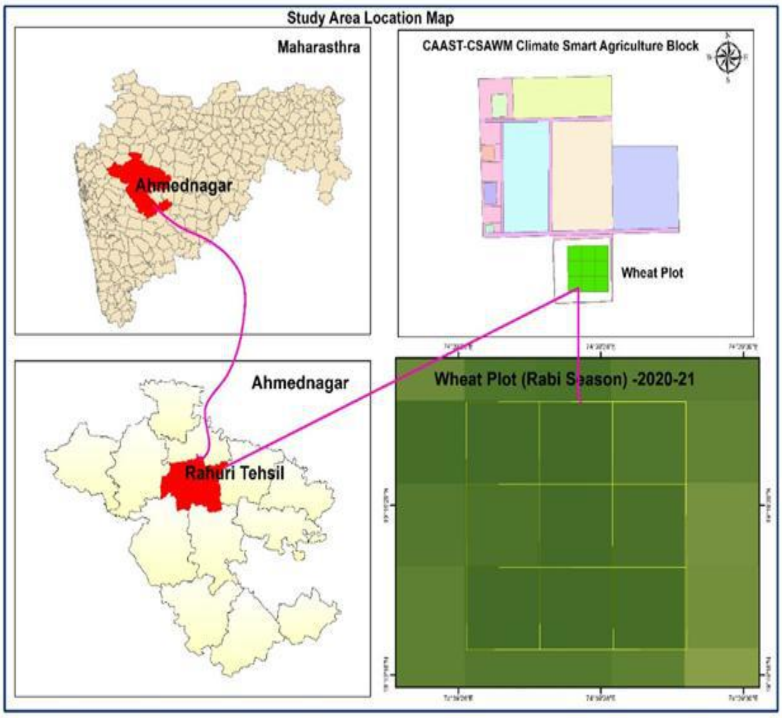

Fig.1. Location of Research Site

This research was conducted during the 2020-2021 agricultural season. Wheat (Triticum aestivum L.), specifically the Phule Samadhan variety, was the focus of the study. This investigation was carried out during the Rabi growing season, with the crop sown at a spacing of 22.5 cm using line sowing. The sowing date was December 6, 2020, and the crop was harvested on April 4, 2021, leading to a total crop duration of 120 days. Surface irrigation was employed as the method of watering, and a fertilizer dose of 120:60:40 N, P_2O_5, K_2O (kg/ha) was applied.

Satellite Data Acquisition

Table 1 Details of the EtrF data products from METRIC – EEFlux (Satellite images) used in the study with year, acquisition dates, day of the year (DOY), Days after planting (DAP), Landsat satellite, and path/row for 2020-2021 rabi season.

Year	Acquisition date	DOY	DAP	Satellite	Path/Row
2020	December 17	352	12	Landsat 8	147/46
2021	January 02	2	28	Landsat 7	147/46

	January 18	18	44	Landsat 8	147/46
	February 03	34	60	Landsat 8	147/46
	February 19	50	76	Landsat 8	147/46
	March 07	66	92	Landsat 7	147/46
	March 23	82	108	Landsat 7	147/46
	April 04	98	124	Landsat 8	147/46

Within the scope of this research study, a total of eight clear sky images were deliberately chosen for examination, Table 1. These specific images were selected due to their comprehensive temporal coverage, ensuring cloud-free conditions for analysis. Subsequently, the chosen images underwent processing using the EEFlux - Google Earth Engine Evapotranspiration flux platform to yield essential data products, namely EtrF and EEFlux- ETa.

Field Data Collection

The daily ETr values estimated with ASCE Penman Monteith method with seasonal average value. The crop coefficient (Kc) values estimated using polynomial equation developed with lysimeter data.

Methods

1. Estimation of actual evapotranspiration (ETa)

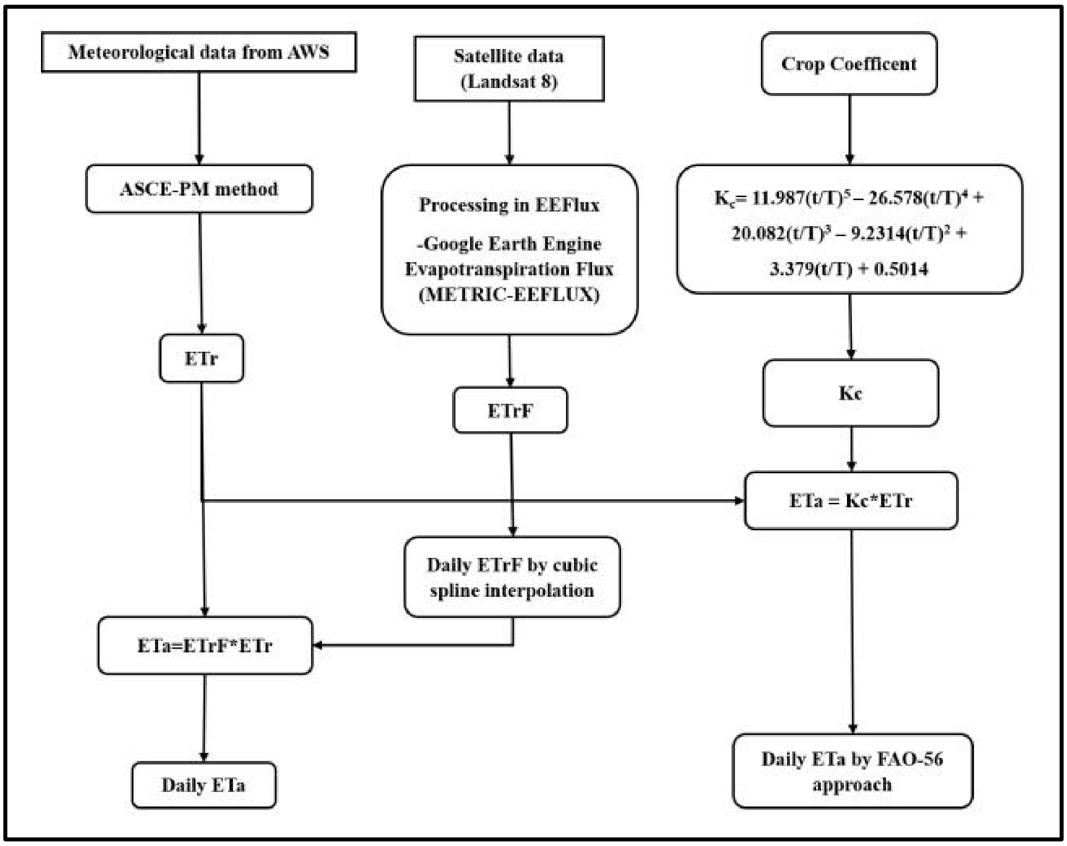

Fig.2 Methodology flowchart of actual evapotranspiration (ETa) estimation

The ETrF values derived from Landsat satellite data using EEFlux application, during the wheat crop growth period. Ultimately, the daily ETa values calculated using EEFlux were compared with respect to daily ETa by the FAO-54 approach with the help of statistical formulas. The detail of the workflow is explained in (Figure 2) flow chart.

1.1 Estimation of crop evapotranspiration (ETa) using FAO-56 approach

FAO-56 methodology (Allen et al., 2007)(Allen et al., 1998) was used to estimate actual crop evapotranspiration (ETa). The estimated actual crop evapotranspiration termed as FAO56-ETa. The crop evapotranspiration is estimated using equation ETa = Kc x ETr.

Where,

ETr = reference crop evapotranspiration (mm/day);

Kc = single crop coefficient that averages crop transpiration and soil evaporation;

The daily crop coefficient for wheat crop was estimated with the functions developed using the lysimeter data (Patil, 2007).

The crop coefficient values are calculated using the function presented in equation;

$Kc=11.987*(t/T)^5 -26.578*(t/T)^4+20.082*(t/T)^3 -9.2314*(t/T)^2+3.379*(t/T)+0.5014$

Where, t = day considered T = total crop duration

1.2 Estimation of actual evapotranspiration (ETa) by EEFlux

EEFlux, or the Google Earth Engine Evapotranspiration Flux, is a specialized application of the METRIC algorithm. It was employed to generate precise evapotranspiration (ET) maps by processing Landsat imagery within the Google Earth Engine infrastructure, focusing on the creation of ETa maps for individual Landsat scenes. EEFlux closely follows the operational METRIC model's approach, functioning as a comprehensive surface energy balance model that provides valuable estimates for key parameters, including net radiation (Rn), sensible heat flux (H), and soil heat flux (G). ETa values were derived as the difference within the surface energy balance equation, as originally established by Allen and colleagues in 2007. In the context of this study, ETa values computed using the METRIC-EEFlux approach were denoted as EEFlux-ETa.

Extraction of ETrF

In this study, Landsat images were processed using Earth Engine Evapotranspiration Flux (EEFlux / METRIC version 0.20.2). ETrF data from METRIC-EEFlux were downloaded for analysis. Mean EtrF values for wheat crops were extracted using a 3 x 3-pixel area (90 x 90 m rectangle) centered on field boundaries in QGIS 2.18.6. Daily EtrF values were derived using cubic spline interpolation. Daily EEFlux-ETa was calculated based on equation $ET_a = ET_rF \times ET_r$ and compared with ETa estimates using the FAO-56 approach for the 2020-2021 growing season. Seasonal ETa was determined by summing daily ETa values within the growing season.

III. RESULTS AND DISCUSSION

This study, carried out during the 2020-2021 season, focused on crop evapotranspiration and crop coefficient using the Earth Engine Evapotranspiration Flux application. It involved estimating reference evapotranspiration (ETr), actual crop evapotranspiration (ETa), crop coefficient based on lysimeter data (Kc), as well as estimating ETa using EEFlux-derived fraction reference evapotranspiration (EtrF).

Estimated Reference Evapotranspiration values

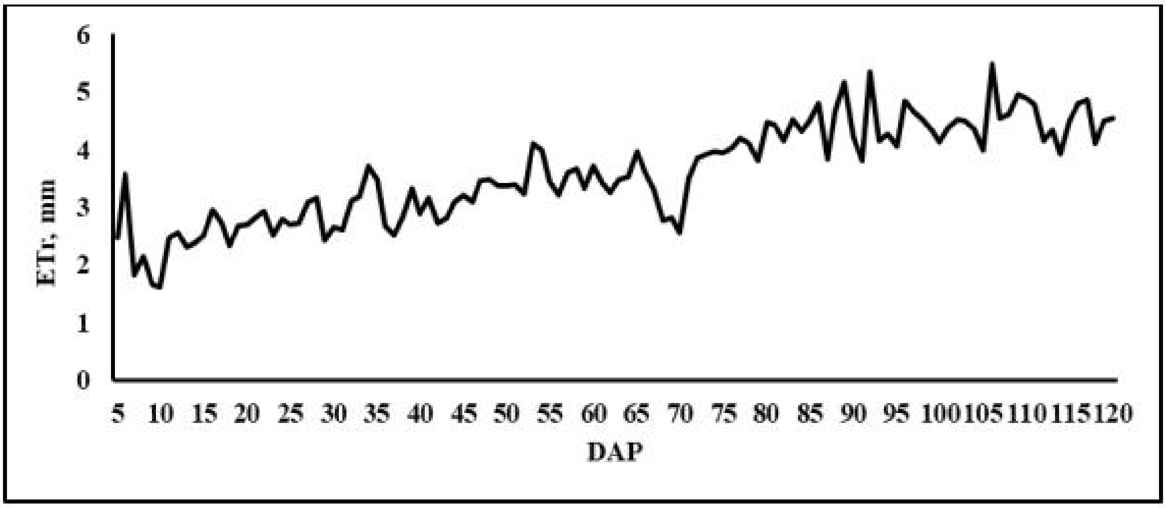

Fig.3 Stage wise ETr (mm) for wheat crop during the 2020 and 2021 growing seasons

Reference evapotranspiration was estimated using the ASCE Penman Monteith Method with data from the Automatic Weather Station at CAAST CSAWM Climate Smart Research Block during the 2020-2021 wheat growing season. Daily ETr values, depicted in Figure 3, demonstrate variations ranging from 1.61 mm to 5.50 mm over the wheat growth period, with an average of 3.57 mm.

Stage wise Crop Coefficient values

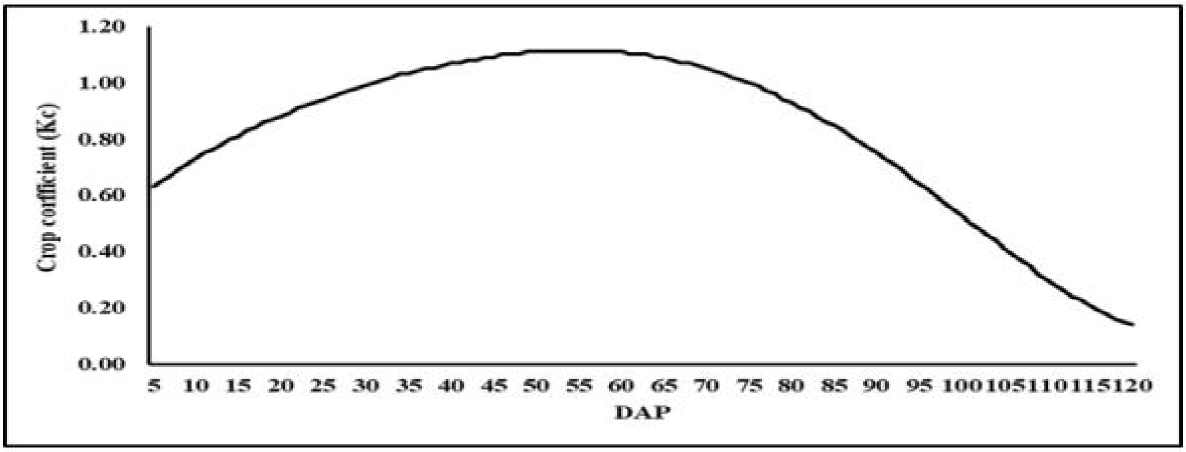

Fig.4 Stage-wise Kc estimated for wheat crop during the 2020 and 2021 growing seasons

Daily crop coefficient (Kc) values were determined using a polynomial equation based on lysimeter data and soil water balance. Stage-wise Kc values were averaged over each respective stage duration. The daily Kc values are visually represented in Figure 4, demonstrating a range from 0.14 to 1.11 during the wheat growth period, with an average seasonal value of 0.81. Estimated Daily FAO-56-ETa (mm)

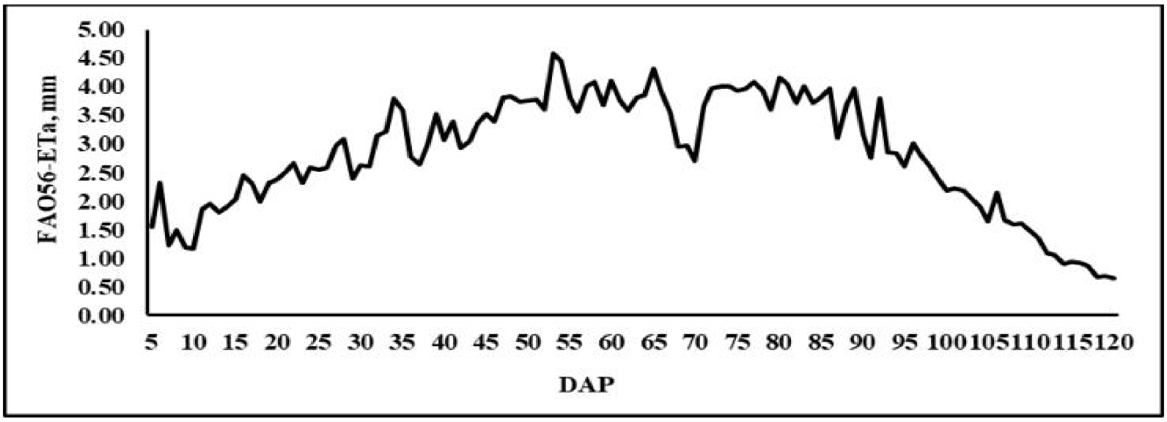

Fig.5 Daily FAO56-ETa (mm) estimated for rabi wheat growing season of 2020- 2021

Daily ETa values were estimated using the FAO-56 approach, calculated as the product of reference evapotranspiration and crop coefficient, denoted as FAO56-ETa. These values are visually displayed in Figure 5. The data reveals that FAO56-ETa varies from 0.64 mm to 4.80 mm throughout the wheat growing period, with an average value of 2.58 mm. The total seasonal ETa accumulates to 336 mm.

Daily ETrF derived from Landsat-8 satellite data

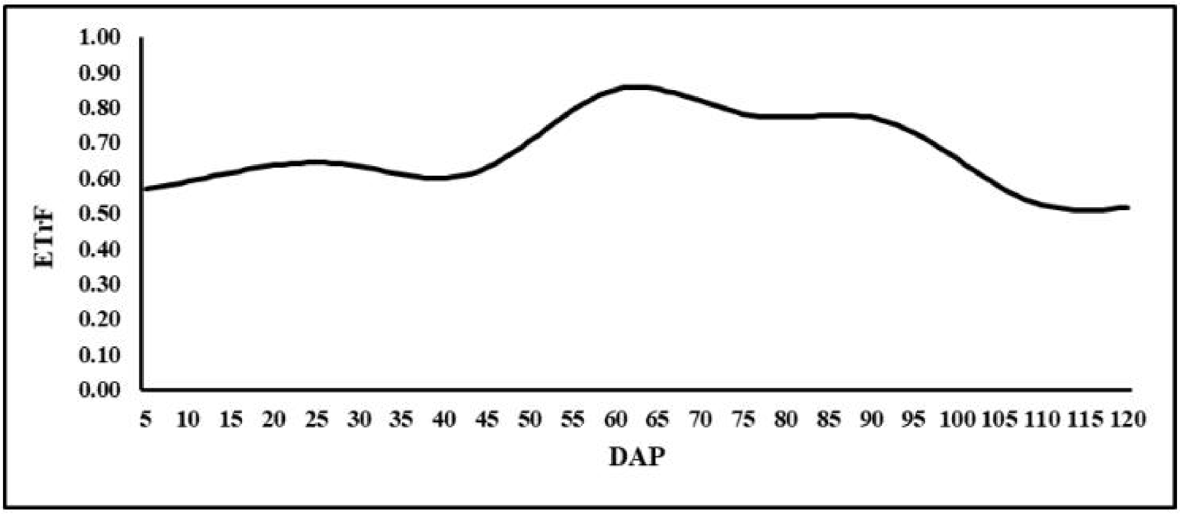

Fig.6 ETrF profile during crop growing period of wheat (2020-2021)

ETrF values, equivalent to the crop coefficient, were extracted from Landsat satellite data through the EEFlux (Google Earth Engine Evapotranspiration Flux) application for available dates within the wheat crop's growth period. These daily ETrF values are visually represented in Figure 6. Notably, ETrF varies from 0.51 to 0.86 throughout the wheat growing period, with a seasonal average of 0.67.

Estimated Daily EEFlux-ETa (mm)

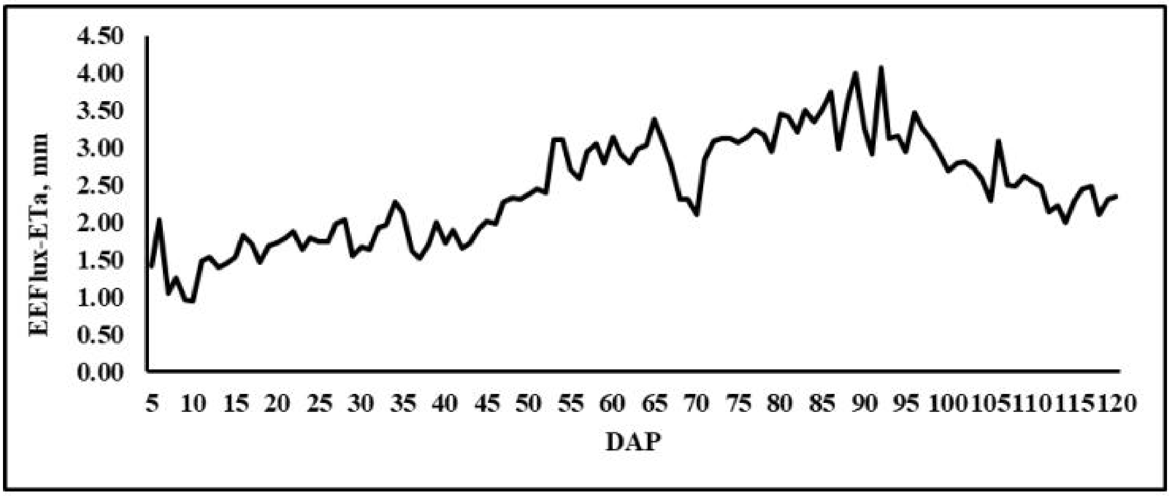

Fig.7 EEFlux-ETa during crop growing period of wheat (2020-2021)

EEFlux (Google Earth Engine Evapotranspiration Flux) was utilized to estimate ETa, referred to as EEFlux-ETa. EEFlux calculates ETa using Landsat satellite data and local weather information. EEFlux-ETa values are illustrated in Figure 7. The data shows that EEFlux-ETa ranges from 0.95 mm to 4.07 mm across the wheat growing season, with an average of 2.41 mm. The total seasonal ETa estimated by EEFlux amounts to 290 mm.

Comparison of EEFlux-ETa and FAO56-ETa

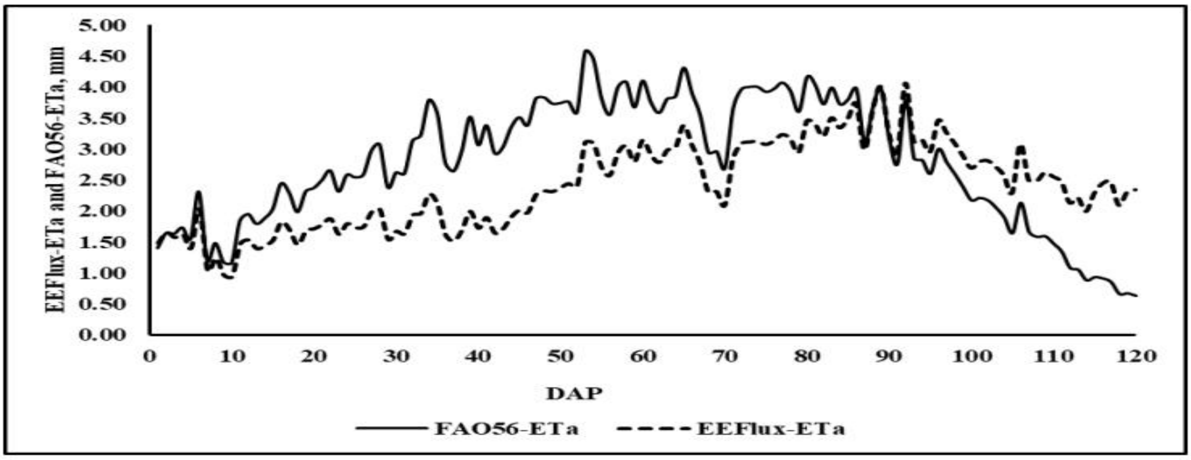

Fig.8 Comparison of EEFlux-ETa and FAO56-ETa during wheat crop growth period during 2020-2021

Figure 8 displays the Comparison of EEFlux-ETa and FAO56-ETa during wheat crop growth period during 2020-2021.

Daily rates exhibit significant variability throughout the growing season, with larger differences between EEFlux-ETa and FAO56-ETa observed on a daily scale. These disparities are most pronounced during the initial and late season stages. In the maturity stage, the majority of energy is allocated to heating the atmosphere rather than transpiration. Post-harvest, ET decreases abruptly, a phenomenon not captured by any method for seasonal ET, resulting in larger differences in ETa. These findings align with previous research comparing measured and estimated ETa. Khan et al. (2019) noted departures ranging from -4.7% to 25.5% for cumulative ET estimates with METRIC-EEFlux across various crops, with larger discrepancies in low ET conditions. Ayyad et al. (2019) reported a 36% overestimation of ETa by EEFlux in Egyptian agriculture compared to the SEBS model, while Duijndam (2016) observed errors ranging from 4% to 176% in EEFlux cumulative ETa estimates in semi-arid regions compared to flux tower measurements. Kadam et al. (2021) reported a 23% underestimation of ETa with EEFlux for winter wheat in dryland fields.

Table 2. Statistical comparison of EEFlux ETa and FAO-56 ETa

Statistical Parameter	Value
Index of Agreement (IA)	0.67
Root Mean Square Error (RMSE)	0.93 mm/day
Normalized root mean square Error (NRMSE)	0.33mm /day

EEFlux-ETa was rigorously compared to FAO56-ETa, employing root mean square error (RMSE), normalized root mean square error (NRMSE), and the index of agreement (IA). The statistical analysis, presented in Table 2, provides a comprehensive overview of ETa comparisons between EEFlux and the FAO-56 approach. Figure 9 visually illustrates the comparison between EEFlux-ETa and FAO56-ETa.

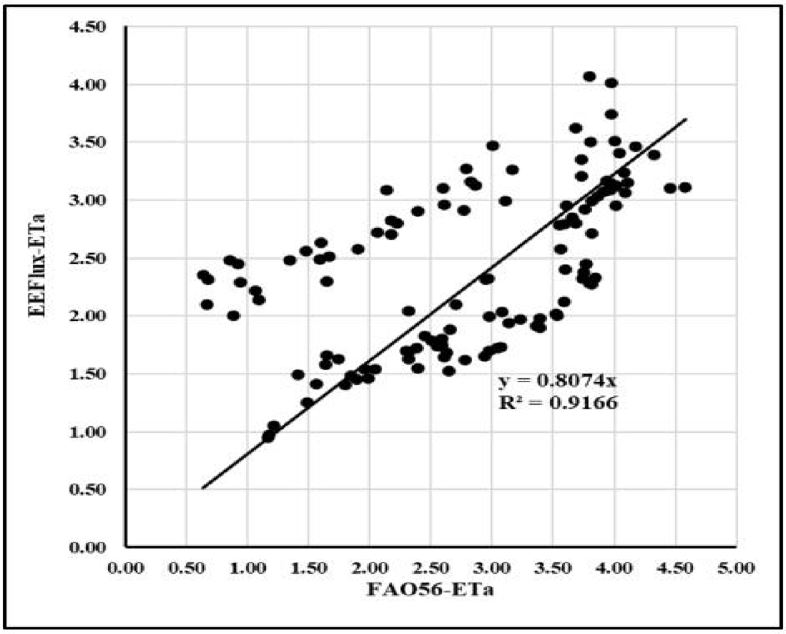

Fig.9 Statistical comparison of EEFlux-ETa and FAO56-ETa during wheat crop growth period during 2020-2021

The IA-index, registering at 0.67, along with a slope of 0.81, indicates a moderate to good correlation between the estimated EEFlux-ETa and FAO56-ETa, supported by an R^2 value of 0.92. Notably, the RMSE reveals a minimal bias, falling below 1 mm/day (RMSE=0.93 mm/day) for wheat. A corresponding NRMSE of 0.33 mm/day confirms this. Discrepancies observed in ETa estimations between EEFlux and the FAO-56 approach can be attributed to potential errors or bias in ETrF derived from satellite data and Kc estimates drawn from lysimeter data.

Comparison of Kc and EtrF during different growth stages

Table 3 Percent deviation of ETrF from Kc estimated using Lysimeter data

Stage	Duration (days)	Kc	ETrF	% Deviation
Initial	15	0.68	0.58	14.74
Development	25	0.96	0.63	35.02
Mid-Season	50	1.02	0.77	24.83
Late-Season	30	0.44	0.60	-45.93

The study calculated the average values of Kc and ETrF at various developmental stages of wheat crop, namely, initial (15 days), development (25 days), mid-season (50 days), and late-season (30 days). The stage-wise average Kc values were found to be 0.68, 0.96, 1.02, and 0.44 during the initial, development, mid-season, and late-season stages, respectively. Similarly, the stage-wise average ETrF values (representing Kc derived from Landsat satellite data) were 0.58, 0.63, 0.77, and 0.60 during the corresponding stages.

The study also determined the percentage deviation of ETrF from Landsat satellite data compared to Kc estimated using lysimeter data, resulting in deviations of 14.74%, 35.02%, 26.83%, and -45.93% for the initial, development, mid-season, and late-season stages, respectively. These daily departures of ETrF values from lysimeter-based Kc estimates are visually presented in Figure 10.

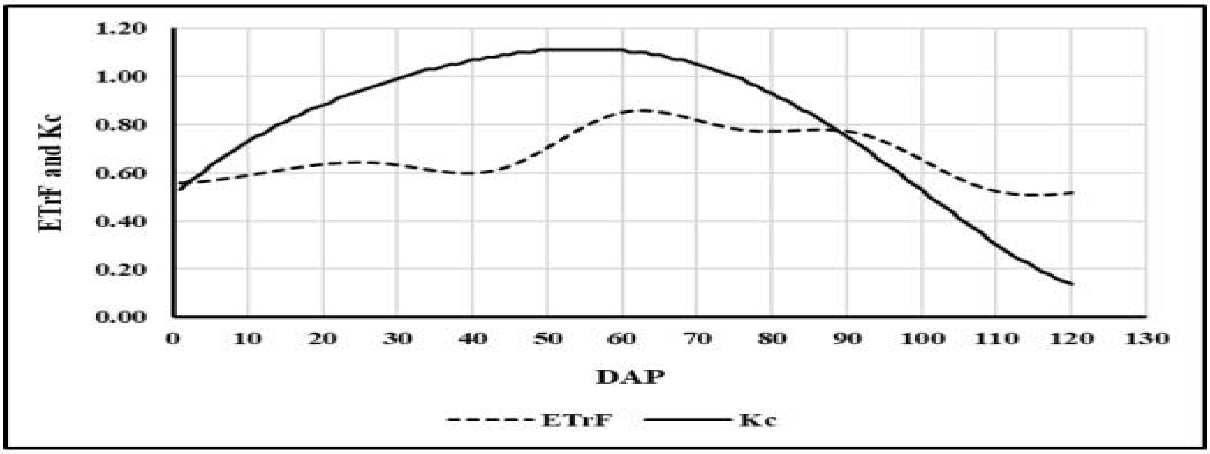

Fig.10 Statistical Comparison of daily ETrF and Kc during wheat crop growing season of 2020-2021

In the study conducted during the Rabi season of 2020-2021, the Earth Engine Evapotranspiration Flux (EEFlux) application showed a 13.69% underestimation of ETa compared to the FAO-56 approach. Additionally, the study revealed a moderate to good correlation between ETa estimated by EEFlux and the FAO-56 approach, with an R^2 of 0.92, IA of 0.67, RMSE of 0.97 mm/day, and NRMSE of 0.33. These findings support the potential use of EEFlux and Google Earth Engine for estimating wheat ETa. However, further assessments across multiple years and locations are necessary to determine its broader suitability for regional ETa estimation.

IV. DISCUSSION

This research explores the estimation of actual crop evapotranspiration (ETa) for wheat crops during the Rabi season. The study involves the assessment of ETa using two different approaches: the FAO-56 method and the EEFlux application in the Google Earth Engine platform. The analysis focuses on daily ET values and their seasonal variations, considering various factors such as crop coefficients (Kc) and reference evapotranspiration (ETr) values.

The findings highlight substantial variations in daily ETr values, Kc during the wheat crop's growth period. Comparisons between the two ETa estimation methods, FAO-56 and EEFlux, reveal an underestimation of ETa by EEFlux, approximately 13.69% on a seasonal basis. The statistical assessment demonstrates a moderate to good correlation between EEFlux and FAO-56-derived ETa, with strong R^2 values and acceptable error metrics.

This research topic underscores the significance of accurate ETa estimation methods for agricultural water management, particularly in regions cultivating wheat during the Rabi season. It opens the door for further investigations into improving the precision and applicability of EEFlux in estimating ETa for various crops and across multiple locations and years. The outcomes have potential implications for optimizing irrigation strategies and enhancing water resource management in agriculture.

Overall, this study reveals a 13.69 % underestimation of EEFlux-ETa compared to ETa estimated via the FAO-56 approach for wheat in the 2020-2021 Rabi season. Notably, a moderate to good correlation was observed between ETa estimates derived from EEFlux and the FAO-56 approach, with a maximum R^2 value and RMSE below 1.00 mm/day. These findings underscore the potential of EEFlux for accurate ETa estimation. However, further research across various years and locations is essential to ascertain its broader suitability for regional ETa estimation.

AUTHOR CONTRIBUTIONS

Conceptualization- S. A. Kadam; Methodology- S. A. Kadam, Vishal Pandey and S. D. Gorantiwar; Validation- M. G. Shinde;Formal analysis- S.A. Kadam and Vishal Pandey; Data curation- M. G. Shinde; Writing—original draft preparation, Vishal pandey; Writing—review and editing, S. A. Kadam, M. G. Shinde and Vishal Pandey; Supervision- S. D. Gorantiwar.

DECLARATION

All authors have read and agreed to the published version of the manuscript.

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