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Estimation of Crop Evapotranspiration for Rabi crops using Spatial and Ground based Observation: A Case Study of village Akodha, Prayagraj

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Abstract

The primary objective of this research is to estimate crop evapotranspiration (ETc) by integrating spatially distributed remote sensing observations with ground-based meteorological data. Grass reference evapotranspiration (ETo) and CROPWAT based evapotranspiration were simulated using satellite-derived ET inputs generated through the Surface Energy Balance System (SEBS) model, along with field-measured meteorological parameters collected from six sampling points during the Rabi season. The SEBS-derived ET values were found to be realistic and successfully captured the seasonal variability across the study area. Using Grass-based ETo, the maximum ETo was observed in March (5.73 mm/ day) corresponding to the highest temperature, while the minimum ETo occurred in December (0.47 mm/day) during the lowest temperature period. Similarly, CROPWAT-derived ETo also peaked in March (4.06 mm/day) and reached its minimum in December (1.04 mm/day), consistent with seasonal temperature variations. These results highlight the potential of satellite-based ET estimation in improving spatial and temporal understanding of crop water requirements during the Rabi season.

Keywords: Evapotranspiration: Surface energy balance: Remote sensing: Grass GIS; CROPWAT.

Introduction

In arid and semi-arid conditions, irrigated agriculture is the major consumptive user of water. Most large irrigation schemes have extremely high losses, with crop evapotranspiration accounting for only 20%-35% of water supplied with remainder being wasted (Tanton and Heaven, 1999). Limited water resources and water scarcity in India are obstructing the agriculture horizontal expanding. In the same time over population increases and agriculture land decreases. As a result, quantities of food will decrease. Reference crop evapotranspiration (ETo) mainly depends on water availability and incoming solar radiation and then reflects the interactions between surface water processes and climate (Sobrino el al., 2007). However, it can be calculated by using pan evaporation from a free water surface; models based on climatologically parameters. FAO-penman-monteith is most accurate for ETo estimation in both humid and arid climatic conditions, it provides ETo estimates for planning and efficient use for agricultural water resources (Yin et al., 2008).

ET is the combination of two separate processes, where liquid water is converted to water vapor (vaporization) from the soil, wet vegetation, open water or other surfaces, as well as from plants by transpiration through stomata (Allen et al., 1998). Evaporation and transpiration occur simultaneously and they are difficult to separate out. ET rate depends on weather conditions, water availability, vegetation characteristics, management and environmental constraints. The main weather variables affecting ET are temperature, solar radiation, wind speed and vapor pressure. There are different methods for estimation of evapotranspiration. These are direct measurement methods and indirect methods which use weather data and soil water balance. These methods can be generally classified as empirical methods (Thornthwaite, 1948) and physical based FAO Penman Montheith (Allen et al., 1998). They vary in terms of data requirement and accuracy. Some models are used to estimate ET such as the Two-Source Energy Balance Model or the CROPWAT model.

CROPWAT model is a reliable model to calculate ET. This model has been provided by the United Nations Food and Agriculture Organization (FAO) and can directly output the ET and irrigation water requirements of crops. At present, the FAO Penman Montheith approach is considered as a standard method for ET estimation in agriculture (Allen et al., 1998). Cropwat is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation. Remote sensing imagery from cameras on board satellites, aerial platforms, airplanes or similar systems has been recognized as an exceptional tool to produce spatial information about ET. Nevertheless, the lack of availability of timely images at the required spatial resolution, to be able to capture the within-field variability of crop conditions over the growing cycle, has been hindering the use of remote sensing approaches in practical applications.

Currently, the operational use of dense time series of remote sensing (RS)-based multispectral imagery at high spatial resolution is able to monitor the crop biophysical parameters related with crop ET and crop water use across the growing season, with suitable temporal and spatial resolutions. One most prominent and direct application of these approaches in agriculture is irrigation management. As described by (Allen et al., 1998), the benefits of these methodologies with respect to most classical information sources (field measurements or general knowledge) are the possibility to cover large areas, enabling sampling at high spatial resolutions and the zonation and/or integration over diverse areas. In addition, these procedures are generally more economical than point measurements. The literature is abundant in RS-based ET models or model variants and validations of these models in different environments, surfaces and managements. Every model has strong scientific bases and is well calibrated for ET assessment at particular temporal and spatial scales. Nevertheless, the translation of ET estimates into irrigation requirements and recommendation needs further development, and it involves additional engineering methods and operative issues. Landsat satellite data have been produced, archived, and distributed by the U. S. Geological Survey (USGS) since 1972. Users rely on these data for historical study of land surface change and require consistent radiometric data processed to the highest science standards. In support of the guidelines established through the Global Climate Observing System, the USGS has embarked on production of higher-level Landsat data products to support land surface change studies. This study aims to estimate crop evapotranspiration (ETc) using satellite-derived ET and ground-based meteorological data.

Materials and Methods

Study area

The research was carried out at the part of Akodha Village in Kaudhiyara Block in Prayagraj District of Uttar Pradesh State, India. It belongs to Prayagraj Division. It is located 26 KM towards South from District headquarters Prayagraj. The study area Akodha district situated between DMS latitude 25.2578° N, and DMS longitude 81.9439°″E the village is 104 meters Above Sea level (Fig. 1). The total Area of Akodha village is 653.62 ha. Akodha Local Language is Hindi. Akodha Village Total population is 7205 and number of houses are 1201. Female Population is 48.1%. Village literacy rate is 55.2% and the Female Literacy rate is 21.8%. The district is endowed with good soil, adequate ground water and all three growing seasons, Rabi, Kharif and Zaid. The major crops grown are wheat followed by pulses and potato. About one third (34.71%) of all wheat produced in the country comes from Uttar Pradesh. Mustard, Gram, vegetables, potato, Pea, Tomato is other important crops.

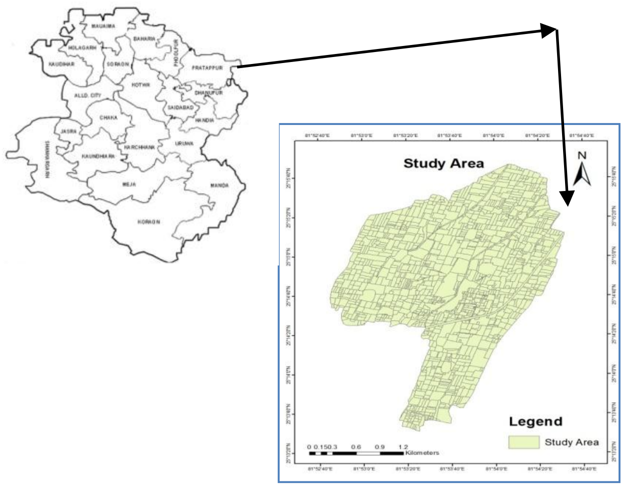

Fig. 1 Geographical location of the study area

Data used

Climatologically data consists of rainfall, maximum and minimum temperature, relative humidity, wind speed and maximum sunshine hours which is used in this study was collected from the School of Forestry, SHUATS, Prayagraj. Landsat 8 satellite data was collected from https://earthexplorer.usgs.gov/. It consists of 11 bands and Meta data. It is desirable to conduct the research on estimation of Crop Evapotranspiration in the part of year basis, i.e., for the period of Rabi season from November 2016 to April 2019 which consist maximum solar radiation period and solar radiation period because generally, the periods for study is such situations will be from the time of maximum evapotranspiration to the time of minimum evapotranspiration as the maximum solar radiation period and from the time of minimum solar radiation. The research period is taken as November, December, January, March, and April.

Surface Energy Balance Equation

In the SEBAL model, ET is computed from satellite images and weather data using the surface energy balance as illustrated in Figure. Since the satellite image provides information for the overpass time only, SEBAL computes an instantaneous ET flux for the image time. The ET flux is calculated for each pixel of the image as a "residual" of the surface energy budget equation:

$$\lambda ET = R_n - G - H \quad (1)$$

Where; λET is the latent heat flux (W/m^2), R_n is the net radiation flux at the surface (W/m^2), G is the soil heat flux (W/m^2), and H is the sensible heat flux to the air (W/m^2).

CROPWAT 8.0 Model

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation. Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 24 "Crop water requirements" and No. 33 "Yield response to water". The input data used for calculating the evapotranspiration are Minimum temperature (°C), Maximum temperature (°C), Sunshine hours (hrs), Wind speed (km/day), Relative humidity (%), Latitude (DMS) Degree Minute Second, Longitude (DMS) Degree Minute Second and altitude. The output given by CROPWAT model is ET_0 evapotranspiration (mm/day).

$$ETo = \frac{0.408\,\Delta\,\mathrm{Rn-G+y}\;900\mathrm{T}+273}{(\mathrm{es-ea})\;\Delta+Y\;(1+0.34\,u2)} \quad (2)$$

Where,

ETo = Reference evapotranspiration (mm/day)

Rn = Net radiation at the crop surface (MJ m^2 /day)

G = Soil heat flux density (MJ m^2 /day)

T = Mean daily air temperature at 2 m height (°C)

$u2$ = Wind speed at 2 m height (m/s)

es = Saturation vapour pressure (kpa)

ea = Actual vapour pressure (kpa)

$es - ea$ = Saturation vapour pressure deficit (kpa)

Δ = Slope vapour pressure curve (kpa/ °C)

T = Psychrometric constant (kpa /°C)

METHODOLOGY

Satellite Data (Landsat 8)

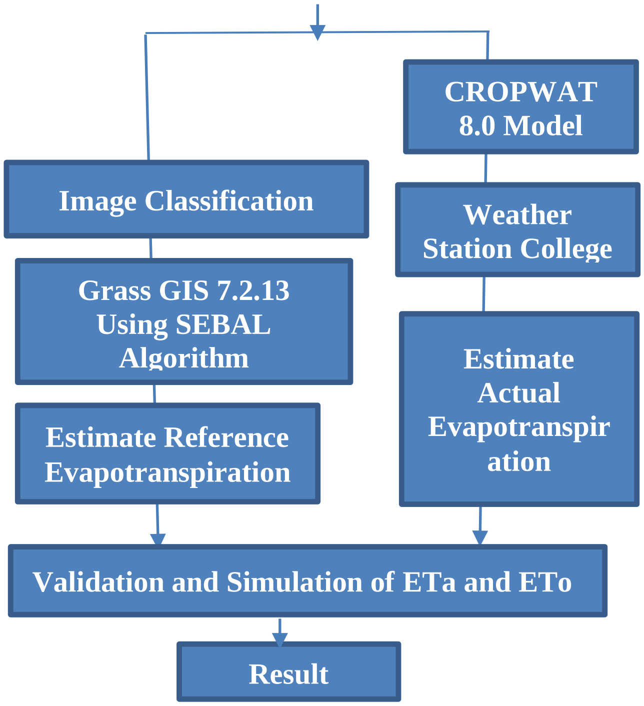

Fig. 2 Flow chart of methodology

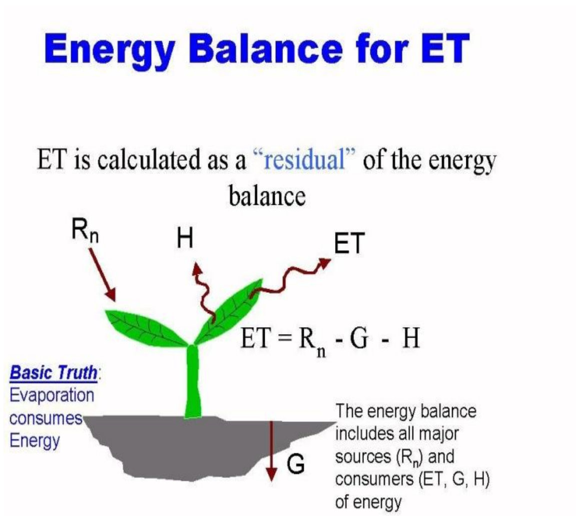

Fig. 3 Surface energy balance for ET

Results and Discussion

Unsupervised Classification

Image Classification is defined as the process of categorizing all pixels in an image or raw remotely sensed satellite data to obtain a given set of labels or land cover themes. The purpose of the classification process is to group all pixels in a digital image into one of different land cover classes. Unsupervised classification is a method which examines a large number of unknown pixels and divides into a number of classes based on natural groupings present in the image values. Besides, unsupervised classification is easy to apply, does not require analyst specified training data and is widely available in image processing and statistical software packages moreover it automatically converts raw image data into useful information so long as there is higher classification accuracy. This method is adopted for this study was based on the use of LandSat 8 ETM+ imagery with the extraction of around pixels containing Vegetation, Soil and Water was identified.

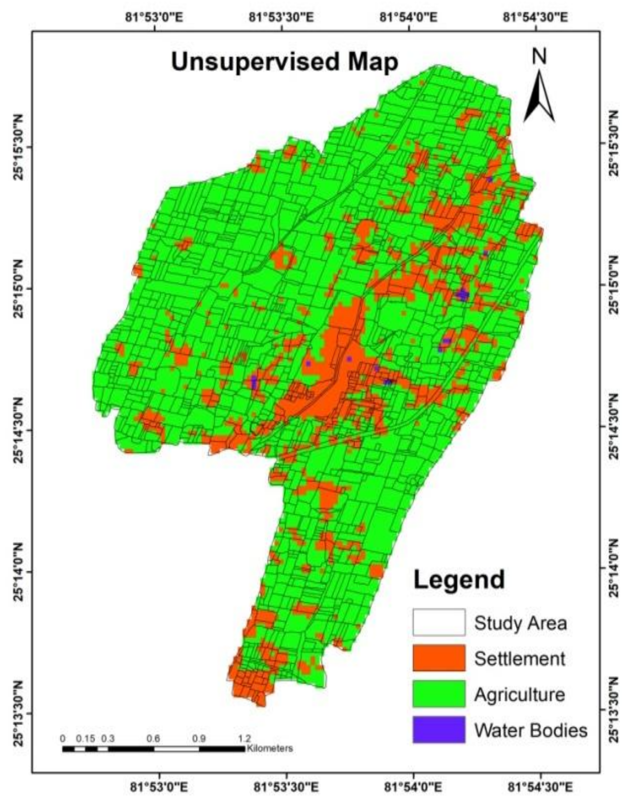

Fig. 4 Unsupervised map of study area

Model Performance

This research successfully demonstrated a method for integrating remotely sensed data and crop ET simulation for monitoring crop growth and predicting water management. In this phase of the research LANDSAT 8 (OLI) data were used to assess wheat, Mustard, Pea, Gram, Potato, Tomato in Akodha village in Prayagraj.

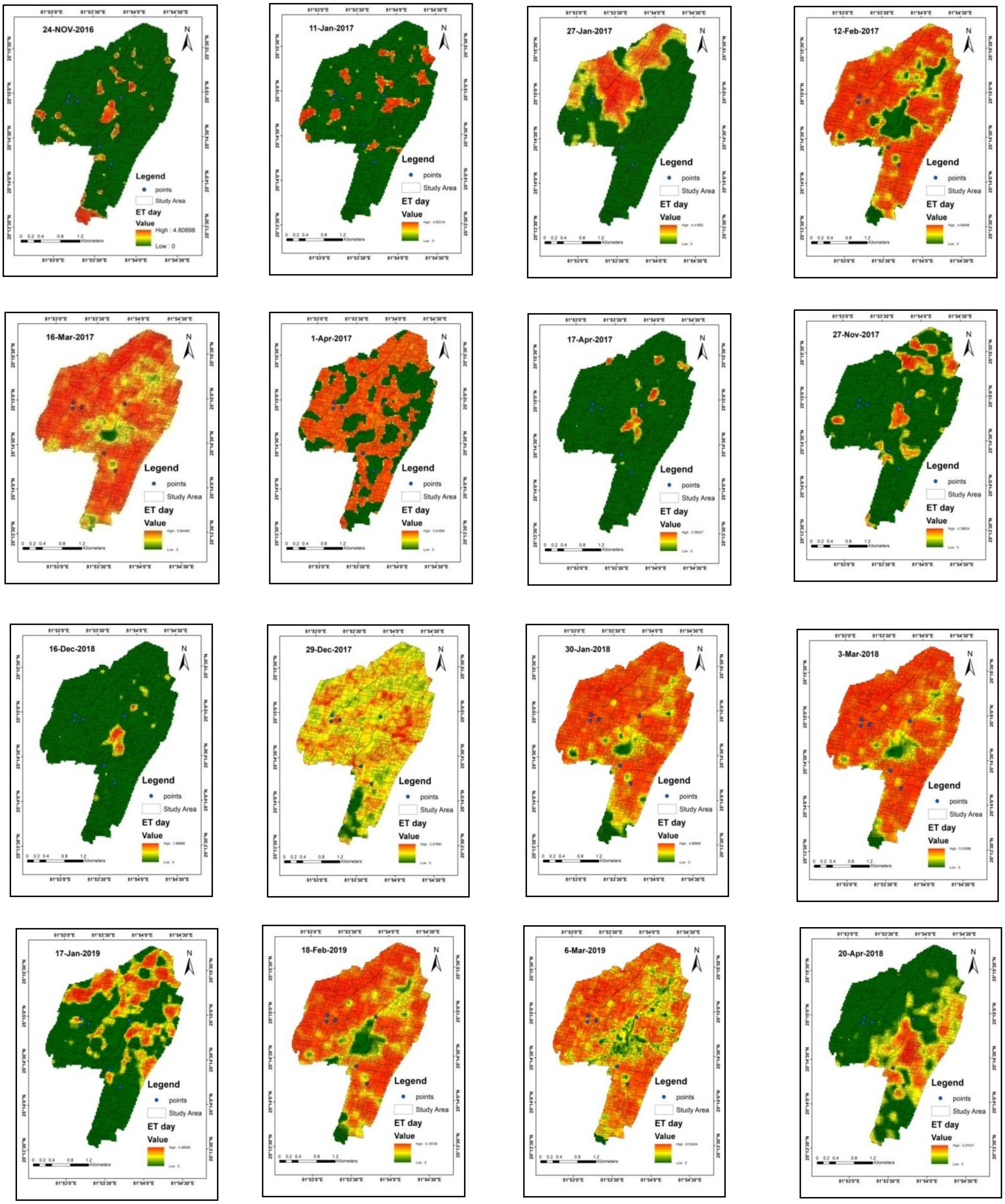

Fig. 5 ET value obtained for the study area (November 2016 – April 2019)

Validation

In this study, Grass ET and Cropwat ET are estimated for Wheat, Mustard, Pea, Gram, Potato and Tomato in Akodha village (Fig. 6). In this area we used the different parameters, namely the radiance values obtained from the satellite imagery data and meteorological data (College of Forestry). Basically, linear regressions were used to explore the relationship between the Cropwat ET and Grass ET i.e. spatially observed data and satellite image radiance data (NIR band of Landsat)

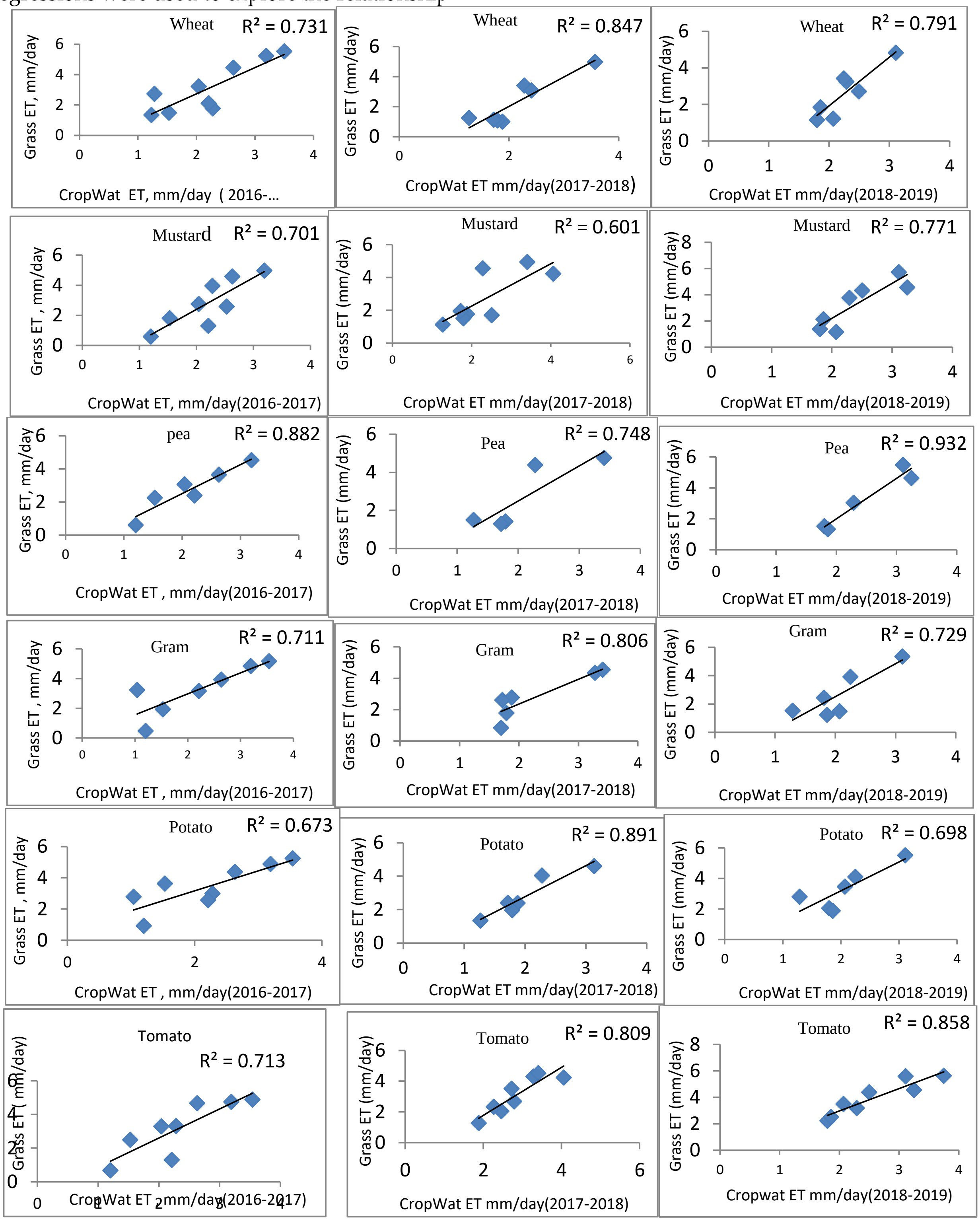

Fig.7 Simulation of Grass ET with Cropwat ET

Conclusions

In this study CROPWAT 8.0 and Grass ET Model was used to determine the reference evapotranspiration in the Akodha village for the time series 2016 to 2019. Daily ET was estimated for Rabi season (2016-2019) of the area from surface energy balance system (SEBS) algorithm using in satellite data from Landsat 8and meteorological station data, because some of the Landsat 8 data were affected by the cloud. It was possible to calculate ET for each land cover class and was assessed the seasonal variation of ET for each land cover class. The maximum ETo was in the month of March i.e., 5.73 mm due to highest temperature in this month and the minimum ETo was in the month of December i.e., 0.47 mm due to minimum temperature in this month. The correlation coefficients are estimated between Grass ET and Cropwat ET, the R^2 value of the model is estimated minimum 0.731 in year 2016-2019 and maximum 0.847 in year 2018 for wheat crop, for mustard minimum 0.601 and maximum 0.771 in year 2016-2019, for pea minimum 0.748 and maximum 0.932 in year 2016-2019, for gram minimum 0.711 and maximum 0.806, for potato minimum 0.673 and maximum 0.891 in year 2016-2019, for tomato minimum 0.713 and maximum 0.858 in year 2016-2019 in Rabi season.

It was found that the ET is calculated in Grass ET is highly dynamic and depends to the change in rainfall amount. When there are no rainfall ET approaches zero. In this phase of the research LANDSAT 8 data were used to assess Evapotranspiration in irrigated area of Akodha village and the model simulation were adjusted to produce the accuracy that matched with estimated Cropwat ET in irrigated area of Akodha village. Comparison of statistically Grass ET and Cropwat ET results to standard user validation, found that the Grass ET results of 2016 to 2019, used in the validation process was significantly better than the accuracy of Cropwat ET estimates. Validation analyses of Grass ET values confirm that the range is significant.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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