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Estimation of Evapotranspiration using Remote Sensing based SEBAL model: A Case Study of Pantnagar Agricultural Farm

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ABSTRACT
Evapotranspiration (ET) is an indicator of total water needed by a crop for their growth. If irrigation will we given in the cropped field as per the ET estimation for that crop, the wastage of water can be controlled. In the present study, evapotranspiration has been estimated using remote sensing technique. For this the experimental farm land of GB Pant University of Agriculture and Technology, Pantnagar Uttarakhand has been used as a case study. The image for the same has been collected from Landsat 8. The ET estimation has been done for the month of February 2018. Surface Energy Balance Algorithm for Land, commonly abbreviated as SEBAL has been used to estimate ET for the acquired image. The Evapotranspiration flux is calculated for each pixel of the image as a "residual" of the surface energy budget equation. The results from this study suggested that for the study area NDVI varied between 0.084 to 0.464. The Surface albedo varied from 0.149 to 0.265 and surface temperature varied from 286.175 K to 291.244 K. Finally, evapotranspiration can have varied from 0.569 mm per day to 1.566 mm per day.
Keywords: *Evapotranspiration, Landsat 8, SEBAL*

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INTRODUCTION

Evapotranspiration (ET) is an indicator of total water needed by a crop for their growth. If irrigation will we given in the cropped field as per the ET estimation for that crop, the wastage of water can be controlled. India still lack a policy which can implement water distribution to agricultural field based on ET estimations. As far as the research progress in ET estimation for cropped area is concerned, it has been done both for point source cropped field as well as grid based, which cover a large geographical area.

Evapotranspiration (ET) consists of two main component processes: evaporation and transpiration. Evaporation is the loss of water from open water surfaces such as oceans, lakes, reservoirs, and rivers, and from soil pores directly to the atmosphere. In the evaporation process, energy is required to convert liquid water to the vapor state. Most of this energy comes from absorbed radiation which dependson latitude, season, cloud cover, air temperature and surface albedo (the fraction of solar shortwave radiation reflected from the earth back into space, which is affected by surface conditions and soil moisture). Transpiration (T) occurs when water absorbed by plant roots is transferred to the leaves via the vascular system and returned to the atmosphere through their stomata. It is noteworthy to highlight that evaporation and transpiration occur simultaneously and it is complex to differentiate them. There are three different expressions for ET: potential evapotranspiration, reference evapotranspiration and actual evapotranspiration. Potential evapotranspiration is the water loss which would occur from a vegetated surface when sufficient moisture is available in the soil such that stomata are fully open and resistance to water vapor transport from bare soil to the atmosphere is minimal. ET_o is defined as the evapotranspiration rate from a hypothetical reference surface with unlimited soil moisture availability.

Researchers have developed many methods to estimate evapotranspiration. Meteorological or climatological methods are based on point data, which cannot provide a good estimation of ET in large areas. Thus, in the last few decades, remote sensing approach for evapotranspiration estimation has gathered lot of attention.

The United Nations Food and Agricultural Organization (FAO) proposed a methodology for computing reference evapotranspiration (ET_0) and crop coefficient (K_c) [7]. The crop coefficients depend on several factors including crop type, stage of crop growth, and canopy height and density [3]. There is no consensus on the suitability of an equation for a given climatic condition and each equation requires rigorous local calibration [6]. However, the Penman-Monteith (P-M) model/ equation is the physically based standard equation for determination of ET_0 from meteorological data [3]. The suitability of P-M equation was assessed by different authors for different climatic conditions [6,9,15]. The SEBI model follows the principles of SEBAL by hypothesizing the reflectance of maximum temperature for dry pixels and the reflectance of minimum temperature for wet pixels [11]. The main distinction between SEBI and SEBAL are the differences in definition, calculation and interpolation of maximum and minimum latent heat fluxes for a given set of layers [10]. The S-SEBI model simplifies the SEBI model by obtaining the extreme temperatures for the dry and wet pixels [11].

The Surface Energy Balance System (SEBS) algorithm was developed by Su (2002) [14] to estimate turbulent heat fluxes and subsequently ET using meteorological and remote sensing data. The SEBS model involves three data sets of information. The first set includes albedo, emissivity, temperature, LAI and vegetation height. The second is a meteorological data set including temperature, air pressure, humidity and wind. The third data set includes direct or modelled solar radiation measurements. In contrast to the SEBAL model, the SEBS model does not assume that the sensible heat flux is zero for wet pixels. Compared to other models such as SEBAL, the SEBS model improves the fundamental theoretical concept of the energy balance equation. Sahoo et al. (2011) [13] used three approaches including the Penman–Monteith-based, Priestley–263 Taylor-based, and Surface Energy Balance System-based models to estimate the global water budget from satellite images. They verified the effects of bias and errors in water budget estimation and their findings provided important information for climate studies at the continental scale. Allen et al. (2011a, b) proposed two main categories, namely RS energy balance techniques and satellite-based ET using vegetation indices. The former evaluates an energy balance through sensible heat flux using different models (e.g. SEBAL, METRIC), coupled with field measurements. Allen et al.'s second category simply employed a vegetation index to estimate crop coefficients based on the close relationship between vegetation (NDVI, VI or LAI) and transpiration. They found that the basal coefficient has the most consistent relationship with NDVI.

In the present study, surface energy balance techniques have been used to estimate instantaneous evapotranspiration. The objective of this study is to spatially distribute the estimate instantaneous evapotranspiration for the farm land of Pantnagar.

MATERIAL AND METHODS

In this study, the experimental farm land of GB Pant University of Agriculture and Technology, Pantnagar which is situated in Kumaon division of Uttarakhand has been selected to estimate the reference ET. The study area has been shown in Fig. 1. Pantnagar is located at coordinates of 28° 58' 41.8728'' N and 79° 23' 58.6032'' E. The satellite image of LANDSAT 8 has been collected from earth explorer for the date 13 February 2018. LANDSAT 8 has in total 11 bands which include visible as well as thermal bands.

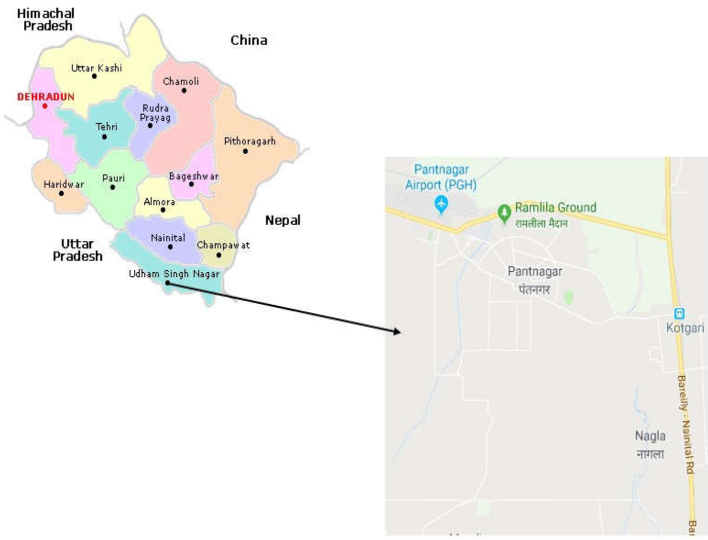

Fig.1. Location of Study Area

Evapotranspiration Estimation

In the present study, Surface Energy Balance Algorithm for Land has been used to estimate ET. Surface Energy Balance Algorithm for Land, which is commonly abbreviated as SEBAL computes an instantaneous ET flux for the acquired image. The Evapotranspiration flux is calculated for each pixel of the image as a "residual" of the surface energy budget equation, which is shown in equation 1.

$\lambda ET = R_n - G - H$ ......(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).

R_n represents the actual radiant energy available at the surface. It is computed by subtracting all outgoing radiant fluxes from all incoming radiant fluxes. Equation 2 is used for net radiation flux calculations.

$R_n = (1-\alpha)R_{s\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1-\epsilon_0)R_{L\downarrow}$.....(2)

Where, $R_{s\downarrow}$ is the incoming shortwave radiation (W/m^2), α is the surface albedo (dimensionless), $R_{L\downarrow}$ is the incoming longwave radiation (W/m^2), $R_{L\uparrow}$ is the outgoing longwave radiation (W/m^2), and ε_0 is the surface thermal emissivity (dimensionless).

Surface Albedo

Surface reflectance (L_λ) for each band is given by equation 3

$$L_\lambda = \frac{(\text{R\_max \_x} - \text{R\_min \_x})}{(\text{QUANTIZE\_max\_x} - \text{QUANTIZE\_min\_x})}(DN - \text{QUANTIZE\_min\_x}) + \text{R\_min \_x} \ldots (3)$$

Where R_max _x is reflectance maximum value for band x; R_min _x is reflectance minimum value for band x; QUANTIZE_max_x is quantize maximum calibrated value for band x; QUANTIZE_min_x is quantize maximum calibrated value for band x; DN is band brightness value.

Reflectivity (ρ_λ) for each band can be calculated using equation 4.

$\rho_\lambda = \frac{\pi L_\lambda}{E_{sun} d_r \cos\theta}$ ......(4)

Where, L_λ is the spectral radiance for each band; $ESUN_\lambda$ is the mean solar exo-atmospheric irradiance for each band (W/m^2/μm) (Values for $ESUN_\lambda$ has been collected from the manual of LANDSAT 8); cos θ is the cosine of the solar incidence angle (from nadir); and d_r is the inverse squared relative earth-sun distance.

d_r can be computed using equation 5. It has been given by Duffie and Beckman (1980) [7].

$d_r = 1 + 0.033 \cos\frac{2\pi . DOY}{365}$...(5)

Where, DOY is the day of the year. In the present study, since the satellite image has been acquired for 13th February 2018, DOY has been taken as 44.

The albedo at the top of the atmosphere (α_{toa}) is computed using equation 6.

$\alpha_{toa} = \sum(w_\lambda \rho_\lambda)$...(6)

w_λ has further been calculated using equation 7.

$w_\lambda = \frac{ESUN_\lambda}{\sum ESUN_\lambda}$ ... (7)

Surface albedo (α) is computed, using equation 8, by correcting the α_{toa} for atmospheric transmissivity

$\alpha = \frac{\alpha_{toa} - \alpha_{path\_radiance}}{\tau_{sw}^2}$ ... (8)

Where τ_{sw} is transmissivity of both direct solar beam radiation and diffuse (scattered) radiation to the surface. In this study, 0.03 has been taken for $\alpha_{path\_radiance}$ .For SEBAL this value has been recommended by Bastiaanssen (2000) [4].

τ_{sw} is calculated using equation 9

$\tau_{sw} = 0.75 + (0.00002Z)$ ... (9)

Where Z is the elevation above sea level (m). For the present study, Z for Pantnagar is taken as 243.8 m.

In this study, equation 10 and equation 11 has been used to calculate instantaneous ET.

$\lambda ET = E_v(R_n - G)$ ...(10)

Where E_v is evaporative fraction.

$InstanteneousET = \frac{\lambda ET}{LatentheatofVaporization}$ ... (11)

Among all the parameters of surface energy balance equation, the estimation of the H is the most complex component. S-SEBI model has a distinctive advantage over other RS-EB models in this aspect [5]. In S-SEBI, the H and λE (or λET) are not calculated separately, the combined value of these two fluxes in the form of Λ is calculated using equation 12:

$$\Lambda = \frac{\lambda E}{\lambda E + H} = \frac{\lambda E}{R_n - G}$$ ... (12)

Λ can be expressed using equation 13

$$\Lambda = \frac{T_H - T_S}{T_H - T_{\lambda E}}$$

... (13)

Finally, ET can be computed using equation 14

$$\mathrm{ET}_c = \lambda E_i^*(R_{nd}/\lambda \cdot R_{ni})$$

... (14)

Where, λ is the latent heat of vaporization (2.45 MJ kg−1), Rni is instantaneous R_n at the time of satellite overpass and R_{nd} is the daily Rn. In the present study, Landsat 8 data has been collected for ET study. This satellite has 11 bands and its spectral information is provided in Table 1.

Table 1 Spectral Information of Landsat 8 data

	Bands	**Wavelength (micrometers)**	**Resolution (meters)**
Landsat 8 Operational Land Imager(OLI) and Thermal Infrared Sensor(TIRS) Launched February 11,2013	Band 1- Coastal aerosol	0.43-0.45	30
	Band 2-Blue	0.45-0.51	30
	Band 3-Green	0.53-0.59	30
	Band 4-Red	0.64-0.67	30
	Band 5- Near Infrared(NIR)	0.85-0.88	30
	Band 6- SWIR 1	1.57-1.65	30
	Band 7- SWIR 2	2.11-2.29	30
	Band 8- Panchromatic	0.50-0.88	15
	Band 9- Cirrus	1.36-1.38	30
	Band 10-Thermal Infrared(TIRS) 1	10.60-11.19	100
	Band 11- Thermal Infrared(TIRS) 2	11.50-12.51	100

Results and Discussion

In this study, daily reference evapotranspiration has been estimated using SEBAL algorithm for agricultural experimental plots of Pantnagar using LANDSAT data. In this section, results obtained from this study along with discussions has been presented.

Normalized Difference Vegetation Index (NDVI) for the Pantnagar experimental farm is shown in Fig. 2. This figure depict that NDVI for the sudy area varies between 0.084 to 0.464. In this study, for calculation of NDVI band 4 and band 5 data of Landsat 8 has been used. Since, at the time of image acquisation, the plots were full of vegetation, NDVI is greater than zero everywhere. In the densly cropped area of Pantnagar, the average NDVI was 0.35, whereas for low crop areas, the average NDVI was 0.05. The areas where NDVI was less is near to road, and also have some nam made construction.

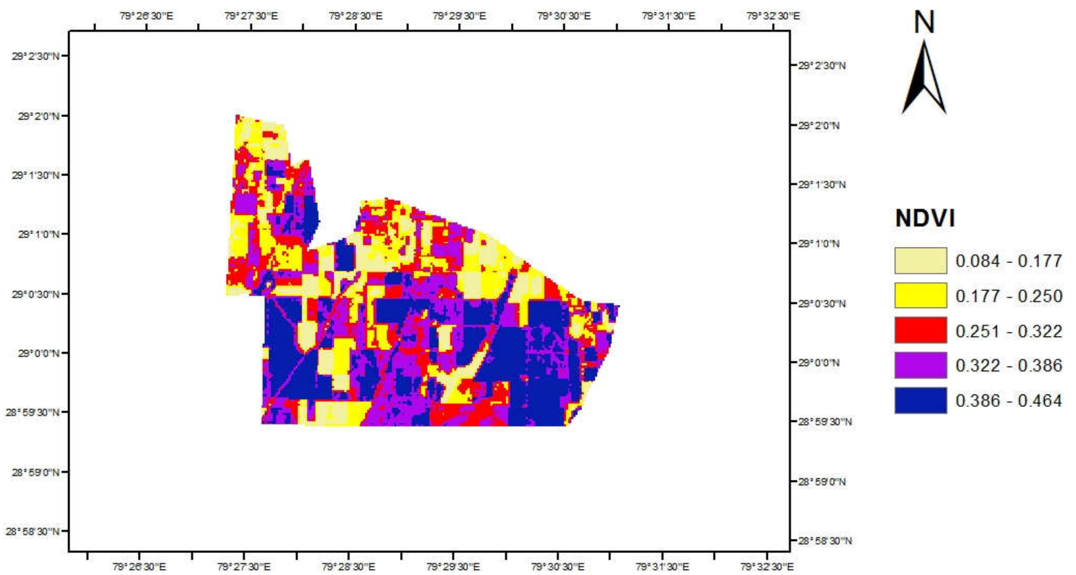

Fig. 2. NDVI for Experiment Farm of Pantnagar

The Leaf Area Index of the study area has been shown in Fig. 3.Leaf area index (LAI) is a dimensionless quantity that characterizes plant canopies. Those regions where LAI is negative has low vegetation or no vegetation at all. The LAI in the present study varies from -0.015 to 1.301. The average LAI for densly cropped area was 0.98. Areas where NDVI is high, LAI is also showing higher values for those regions.

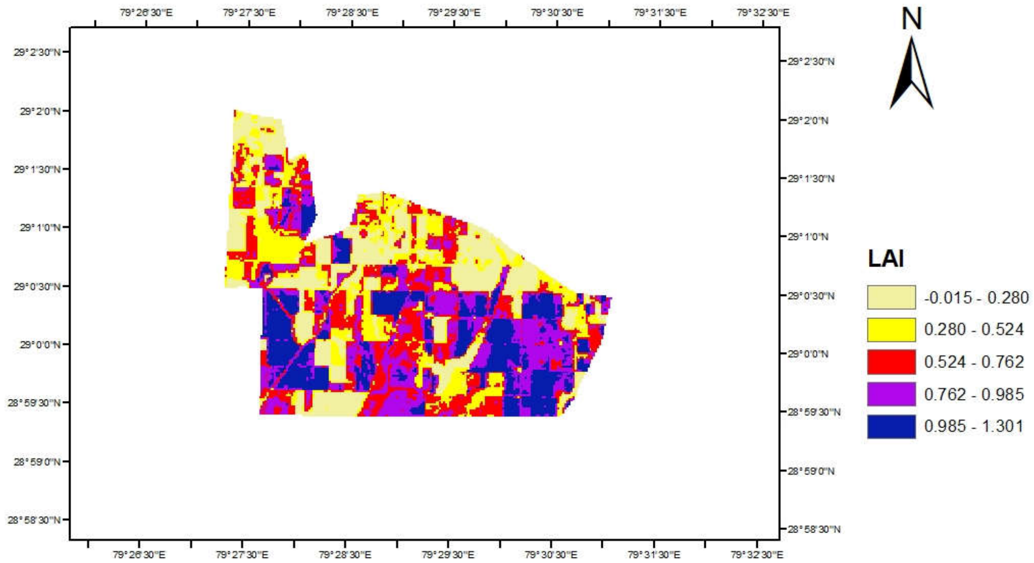

Fig. 3. LAI for Experiment Farm of Pantnagar

The surface albedo of the study area has been shown in Fig. 4. The Fig. 4 depicts that the surface albedo has a range of 0.149 to 0.265 in the study area. Since in February, most part of the farm land was in cropped condition, albedo is quit low there. Albedo might be higher at those places where farm land is not under crop or has some man made feature like farm building. The average albedo for densly cropped areas was 0.21 and for bare land or low cropped areas, it was 0.15.

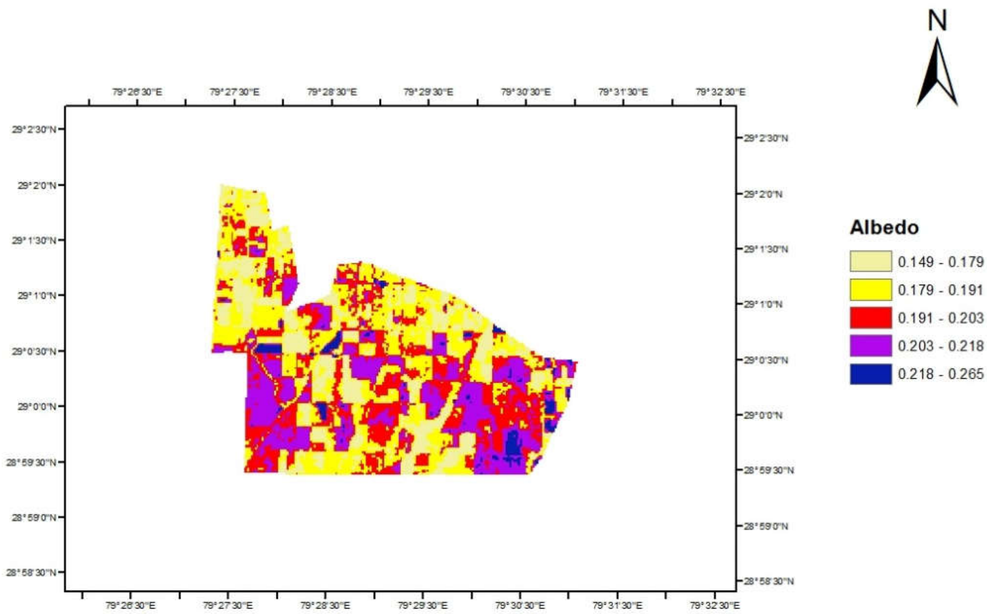

Fig. 4. Surface Albedo of the Study Area

The surface temperature of the study area is shown in Fig. 5. From Fig. 5, it can be depicted that the surface temperature of the study area varied from 286.175 K to 291.244 K. The temperature of February month lies in this range.

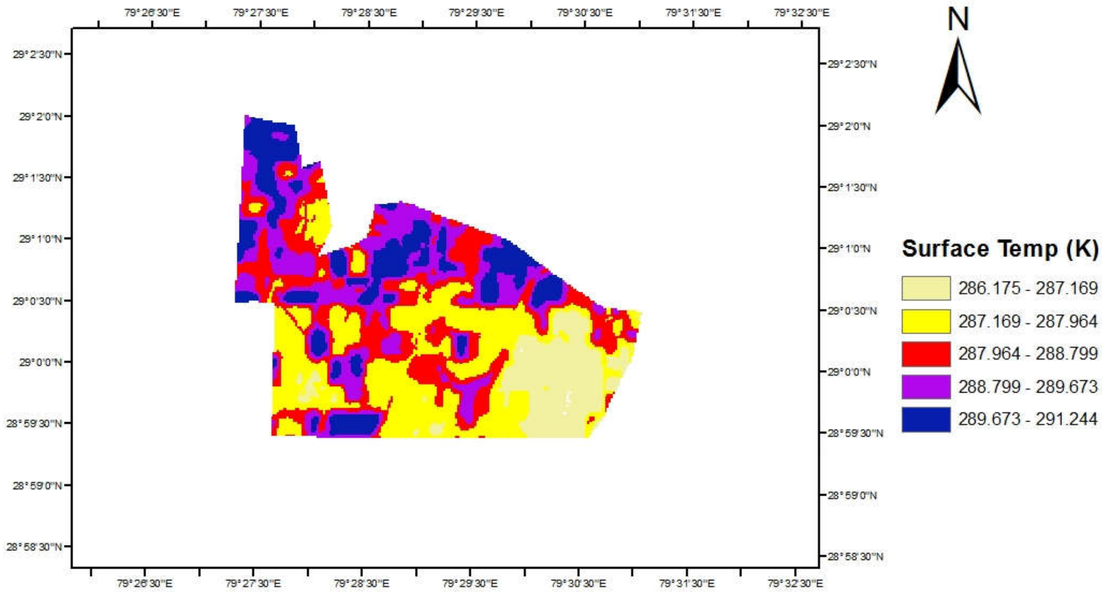

Fig. 5. Surface Temperature of the Study Area

The soil heat flux, in units of W/m^2, is shown in Fig. 6. It can be depicted that the values of soil heat flux vary between 30.276 W/m^2 to 32.972 W/m^2.

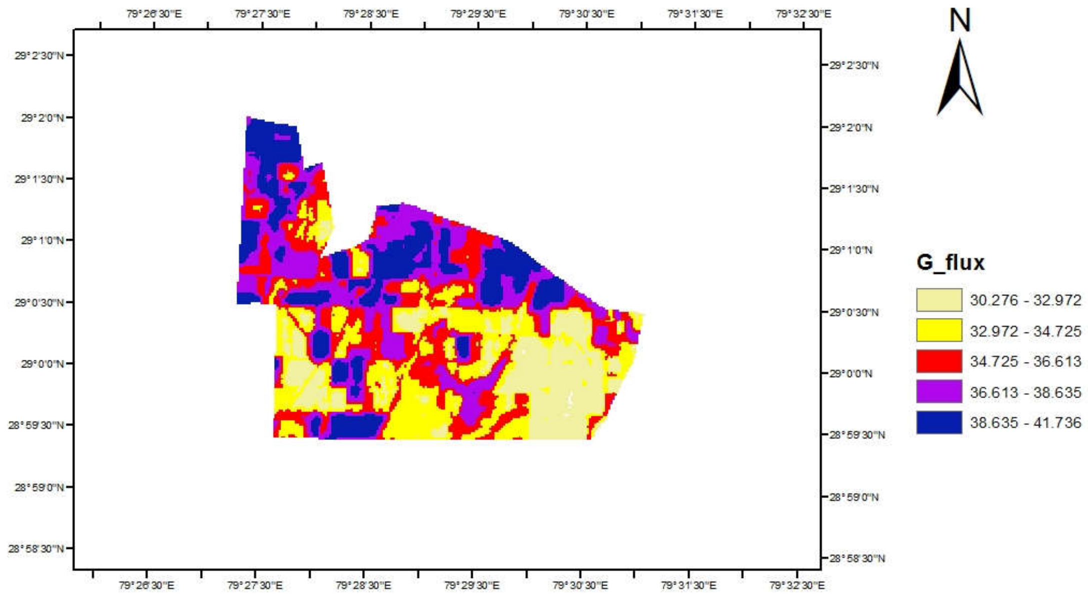

Fig. 6. Soil Heat Flux of the Study Area

The net radiation, in units of W/m^2, at the surface of Pantnagar farm is shown in Fig. 7. Net amount of radiant energy that is available at the surface for warming the soil, warming the air, or evaporating soil moisture. Fig. 7 suggest that net radiation at the surface varies from 395.01 W/m^2 to 481.622 W/m^2.

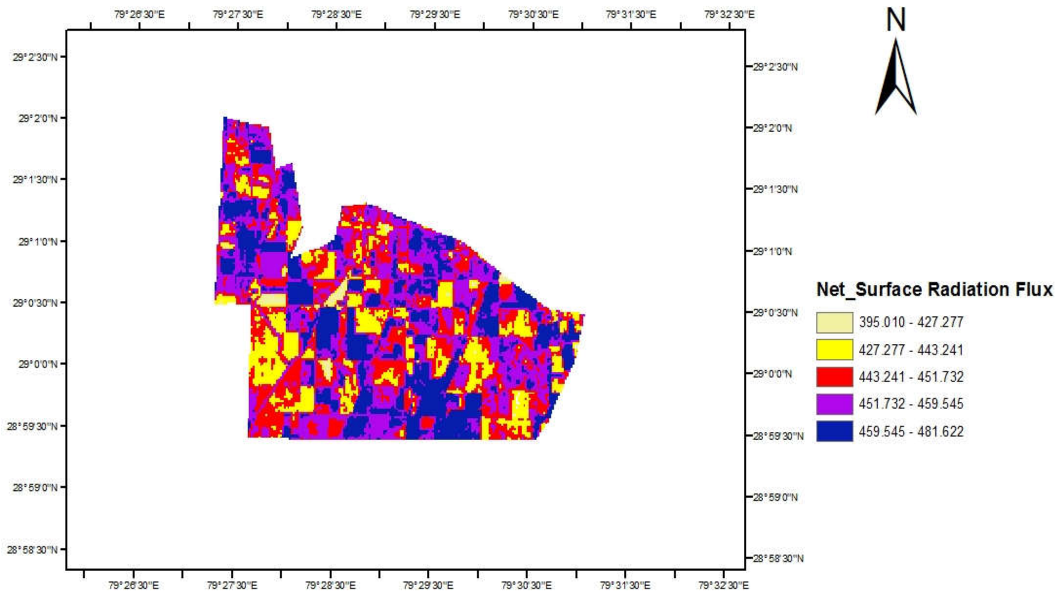

Fig. 7. Net Radiation at the Surface of the Study Area

Evaporative fraction in the study area is shown in Fig. 8. The evaporative fraction for densely cropped areas is in the range of 0.569 to 1.566. For densely cropped areas, average evaporative fraction is about 1.35. For other regions, it may be 0.75.

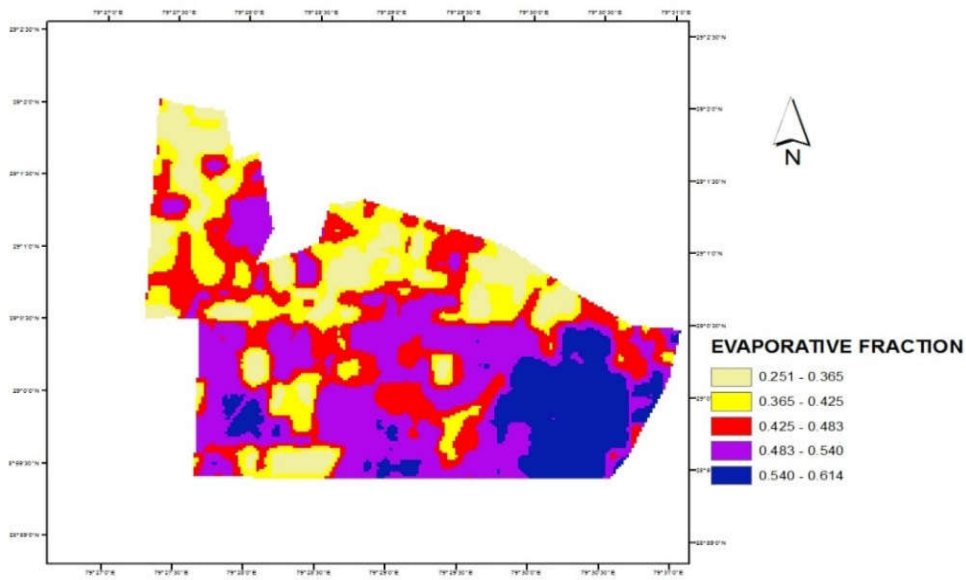

Fig. 8. Evaporative Fraction at Study Area

Finally, the evapotranspiration loss for the study area has been shown in Fig. 9. Fig. 9 suggested that the evapotranspiration can varied from 0.569 mm per day to 1.566 mm per day. During the month of February, cloud cover was all over the nearby places when the Landsat 8 image was acquired. Also, due to full coverage of crop during this season in Pantnagar, the ET loss might be higher for this month. The average instantaneous ET rate at densely cropped area was 1.3 mm/ day and for low vegetative areas, it was 0.9 mm/ day.

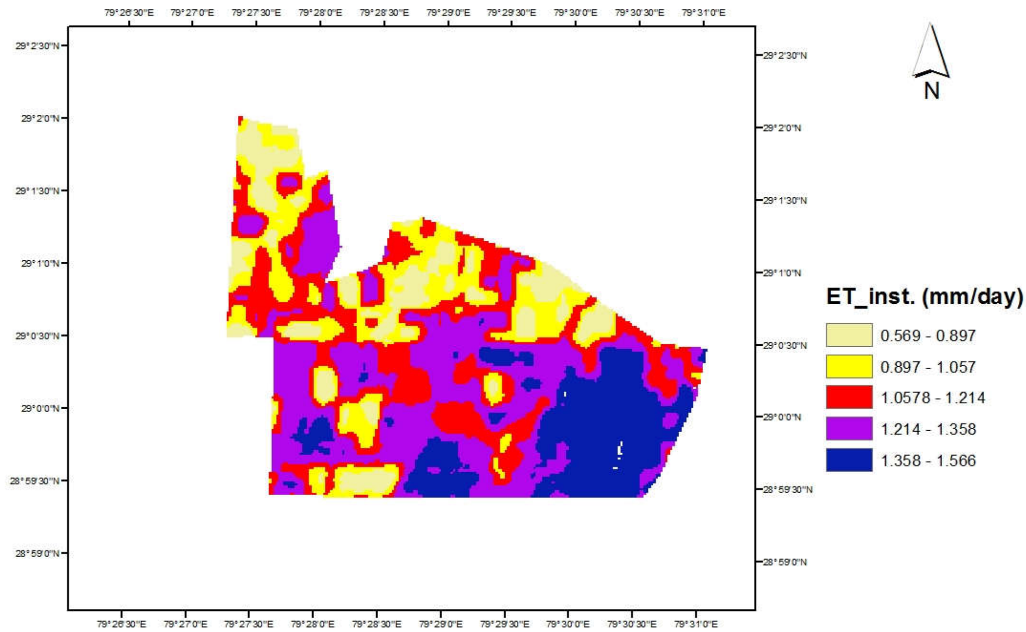

Fig. 9. Instantaneous Evapotranspiration Loss (mm/ day) at Study Area

Conclusions

In the present study, Instantaneous evapotranspiration has been calculated using Landsat 8 imagery. The study area was farm lands of Pantnagar. It was found that for this study area NDVI varies between 0.084 to 0.464,the LAI varies from -0.015 to 1.301,Surface albedo has a range of 0.149 to 0.265, Surface temperature varied from 286.175 K to 291.244 K,Soil heat flux between 30.276 W/m^2 to 32.972 W/m^2,Net radiation at the surface from 395.01 W/m^2 to 481.622 W/m^2. The Evaporative fraction for densely cropped areas is in the range of 0.25 to 0.61 and finally Evapotranspiration varied from 0.569 mm per hour to 1.566 mm per hour.

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