Evapotranspiration Estimation using Geo-Spatial Techniques

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Abstract— Water is one of the most critical resources for human life and survival. Increasing population and existing climate change scenario is posing a major challenge to the global fresh water resource. This challenge is more visible in agriculture sector, especially of water stressed countries, as it is often the biggest user of fresh water supplies. India is a classic case of this unfolding scenario. India is already categorized as water stressed country in terms of per capita freshwater availability (1,720 cubic meters in 2019). Out of the 4 per cent share of global freshwater availability in India, almost 78% share of water is consumed by the agriculture sector. UN Population shows that India will be most populous country on this planet surpassing China by 2024. Evapo-transpiration (ET) is a component of Hydrologic Cycle through which most of the water is lost to the atmosphere. Few research papers suggest that the average ET rates of rice were 2.8–5.7 mm/day during the first crop season (May–September) and 6.2–9.1 mm/day during the second crop season (September–January). ET varies spatially and temporally, it can be better understood using Geospatial data. By reviewing all the available ET data in public domain, it is understood that ET is available in coarse resolution. The goal of this project is to estimate Evapo-transpiration. It is derived using the Simplified Surface Energy Balance (SSEB) model, which is now parameterized for operational applications, renamed as SSEBop. The innovative aspect of the SSEBop is that it uses predefined boundary conditions that are unique to each pixel for the "hot" and "cold" reference using multi-spectral satellite imagery of Landsat-8, 30m spatial resolution for mapping ET. The study can successfully delineate the areas of low and high ET. The derived ET data would be useful for various applications such as assessment of water productivity.

Keywords: Evapo-transpiration, SSEB, Landsat-8

I. INTRODUCTION

Evapotranspiration (ET) refers to the physical processes whereby liquid water is vaporized from evaporating surfaces into the atmosphere. It generally consists of evaporation and transpiration. Evaporation accounts for the processes whereby liquid water is converted to water vapour and lost from lakes, rivers, pavements, soils and wet vegetation surfaces. Transpiration accounts for the vaporization of liquid water within the plant from leaf surfaces through stomata. In plants nearly all the water taken up from soil is lost by transpiration and only a tiny fraction is used within plants. The term ET is generally used because evaporation and transpiration occur simultaneously and there is no easy way to distinguish between. When a plant is small and the canopy shades little of the ground area, ET is predominated by evaporation. However, as the plant develops over the growing period and the canopy shades more and more of the ground area, or even completely covers the soil surface, transpiration becomes the main process.

Commonly used terms relevant to ET consist of reference ET (ET_o), fractional ET (ET_f) and actual ET (ET_a). ET_o refers to the ET from a reference surface with sufficient water supply, usually a hypothetical grass surface with specific characteristics. The concept of ET_o was introduced to study the evaporative demand of the atmosphere independently of plant type, development stage and management activities. ET_f refers to the ET of plants that are grown in large fields under excellent agronomic, soil water and management conditions, and achieve full production under given climatic conditions. It differs distinctly from ET_o as the ground cover, canopy properties and aerodynamic resistance of the plant are different from the hypothetical grass surface. ET_a is the ET of plants based on the non-optimal management and environmental constraints such as the soil salinity, low soil fertility, water shortage or water logging, and presence of pests and diseases. ET_f acts as the driving force in ETa modelling and constitutes the upper limit for ET_a.

II. OBJECTIVES

- First is calculating NDVI values from the satellite image.
- Second, generating Land Surface Temperature maps for study area and identifying the hottest temperature and coolest temperature.
- Third, estimation of ET fraction from LST maps.
- Fourth, calculating the actual daily Evapotranspiration values using ET fraction and ET reference.

III. STUDY AREA

Kondamallepally is a Mandal of Nalgonda district of Telangana state, which is located 60 KM towards South from District headquarters Nalgonda. It isgeographically located in the southern part of Telangana State. It lies between 16.7153° N and 17.508 ° N latitude and 78.9777°E and 79.25 °E Longitude. Kondamallepally is surrounded by Chandampet Mandal towards South, Pedda AdiserlaPally Mandal towards East, Gundlapally (Dindi) Mandal towards west, Nampally Mandal towards North. According to 2011 census, Total population of Kondamallepally is 6083. Males are 3150 and Females are 2,933 living in 1310 Houses. Total area of Kondamallepally is 672 hectares and situated at an altitude of 224 m above mean sea level (MSL). The town is connected by road to Kakinada, Badrachalam, Sreesailam and Hyderabad etc. The nearest city with more than 5 lakh population is Hyderabad which is at a distance of 100 km.

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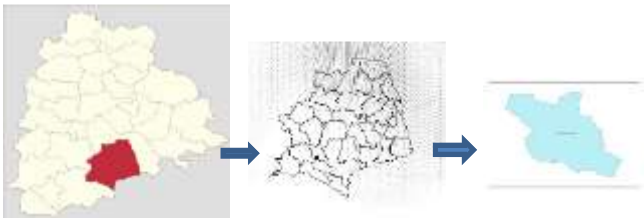

Fig. 1: Location map of study area

IV. METHODOLOGY

Evapotranspiration of the study area can be retrieved following the steps of figure shown below.

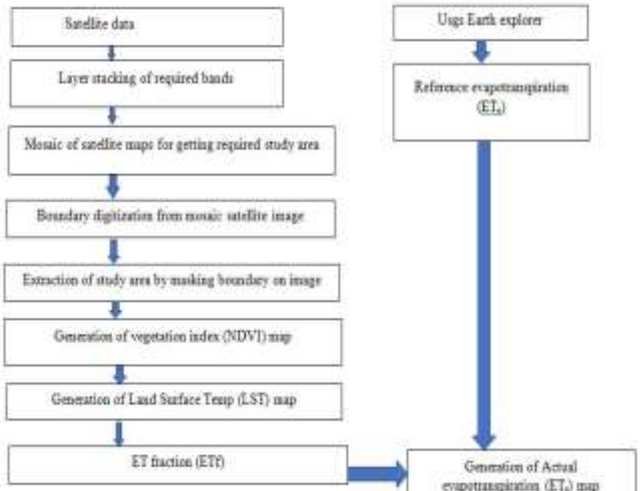

Fig. 2: Flowchart of Methodology

The data of Landsat 8 is available at the Earth Explorer website free of charge. In this study, the TIR band 10 was used to estimate brightness temperature and bands 4 and 5 were used for calculating the NDVI. The metadata of the satellite images used in the algorithm is presented in the satellite data.

A. *Input Bands:*

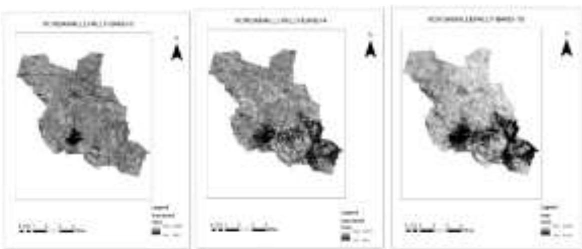

Fig. 4:

B. *Preparation of NDVI Map:*

Landsat visible and near-infrared bands were used for calculating the Normal Difference Vegetation Index (NDVI). The importance of estimating the NDVI is essential since the amount of vegetation present is an important factor and NDVI can be used to infer general vegetation condition. The calculation of the NDVI is important because, afterward, the proportion of the vegetation (P_v) should be calculated, and they are highly related with the NDVI, and emissivity (e) should be calculated, which is related to the *Pv*.

$$NDVI = \frac{\text{NIR (band 5) - RED (band 4)}}{\text{NIR (band 5) + RED (band 4)}}$$

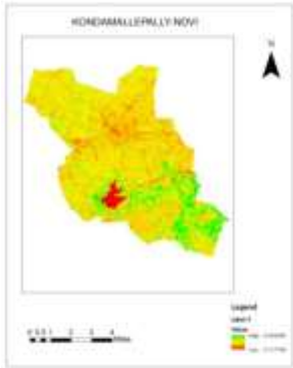

Fig. 4: NDVI map of study area

C. *Top of Atmospheric spectral radiance(Lλ):*

The first step is input the Band 10. After inputting band 10, in the background, the tool uses formulas taken from the USGS webpage for retrieving the top of atmospheric (TOA) spectral radiance ($L\lambda$).Using the radiance rescaling factor, Thermal Infra-Red Digital Numbers can be converted to TOA spectral radiance.

$$L_\lambda = M_L \text{ X } Q_{cal} + A_L$$

Where: L_λ = TOA spectral radiance (Watts/ (m^2 x μm))
M_L = multiplicative rescaling factor for Band 10,
A_L = additive rescaling factor for Band 10
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

D. *Top of Atmospheric Brightness Temp (BT):*

After the digital numbers (DNs) are converted to reflection, the TIRS band data should be converted from spectral radiance to brightness temperature (BT) using the thermal constants provided in the metadata file. The following equation is used in the tool's algorithm to convert reflectance to BT

$$BT = \frac{K_2}{\ln\left[(K1/L\lambda) + 1\right]} - 273.15$$

Where $K1$ and $K2$ stand for the band-specific thermal conversion constants from the metadata. For obtaining the results in Celsius, the radiant temperature is revised by adding the absolute zero (approx.−273.15∘C)

E. *Proportion of Vegetation (Pv):*

P_v is calculated according to the following equation.

$$Pv = \left(\frac{\text{NDVI - NDVI}min}{\text{NDVImax - NDVI}min}\right)^2$$

Where: Pv = Proportion of Vegetation
NDVI = DN values from NDVI Image
NDVI min = Minimum DN values from NDVI Image
NDVI max = Maximum DN values from NDVI Image

F. *Land Surface Emissivity (e):*

Land surface emissivity (LSE) is the average emissivity of an element of the surface of the Earth calculated from NDVI values.e = 0.004 * Pv + 0.986
Where: e = Land Surface Emissivity
Pv = Proportion of Vegetation
Land Surface Temperature (LST):
Land surface temperature (LST) is explained as the temperature felt when the land surface is touched with the hands or the skin temperature of the ground. As the most

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important aspects of the land surface, LST has been a main topic for developing methodologies to be measured from space. LST is an important factor in many areas of studies, such as global climate change, hydrological and agricultural processes, and urban land use/land cover. Calculating LST from remote sensed images is needed since it is an important factor controlling most physical, chemical, and biological processes of the Earth.

$$LST=\frac{BT}{\{1+[(\lambda BT/\rho)Ln\ e]\}}$$

Where:
BT = Top of atmosphere brightness temperature (°C)
λ= Wavelength of emitted radiance
e = Land Surface Emissivity
$\rho=h\frac{c}{\sigma}$=1.438x10^{-2} mK
Where σ is the Boltzmann constant (1.38 × 10^{-23} J/K),
h is Planck's constant (6.626 × 10^{-34} J s), and
c is the velocity of light (2.998 ×10^{8}m/s)

Fig. 5: Land Surface Temperature(LST)

G. ET Fraction (ET$_f$):

$$ET_f=\frac{TH-Tx}{TH-TC}$$

Where T_H is the average of the three *hot* pixels selected for a given scene
T_C is the average of the three *cold* pixels selected for that scene;
T_x is the land surface temperature value for any pixel in the composite scene

H. Reference (ETo):

ETo is the reference Evapotranspiration data available in usgsearthexplorer.

I. ET Actual (ETa):

Actual evapotranspiration is obtained by multiplying fractional evapotranspiration with reference evapotranspiration.

$$ET_a = ET_f * ET_o$$

Where ET_f= ET fraction and ET_o=ET reference.

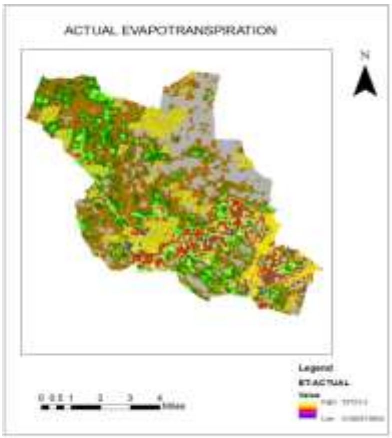

Fig. 6: Actual Evapotranspiration

V. RESULTS

The results obtained by using simplified surface energy algorithm are listed below.

NDVI, brightness temperature, LSE, and LST of an area determined using Arc GIS. NDVI Maps shows that NDVI values are maximum at water bodies and minimum at dry areas. From land surface temperature image it is clear that the temperature values are matching with the normal earth temperature. Thus, LST can be estimated using Landsat 8 with multiband OLI and TIR images and the calculated values are acceptable. Approximately 62.82% of the total area, surface temperature lies in the range of 30 -40°C. ET fraction values are calculated using LST values. The ET fractions are comparable to the commonly used crop coefficient (Kc) and thus are directly multiplied with ET reference values to obtain actual ET estimates. From actual ET map it is clear that the evapotranspiration is maximum at water bodies and agriculture areas. And the maximum actual daily Evapotranspiration value for the study area is 32725.2 micro meters, which is in the range of average evapotranspiration in India. Thus the calculated ET values are acceptable.

VI. CONCLUSION

The objectives of this study was achieved with the demonstration of the successful coupling of remotely sensed data and a simplified surface energy balance (SSEB) by calculating NDVI values from satellite image, generating LST maps, estimating fraction ET and producing actual ET in irrigated agricultural areas of the Kondamallepally mandal in Nalgonda dist. of Telangana state .

With this approach the Evapotranspiration values of a surface area are calculated very fast and accurate. With the help of this ET data more water losing areas are identified and suitable measures can be taken to avoid water losses. Based on the availability of water and the evapotranspiration rate in particular area suitable crops can be suggested to the farmers to obtain better crop yield. Thus it is the best method measure evapotranspiration using remote sensing and GIS techniques.

ACKNOWLEDGMENT

It is my pleased and remarkable benefit to communicate my sincerest and overpowering appreciation to Jella Kiran, Scientific Officer TRAC – Hyderabad and Jogu Venkatesh,

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Associate Professor, Department of Spatial Information Technology, JNTU, Hyderabad, Telangana for their significant direction and academic exhortation granted during this exploration work. We are thankful to the unknown analysts and editors for their important remarks to improve the nature of the examination article.

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