

**QUANTIFICATION OF EVAPOTRANSPIRATION
USING *EEFLUX* TOOL AND COMPARISON BY
EMPIRICAL METHODS IN MAIZE (*Zea mays* L.)**

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
AGRICULTURAL METEOROLOGY
(Minor subject: Soil science)**

By

**Deepan R
(L-2020-A-28-M)**

**Department of Climate Change and Agricultural Meteorology
College of Agriculture
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LUDHIANA - 141004**

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CERTIFICATE I

This is to certify that the thesis entitled, “**Quantification of evapotranspiration using *EEFLUX* tool and comparison by empirical methods in maize (*Zea mays* L.)**” submitted for the degree of **Master of Science**, in the subject of **Agricultural Meteorology** (Minor subject: **Soil Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mr. Deepan R (L-2020-A-28-M)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

(Dr Som Pal Singh)
Major Advisor
Professor
Department of Climate Change and
Agricultural Meteorology
Punjab Agricultural University
Ludhiana-141 004

CERTIFICATE II

This is to certify that the thesis entitled, “**Quantification of evapotranspiration using *EEFLUX* tool and comparison by empirical methods in maize (*Zea mays* L.)**” submitted by **Mr. Deepan R (L-2020-A-28-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Agricultural Meteorology** (Minor subject: **Soil Science**) has been approved by the Student’s Advisory Committee along with External Examiner after an oral examination on the same.

(Dr. Som Pal Singh)
Major Advisor

(Dr. G.S. Mahi)
External Examiner
Associate Professor (Retd.)
Department of Agricultural Meteorology
Punjab Agricultural University
Ludhiana-141004

(Dr. P.K. Kingra)
Head of the Department

(Dr. Sandeep Bains)
Dean, Postgraduate Studies

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(Deepan R)

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ABSTRACT

Evapotranspiration (ET) is one of the most important parameter in agriculture and to water management and irrigation requirement. Under the present scenario of Climate change and Global warming, importance of ET measurement and its validation assumes a great significance. There are various techniques used to estimate actual measurement of ET in the field condition. However, researchers have developed state of the art instrument to measure it in the field condition and instruments of varying accuracy are available. The instrument can measure point value of ET for being placed at particular location in the field and therefore the spatial accuracy of the data is bound to reduce to a certain extent. On the other hand, the empirical estimation of ET has its own limitation owing to the requirement of huge data set to estimate the ET to near accuracy. Google EEFlux is a web-based tool which utilizes the satellite-based information to provide the ET rate on spatio-temporal scale. Therefore, an effort has been put forth to estimate ET using the Google EEFlux for maize crop. The ET has been estimated using the Google EEFlux for maize crop sown in the field experiment at the Research Farm, Department of Climate Change and Agricultural Meteorology, PAU during the *kharif* season of 2020-21. The ET was also computed using Penman's equation geeSEBAL, NRSC-NHP, Cropwat 8.0 and FAO Ref-ET calculator for PMH-1 and PMH-2 varieties of maize during the same period grown under three sowing environments. The relationships were developed between ET (Google EEFlux), ET (geeSEBAL), ET(NRSC-NHP) and ET (FAO-ETo calculator). The relationships indicated a significant association between the ET obtained by both these methods. The data generated can help the researchers to fine tune treatments and also to reorient the irrigation and management research programs.

Key words: ET, Google EEFlux, geeSEBAL, Remote Sensing, Maize.

Signature of Major Advisor

Signature of the Student

ਖੋਜ ਦਾ ਸਿਰਲੇਖ	: EEFLUX ਟੂਲ ਦੀ ਵਰਤੋਂ ਕਰਕੇ evapotranspiration ਦੀ ਮਾਤਰਾ ਅਤੇ ਮੱਕੀ (<i>Zea mays</i> L.) ਵਿੱਚ ਅਨੁਭਵੀ ਤਰੀਕਿਆਂ ਦੁਆਰਾ ਤੁਲਨਾ
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ਸਾਰ ਅੰਸ਼

Evapotranspiration (ET) ਖੇਤੀਬਾੜੀ ਅਤੇ ਪਾਣੀ ਪ੍ਰਬੰਧਨ ਅਤੇ ਸਿੰਚਾਈ ਦੀ ਲੋੜ ਲਈ ਸਭ ਤੋਂ ਮਹੱਤਵਪੂਰਨ ਮਾਪਦੰਡਾਂ ਵਿੱਚੋਂ ਇੱਕ ਹੈ। ਜਲਵਾਯੂ ਪਰਿਵਰਤਨ ਅਤੇ ਗਲੋਬਲ ਵਾਰਮਿੰਗ ਦੇ ਮੌਜੂਦਾ ਦ੍ਰਿਸ਼ ਦੇ ਤਹਿਤ, ET ਮਾਪ ਦੀ ਮਹੱਤਤਾ ਅਤੇ ਇਸਦੀ ਪ੍ਰਮਾਣਿਕਤਾ ਬਹੁਤ ਮਹੱਤਵ ਰੱਖਦੀ ਹੈ। ਫੀਲਡ ਸਥਿਤੀ ਵਿੱਚ ET ਦੇ ਅਸਲ ਮਾਪ ਦਾ ਅੰਦਾਜ਼ਾ ਲਗਾਉਣ ਲਈ ਕਈ ਤਕਨੀਕਾਂ ਵਰਤੀਆਂ ਜਾਂਦੀਆਂ ਹਨ। ਹਾਲਾਂਕਿ, ਖੋਜਕਰਤਾਵਾਂ ਨੇ ਇਸ ਨੂੰ ਖੇਤਰ ਦੀ ਸਥਿਤੀ ਵਿੱਚ ਮਾਪਣ ਲਈ ਆਧੁਨਿਕ ਯੰਤਰ ਵਿਕਸਿਤ ਕੀਤਾ ਹੈ ਅਤੇ ਵੱਖ-ਵੱਖ ਸ਼ੁੱਧਤਾ ਵਾਲੇ ਯੰਤਰ ਉਪਲਬਧ ਹਨ। ਸਾਧਨ ਖੇਤਰ ਵਿੱਚ ਕਿਸੇ ਖਾਸ ਸਥਾਨ 'ਤੇ ਰੱਖੇ ਜਾਣ ਲਈ ET ਦੇ ਬਿੰਦੂ ਮੁੱਲ ਨੂੰ ਮਾਪ ਸਕਦਾ ਹੈ ਅਤੇ ਇਸਲਈ ਡੇਟਾ ਦੀ ਸਥਾਨਿਕ ਸ਼ੁੱਧਤਾ ਇੱਕ ਨਿਸ਼ਚਿਤ ਹੱਦ ਤੱਕ ਘਟਣ ਲਈ ਪਾਬੰਦ ਹੈ। ਦੂਜੇ ਪਾਸੇ, ET ਦੇ ਅਨੁਭਵੀ ਅੰਦਾਜ਼ੇ ਦੀ ਆਪਣੀ ਸੀਮਾ ਹੈ ਕਿਉਂਕਿ ET ਦਾ ਅੰਦਾਜ਼ਾ ਲਗਭਗ ਸ਼ੁੱਧਤਾ ਲਈ ਵਿਸ਼ਾਲ ਡੇਟਾ ਸੈੱਟ ਦੀ ਲੋੜ ਹੈ। Google EEFlux ਇੱਕ ਵੈੱਬ-ਆਧਾਰਿਤ ਟੂਲ ਹੈ ਜੋ ਸੈਟੇਲਾਈਟ-ਆਧਾਰਿਤ ਜਾਣਕਾਰੀ ਦੀ ਵਰਤੋਂ ਸਪੇਸਿਓ-ਟੈਂਪੋਰਲ ਸਕੇਲ 'ਤੇ ET ਦਰ ਪ੍ਰਦਾਨ ਕਰਨ ਲਈ ਕਰਦਾ ਹੈ। ਇਸ ਲਈ, ਮੱਕੀ ਦੀ ਫਸਲ ਲਈ Google EEFlux ਦੀ ਵਰਤੋਂ ਕਰਦੇ ਹੋਏ ET ਦਾ ਅਨੁਮਾਨ ਲਗਾਉਣ ਲਈ ਇੱਕ ਕੋਸ਼ਿਸ਼ ਕੀਤੀ ਗਈ ਹੈ। ਈਟੀ ਨੇ 2020-21 ਦੇ ਸਾਉਥੀ ਸੀਜ਼ਨ ਦੌਰਾਨ ਰਿਸਰਚ ਫਾਰਮ, ਜਲਵਾਯੂ ਪਰਿਵਰਤਨ ਅਤੇ ਖੇਤੀਬਾੜੀ ਮੌਸਮ ਵਿਗਿਆਨ ਵਿਭਾਗ, ਪੀਏਯੂ ਵਿਖੇ ਖੇਤ ਪ੍ਰਯੋਗ ਵਿੱਚ ਬੀਜੀ ਮੱਕੀ ਦੀ ਫਸਲ ਲਈ ਗੂਗਲ EEFlux ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਅਨੁਮਾਨ ਲਗਾਇਆ ਗਿਆ ਹੈ। ET ਦੀ ਗਣਨਾ Penman ਦੇ ਸਮੀਕਰਨ geeSEBAL, NRSC-NHP, Cropwat 8.0 ਅਤੇ FAO Ref-ET ਕੈਲਕੁਲੇਟਰ PMH-1 ਅਤੇ PMH-2 ਕਿਸਮਾਂ ਲਈ ਮੱਕੀ ਦੀਆਂ ਤਿੰਨ ਬਿਜਾਈ ਵਾਲੇ ਵਾਤਾਵਰਣਾਂ ਅਧੀਨ ਉਗਾਈ ਗਈ ਉਸੇ ਸਮੇਂ ਦੌਰਾਨ ਕੀਤੀ ਗਈ ਸੀ। ET (Google EEFlux), ET (geeSEBAL), ET (NRSC-NHP) ਅਤੇ ET (FAO-ET₀ ਕੈਲਕੁਲੇਟਰ) ਵਿਚਕਾਰ ਸਬੰਧ ਵਿਕਸਿਤ ਕੀਤੇ ਗਏ ਸਨ। ਉੱਥੇ ਸਬੰਧਾਂ ਨੇ ਇਹਨਾਂ ਦੋਵਾਂ ਤਰੀਕਿਆਂ ਦੁਆਰਾ ਪ੍ਰਾਪਤ ਕੀਤੀ ET ਦੇ ਵਿਚਕਾਰ ਇੱਕ ਮਹੱਤਵਪੂਰਨ ਸਬੰਧ ਨੂੰ ਦਰਸਾਇਆ ਹੈ। ਤਿਆਰ ਕੀਤਾ ਗਿਆ ਡੇਟਾ ਖੋਜਕਰਤਾਵਾਂ ਨੂੰ ਇਲਾਜਾਂ ਨੂੰ ਵਧੀਆ ਬਣਾਉਣ ਵਿੱਚ ਮਦਦ ਕਰ ਸਕਦਾ ਹੈ ਅਤੇ ਸਿੰਚਾਈ ਅਤੇ ਪ੍ਰਬੰਧਨ ਖੋਜ ਪ੍ਰੋਗਰਾਮਾਂ ਨੂੰ ਮੁੜ ਸਥਾਪਿਤ ਕਰਨ ਵਿੱਚ ਵੀ ਮਦਦ ਕਰ ਸਕਦਾ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ET, Google EEFlux, geeSEBAL, ਰਿਮੋਟ ਸੈਂਸਿੰਗ, ਮੱਕੀ।

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CHAPTER I

INTRODUCTION

Agriculture background goes back to ten thousand years and is the major source of livelihood in India and contributes to a great extent of the GDP. In addition, the sector recruits about 50 per cent of the entire manpower. The rising population in Indian urban and rural areas drives these demands. Yet it faces a lot of issues within the agriculture sector as it is dependent on climate change and weather. The farmers are mostly reliant on weather and most of the time do not have access to the latest technologies, forcing them to perform their agricultural practices within the enough resources which leads to a lower productivity in this sector.

This bane has ceased the Indian agriculture sector from growing to its full potential as it could be a boon with the help of Artificial Intelligence (AI). According to a report from NASSCOM - Ernst and Young titled 'Leveraging AI to maximize India's agriculture output', AI is expected to be a very useful tool in order to promote growth in India's agricultural sector. It will have a vital role in relieving the sector from stressful conditions and will furnish to its shift towards data driven farming. Indian agriculture has traditionally relied on rain, and climate change has made farmers extremely vulnerable to crop failures. Injecting the knowledge about artificial intelligence in the agricultural life cycle will help to reduce the uncertainty and risk in agricultural operations. The use of artificial intelligence in agriculture may change the lives of millions of farmers in India.

Evaporation and transpiration results in evapotranspiration. Water evaporates from land and water surfaces, transpires from plants, and then condenses back into the atmosphere when the earth's surface warms. This combined process is referred as evapotranspiration (ET). ET is the inverse of precipitation in that it is water that departs the land surface and returns to the atmosphere as water vapour, rather than water falling from the atmosphere to the land. Water from evapotranspiration condenses, creates clouds, and falls back to earth in other parts of the atmosphere. Because ET is the second-largest component of the water cycle, it is crucial information for deciding how much irrigation water to apply to crops and for managing water on a broader scale (after precipitation). Evapotranspiration is commonly used to calculate consumptive water usage, which refers to all water in a system that cannot be retrieved or reused, including water ingested by plants or humans, evaporated, or contaminated. Because it re-enters the atmosphere and goes away from the nearby area, water that evaporates and transpires is effectively "consumed" and cannot be reused within a watershed. As a result, ET is defined as the amount of water evacuated from a local system after being applied to or falling on the terrain. Water that enters local drainage or stream systems or recharges groundwater basins is excluded. However, estimating ET is more

difficult than estimating other weather parameters and requires complex methods and equipment. Using field-based technology, spatial measurement of ET remains a difficulty. Satellite remote sensing is a promising approach for providing reasonable estimations of spatial ET. Due to the limitation of ET measurement, it becomes one of the major data gaps in water resources management, and is difficult to estimate the additional spatial variability of ET. Satellite-based ET estimation has great potential in water resource planning because it can estimate agricultural water use at farmland landscape and basin scale. But just like a coin has two uncertainties, ET derived from satellite data is a major problem. ET is one of the main components of the water budget and it plays an important role in the hydrological cycle and water resources management. It's importance further assumes significance because of the climate change and climate variability all over the world. ET can be measured in the field conditions using lysimeter and can also be estimated using empirical methods.

However, the rate of ET is either limited or it is not accessible as far as the accuracy is concerned and puts a barrier in crop water requirement of various field crops. A reference gathered from the alfalfa crop or well-watered grass is known as reference ET. It is one of the important parameters obtained from the grided weather data. The real ET between Landsat satellite overpasses is calculated using reference ET data, which occur of eight-day interval with two Landsat satellites in orbit. If there is cloud cover it becomes a obstruction for the satellite processing. For each satellite overpass date, the fraction of reference ET is derived by dividing the satellite ET on the overpass date by the reference ET. The daily reference ET values are then multiplied by a fraction of the daily reference ET values and linearly interpolated for all days between clear satellite overpass dates, one image pixel at a time to create a daily time series of real ET for each pixel. These daily pixel-level real ET time records are then averaged over monthly and annual time intervals.

Maize (*Zea mays* L.) is the queen of cereals and is a widely planted crop in the world after rice and wheat. Grown in tropical and subtropical to temperate climates, it is the most important crop for billions of people, used as food, feed and industrial raw materials. It has become the dominant cash crop globally because 83% of its global production is used in the starch feed and biofuel industries. In addition, more than 3,000 value-added products have been manufactured. Due to its wide range of uses, it is the main driving force in the world agricultural economy. Among maize producing countries, India ranks fourth in area and seventh in production. In 2018-19, the planting area reached 9.2 million hectares" (Anonymous 2020). "India produced 1.73 million tons of corn in 1950-51 and increased to 27.8 million tons in 2018-19" (Anonymous 2020), and production increased almost 16 times. Although Indian maize production is low, the average daily maize consumption in India is equivalent to many of the major maize producing countries. In India, maize is grown mainly in the two seasons, kharif and rabi. Kharif maize accounts for approximately 83% of maize,

out of which 70% is still planted under rainfed conditions despite under pressure, while rabi maize occupies the remaining area. When compared to rabi maize (4436 kg/ha), which is mainly grown in a safe ecosystem, the stress-susceptible ecology results in lower productivity of kharif maize (2706 kg/ha). Recently, the maize planting area in Punjab, Haryana, and western Uttar Pradesh has also increased rapidly during last spring. Unfortunately, the data about the region and production are not well documented. Among cereals, maize has the highest area and productivity and the major maize growing states are Madhya Pradesh, Karnataka and Rajasthan. As per sources, India exported about 2,23,050 MT of Maize in the month of October 2020, out of which 1,63,851 MT was exported to Bangladesh and around 55,776 MT was exported to Nepal. In Punjab it occupied total area of 281,700 Acres with total production of 423000 tonnes and average yield of 37.08 quintal per hectare during 2017-18 (Anonymous 2017-18). It is mainly sown in the regions of Hoshiarpur, Ludhiana, Roopnagar, Shaheed Bhagat Singh Nagar, Amritsar, Gurdaspur, Jalandhar Kapurthala, Patiala, SAS Nagar and Fatehgarh Sahib.

EEFlux (Earth Engine Evapotranspiration Flux) is a Google Earth Engine-based improved version of METRIC. It is an application of the METRIC ET mapping algorithm in Earth Engine, which is used to process Landsat and MODIS images. The residual from the surface energy balance is computed as $ET = R_n - G - H$, where R_n is the net radiation, G is the ground heat flux, and H is the sensible heat flux. The surface energy balance is driven by the Landsat thermal band, while the shortwave band is used to assess the amount of albedo in plants and surface roughness. The EEFlux platform is built and developed on Google Earth Engine (GEE) based on the METRIC algorithm to digitize data entry, operation and speed up the ET calculation process (Allen *et al* 2007). EEFlux makes use of Landsat picture data hosted on GEE, a cloud platform that allows users to quickly obtain ET maps of any Landsat 5, 7, or 8 scenes (Allen *et al* 2015). EEFlux can also quickly generate intermediate product maps for specific Landsat scenes, such as NDVI, Albedo, ET, base map, land cover and surface temperature. However, crop water consumption estimation utilizing the METRIC algorithm in the Google EEFlux version should be investigated further, since this novel remote sensing tool has the potential to improve irrigation management in huge fields with high geographic variability at a cheap cost. Since, the estimation of ET is complicated and complex process, EEFlux tool will provide an alternate and simplified method to estimate ET. Google earth is a computing programme that creates a three-dimensional picture of the earth using satellite photos. The programme maps the earth by superimposing satellite pictures, aerial photography, and GIS data on a 3D globe, allowing users to view towns and landscapes from different perspectives. Users can travel around the world by typing an address and location, or by using a keyboard or mouse.

The results have been compared with other remote sensing tools like geeSEBAL for

validation. The geeSEBAL runs an alternate algorithm that of EEFlux. geeSEBAL (Bastiaanssen *et al* 1998) developed and verified the Surface Energy Balance Algorithm for Land (SEBAL) to estimate evapotranspiration (ET) from the energy balance equation ($R_n - G = LE + H$), where LE, R_n , G, and H are Latent Heat Flux, Net Radiation, Soil Heat Flux, and Sensible Heat Flux, respectively. LE is calculated by SEBAL as a residual of other energy flows ($LE = R_n - LE - G$). The SEBAL method features an internal calibration that assumes a linear relationship between dT and LST over domain area, where dT is intended as a vertical air temperature (T_a) floating above the ground surface, taking two extreme circumstances into account. At the hot and dry extremes, LE is zero and H equals available energy, whereas at the cold and wet extremes, H is zero and LE equals available energy. Allen *et al* (2015) proposed an automatic calibration approach to reflect extreme situations in METRIC (adaptable for SEBAL) by selecting endmembers from pre-defined percentiles of LST and NDVI. Allen *et al* (2015) defined a subset of endmembers within the top 5% of NDVI and the bottom 20% of LST to pick cold extreme situations, while endmembers within the top 10% of NDVI and the bottom 20% of LST are used to select hot extreme conditions.

The data is also compared with NRSC data for comparison. It is under the umbrella of the National Hydrology Project (NHP), it had implemented an operational Satellite-based Evaporative Flux Monitoring System for India under the activity "Development of Satellite based Regional Evaporative Flux Monitoring System for India". Towards this initiative NRSC has developed a framework using the space-based inputs and other ground-based data to derive a daily operational Evapotranspiration (ET) product for the country. NRSC data runs on IRS satellite which yield daily ET as 3-day period. NRSC data is provided under NHEP programme. Cropwat and ET_0 is also used to determine the evapotranspiration where the data like rainfall, humidity, maximum and minimum temperature, sunshine hours and windspeed is inflexed as input and ET as ejected as output. The Observed data is obtained through FAO-penman method. It is chosen for Observed data since, modified penman method is already used in Cropwat. The Cropwat and ET_0 data is equivalent to the observed data obtained from FAO-penman method. Mapping software like Qgis is used for picturization and colorization of the tiff file downloaded from the satellite sources.

CHAPTER II

REVIEW OF LITERATURE

A brief series of the studies conducted at the national and international level relevant to the present study entitled, Quantification of evapotranspiration using EEFflux tool and comparison by empirical methods in maize (*Zea mays* L.) has been reviewed and presented below:

Akpalu *et al* (2008) had analysed the effect of climatic variability on maize yield by using Generalised Maximum Entropy (GME) Estimator and Maximum Entropy Leuven Estimator (MELE). They used two climatic indices rainfall and temperature, combined these indices with various input variables. The GME estimator and MELE will show the influence of climate change on maize yield in their region. The MELE results, which showed better data indicate that a portion of decrease in mean precipitation may result in a higher harmful impact on maize production than an equal percentage increase in mean temperature owing to climate change. The elasticity value of temperature and precipitation are 0.383 and 0.416, respectively. There is sufficient data to suggest that the average temperature has risen. Also, the mean rainfall is anticipated to drop while variation increases. This would have a detrimental influence on the yield and possess a serious danger to food security in the region. Whereas, the rest of the region, where government supplies around half of the maize. This study also discovered that irrigation had a beneficial impact on yield, albeit with a lesser elasticity than precipitation. Irrigated farms outperformed dry-land farms in terms of yield, with an elasticity coefficient difference of 0.356. This suggests that, everything else being equal, irrigation may minimise the impact of decreasing precipitation on yield.

Allen *et al* (2005) estimated ET using a new remote sensing tool SEBAL and METRIC and found out ET as a residue or remaining portion of a surface energy balance with the help of SEBAL and METRIC. METRIC and SEBAL tools use satellite image data collected through Landsat and other remote-sensing satellites that record the part of electromagnetic spectrum like thermal infrared, visible and near-infrared radiation. Generally, ET is calculated on a pixel-by-pixel basis for the instantaneous time of the satellite image. This process is based on a complete energy balance for individual pixel, where ET is predicted from the remaining portion or residual amount of energy from the classical energy balance, where ET is net radiation – heat to the soil and to the air. For the sugarbeet crop, the difference between METRIC (714 mm) and lysimeter measurement (718 mm) was less than 1% during the growing season. The inaccuracy that resulted during specific days was spread randomly and have a tendency to cancel. These comparisons are based on a small sample, but they are most likely normal. Errors of up to 20% might possibly be tolerated by water user groups if dispersed randomly. The ET derived through METRIC is cost effective to generate

for larger areas than usual ET data.

Choi *et al* (2009) conducted an experiment of three surface energy balance algorithms over a maize and soybean production region during SMACEX. The three models had reasonable agreement with the flux tower observations, resulting in RMSE values of 20-30 W/m². However, from the three models, scatter and bias in H and LE were larger, with RMSE values from the TIM model attaining over 150 W/m². The study reported that TSEB and METRIC produced similar result with measured heat fluxes with RMSE of 50-75 W/m². The extent of the model differences was found to be closely proportional to the a portion of vegetation cover/LAI. The biggest variations, particularly in H, were reported in most cases over moderately vegetated areas with LAI 2. Model differences in accessible energy, R_{N-G}, tended to modulate LE differences. Inter-model biases were found to be large in H and there was a strong linear relationship between METRIC and TSEB, as both showed reasonable agreement with tower fluxes. The METRIC ETrF value for the hot pixel condition has been changed from 0.1 to 0.4-0.5, that has been derived from the water balance model had reduced the bias in H. Yet, it increased the bias in LE due to model variances in remaining energy. The study findings imply that in an agricultural area with high NDVI value and no area of bare land, METRIC needs a special attention at the hot pixel in specification of ETrF including adjustment of minimum ET based on vegetation and residual evaporation from the soil.

Cuesta *et al* (2020) conducted a study on METRIC-GIS for calculating crop ET under GIS environment. The tool they developed reduces computational time by maximum 50%, providing a more user-friendly substitute to other existing platforms that use METRIC. These findings imply that using METRIC in an agricultural area with high NDVI and no areas of completely bare soil at the thermal pixel scale necessitates paying special attention to the specification of ETrF at the hot pixel location, including adjusting the minimum ET based on the amount of vegetation in addition to residual evaporation from soil. It also facilitates data input introduction in an easier way. When METRIC-GIS was used instead of METRIC-erdas, computational time was reduced by up to 50%. The new tool facilitates the discovery of potential calibration and pixel review, which provides a valuable alternative to ensuring that selected pixels fulfill the established parameters. METRIC-GIS maize Kc values agreed statistically with those reported in the FAO-56 document, with the added benefit of providing information about the spatial component related to irrigation/agronomical management at the field size.

Filgueiras *et al* (2019) experimented the dynamics of actual crop evapotranspiration based on SEBAL and metric-EEFlux and found out that product available by EEFlux presents a higher estimate of evapotranspiration when compared to SEBAL for the areas with lower NDVI values and higher surface temperature. ET_a from the EEFlux tends to be greater than

Et-SEBAL for the study region. However, when ETa values were greater, the ETa-SEBAL product estimated higher evapotranspiration rates than ETa-EEFlux, whose values were largely connected to higher NDVI values. The evapotranspiration rate between 2.5 and 3.5 mm had the highest agreement of the ETa values between the products. EEFlux and Et-SEBAL showed similar results in estimating NDVI. Hence this shows that EEFlux can be used in future for estimating NDVI. The evapotranspiration value was higher at initial stages for EEFlux and then which was on par with SEBAL. The greatest disparity in evapotranspiration products occurred at the start of the crop cycle, when the locations still had exposed soils. The average difference between the ETa-SEBAL and ETa-EEFlux products was 0.20 mm.

Foolad *et al* (2018) conducted a comparison study of EEFlux and METRIC. The results showed that EEFlux and metric show similar values in calculating Etrf and Eta for crop lands. The study included in-depth comparisons of EEFlux and METRIC. Three products, Ts, Albedo, and NDVI that obtained through EEFlux and metric have been equal. Their R^2 and slope values are nearly equal to one, and their RMSE values are quite modest. The slope for NDVI is greater than one because the METRIC version computes NDVI using top-of-atmosphere reflectance measurements rather than surface reflectance values, like EEFlux does. The Rn and H products of the two models are also similar, with R^2 and slope near to 1. On comparing the two products based on their magnitudes, the RMSE values are relatively tiny. Among the two versions, EEFlux evaluates the G in different equation and metric evaluates G in a different equation. So, the G values among metric and EEFlux varies with a increased value of around 20 W/m^2 when compared to the metric version. Though G value varies, other values like R and RMSE were within the limits. Furthermore, the systematic bias in G is largely cancelled out during ETrF generation due to the self-reducing bias reduction applied internally in EEFlux and METRIC. However, for daily ETa, EEFlux displayed a considerable bias compared to METRIC, with RMSE surpassing 2 mm/d and a slope of 1.3. Given the similarities in ETrF, the larger calculation of ETa from EEFlux can be attributed to the conversion of ETrF to ETa by multiplying by daily ETr, which is taken from synoptic gridded weather data. The positive correlation among metric and EEFlux among ETrF and poor correlation for H is can be explained by systematic differences in estimates for G that is both the versions use different equation to calculate G, which are embedded in the estimates for H. It is then removed from the ET estimates during the ET estimation steps due to METRIC and EEFlux's internal, systematic bias correction. Differences in H can also be traced back to the sources utilised to compute instantaneous ETr, as previously stated, with greater ETr estimations in EEFlux producing lower values for H during the surface energy balance calibration. METRIC generally employs ground-based weather data for hourly and daily ETr calculation, whereas EEFlux uses gridded weather data sets. The computed ETr

values utilised in computations can differ due to variances in weather data origin and aridity biases inherent to gridded weather data sets. Most of the METRIC applications uses a single ETr value for an entire Landsat image for both energy balance calibration and interpolation to 24-hour periods. ETr values used in EEFlux can vary across the image due to the gridded weather data, which has a grid spacing of approximately 12 km for NLDAS-2 hourly data in the CONUS and 4 km for GRIDMET 24-hour data. In a crop land, the EEFlux calculated ETrF and ETa values are on par with those obtained by professional METRIC users and are seen in positive correlation. The differences seen between both the versions were greater for non-agricultural land uses, showing that the EEFlux methods need to be improved as it is newly evolved. At the hot pixel calibration end point, EEFlux is straining to account for background evaporation. These non-agricultural pixels have lower ET and more disturbed in the overall energy balance equation that resulted in bias and error. These bias were origination from the hot pixel that were given to ETrF and resulted in excessive damage to non-agriculture or crop land pixels.

French *et al* (2015) examined ET in cotton crop using remote sensing tools like TSEB and METRIC energy balance models and found that METRIC version is preferable when model ancillary data are scarce, whereas TSEB is preferred when support data are abundant. ET estimation modelling in further trend should give importance in implementing both the versions in order to achieve greater opening in ET accessibility. This study was focused on TSEB and METRIC evaluating ET. The comparison structure was designed to eliminate model components that are irrelevant to LST remote sensing. Both models were determined to be around 1.9 mm/day accurate. At 1-m and 30-120-m scales, TSEB and METRIC functioned well and resolved episodic and seasonal ET fluctuations. The sensitivity in the study appears to be occasionally systematic, with the former one being more sensitive to Land-surface temperature variations in less dense cotton cover and latter one being more sensitive during mature stages of the crop. An alternate time scaling strategy to the generally used constant EF approach was evaluated and found to function well in two cases, although further data under partly overcast conditions is required to confirm its consistency. To find the ability of these remote sensing tools, a short and simple experiment in crop water stress detection tool and tests were done. The test also resonates with correlating temporal changes of EF to moisture that have been drained or depleted. The findings revealed some signaling in the early stages of development. However, EF fluctuations failed in tracking the reduction of water that happened in root zone for the majority of the seasons. A study of the effect of overpass frequency on ET accuracy found that an 8-day overpass frequency outperformed 16-day observation intervals by a significant margin. Model complexity and the availability of auxiliary data must be considered while selecting a model. In this study, none of the component significantly pressurized the implementation. The METRIC technique is preferred

among the two, when surface conditions are not known. The TSEB technique is recommended when surface conditions are adequately limited because to its capacity to adapt to known biophysical parameters. Estimates from the model allowed us to test the effect of overpass frequency. Weekly overpasses are mandatory for irrigation scheduling and decision-making systems. They are highly favoured in other water applications like as water district accounting, but it remains to be seen whether the gains in ET are significant enough to justify the higher expenditures of more satellite platforms.

Gabr (2021) studied about Modelling using net irrigation and finding the water requirements of the crop using two models, FAO-CROPWAT 8.0 and CLIMWAT 2.0 and concluded that better water management should be adopted with a particular focus on improving irrigation efficiency. To reduce the requirement of water and improve the irrigation efficiency, changing the cropping patterns will favour both horticulture crops and also cereals. The various crop patterns water balancing scenarios for the district demonstrate that producing berseem clover and cotton crops results in a 22.1 percent increase above the licenced irrigation water limit. Green bean and sugar beet crops, on the other hand, will save 23.1 percent of the approved water allocation limit. Improving irrigation efficiency by up to 65% in AER 1 and 80% in AER 2 results in a gross irrigation water requirement of 641.4 million m³, a licenced allocated water of 1012.5 million m³, and a saved water ratio of 36.7 percent of the licenced allocated water.

Gangwar *et al* (2017) studied about Estimation of Crop Water Requirement Using a remote sensing model CROPWAT 8.0 and concluded that knowledge about crop water requirement is essential for better irrigation practices and scheduling. The study estimated both ET_c and Eta using the Cropwat model. The ET_c will be different for different growth stages as mentioned in FAO. The reference ET was lowest in December due to less exposure of sun and maximum in the month of May. This shows the positive correlation between E_{to} and sunlight. the factors like solar radiation and temperature are most important among all for ET. From the study, maximum water is required for the wheat crop followed by mustard. The water requirement was low in the case of gram and pulses. Since the irrigation requirement for the crop has been more, it can be concluded that effective rainfall in this region has been steadily decreasing over the decades. Hence, knowledge about crop water requirement is useful for irrigation scheduling and management.

Geerts *et al* (2009) conducted a study about Shortage of irrigation as an on-farm tactic to maximize crop water productivity in dry areas and found out drought tolerance changes in accordance to the genotype and phenological stage. From the findings, a sound knowledge about the crop and its drought tolerant capacity has to be known. Coupling the field research with deficient irrigation strategies, the modelling can be excelled. This is supported by gradual development of the above strategies. The relationship between ET_c and

yield is presented as a paradigm for assessing a crop's drought sensitivity during the season or at a given growth stage. The functions of the crop that deal with the aspect of water and plant were found to be not linear and crop specific. The difference is seen more during the various growth stages, traits and in their location. Calculating the amount of ET that is needed for optimal water productivity within these functions provides a importance of agronomic value of using deficit irrigation in a particular context. The validity of the models explaining crop development and yield response to water, which can only be generated from qualitative field work, determines the quality and broad applicability of developed DI methods.

Jabeen *et al* (2017) determined the effect of climate change on maize crop using CERES-Maize model. This study reported that grain yield had a positive and negative relation with CO₂ concentration in air and air temperature respectively. ET increases greatly as temperature rises and decreases as temperature falls. There is an almost 60% difference in ET between these two cases. The increase in temperature causes a large increase in ET rate of 66 percent. In 1993, there was a significant decline in ET. Under the weather circumstances of temperature increase, the highest drainage rate of 384 mm was measured in the year 2001. While temperature decreases create the lowest discharge of roughly 93 mm in 2008. A considerable difference of around 75% was detected between these two temperature change scenarios. Maximum nitrogen leaching occurred in the highest temperature scenario, while the lowest rate of nitrogen leaching occurred in the 1°C temperature scenario. Significant decrease in crop growth period and yield is caused by the temperature increase. There was a direct relationship between grain yield and CO₂ concentration, which suggests that increasing CO₂ would improve grain yield while maintaining the temperature same.

Kamali *et al* (2018) studied about the purpose of maize water requirement using remote sensing data and SEBAL and found out that these tools help in easier way of estimating the maize water requirement than traditional methods. These maize evapotranspiration values were calculated with the help of weather data and the FAO Penman-Monteith method. The maize water requirements for the available references were then determined using the RB, NWD, and FAO56 suggested K_c values. K_c value for maize was calculated by dividing maize ET to ET₀ and comparing it to the suggested K_c values by RB, NWD, and FAO. Landsat 7 values were removed from analyzing. The resulting curve revealed that the K_c value is not constant at this stage, and is 0.1 for the first ten days of growth and 0.4 for the next ten days. ET₀ was calculated using the FAO Penman-Monteith method. Their frequency distribution was examined, and it was discovered that it is normal. ET₀ values have increasingly trended from west to east and north to south, according to east-west and north-south tendencies. By computing ET₀, the K_c value was calculated in three stages: 0.1, 0.4, and 0.22 for the first, second, and mid stages, respectively. It agrees that it is preferable to avoid using a constant crop coefficient throughout the entire early stage, as

advised by FAO.

Khan *et al* (2020) conducted Study in Sindh using Satellite-derived Actual ET. The study shows that satellite-based consumptive water use of Sindh canals' command areas provide mathematically sound data essential for developing knowledge-based policies and recommendations for efficiently managing. The study was conducted for the years 2018-19 and kharif and rabi season. The highest values of ET were observed during Kharif 2018. Surplus flows are generally available during the Kharif season, however deficit or negative flows were seen during both Rabi seasons. During the Kharif 2018 season, the Fuleli canal off shooting from the Kotri Barrage had the largest excess flow of 2.0 MAF. The Rohri canal CCA remained in deficit in our analysis due to strong consumptive needs in all seasons. The predicted water balance information aids in flow management by altering canal flows by reducing surplus quantities and reallocating them to water deficiency locations. Water flows can be regulated based on the consumptive water needs of a Culturable Command Area to achieve optimal water balance in the province. This study can also aid in crop selection in a certain CCA in relation to available water amount. If the demand for water is significantly greater than the available supply, high water-intensive intensities may need to be managed in a CCA. A more effective and water-efficient cropping pattern for farmers may aid in meeting the sustainable development aim of water conservation.

Longshuai *et al* (2020) experimented coupling ET partitioning along with water passage to identify the water uptake features of wheat and maize in an intercropping system. Their study had proven that balanced use of water resources in the intercropping system can be used to make efficient use of water and improve the crop management practices in the area. In this study, ET was calculated using the water balance and not with surface energy balance method. Select the average value across consecutive three-day periods. During the three-day span, when there was no rain, these times were chosen at random. Data revealed that evapotranspiration and rainfall were extremely well matched. During the subsequent crop stage, on two sowing dates, former one with intercrop wheat was of lower soil water storage than that of later one. However, the difference was not statistically significant until 179 days following wheat planting. Because there had been a lot of rain before the test, SWS in maize had greatly increased 179 days after wheat planting in 2015. Compared to sole maize at this time, SWS in intercropped maize was substantially higher. In comparison to sole wheat, the SWS in intercropped wheat was substantially higher. In 2015 and 2016, intercropped wheat had evapotranspiration that was 56.8 mm and 58.9 mm more than that of sole wheat throughout the growth period (ET_g). Wheat intercropped with other wheat had a similar T/ET ratio to wheat grown alone. The Transpiration and ET of the wheat which was sown along with another crop were greater than the other one. This data has been compared from the sowing stage to maturity stage. Eta daily of the former wheat during the growth stage showed

positive correlation with sole wheat. Wheat intercropped with other crops had higher daily transpiration than wheat grown alone. Following harvest, intercropped wheat evaporation from the soil was lower than that of sole wheat. Evaporation of soil water has no effect on grain yield. The impact of evaporation and its progressive control could be one of the most important water-saving measures in semi-arid agricultural areas. The parameter that is important and is directly proportional to the soil water evaporation is radiation. The presence of canopy interception evaporation limits the availability of total field water input and can result in severe water loss in agricultural settings. The water balance approach and the direct method (sap flow plus micro-lysimeter plus canopy interception) were combined in this study to assess the quantity of water transport between wheat and maize intercropping strips. The findings demonstrated that intercropping had a significant impact on crop water use. When compared to sole cropping, intercropped wheat and intercropped maize consumed significantly more water during the growing period of each crop.

Norman *et al* (2009) studied about use of remote sensing for evapotranspiration monitoring over land surfaces and the results showed that exertions are being focused towards simplifying the parameter requirements of complex models. Simple ways for calculating soil heat performant appear to be promising for working purpose applications. The surface temperature can be used to calculate the state of the surface and the amount of energy going into H and LE. Satellite remote sensors are the only method capable of providing a consistent and commercial surface temperature reading. Multiple terrain elements influence all of the wavebands employed by satellite-based instrumentation. As a result, a remotely sensed signal cannot be completely associated with a surface that is limited to one feature. The semi-empirical techniques are then needed to translate captured radiances into physical values that are helpful in surface energy balance modelling. The remote sensing that utilizes satellite imagery can yield us critical information that are useful for assessment of Evapotranspiration from field to global level or scales at acceptable temporal resolutions. The non-uniqueness in related observed radiances in correspondence to landscape features makes it difficult for remote sensing techniques to apply on different surfaces difficult without ground truth data. The discovery is that T_{rad} is not equal to T_{aero} . Most models are vulnerable to inaccuracies in $(T_{aero} - T_{air})$, because T_{air} measurements at the time and location of the T_{rad} observation are rarely available. Owing to the differences in crop density with NDVI value and soil, temperatures can be large depending on soil water conditions, supplementary relation among these factors cannot be ignored in general. On the pixel scale, thermal emissivity is just approximate. Significant inaccuracies in T_{rad} measurement are caused by atmospheric adjustments and satellite calibrations, which are not always well understood. Remote observations can be covered in short span of time whereas fluxes on hourly and daily that are correlated takes more time to be covered. Larger pixel-size satellites (1-4 km) can offer

sufficient frequency of observations in time (e.g., GOES), however there may be uncertainties due to averaging over diverse subpixel areas. Surface flux estimates that are continuous (hourly or daily) are the most informative, as clouds cause remote measurements to be sporadic.

Pereira *et al* (2015) estimated the Crop evapotranspiration with FAO56-PM method and their study revealed that the effective implementation of the FAO-PM reference ET and K_c approaches yields precise and accurate output yet it also a relatively high level of toughness in terms procedures, transferability and repeatability of the K_c method. Further development in simplifying the complex method is required. The FAO56 dual K_c approach necessitates daily precipitation and reference ET inputs, which were previously relied exclusively on meteorological variables gathered from weather stations. Over the next fifteen years, applications of the FAO56 style K_c -ETref approach will be increasingly used with gridded weather data to construct crop ET "surfaces." The computation processes will be implemented in geographic information systems and programmed in modern languages such as Python and Java-script. The FAO56 style of K_c -ETref approach, which is heavily based on FAO24, has been incorporated into a variety of computer models and software used in irrigation scheduling, irrigation system design, water resource planning, where water demands are required, and hydrologic modelling, where water consumption by vegetation and crops is required. The crop coefficient - reference ET method is a reliable method that allows for the derivation and implementation of K_c curves in a variety of climates and places. The FAO56 dual K_c technique estimates the effects of surface wetness by precipitation and irrigation on evaporation from soil and total ET rate, particularly during vegetation development and dormant vegetation growth phases such as winter. The K_c approach, despite its simplicity in design and construction, successfully incorporates a number of consistent and compensatory elements that separate the ET of any individual crop from that of the reference ET. This feature has drawn a diverse and huge number of users, ranging from non-scientific commercial and operations users to reasonably advanced research users that require high accuracy in estimates.

Roja *et al* (2020) conducted experiment on Estimation of Crop Water Requirement of Maize Crop Using FAO CROPWAT 8.0 Model in North coastal districts of Andhra Pradesh and concluded that efficient water management is crucial for normal rainfall years and critical for deficit rainfall years. The model predicted the daily, decadal, and monthly crop water requirements of the maize crop at various stages of growth. It has been discovered that there is no yield reduction in maize crop with maximum rainfall efficiency at 80 percent critical depletion and refilling the soil to field capacity, whereas the detailed results of total gross irrigation, total net irrigation, actual water use by crop, and potential water use by crop show that there is no yield reduction. It was discovered that output reductions will not occur at any

growing stage with maximal rainfall efficiency, as predicted with irrigation at 100% critical depletion and by replenishing the soil to field capacity. Higher temperatures increase evapotranspiration and necessitate a more frequent irrigation plan. Agricultural sowing and planting dates fluctuate, causing crop production times to shift, which has an impact on crop water requirements. Proper and optimal irrigation scheduling using CROPWAT 8.0 enabled efficient water consumption. Irrigation was considered for 80 percent of essential soil moisture loss. This model estimated the daily, decadal, and monthly crop water requirements of a maize crop at various stages of growth. The crop water and irrigation requirements for maize crop are 238.6 mm and 212.6 mm, respectively. According to the study, good water management becomes vital in normal or low rainfall years.

Singh *et al* (2012) estimated the evapotranspiration for different season from satellite pictures with temporal resolution and determined the reliability of various methods for assessing the seasonal ET from temporal remotely sensed images with the methods named cubic spline fixed and linear. The predicted energy flows matched the measured energy fluxes at the moment of satellite overhead reasonably well. The estimated Rn was within 10% of the measured value, with a strong R2, demonstrating that the model is capable of estimating this energy component. The factors like heat transfer, specific heat that has been fluctuating due to moisture content and crop vegetation, the final output of the G is very less. This leads to obstruction in prediction of modelling. The calculated and measured LE have a high correlation. In both models ET is the Residual and leftover energy utilized for ET activities. Model estimations were 22 percent higher on average than EC tower readings. Even though the maize crop was sown in all the locations, Evapotranspiration at site 2 was lower when compared to dry land location. Even throughout the non-growing season, the model operated admirably. Throughout the year the results showed negative correlation but, during the October the estimated monthly Evapotranspiration using first method showed positive correlation with the EC tower-measured monthly ET. At the maturity period, most of the energy that is leftover is used for evaporation process rather than transpiration process. Once the crop is harvested, ET decreases abruptly, which is not caught by any of the two seasonal ET approaches. Following that, monthly ET for end of the year was nicely predicted, despite the fact that no image was supplied for November. According to the findings, the difference between observed and simulated mean monthly ET ranged from 17.8 percent to 35.1 percent. The spatial distribution of seasonal ET was similar using all three techniques. Seasonal Evapotranspiration was higher along the water streams and lower in urban areas. Though these photos appear to be comparable on the surface, the seasonal ET values varied slightly. The majority of pixels in individual interpolation case agreed well with the other method. The cubic spline method produced the lowest standard error of the three methods tested. It is proposed that this strategy be tested for numerous years in order to examine the inter-annual

variation.

Verma *et al* (2020) studied about Estimation of Water Requirement for rice using FAO-CROPWAT-8.0 Model in Uttarakhand. The maximum ET₀ was discovered to be high in the month of May, which is mostly due to high temperature and wind velocity, whereas it is lowest in the month of January. The month of July has the most effective rainfall, while December has the least. For the research area, crop water requirements are higher in July than in June, implying high reference evapotranspiration during the same months. This crop water requirement will aid with water management in the research area, as well as irrigation scheduling. This study provides a foundation for efficient water management planning and, eventually, increased water use efficiency.

Wagle *et al* (2017) investigated the concept of five-surface energy balance models for estimating daily evapotranspiration in sorghum, and their findings demonstrate the importance of a soil moisture or plant water stress component in SEB models for the development of their performance, particularly in extremely dry or wet environments. These findings imply that some modifications to SEB models are required for proper energy partitioning. SEBAL's sensitivity study to its input parameters revealed that increasing hot/cold pixel temperatures at H was reduced and LE estimations went to its peak. If applying the same procedure while reducing the hot/cold pixel temperatures H peaked and LE were reduced at estimates. ETEC, ET₀, and anticipated ET grew at the start of the growing season, peaked during peak growth, and then fell when crop senescence began. Because precipitation and canopy development have a large impact on ET. ET rates fell precipitously during dry periods and increased promptly following rainstorm occurrences. When soil moisture was at the tenth percentile, all SEB models significantly overestimated ET, that resulted in poor performance. But while the moisture content in the soil is increases, their performance improved exponentially. The SEB models had a drawback of peaking the values during the rainfall period that results during separation of available energy. Coming the point, S-SEBI has more drawback than SEB model. It peaked the value by 16% in 2012 and under calculated the value by 15% in the success year. In the 2012 and 2013 growth seasons, SEBAL overestimated ET by about 11 and 15 percent, respectively. SEBS overestimated ET by around 21 and 4.9% in the 2012 and next growing seasons, respectively. SSEBop Peaked ET by 18.5 percent in the 2012 year and underestimated it by about 10 percent in the 2013 growing season, but METRIC peaked in both the year by about 26 and 32 percent, respectively. Models were ranked SEBAL > SSEBI > METRIC > SEBS > SSEBOP based on R₂ (closer to 1 is better). Models were ranked in the order S-SEBI > SEBAL > SEBS > SSEBop > METRIC based on NSE (closer to 1 is better). Models were ranked in the order S-SEBI > SSEBop > SEBS > SEBAL > METRIC based on PBias (lower is better). Models were evaluated in the order of S-SEBI > SEBAL > SEBS > SSEBop > METRIC based on

RMSE (lower is better).

Zhang *et al* (2016) studied about the actual ET estimation using remote sensing and concluded that advancement in the remote sensing will enhance the capabilities in ET for monitoring the global water and energy cycles which includes availability of water resources, ecosystem responses and feedbacks to climate change and human impacts first remote sensing method based on energy estimation. It works on the approach of SEB expression and land surface flux along with remotely measured temperatures. One-source SEB models, also known as one-layer models, solve for E as the remainder term. Surface controls are calculated from one source in resistance models, but contributions from soil and vegetation components are unknown. Two-source SEB models account for the individual contributions of soil and vegetation to the total heat flux. The Simple Remote Sensing Evapotranspiration model is based on two-source SEB equations with some simplifications and parameterizations (Sim-ReSET). Sim-ReSET avoids calculating aerodynamic drag using a dry bare reference floor and assuming that the wind speed is homogeneous at the upper limit of the atmospheric surface layer, making it easier to use for predicting E with regular and routine RS data. The SEB models were among the first Remote Sensing (RS) approaches used to map ET, and their accuracy is highly dependent on the quality and reliability of the thermal RS inputs. These models can also be developed using inputs simply derived from RS. The main disadvantage is that they only work under clear skies, since thermal RS data, their main input data source, can only be trusted under clear skies. With the rapid development of RS technologies and the widespread availability of RS data over the past three decades, a diverse set of approaches to RS-based E estimation has emerged. Although there are numerous RS ET models and techniques, there is no consensus on which is best as each method has advantages and disadvantages compared to the other. To reduce the RS-ET uncertainty, an ensemble approach and more advanced data fusion algorithms have been developed, which can result in a superior ET product.

CHAPTER III

MATERIALS AND METHODS

The present study entitled, Quantification of evapotranspiration using EEFlux tool and comparison by empirical methods in maize (*Zea mays* L.) was carried out during the *kharif* 2021. Detailed information on various meteorological parameters, materials used, equations, and methodologies employed throughout the study period are briefly presented in this chapter under following sections.

3.1 Location

The study was carried out at the research farm, Department of Climate Change and Agrometeorology, Punjab Agricultural University, Ludhiana campus. (Latitude of 30°53'56.34"N, longitude of 75°48'4.53"E and average elevation of 247 m) in which Maize crop was cultivated, in *kharif* 2021.

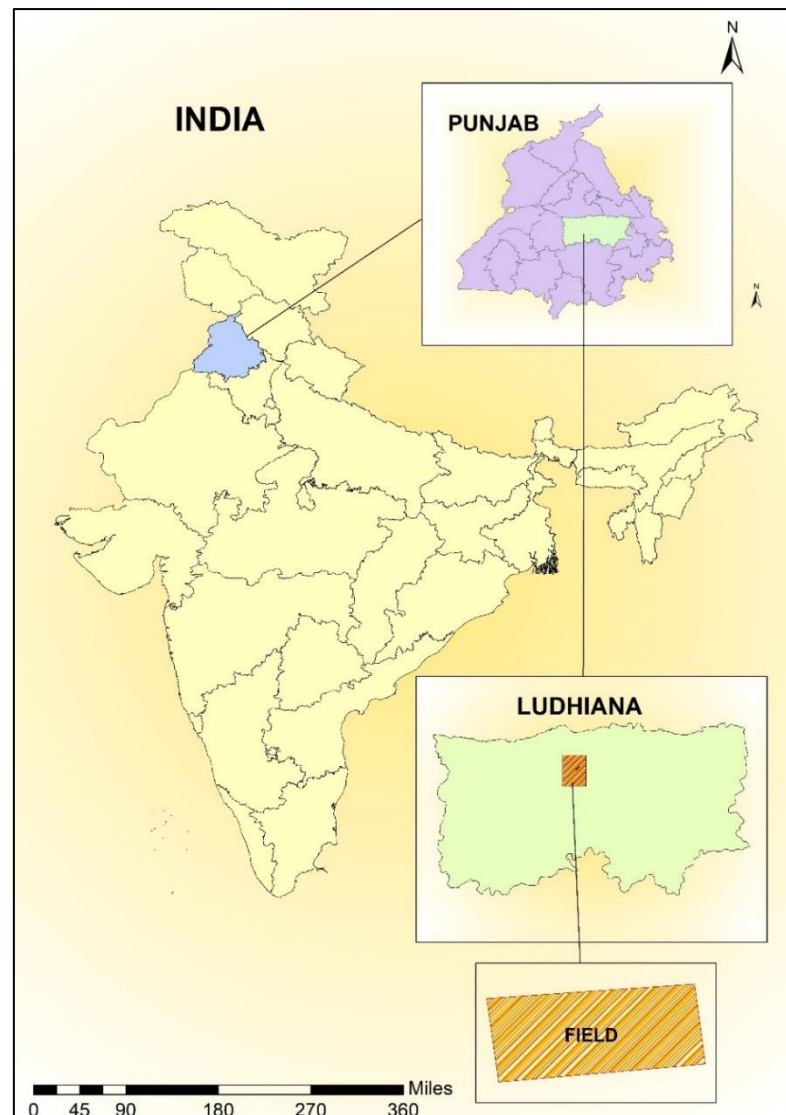


Fig. 3.1: Location of the Study

3.2 Punjab and administrative setup

Punjab state is located on the north western border of the country that is known for its rich potential in water resources. The state name originated due to the clustering of five river. Thus yielded the name Punjab. The state holds the area of about 50,370 sq.km. it has latitude of 29.30°N to 32.32°N and longitude of 73.55°E to 76.50°E respectively. The state is an agrarian economy where main occupation is agriculture. The soil is mostly alluvial and fertile plain, as it has more water sources colliding in the territory.

3.3 Climate

The climate in the Punjab is influenced by vagaries of climate and season. This is due to the impact of Himalayas, western disturbance and also because of its sub-tropical region. The summers are too hot and winters are too cold. The maximum temperature occurs during the month of mid-May and June, which remains average of 40°C. This is due to hot and dry westerly wind called 'loo' that blows during noon which increases the temperature. This loo is desiccating and scorching. The average annual rainfall of the region is 650mm and has been declining since 1980. It receives most of the rainfall from monsoon, that is useful for growing kharif crops. The Shivalik ranges in Punjab region receives most of the rainfall and desert in west receives least rainfall.

Table 3.1: Weather parameters recorded in Agrometeorological observatory (Kharif 2020-21)

Month	Temperature(°C)		Relative humidity (%)		Rainfall (mm)	Wind Velocity (km/hr)
	Maximum	Minimum	Morning	Evening		
May	36.4	22.6	57	32	37.3	6.0
June	36.3	25.4	68	42	84.8	5.4
July	35.4	30.3	76	62	271.2	5.5
August	33.8	27.2	82	63	107.6	3.6
September	31.8	25.4	86	68	295.8	3.2

3.4 Experiment No. 1

Quantification of Evapotranspiration using EEFlux tool and comparison by empirical methods in Maize (*Zea mays* L.)

3.4.1 Satellite dataset

Satellite data representing the study area has been downloaded through EEFlux. Images from the Landsat 7 and 8 satellites OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) were used as satellite data in 2021. According to the US Geological Survey, the Landsat 8 satellite used has a spatial resolution of 30 meters and a temporal resolution of 16 days (USGS). Priority was given to photographs without clouds in

the selection process, and images were provided on a regular basis throughout the growth period for better evaluation. When the cloud cover is more in Landsat 8 images, which yields the images every 16 days, we prefer Landsat 7 images. Following these criteria, multiple images were chosen and obtained during various phases of the growing season.

3.4.2 Visualization of tiff file

The downloaded tiff file is colorized using a mapping software Q-GIS. Once the tiff file is colorized, it is then labelled with the information collected through the experiment No.2.

Table 3.2: Actual Evapotranspiration (ETc) data recorded during crop growing season

Data	Spatial Resolution (m)	Period
Actual Evapotranspiration	30 x 30	25 th May
		5 th June
		15 th June
		25 th June
		30-May
		03-Jun
		06-Jun
		19-Jul
		21-Jul
		23-Jul
		04-Aug
		13-Aug
		23-Aug
		04-Sep
14-Sep		

3.4.3 Computation of ET

EEFlux yields many parameters like albedo, surface temperature, actual ET and etc. The parameter taken for the computation is E_{T_0} i.e., Reference evapotranspiration (E_{T_0}). After which the E_{T_0} is multiplied with respective K_c value for final parameter viz. actual ET. Crop productivity data was also used to calculate water use efficiency (WUE). Evapotranspiration is approximated by the WUE. According to Equation (1), it is estimated using maize production data as well as crop water consumption data during its respective cycle (Geerts and Raes 2009).

$$\mathbf{WUE} = \frac{Y}{10} - \mathbf{ET}_{all} \quad (1)$$

Where,

WUE - water use efficiency, (kg m^{-3})

Y - maize yield, (kg ha^{-1}) and

\mathbf{Et}_{all} - total ET throughout the growing cycle (mm).

3.4.4 Actual evapotranspiration (METRIC algorithm)

Images from the Landsat 7 and 8 satellites were processed using Earth Engine Evapotranspiration Flux (EEFlux version 0.20.17). According to Equation (2) (Allen *et al* 2005), evapotranspiration is residual energy that is left after subtracting sensible heat flux and soil heat flux from the net radiation. This is given by

$$\mathbf{LE} = \mathbf{Rn} - \mathbf{H} - \mathbf{G} \quad (2)$$

Where,

LE -latent heat flux (spent energy in the evapotranspiration process) (W m^{-2}),

Rn -net radiation, (W m^{-2})

G - heat flux in the soil, (W m^{-2}) and

H -sensible heat flux, (W m^{-2}).

EEFlux calculates the surface energy balance as and also other parameters like vegetation, albedo, land surface temperature, cloud cover and etc. using the thermal and shortwave bands from Landsat. Automated image calibration is used in the current version of EEFlux. The "hot" and "cold" portions (pixels) of the scene's surface temperature spectrum are assigned values for EToF in order to calibrate EEFlux. ET is denoted by ETrF, which represents ET as a fraction of reference ETr. The ETr is calculated in EEFlux using the "tall" alfalfa reference defined by the ASCE Standardized Penman-Monteith equation. ETrF is analogous to the commonly used 'crop coefficient.' ETrF is equal to EFact / ETr. The latent heat flux is calculated individually for every pixel at the exact moment and instantaneous ET is derived by dividing the LE by the latent heat of vaporization. according to Equation (3)

$$\mathbf{Et}_{inst} = 3600 \mathbf{LE} / (\lambda \rho \omega) \quad (3)$$

Where,

\mathbf{Et}_{inst} - instant evapotranspiration, (mm h^{-1}) and 3600 converts seconds to hours.

λ - heat of vaporization, (J kg^{-1})

ρ_w - density of water, (1000 kg^{-3}).

ET is derived as reference evapotranspiration and denoted as ETo. The ETo is calculated in EEFlux with the help of grass crop as a reference, according to Equation (4). It is then multiplied with Kc value to get actual evapotranspiration (ETc)

$$\mathbf{ET} = \mathbf{ETinst} / \mathbf{Eto} \quad (4)$$

EToF is used as a vehicle to extrapolate ET from the immediate transit of the satellite to the

24-hour period. As a result, the ET_a daily is derived by multiplying ET_{oF} for each individual pixel by ET_o of the site. The consistency is taken care by satellite that overpasses every 24 hours. according to Eq. (5).

$$ET_a = (ET_{oF})/ET_o \quad (5)$$

3.4.5 Reference Evapotranspiration

The maximum and minimum temperatures, solar radiation, wind speed, relative humidity and precipitation data are obtained from the meteorological station located in the study area and was used to calculate the reference evapotranspiration (ET_o). As metric algorithm requires ground observation, the ground data is taken from the system installed in the ground of elevation 247m. The ET_o estimates for the days of satellite passage were calculated using the Penman-Monteith equation (FAO 56) and the FAO-ET_o software, as described by (Allen *et al* 1998). After obtaining the ET_o, the K_c value was taken as per FAO. The K_c value of maize were 0.3, 0.6 and 1.15 respectively during crop growing season.

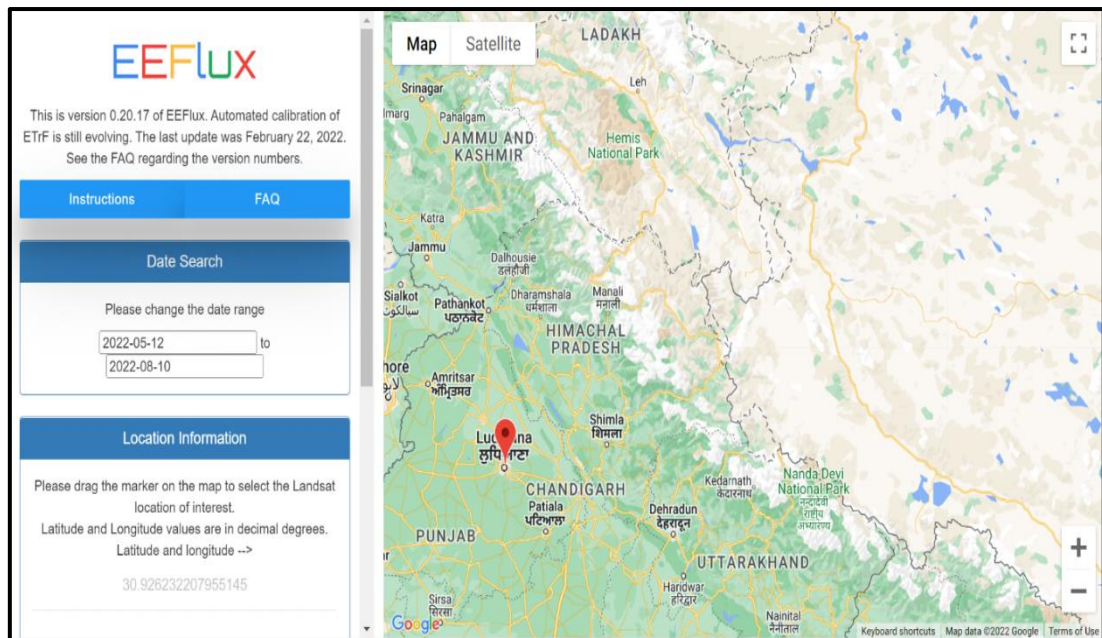


Fig. 3.2: Interface of Google EEFlux

3.5 GEE Surface Energy Balance Algorithm for Land (SEBAL)

The ET values obtained were also compared with twin sister of EEFlux called geeSEBAL. Surface Energy Balance Algorithm for Land (SEBAL) was developed and validated to estimate evapotranspiration (ET) from energy balance equation ($R_n - G = LE + H$) (Bastiaanssen *et al* 1998), where LE, R_n, G and H are Latent Heat Flux, Net Radiation, Soil Heat Flux and Sensible Heat Flux, respectively. SEBAL estimate LE as a residual of others energy fluxes ($LE = R_n - LE - G$) The internal calibration of the SEBAL algorithm assumes a linear relationship between dT and LST over domain area, where dT is intended as a vertical air temperature (T_a) floating above the ground surface, taking two extreme circumstances into account. LE is zero and H equals available energy at the hot and dry

extremes, whereas H is zero and LE equals available energy at the cold and wet extremes. (Allen *et al* 2015) proposed an automatic calibration approach for representing extreme circumstances in METRIC (adaptable for SEBAL) by picking end members from pre-defined percentiles of LST and NDVI. To pick cold extreme situations (Allen *et al* 2015) specified a subset of end members within the top 5% of NDVI and the bottom 20% of LST, whereas end members within the top 10% of NDVI and the bottom 20% of LST are used to select hot extreme conditions.

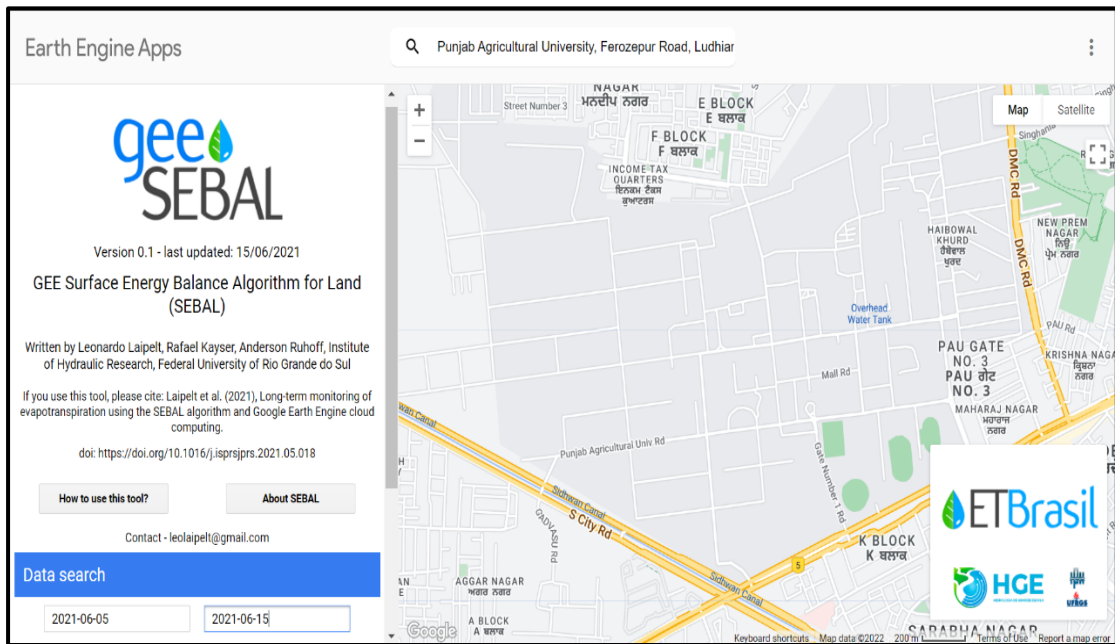


Fig. 3.3: Interface of geeSEBAL

3.6 NRSC-NHP portal

The National Remote Sensing Centre (NRSC) has been selected as one of the NHP's Central Implementing Agencies (IA) to provide satellite data-based hydrological products and services. As part of this, NRSC is developing geospatial products and services for the water resources sector, as well as early flood warning systems and DSS for irrigation water management, as well as modelling and dissemination of hydrological products to support water resource management and capacity building for NHP stakeholders.

Under the National Hydrology Project (NHP), spatial AET is estimated using with energy balance and water balance approach. Computational framework is developed using satellite and meteorological datasets for near real time daily AET product at 3' x 3' spatial resolution over the entire Indian sub-continent. ET geoportal consists of daily and 3 daily experimental actual evapotranspiration products based on energy balance and water balance approach. Energy balance based AET products are presently available for the clear sky condition. AET is valid for terrestrial features excluding water and snow. Visualization of AET trend is also available on the ET geo-portal at any given location.

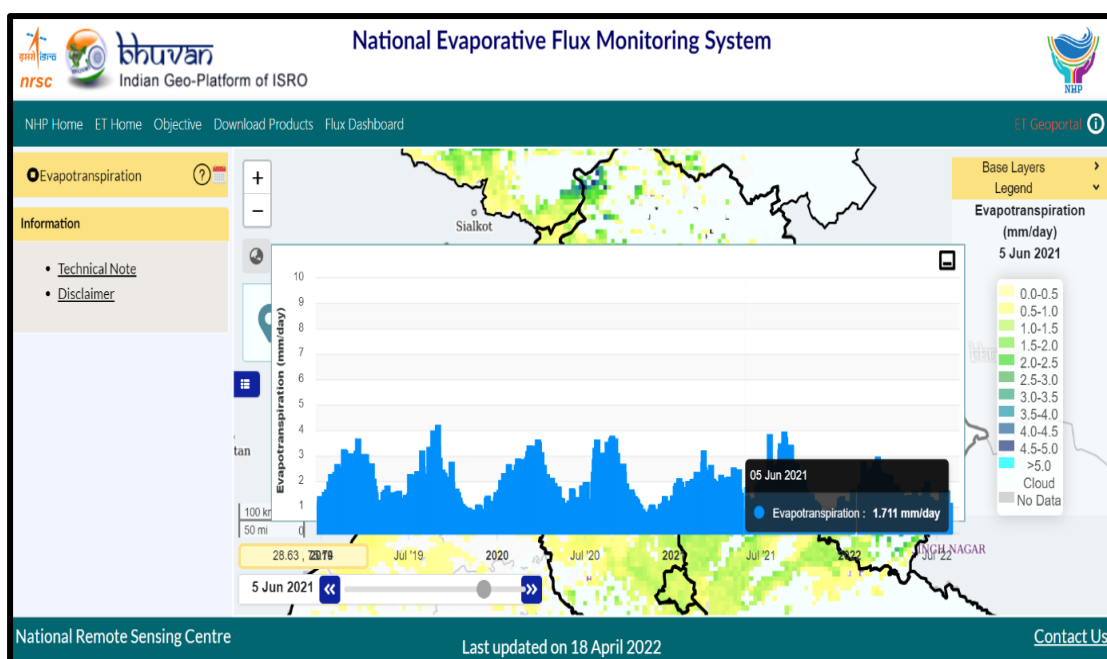


Fig. 3.4: Interface of NRSC-NHP portal

3.7 Comparison of ET values

The observed (Raw) and simulated (EEFlux) value of actual ET have been compared with various remote sensing tools like FAO-ETo calculator, geeSEBAL and NRSC-NHP data for validation.

A. Experiment No.2- Estimation of ET using Empirical methods and CROPWAT 8.0

Treatment details

Crop	: Maize (<i>Zea mays</i> L.)
Replications	: Three
No. of treatments	: 24
Total no. of plots	: 72
Experimental design	: Factorial Split Plot Design

Varieties (Main plot treatments)

PMH-1	V ₁
PMH-2	V ₂

Dates of Sowing (Main plots)	: 25 th May (D1)
	5 th June (D2)
	15 th June (D3)
	25 th June (D4)

(b) Fertilizer doses (Sub plots)	: Three
	: 100 kg ha ⁻¹ (N1)
	: 125 kg ha ⁻¹ (N2) (Recommended)

: 150 kg ha⁻¹ (N3)

(c) Growth stages

Table 3.3: Growth stages of maize crop

Growth stages	No of days taken	Description
VE	5	Coleoptile emerges
V1	9	Collar of first leaf visible
V2	12	Collar of second leaf visible
VT	55	Tasseling
R0	57	Anthesis or male flowering
R1	59	Silks are visible
R2	71	Blister stage
R3	80	Milk stage
R4	90	Dough stage
R5	102	Dent stage
R6	112	Physiological maturity

3.8 Cultural practices

3.8.1 Field preparation

The field was prepared with the tractor drawn disk harrow and cultivator, and made ready for sowing of the crop.

3.8.2 Sowing

The seeds of PMH1 and PMH2 were sown at 3-5cm deep in lines with seed-cum-fertilizer drill on field. After that light and frequent irrigation was given.

3.8.3 Irrigation

The field was given 4 irrigations at 15 days interval.

3.8.4 Fertilizer application

The fertilizer was applied as per recommendation of PAU at the rate of 110 kg N/acre in the form of urea, 55 kg P₂O₅/ acre in the form of DAP and 20 kg K₂O in the form of MOP. Maize is an exhaustive crop which gives a yield of 15 to 25 kg grain per kg of applied nitrogen. Maize responds to 120 to 150 kg ha⁻¹ of N, 50 to 80 kg ha⁻¹ of P and 40 to 60 kg ha⁻¹ of K. Phosphorus and potassium were applied as basal dose. Nitrogen was split applied thrice viz., at sowing, knee height stage (35 to 40 DAS) and at tasseling stage respectively.

3.8.5 Weed Management

The removal of weeds from the plot was done manually as per requirements: Two hand weeding were done at 15 days interval.

3.8.6 Harvesting and Threshing

Grain crop is harvested when the cob sheath turns brownish, grains become hard and dry and they do not contain more than 20% moisture. Stalks and leaves may remain green at harvest. Cobs are removed along with the sheath and separated. Dried cobs are thrashed either by mechanical threshers or manual labors. Seeds are cleaned and winnowed. The crop was harvested manually at maturity.

3.9 Meteorological observations

3.9.1 Maximum and Minimum temperature

3.9.2 Relative humidity

3.9.3 Bright sunshine hours

3.9.4 Wind speed

Following meteorological data was obtained from the agrometeorological observatory.

3.10 Micrometeorological observations

3.10.1 Photosynthetically active radiation

It was calculated by using quantum sensor and calculated as:

$$\text{Intercepted PAR (\%)} = (IPAR - (TPAR + RPAR) * 100) / IPAR$$

Where,

IPAR = Incoming PAR

TPAR = Transmitted PAR

RPAR = Reflected PAR

3.11 Phenological observations

Date of phenological phases of the crop was recorded during tasseling, 50% silking, dent and physiological maturity stages of maize crop.

3.12 Biometric observations

3.12.1 Yield data

Yield data was collected at the time of harvesting.

3.13 Estimation of ET Modified Penman Formula:

$$ET_o = W.R_n + (1-W).f(u).(e_a - e_d)$$

Where,

W.R_n = Radiation term

(1-W).f(u).(e_a-e_d) = Aerodynamic term

In which,

- ET_o - the reference crop ET in mm/day.
- e_a - saturation vapour pressure in mbar at the mean air temperature in °C.
- e_d - mean actual vapour pressure of the air in mbar.
- F(u) - a wind related function.

- (1-W) - a temperature and elevation related weighting factor for the effect of wind and humidity on ET_o .
- W - weighing factor for radiation on ET_o .
- R_n - net radiation
- $e_d = e_a \times R_H \text{ mean} / 100$
- R_H - relative humidity determined by dry and wet bulb temperature.
- $R_n = R_{ns} - R_{nl}$
- R_{ns} - net incoming shortwave solar radiation

$$\text{Where } R_{ns} = R_a(1-a)(0.25+0.50n/N)$$

- R_{nl} - the net longwave radiation

$$\text{Where } R_{nl} = f(t).f(e_d).f(n/N)$$

3.14 Cropwat estimation

The observed values like maximum and minimum temperature, Rh and etc collected during the various stages of maize are computed in Cropwat 8.0 for comparison and observed.

Country: INDIA		Station: Ludhiana					
Altitude: 247 m.		Latitude: 30.98 °N		Longitude: 75.81 °E			
Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun %	Rad MJ/m ² /day	ETo mm/day
January	17.0	31.3	47	1.2	79	13.3	2.84
February	19.3	34.3	37	1.3	81	16.6	3.90
March	22.5	37.5	30	1.4	81	20.5	5.26
April	26.0	39.3	34	1.6	74	22.7	6.46
May	27.2	40.0	37	2.6	65	23.0	8.11
June	25.0	35.6	54	4.1	45	19.5	7.44
July	23.8	32.5	64	4.2	34	17.0	5.90
August	23.5	32.1	63	3.5	39	16.8	5.44
September	23.3	31.9	65	2.4	45	15.7	4.49
October	22.4	32.4	61	1.1	75	16.8	3.71
November	19.2	31.0	56	0.9	68	12.8	2.68
December	16.6	30.3	51	0.8	76	12.1	2.20
Average	22.1	34.0	50	2.1	64	17.2	4.87

Fig. 3.5: Output of Cropwat 8.0

3.15 Gravimetry

This is a conventional procedure for collecting and weighing soil samples from the field (in wet conditions). The difference in moisture content is analyzed through gravimetry.

3.16 Statistical analysis

Statistical analysis was done using data mining software called orange.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the present study entitled Quantification of evapotranspiration using EEFlux tool and comparison by empirical methods in maize (*Zea mays* L.) obtained from current data analysis regarding the assessment of ET using google EEFlux, geeSEBAL, NRSC and empirical methods has been presented in the graphs, tables and maps generated by Q-GIS 3.24.3, Orange and are discussed under the following headings and subheadings:

4.1 Meteorological and yield parameters during growth season

- 4.1.1 Temperature – maximum and minimum during crop growing season.
- 4.1.2 Relative humidity during crop growing season.
- 4.1.3 Sunshine hours during crop growing season.
- 4.1.4 Total rainfall during crop growing season.
- 4.1.5 Windspeed during crop growing season.
- 4.1.6 Yield parameters during crop growing season.

4.2 Quantification of evapotranspiration using

- 4.1.1 Modified penman method
- 4.1.2 Gravimetry
- 4.1.3 Google EEFlux
- 4.1.4 geeSEBAL
- 4.1.5 ETo Calculator and Cropwat
- 4.1.6 NRSC-NHP data

4.3 Comparison of ET

- 4.3.1 Observed ETc and EEFlux ETc
- 4.3.2 Observed ETc and geeSEBAL
- 4.3.3 Observed ETc and NRSC
- 4.3.4 EEFlux ETc and geeSEBAL
- 4.3.5 EEFlux ETc and NRSC
- 4.3.6 geeSEBAL and NRSC

4.4 Correlation of different remote sensing techniques

Correlation of observed ETc with EEFlux ETc, geeSEBAL and NRSC

4.1 Meteorological and yield parameters

These meteorological parameters have affected the growth of the crop and also the satellite derived images. The maximum temperature, wind speed and bright sunshine hour affects the ET in positive way while the relative humidity has negative impact. The various meteorological parameters that affect ET during the crop growing season are:

4.1.1 Temperature- maximum and minimum temperature during crop growing season

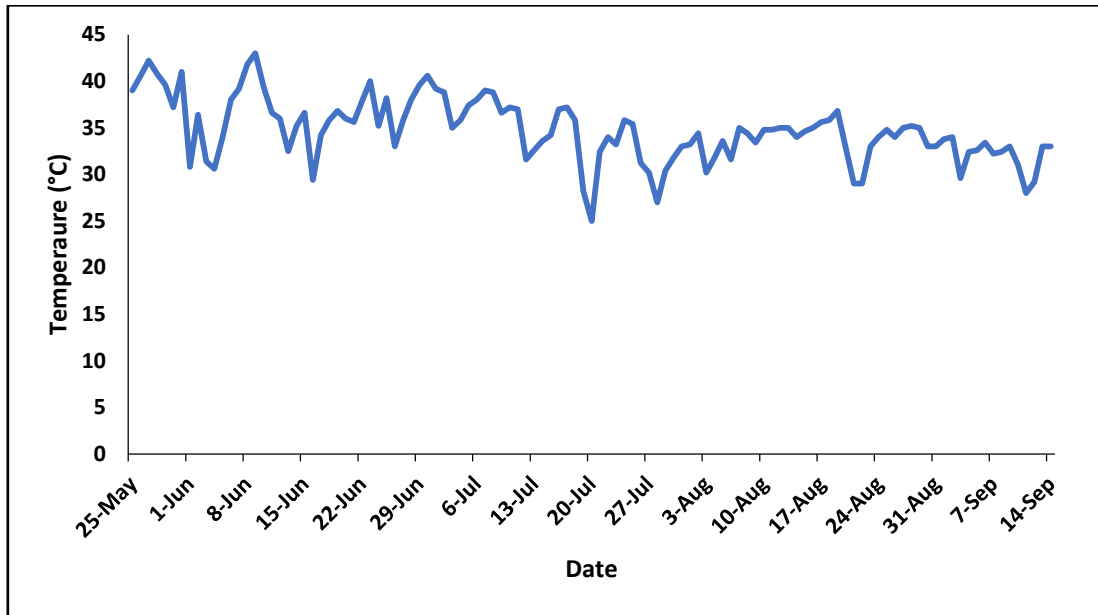


Fig. 4.1: Maximum temperature (T_{\max}) during crop growing season

The maximum temperature during the crop growing season has average of about 28.7°C for the growth period. The maximum temperature was recorded 43°C during June-9 2022, followed by 42.2°C on May 27.

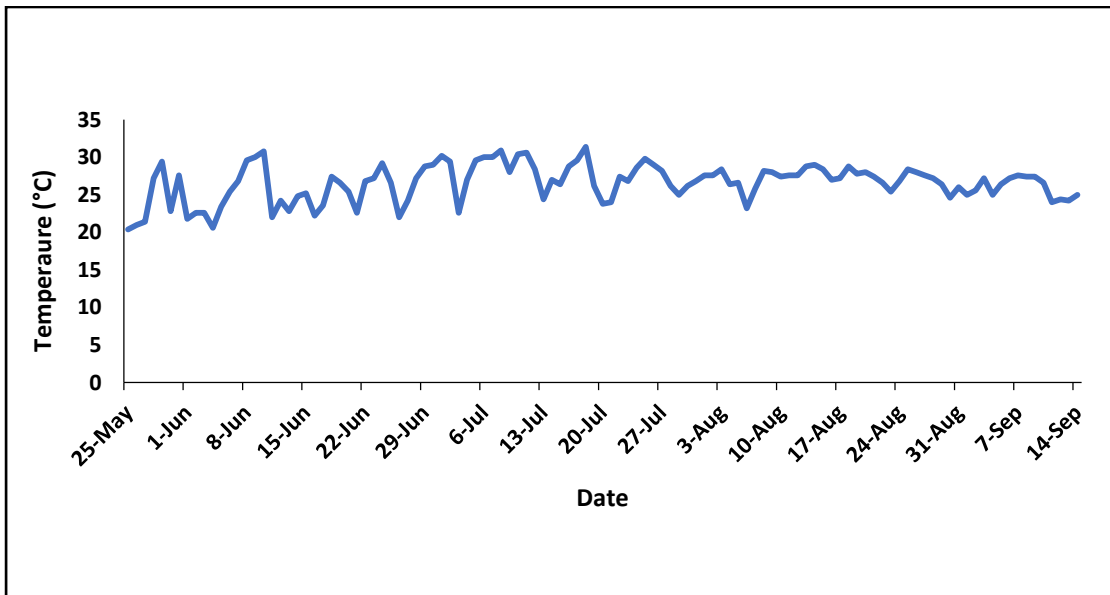


Fig. 4.2: Minimum temperature (T_{\min}) during crop growing season

The Minimum temperature during the crop growing season has average of about 21.4°C for the growth period. it attains the maximum temperature during maximum temperature was recorded 43°C during June-9 2022, followed by 42.2°C on May 27.

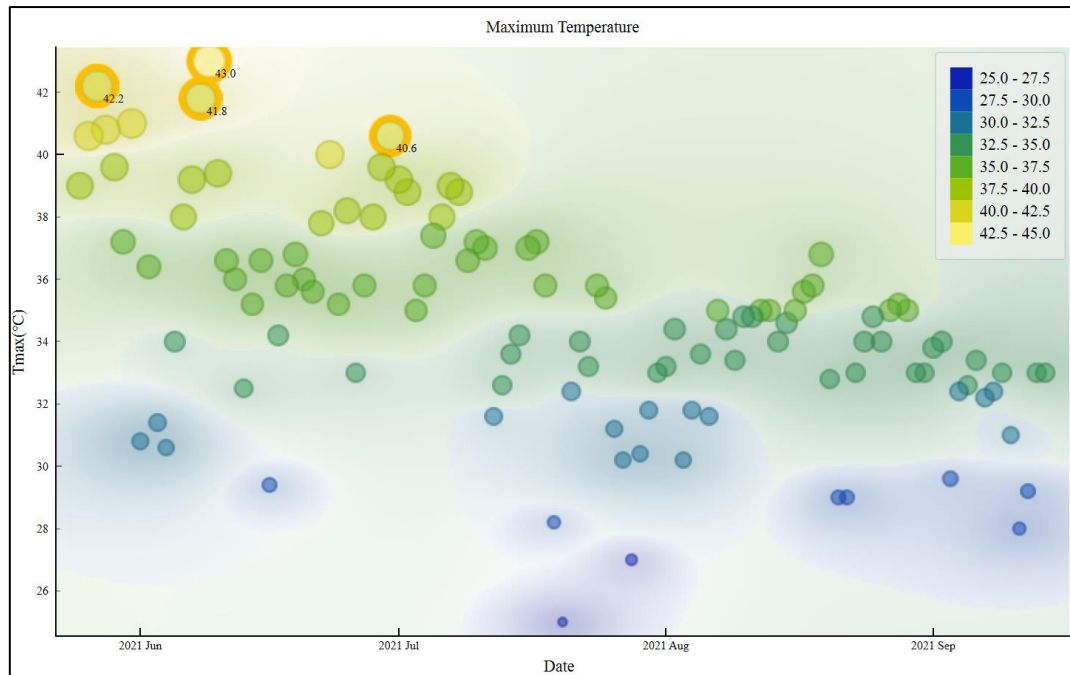


Fig. 4.3: Scattered plot of maximum temperature (T_{max})

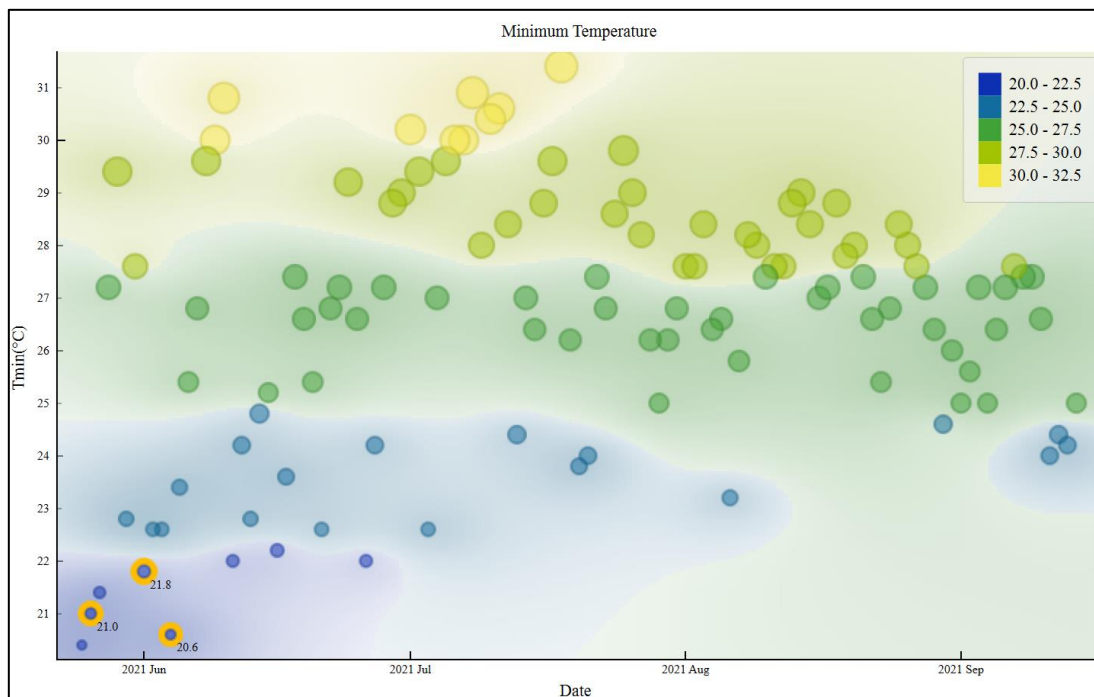


Fig. 4.4: Scattered plot of minimum temperature (T_{min})

The impact of high temperature has resulted in high evapotranspiration during the initial sowing days. Even though K_c value was less during initial season, it showed higher ET_c due to the higher temperature. Hence, ET has direct relationship with temperature, higher the temperature, higher the ET (Al sudani 2019).

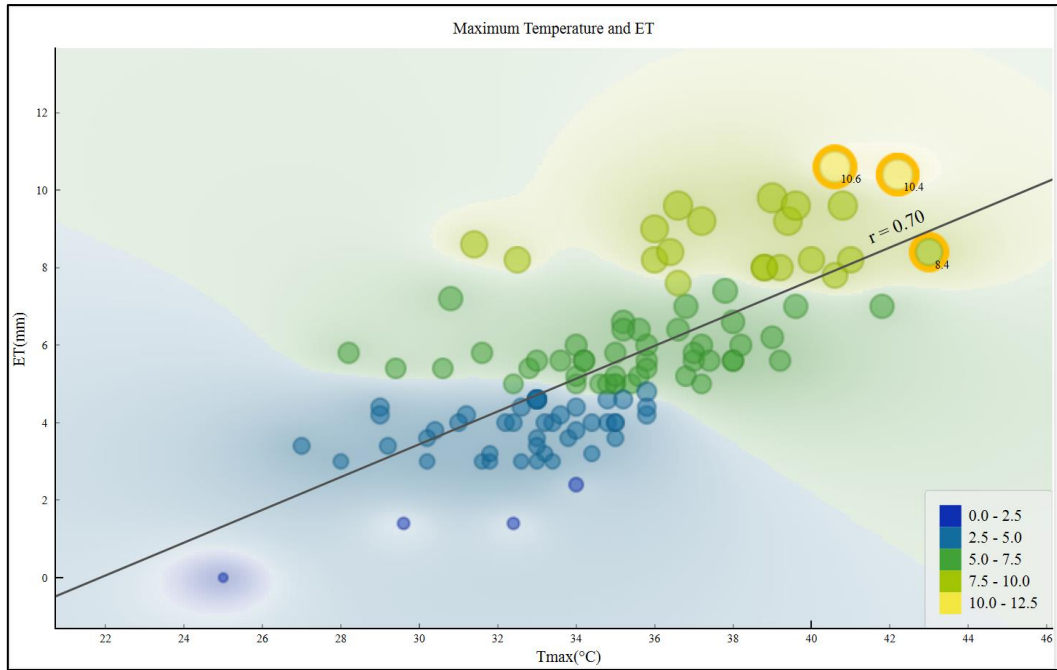


Fig. 4.5: Correlation between maximum temperature (T_{max}) and evapotranspiration (ET)

4.1.2 Relative Humidity

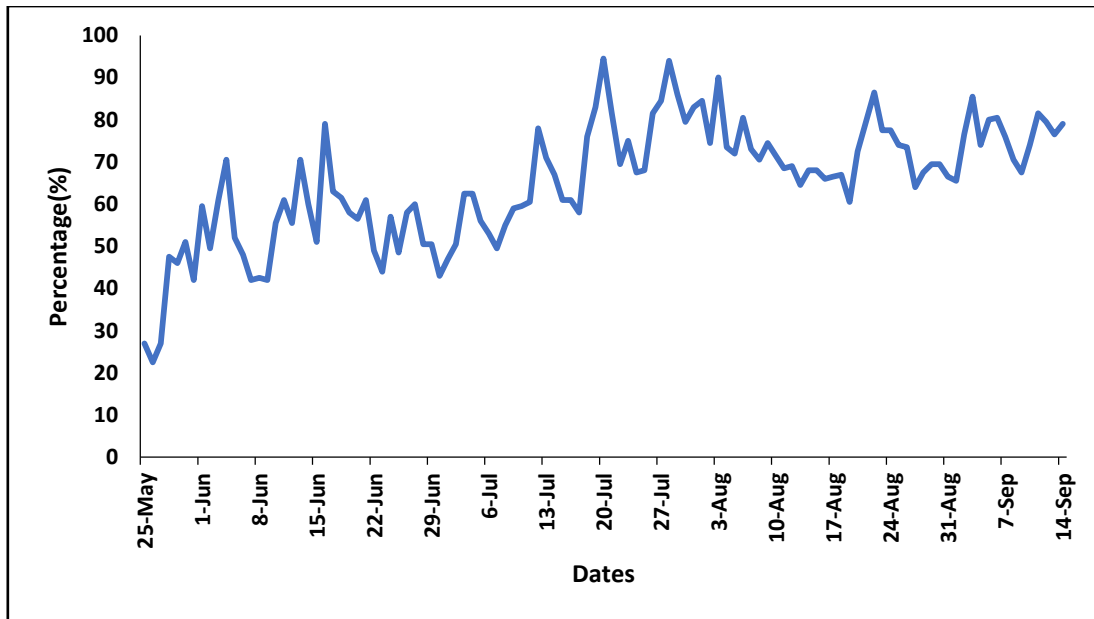


Fig. 4.6: Mean relative humidity (RH) of during crop growing season

Relative humidity is the amount of water vapour present in the air, the percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature. Maximum relative humidity was 94.5% observed during July 20 and minimum of 27% during 25th June.

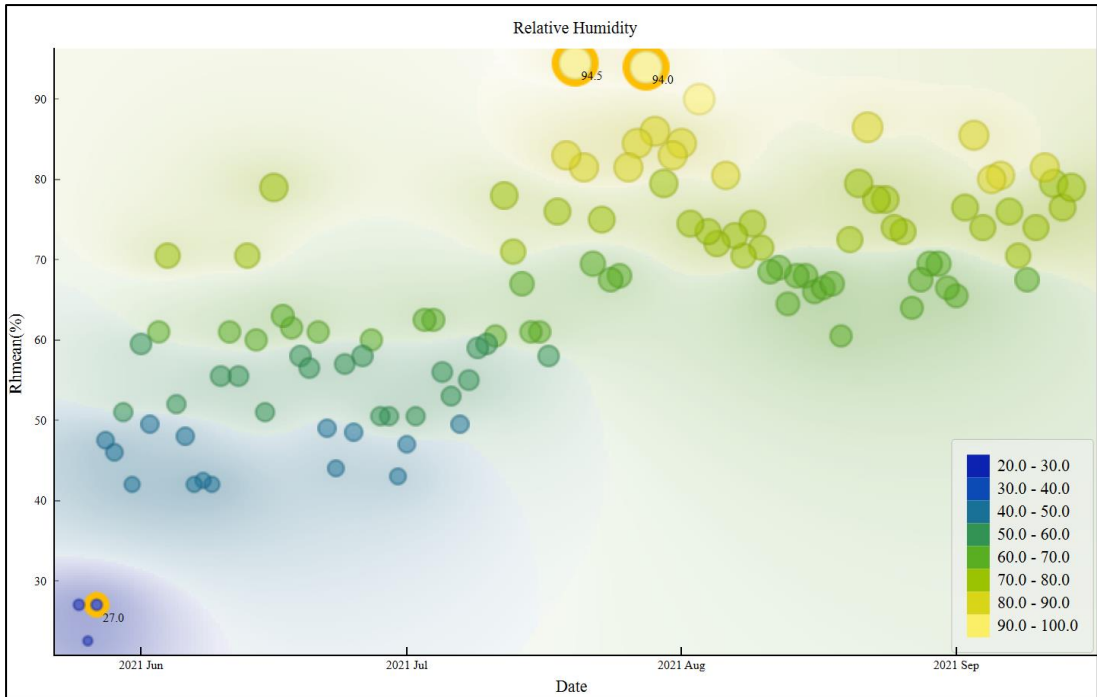


Fig. 4.7: Scattered plot of mean relative humidity (RH) during crop growing season

Relative humidity has a direct relationship with the rainfall and affects inversely the ET. Hence higher the relative humidity, lower the ET (Valipour 2014). The below chart shows the relationship between relative humidity and ET, where lowest ET was recorded during highest humidity condition and highest ET was recorded during lowest humidity condition.

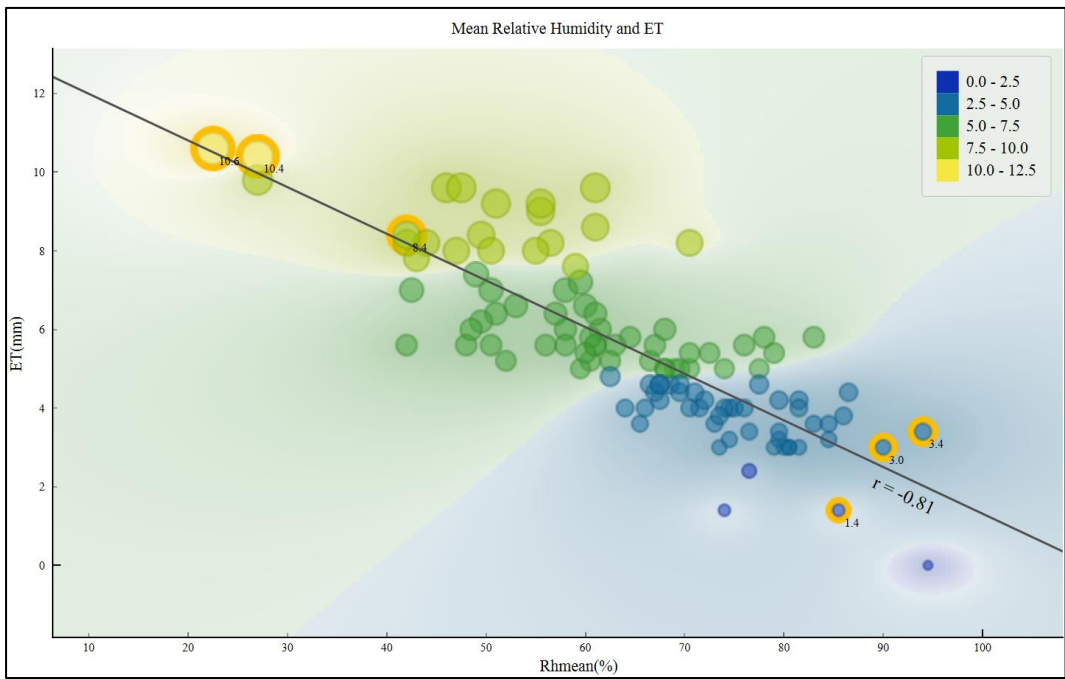


Fig. 4.8: Correlation between mean relative humidity (RH) and evapotranspiration (ET)

4.1.3 Total Rainfall

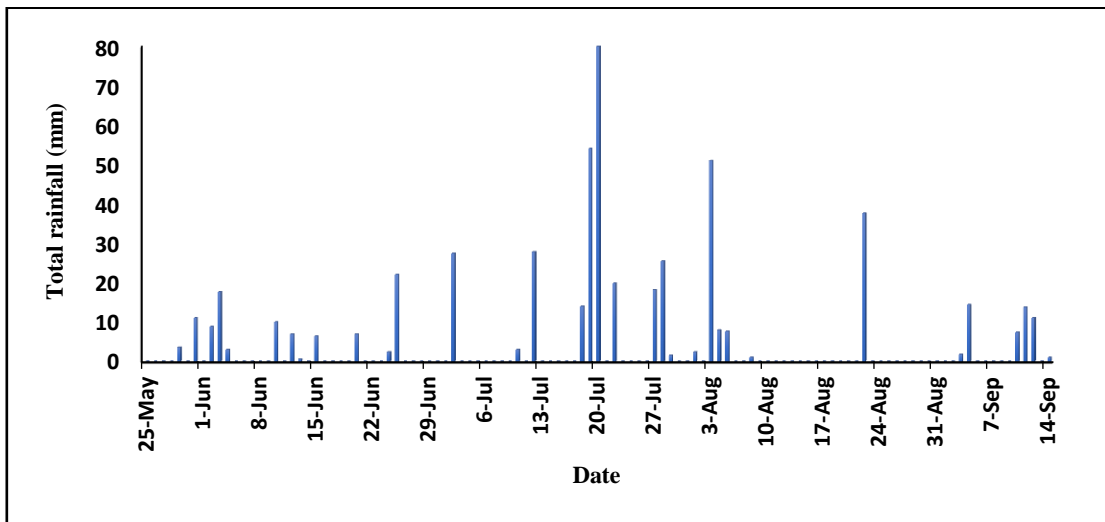


Fig. 4.9: Total rainfall during crop growing season

Rainfall makes it difficult for the satellites to capture and process the images, as the pathway is blocked by the clouds. Maximum rainfall of 80mm/hr. was recorded on July 20, where high relative humidity has been experienced. Due to rainfall, geeSEBAL cannot process the data for three dates that resulted in no data. There is also a bias in EEFflux tools also when the rainfall occurs, as it gives underestimates the value of ET on the next day of rainfall.

Following chart depicts the period of rainfall during the growth season and also maximum

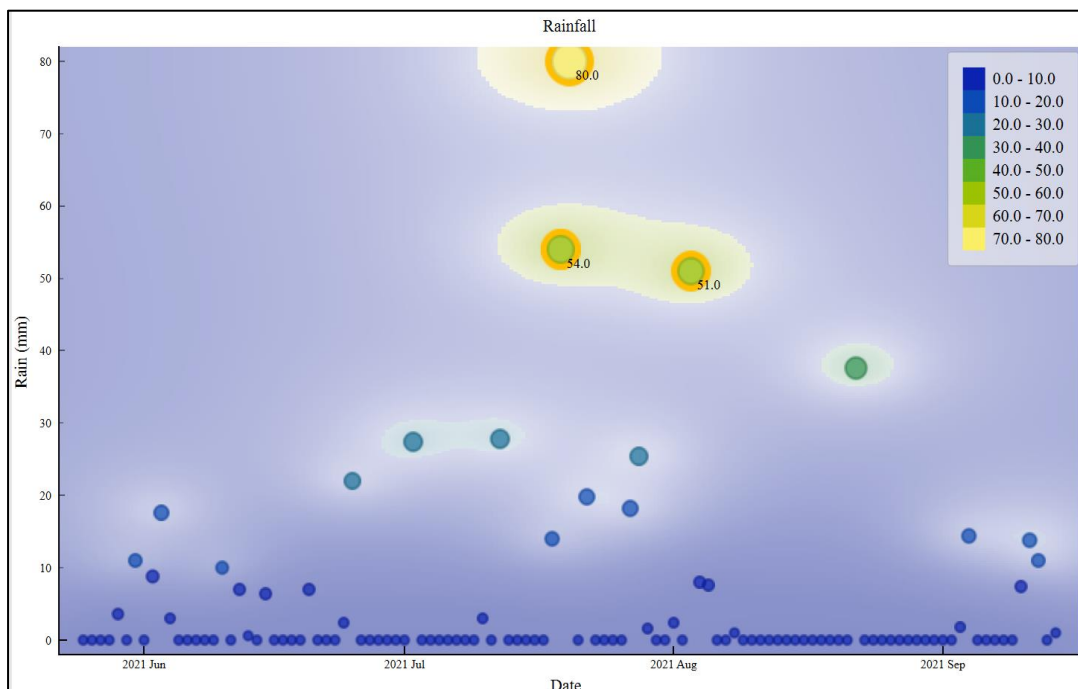


Fig. 4.10: Scattered plot of rainfall during crop growing season

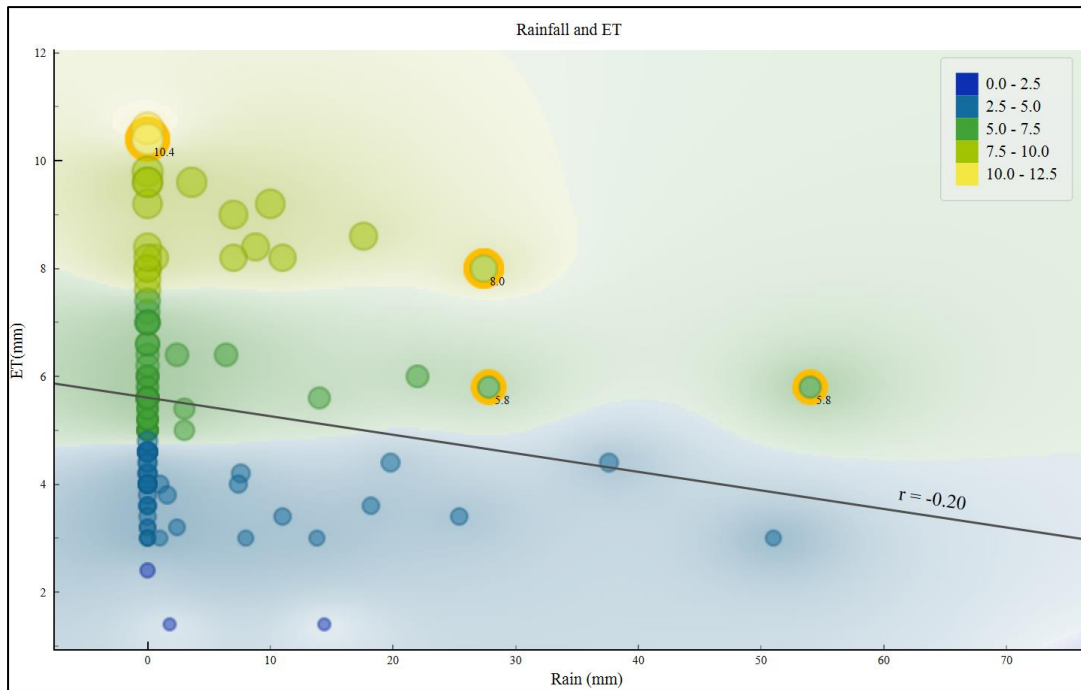


Fig. 4.11: Correlation between rainfall and evapotranspiration (ET)

Rainfall has positive relationship with relative humidity and inverse relationship with ET (Feng *et al* 2016). This chart depicts the relationship between rainfall and Et. Lower the rainfall higher is the ET.

4.1.4 Sunshine Hours

Bright sunshine hour is total hours of sunlight during the day that has been utilized by the plant to prepare their food and uptake photosynthesis. Higher the BSS, higher the ET. Maximum bright sunshine hour was observed during May 25th of 13.2 hours/day and lowest was 0.8 hours/day in August 8th. Following chart depicts the period of bright sunshine hours during the growth season and also, it's trend. The missing data was given the value of zero to avoid the bias. Et was sensitive to sunshine hours (Tabari *et al* 2014) and was most sensitive in arid places like Rajasthan.

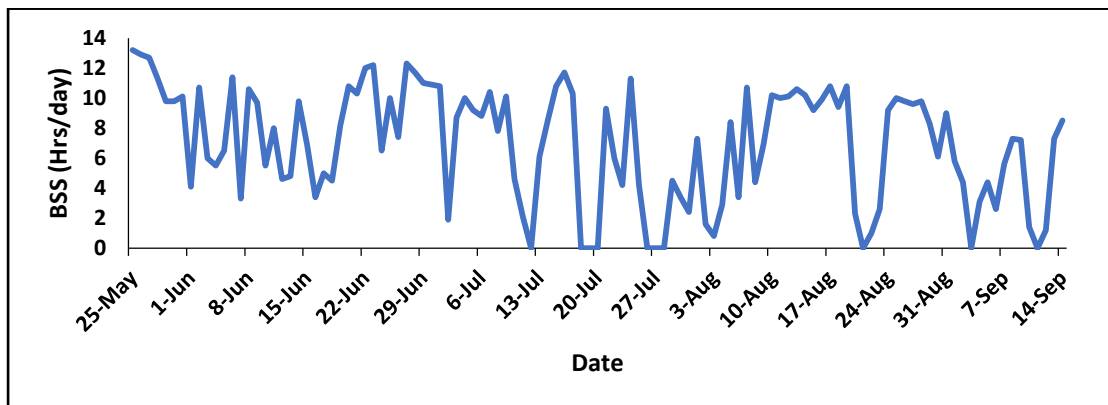


Fig. 4.12: Bright sunshine hours during crop growing season

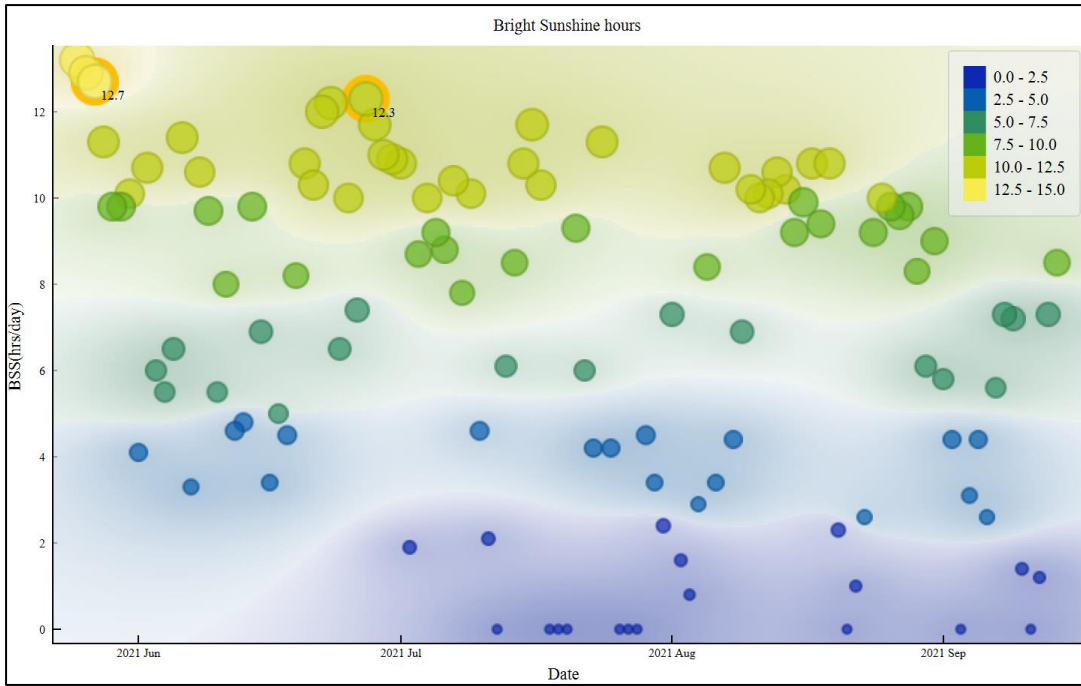


Fig. 4.13: Scattered plot of bright sunshine hours during crop growing season

It is C₄ plant and requires bright sunshine hours associated with water supply. Prolonged cloudiness is harmful to the growth of the crop.

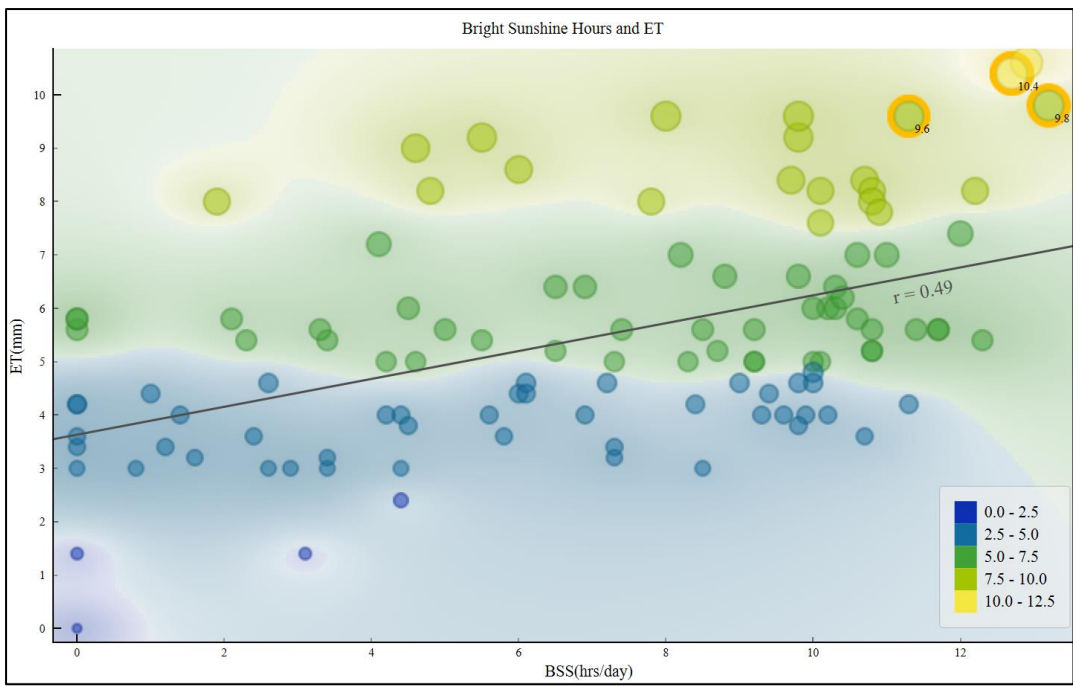


Fig. 4.14: Correlation between bright sunshine hours and evapotranspiration (ET)

Bright sunshine hours have a direct and positive relationship with temperature and also with ET. Hence, higher the sunshine hours more will be the Et. Lower Et was recorded during minimum sunshine hours and maximum ET was recorded during maximum sunshine hours.

4.1.5 Wind speed

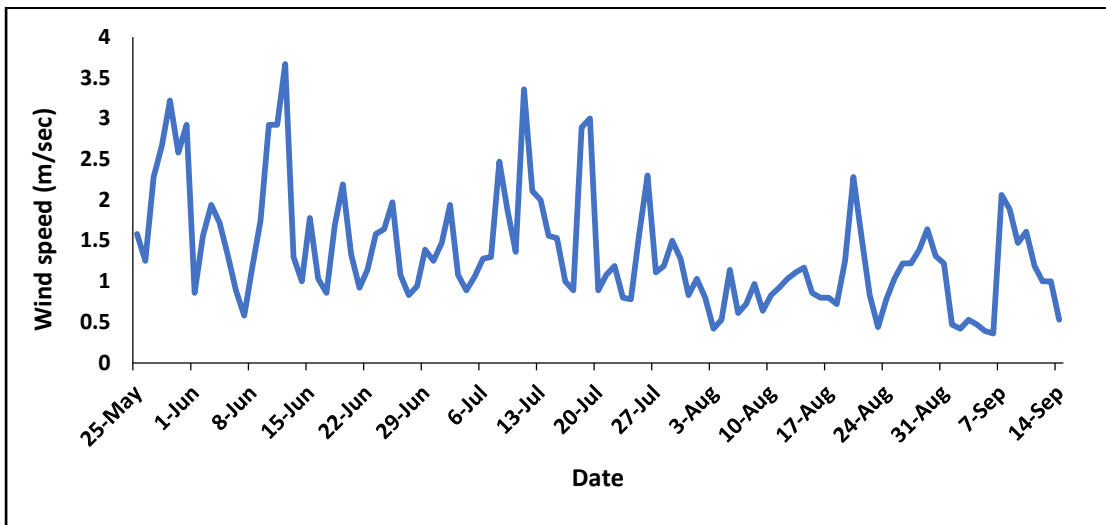


Fig. 4.15: Wind speed during crop growing season

Wind speed, for instance, can affect the rate of evapotranspiration or the magnitude of water demands. If wind is blowing with higher intensity, evaporation rate will be greater because it weakens the boundary layer and mass transport becomes more efficient, particularly in turbulent flow (Tabari *et al* 2014). These varieties have larger and wider leaves and hence may tolerate mild wind velocity.

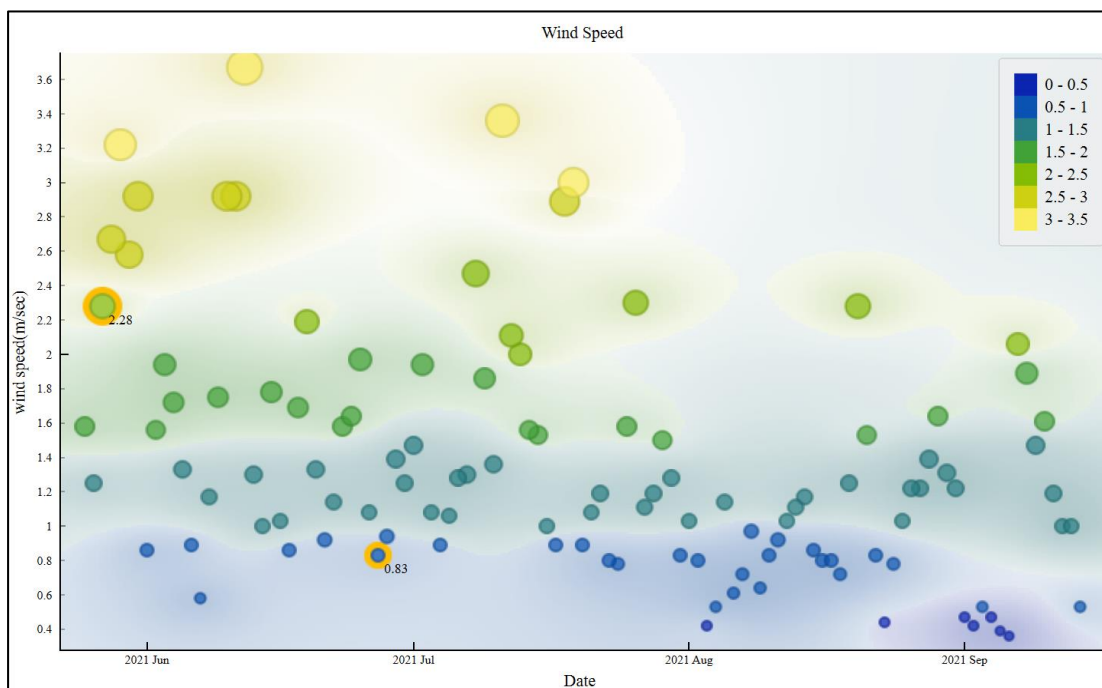


Fig. 4.16: Scattered plot of wind speed during crop growing season

Most of the wind speed distribution is between 1-2m/s and maximum. Wind speed was lowest during September 9th of about 0.36m/s and highest during June 12th of about 3.67m/s. The Below chart depicts the period of wind speed during the growth season and the below chart shows the relationship between windspeed and Eto.

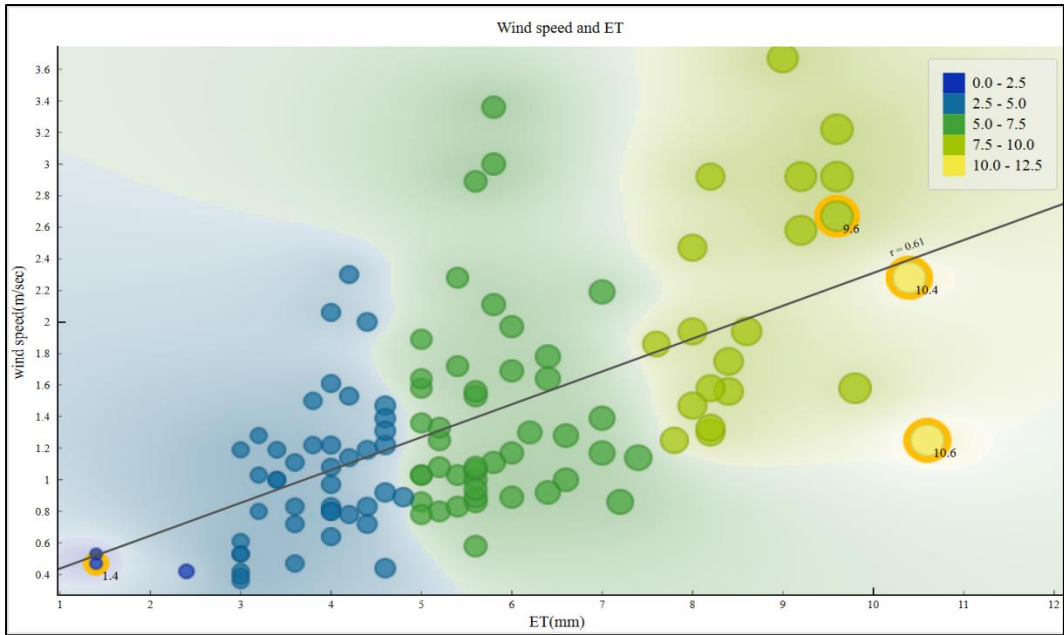


Fig. 4.17: Correlation between wind speed and evapotranspiration

4.1.6 Yield Parameters

Table 4.1: Grain yield ($q\ ha^{-1}$) and Evapotranspiration of maize cultivars

Varieties	Yield ($q\ ha^{-1}$)			
	25 May (D_1)	5 June (D_2)	15 June (D_3)	25 June (D_4)
PMH1	50.00	49.23	46.64	42.05
PMH2	43.46	45.07	42.39	39.06
CD (P=0.05%)	Varieties			2.73
	Dates			3.86
	Interaction			NS

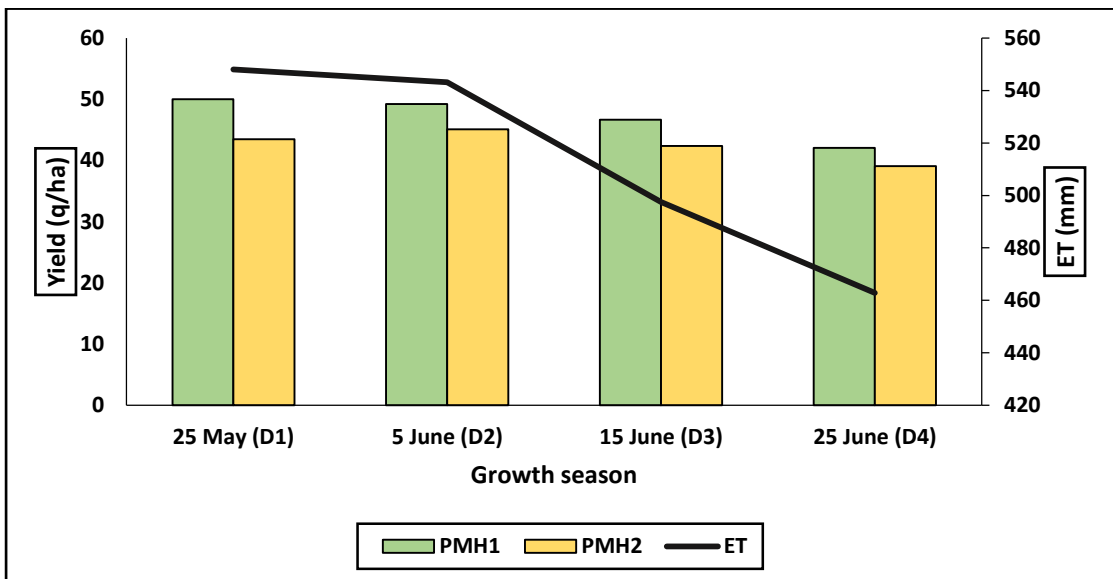


Fig. 4.18: Yield and ET of maize cultivar during crop growing season

The yield of the maize cultivar steadily decreases as the amount of ET decreases. This shows the relationship between yield and ET, when ET is high, yield is high and the vice-versa. The yield of maize for variety PMH-1 was highest for D1 followed by D2, D3 and D4. In May 25 sowing (D1), high temperature was observed throughout the growth season which resulted in maximum yield and ET and the delay in the sowing dates resulted in reduced yield and ET. More delay in the sowing resulted in less ET as the temperature began to drop down, which in turn affect the yield of the crop.

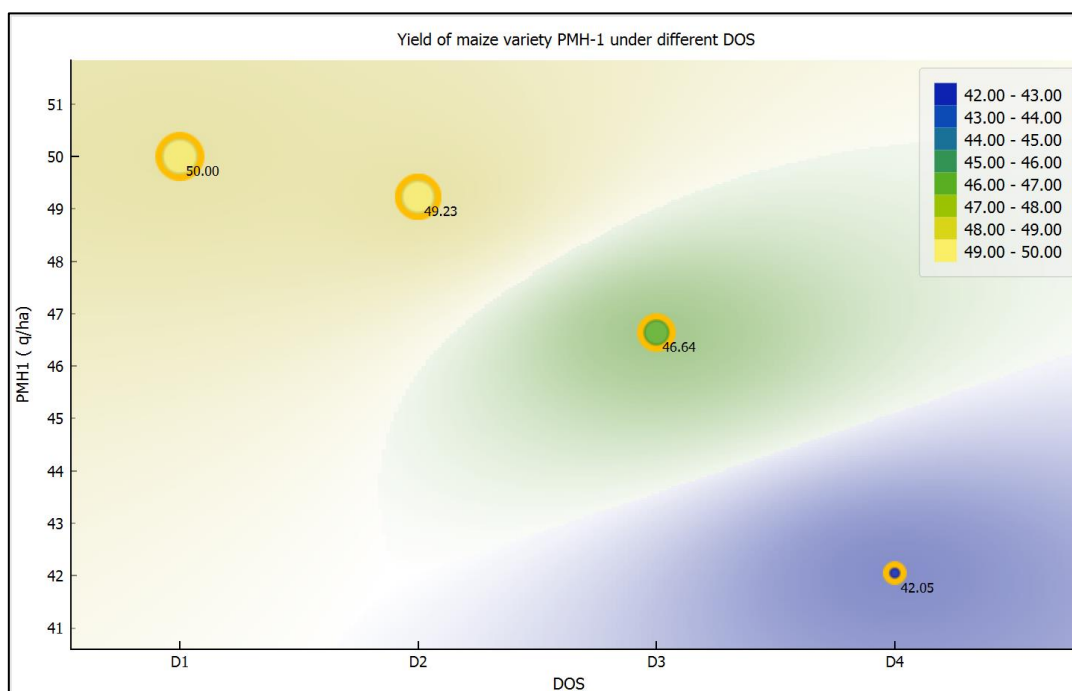
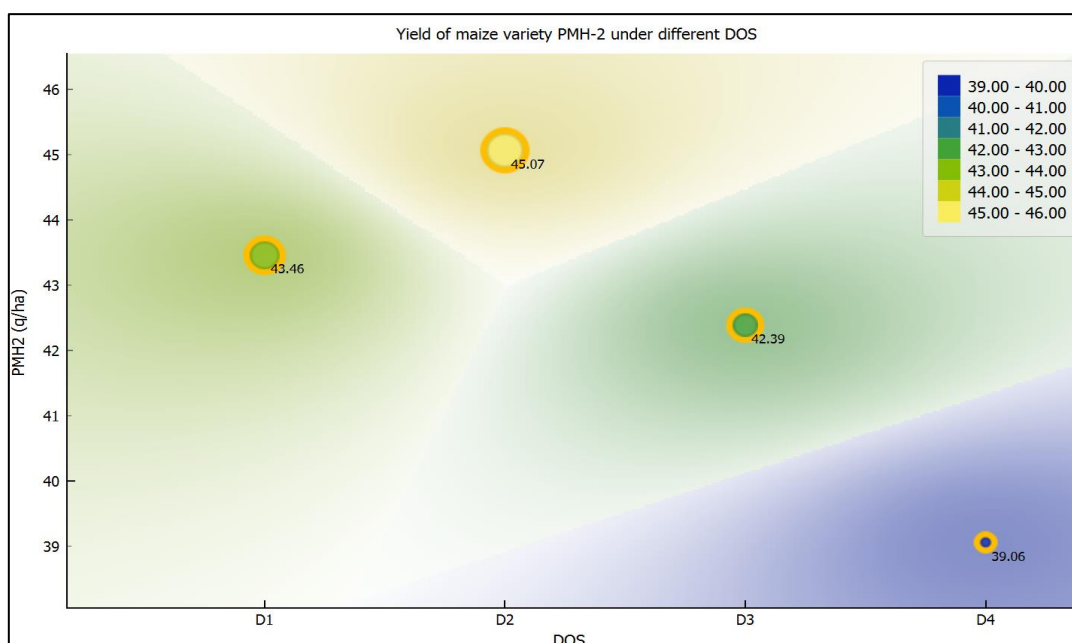


Fig. 4.19: Scattered plot of yield during different days of sowing for PMH-1



4.20: Scattered plot of yield during different days of sowing for PMH-1

Among the dates of sowing, D1 resulted in maximum grain yield, but it was significantly at par with the grain yield produced by D2 which in turn significantly at par with the grain yield produced by D3 and which in turn significantly at par with the grain yield produced by D4. The grain yield of cultivar PMH1 was significantly higher than the cultivar PMH2. Similar results have been yielded by Tabari *et al* (2014).

4.2 Quantification of Evapotranspiration using

4.2.1 Modified penman method

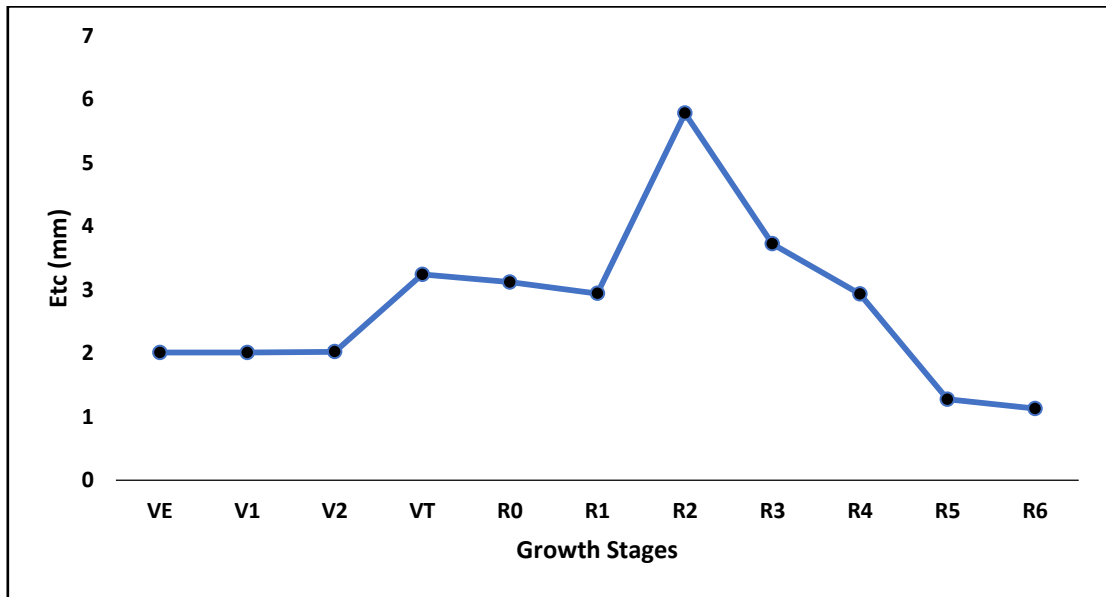


Fig. 4.21: Actual evapotranspiration (ETc) using modified penman method

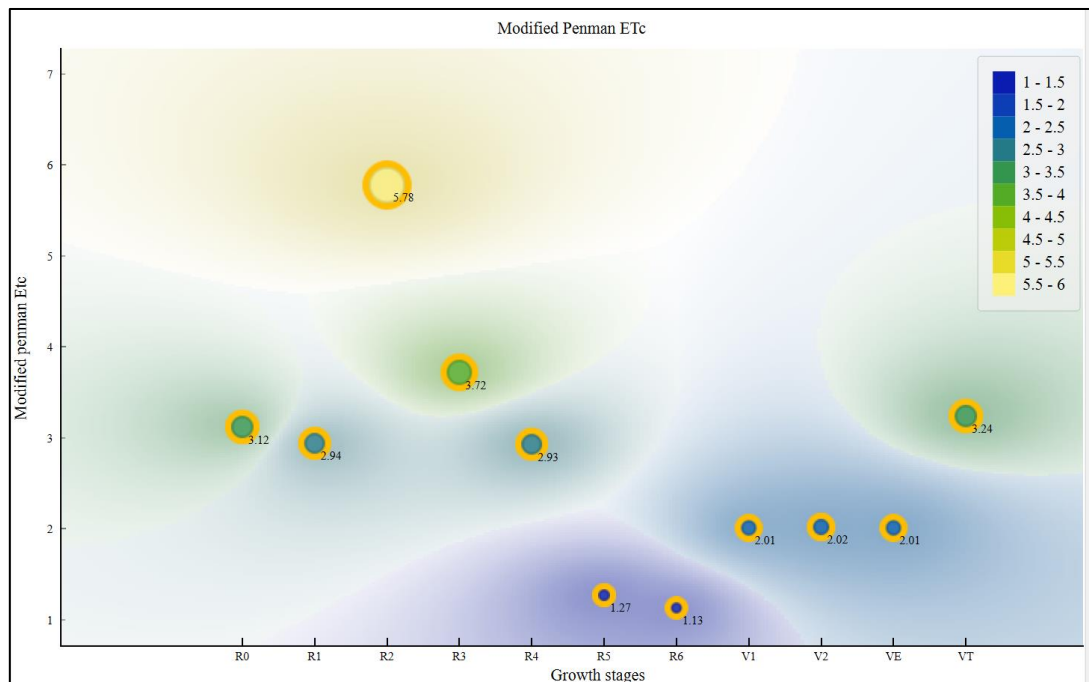


Fig. 4.22: Scattered plot of modified penman ETc

The values yielded by modified penman method are on par with the FAO-ET_o calculator. Hence it is taken as observed value for the experiment. From the above graph. It can be seen that ET_c values are increasing from VE stage upto R1 stage and attains peak value during R2 stage, followed by R3 stage. It starts decreasing from R4 stage and attains minimum value in R6 stage.

4.2.2 Gravimetry

This is a conventional procedure for collecting and weighing soil samples from the field (in wet conditions). The weighed sample is oven dried overnight at 105-110°C and weighed again. The difference in weight is referred to as water content. An inaccuracy may occur due to oxidation of organic components, as well as while cooling the sample after removing it from the oven before weighing. The moisture content is low in this soil as the soil is sandy to sandy loam. This resulted in very low moisture content even during rainfall.

$$\% \text{ moisture} = \frac{\text{Weight of fresh soil} - \text{Weight of oven dry soil} \times 100}{\text{Weight of oven dry soil}}$$

Table 4.2: Moisture percentage (%) during crop growing season

Growth stages	Dates	Observed ET _c	Eeflux ET _c	Moisture percentage (%)
VE	30-May	2.01	2.19	10.7
V1	03-Jun	2.01	2.34	16
V2	06-Jun	2.02	2.34	12
VT	19-Jul	3.24	3.48	19
R0	21-Jul	3.12	1.73	13.2
R1	23-Jul	2.94	3.4	13
R2	04-Aug	5.78	5.02	11
R3	13-Aug	3.72	5.02	9
R4	23-Aug	2.93	3.42	12.6
R5	04-Sep	1.27	1.59	10.8
R6	14-Sep	1.13	1.68	12

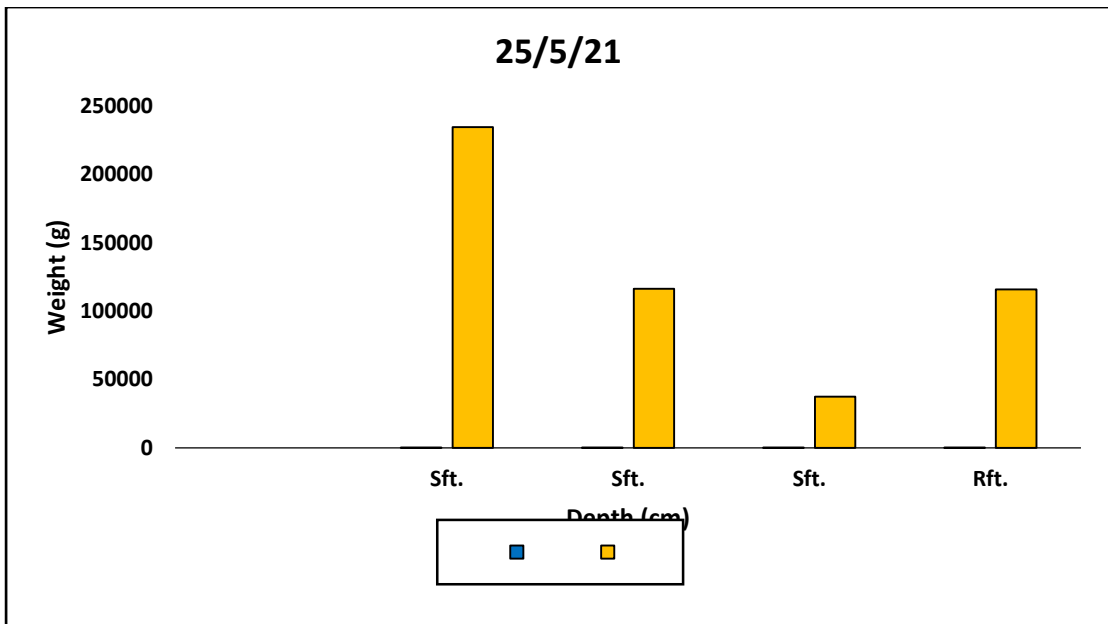


Fig. 4.23: Wet and dry weight of the soil at the different depth

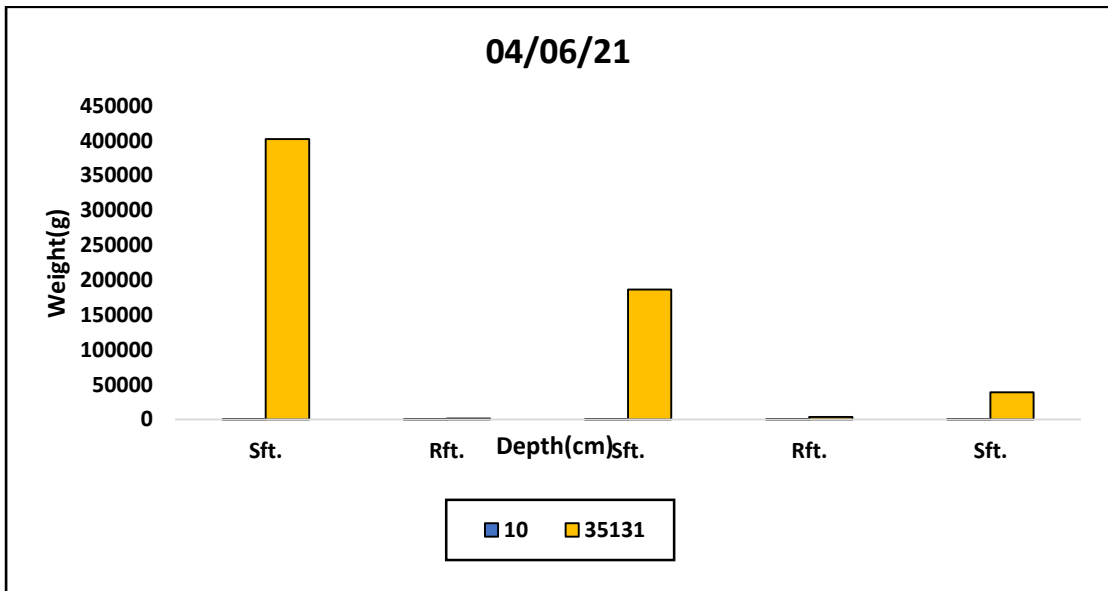


Fig. 4.24: Wet and dry weight of the soil at the different depth

This method is done to show the change in the moisture content and glimpse of water content in the soil. The 25th may record high temperature and high et and hence lower moisture content in the top soil. Whereas, in the case June 4th, it received a rainfall of about 17mm the previous day that resulted in higher moisture content in the soil. This resulted in lower Et and temperature.

4.2.1 Google EEFlux

The google earth engine flux runs in earth engine API, in which the image we obtain is already processed. It is based on METRIC algorithm. The EEFlux images taken were mostly of Landsat 8 and 7 images, which is obtained in tiff file. The actual ET obtained through EEFlux is on par with Observed ET.

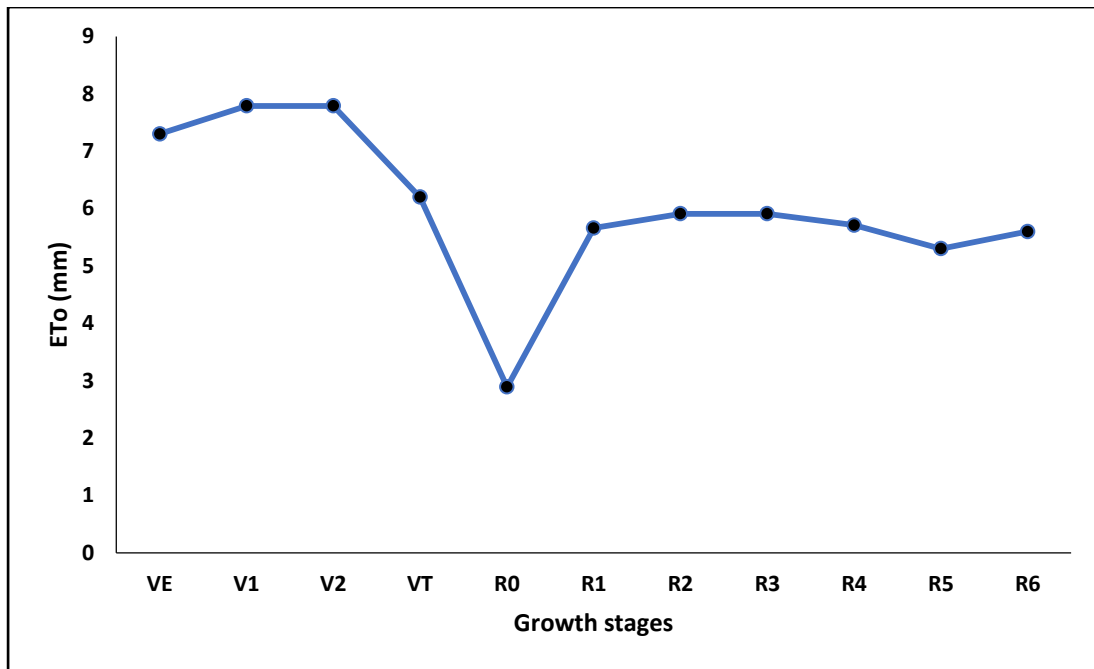


Fig. 4.25: Reference evapotranspiration (ETo) of EEFlux during crop growing season

This chart depicts the accuracy of EEFLUX with observed data during growth stage of maize. The EEFlux mechanism is purely based on metric algorithm which runs on energy balance equation. The variation may be due to the high temperature on 25th may and followed by rainy week which is shown in table 4.1. The high ET on May 25th is due to the presence of more sunshine hours and high temperature as seen clearly in the table 4.2. The rate of evapotranspiration increases with increasing temperature. The higher the rate of evapotranspiration, the stronger the temperature gradient and the warmer the air. When the evaporating surface is warmer, it extracts less sensible heat from the air, resulting in less evapotranspiration. The sudden drop in ET is due to the impact of rainfall, in which may 31st has nearly 11mm/day that has affected the sensors of satellite. This resulted in the wetness of the surface. As the humidity is high during these days, warm humid air moving over a cool surface may affect the evapotranspiration and reduces it, because the vapour pressure of the humid air is more than the water surface that is undergoing evapotranspiration. Heat is exchanged between cool surface and the overlying warm humid air causes the air to be cooled to its dew point. The ET values starts increasing linearly and then attains the maximum value during the R2 stage and then decreases during harvest stage. But due to the meteorological parameters, this is not seen in this scenario. This shows the importance of role of meteorological parameters and weather forecasting (Saglam 2010).

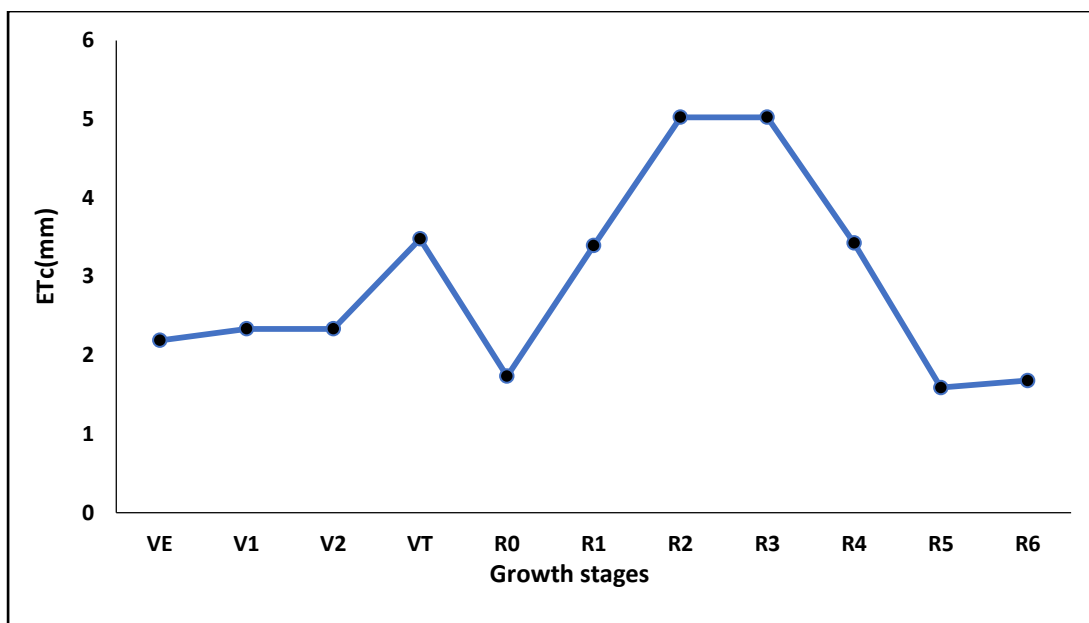


Fig. 4.26: Actual evapotranspiration (ETc) of EEFlux during crop growing season

Table 4.3: Meteorological parameters during sowing week

Date	Rainfall (mm)	Rh mean (%)	BSS (hrs./day)
25-May	0	27	13.2
26-May	0	22.5	12.9
27-May	0	27	12.7
28-May	0	47.5	11.3
29-May	3.6	46	9.8
30-May	0	51	9.8
31-May	11	42	10.1
01-Jun	0	59.5	4.1
02-Jun	8.8	49.5	10.7
03-Jun	17.6	61	6
04-Jun	3	70.5	5.5
05-Jun	0	52	6.5
Average	3.6	46.3	9.3

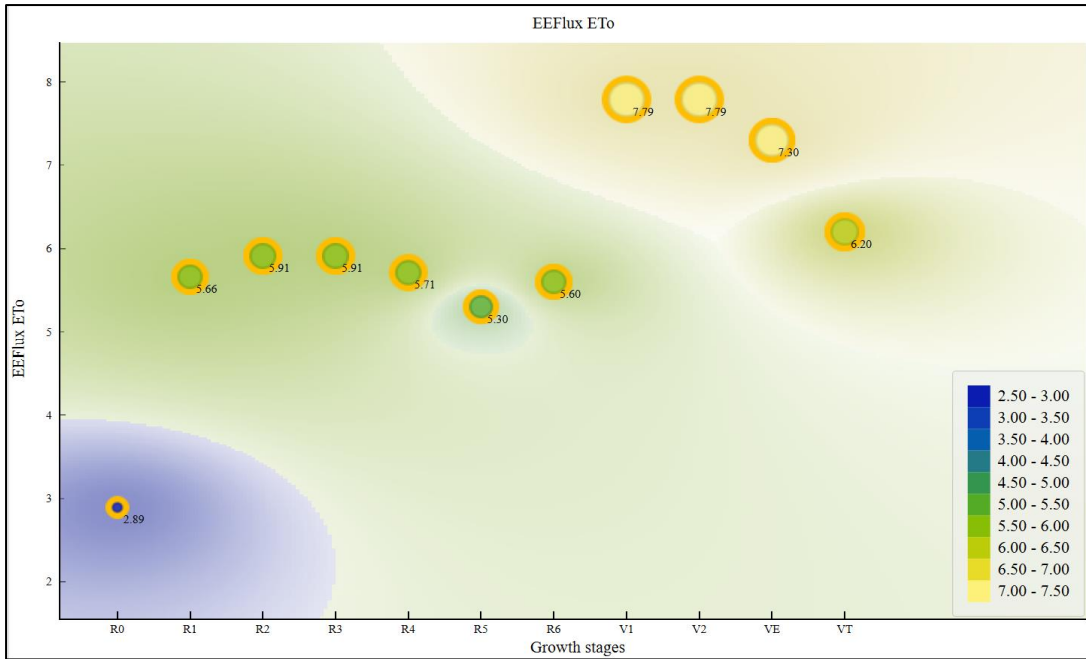


Fig. 4.27: Scattered plot of EEFlux reference evapotranspiration (ETo)

The Fig. 4.27 depicts the reference evapotranspiration that was observed during the growth period. Here the ET is decreasing exponentially from sowing to harvesting and this is due to the meteorological parameters. The green zone depicts Ref-Et from the range of 5.00-5.50, which clearly dominates in the growth period. This higher Ref-Et are due to higher temperature as shown in table 4.1. Warmer the air, stronger the temperature gradient and higher the rate of evapotranspiration.

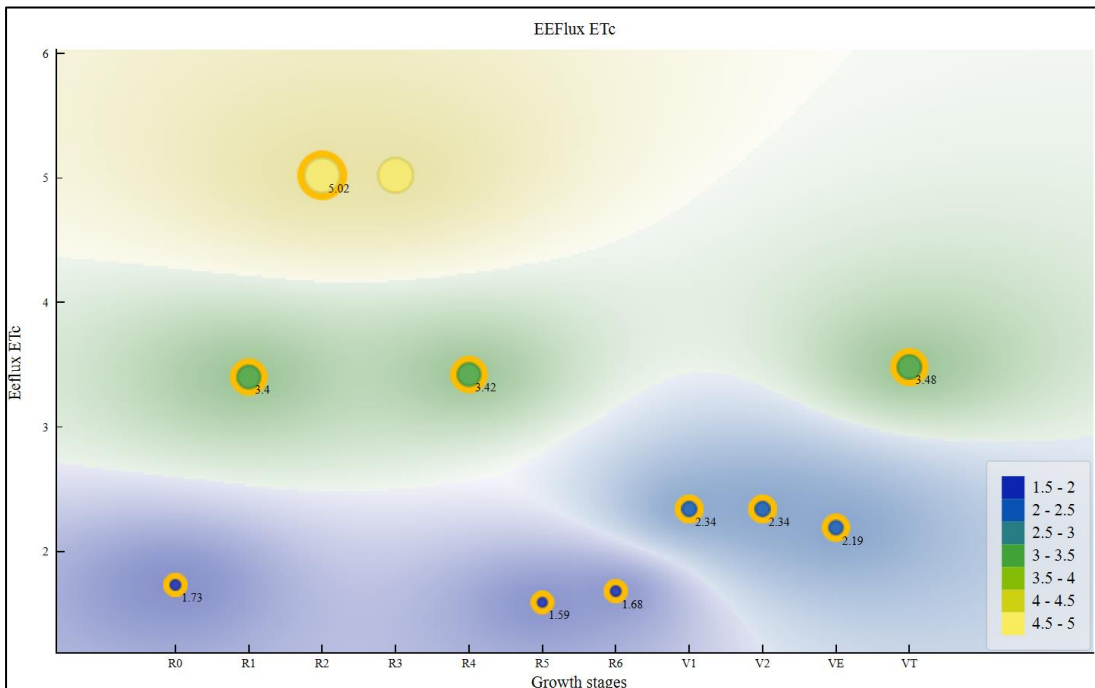


Fig. 4.28: Scattered plot of EEFlux actual evapotranspiration (ETc)

The actual ET is neither concentrated on one zone instead, it is spread throughout entire regions. The actual evapotranspiration is exponentially increasing upto R3 stage and then starts decreasing. This is similar to the results shown in the Fig. 4.26. Actual ET is calculated by multiplying the ref-ET with Kc value given by FAO for different stages. Kc values include 0.3 during sowing and emergence stage which includes VE, V1 and V2 stages. Kc value of 0.6 for the stages Vt, R0, R1 and Kc value of 0.85(maximum) for R2, R3 stages. After this, Kc value will start to decrease from 0.85 to 0.6 and finally to 0.30, for the stages R4, R5, R6 respectively. Actual ET is preferred for the comparison, as it has direct relationship with consumptive water use. Also, the other remote sensing tools like geeSEBAL and NRSC-NHP yields us only Actual ET rather than producing multiple ET products like EEFlux.

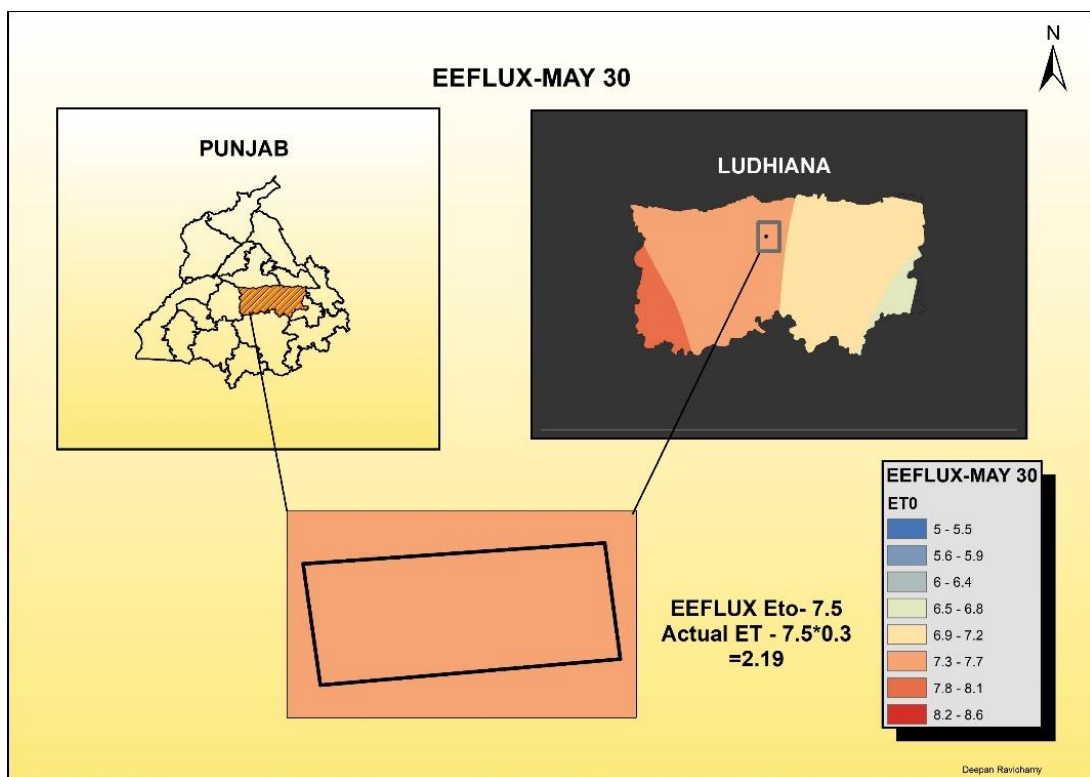


Fig. 4.29: Output of actual evapotranspiration (ETc) using EEFlux

4.2.3 geeSEBAL

geeSEBAL can be called as twin brother of google EEFlux, as it is also used for same purpose, except the fact that, geeSEBAL exclusively gives only actual ET, whereas, EEFlux yields actual, reference, calibrated ET. As the name suggests, geeSEBAL runs on SEBAL algorithm. geeSEBAL could not produce all the image due to impact of cloud and SEBAL algorithm, the values are not plotted for it. The actual ET obtained using geeSEBAL is not accurate the exact reason of it is not found. geeSEBAL is completely focused on atmospheric phenomenon rather than METRIC which focuses on ground observation system. the exact reason of it is not found. geeSEBAL is completely focused on atmospheric phenomenon. This

can be both advantage and also disadvantage to geeSEBAL. In this study, this seems to be disadvantage and geeSEBAL over estimates the actual evapotranspiration (ETc).

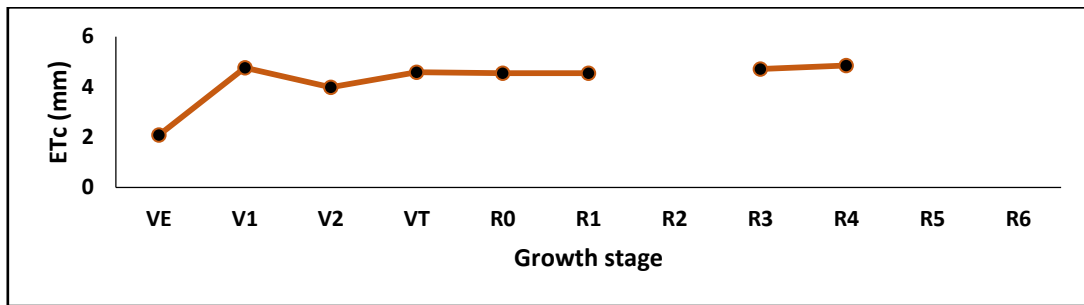


Fig. 4.30: Actual evapotranspiration (ETc) of geeSEBAL during crop growing season

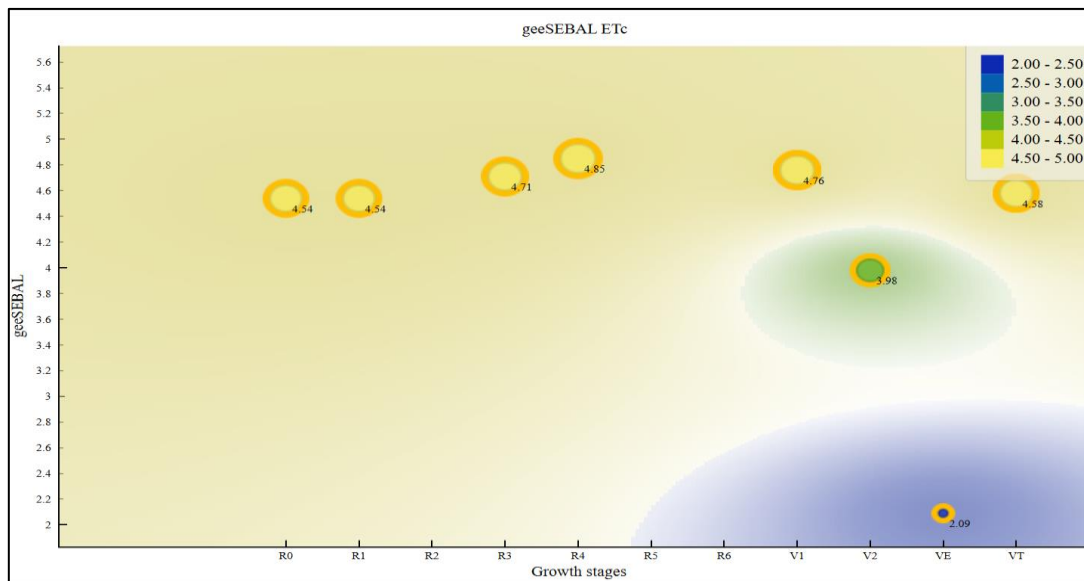


Fig. 4.31: Scattered plot of geeSEBAL actual evapotranspiration (ETc)

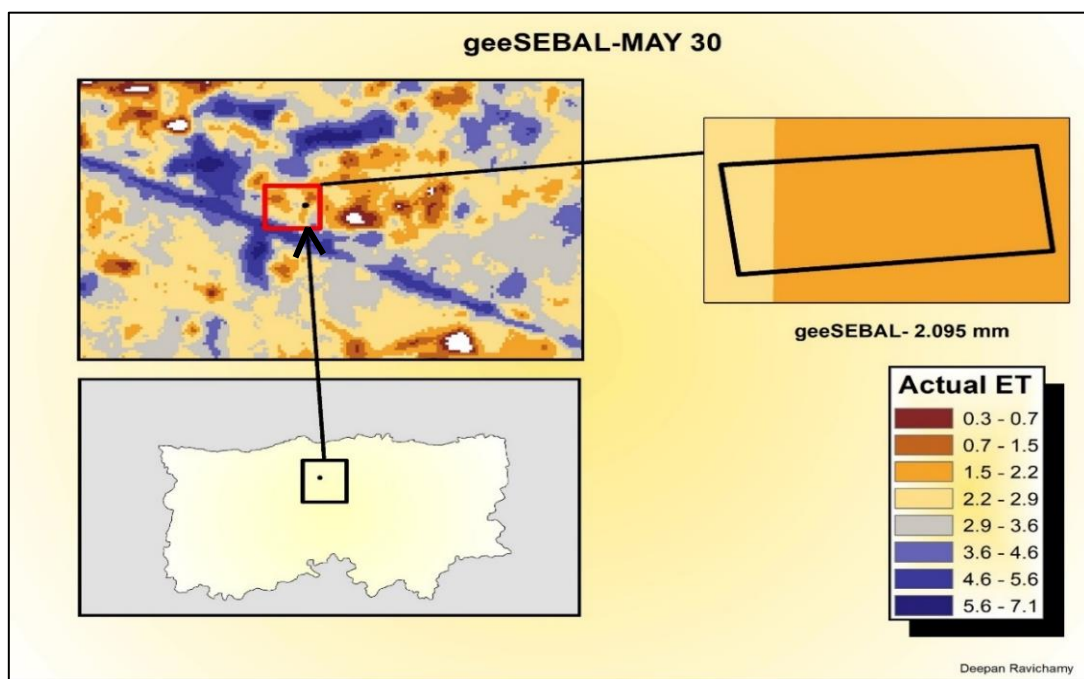


Fig. 4.32: Output of actual evapotranspiration (ETc) using geeSEBAL

4.2.1 ETo calculator and Cropwat

The data obtained from the ETo calculator is also used as base for comparison as modified penman method is complex and time consuming. Since it uses the same Penman-monteith equation as tool to calculate the ET. The weather data like maximum temperature, minimum temperature, sunshine hours, rainfall, windspeed and humidity is fed into the column and then ETo is calculated. It can be seen in the table. The Kc value is then multiplied with the ETo value and actual ET is predicted.

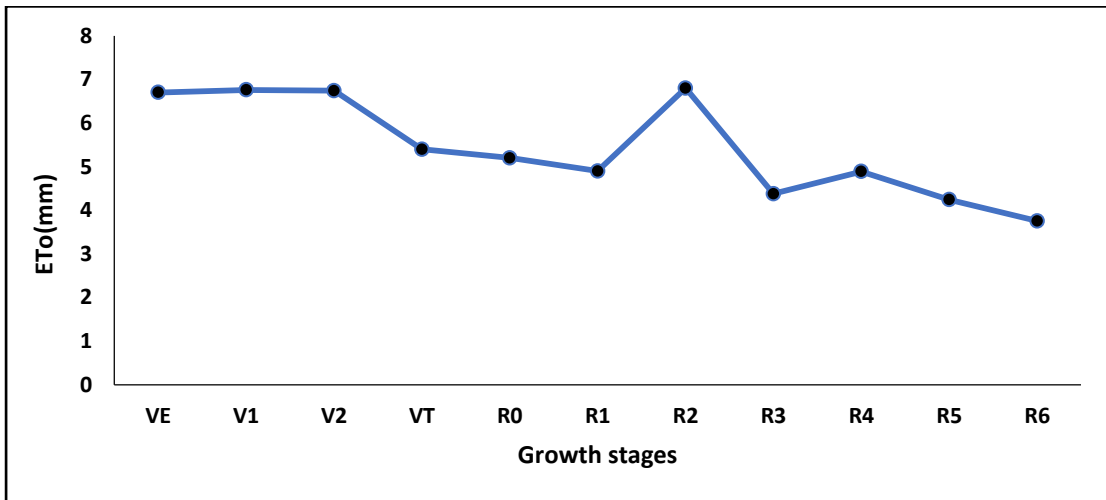


Fig. 4.33: Reference Evapotranspiration (ETo) of Ref-ETo calculator during crop growing season

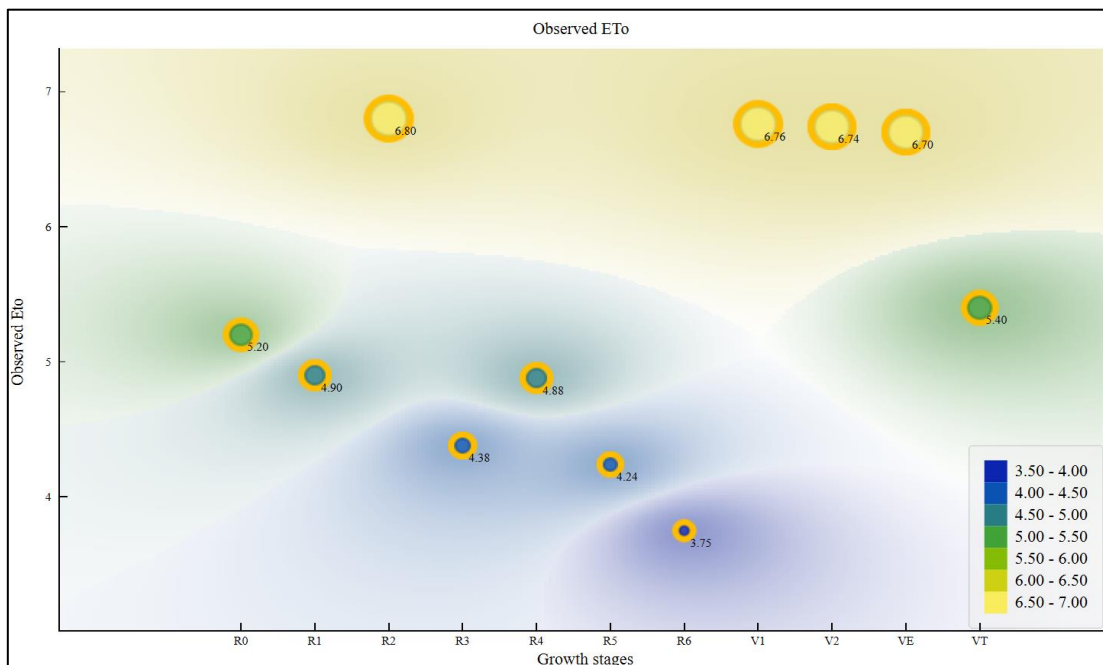


Fig. 4.34: Scattered plot of Ref-ETo calculator reference evapotranspiration (ETo)

The Ref-ET is neither concentrated on zone instead, it is spread throughout entire regions. It is high for the initial sowing season as there is high temperature seen in Fig. 4.34. The Observed ETo yielded values of average of 6.7 during the stages of VE, V1 and V2. The

value of actual ET starts to decrease as the impact of weather is exponentially reduces. It has 5.4 mm/hr as it proceeds towards tasseling stage. This stage is barrier between vegetative and reproductive stage. The values start to vary until the R3 stage, as it peaks to 6.8mm/hr, the highest during the season and gradually reduces to 3.75mm/hr during the harvest stage.

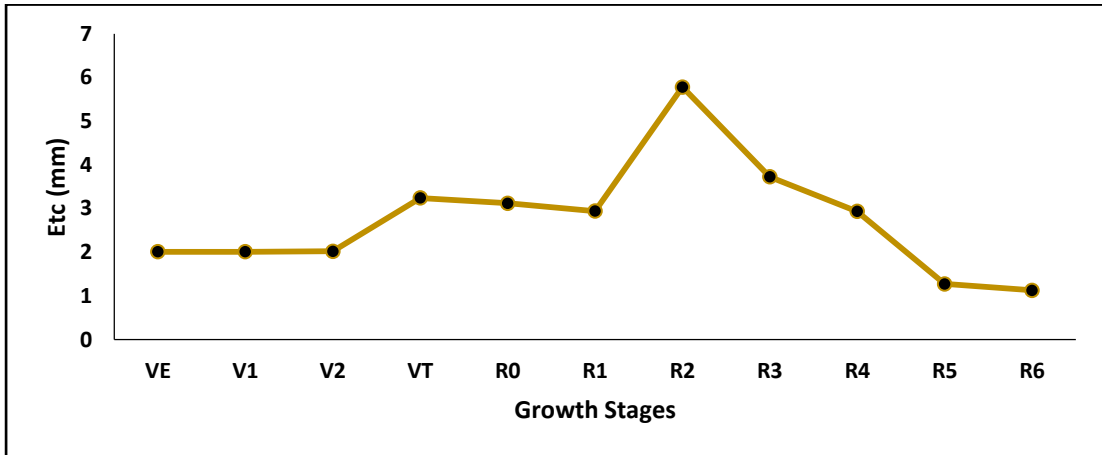


Fig. 4.35: Actual evapotranspiration (ETc) of Ref-ETo calculator during crop growing season

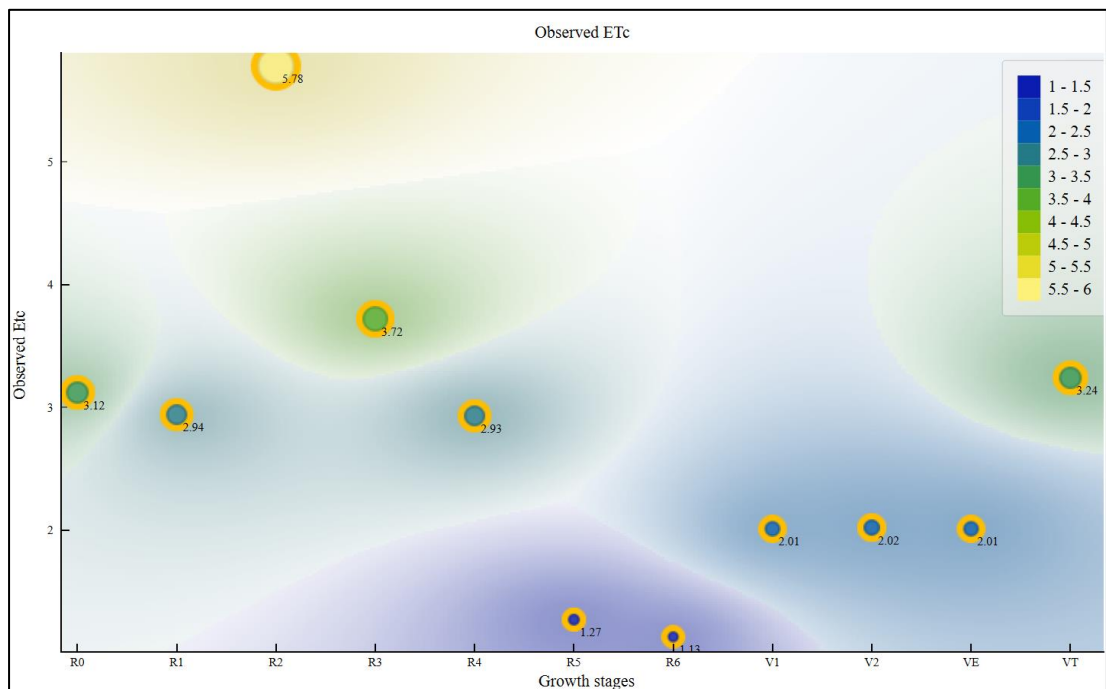


Fig. 4.36: Scattered plot of Ref-ETo calculator reference evapotranspiration (ETo)

The Observed ETc is also neither concentrating on single region like Ref-ETo. This chart shows the correct sequence of ETo value increasing and attaining the peak value and then decreasing. The ETc value starts from 2.01 during the initial stage and follows up the increasing sequence like 2.37, 3.24mm/hr. It attains the peak at 5.78mm/hr during R3 stage and then gradually decreases to 1.68mm/hr, as it proceeds towards harvesting stage.

4.2.4 NRSC-NHP Data

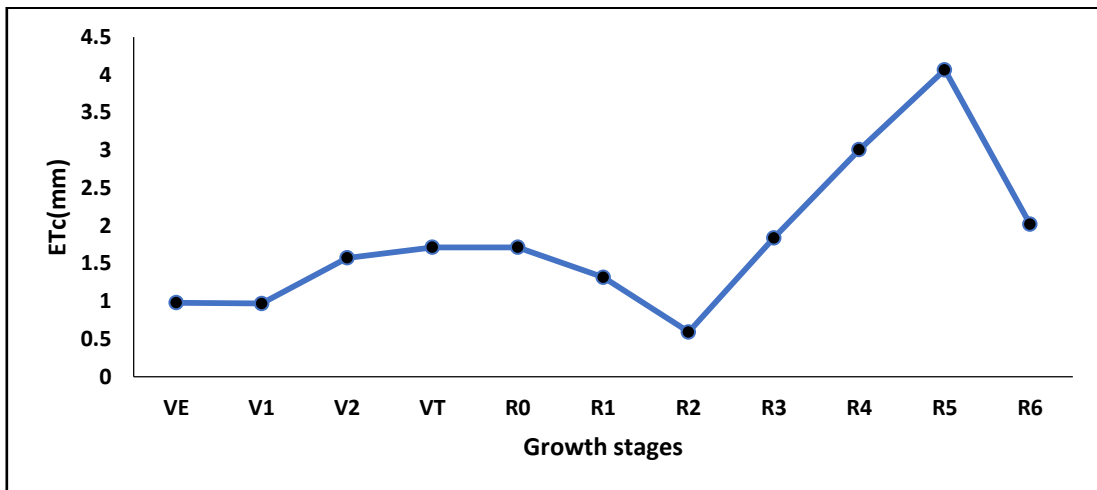


Fig. 4.37: NRSC-NHP actual evapotranspiration (ETc) for during crop growing season

NRSC-NHP data is underestimating the ET since the resolution is of 55X55 km. It can be only used in large scale area like districts or states. For the purpose of small experimental area or field, it cannot be used. It yields only actual Et of the place, yet it has a advantage over other remote sensing tools in terms of daily actual ET processing. It gives us daily actual ET for a place from 2017 to current date.

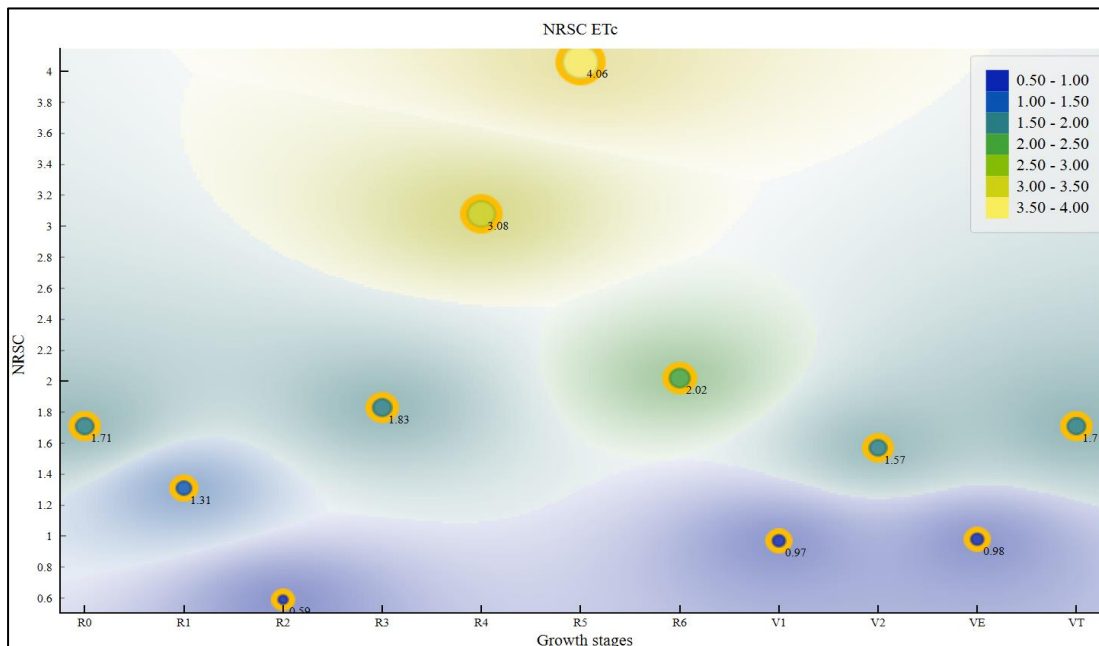


Fig. 4.38: Scattered plot of NRSC-NHP actual evapotranspiration (ETc) during crop growing season

The actual ET of NRSC data is also neither concentrated on single zone, yet the prediction is not on par with the other remote sensing tools. The ET value starts increasing from date of sowing, but attains the peak value during the R5 stage. This shows the error of NRSC in predicting the Actual ET.

4.3 Comparison of data

4.3.1 Observed ETc and EEFLUX ETc

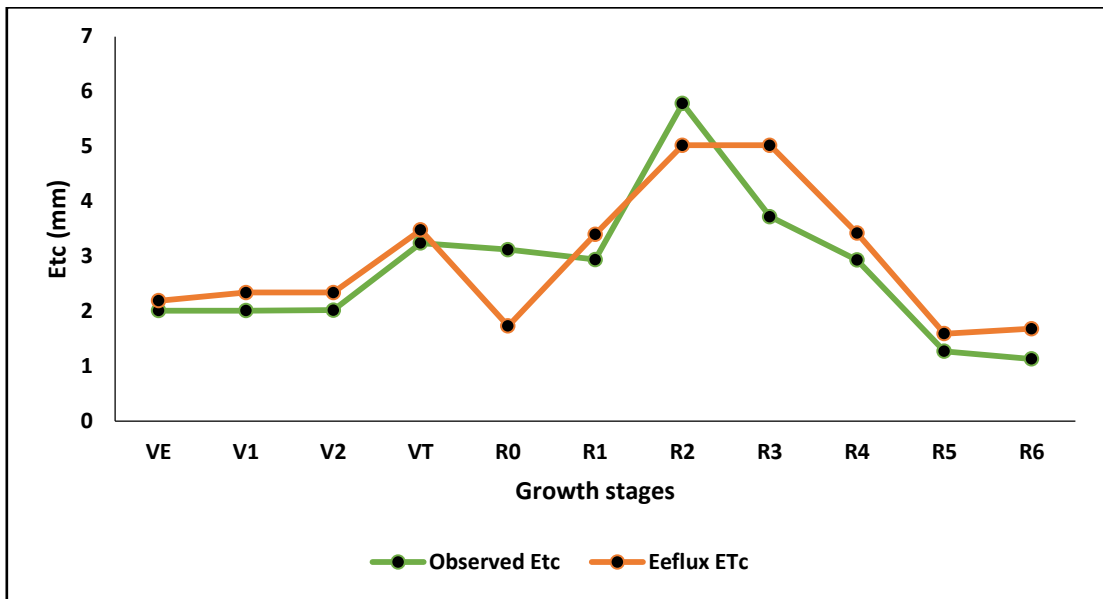


Fig. 4.39: Actual evapotranspiration of observed ETc and EEFLUX ETc during crop growing season

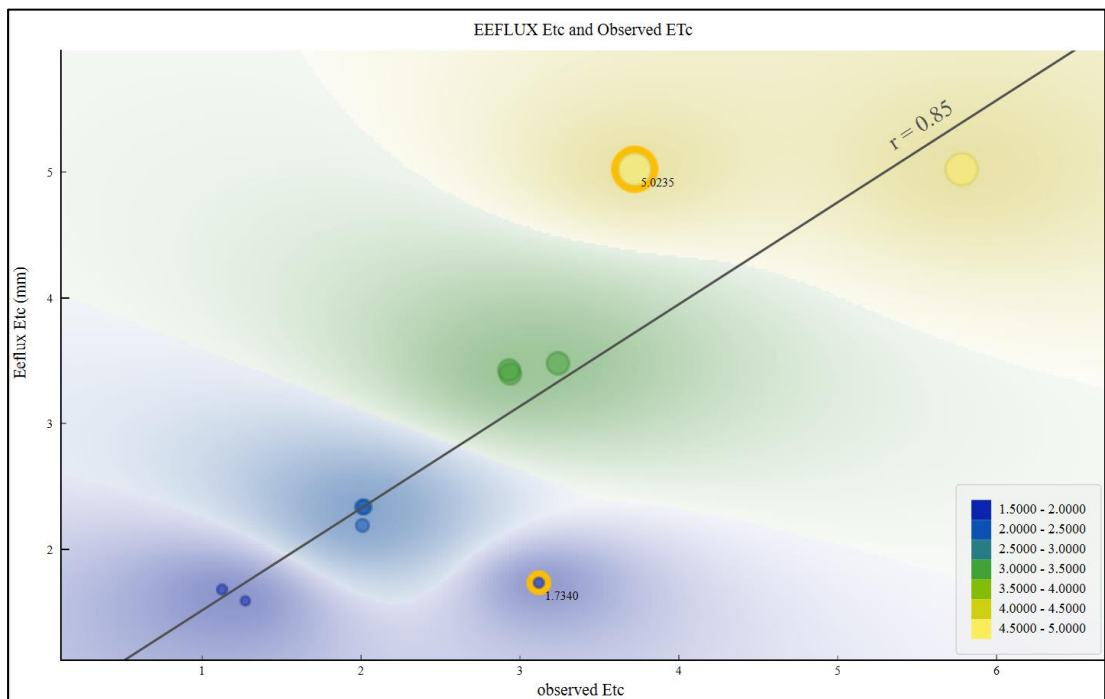


Fig. 4.40: Correlation between EEFLUX ETc and observed ETc

A positive correlation between EEFLUX and Observed ETc indicates that the values yielded by EEFLUX are on par with the values of Observed data. There is slight variation in EEFLUX ETc on 20th July and 4th August due to impact of rainfall. The ETc in both the cases peak during R2 stage, followed by R3 stage and gradually decreases after that.

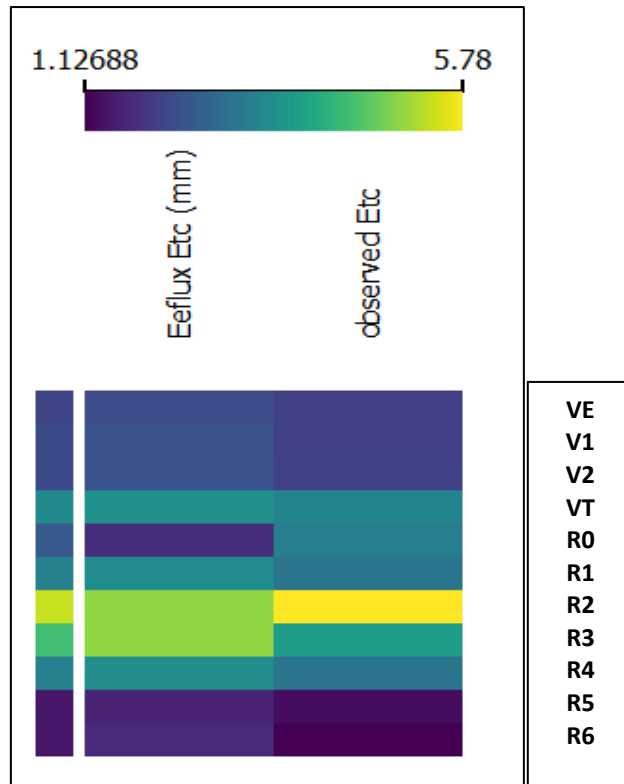


Fig. 4.41 Heat map of EEFlux ETC and observed ETC

4.3.2 Observed ETC and geeSEBAL

geeSEBAL and Observed ETC also shows a slight positive relationship of 0.55 correlation. The correlation is less due to the factor of unavailability of Landsat images during three occasions. Following chart depicts the correlation between geeSEBAL and Observed ETC.

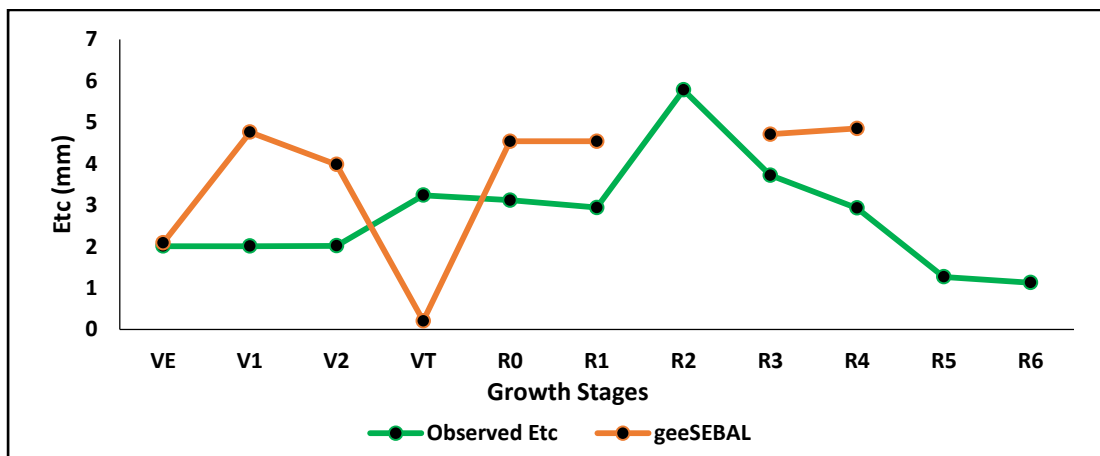


Fig. 4.42: Actual evapotranspiration of observed ETC and geeSEBAL ETC during crop growing season

Highest difference was observed during V0 stage and least difference was observed in R3 stage. The Heat map of geeSEBAL and Observed data was used to picturize a clear understanding of the correlation among the two. Following Fig. 4.42 represents the heat map.

The slight green tiles to dark green tiles represent the positive relation between geeSEBAL and Observed data.

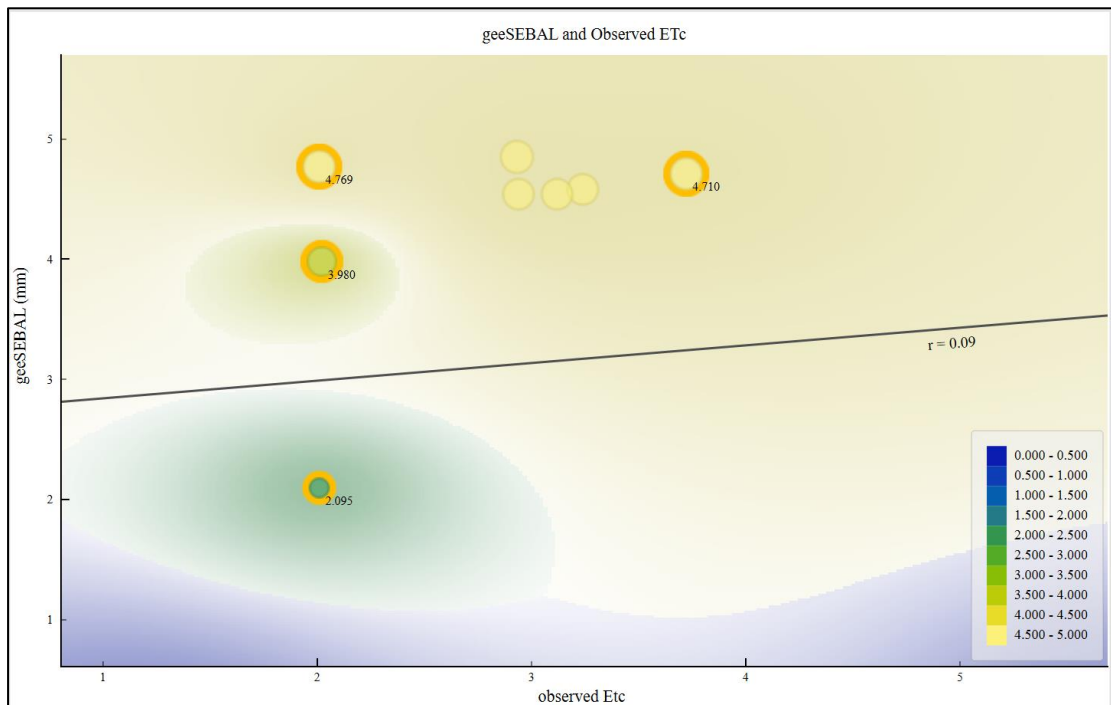


Fig. 4.43: Correlation between geeSEBAL ETC and observed ETC

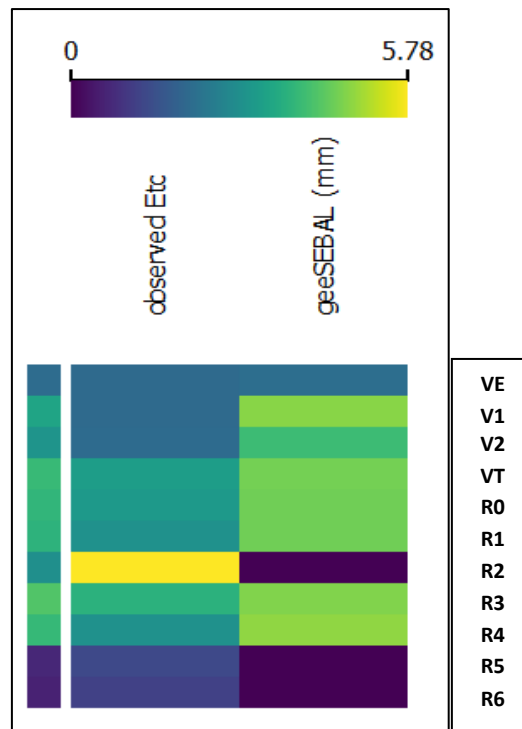


Fig. 4.44: Heat map of geeSEBAL ETC and observed ETC

(By combining class variable and attributes on x and y axes, we see where the attribute values are the strongest and where the weakest, thus enabling us to find typical features for each class.)

4.3.3 Observed ETc and NRSC

Though the frequency of the NRSC-NHP data is 3 days, it doesn't give us positive correlation with Observed ETc. there is a bias in the NRSC-NHP data as all other Remote sensing tools have their value peaked at R₂, but not in this case. The reason is not known and the correlation among the NRSC-NHP data and Observed ETc is depicted in the following Fig. 4.46

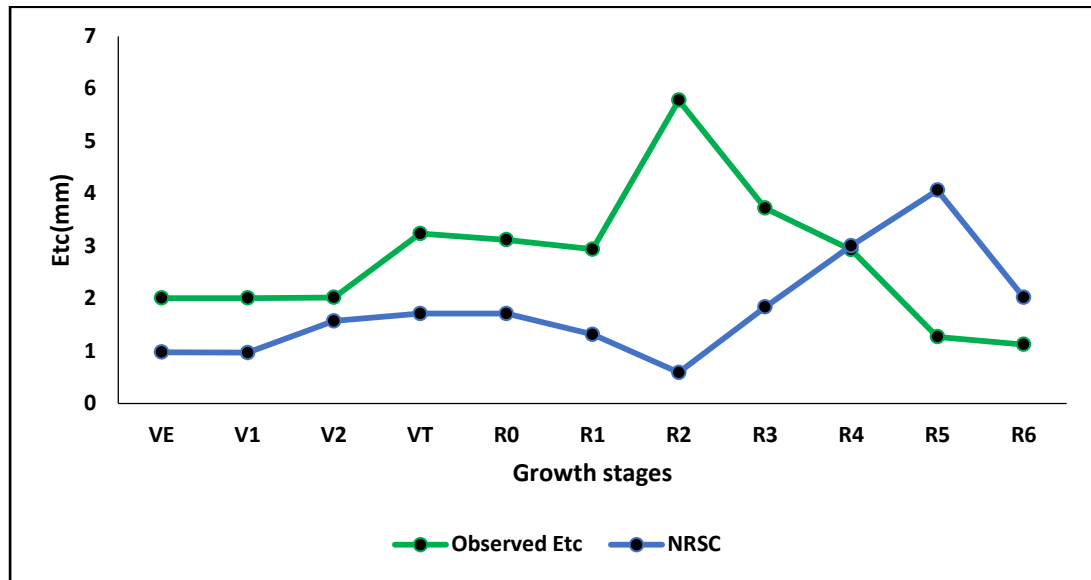


Fig. 4.45: Actual evapotranspiration of observed ETc and NRSC ETc during crop growing season

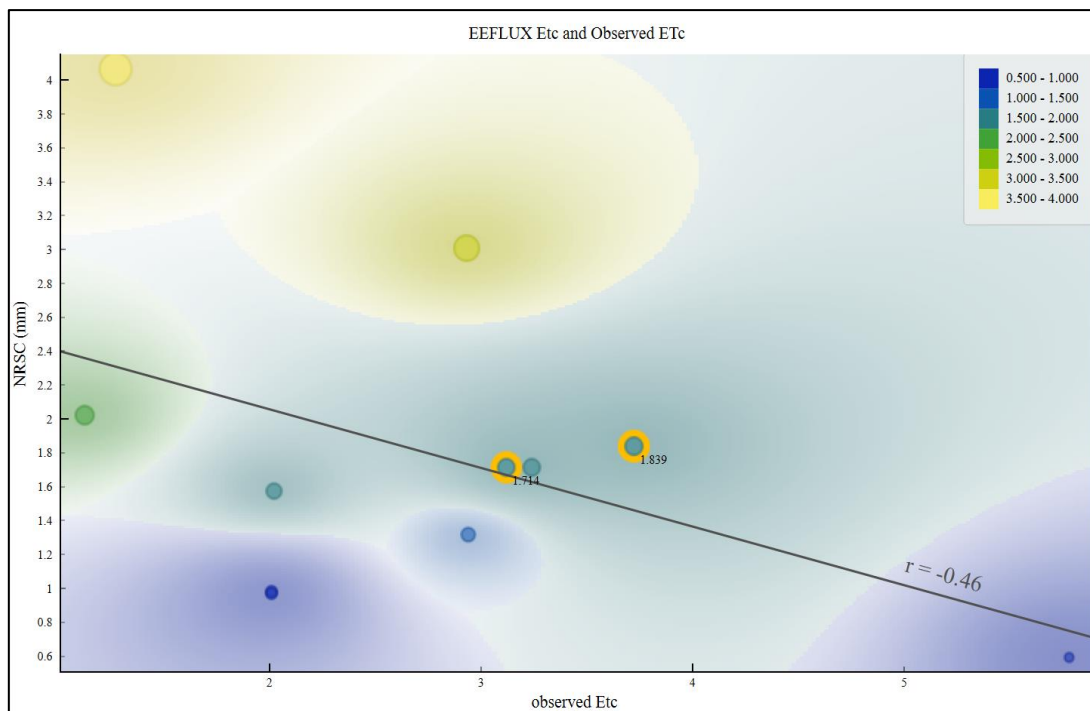


Fig. 4.46: Correlation between NRSC ETc and observed ETc

Since the values of NRSC-NHP is not on par with The Observed data, different tiles show different color. There is no similarity in the tiles which represents poor correlation among them. The relationship between the NRSC-NHP and Observed ETc is negative correlation. As it is newly launched scheme under NHP, the working and estimation of ET is not known.

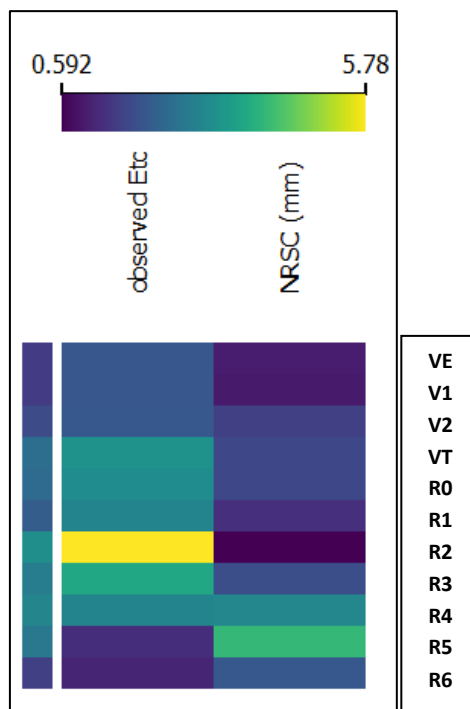


Fig. 4.47: Heat map of NRSC ETc and observed ETc

4.3.4 EEFlux and geeSEBAL

These two can be called twin brothers, as both of them use same satellite for processing but, use different algorithm viz. METRIC and SEBAL. geeSEBAL cannot process during three growth stages due to unavailability of image. Due to this, the correlation between these two have been reduced. The climatic factor during the growth also possesses a barrier to the image collection.

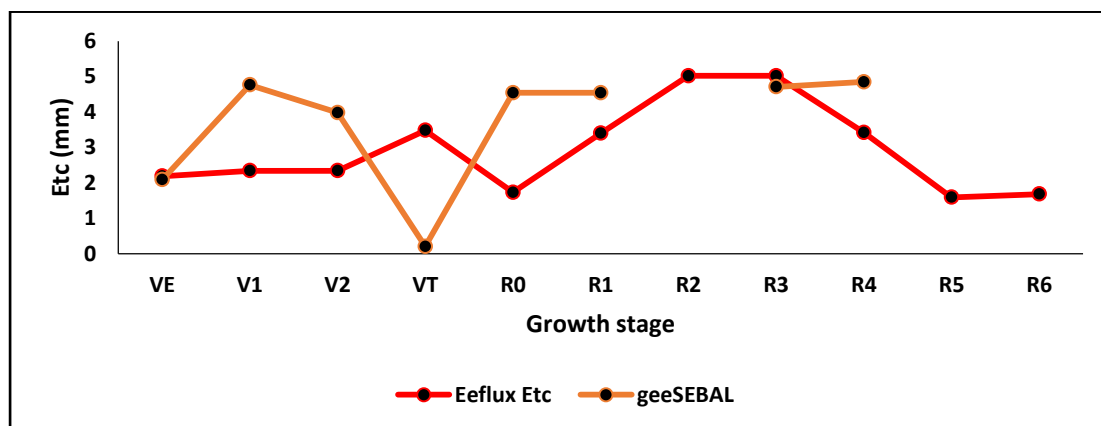


Fig. 4.48: Actual evapotranspiration of EEFlux ETc and geeSEBAL ETc during crop growing season.

The correlation between EEFlux and geeSEBAL have been depicted in the Fig. 4.49. The value of geeSEBAL is on par with EEFlux only during initial stage i.e. VE and R3 stage. The Least correlation occurred during R0 stage.

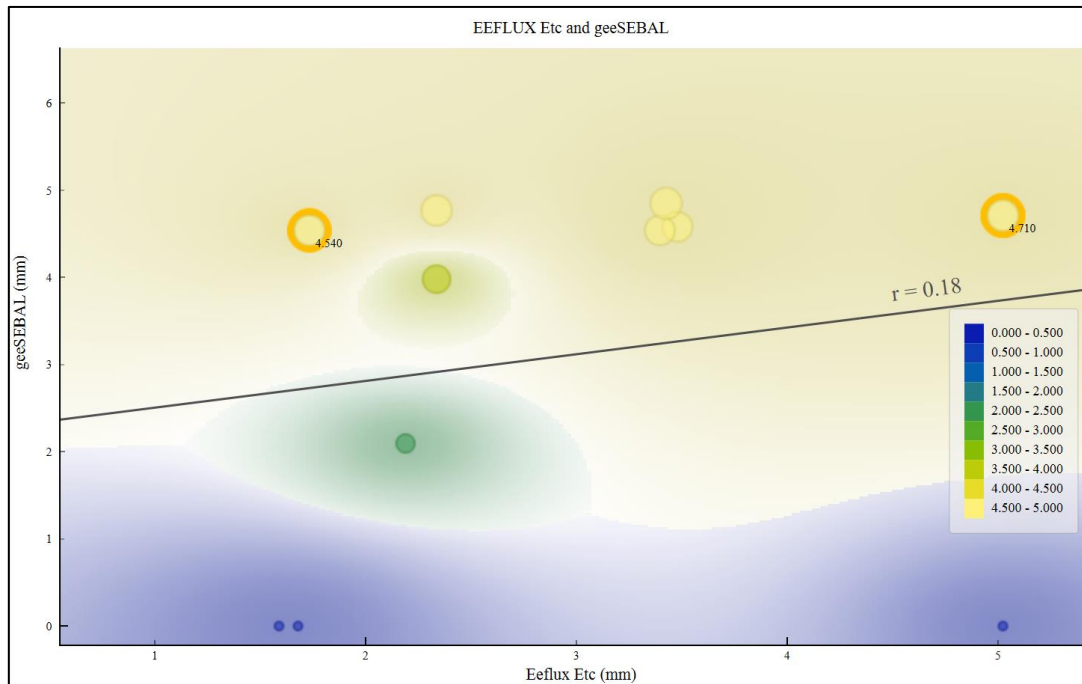


Fig. 4.49: Correlation between EEFlux ETC and geeSEBAL ETC

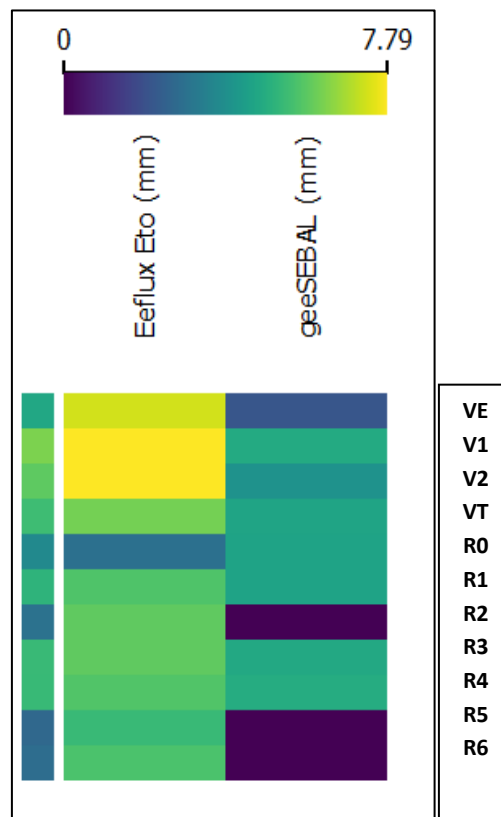


Fig. 4.50: Heat map between EEFlux ETC and geeSEBAL ETC

4.3.5 EEFLUX and NRSC

EEFLUX is a tool for assessment of ET whereas NRSC-NHP data is collection of actual ET datum processed and accumulated in a window. NRSC yield 3 day frequency and also gives us daily actual ET, but the values are not par neither with EEFLUX not Observed data. Maximum difference occurred during most of the cases and minimum difference occurred during R₀ stage.

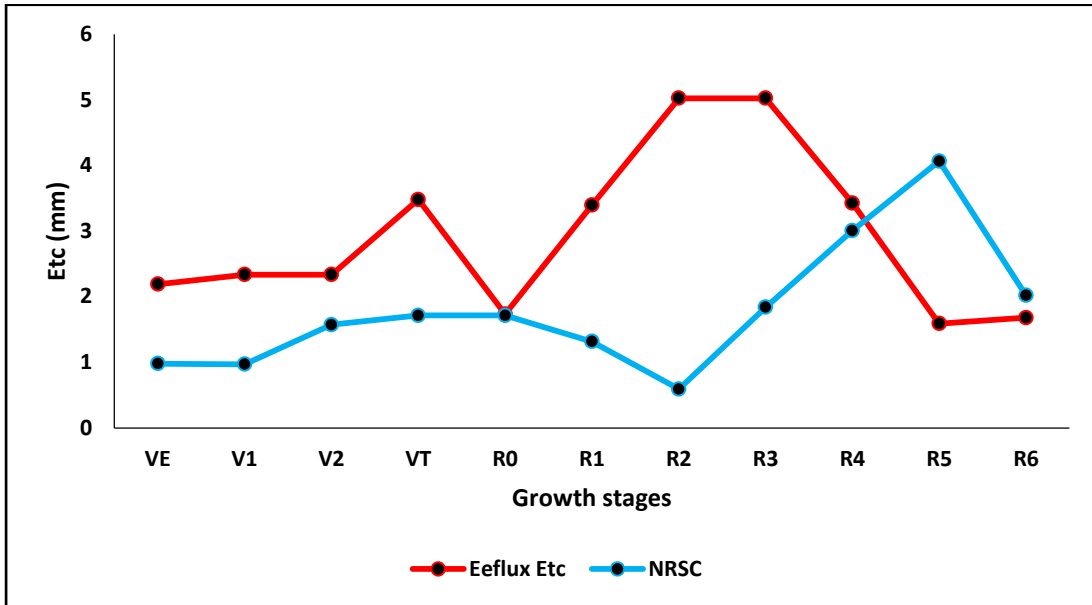


Fig. 4.51: Actual evapotranspiration of EEflux Etc and NRSC Etc during crop growing season.

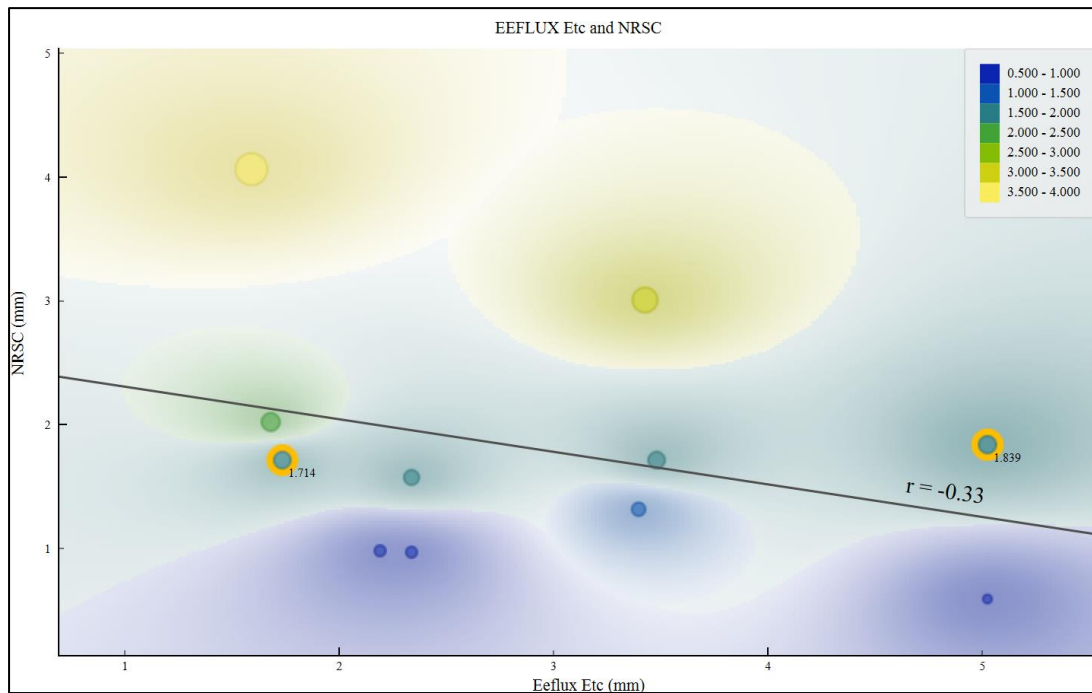


Fig. 4.52: Correlation between EEFLUX Etc and NRSC Etc

The NRSC data also has an anomaly in R2 stage as every other technique resulted in higher ETc value, NRSC resulted in lower value.

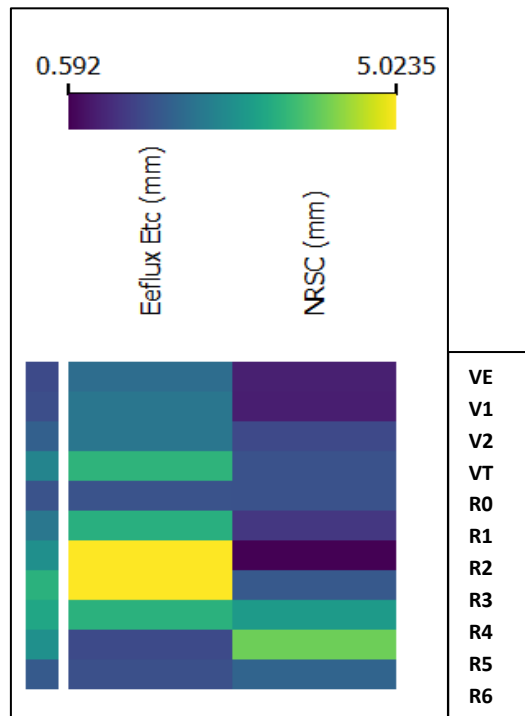


Fig. 4.53: Heat map between EeFlux ETc and NRSC ETc

4.3.6 geeSEBAL and NRSC

geeSEBAL resulted in over-estimation of actual evapotranspiration and NRSC-NHP resulted in under-estimation. As both the remote sensing tools resulted in negative relationship with the observed value, the correlation among them also resulted in same. As geeSEBAL has atmospheric hindrance and NRSC is new and working is not known, these resulted in negative correlation.

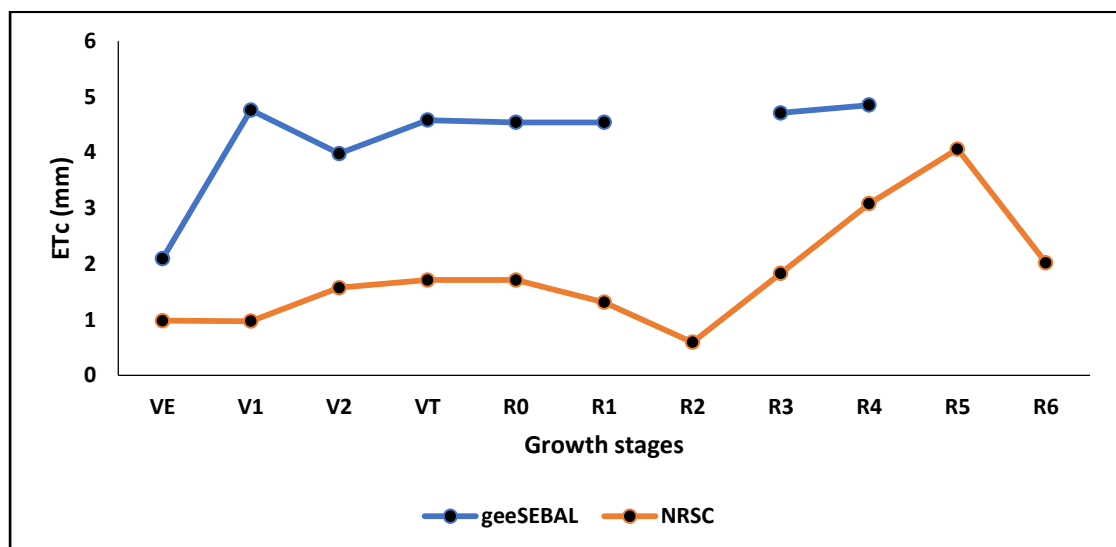


Fig. 4.54: Actual evapotranspiration of geeSEBAL ETc and NRSC ETc during crop growing season

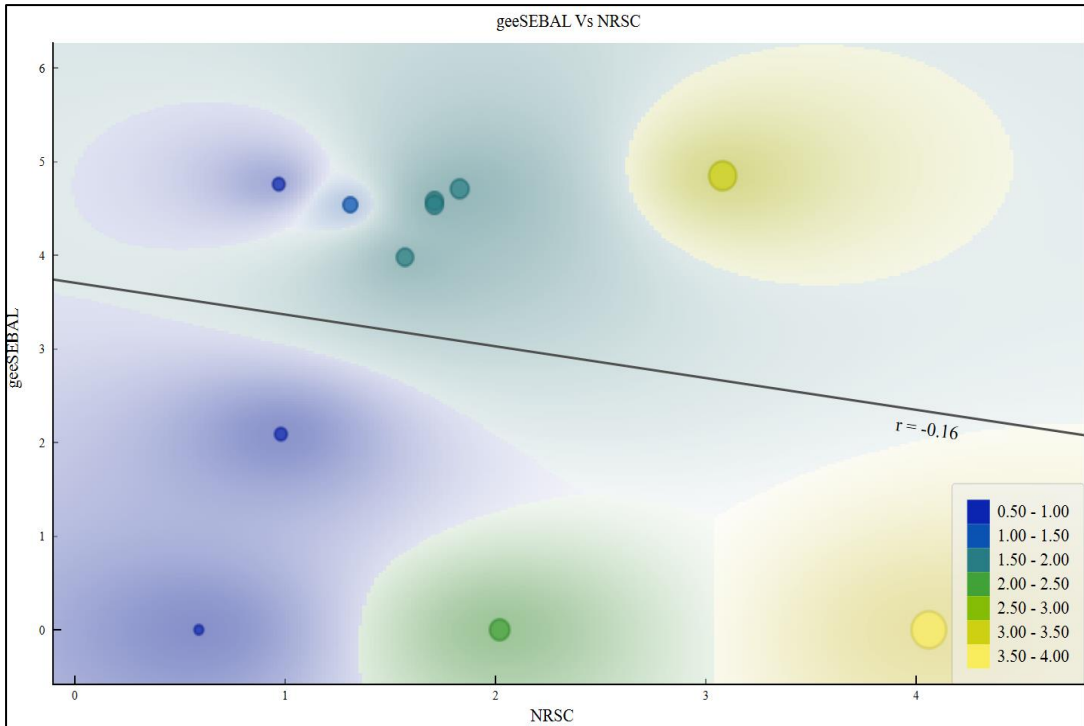


Fig. 4.55: Correlation between geeSEBAL ETc and NRSC ETc

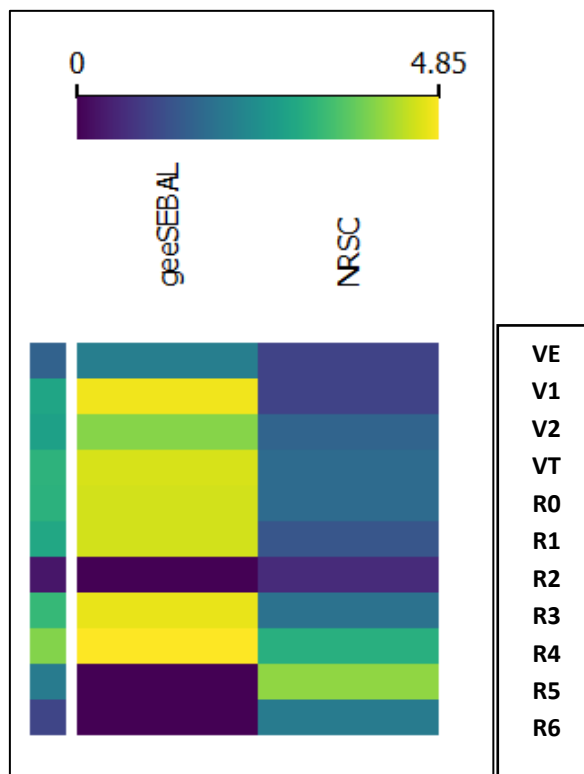


Fig. 4.56: Heat map between geeSEBAL ETc and NRSC ETc

4.4 Correlation of Different Remote sensing techniques

Correlation of EEFlux ETc, geeSEBAL, NRSC and Observed ETc have been clustered in a single figure, with Observed data being the base is shown below:

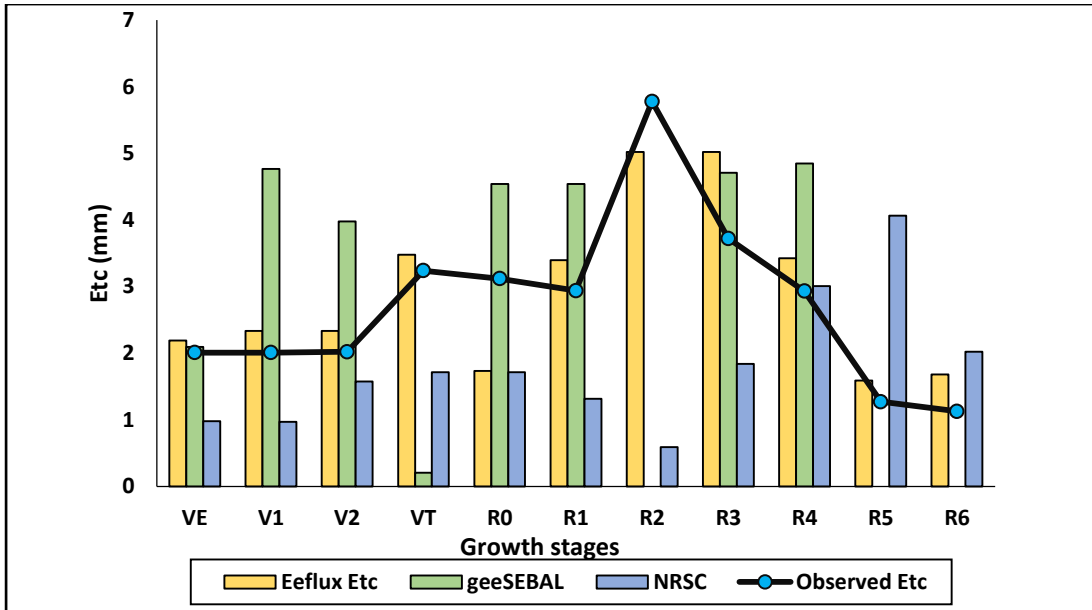


Fig. 4.57: Correlation between EEFlux ETC, geeSEBAL ETC, NRSC ETC and observed ETC

From the above figure 4.57, it can be concluded that ETC value peaked on R2 stage, followed by R3 stage and started decreasing from R4 stage. The EEFlux and observed value seems to be mostly in same palette while the NRSC data seems to be different.

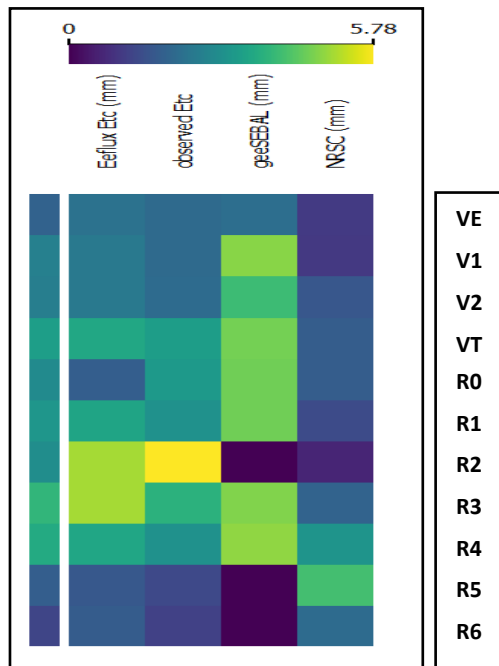


Fig. 4.58: Heat map between EEFlux ETC, geeSEBAL ETC, NRSC ETC and Observed ETC

CHAPTER V

SUMMARY

The Indian subcontinent is an agrarian economy which mainly deals with the agriculture and allied enterprises. The sector comprises of more than half of the country's population which shows the importance of it. The primary source of agriculture sector is water resource in which evapotranspiration (ET) plays a significant role in it. The knowledge about the evapotranspiration increases day by day owing to the trends in climate change. The farmers unsure about the evapotranspiration importance in the water budget, sometime may give higher irrigation during rainy days and lower irrigation during high temperature day. This drawback of negligence of evapotranspiration can be overcome with the help of remote sensing tool called EEFlux. Though, there are many instruments and techniques to compute the ET, remote sensing tool have an edge over others. EEFlux is a web-based application that runs on google earth engine based on METRIC algorithm. To validate and measure the ET in actual field condition using EEFlux, an effort has been put forth to estimate ET using the Google EEFlux for maize crop. The ET has been estimated using the Google EEFlux for maize crop sown in the field experiment at the Research Farm, Department of Climate Change and Agril Meteorology, PAU during the *kharif* season of 2020-21. The ET was also computed using Penman's equation, geeSEBAL, FAO Ref-ETo calculator and NRSC-NHP data for maize. The relationships were developed between ET (Google EEFlux), ET (geeSEBAL), ET(NRSC-NHP) and ET (FAO ETo calculator). The main objective of the study was to

1. To estimate Evapotranspiration using EEFlux tool.
2. To compare the EEFlux output with empirical methods and measure in actual field conditions.
3. To find out the relationship of EEFlux output with growth and yield parameters of Maize.

The above data was analysed using various software and tiff file images were colorized using Q-Gis and Arc-Map. The statistical analysis was done with the help of software called Orange.

The salient findings of the study have been summarized as follows:

- ❖ The ET estimated using EEFlux has shown positive relationship with observed ET that is taken as base. As PAU has ground observation system, METRIC algorithm has an advantage over SEBAL algorithm as the latter is completely atmospheric algorithm. The high ET on May 25th was due to the presence of more sunshine hours and high temperature. The rate of evapotranspiration increases with increasing temperature. The higher the rate of evapotranspiration, the stronger the temperature

gradient and the warmer the air. When the evaporating surface was warmer, it extracts less sensible heat from the air, resulting in less evapotranspiration. The sudden drop in ET is due to the impact of rainfall, in which may 31st has nearly 11mm/day that has affected the sensors of satellite. This resulted in the wetness of the surface. The actual evapotranspiration is exponentially increasing upto milking stage (R3) and then starts decreasing until it attains minimum ETc at harvesting stage (R6).

- ❖ geeSEBAL runs on SEBAL algorithm. It could not produce all the image due to impact of cloud and SEBAL algorithm, as it is completely focused on atmospheric phenomenon rather than METRIC which focuses on ground observation system. The geeSEBAL over-estimates the ETc and at the harvesting stage (R6) where every other tool computed the value low, geeSEBAL computed the highest value. It is due to the hindrance of the cloud and also the SEBAL algorithm.
- ❖ FAO Ref-ETo and CROPWAT calculator is similar to the results obtained from penman-monteith equation and there is no bias in computing it, as the meteorological parameters like maximum temperature, minimum temperature, sunshine hours, rainfall, windspeed and humidity are taken from the nearby observatory and fed as input, the calculator only computed and gives us output. It is taken as base for the study.
- ❖ NRSC-NHP data is underestimating the ET since the resolution is of 55×55 km. It can be only used in large scale area like districts or states. For the purpose of small experimental area or field, it cannot be used. It yields only actual Et of the place, yet it has an advantage over other remote sensing tools in terms of daily actual ET processing. The ET value starts increasing from date of sowing, but attains the peak value during the Dent stage (R5). This shows the error of NRSC in predicting the Actual ET.

The values obtained from each method is compared with the observed ETc for validation.

- ❖ A positive correlation between EEFlux and Observed ETc indicates that the values yielded by EEFlux are on par with the values of Observed data. There is slight variation in EEFlux ETc on 20th July and 4th august due to impact of rainfall. The ETc in both the cases peak during R2 stage, followed by R3 stage and gradually decreases after that.
- ❖ geeSEBAL and Observed ETc shows a slight positive relationship of 0.55 correlation. The correlation is less due to the factor of unavailability of Landsat images during three occasions and SEBAL algorithm. Another fact is our Indian subcontinent lies in tropical and in sub-tropical region. Cloud formation is rapid and it causes hindrance to the sensor the satellite as still geeSEBAL has most of the images running in Landsat 7.

- ❖ Even though the NRSC-NHP data frequency is 3-day period, it resulted in negative correlation with observed ET_c.
- ❖ The finding of the study ensures that EEFlux can be chosen as a remote sensing tool for estimation of evapotranspiration in the sub-tropical region rather than SEBAL algorithm.
- ❖ The bias in the both remote sensing tools can be overcome with the help of satellite like Landsat-9 and Sentinel-1, which can penetrate the cloud that causes hindrance for the obtaining information.
- ❖ The computation of ET_c in NRSC-NHP data is not known and brief study is required in future.

As the sub-continent is agrarian economy and nearly 54% of labor force is involved in agriculture, the GDP yielded to economy is still one-third of the total labor force (17%). If the utilizers came to know about the ET using simple and effective tool like EEFlux, an awareness will be created which in turn fill the data gap of ET. Once the users are aware about the ET and its utilization, there will be a proper management of water and increase in the efficiency of the irrigation. This in turn will increase the availability of water for the crop production and result in good yield. The Good yield which farmer's make out of it will tend to increase their income which will eventually increase the national income. Thus is the importance of evapotranspiration and role of Remote Sensing tool like EEFlux

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VITA

Name of the Student : Deepan R
Father's name : Ravichamy P
Mother's name : Manimegalai R
Nationality : Indian
Date of Birth : 22.10.1998
Permanent Home Address : Plot No. 61-A, 4th Cross, Vasan Valley
Trichy, Tamil Nadu - 620102
Email : deepanravichamy@gmail.com

EDUCATIONAL QUALIFICATIONS

Bachelor's degree : B. Sc. Agriculture
University and Year of award : Tamil Nadu Agricultural University, Madurai
2020
OCPA : 7.77/10.00
Master's degree : M. Sc. Agricultural Meteorology
University and Year of award : Punjab Agricultural University, Ludhiana
2022
OCPA : 8.08/10.00
Title of Master's thesis : Quantification of evapotranspiration using
EEFLUX tool and comparison by empirical
methods in maize (*Zea mays* L.)
**Awards/ Distinctions/
Fellowships/ Scholarships** : ICAR – National Talent Scholarship (NTS)
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