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Mapping of Water Stress Affected Horticulture Crop Areas using Remote Sensing in Srinivaspur Taluk, Kolar District, Karnataka

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Abstract

In the arid and semi-arid agroecological regions, crop stress due to shortage of soil moisture reduces the production potential of horticulture crops. Farmers need an appropriate tool to assess the crop water stress and schedule irrigation. The present study was carried out in Srinivaspur taluk of Kolar district which is in the semi-arid track of Karnataka where the ground water levels are going down. A remote sensing-based crop water stress index (CWSI) was developed using the values of canopy temperature and concurrent air temperature measured with a handheld infrared thermometer at 40-point locations which were interpolated to cover the entire study area. Digital image classification of sentinel-2A multispectral instrument (MSI) data, acquired during March to May 2022 was used for identification of horticulture cropped areas and associated land use land cover (LULC) types.The random forest (RF) algorithm-based classification of remotely sensed digital data permitted identification of horticulture crops with an accuracy of 90 per cent at Kappa coefficient of 0.81. Using the data from the operational land imager (OLI) of Landsat-8 acquired on 1st May 2022, the normalized difference vegetation index (NDVI), which is needed for estimating the proportion of vegetation (PV), in calculating emissivity (E) was generated. Data from thermal infrared sensor (TIRS) of Landsat-8 were used to generate the brightness temperature (BT). Land surface temperature (LST) map was generated by integrating the BT and E through raster analysis using ArcMap GIS software.The LST values for horticulture crops ranged from 23ºC (low) to 32ºC (high). The CWSI values for the study area ranged from 0.02 (no water stress) to 0.37 (horticulture crops severely affected by water stress). Horticulture crop areas experiencing water stress were identified with an accuracy of 87.5 per cent. The technique developed here could be used for scheduling irrigation of horticulture crops in the semi-arid regions of Karnataka.

Keywords : Horticulture, Infrared thermometer, Remote sensing, CWSI, NDVI, Brightness temperature, LST

Agro-climatic conditions prevailing in Karnataka state are highly favourable to grow different types of horticultural crops. This sector is playing an important role in the economy of the state and providing employment to a large number of farmers. Production of horticulture crops depend on critical inputs like fertilizers and irrigation at the appropriate time during their growth. Lack of adequate rainfall or required quantity of irrigation and unexpected dry spells will result in crop water stress at different growth stages of a horticulture crop. When a crop experiences water stress, stomatal closure followed by reduction in rate of transpiration leading to rise in canopy temperature (T_c) occur. Severe water stress reduces photosynthesis and yield of crops. Wherever the evapotranspiration (the demand component) is in excess of rainfall and / or irrigation (the supply component) there is a reduction in photosynthetic capacity and length of crop growing period. Hence, detecting the crop water stress in advance and planning precise irrigation schedules would help in protecting the production potential of horticulture crops.

Plant canopy temperature has long been recognized as an indicator of crop water stress (Gates, 1964 and Weigand & Namken, 1966). Monteith & Szeicz (1962) and Tanner (1963) were among the first to use infrared thermometry to determine T_c. Some of the earliest studies reporting the use of T_c as a crop water stress indicator are by Idso *et al.,* 1977, Jackson *et al.*, 1977. They measured the difference in T_c minus air temperature (T_a) and related with yield and water requirements of crops. Subsequently, several researchers have used T_c and T_a and developed a Crop Water Stress Index (CWSI)and used it for quantitative evaluation of crop water stress (Jackson *et al.,* 1981 for more details., Saleh *et al.,* 2013; Potgieter *et al.,* 2014; Hiba *et al.,* 2019 and Afshin *et al.,* 2021).

The field of thermal infrared (TIR) remote sensing from satellite platforms has become fully operational in our country and elsewhere in the world. It is used for collection, analysis and interpretation of electro magnetic radiation 'emitted' from the target's surface in the spectral region of 3 to 15 µm, especially in the atmospheric window between 8-14 µm wave length. TIR sensors are used to measure Land Surface Temperature (LST) by several researchers (Jose *et al.,* 2004; Ayat *et al.,* 2018; Mohammad *et al.,* 2018 and Yaw *et al.,* 2021). LST measures the radiance emitted from the earth's surface, where incoming solar radiation interacts with and warms the bare ground, or the canopy's surface in vegetated regions. It is a blend of vegetation and bare ground temperatures.

The use of satellite-based remote sensing for area and production estimation of horticulture crops and preparation of LULC maps has been successfully demonstrated by Yadav *et al.* (2001) and Nageswara Rao *et al.* (2004). Several researchers have applied modern methods for digital data analysis of remotely sensed data such as Random Forest, Support Vector Machineand Classification and Regression Tree (Thanh *et al.,* 2020; Harpinder *et al.,* 2021 and Kotapati *et al.,* 2021) which gave better accuracy when compared with conventional supervised classification algorithms.

In the arid and semi-arid parts of Karnataka state, deficient rainfall and lack of irrigation facilities result in crop water stress at different crop stages and under diverse environmental conditions. There is a need for assessing the location, extent and severity of the crop area affected by water stress. Such an assessment is more important in horticulture crops that are nurtured over a long period investing huge resources by the farmers. Also, an accurate assessment of the horticulture areas affected by water stress (drought) is needed in recommending precision irrigation. In this study an attempt has been made to (i) measure canopy temperature and concurrent air temperature using hand-held Infrared thermometer, (ii) identify and map the water stressed horticulture areas using CWSI, (iii) estimate LST from satellite remote sensing and relate the same with the areas of major horticulture crops affected by water stress.

Material and Methods

Study Area: Srinivaspur taluk in Kolar district of Karnataka state is located at 13º 20' N latitude and 78º 13' E (Fig. 1). It has an average elevation of 819 metres. Five Hoblis, including Srinivaspur (Kasaba), Ronur, Yeldur Nelavanki and Rayalapadu make up the taluk. It covers an area of 860 square kilometre. The taluk receives an annual average rainfall of 722 millimetres, which is less than the district average. The taluk has no perennial river, however Kushavati stream, a tributary of the Papaghni river, flows through it.Horticultureis the major occupation of the people with Mango and Tomato cultivation as the major commercial

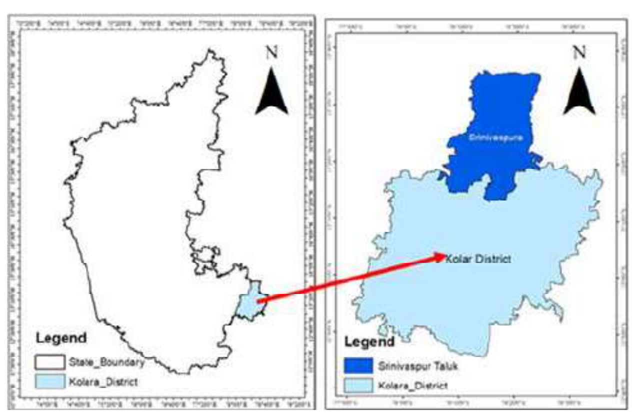

Fig.1 : Location map of Srinivaspur taluk, Kolar district, Karnataka state

Fig. 2 : Hand-held Infrared thermometer (A) and Ground truth image (B)

crops. Srinivaspur taluk has all 63 varieties of mangoes and is a major producer of mangoes in the Karnataka state.

Satellite Data used: Landsat-8 OLI band 4 (Red, 0.64 - 0.67 µm), 5 (NIR, 0.845–0.885 µm) and TIRS band 10 (10.6-11.2 µm) data of 1st May 2022 with spatial resolution of 30 m collected from USGS Earth Explorer was used to generate LST map. Sentinel-2A MSI data with spatial resolution of 10 m and 20 m acquired during March to May 2022 was used to identify and generate horticulture crop map.

Canopy Temperature and Air Temperature Data: An infrared thermometer was used to measure the canopy and concurrent air temperature (Fig. 2) at 40-point locations during April 10th to May 7th of 2022 (10:00 AM to 04:00 PM). Its measuring range is between -50 to 400ºC, resolution of 0.1ºC, with an accuracy of +/- 1.5ºC, operating at the wave length 8 to 14 micro meters at a distance spot ratio: 12:1. The data thus collected was used to calculate the CWSI.

Meteorological Data: Air temperature and relative humidity (RH) were collected from Karnataka State Natural Disasters Monitoring Centre (KSNDMC) to calculate Vapour Pressure Deficit (VPD).

Ground Truth: For training the algorithm and for validation of the accuracy of identification of horticulture areas, several ground truth samples of horticulture and associated LULC types were collected using Note-Cam mobile app that has provision to record the geographic coordinates (lat-long).

CWSI calculation and map generation: The CWSI was calculated in four steps: (i) estimation of temperature differences of irrigated and dry (unirrigated) horticulture canopies and concurrent air temperatures, (ii) calculation of VPD, (iii) generation of corrected lower and upper limits of canopy minus air temperature and (iv) calculation of CWSI.

i) Estimation of canopy minus air temperature differences:

$$\delta T_{Irr} = (Tc - Ta)$$
$$\delta T_{Dry} = (Tc-Ta)$$

δT_{Irr} - Difference between canopy and concurrent air temperature of irrigated crop.

δT_{Dry} - Difference between canopy and concurrent air temperature of dry crop.

Tc - Canopy temperature.

Ta - Air temperature.

ii) The VPD was calculated using RH data in MS excel.

$$VPD = es-ea$$

es - Saturated Vapour Pressure.

ea - Actual Vapour Pressure.

$$es = 610.78 * \exp \frac{(17.27 * Ta)}{(Ta + 238.3)}$$

Ta - Air Temperature.

$$ea = es \frac{RH}{100}$$

RH – Relative Humidity.

iii) The upper (δT_{UL}) and lower (δT_{LL}) limits equations are as given below:

$$\delta T_{ul} = 0.0089\ (VPD) + 1.1203$$
$$\delta T_{LL} = -0.6461\ (VPD) - 1.7874$$

iv) The CWSI was calculated as follows

$$CWSI = \frac{\delta T_x - \delta T_{LL}}{\delta T_{UL} - \delta T_{LL}}$$

Where:

δT_x - Measured difference between canopy and concurrent air temperature.

δT_{UL} - Upper base line equation (Non transpiring, unirrigated crop).

δT_{LL} - Lower base line equation (Transpiring, Irrigated crop).

The calculated CWSI values were interpolated using Inverse Distance Weighted (IDW) method in ArcMap 10.3 to generate CWSI map for Srinivaspur taluk.

LST calculation and map generation:The LST map was generated for the study area as follows.

Step 1: Top of Atmosphere (TOA) spectral radiance of the TIR band was calculated using the following formula:

$$L\lambda = ML*Qcal + AL - Oi$$

Where:

$L\lambda$ - TOA spectral radiance (Watts/(m^2*sr*µm))

ML - Radiance Multiplicative Band (No.)

AL - Radiance Add Band (No.)

Qcal - Quantized and calibrated standard product pixel values (DN) (TIR band)

Oi - correction value for band 10

Step 2: Converting TOA spectral radiance to Brightness Temperature (BT). TIR band data was converted from spectral radiance to BT using the thermal constant values in Metadata file as shown below.

$$BT = K2 / 1n\left(\frac{K1}{L\lambda} + 1\right) - 273.15$$

Where:

BT - Brightness Temperature (°C)

$L\lambda$ - TOA spectral radiance (Watts/(m^2*sr*))

K1 & K2 - Calibration Constants for Bands (Nos)

Step 3: Normalized Difference Vegetation Index (NDVI) was calculatedas given below.

$$NDVI = \frac{NIR\ (Band\ 5) - RED\ (BAND\ 4)}{NIR\ (Band\ 5) + RED\ (BAND\ 4)}$$

Where,

RED - DN values of Band 4 (Landsat-8, OLI)

NIR - DN values of Band 5 (Landsat-8, OLI)

Step 4 : Proportion of Vegetation (PV) was calculated using NDVI values as shown below:

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

Where:

PV - Proportion of Vegetation.

NDVI - NDVI Map values.

$NDVI_{min}$ - Minimum(Lowest) value from NDVI image.

$NDVI_{max}$ - Maximum value from NDVI image.

Step 5: Land Surface Emissivity (E) was calculated as per Jose *et al.* (2004) under the following three conditions.

(i) NDVI < 0.2 (where the land is covered with soil, and E value of 0.97 assigned).

(ii) NDVI > 0.5 (where the land is covered with good vegetation and E value of 0.99 assigned)

(iii) 0.2 < NDVI < 0.5 (where the land is mixture of soil and vegetation the following formula was used to estimate emissivity).

$$E = 0.004 * PV + 0.986$$

Where:

E - Land Surface Emissivity.

PV - Proportion of Vegetation.

0.986 corresponds to a correction value of the equation.

Step 6: Land Surface Temperature (LST) Calculation.

$$LST = BT / 1 + (\lambda * \frac{BT}{C^2}) * \ln(E))$$

Where:

BT - Brightness Temperature (°C)

λ - Wavelength of emitted radiance for band 10 (10.8)

c^2 - (h*c/s) =14388 mk

h - Planck's Constant = $6.626*10^{-34}$ Js

S - Boltzmann constant = $1.38*10^{-23}$ J/K

c - velocity of light =$2.998*10^{8}$ m/s

E - Land Surface Emissivity

The sequence of steps involved in the entire methodology of mapping the horticulture cropps affected by water stress is schematically presented in Fig.3.

***Horticulture Crop areas and associated LULC classification*:**Classification of horticulture crops and associated LULC was performed using Sentinel-2A MSI data ofgreen (0.560 µm), red (0.665 µm) and near-infrared(NIR) (0.842 µm) bands with a spatial resolution of 10 meters.The RF algorithm available on Google Earth Engine (GEE) platform was used. Ground truth collected at about 40 locations was used for training thealgorithm and evaluate its performance.Thus the horticulture crop map was generated. Whereever

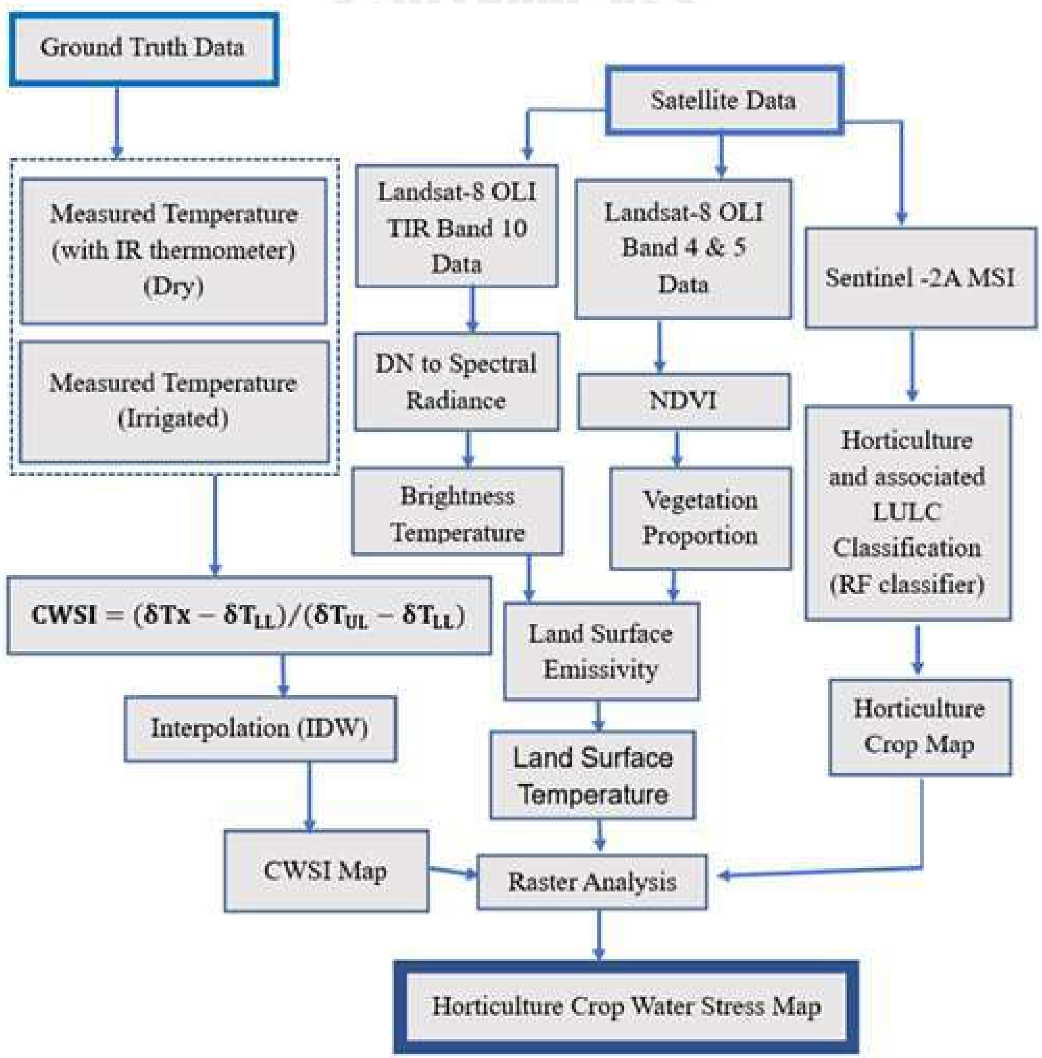

Fig. 3 : A schematic of steps involved in identification and mapping of horticulture crops affected by water stress

the RF algorithm had thrown out misclassified pixels (due to other tree cover types), a digital mask was applied to eliminate the non-horticulture cover types and then classified. To further improve the classification accuracy, spectral bands covering Red Edge-3 (0.783 µm), shortwave infrared (SWIR) -1 (1.375 µm) and SWIR-2 (1.610 µm) of Sentinel -2AMSI data with a spatial resolution of 20 meters was used. Areas of horticulture crops affected by water stress were extracted by overlaying LST raster with horticulture raster layer. Similar operation was carried out with CWSI raster layer and horticulture layer. The spatial analyst tool (extract by mask) available in ArcMap 10.3 GIS was used for carrying out the overlay analysis and extraction of horticulture cropped areas affected by water stress.

RESULTS AND DISCUSSION

CWSI map of Srinivaspur taluk: The interpolated CWSI mapis shown in Fig. 4. The CWSI values ranging from 0.02 to 0.14 have been found to be areas of less or nocrop water stress (in shades of blue colour). Values ranging from 0.15 to 0.21 are areas of moderate crop water stress represented in yellow colour, while the values ranging from 0.22 to 0.37 (high) are crop water stressed areas due to less irrigation / rainfed horticulture croparea (shades of red and orange colour).

NDVI map of Srinivaspur taluk: The NDVI values in the study area were found to range from -0.29 to 0.56., where -0.29 NDVI value represents water shown as red in colour. The NDVI values ranging from 0.3 to 0.56 represent dense vegetation having healthy horticulture and other plantations / tree cover types represented in shades of yellow and green colours (Fig. 5).

PV map: PV map generated is shown in Fig. 6. Water bodies, built up and other places which have very less or no vegetation are represented in red color. Surfaces

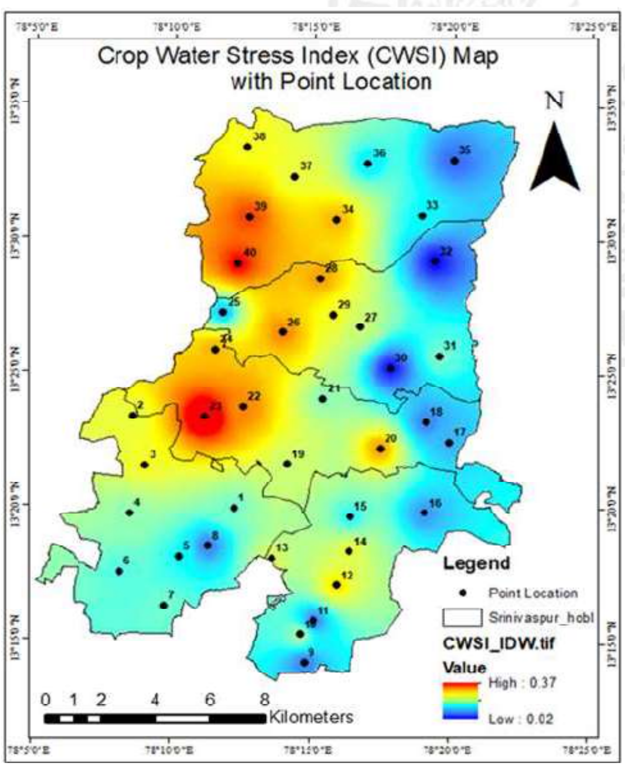

Fig. 4 : CWSI map of Srinivasapura taluk showing lowest (dark blue) and highest (red) CWSI values along with point locations where T_c measurements were made (ground truth)

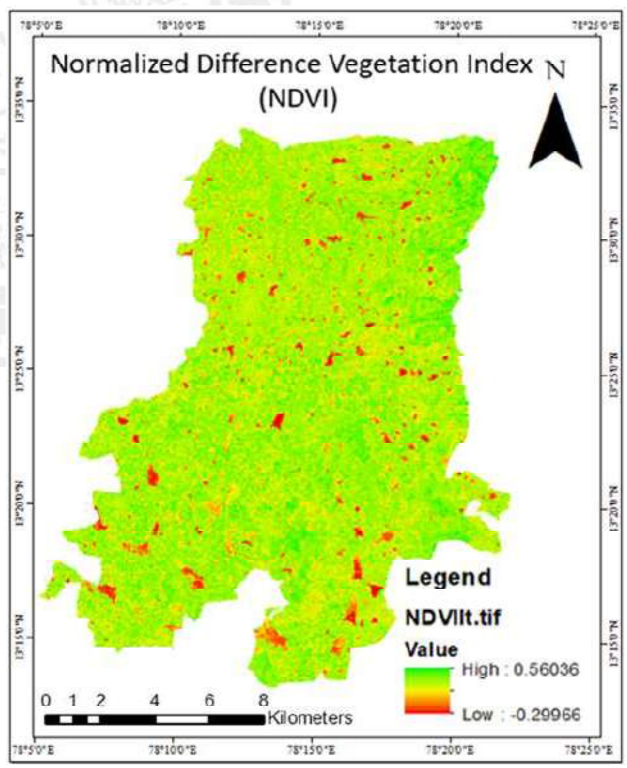

Fig. 5 : NDVI map of Srinivaspur taluk that was used estimate the proportion of vegetation. Lowest values (red colour) indicate water bodies and high values represent good healthy vegetation cover

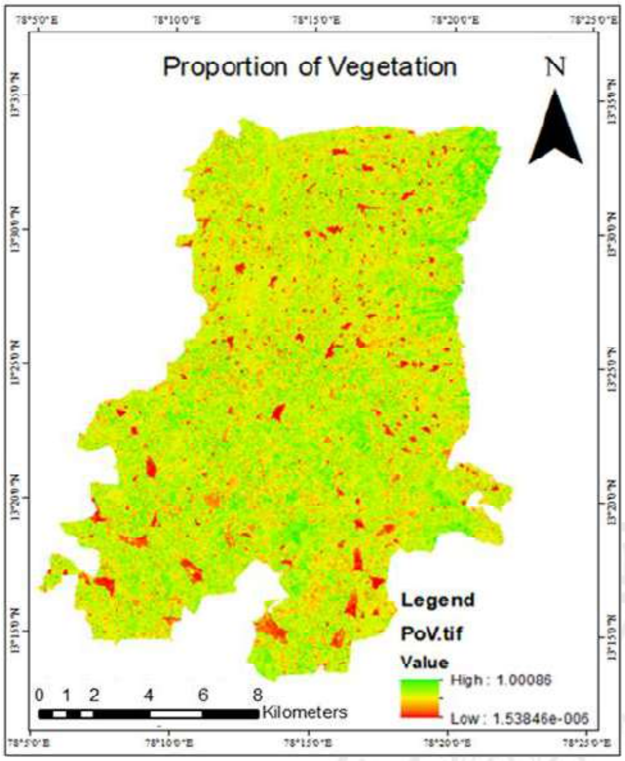

Fig. 6 : Proportion of Vegetation (PV) map of Srinivaspur taluk

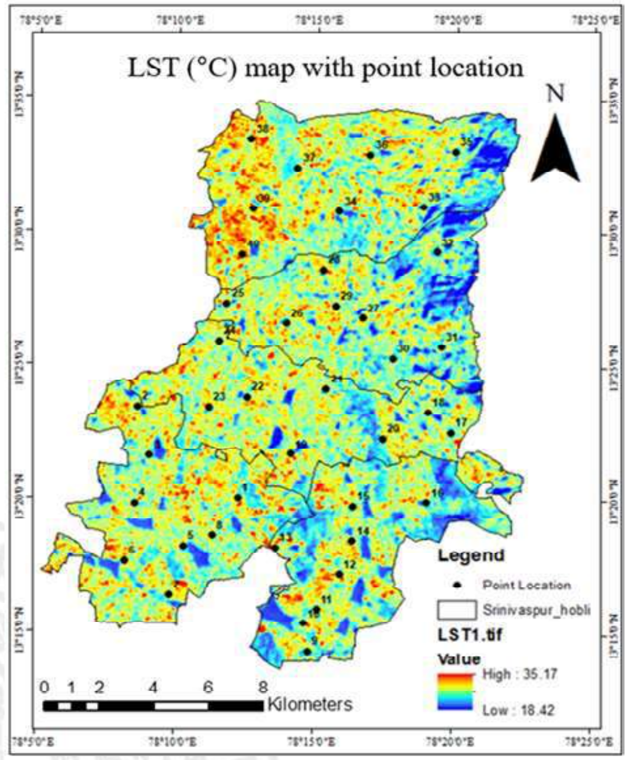

Fig. 7: Land Surface Temperature (LST) map of Srinivaspur taluk

which have dense green cover including horticulture and other plantation / tree cover types are represented in green color (PV is higher in those pixels).

LST map: The LST map generated for the study area is shown in Fig.7. The LST of water and dense vegetation ranged between 18 to 29 degrees

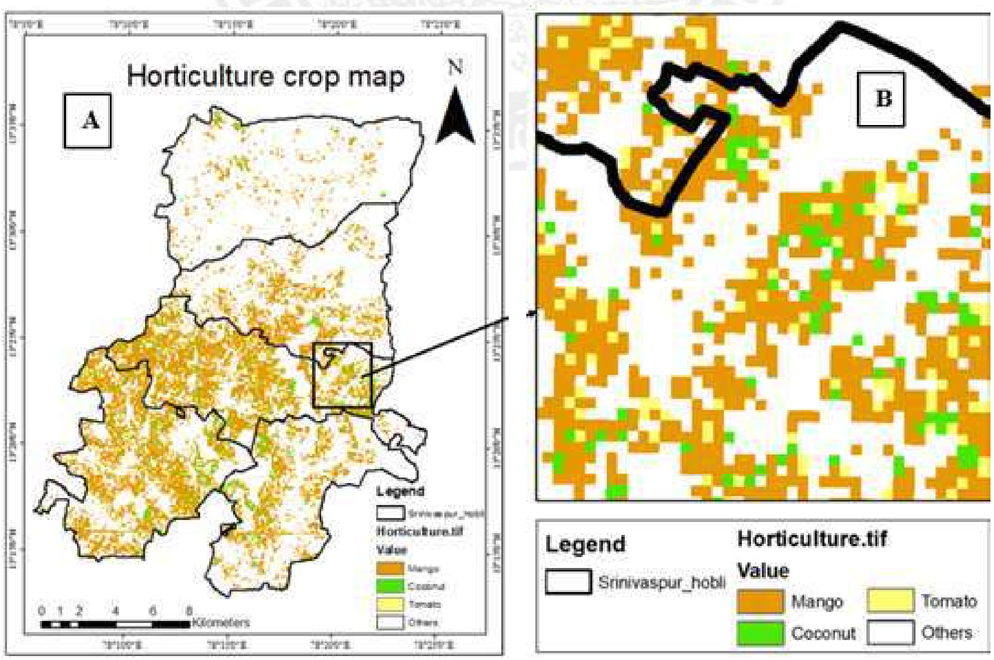

Fig. 8 : Horticulture crop map of Srinivaspur taluk (A) and a part of it enlarged (B)

centigrade, due to evaporation from water and transpiration from vegetation, which are represented as shades of blue in colour. Built-up, open space and water-stressed vegetation appeared in higher temperature range (30 to 35 degree centigrade), may be due to emitted heat from built-up and lower transpiration rate from vegetation, represented in shades of yellow and red colour.

Horticulture crop map: The horticulture crop map, a part of it enlarged (Fig. 8) shows three major horticulture crops in the study area. Among them Mango is the most dominant followed by Tomato and Coconut.The horticulture crop map shown here has an accuracy of 90 per cent at 0.81 kappa coefficient.

CWSI map for horticulture area: The CWSI map extracted for horticulture areas and part of it enlarged is shown in Fig. 9. The CWSI values have been categorized into 5 groups: very low (0.02 - 0.07), low (0.08 - 0.14), moderate (0.15 - 0.21), high (0.22 - 0.28) and very high (0.29 - 0.37). Very low and low represented in shades of blue colour (low or no water stress), moderate CWSI values represented in yellow colour. High and very high CWSI values in shades of red and orange colour (water stressed crop area as a result of inadequate irrigation or rainfed horticulture crop).

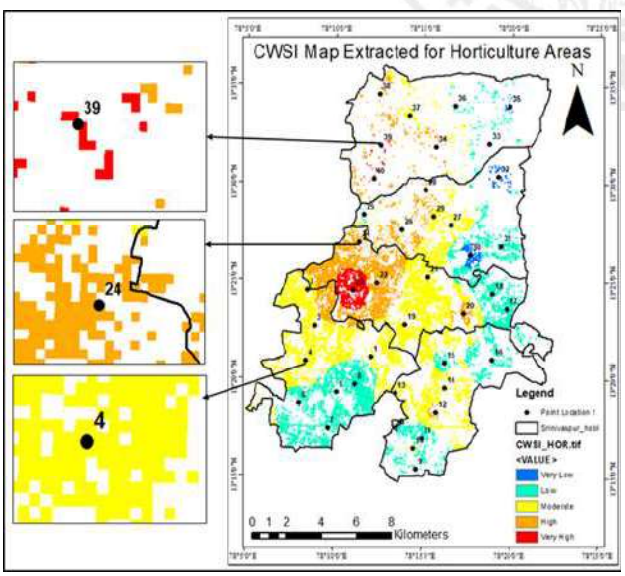

Fig. 9 : CWSI map extracted for horticulture areas of Srinivaspur taluk

LST map for horticulture area: LST map extracted for horticulture areas and a part of it enlarged (Fig. 10). The LST values have been categorized into five groups: very low (23°C - 24°C), low (25°C - 26°C), moderate (27°C - 28°C), high (29°C - 30°C) and very high (31°C - 32°C). The low and very low LST values(23°C to 26°C) indicate healthy horticulture crop that are transpiring normally without any water stress (shades of blue colour). Horticulture crops having lower rate of transpiration due to inadequate irrigation or rainfed conditions showed higher temperatures ranging from 29°C to 32°C (shades of red and orange colour).

The Comparison between CWSI and LST: It may be noted from the Fig. 9 and 10 and the enlarged insets that at point location 39, the values of CWSI (very high) and LST (high) are fairly comparable confirming that the horticulture crops there are affected by water stress. At point location 24, the CWSI value (high) and LST values (low to very high) indicate medium to high water stress affected horticulture gardens. At point location 4, both CWSI and LST are moderate and low respectively indicating that the horticulture crop area is experiencing low water stress. Such comparisonmade for 40-point locations showed 27 per cent perfect match, 37.5 per cent almost matching, 22.5 per cent fairly matching and 12.5 per cent not

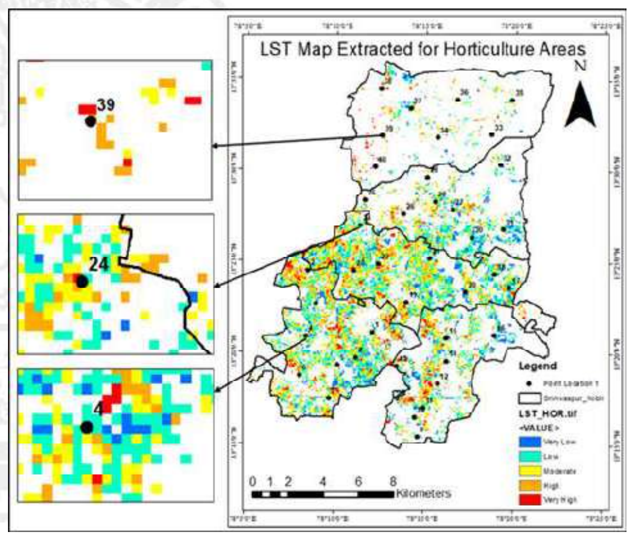

Fig. 10 : LST map extracted for horticulture areas of Srinivaspur taluk

matching. It may be noted that the results are highly encouraging not with standing the fact that the comparison is between ground-based point locations with the spatial data generated from satellite sensors having spatial resolution of 100 meters resampled to 30 meters.

In the present study the CWSI calculations were made based on point data collected by an IR thermometer having temperature measurement range between -50ºC to 400ºC with an accuracy of +/- 1.5ºC. On the other hand, the map showing area under horticulture crops was prepared using 20-meter spatial resolution data from Sentinel 2A MSI. The LST map was prepared using Landsat-8 OLI having spatial resolution of 30 meters and TIR sensors having 100 meters spatial resolution resampled to 30 meters. The use of multiple sensors from different satellites with varied spatial resolutions and comparing the same with point data resulted in some mismatch which is not surprising. Further studies can be carried out based on collecting a larger number of ground truth points appropriate for the spatial resolution of remotely sensed data.

Handheld infrared thermometry has been found to be a good tool to measure canopy temperature of horticulture crops and concurrent air temperature as point data. The observed canopy temperature was ranging between 28.3ºC to 39.3ºC and that of air ranged from 32.1ºC to 42.6ºC in the month of April-May 2022. The CWSI was found to vary between 0.02 (no water stressed horticulture crop areas) to 0.37 (water stressed horticulture crop areas). The horticulture crop map prepared using Sentinel 2A MSI data gave an accuracy of 90 per cent at 0.81 kappa coefficient. The NDVI derived from Landsat-8 OLI helped in calculating fraction of vegetation cover that was used to estimate emissivity which is an important step in generating LST. Two overlay operations: i) involving CWSI map and horticulture crop map and ii) LST with horticulture map - enabled accurate identification of horticulture crops affected by water stress (accuracy of 87.5%) into 5 levels of stress: Very Low, Low, Moderate, High and Very High. It is hoped that the study would help the farmers and researchers to utilize thermal sensors, either hand-held or satellite-borne, for practicing precision irrigation management in horticulture.

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