# Comparison of satellite image-based vegetation indices for extraction and mapping of litchi (*Litchi Chinensis*) cultivation area in Muzaffarpur district, Bihar, India

**Bhartendu Sajan[1], Varun Narayan Mishra[2]**

[1]*Centre for Climate Change and Water Research*
*Suresh Gyan Vihar University, Jaipur-302017, Rajasthan, India*
*sajanthakur4994@gmail.com*
[2]*Centre for Climate Change and Water Research*
*Suresh Gyan Vihar University, Jaipur-302017, Rajasthan, India*
*varunnarayan.mishra@mygyanvihar.com*

***Abstract:*** ***The aim of present study was to evaluate the suitability of various vegetation indices (VIs) to extract litchi cultivation area in Muzaffarpur district of Bihar, India. VIs computed from the multispectral bands of Landsat satellites have been used in delineating litchi cultivation areas from other land cover categories. In this study, ten selected VIs have been applied and compared their effectiveness in litchi cultivation area mapping for years 2016 and 2020 respectively. The results showed that the Normalized Green Blue Difference Index (NGBDI) was found to be most appropriate for extracting and mapping the litchi cultivation area. The area statistics of litchi cultivation was validated and are in closer correspondence with the data reported by the state horticulture department. It was found that the area of Litchi cultivation field is increased from 10272.79 ha to 10400.63 ha during the period of 4 years (2016-2020) in the area under investigation. The spatial distribution maps of litchi fruit represent a vital reference suitable for developing a regional action plan to promote its cultivation and benefits to farmers.***

***Keywords:*** **Litchi, Satellite image, Vegetation Indices, Accuracy, Landsat 8.**

**(Article history: Received: March 2022 and accepted May 2022)**

## I. INTRODUCTION

India is the second largest producer of Litchi (*Litchi chinensis*) with the production of 594,000 metric tonnes in area of 84 thousand hectares as per ICAR- National Research Centre on Litchi [ICAR-NRCL]. Litchi is a delicious juicy fruit and one of the popular fruits among all-horticulture crops. It is also a part of Coordinate Horticulture Assessment of Management using geoinformatics (CHAMAN) project. Bihar is the highest Litchi producing state in India with varieties such as Shahi, Purbi, China, etc. Muzaffarpur district of Bihar is world renowned for a variety of litchi with GI tag as 'Shahi Litchi' according to Geographical Indications Registry by Ministry of Commerce and Industry, Govt. of India (http://www.ipindia.nic.in/registered-gls.htm). In India, orchards consist of trees planted in a regular or irregular pattern, with other agricultural products, grass, or fallow covering the ground in between. As a result, there is a lot of heterogeneity within a single orchard field. Therefore, it is vital to adopt effectual technologies in mapping farmlands and orchard field at different observational scales with a high temporal coverage [1].

Remote sensing techniques provide both a synoptic view and frequent observation and have been used widely to provide up-to-date and reasonably reliable information for cropland mapping and management [2 – 5]. In the past, earth observation datasets acquired from Landsat series satellites have been utilized for identification and mapping other horticulture crops with reasonable accuracies [5 – 8].

The development of spatial, temporal, spectral and radiometric resolutions in space-borne remote sensing technology is successfully leading to more precise and intensified agricultural research [10 – 12]. In agriculture, these datasets provide not only an objective basis (depending on resolution) for macro and micro management of agricultural production, but also, in many cases, the information needed for crop yield estimation [13]. A number of studies on the discrimination of the plantation of fruit crops have been conducted in the past [7, 14, 15] compared the LISS-III and LISS-IV datasets for inventory development of banana and citrus orchards. Recently a study is reported by [9] for the discrimination of mango orchards using LISS IV images derived textural features. The applicability of remote sensing and the various VIs derived from these techniques, on the other hand, is often dependent on the instruments and platforms used to decide which solution is best for a given problem [10].

Simple VIs that combines visible and NIR bands have greatly improved the sensitivity of green vegetation detection [27]. When using different VIs, different environments have their own set of variable and dynamic characteristics that must be considered. As a result, each VI has its own green vegetation expression, suitability for particular uses, and some limiting factors [23] Thus, choosing a new VI for realistic applications should be done carefully by considering and evaluating the advantages and disadvantages of existing VIs, and then integrating them to be used in a specific setting [26]. The use of VIs can be adapted to particular applications, instrumentation, and platforms in this way. New VIs can be established with the advancement of hyper spectral and multi spectral remote sensing technologies, which will expand research areas [17].

Vegetation indices are a useful tool for monitoring vegetation cover, growth cycle, and yield estimation, and they may also be used to better manage horticulture crops. Our basic thought for analysing the vegetation indices reviews was to collect the VIs in terms of agricultural applications [26]. The vegetation indices are formed to focus on different properties of the vegetation and provide information about bio-mass, leaf area, and plant health, based on calculations of different bands of the electromagnetic spectrum [27]. Additionally, the usage and applications of VIs in precision agriculture were investigated.

Following a thorough search of the literature, we discovered that no previous study has used vegetation indices to extract Litchi cultivation area. As a result, this is the first study to extract the Litchi cultivation area using several vegetation indices. This study aims to analyse and compare various vegetation indices for their potential to extract Litchi cultivation area using multi-temporal Landsat images of the years 2016 and 2020. This work establishes a semi-automated approach using Landsat satellite data and associated vegetation indices to extract fine-scale Litchi cultivation area in Muzaffarpur district of Bihar, India. This research will be extremely valuable in agricultural planning, developing policies for Litchi producers, and managing and monitoring the Litchi crop regions. This knowledge is of critical significance for the department of horticulture management as well as for the farmers involved in Litchi cultivation.

## II. STUDY AREA

Muzaffarpur district is located between 25° 53′ N to 26° 25′ N latitude and 84° 50′E to 85° 45′ E longitude covering the geographical area of 3,175.9 km$^2$. It is one of the thirty-eight districts of Bihar state, India. The district lies in the fertile region of Gangetic plain. The litchi crop, which is available from May to June, is mainly cultivated in the Muzaffarpur and surrounding districts, in an area of about 15,800 hectares producing about 230,000 tonnes every year. Muzaffarpur is famous for Shahi litchi and known as the Litchi Kingdom. Shahi litchi is set to become the fourth product from Bihar, after jardalu mango, katarni rice and Magahi paan (betel leaf) to get the Geographical Indication (GI) tag. The location map of the study area is show in Fig. 1.

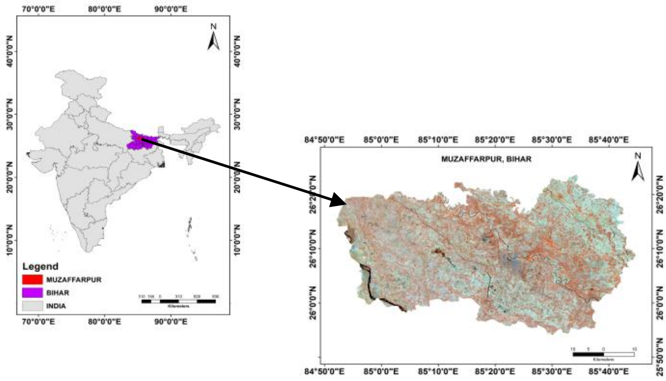


Fig. 1. Location Map of the Study area.

## III. MATERIALS AND METHODOLOGY

### A. *Data used*

In this study, satellite data of Landsat-8 OLI acquired on 23 May, 2016 and 13 May, 2020 were used and analysed. The path and row are 141 and 42 respectively. Satellite datasets were collected from the official website of United States Geological Survey (http://glovis.usgs.gov). The extensive ground truth of Muzaffarpur district, including field information of litchi cultivation, was collected with the assistance of hand-held GPS. Field data collection was performed to develop training samples to be utilized in classification and mapping stage.

### B. *Methodology*

#### i. *Image pre-processing*

Pre-processing of satellite images prior to change analysis is critical in order to develop a more direct link between the acquired data and bio-physical processes [24]. The multi-temporal datasets were first imported and layer stacked to generate false colour composite (FCC) using bands 4, 3 and 2 for all the images. All the Landsat images were geometrically and atmospherically corrected to improve the analyst's ability of interpretation. It is necessary to execute geometric rectification to derive spatially corrected thematic maps. So, all the Landsat images were co-registered through the process of image-to-image registration. The first-degree polynomial equation and nearest-neighbour resampling technique was applied during the course of image transformation.

The satellite images were processed for atmospheric correction and converted into the top of atmosphere (TOA) reflectance. It is a unitless measurement which provides the ratio of reflected radiation to the incident solar radiation on a given surface. By converting raw DN values to TOA and surface reflectance, the atmospheric impacts on the reflected wavelengths are removed so that the desired indices can be derived for further use.

*ii. Vegetation indices (VIs)*

Since different vegetation indices shows different properties for distinguishing vegetation categories and other land cover features. In this study ten different vegetation indices such as normalized difference vegetation index (NDVI), visual atmospheric resistance index (VARI), difference vegetation index (DVI), Generalized Difference Vegetation Index (GDVI), ratio vegetation index (RVI), green ratio vegetation index (GRVI), normalized difference short wave based vegetation index (NDSBVI), green normalized difference vegetation index (GNDVI), infrared percentage vegetation index (IPVI), normalized green blue difference index (NGBDI) have been applied to extract and map litchi cultivation area in Muzaffarpur district.

*a. Normalized Difference Vegetation Index (NDVI):*

NDVI is a simple graphical indicator that can be used to analyse remote sensing measurements, often from a space platform, assessing whether or not the target being observed contains live green vegetation [18]. It is the most widely used VI and can be calculated using the surface reflectance of red (R) and near-infrared (NIR) bands given as:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}} \qquad (1)$$

*b. Visual Atmospheric Resistance Index (VARI)*

VARI was originally designed for satellite imagery. It's minimally sensitive to atmospheric effects, allowing for vegetation to be estimated in a wide variety of environments [12] As sunlight reaches the earth's atmosphere, it is scattered in all directions by the gasses and particles in the air. But blue light tends to scatter more than all the other colours because it travels in smaller wavelengths than the rest of the visual spectrum. This vegetation index accounts for presence of blue in its calculation of spectral data. It can be calculated using the surface reflectance of green (G) and red (R) bands as below:

$$VARI = \frac{(\mathrm{G} - \mathrm{R})}{(\mathrm{G} + \mathrm{R} - \mathrm{B})} \qquad (2)$$

*c. Difference Vegetation Index (DVI)*

The DVI is very sensitive to the changes in soil background and can be applied to monitor the vegetation ecological environment [24] So, DVI is also called as environmental vegetation index (EVI). It can be calculated using the surface reflectance of near-infrared (NIR) and red (R) bands as given below:

$$DVI = NIR - RED \qquad (3)$$

The DVI is extremely sensitive to the changes in soil backdrop. It can be used to track the vegetation's biological environment and is simpler than the NDVI.

*d. Generalized Difference Vegetation Index (GDVI)*

GDVI shows a better correlation with the leaf area index (LAI) and has higher sensitivity and dynamic range in the low vegetated land cover than other vegetation indices. The range of GDVI is higher than the NDVI. It can be calculated using the surface reflectance of near-infrared (NIR) and green (G) [19] bands as given below:

$$GDVI = NIR - GREEN \qquad (4)$$

*e. Ratio Vegetation Index (RVI)*

RVI is one of the first VI proposed by [12] It is based on the principle that leaves absorb relatively more red than infrared light. RVI can be expressed by using the surface reflectance of near-infrared (NIR) and red (R) bands as given below:

$$RVI = RED/NIR \qquad (5)$$

*f. Green Ratio Vegetation Index (GRVI)*

This index is sensitive to photosynthetic rates in forest canopies, as green and red reflectance are strongly influenced by changes in leaf pigments. GRVI can be expressed by using the surface reflectance of near-infrared (NIR) and green (G) [19] bands as given below:

$$\mathrm{GRVI} = \mathrm{NRI/GREEN} \qquad (6)$$

It is sensitive to photosynthetic rates in vegetation canopies, as green and red reflectance are strongly influenced by the changes in leaf pigments.

*g. Normalized Difference Short Wave Based Vegetation Index (NDSBVI)*

It is used for an automatic extraction of annual cropland types and to discriminate plantation from crop. This index uses the reflectance value from Red (R), near-infrared (NIR) and short-wave infrared (SWIR) [10] It can be expressed as:

$$\mathrm{NDSBVI} = \frac{\mathrm{SWIR} - \mathrm{R}}{\mathrm{SWIR} + \mathrm{R}} \quad (7)$$

*h. Green Normalized Difference Vegetation Index (GNDVI)*

It is a vegetation index for estimating photo synthetic activity and a commonly used vegetation index to determine water and nitrogen uptake into the plant canopy [9] GNDVI can be expressed as:

$$\mathrm{GNDVI} = \frac{\mathrm{NIR} - \mathrm{G}}{\mathrm{NIR} + \mathrm{G}} \quad (8)$$

*i. Infrared Percentage Vegetation Index (IPVI)*

[24] recognized that the red radiance subtraction in the numerator of NDVI formula was irrelevant and proposed the infrared percentage vegetation index (IPVI). It can be calculated as given below:

$$\mathrm{IPVI} = \frac{\mathrm{NIR}}{\mathrm{NIR} + \mathrm{R}} \quad (9)$$

*j. Normalized Green Blue Difference Index (NGBDI)*

NGBDI is suitable for the extraction of vegetation from the image, because there was little overlapping [21]. This index uses the reflectance value from green (G), and blue (B) bands. It can be expressed mathematically as:

$$NGBDI = G - B/G + B \quad (10)$$

*iii. Classification method*

The classification of litchi and other categories was performed using supervised maximum likelihood classification (MLC) method. MLC is a widely used classification method based on the assumption of normal distribution of each spectral category. It uses the training signatures captured directly from the satellite image to be classified. On the other hand, the effectiveness of MLC relies on exact assessment of the mean vector along with the covariance matrix for every spectral category data [22]. The training signatures for recognized categories are created by the analyst and then the classifier assigns each pixel to the class for which the signature is most comparable [23] In this study, the satellite datasets were classified into three classes such as litchi cultivation area, crop land, and non-crop land.

*iv. Accuracy assessment*

Accuracy assessment is one of the most critical elements in the classification process [9] The goal of accuracy assessment is to determine how well pixels were sampled into the appropriate land cover groups. Furthermore, locations that could be readily identified on Landsat image and Google earth were prioritised for the selection of testing samples in accuracy assessment. The error matrix-based statistics are commonly utilized to evaluate the classification results. Thus, overall accuracy (OA), producer's accuracy (PA), and user's accuracy (UA) are then computed from the error matrix. In this study accuracy assessment is performed for the thematic maps of years 2016, and 2020 respectively.

## IV. RESULTS AND DISCUSSION

Satellite data of years 2016 and 2020 have been used for calculating different vegetation indices to extract Litchi cultivation area. We have used ten different vegetation indices such as NDVI, VARI, DVI, GDVI, RVI, GRVI, NDSBVI, GNDVI, IPVI and NGBDI to extract litchi cultivation areas in Muzaffarpur district. The characteristics curve of landscape categories including litchi cultivation area, agricultural land, fallow land, built up land, bare land, wetland, water bodies using different VIs are shown in Fig 2.

Fig. 3 shows NDVI maps for years 2016 and 2020. NDVI is not showing very good results to extract litchi cultivation area because of its mixing with other categories in the study area. The area statistics of litchi cultivation using NDVI is 54612 hectares for year 2020. In Figure 2 the graphical representation of the value range of NDVI for litchi cultivation is not separable from other landscape categories.

Fig. 4 shows the VARI maps which is intended to highlight vegetation in the visible spectrum while minimising the illumination differences and atmospheric impacts. In this study VARI based area statistics of litchi cultivation was found to be 320516 hectares in year 2020. The value ranges of VARI for litchi cultivation is mixing with agriculture crop and wetlands.

Fig. 5 shows DVI maps for years 2016 and 2020. In this study DVI provided quite good results than other indices. But it is not suitable to extract litchi cultivation area more accurately because it mixed up with agricultural land and other vegetation classes. Total litchi cultivation was calculated as 210123 hectares by using DVI for year 2020. The value ranges of DVI for Litchi cultivation area is mixing with agriculture crop field and other classes as well.

GDVI based maps of litchi cultivation area for the years 2016 and 2020 are shown in Fig. 6. The values of GDVI for litchi cultivation area is found to be overlapped with that of agricultural land and other classes.

Fig. 7 shows the RVI maps for the year 2016 and 2020. In this index, the total area of litchi cultivation based on RVI is 34,567 hectares. The value ranges of RVI for litchi cultivation area is slightly mixing with other classes.

GRVI based maps of litchi cultivation area for the years 2016 and 2020 are shown in Fig. 8. The calculated litchi cultivation area based on GRVI is 31,014 hectares for year 2020. The value ranges of litchi cultivation area are slightly mixing with wetlands categories.

Fig. 9 shows the NDSBVI maps for the year 2016 and 2020. The NDSBVI values for litchi cultivation are found to be mixed with wetland category. The total litchi cultivation area calculated based on NDSBVI and found to be 20346 hectares for the year 2020.

GNDVI based maps for the years 2016 and 2020 are shown in Figure 10. The calculated area of Litchi cultivation based on GNDVI was found to be 18164 hectares for the year 2020. The values of GNDVI for litchi cultivation areas mixed with that of agricultural land leading to the variation in actual area.

Fig. 11 shows the IPVI maps for the years 2016 and 2020. The total Litchi cultivation area based on IPVI is calculated as 18,915 hectares in Muzaffarpur district which is different from the actual statistics of 10,970 hectares. This difference is due to the mixing of litchi cultivation area with wetlands and other categories.

The NGBDI based maps of years 2016 and 2020 are shown in Figure 12. The value ranges of NGBDI for different categories are shown in Fig. 12. The value ranges of NGBDI are very well separable from other landscape categories. Total area of litchi cultivation based on NGBDI is computed to be 10,400.63 hectares for the year 2020. It is closely resemblance with the statistics of the litchi cultivation as 10,970 hectares for the year 2020 reported by the Department of Horticulture, Government of Bihar. NGBDI is found to be most effective and reliable index among all in extracting the litchi cultivation area.

The comparative analysis of the ranges of spectral values of different VIs for various landscape categories are examined. It is observed that the spectral value of litchi crop is mixing with other categories for different indices including NDVI, GNDVI, RVI, GRVI, DVI, GDVI, VARI, NDSBVI, and IPVI. So, it is difficult to extract litchi cultivation area using the indices having mixed spectral values. Only the NGBDI is showing the separable spectral response curve for litchi crop and other categories. The value range is also different from other classes. As a result, NGDBI provided most reliable result and found to be more effective in extracting litchi cultivation area. On the basis of NGBDI, litchi cultivation area is calculated to be 10272.79 hectares and 10400.63 hectares in years 2016 and 2020 respectively. The litchi cultivated area increased between 2016 to 2020 by 127.84 hectares. The reasons behind increment in litchi cultivation area may be the economic importance of Litchi. Other reason may be the climatic condition of Muzaffarpur district which is very suitable the litchi cultivation. In this study, the estimated area of litchi cultivation is validated with the statistics reported by the department of Horticulture, Government of Bihar and it is found to be almost same.

### *A. Accuracy assessment and spatial distribution of litchi cultivation*

Table 1 shows the overall classification accuracy for MLC based classified maps of 2016 and 2020 considering agricultural land, non-agricultural land and litchi cultivation area. The OA was found to be 72.82% and 73.40% for years 2016 and 2020 respectively. Detailed information about the UA and PA for the litchi cultivation area, agricultural land, and non-agricultural land are given in Table I.

TABLE I. ACCURACY ASSESSMENT RESULTS OF MLC-BASED CLASSIFICATION

| **Year** | **Classes** | **UA (%)** | **PA (%)** | **OA (%)** |
|---|---|---|---|---|
| 2016 | Agricultural land | 66.67 | 62.50 | 72.82 |
| | Litchi cultivation area | 80.00 | 77.42 | |
| | Non- agricultural land | 71.87 | 79.31 | |
| 2020 | Agricultural land | 71.87 | 63.88 | 73.40 |
| | Litchi cultivation area | 83.33 | 75.75 | |
| | Non- agricultural land | 65.62 | 80.76 | |

Further the spatial distribution of block wise litchi cultivation area is shown in Figure 14. The area statistics of litchi cultivation during 2016 to 2020 along with the statistics collected from the department of horticulture, Government of Bihar are shown in Table II.

Additional empirical studies should be executed by exploiting multispectral Landsat images and derived indices for yield prediction. Various data mining and statistical methods can also be applied to analyse several influencing factors. This work can further be explored by considering the socio-economic factors, weather conditions, soil properties etc. that affects the yield production of litchi fruit.

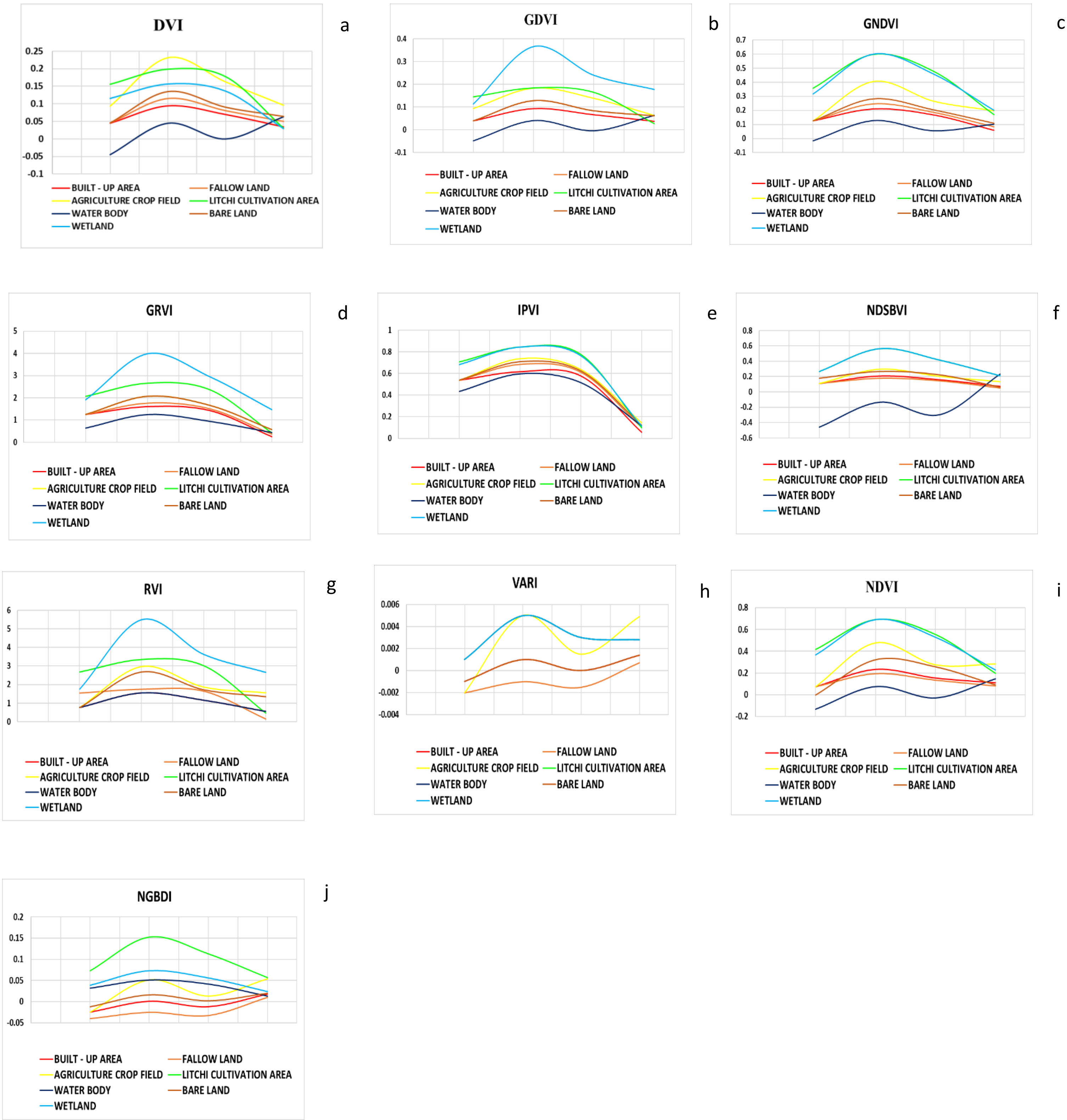


Fig. 2. Characteristics curve of landscape categories based on selected VIs

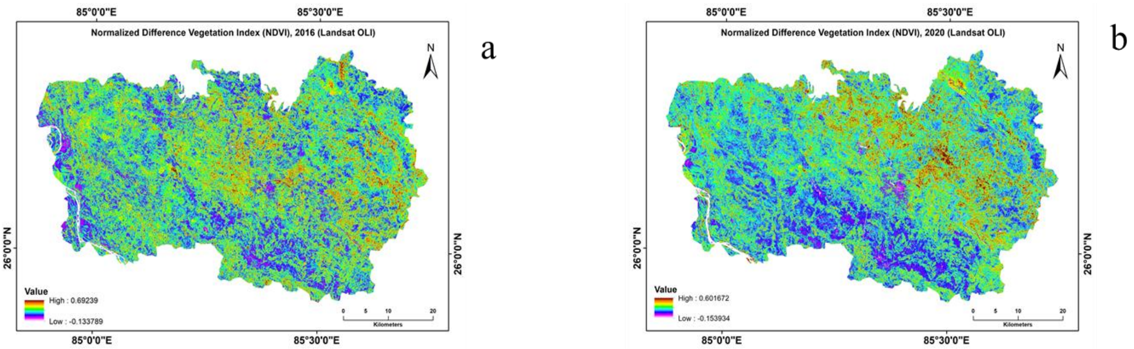


Fig. 3. NDVI maps for year (a) 2016; and (b) 2020

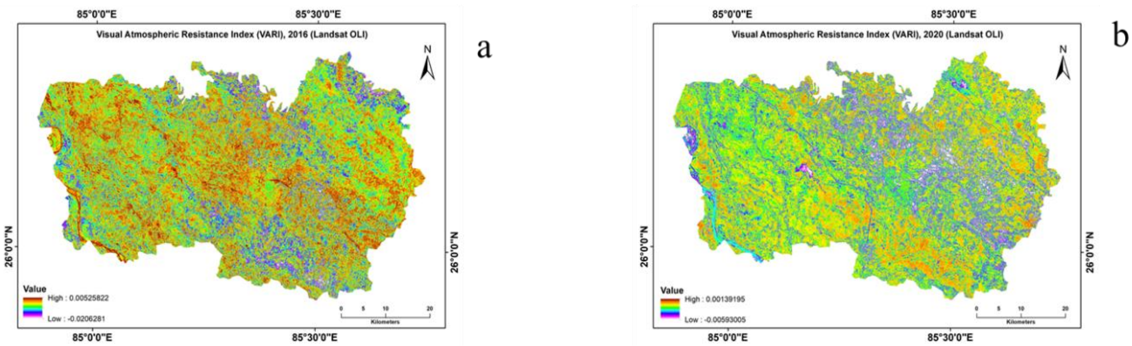


Fig. 4. VARI maps for year (a) 2016 and (b) 2020

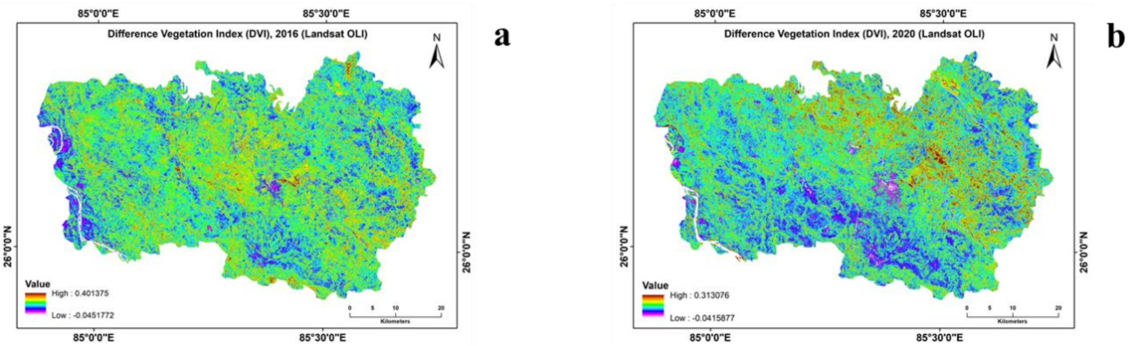


Fig. 5. DVI maps for year (a) 2016; and (b) 2020

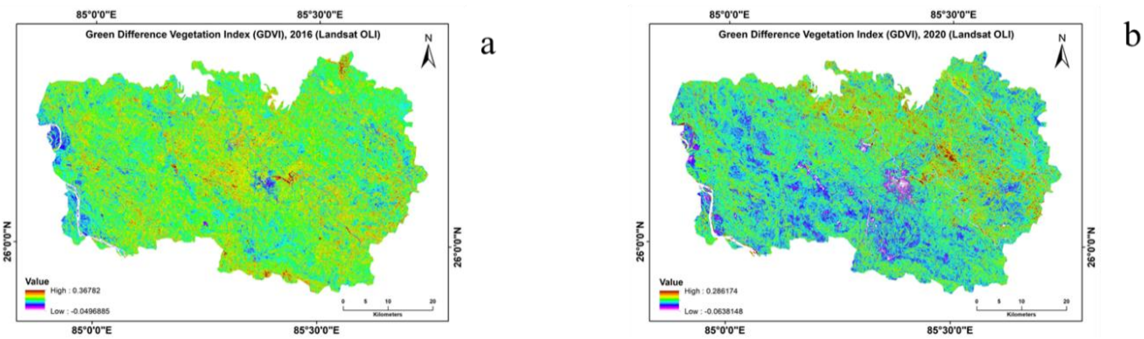


Fig. 6. GDVI maps for year (a) 2016; and (b) 2020

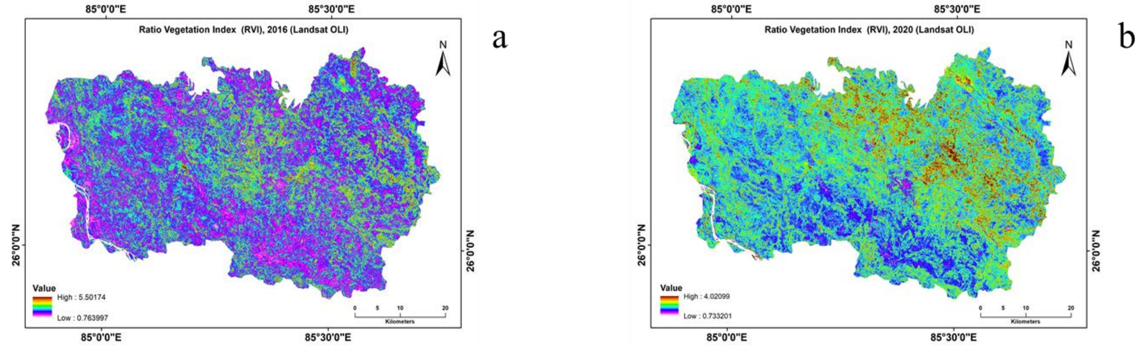


Fig. 7. RVI maps for year (a) 2016 and (b) 2020

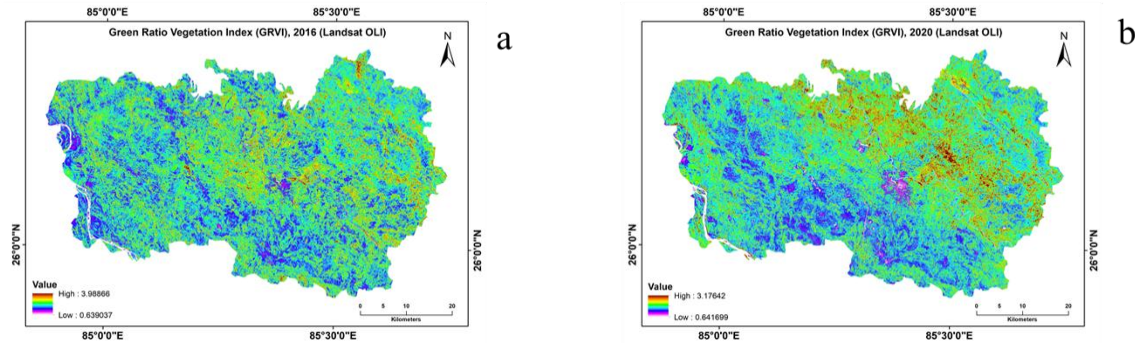


Fig. 8. GRVI map for year (a) 2016 and (b) 2020

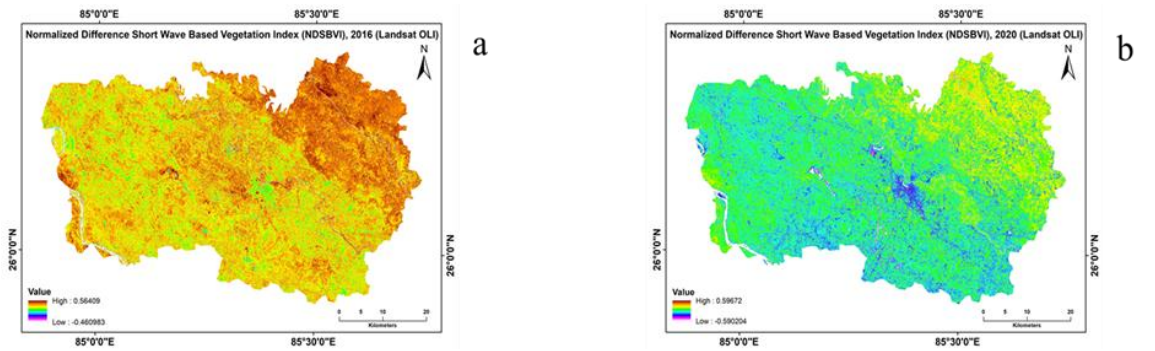


Fig. 9. NDSBVI maps for year (a) 2016; and (b) 2020

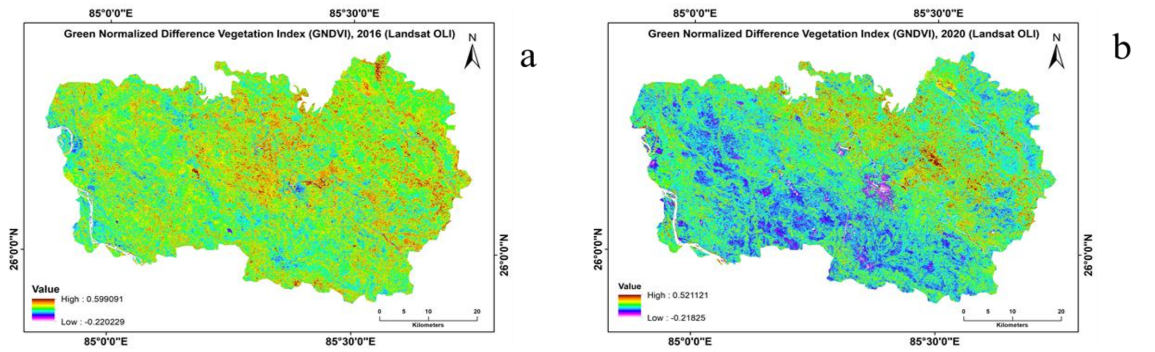


Fig. 10. GNDVI maps for year (a) 2016 and (b) 2020

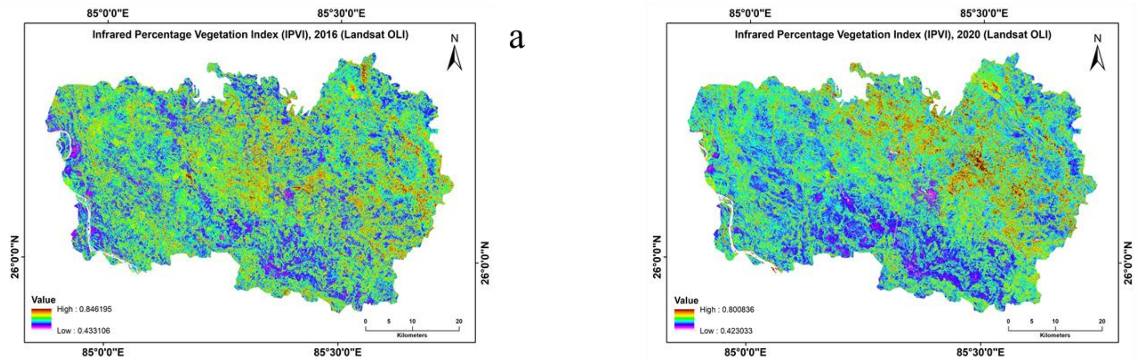


Fig. 11. IPVI maps for year (a) 2016 and (b) 2020

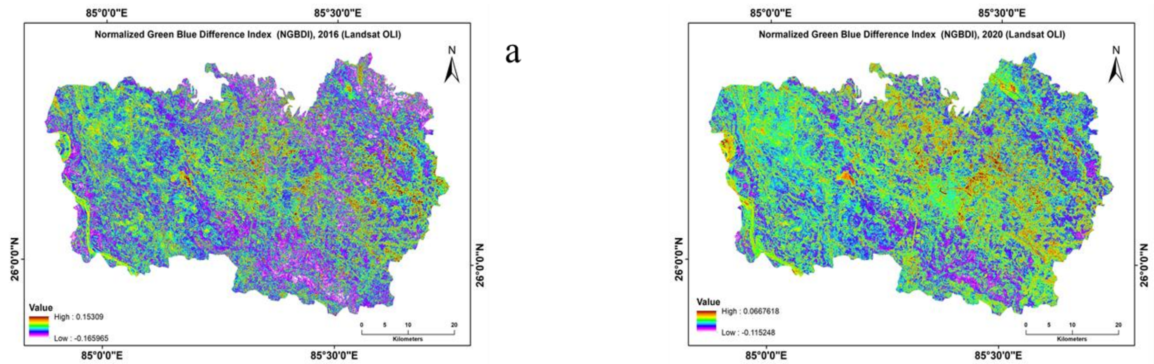


Fig. 12. NGBDI map for year (a) 2016 and (b) 2020

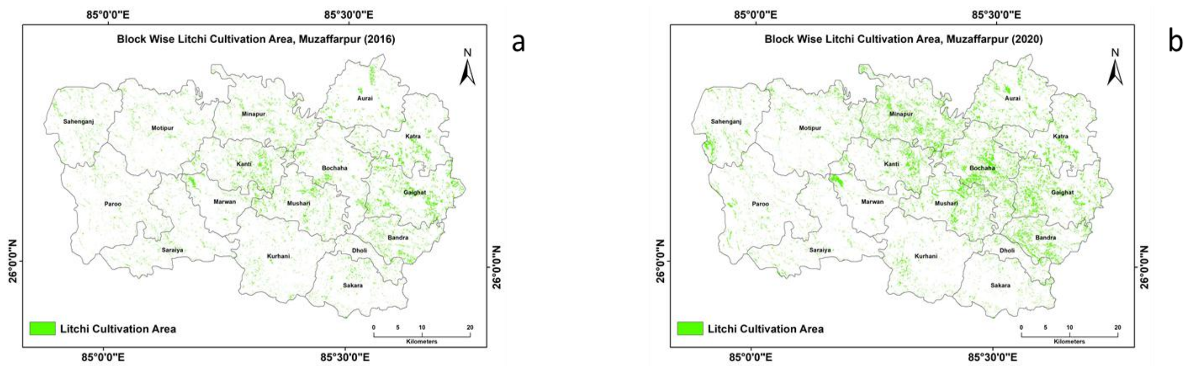


Fig. 13. Block wise Litchi cultivation area for the year (a) 2016, and (b) 2020

TABLE II: AREA STATISTICS OF LITCHI CULTIVATION FOR YEAR 2016 AND 2020

| S. No. | Block Name | Litchi cultivation area (hectares) | | | |
|---|---|---|---|---|---|
| | | Area statistics based on NGBDI | | Area statistics based on Department of Horticulture | |
| | | 2016 | 2020 | 2016 | 2020 |
| 1 | MUSHAHARI | 1115.21 | 1122.21 | 1132 | 1152 |
| 2 | MINAPUR | 1110.02 | 1115.02 | 1125 | 1145 |
| 3 | BOCHAHAN | 879.75 | 907.10 | 915 | 952 |
| 4 | AURAI | 490.55 | 504.05 | 514 | 514 |
| 5 | KATRA | 407.88 | 413.03 | 433 | 433 |
| 6 | GAIGHAT | 563.86 | 575.15 | 618 | 641 |
| 7 | MURAUL | 870.99 | 880.05 | 917 | 940 |
| 8 | SAKARA | 700.81 | 710.06 | 750 | 750 |
| 9 | KURHANI | 733.88 | 744.03 | 785 | 800 |
| 10 | KANTI | 810.7 | 815.93 | 860 | 900 |
| 11 | SARAIYA | 837.11 | 842.26 | 878 | 898 |
| 12 | PAROO | 753.36 | 761.99 | 806 | 806 |
| 13 | SAHEBGANJ | 590.94 | 598.79 | 609 | 609 |
| 14 | MOTIPUR | 407.73 | 410.96 | 420 | 430 |
| Total | | **10272.79** | **10400.63** | **10762** | **10970** |

## V. CONCLUSIONS

This work demonstrates a quick and effective approach to discriminate litchi cultivation areas using different vegetation indices based on multispectral Landsat 8 images of the years 2016 and 2020. When seen in the satellite images, litchi trees have distinct spectral pattern. A comparative assessment of the performance of different VIs is conducted to extract litchi cultivation area in the study region. Out of all tested VIs, NGBDI performed well in separating litchi cultivation area form other land cover categories. Other VIs showed mixed spectral pattern and failed to significantly extract the litchi cultivation area. The NGBDI showed totally different value ranges for litchi and other land cover categories. So, it is most suitable VI to extract Litchi cultivation area among all indices. An accurate and reliable information of litchi cultivation areas may provide both on-farm and off-farm work, allowing many people to make a livelihood option. Growing litchi on their homesteads provides an additional source of revenue for small and marginal farmers.

## VI. ACKNOWLEDGEMENT

Authors would like to express sincere thanks to USGS (United States Geological Survey) for free access to the Landsat satellite images used in this study. Authors gratefully acknowledge the Department of Horticulture, Government of Bihar for providing data of litchi cultivation area in Muzaffarpur district.

REFERENCES

[1] P. B. Shirsath, V. K. Sehgal and P. K. Aggarwal, "Downscaling regional crop yields to local scale using remote sensing.," Agriculture, vol. 10, no. 3, 2020.

[2] T. Sivasankar, P. K. Sharma, M. N. S. Ramya, P. Venkatesh, and G. D. Bairagi, "Evaluation of multi-temporal Sentinel-1 dual polarization SAR data for crop type classification," in Advances in Environmental Engineering and Green Technologies, Hershey, PA: IGI Global, 2020, pp. 44–61.

[3] V. N. Mishra, R. Prasad, P. Kumar, P. K. Srivastava and P. K. Rai, "Knowledge based decision tree approach for mapping spatial distribution of rice crop using C-band synthetic aperture radar derived information," J. Appl. Remote Sens., vol. 11, no. 4, 2017.

[4] F. Hannerz and A. Lotsch, "Assement of Remotely sensed and statistical inventories of African agriculture fields.," Int. J. Remote Sens., vol. 29, no. 13, pp. 3787-3804, 2008.

[5] C. Jin, X. Xiao, J. Dong, Y. Qin and Z. Wang, "Mapping paddy rice distribution using multi temporal Landsat imagery in the snajiang plain, northest China.," Front. Earth Sci., vol. 10, pp. 49-62.

[6] M. Schmidt, M. Pringle, R. Devadas, R. Denham and D. Tindall, "A frameworf for large area mapping of past and present cropping activity using seasonal Landsat images and time series matrics.," Remote Sens., vol. 8, no. 4, 312, 2016.

[7] V. Singh, A. N. Patel, A. Dalwadi, J. Kathota, J. Suthar and M. H. Kalubarme, "Horticulture fruit crop plantations mapping using geo-informatics in Gujrat state, India.," International Journal of Advanced Remote Sensing and GIS, vol. 6, no. 2, pp. 2033-2049, 2017.

[8] R. Nagori, "Discrimination of mango orchards in Malihabad, India using textural features.," Geocarto Int., vol. 36, no. 9, pp. 1060-1074, 2021.

[9] J. Liu, J. Shang, B. Qian, T. Huffman, Y. Zhang, T. Dong, Q. Jing and T. Martin, "Crop Yield Estimation Using Time Series MODIS Data and the Effects of Cropland Masks in Ontario, Canada.," Remote Sens., vol. 11, no. 20, 2019.

[10] S. Mondal, J. C., N. K. Sinha, H. Rajan, T. Roy and P. Kumar, "Extracting seasonal croping using multitemporal vegetation indices from IRS LISS-III data in Muzaffarpur District of Bihar, India.," Egypt. J. Remote Sens. Space Sci., vol. 17, no. 2, pp. 123-134, 2014.

[11] P. Kumar, R. Prasad, A. Choudhary, V. N. Mishra, D. K. Gupta and P. K. Srivastava, "A statistical significance of difference in classification accuracy of crop types using different xlassificatio algorithms.," Geocarto Int., vol. 32, no. 2, pp. 206-224, 2017.

[12] A. K. Mahlein, E. C. Oerke, U. Steiner and H. W. Dehne, "Recent advances in sensing plant diseases for precision crop protection.," Eur. J. Plant Pathol., vol. 133, pp. 197-209, 2012.

[13] A. Martynenko, K. Shotton, T. Astatkie, G. Petrash, C. Fowler, W. Neily and A. T. Critchley, "Thermal imaging of soybean response to drought stress: the effect of Ascophyllum nodosum seaweed extract.," Springer Plus., vol. 5, 1393, 2016.

[14] D. J. Mulla, "Twenty-five year of Remote Sensing in precision agriculture: key advance and remaining knowledge gape," Biosyst. Eng., vol. 114, no. 4, pp. 358-371, 2013.

[15] P. Kumar, D. K. Gupta, V. N. Mishra and R. Prasad, "Comparison of support vector machine, artficial neural, network, and spectral angle mapper algorithms for crop classification using LISS IV data.," Int. J. Remote Sens., vol. 36, no. 06, pp. 1604-1617, 2015.

[16] F. Hannerz and A. Lotsch, "Assement of Remotely sensed and statistical inventories of African agriculture fields.," Int. J. Remote Sens.., vol. 29, no. 13, pp. 3787-3804, 2008.

[17] F. Vuolo, G. D. Urso, C. D. Michele, B. Bianchi and M. Cutting, "Satellite based irrigation advisory servuces: a common tool for different experince from Europe to Australia," Agric. Water Manag., vol. 147, pp. 82-95, 2014.

[18] M. Usman, R. Liedl, M. A. Shahid and A. Abbas, "Land use/land cover classification and its change using multi-temporal MPDIS NDVI data.," J. Geogr. Sci., vol. 25, 2015.

[19] J. W. Rouse, J. R. H. Haas and J. A. Schell, "Monitoring vegetation system in the great plains with erts.," in Third Earth Resources Technology Satellite-, Washinton D.C., 1973.

[20] R. P. Sripada, R. W. Heiniger and J. G. White, "Aerial colour infrared photography for determining late season nitrogen requirements in corn.," Agronomy Journal, vol. 97, no. 5, pp. 1443-1451, 2005.

[21] J. Verrelst, M. E. Schaepman, B. Koetz and M. Kneubuhler, "Angular sensivity analysis of vegetation indices derived frpm CHRIS/PROBA data.," Remote Sens. Environ., vol. 112, no. 5, pp. 2341-2353, 2008.

[22] J. A. Richards, Remote sensing digital image analysis., vol. 5, Heidelberg: Springer, 2013.

[23] F. Orlando, E. Movedi, L. Paleari, C. Gilardelli, M. Foi, M. D. Oro and R. Confalonieri, "Estimating leaf area index in tree species using the Pocket LAI smart app.," Appl. Veg. Sci., vol. 18, no. 4, pp. 716-723, 2015.

[24] R. E. Crippen, "Calculating the vegetation index faster.," Remote Sens. Environ., vol. 34, no. 1, pp. 71-73, 1990.

[25] I. Pocas, T. A. Paco, P. Paredes, M. Cunha and L. S. Pereira, "Estimation of actual crop coefficients using remotely sensed vegetation indices and soil water balance modelled data.," Remote Sens-Basel, vol. 7, no. 3, pp. 2373-2400, 2015.

[26] R. Giovos, D. Tassopoulos, D. Kalivas, N. Lougkos and A. Priovolou, "Remote Sensing Vegetation Indices in Viticulture:," Agriculture, vol. 11, no. 5, 18 May 2021.

[27] J. L. Hatfield, J. H. Prueger, T. J. Sauer, C. Dold, P. O. Brien and K. Wacha, "Applications of Vegetative Indices from Remote Sensing to Agriculture: Past and Future," inventions, vol. 4, no. 4, 6 December 2019.

AUTHOR PROFILE

**Bhartendu Sajan**

M.A in Geography and PGDM in Remote Sensing and GIS from Banaras Hindu University, Varanasi. Currently pursuing Ph.D. from Centre for Climate Change and Water Research, Suresh Gyan Vihar University, Jaipur.

**Dr. Varun Narayan Mishra**

Currently working as an assistant Professor at Centre for Climate Change and Water Research, Suresh Gyan Vihar University, Jaipur. He Completed Ph.D. from IIT (BHU), Varanasi. He received his M.Tech. degree in Remote Sensing from Birla Institute of Technology, Mesra, Ranchi. His main research interests are digital image processing & analysis, machine learning techniques, land use/land cover mapping, land change analysis & modelling.