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Remote sensing and GIS based vegetable pea (*Pisum sativum* L.) Crop acreage estimation for Jabalpur district of Madhya Pradesh

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Abstract
Monitoring croplands accurately is crucial for making decisions such as managing crops, and crop damage claims handling, particularly within central India here because of the uncertainty of the weather, crop inconsistency is high. Vegetable Pea acting a crucial part in ensuring food & nutritional security of large number of vulnerable populations residing in central India. Many Asian countries include reliable data on the cultivated area for crops as part of their national vegetable production and supply accounting. To improve the accuracy of cultivated area assessments, these countries are increasingly turning to remote sensing tools. This study specifically focuses on using Remote Sensing (RS) and Geographical Information System (GIS) techniques for estimating area of vegetable pea cultivation within Jabalpur district, Madhya Pradesh. Accurately identifying the crop and estimating its acreage at the regional or district level requires high-resolution satellite data. Therefore, this study utilized Sentinel-2A satellite data for the analysis. The Maximum Likelihood Classification method was employed for satellite image classification. According to the RS and GIS analysis, the estimated area for the year 2021 is 31091.42 hectares.

Keywords: Vegetable pea, crop mapping, acreage estimation, supervised classification

Introduction
In Central India, the high variability in rainfall makes it highly vulnerable (Lohare *et al*., 2024) [8]. A study by Kumar *et al*. (2023) [5] emphasized a notable change in the seasonal rainfall pattern after 1998, which has encouraged scientists and decision-makers to focus on water-intensive agricultural methods and encourage climate adaptability in order to ensure a sustainable future for the area. In Madhya Pradesh, over 70% of the population living in villages depends directly or indirectly on agriculture for their livelihood (Lohare *et al*., 2025) [10]. Gumma *et al*., 2016 [3] and Gumma *et al*., 2020 [4] stated that the changing rainfall conditions over the years highlight the significance of croplands are constantly being observed to guarantee sustained agricultural output. Statistics and the amount of cropland at district scale are crucial for decision-making on agricultural insurance as well as ensuring food security and sustainable agriculture.
The increasing demand for food supply puts pressure on agricultural lands and disrupts the natural ecosystem as a consequence (Patil *et al*., 2017; Sharma and Seth 2010) [12, 13]. Globally, agricultural activities are a major concern for ecosystem degradation, making sustainable land management and monitoring of land use changes related to farming crucial issues (See *et al*., 2015; Sharma *et al*., 2015) [21, 15]. Crop mapping plays a significant role in sustainable agricultural practice and addressing environmental challenges caused by environmental issues in addition to other motivators. Crop categorization offers crucial data that is helpful in many agricultural resource management initiatives. Several global agricultural assessment systems have been working for decades. In their comparison of eight farming monitoring techniques, Fritz *et al*. (2013) [2] highlighted the lack of accuracy of crop type maps-which are thought to be of the greatest significance. Administrators and legislators need reliable and current crop coverage data in order to develop agriculture efficiently and promptly and to make crucial choices about publicly traded distribution, export purposes, importation, and other related matters. This is especially true if the crop area exhibits significant variation between years but the crop yield is usually steady.

India has a long history of producing quality data and an exceptional system of administration. Nevertheless, if regional plan becomes more important, more data with the crop region must be collected. This data may help the area develop quickly by revealing things like the types of crops cultivated there, the availability of irrigation, the type of soil, and so forth.

Biggs *et al*., 2006 [1] in their study highlighted that information on crop area gathered by several agencies, including the department of regional revenues, the agricultural sector, and water resources, typically exhibit discrepancies of up to 30%, indicating that the data does not accurately reflect the effective seasonally area grown. Precise data on the acreage of different crops is highly demanded for production estimates by policymakers (Lohare *et al*., 2023a) [6]. Statistical-based surveys by different department personnel on a manual basis are time-consuming and error-prone. Moreover, these manual-based statistical surveys for larger areas are unreasonable and inadequate. Because satellite imagery provides extensive coverage and a quick revisiting time for a given location, it is frequently utilized to estimate huge areas of cropland precisely (Wu and Li, 2012) [22].

Geospatial technology is often used to accurately map crops, with a focus on estimating crop acreage at local and countrywide scales. Previous research works have primarily concentrated for classifying small-scale crops using remote sensing, particularly utilizing Landsat satellite imageries with resolution of 30 m spatial basis. Researchers have also employed Indian Remote Sensing (IRS) series satellite imageries with resolution of one km spatial basis for crop mapping at the state or country level. However, coarse spatial resolution satellite data has limitations when it comes to mapping crops at the regional level, impacting the accuracy and assessment of crop area at district or regional scales. The emergence of Sentinel series satellite data, such as Sentinel-2 with its fine spatial resolution (10 m) and short revisit time (5 days), has opened up significant opportunities for regional crop mapping. Various researchers have evaluated the usefulness of Sentinel-2 satellite images for identifying different kinds of crops and usage in agriculture. They have applied this technology to estimate crop acreage for different crops in various regions around the world. Notably, there has been no study conducted in Central India for estimating the acreage of vegetable pea. The present study aimed to assess the possible use of Sentinel-2A satellite data for estimating acreage of vegetable pea in Jabalpur district for the year 2021. With agricultural insurance becoming more and more important in India and users needing access to spatial data about crop kind, health, and stress at the farm level, the main focus of the study was on mapping of crops for insured agriculture and crop productivity model. It has never been easy to accurately record the spatial diversity of crops in Central part of India, where a large number of crops are farmed in limited areas. The study addressed these challenges by focusing on gathering field data, interpreting it, performing quality assurance, and classifying it to produce the best outcomes. State agriculture agencies' area statistics and ground corroboration sites were used to validate the classification results.

Materials and Methods

Study area

Jabalpur district is situated within the Mahakausal region, Madhya Pradesh, spanning from 22° 49' 42" N to 23° 37' 5" N latitude and 79° 20' 56" E to 80° 35' 10" E longitude. Jabalpur is the largest city of Mahakausal region and lies in eastern part of Narmada basin. With a land area of 5053 km^2, the district has a population of approximately 2.46 million people, resulting in a population density of about 473/km^2. Known for its deep black cotton soil, the region is suitable for growing cereals, pulses, oilseed, and horticultural crops, with a humid subtropical climate typical of north-central India. The maximum temperature in May ranges from 40-43 °C, while the minimum temperature in January ranges from 8-10 °C. Jabalpur district’s average annual rainfall is 1358 mm, with 70% of total geographical area under cultivation and a total irrigated area of 28%. In addition to affecting agricultural output, landholding size also affects the precision of spatial maps prepared using satellite data. Using satellite data with high spatial clarity is crucial because of the significant variation in crops and smaller the ownership of land. Based on Agriculture Census Input Survey, marginal landholdings (less than 1 ha) account for around 17% of the total cultivated area in the Jabalpur districts, small holdings (1-2 ha) for 24% of the cultivated area, and semi-medium to medium-sized holdings comes out to be the remaining 59%. Sentinel-2 satellite data with a fine spatial resolution of 10 meters was chosen to map the small to medium-sized farm areas, which make up the major crop area of the district. Location map of the district can be depicted in Figure 1.

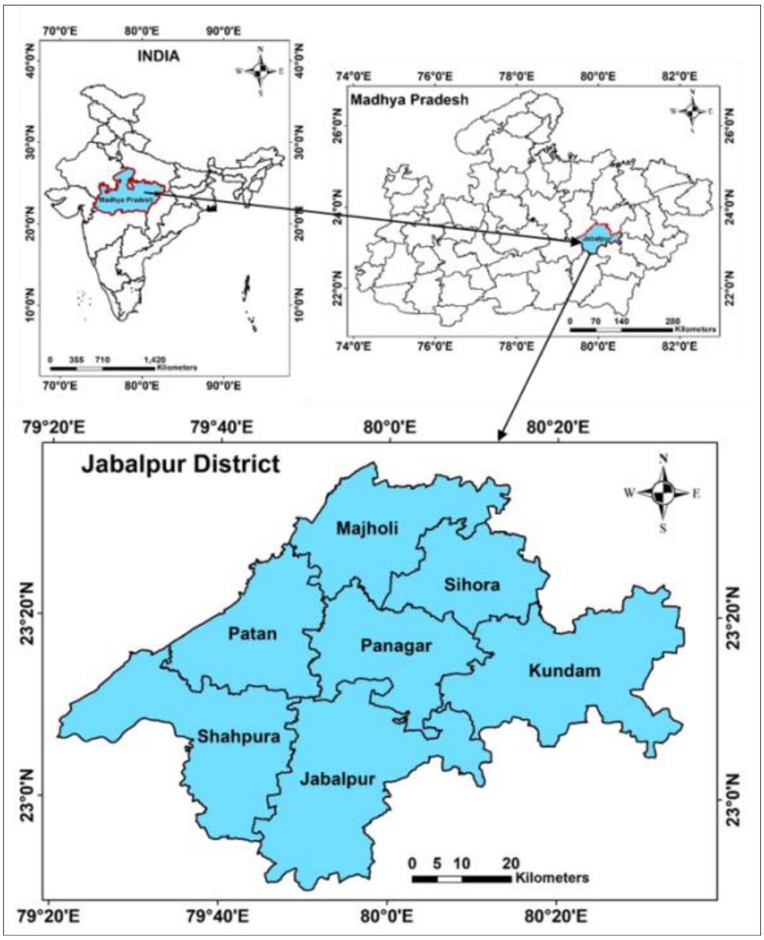

Fig 1: Location map of study area

In Jabalpur district, the principal crops sown during the Rabi season are vegetable peas, wheat, and gram. Vegetable Pea has been named the One District One Product (ODOP) for the region.

Sentinal-2A Data

The Sentinel-2A provides fine spatial resolution satellite data of 10 m and surface reflectance of 6-day through the E U Copernicus Program, making it suitable for fine-scale vegetation monitoring (Xiong, *et al*. 2017) [23]. For crop discrimination fine spatial resolution data is required So, for this study Sentinel-2 satellite data has been used. Bands 2, Band 3 Band 4 and Band 8 has 10 m spatial resolution and temporal resolution of 6 days which helps in crop identification. To cover the necessary region, we acquired four tiles from (https://scihub.copernicus.eu/). The tiles were pre-processed and mosaicked using ERDAS Imagine to create a single composite image.

Ground Data Collection

For data collection on the ground, we used the Global Positioning System (GPS) device to obtain accurate locations of earth features. The ground truth data was collected of study area during Rabi season 2021, which corresponds to the period when the satellite image was acquired. Specifically, we focused on areas where vegetable peas were predominantly grown and occupied extensive land. From 149 ground locations data of vegetable pea's fields' locations, along with 453 points for the Land Use/Land Cover (LULC) map distributed across the Jabalpur district. Ground truth information encompassed various classes including forest, water-bodies, agriculture, built-up/habitation areas, and lands occupied by fallow/open.

Methodology

Our research involved three main components: unsupervised classification using the ISODATA approach, estimation of crop acreage, and accuracy assessment. We evaluated the classification precision by analyzing a confusion matrix of the classification results. The following sections provide details on each of these components.

Unsupervised classification with ISODATA approach:

Unsupervised classification involves computer-assisted pixel-based classification, with the user determining the number of classes based on the spectral classes formed from numerical data in satellite images (Sharma *et al*., 2008) [16]. Utilizing clustering techniques, pixels are grouped according to their spectral matching in order to create a normal, statistical grouping of information. The computer automatically analyzes and groups the data into classes using feature spaces, although the user does not have control over certain inputs such as the number of classes, maximum iteration, and change threshold. Upon classification, the user must interpret, name, and color code the data according to the classes.

Unsupervised approaches are suitable for large areas with diverse vegetation types and challenging landscape variations that make finding homogeneous training sites difficult. In this study, the ISODATA algorithm was employed for unsupervised image pixel classification into spectral clusters, with each cluster representing a group of pixels in the input bands with similar spectral characteristics. ISODATA acted as an unsupervised classifier by recognizing multi-temporal patterns in the database. Following the unsupervised classification of the LULC map, its accuracy was assessed by overlaying ground truth points.

Estimation of crop acreage

In the past, crop area estimation relied solely on survey methods, which were time-consuming and required a lot of labour. However, advancements in science and technology have introduced new tools such as remote sensing, allowing for rapid observation of specific objects within a short timeframe. Maps of land usage and cover can be produced using remote sensing, and classified satellite imagery to estimate the area of any theme. Discriminating between different crop types is a crucial aspect of image classification. By incorporating satellite data as an auxiliary variable alongside survey data, the accuracy of area estimates can be enhanced at both the design and estimation levels. At the design level, satellite data is utilized for area frame construction and stratification, while at the estimation level, it is employed to improve previously developed estimators. In a recent study, crop acreage estimation was carried out using the ISODATA technique, an unsupervised classification method. The agricultural area was identified from the land use and land cover map, and a supervised classification approach was used to create a map specifically for vegetable pea crops, with the assistance of ground truth points. Additionally, an accuracy assessment of the crop map was conducted.

Accuracy Assessment

Assessing the accuracy or validating remote sensing data processing is an important step (Sharma *et al*., 2012) [15]. When comparing a classified image's accuracy with historical data, the most typical method is to show the percentage of the map region that has been properly categorized (Sharma *et al*., 2018) [20]. This claim can be verified by contrasting the precision of the grouping obtained from a sample of the information being classified displayed as a matrix of error, which is also occasionally called a confusion matrix or contingency table. Since it provides a straightforward means of determining the specific correctness of each class, an error matrix is a useful tool for illustrating the accuracy of the thematic map that is generated (Sharma *et al*., 2011) [14].

A matrix of error utilized to calculate different accuracy like user's accuracy and overall accuracy, (Patil and Sharma 2013; Lohare *et al*., 2023b) [11, 7]. By dividing the total number of investigated pixels in the classification by the sum of the entries in the "from-to" agreement of the error matrix, one may determine the overall accuracy for the picture classification (Sharma *et al*., 2016) [19]. The estimation of the kappa coefficient (k) is now a required part of nearly all accuracy evaluations (Sharma *et al*., 2014; Lohare *et al*., 2024) [17, 9].

In the GIS environment, a total of 149 at random points were generated over the complete categorized map for the vegetable pea classed map, and a total of 453 points were generated to evaluate the correctness of the LULC classed map. The classified data was also verified with the ground information's or and Google Earth.

Formula for Cohen's kappa is calculated as

$$K=(p_o - p_e) / (1-p_e)$$

Where,

p_o: Relative observed agreement among raters

p_e: Hypothetical probability of chance agreement

Results and Discussion

Prior to creating a crop map for the study area, a land use and land cover (LULC) classification was conducted. The study area was found to have five major land usage and land cover categories, including agricultural land, built-up land, open/barren/wasteland, forest and water bodies within study area. A false color composite of the study area for the year 2021 is shown in Figure 2. Figure 3 displays the ground truth points collected for different LULC classes. The LULC map is depicted in Figure 4.

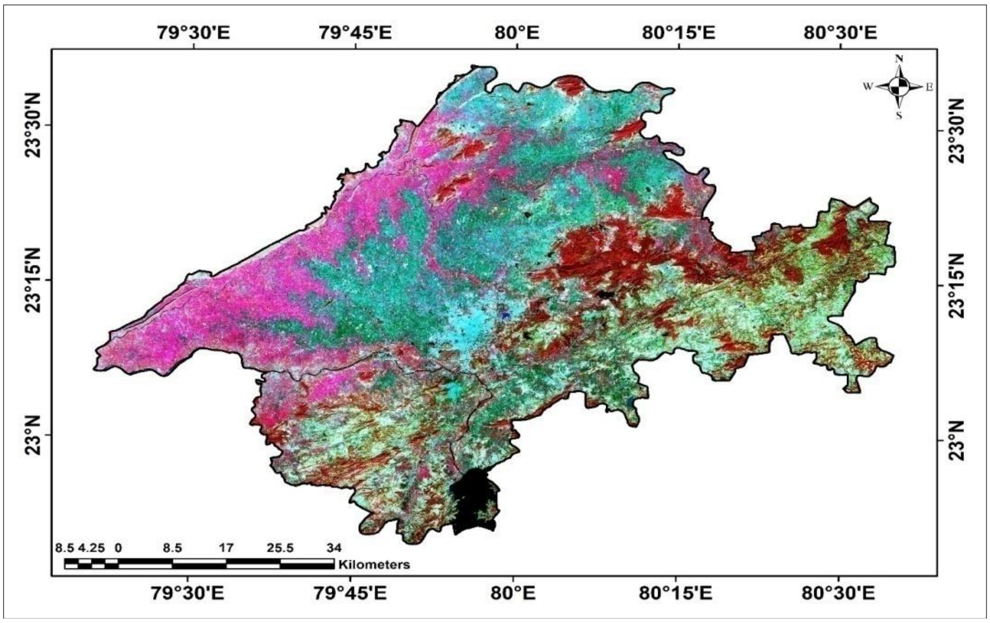

Fig 2: FCC of Jabalpur District for 4 December 2021

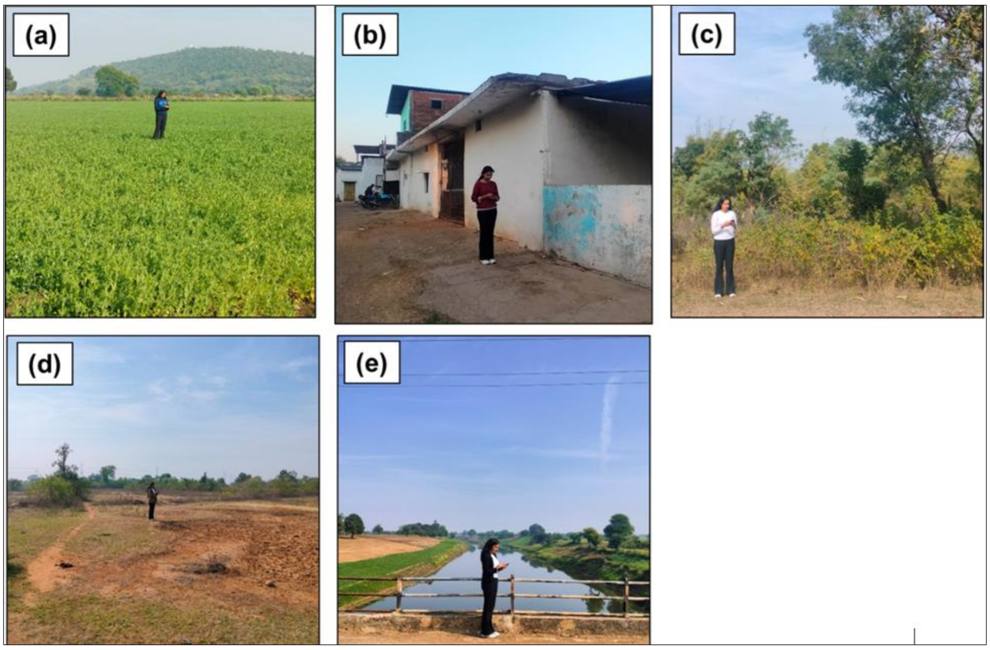

Fig 3: Displays the set of actual data points for various land use and land cover (LULC) categories found in the research area, including (a) Agricultural land, (b) Urban areas, (c) Forested areas, (d) Open/barren/waste land, and (e) Water bodies.

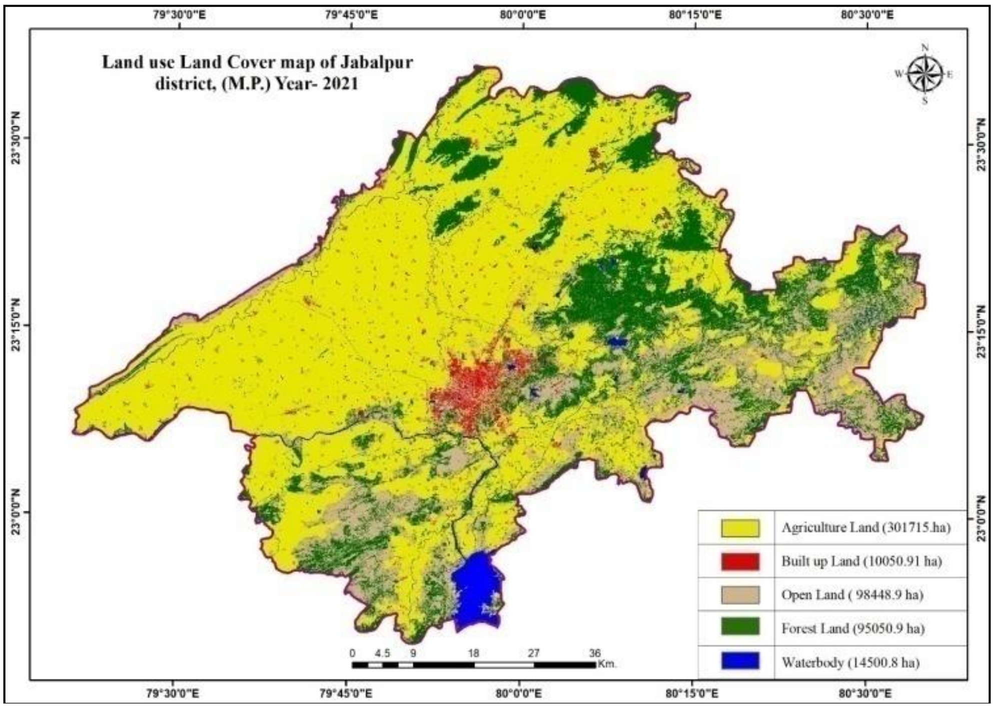

Fig 4: Map of land usage and land cover of Jabalpur district in 2021

Table 1: Distribution of Land Use Land Cover classes for the year 2021

LULC Class	LULC Area	
	ha	%
Agriculture	301715	58.05
Built-up Land	10050.91	1.93
Open/Barren/Waste Land	98448	18.94
Forest	95050.9	18.29
Waterbody	14500.8	2.79
Total	519765.6	100

Table 1 displays the LULC statistics for Jabalpur district in 2021. The data reveals that agricultural land accounted for the largest portion at 301715 hectares (58.05%) followed by open/barren/wasteland at 98448 hectares (18.94%) and forest at 95050.9 hectares (18.29%). Additionally, the district had a small area of waterbody at 14500.8 hectares (2.79%) and the least coverage on built-up land at 10050.91hectares (1.93%).

The LULC data was used to mask the agricultural area, following which a spatial map of vegetable pea crops was created. The ERDAS IMAGINE®2020 software was utilized to analyze Sentinel-2A satellite data and estimate the acreage of vegetable pea crops within the agricultural land. To establish the crop class of vegetable pea in the spatial data, it was necessary to collect ground truth points to create a signature set for vegetable pea. Signatures were created using 50 points from 121 ground locations, and the non-green pea fields were predominantly used from the subset of data to generate signatures for the non-pea class, with a higher number of locations than the green pea fields. For the year 2021, a maximum likelihood classifier was employed to conduct supervised classification. The distribution of ground truth points for validating vegetable pea crops is depicted in Fig 5, while Table 2 presents the accuracy assessment for the classification of vegetable pea crops.

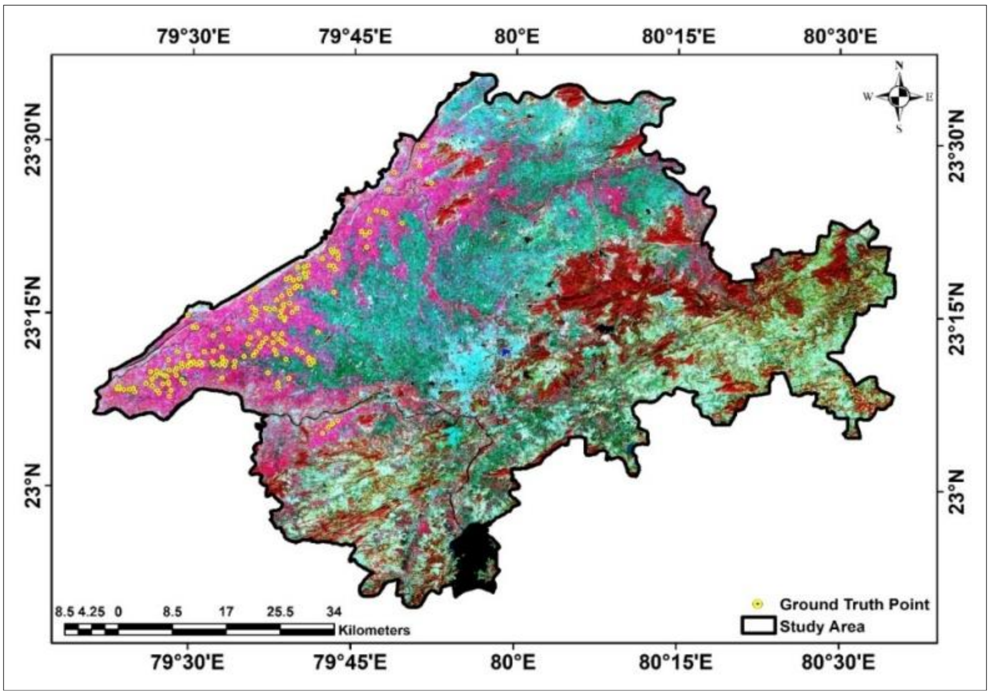

Fig 5: Spatial distribution of ground truth points for validating vegetable pea crop

The spatial analysis estimated the vegetable pea crop area for 2021, and the results are shown in Figure 6.

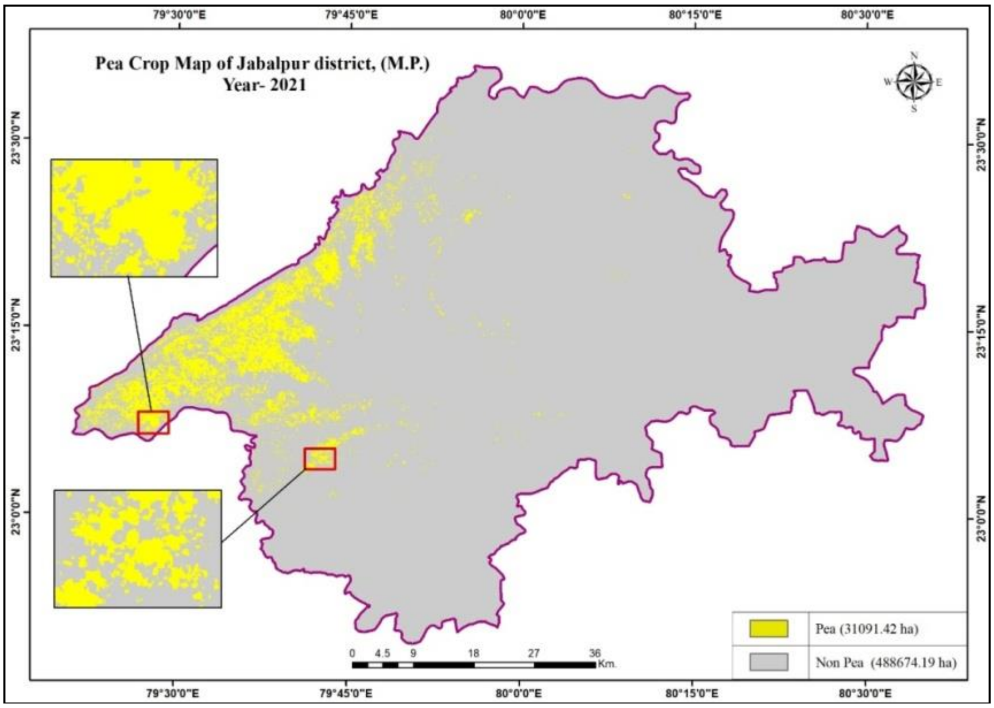

Fig 6: Acreage of vegetable peas grown in Jabalpur district in 2021.

Table 2: Accuracy assessment of classified crop map

S. No.	Class	Pea	Others	Total	User's Accuracy	Kappa
1.	Pea	112	9	121	0.93	0
2.	Others	0	33	33	1	0
3.	Total	112	42	154	0	0
	Producer's Accuracy	1	0.79	0	0.94	0
	Kappa	0	0	0	0	0.84

The numerical value of k equal to 1 represents complete agreement among the categories, whilest, if k equal to 0, then the measured agreement and the likelihood of agreement are equal. Excellent to very good agreement is indicated by a number greater than 0.75, conversely, medium to excellent agreement is indicated by a number between 0.40 and 0.75. Weak agreement between the classification categories is indicated by a value of 0.4 or less. Based on these criteria, the kˆ value of 0.94 in preent study shows a complete agreement.

The aforementioned statement indisputably show that the crop map preparation process's satellite image categorization method is excellent.

A comparison between the remote sensing-based estimation of vegetable pea acreage and government data is presented in Table 3. In Jabalpur district, the cultivation area of vegetable pea in 2021 was determined to be 31091.42 hectares using Supervised Maximum Likelihood (MXL) algorithm using RS and GIS. Vegetable pea covered 10.3% of the agricultural land in 2021.

Table 3: Comparison of estimated crop area with government data

Year 2021	Government Data	RS & GIS based estimated data	Relative Deviation In Percentage%
Area (ha)	30500	31091.42	1.93

The crop acreage estimation shows a 1.93 percent deviation between government data and remote sensing data.

Conclusions

The combination of remote sensing and GIS technology can not only decrease the workload of field surveys but also enhance the quality of information by merging both data sources. Remote sensing has proven to be effective and advantageous due to its wide area coverage, comprehensive view, and satellite responsiveness, enabling the provision of information for large areas in a shorter time. In Jabalpur District, the Vegetable Pea crop area for 2021 is 31091.42 hectares. The accurately classified crop map, validated with government ground data, confirms the effectiveness of the RS and GIS approach. The research demonstrated the possibilities for mapping crops at the field scale using ground data and Sentinal 2 satellite images. Further research is necessary to evaluate site suitability based on the full range of geographical information in current planning areas, considering the specific biological and agroecological requirements of the selected crops.

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