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Satellite-Based Identification of Rice Cropland, Crop Parameters, and Yield Prediction Using an Integrated GIS Approach in Karnal District, Haryana

Geeta Devi[1], Dr. Shailesh Kumar[2]

[1] Research Scholar, Computer Science & Engineering (CSE), School of Engineering & Technology(SET), Om Sterling Global University(OSGU), Hisar(Haryana)-125001.

[2]Professor & Dean, Computer Science & Engineering (CSE), School of Engineering & Technology(SET), Om Sterling Global University(OSGU), Hisar(Haryana)-125001.

Email: kashyapgeeta10@gmail.com, deanset@osgu.ac.in.

Abstract:

Accurate estimation of crop area and yield is essential for agricultural planning, food security assessment, and resource management. The present study focuses on the satellite-based identification of rice cropland, crop parameter analysis, and yield prediction using an integrated GIS approach in Karnal district, Haryana. Multi-temporal satellite data from Sentinel-2 and Landsat-8 were used to identify rice cropland and derive important crop parameters using vegetation indices such as NDVI, SAVI, RGVI, LAI, MSI, and NDWI. These indices were generated using raster algebra operations in a GIS environment to assess vegetation vigor, crop health, and moisture conditions during the rice growing season.

The spatial analysis revealed significant variation in rice cultivation across different blocks of Karnal district. Assandh block recorded the highest rice cultivation area (87.5%), followed by Nissing (83.2%) and Nilokheri (81.7%), whereas Karnal block showed the lowest rice area (54.8%) with comparatively higher non-crop land (26.7%). Field observations were conducted through Crop Cutting Experiment (CCE) to obtain ground truth data for yield estimation and model validation. The CCE carried out in Sagga village (Plot No. 117//34) for the rice variety P-126 recorded a dry grain yield of 52.45 kg from a 100 m² plot, which corresponds to an estimated yield of 5,245 kg/ha (5.245 t/ha).

Based on the satellite-derived rice area of 187,186.30 hectares in Karnal district, the total rice production was estimated to be approximately 981,790 tonnes (9.82 lakh tonnes) during the Kharif season. The integration of satellite imagery, GIS-based spatial analysis, and field-based CCE observations demonstrated high potential for accurate identification of rice cropland and reliable crop yield prediction. The study highlights the effectiveness of geospatial technologies in supporting agricultural monitoring, crop management, and decision-making at the district level.

Keywords: *Crop Parameters, Yield Prediction, Crop Cutting Experiment, GIS, Remote Sensing, Rice.*

Introduction:

Rice (*Oryza sativa L.*) is one of the most important staple food crops in the world and plays a crucial role in ensuring food security, particularly in Asian countries such as India. More than half of the global population depends on rice as a primary source of calories, making accurate assessment of rice cultivation area and yield essential for agricultural planning and policy formulation (FAO, 2021). In India, rice is cultivated extensively in the Indo-Gangetic plains, including the state of Haryana, where it forms a major component of the rice–wheat cropping system and contributes significantly to national food production (Government of India, 2022). Traditional methods of crop area estimation and yield assessment mainly rely on field surveys and Crop Cutting Experiments (CCE). Although these methods provide reliable ground-based information, they are time-consuming, labor-intensive, and limited in spatial coverage (Lobell et al., 2015). With the advancement of Remote Sensing and Geographic Information Systems (GIS), satellite imagery has become an efficient tool for monitoring agricultural crops over large areas. Satellite data provide repetitive and synoptic coverage, which enables accurate mapping of crop areas and monitoring of crop growth dynamics (Xiao et al., 2006; Thenkabail et al., 2012).

Remote sensing techniques allow the extraction of crop-related biophysical parameters through spectral indices derived from satellite imagery. Vegetation indices such as the Normalized Difference Vegetation

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Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and other spectral indicators are widely used to monitor vegetation vigor, biomass, and crop growth stages (Tucker, 1979; Huete, 1988). These indices are strongly related to crop health and productivity and therefore can be effectively used for crop identification and yield estimation (Doraiswamy et al., 2005).

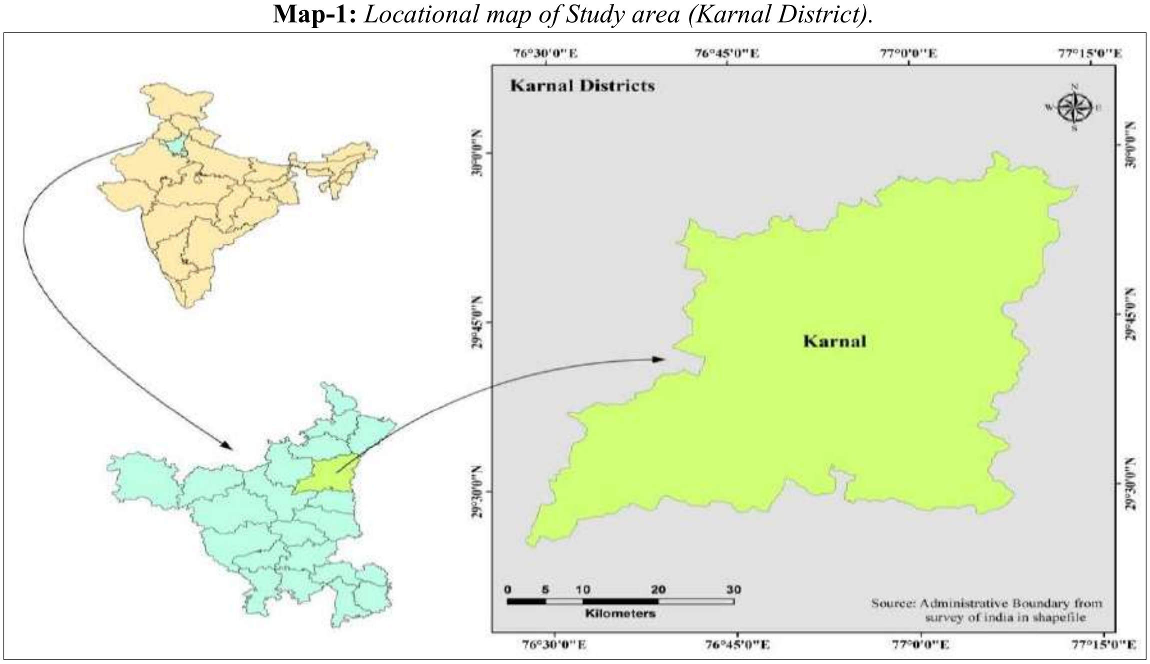
Recent advances in Earth observation technologies, particularly satellites such as Sentinel-2 and Landsat, provide high spatial and temporal resolution data that are highly suitable for agricultural monitoring. These datasets allow continuous observation of crop phenology and support the estimation of crop parameters such as leaf area index, canopy cover, and moisture stress (Drusch et al., 2012; Roy et al., 2014). Integration of satellite-derived vegetation indices with GIS-based spatial analysis has significantly improved crop mapping and yield prediction accuracy in many agricultural regions (Bolton & Friedl, 2013).

The Karnal district of Haryana is one of the major rice-producing regions in north-western India and is characterized by fertile alluvial soils, well-developed irrigation systems, and intensive rice–wheat cropping practices. Monitoring rice cultivation and predicting yield in this region is important for agricultural planning and food security. Therefore, the present study focuses on the satellite-based identification of rice cropland, analysis of crop parameters, and yield prediction using an integrated GIS approach in Karnal district, Haryana.

Study Area

The present study was conducted in Karnal district, located in the northern part of the state of Haryana, India. Karnal lies between approximately 29°25′N to 30°00′N latitude and 76°30′E to 77°15′E longitude. The district is bounded by Yamunanagar district in the north, Kurukshetra in the northwest, Kaithal in the west, Panipat in the south, and the Yamuna River forming the eastern boundary with Uttar Pradesh.

Map-1: *Locational map of Study area (Karnal District).*



Source: Administrative Boundary from Survey of India and map composed in GIS software.

Karnal district forms part of the fertile Indo-Gangetic alluvial plains, which are well known for intensive agricultural activities.

Agriculture is the dominant economic activity in the district, with major crops including rice and wheat cultivated under irrigated conditions. The region benefits from a well-developed irrigation system consisting of canals and groundwater resources, which supports high agricultural productivity. Due to its significant role in rice production and the availability of extensive agricultural land, Karnal district has been selected as the study area for analyzing rice cropland extent and crop parameters using satellite imagery and GIS techniques. The geographic location and favorable agro-climatic conditions make the district suitable for studying crop growth patterns and yield estimation through geospatial methods.

Methodology:

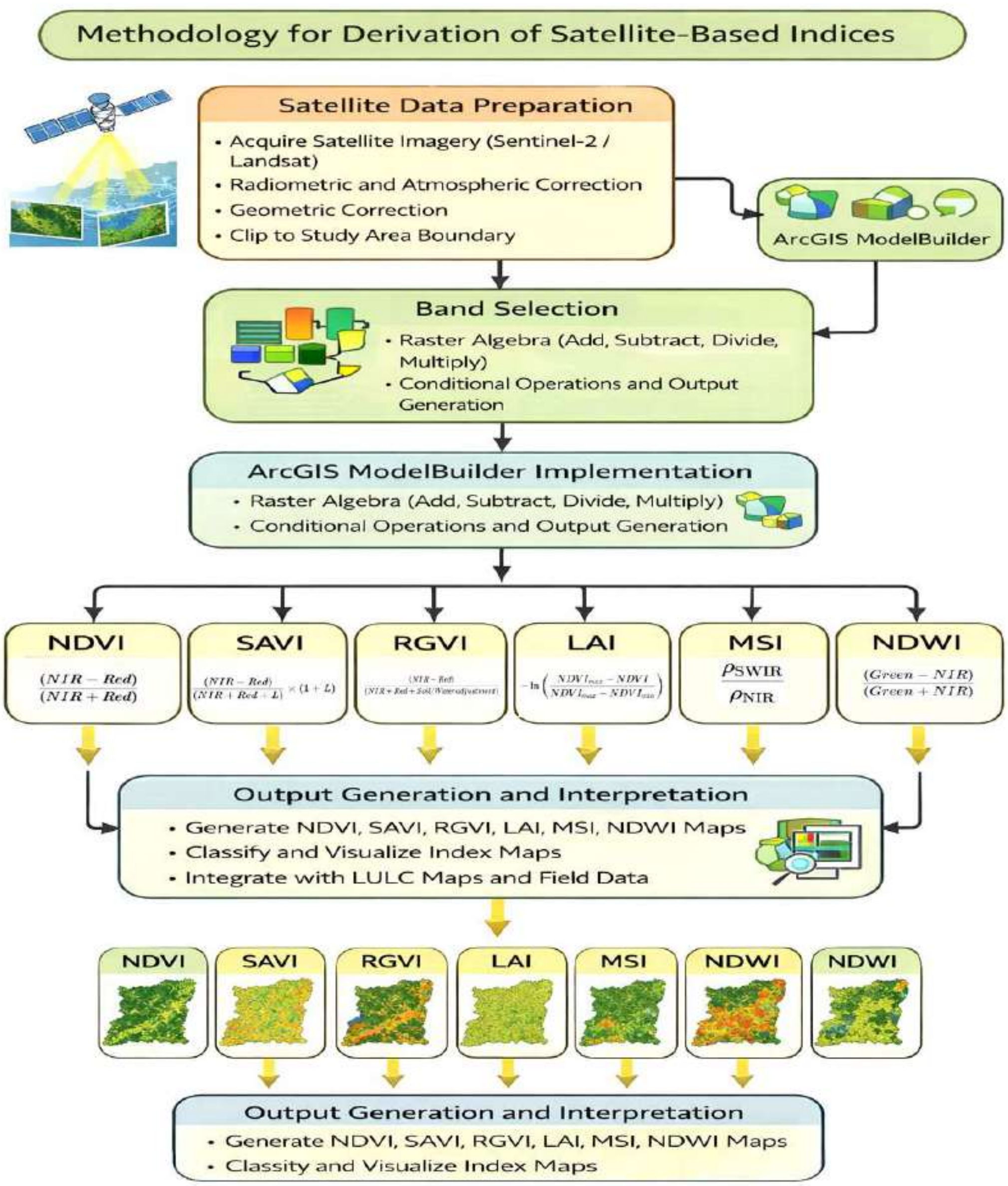
The present study uses satellite imagery and GIS techniques to derive various vegetation and water-related indices for analyzing crop conditions and environmental parameters in the study area. The overall methodology consists of satellite data preparation, band selection, index computation using ArcGIS Model Builder, and output generation with interpretation.

Satellite Data Preparation

- Satellite imagery from Sentinel-2 and Landsat-8 sensors was used for the analysis. The acquired satellite data were first preprocessed to ensure accuracy and reliability. Radiometric and atmospheric corrections were applied to remove sensor and atmospheric distortions. Geometric correction was performed to align the images with the correct geographic coordinate system. Finally, the images were clipped according to the study area boundary to focus the analysis on the selected region.

Band Selection

- After preprocessing, relevant spectral bands were selected for the calculation of different indices. The Red, Green, Near Infrared (NIR), and Shortwave Infrared (SWIR) bands were primarily used. Raster algebra operations such as addition, subtraction, multiplication, and division were applied to combine these bands and generate spectral indices. Conditional operations were also used to process and refine the outputs.



ArcGIS Model Builder Implementation

- The computation of spectral indices was automated using ArcGIS ModelBuilder. Raster algebra tools were integrated into the model to systematically calculate different indices. The model processes the selected bands and generates output rasters for each

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index through predefined formulas and conditional operations.

Derivation of Spectral Indices

- Several vegetation and water-related indices were derived to analyze vegetation health, moisture conditions, and water bodies in the study area. These include:
- **NDVI (Normalized Difference Vegetation Index)**

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

- **SAVI (Soil Adjusted Vegetation Index)**

$$SAVI = \frac{(NIR - Red)}{(NIR + Red + L)} \times (1 + L)$$

- **RGVI (Ratio Green Vegetation Index)**

$$RGVI = \frac{(NIR - Red)}{(NIR + Red + Soil/Wateradj}$$

- **LAI (Leaf Area Index)**

$$\text{LAI} = -\ln\left(\frac{NDVI_{max} - NDVI}{NDVI_{max} - NDVI_{min}}\right)$$

- **MSI (Moisture Stress Index)**

$$\text{MSI} = \frac{\rho_{\text{SWIR}}}{\rho_{\text{NIR}}}$$

- **NDWI (Normalized Difference Water Index)**

$$\textbf{NDWI} = \frac{(Green - NIR)}{(Green + NIR)}$$

Output Generation and Interpretation

- The calculated indices were used to generate spatial maps representing vegetation health, moisture stress, leaf area density, and water distribution. These index maps were further classified and visualized using GIS techniques. Finally, the results were integrated with Land Use/Land Cover (LULC) maps and field observations to interpret crop conditions and environmental characteristics in the study area.

Crop Cutting Experiment (CCE) and yield forecasting:

This systematic process provides reliable primary data for agricultural statistics and yield forecasting.

The Crop Cutting Experiment (CCE) is a field-based scientific method used to estimate crop yield through systematic sampling and measurement. The process begins with planning and selection of villages and fields, where representative agricultural plots are randomly chosen within the study area. After selection, a sample plot of standard size (usually 5 m × 5 m or 10 m × 10 m) is demarcated in the selected field. All crops within this marked plot are harvested manually, ensuring that the entire produce inside the frame is collected.

Figure-1: *Systematic process Yield Calculation.*

The harvested crop is then threshed to separate grains from straw, and the weight of the grains is recorded along with moisture content measurement to maintain standard yield conditions. The measured grain weight from the sample plot is subsequently converted into yield per hectare using standard agricultural conversion methods. Finally, the CCE data is analyzed to estimate crop productivity and can also be used as ground truth data for validating satellite-based crop yield prediction models and geospatial analysis.

Result and Discussion:

The integration of satellite imagery and GIS techniques enabled the identification and spatial analysis of rice cropland and associated land use categories in Karnal district. The results indicate that rice cultivation occupies a major portion of the agricultural landscape, though its distribution varies considerably across different blocks of the district.

Crop Type Identification:

The identification of rice cropland in Karnal district was carried out using satellite-derived vegetation and moisture indices, including NDVI, RGVI, NDWI, SAVI, LAI, and MSI. These indices helped in distinguishing rice fields from other land-use categories based on vegetation vigor, canopy density, and moisture conditions during the rice growing season. The spatial distribution of these indices provides important insights into crop growth conditions and agricultural patterns in the study area.

The Normalized Difference Vegetation Index (NDVI) map shows the spatial variation in vegetation health and density across Karnal district. Areas with higher NDVI values indicate dense and healthy vegetation cover, which corresponds mainly to actively growing rice crops during the Kharif season. Higher NDVI values are particularly visible in blocks such as Assandh, Nissing, and Nilokheri, indicating vigorous crop growth due to favorable irrigation and fertile soils. Lower NDVI values are mainly observed in non-

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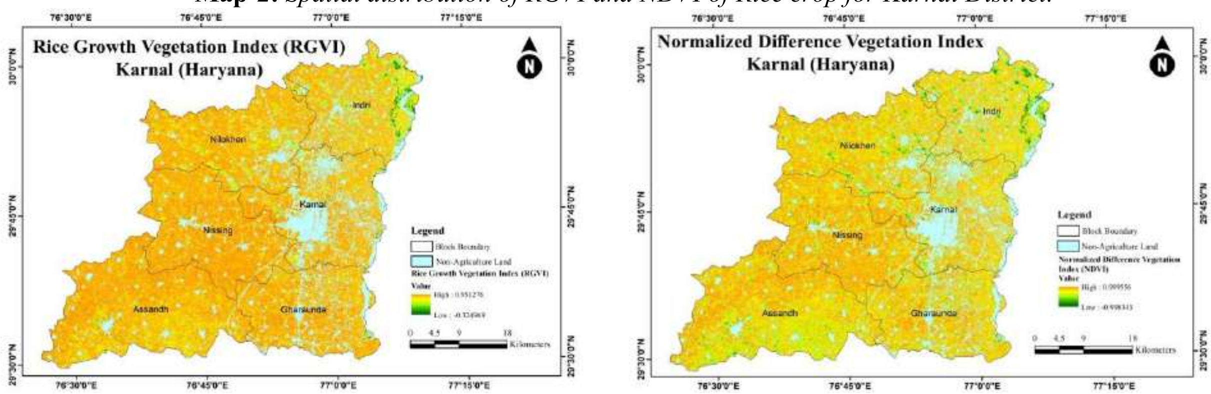
agricultural land, fallow fields, and built-up areas, especially around the Karnal urban region.

The Rice Growth Vegetation Index (RGVI) further highlights rice crop growth by emphasizing spectral responses related to chlorophyll activity. The RGVI map shows higher values in areas dominated by rice cultivation, particularly in Assandh and Nissing blocks, where rice covers a large proportion of the geographical area. These high RGVI values indicate active photosynthetic activity and healthy crop development. Conversely, lower RGVI values are observed in non-crop areas and regions with sparse vegetation.

Map-2: *Spatial distribution of RGVI and NDVI of Rice crop for Karnal District.*

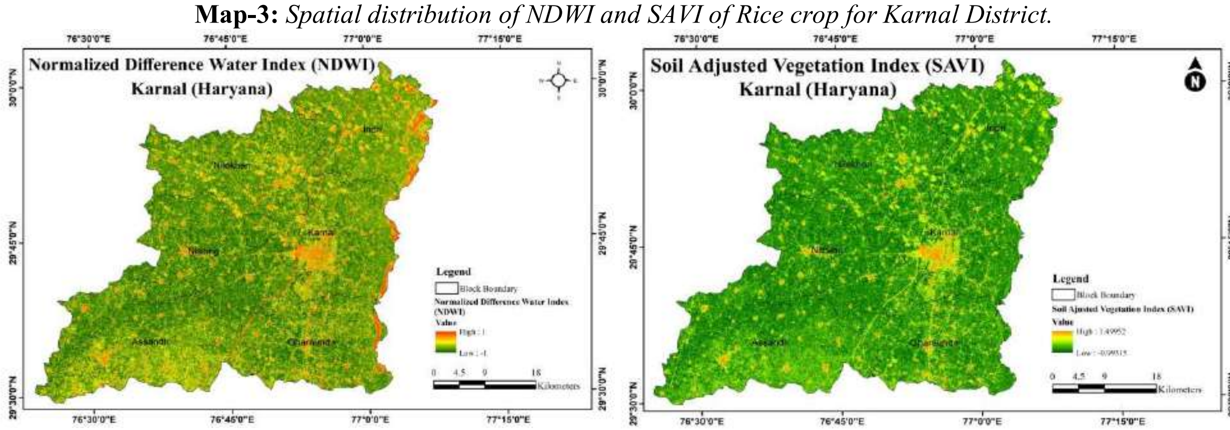


Source: Satellite Image (Sentinel-2C) Date of image: 15-09-2025.

The Normalized Difference Water Index (NDWI) map reflects the moisture conditions in vegetation and soil. Since rice is cultivated under waterlogged conditions, higher NDWI values correspond to irrigated paddy fields. The NDWI distribution indicates widespread moisture availability across the district, especially in the central and western parts where irrigation infrastructure is well developed. Areas with relatively lower NDWI values represent non-agricultural land or fields with lower water content.

The Soil Adjusted Vegetation Index (SAVI) provides a clearer representation of vegetation cover by minimizing soil background effects. The SAVI map shows dense vegetation cover in most agricultural areas of the district, confirming the presence of well-developed crop canopy during the rice growing season. Lower SAVI values are mainly associated with fallow lands and exposed soil surfaces.

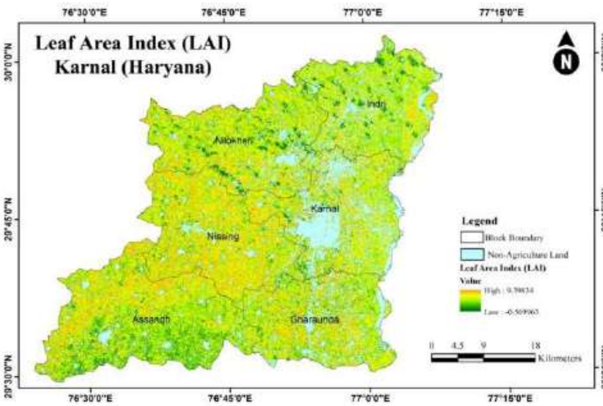
Map-3: *Spatial distribution of NDWI and SAVI of Rice crop for Karnal District.*

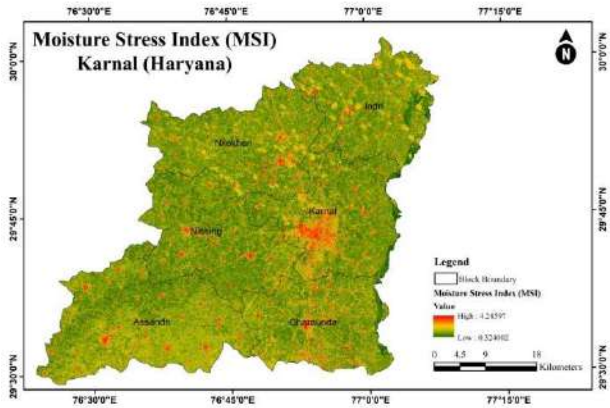


Source: Satellite Image (Sentinel-2C) Date of image: 15-09-2025.

The Leaf Area Index (LAI) map indicates the density of crop canopy and leaf biomass. Higher LAI values represent dense rice crop growth and advanced crop stages, while moderate values indicate developing vegetation. The spatial pattern of LAI suggests that large parts of the district exhibit moderate to high canopy density, reflecting favorable crop growth conditions during the study period.

Map-4: *Spatial distribution of LAI and MSI of Rice crop for Karnal District.*





Source: Satellite Image (Sentinel-2C) Date of image: 15-09-2025.

The Moisture Stress Index (MSI) was used to assess moisture stress conditions in vegetation. Lower MSI values indicate sufficient water availability in irrigated rice fields, while higher MSI values indicate areas experiencing moisture stress. The MSI map shows that most rice-growing areas in Karnal district experience low moisture stress due to the availability of canal irrigation and groundwater resources.

Distribution of Rice and Other Land Uses in Karnal District.

Table-4.1 presents the land use / land cover (LULC)–based area distribution of the study area, highlighting the dominance of rice cultivation and the relative extent of fallow and non-crop land within Karnal district. The total geographical area considered in the analysis is 246,265.3 hectares, which has been classified into three major categories using satellite imagery and GIS techniques.

Rice emerges as the predominant land use, covering 187,186.3 hectares, which accounts for 76.0% of the total area. This exceptionally high proportion clearly indicates that Karnal district is a rice-dominated agricultural region. The extensive rice coverage reflects the presence of assured canal and groundwater irrigation, fertile alluvial soils, favorable agro-climatic conditions, and intensive rice-based cropping systems. Such dominance also explains the district's significant contribution to rice production at the state level and underlines the pressure on water resources associated with paddy cultivation

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Table-1: *Area Estimation of LULC/crop for Karnal District.*

Sr. No.	LULC/Crop	Area (in Hectare)	Area (in %)
1	Rice	187186.3	76.0
2	Fallow Land	23146.4	9.4
3	Non Crop Area	35932.6	14.6
Total		**246265.3**	**100**

Source: Area estimated by satellite image (Sentinel-2) using GIS software.

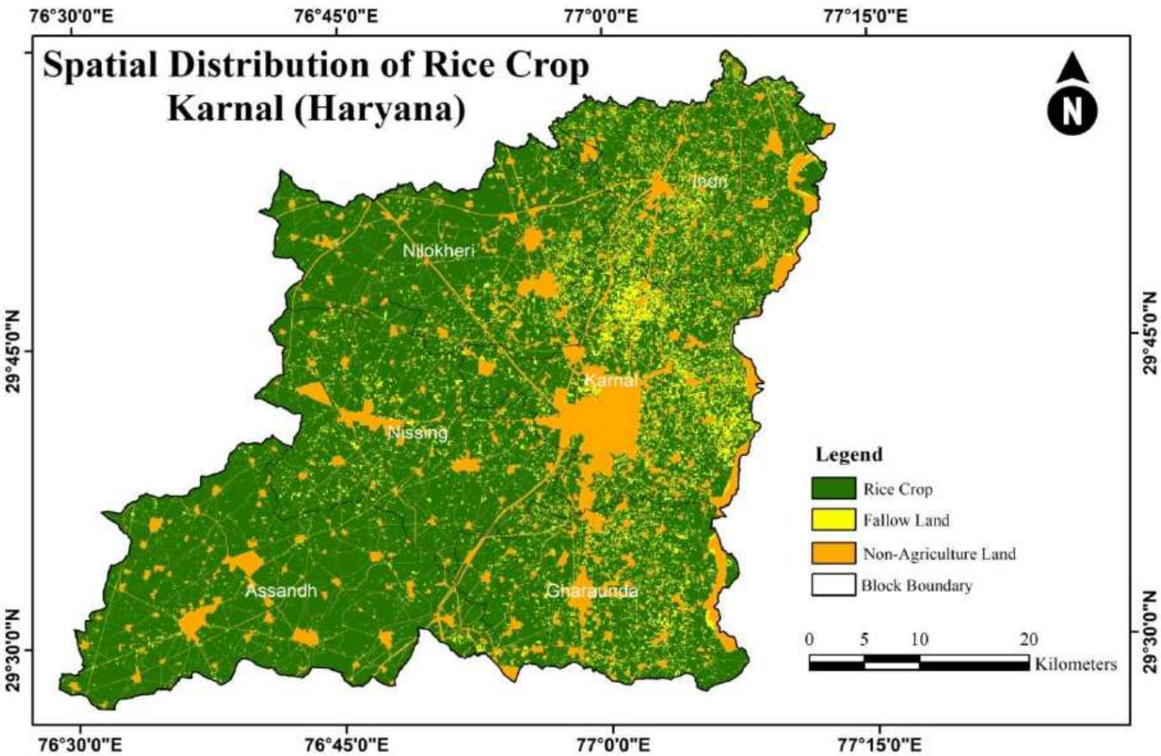
The fallow land category occupies 23,146.4 hectares (9.4%) of the total area. These lands represent agricultural fields that were temporarily uncultivated during the study period due to factors such as crop rotation practices, land preparation, moisture stress, or management decisions by farmers. Although fallow land forms a smaller share compared to rice, its presence highlights seasonal and management-related variability in land use, and it also indicates potential scope for improved land utilization or crop diversification.

The non-crop area, which includes built-up land, roads, settlements, water bodies, and other non-agricultural surfaces, covers 35,932.6 hectares, accounting for 14.6% of the district area. This proportion reflects the influence of urbanization, infrastructure development, and industrial growth, particularly around Karnal city and major transport corridors. The relatively moderate share of non-crop land indicates that, despite urban expansion, Karnal district retains a strong agricultural character.

Explanation of the Spatial Distribution of Rice Crop Map for Karnal District

The map-4.1 depicts the spatial distribution of rice cultivation across Karnal district, classified into rice crop (green), fallow land (yellow), and non-agricultural land (orange), with block boundaries overlaid. It provides a clear visual representation of how rice dominates the agricultural landscape while highlighting areas influenced by urbanization and temporary land-use changes.

Map-5: *Spatial distribution of Rice crop in Karnal District.*



Source: Area estimated by satellite image (Sentinel-2C sensing date 15-Sept.-2025).

Dominance of rice cultivation: Large, continuous green patches across the district indicate that rice is the principal Kharif crop. The most extensive and compact rice tracts are visible in Assandh, Nissing, and Nilokheri blocks, reflecting intensive paddy cultivation supported by assured canal and groundwater irrigation, fertile alluvial soils, and level terrain. These areas form the core rice belt of the district.

Moderate rice coverage with variability: In Gharaunda and Indri, rice remains dominant but appears more fragmented, interspersed with fallow land. This pattern suggests greater variability in cropping intensity, possibly due to rotational practices, localized water constraints, or management decisions during the season.

Urban influence and non-crop areas: The Karnal block shows a conspicuous concentration of non-agricultural land (orange) around the urban core and along major transport corridors. Here, rice coverage is comparatively lower and more discontinuous, indicating the impact of urban expansion, infrastructure, and mixed land use on agricultural extent.

Fallow land distribution: Yellow patches (fallow land) are scattered throughout the district but are relatively more noticeable in Indri, Gharaunda, and Karnal blocks. These areas likely represent fields left uncultivated temporarily due to crop rotation, land preparation cycles, moisture conditions, or short-term management choices.

The map 4.1 confirms that Karnal district is predominantly rice-dominated, with spatial variation driven by irrigation availability, urbanization, and land management practices. This spatial pattern provides a critical baseline for subsequent analyses of crop health, phenology, biomass, yield estimation, and moisture stress using satellite-derived indices, and it supports targeted water resource and agricultural planning at the block level.

Table-4.2 presents a comparative block-wise distribution of rice cropland, fallow land, and non-crop areas across the six administrative blocks of Karnal district, based on satellite-derived land use/land cover analysis. The table clearly brings out the spatial variability in rice cultivation intensity and reflects the combined influence of irrigation availability, urbanization, and land management practices at the block level.

Among all blocks, Assandh exhibits the highest concentration of rice cultivation, with 47,094.9 hectares (87.5%) of its total geographical area under rice. This highlights Assandh as a highly rice-intensive block, characterized by assured irrigation, fertile alluvial soils, and minimal land diversion to non-agricultural uses. Similarly, Nissing and Nilokheri blocks also show strong dominance of rice, covering 83.2% and 81.7% of their geographical areas respectively. These blocks together form the core rice-growing belt of Karnal district, contributing significantly to district-level rice production.

Table-2: *Block-wise Area Distribution of Rice and Other Land Uses in Karnal District.*

Sr. No	Block	Geographical Area in Hectare	Rice in Hac. (%)	Fallow Land in Hac. (%)	Non Crop Area in Hac. (%)
1	Assandh	53846.7	47094.9 (87.5)	1599.5 (3)	5152.3 (9.6)
2	Nissing	41101.1	34176.2 (83.2)	2738.4 (6.7)	4186.4 (10.2)
3	Gharaunda	35211.8	25661.5 (72.9)	3822.7 (10.9)	5727.6 (16.3)
4	Indri	34953.1	24703.5 (70.7)	5097.1 (14.6)	5152.5 (14.7)
5	Karnal	40101.9	21980.8 (54.8)	7433.8 (18.5)	10687.2 (26.7)
6	Nilokheri	41024.3	33511.8 (81.7)	2487.1 (6.1)	5025.4 (12.2)

Source: Area estimated from the map-4.1.

In contrast, Gharaunda and Indri blocks show a relatively lower share of rice cultivation, accounting for 72.9% and 70.7% of their geographical areas respectively. These blocks also have a higher proportion of fallow land, particularly Indri, where fallow land constitutes 14.6% of the area. The presence of larger fallow tracts may be linked to cropping pattern diversification, land preparation cycles, irrigation variability, or temporary withdrawal of land from cultivation.

The Karnal block displays a distinctly different land-use structure compared to other blocks. Rice occupies only 54.8% of its geographical area, which is the lowest among all blocks. At the same time, Karnal block has the highest proportion of fallow land (18.5%) and non-crop area (26.7%). This pattern clearly reflects the impact of urban expansion, infrastructure development, industrial activities, and mixed land use associated with Karnal city and its surroundings, leading to reduced agricultural dominance.

Crop Cutting Experiment (CCE):

The Crop Cutting Experiment (CCE) in the present study was conducted using a 10 m × 10 m (100 m²) sample plot, which is a standard and widely accepted plot size for reliable yield estimation. The experiment was carried out in Karnal District, at Village Sagga, located in Murabba No. 117 and Killa No. 34. The selected plot was carefully chosen to be representative of the surrounding field conditions, ensuring uniformity in crop stand, soil characteristics, and management practices.

Table-3: *Crop Cutting Experiment (CCE) – Field Observation of Rice crop (study area)*

Village	Plot / Khasra No.	Date of Sowing	Date of Harvesting	Crop Duration (Days)	Variety	Plant Height	Fresh Biomass (kg)	Fresh Grain Weight (kg)	Dry Grain Weight (kg)
Sagga	117//34	24-Jun-25	4-Oct-25	150–155	P-126	3 feet 1 inch	160.96	55.85	52.45

Source: Primary Field observation by the scholar.

All crop plants within the demarcated 10×10 m area were harvested manually at maturity. Observations related to crop growth and yield parameters, including plant height, fresh biomass, dry biomass, fresh grain weight, and dry grain weight, were systematically recorded. The harvested yield obtained from the sample plot was later extrapolated to a per-hectare basis, providing an accurate estimate of crop productivity for the study area. This CCE dataset serves as ground truth information, which is crucial for validating satellite-derived estimates of biomass and yield.

Thus, the CCE conducted at Village Sagga (Murabba 117, Killa 34) forms a critical link between field-level observations and satellite-based analysis, enhancing the reliability of biomass and yield estimation and supporting geospatial assessment of crop performance in Karnal district.

Yield Estimation:

Yield Estimation refers to the process of quantifying crop output per unit area using field observations and geospatial techniques. In agricultural studies, yield is commonly estimated through Crop Cutting Experiments (CCE), where harvest data from a representative sample plot are extrapolated to a hectare scale to obtain reliable yield values.

Table-4: *Total Rice Production Estimation Based on CCE Yield.*

Parameter	Value	Unit / Description
District	Karnal	Haryana
Crop	Rice	Kharif season
CCE Plot Size	10 m × 10 m	100 m²
Yield from CCE Plot	52.45	kg per 100 m²
Estimated Yield per Hectare	5,245	kg/ha (5.245 t/ha)
Total Rice Cultivated Area	187,186.30	hectares
Estimated Total Rice Production	981,790	Tonnes (9.82 lakh tonnes)

Source: Primary Field observation by the scholar.

The table presents the estimation of total rice production in Karnal District based on Crop Cutting Experiment (CCE) observations. The CCE was conducted using a standard 10 m × 10 m (100 m²) sample plot, from which a yield of 52.45 kg of rice was recorded. This plot-level yield was extrapolated to a per-hectare basis, resulting in an estimated yield of 5,245 kg per hectare (5.245 t/ha), which reflects the average productivity of rice under field conditions in the study area.

Using this hectare-level yield, total rice production was calculated by multiplying it with the total rice cultivated area of 187,186.3 hectares. The resulting estimate indicates a total rice production of approximately 981,790 tonnes (about 9.82 lakh tonnes). This table clearly demonstrates how field-based CCE data can be scaled up to district-level production estimates, providing a reliable and scientifically grounded measure of crop output.

Overall, the table highlights the importance of CCE as a ground-truthing tool for production estimation and serves as a strong baseline for validating satellite-based biomass and yield models. The close linkage between plot-level measurements and large-area estimates ensures greater accuracy in agricultural assessment and supports informed planning, monitoring, and policy decision-making.

Conclusion:

The present study demonstrates the effectiveness of integrating remote sensing and Geographic Information System (GIS) techniques for the identification of rice cropland, analysis of crop parameters, and yield estimation in Karnal district, Haryana. Multi-temporal satellite imagery from Sentinel-2 and Landsat-8 was successfully utilized to derive vegetation and moisture indices such as NDVI, RGVI, SAVI, LAI, NDWI, and MSI, which helped in identifying rice-growing areas and assessing crop health, canopy density, and moisture conditions during the Kharif season.

The spatial analysis revealed that rice cultivation occupies a significant portion of the agricultural landscape in Karnal district, with Assandh, Nissing, and Nilokheri blocks showing the highest concentration of rice cultivation, while Karnal block recorded relatively lower rice area due to higher non-crop and fallow land. The spectral indices clearly reflected variations in vegetation vigor and crop growth across the district, confirming the suitability of satellite-based methods for crop type identification and monitoring.

Field-based Crop Cutting Experiment (CCE) observations provided reliable ground truth data for yield estimation and validation. The CCE results indicated a rice yield of approximately 5,245 kg/ha (5.245 t/ha), which, when combined with the mapped rice cultivation area of 187,186.30 hectares, resulted in an estimated total rice production of about 981,790 tonnes (9.82 lakh tonnes) in the district.

Overall, the study highlights that the integration of satellite-derived vegetation indices, GIS-based spatial analysis, and field observations offers a reliable and efficient approach for crop monitoring and yield prediction at the regional scale. Such geospatial techniques can support agricultural planning, crop management, and policy decision-making, ultimately contributing to improved agricultural productivity and food security.

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