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Estimation of rice area in KWD region using geospatial tools

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***Abstract*— *The estimation of crop areas was recognized as crucial for assessing agricultural production, supporting food security, and guiding policy decisions. In India, rice cultivation was particularly significant, especially in Andhra Pradesh, where remote sensing technologies like Landsat 9 improved the accuracy of mapping and monitoring crop areas compared to traditional field survey methods. These advancements helped optimize resource allocation, enhance market forecasting, and detect shifts in cropping patterns. The study aimed to estimate rice area in the KWD region during the kharif season of 2023 using geospatial tools. A combination of satellite imagery and ground truth data was employed. Landsat 9 data were utilized to estimate rice areas during the kharif season, and this data was processed using ENVI software. The Random Forest classification method was applied to distinguish rice areas, achieving an overall accuracy of 94.3% with a Kappa coefficient of 0.81, indicating almost perfect agreement. The total rice area in the study region was estimated at 127,565 ha, with the largest area recorded in Bapatla (12,299 ha) and the smallest in Pedanandipadu (3 ha). A 4.4% underestimation was observed when compared to the Department of Agriculture (DoA) statistics, which reported 133,402 ha.*

***Keywords*— Geospatial tools, Remote sensing, Landsat 9, ENVI software, Random Forest classification**

I. INTRODUCTION

Accurate estimation of crop area is essential for assessing agricultural productivity, supporting food security planning, and enhancing market forecasts. Reliable crop area data allows governments and organizations to track production trends, optimize resource allocation, and anticipate future demands (Raman *et al*., 2017). Additionally, this data plays a significant role in managing agricultural subsidies, insurance schemes, and disaster relief efforts. Early detection of changes in cropping patterns, often influenced by climate factors, is made possible through accurate estimates. It also informs decisions related to imports, exports, and maintaining food supply balance, while helping capitalize on market opportunities when surplus production occurs (Husak *et al*., 2007; Karydas *et al*., 2015).

In India, rice is the most widely cultivated crop, serving as a staple food for the population, providing livestock fodder, and creating employment opportunities in rural areas. Andhra Pradesh is a major rice-growing region, with paddy cultivation extending over 2.2 million ha during the *kharif* and *rabi* seasons. The districts of West Godavari, East Godavari, and Krishna are key contributors to rice production, not only within the state but also at the national level (apseeds.ap.gov.in). Accurate estimation of rice cultivation areas helps inform decisions related to water management, fertilizer distribution, and market trends, which are crucial for policy-making on trade, resource allocation, and disaster preparedness (Wang *et al*., 2015; Dong *et al*., 2016; Zhu *et al*., 2021).

Traditionally, crop area estimation in India has been based on field surveys carried out by local authorities, who gather data through direct observation (www.mospi.gov.in). While periodic inspections aim to ensure accuracy, these manual methods often result in errors due to the subjective nature of observations and limited data coverage (Li *et al*., 2014).

Recent advances in remote sensing (RS) technologies offer a more efficient alternative. RS uses satellite imagery to monitor large areas, enabling real-time data collection while reducing the time and labor required (Mosleh *et al*., 2015). The integration of RS with Geographic Information Systems (GIS) allows for precise mapping of crop areas and seasonal variations. This approach reduces human error, improves insights into crop health, and enhances the accuracy of area estimations at both regional and global levels (Tian *et al*., 2017).

In this context, the present study focuses on mapping rice cultivation areas using medium-to-high-resolution optical satellite data. The free Landsat 9 time series, provided by the United States Geological Survey (USGS), was utilized to investigate the effectiveness of remote sensing technologies in this task. The study hypothesizes that the Landsat 9 time series will provide highly accurate identification of rice crops (Zhao *et al*., 2015).

II. MATERIALS AND METHODS

Study Area

The Krishna Western Delta (KWD) of Andhra Pradesh spreads from longitude 80° 10'E to 80° 39'E and latitude 15° 50'N to 16° 30'N. It has an area of 1895 square kilometres and a perimeter of approximately 226.48 km. The elevation ranges from 3.5 meters to 15 meters above sea level. The study area is located in the Guntur district of Andhra Pradesh. It includes mandals such as Bapatla, Kakumanu, Pedanandipadu, Prathipadu, Guntur, Pedakakani, Duggirala, Mangalagiri, Tadepalle, Chebrolu, Vatticherukuru, Ponnur, Tsundur, Tenali, Kollipara, Kollur, Vemuru, Amruthalur, Bhattiprolu, Nagaram, Pittalavanipalem, Karlapalem, Repalle, and Nizampatnam. The KWD experiences a semi-arid climate with an annual rainfall range from 960 mm to 1100 mm. Most of the rainfall is received during the southwest monsoon period. Summers are hot and dry. The predominant soil composition consists of clay and loamy sandy soils, which account for around 85% of the total area.

The total rice area in the study area *i.e*., Krishna Western Delta of Guntur was derived with the use of optical data that is Landsat 9 OLI/TIRS satellite data. Since rice cultivation in KWD takes place between August and December of every year, we focus our analysis of Landsat 9 satellite data only on this period. For this reason, Landsat 9 data were downloaded for the period on 12 November 2023. The processing procedures included layer stacking, subsetting, training data creation, Random Forest supervised classification, cloudy pixel removal and accuracy assessment all of which were implemented using the QGIS and ENVI Softwares.

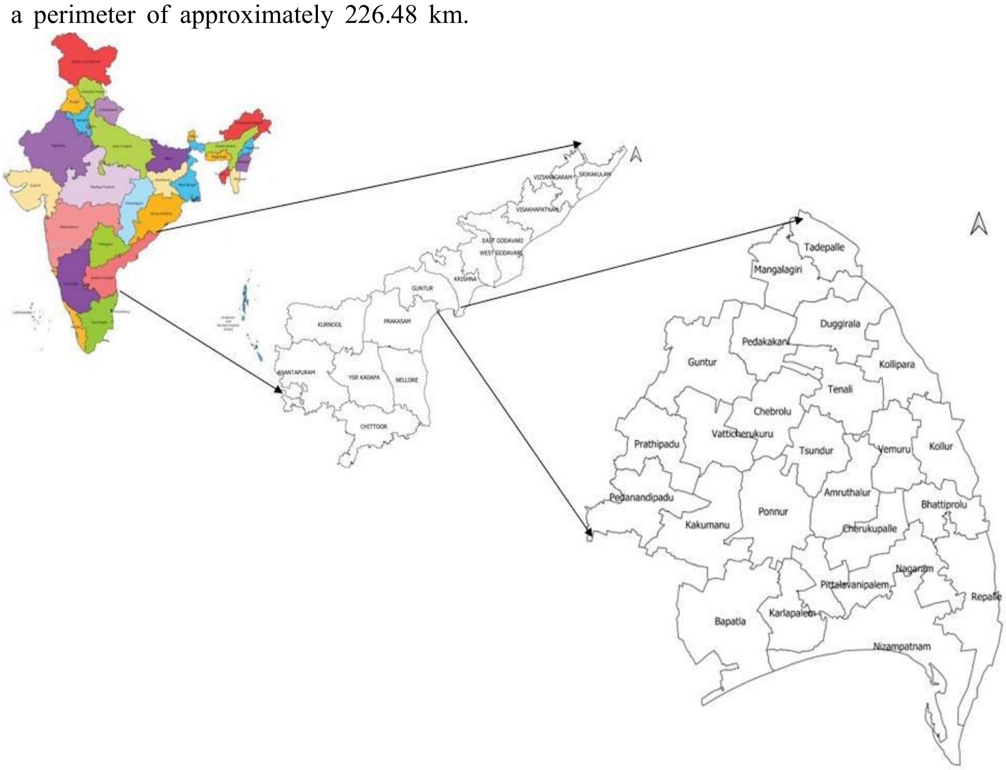

Fig. 1 Location of the Krishna Western Delta of Guntur district

Ground truthing (GT) is a process that validates remote sensing image characteristics by comparing them to real-world observations (Bolun *et al.,* 2017). GT was conducted during the rice crop's peak vegetative stage on 29th August 2023, to assess the seeded area during the *kharif* season. Total 88 ground truth samples were collected out these 73 rice and remaining 15 were non rice samples.

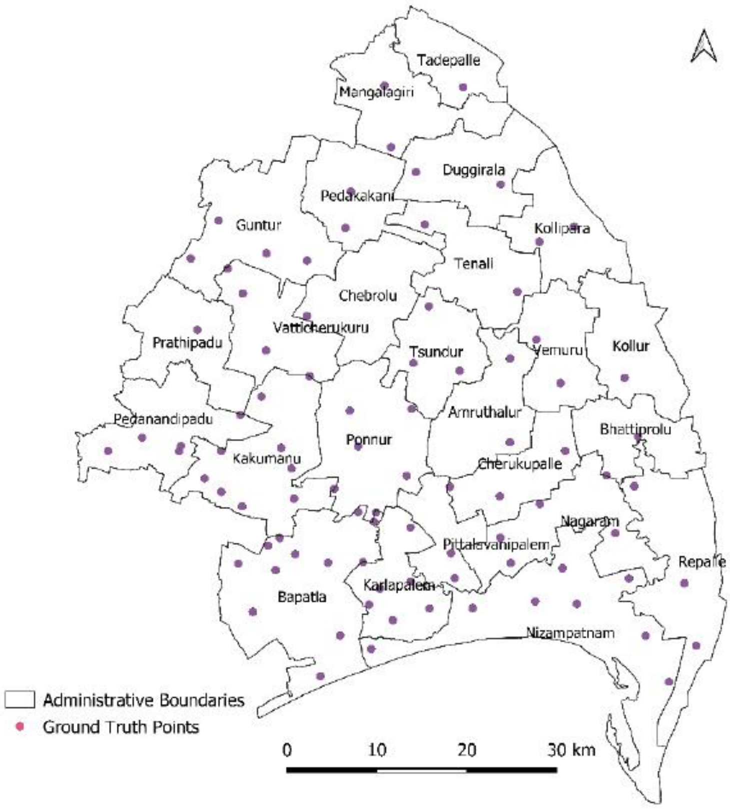

Fig. 2 Distribution of ground truth points across the KWD region

Methodology

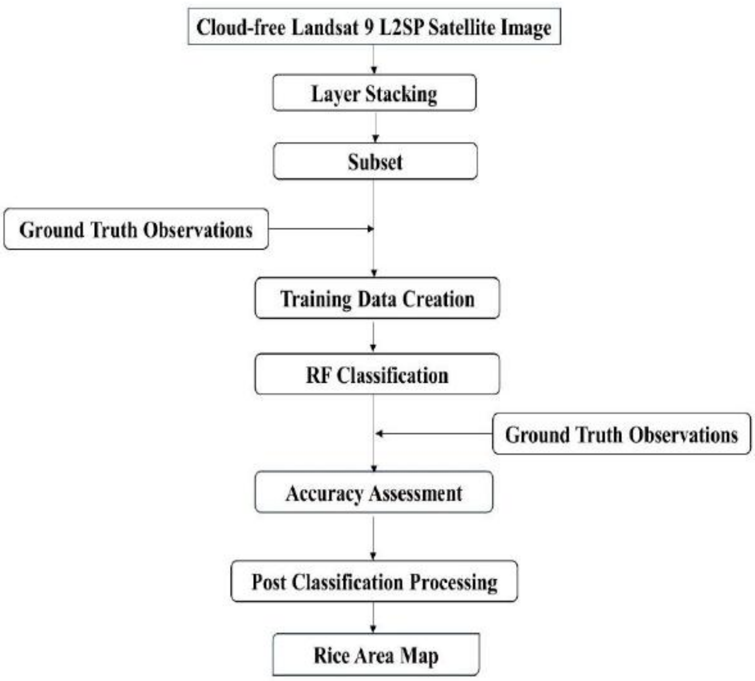

Fig 3 Flow chart of methodology to estimate rice area

Landsat 9 Level 2 data was downloaded from USGS Earth Explorer and pre-processed for atmospheric correction and surface reflectance. The data was then extracted and imported into ENVI software, where bands 6, 5, 4, and 3 were stacked into a single multi-band image using the collocation tool, preserving individual band details.

For supervised classification, distinct spectral signatures were developed by gathering training samples from known locations. In this study, 60% of the signatures were for rice crops, with the remaining 40% representing other land uses such as water bodies, horticulture, and settlements. These signatures were recorded as ESRI shapefiles using QGIS software and validated through comparison with ground truth photos and satellite imagery.

The Random Forest algorithm was used for classification, where multiple decision trees built from training data provided robust results. Each tree voted, and the majority class was assigned to each pixel, producing an accurate land cover map based on spectral data. This approach effectively reduced errors and improved classification outcomes.

The accuracy of the rice area map was evaluated by comparing the classified land cover with spatially and temporally consistent reference data, and the results were summarized using an error matrix. Cohen's kappa coefficient was employed to measure classification reliability, accounting for the possibility of agreement by chance, making it more robust than simple percent agreement (Sharma *et al*., 2022).

Post-classification refinement is crucial for correcting misclassifications and enhancing map accuracy. Techniques such as filtering remove isolated pixels and small clusters to improve coherence, while manual expert edits address errors that automated processes may overlook. The inclusion of ancillary data, such as topographic and land use maps, adds context that spectral data alone cannot provide, improving the distinction between features like forests and agricultural fields on varying terrains.

The refined map is then masked with a land use map to exclude irrelevant areas, reducing misclassifications and aligning the output with the study's objectives. This ensures a more accurate and reliable tool for decision-making.

The final map, after refinement and validation, represents rice fields with distinct symbols for easy interpretation. It helps stakeholders make informed decisions by clearly delineating rice cultivation areas. The cultivated area in ha was calculated in QGIS software by multiplying pixel counts with the pixel size, using the equation proposed by Siddiquee *et al*. (2021).

Area (ha) = pixel number × pixel size,

Where **pixel size = 30×30 = 900m² = 0.09 ha**

III. RESULTS AND DISCUSSION

The classified raster image of rice cultivation in the Krishna Western Delta (KWD) of Guntur district (Fig. 1) showed that rice is the primary crop during the Kharif season across the study area. Rice cultivation was observed in all mandals, with Pedanandipadu, Prathipadu, Tadepalli, Mangalagiri, and Guntur focusing primarily on the lower southeastern regions, where canal water was accessible. In Nizampatnam mandal, factors such as water-borne salts, aquaculture, the inland influx of brackish water during tidal events, and freshwater aquifer contamination caused salt accumulation on approximately 40% of the land. This accumulation rendered the soil unsuitable for rice cultivation until the salts were flushed out, resulting in delayed sowing, further impacted by the late arrival of canal water in this tail-end area of the KWD. In Bapatla, Amruthalur, Vemuru, Cherukupalli, Nagaram, Pittalavanipalem, and Ponnuru mandals, over 85% of the net cultivable area was estimated to be under rice cultivation.

In the southern part of the study area, the land slope was unsuitable for rice farming. To manage this, farmers constructed extensive bunds to conserve water, leading to a landscape where rice fields were interspersed with non-rice areas. In the western part of Kakumanu mandal, located within the Nagarjuna Sagar right canal command area, irrigation water was provided in late September, supplemented by water from the Prakasam barrage. Terrain changes in this region caused delays in sowing, extending the rice cultivation period until the end of the Kharif season.

The rice area, as depicted in the raster image, was analyzed using the zonal histogram module of QGIS, applying administrative boundaries. The total estimated rice area in the Krishna Western Delta of Guntur district for the *kharif* 2023 season was 1,27,565 ha (Table 4.2). The estimated rice area, obtained using the Random Forest supervised classification technique, was compared with the mandal-wise rice area figures provided by the Department of Agriculture, Government of Andhra Pradesh, for the same season. Bapatla recorded the largest estimated rice cultivation area (12,299 ha), followed by Ponnuru (12,077 ha) and Nagaram (10,184 ha), while Pedanandipadu (3 ha), Prathipadu (57 ha), and Tadepalli (169 ha) had the smallest areas.

The comparison between the estimated and reported rice areas revealed an underestimation of 5,837 ha, a deviation of 4.4%. Karlapalem mandal had the smallest deviation at 0.2%, while Bhattiprolu showed a 3.1% variance. The largest deviation occurred in Pedanandipadu mandal, with a 97.5% difference, likely due to rice cultivation on narrow strips adjacent to streams using borewell irrigation, with most of the sowing occurring in September. Additionally, narrow strips of land (less than 150 m) bordered by vegetation near drains complicated the precise identification of rice cultivation areas. Bapatla mandal showed the largest overestimation of rice area, exceeding 4,037 ha, followed by Ponnuru with an overestimation of 1,517 ha. The most significant misclassifications occurred in Repalle (2,505 ha) and Kakumanu (2,214 ha) mandals, likely due to water accumulation in seasonal fallows and the misidentification of annual grasses in waterlogged areas as rice fields, leading to the misclassification of non-rice areas.

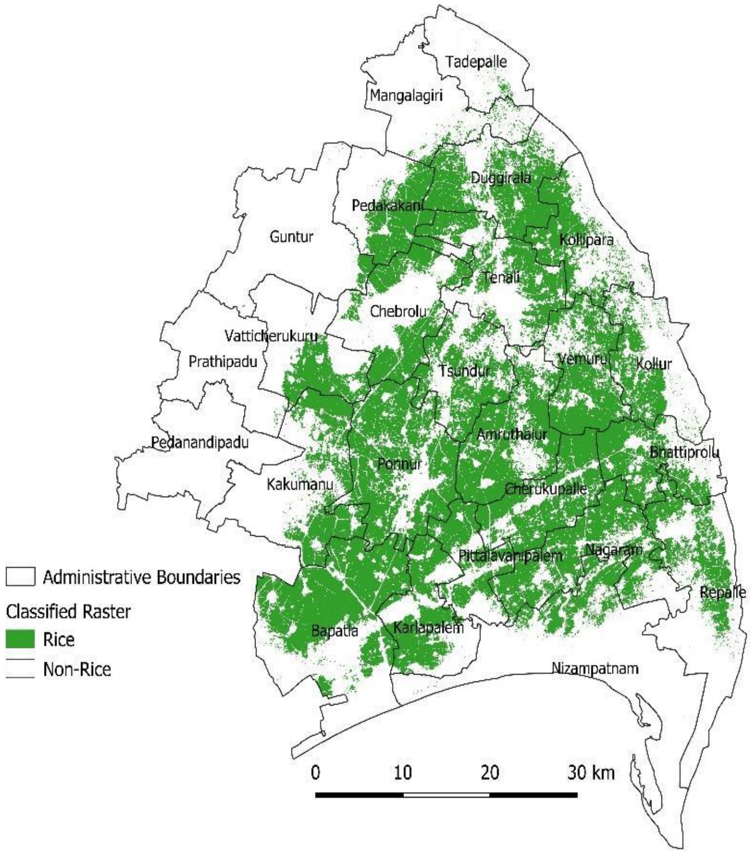

Fig. 4 Estimated rice area map of the KWD region kharif 2023

Table 1 Comparison of estimated and reported Department of Agriculture rice cultivated area in KWD region during kharif 2023

S.No	Mandal Name	Normal Area(ha)	DoA reported area(ha)	Estimated area (ha)	Difference (ha)	Deviation (%)
1	Amruthalur	10402	9910	8402	-1508	-15.2
2	Bapatla	13206	8733	12770	4037	46.2
3	Bhattiprolu	5942	5536	5362	-174	-3.1
4	Chebrolu	6025	4389	5497	1108	25.2
5	Cherukupalle	7402	6721	7086	365	5.4
6	Duggirala	8665	8078	7534	-544	-6.7
7	Guntur	679	543	458	-85	-15.7
8	Kakumanu	10089	8254	6040	-2214	-26.8

9	Karlapalem	6427	5140	5152	12	0.2
10	Kollipara	6252	5872	4806	-1066	-18.2
11	Kollur	4976	4286	3929	-357	-8.3
12	Mangalagiri	2427	1979	632	-1347	-68.1
13	Nagaram	10720	8218	8854	636	7.7
14	Nizampatnam	5260	3996	3288	-708	-17.7
15	Pedakakani	5303	4531	4918	381	8.4
16	Pedanandipadu	112	119	3	-116	-97.5
17	Pittalavanipalem	4921	4407	3952	-455	-10.3
18	Ponnur	13073	10560	12077	1517	14.4
19	Prathipadu	357	264	57	-207	-78.4
20	Repalle	10373	7500	4995	-2505	-33.4
21	Tadepalle	674	579	169	-410	-70.8
22	Tenali	7958	6500	6017	-483	-7.4
23	Tsundur	8058	7231	5442	-1789	-24.7
24	Vatticherukuru	3330	2802	3241	439	15.7
25	Vemuru	8032	7254	6884	-370	-5.1
	Total	160663	133402	127565	-5837	-4.4

Accuracy assessment of rice area map

The rice area map generated using supervised classification was confirmed with ground truth data, and the findings are described in Table 4.

Table 2. Error matrix for validation of estimated rice area

Actual Class from Survey	**Predicted Class from Map**				**UsersAccuracy (%)**
	Class	**Rice**	**Non-Rice**	**Total**	
	Rice	69	4	73	**94.5**
	Non-Rice	1	14	15	**93.3**
	Total	70	18	88	**0**
	Producers Accuracy (%)	**98.6**	**77.8**		**94.3**

Kappa coefficient

$$\text{Kappa Index} = \frac{(Observed\ Accuracy - Expected\ Accuracy)}{(1 - Expected\ Accuracy)}$$

$$= \frac{(Po-Pe)}{(1-Pe)} = \frac{(0.94-0.67)}{(1-0.67)} = \frac{0.27}{0.33} = 0.81$$

A classification error matrix was generated using 88 ground truth observations, of which 73 were classified as rice and 15 as non-rice. Of the 73 rice observations, 69 were correctly identified, while 4 were misclassified as non-rice. Similarly, 14 of the 15 non-rice observations were accurately classified, with 1 misclassified as rice.

The user accuracy for the rice class was 94.5%, indicating a high level of accuracy in identifying rice areas. For the non-rice class, the user accuracy was 93.3%. The producer accuracy, reflecting the model's ability to correctly identify actual rice areas, was 98.6% for rice and 77.8% for non-rice.

The overall classification accuracy reached 94.3%, supported by a kappa coefficient of 0.81, indicating strong agreement between the classification results and the ground truth data. These results align with previous studies: Bhatt and Nain (2018) reported an overall accuracy of 92.88% and a kappa coefficient of 0.89, Chen *et al*. (2016) achieved 86.2% accuracy with a 0.72 kappa coefficient, and Chang *et al*. (2020) noted 91.9% accuracy and a 0.83 kappa coefficient, all demonstrating a high degree of classification reliability.

IV. CONCLUSION

Accurate estimation of rice areas in the Krishna Western Delta (KWD) is critical for agricultural planning, resource management, and policy formulation, particularly in rice-dominated regions like Andhra Pradesh. Traditional field survey methods for area estimation are often subject to inaccuracies and inefficiencies. However, with the advent of geospatial technologies, remote sensing (RS) and Geographic Information Systems (GIS) offer more precise and efficient methods for crop area estimation. In this study, Landsat 9 satellite data from November 2023 was utilized to estimate the rice area in KWD during the Kharif season. The analysis was performed using ENVI and QGIS software, applying Random Forest supervised classification to distinguish between rice and non-rice areas. Ground truthing, conducted in August 2023, validated the satellite data. The classification accuracy was evaluated using an error matrix, which included user and producer accuracies, as well as commission and omission errors. Additionally, the overall accuracy and Cohen's Kappa coefficient were calculated to assess the reliability of the results. This method significantly reduces errors and provides a reliable framework for accurate rice area estimation, supporting better decision-making in agricultural planning and resource allocation.

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