Original Research Article

Spatial Analysis of Crop Diversity in Telangana: Implications for Agricultural Sustainability

Abstract:

Aim: In this study, the crop diversity index (CDI) was computed for the Telangana Rabi season at the mandal levelusing crop area data derived from remote sensing.

Place and duration of study: Telangana, between 2017 to 2021-22.

Methodology: Sentinel 2A and 2B MSI L2A products were processed to obtain time series normalized difference vegetation index (NDVI) images. Major rabi crops were identified by extracting pure cropped pixels based on ground truth data using the NDVI composite index, which includestemporal profiling of NDVI values over time.A hybrid method, combining phenology based decision rules and unsupervised classification, was employed to delineate rabi crop area.

Result:The cropped area estimates from remote sensing showed a strong positive correlation with data provided by government agencies. To asses agricultural diversification at the mandal level, the Gibbs and Martin formula (1962) of crop diversification index was used to generate the crop diversity index, focusing solely on the net planted area of crops during rabi season.

Conclusion: The resulting thematic crop maps, area estimates, and CDI maps serve as valuable tools for scientists and policymakers, aiding in the development of targeted technologies and strategies to enhance agricultural productivity and sustainability at the mandal level. Promoting crop diversity and supporting diverse crop irrigation infrastructure can mitigate the adverse effects of monocropping and enhance the resilience of Telangana's agricultural sector.

Keywords: Remote sensing, Sentinel 2A and 2B MSI L2A, Crop area maps, Crop Diversity Index.

1. INTRODUCTION

India is primarilyan agrarian economy, contributing 17% of its gross domestic product (GDP) andinvolving around 70% of its working population inagriculture and related sectors.Agriculture and related industries play a significant role in the economies of several Indian states. Telangana state's agriculture and allied sectors contribute 18.7% of the total GDP at the current price in 2021-22. However, it's important to keep in mind that agriculture's contribution to the GDP has been declining over time as other economic sectors have grown drastically [1]. Therefore, research and effective planning are indispensable in the agricultural sector for accelerating the growth and developmentof the farming community. The concept of crop diversity was used to gauge and study the level of agricultural advancement, as it is highly dependent on the region's geo-climatic variables, socioeconomic situations,

and technological advancement. Crop diversification boosts calorie production without compromising nutrient availability and acts as a tool for climate resilience and resource use effectiveness [2].

The term "crop diversification" refers to the practice of growing a variety of crops in arable land, which contradicts crop specialization. The diversity with the cultivation of multiple crops demonstratesthe relative areal strength of a region. Crop diversification takes place as a consequence of technological advances, changes in consumer behavior and demand pattern, irrigation development, accessibility to marketing infrastructure, new trade arrangements, and macro-economic reforms in the agriculture sector. It is a key tactic for attaining the goals of ensuring food and nutrition security, income growth, reducing poverty, and creating jobs, as well as for making holistic use of land and water resources, promoting sustainable agricultural development, and improving the environment [3].

As crop diversification is dynamic in nature and may alter with time and location. It needs reliable and accurate net sown crop area for all the crops grown in a region at the mandal level, which can be served from remote sensing techniques. Remote sensing has long been recognized as an inevitable tool for large-scale crop area assessment [4-7]. The European Space Agency deployed Sentinel-2A and 2B, in the year 2015 and 2017. These optical imaging satellites store the reflectance value of the earth's surface as pixels in 13 bands [8]. The two satellites working together offer optical images at every 5-day interval having 10-meter spatial resolution. Many studies concluded that sentinel 2 based crop area estimates are near to actual data, with high spatial and temporal resolution [9-12].

In Telangana state,crop diversification is essential in the view of excess paddy production due to the mono-cropping of paddy and its specialization. Crop diversification practice in the state ensuresavoiding glut in the production of paddy grains and encouragesthe cultivation of other food grains like pulses and oilseed production. This strategy plays a crucial role in the present context, aiming to stabilize farmers' income during challenging situations, maintain stable food grain prices in the domestic market, and foster the opportunity for export due to surplus production in Telangana.This study also helpsscientists and policymakers to understand theTelangana rabi season crops distribution at the mandal level and crop diversity driving factors. Eventually crop diversification improvement strategies can be designed at the mandal level scale for effective implementation at the field level.It should be noted that there aren't many studies on this topic for this state. In this context, the Telangana state is selected for analyzing the spatial and temporal dynamics in the crop diversity index at the mandal level.

2. STUDY AREA

The study was conducted during the Rabi season in Telangana, a state of India. The state has a land area of 1,12,077 square kilometers, located in the center of the Indian peninsula on the Deccan plateau (Fig I). The Rabi crop accounts for 40% of the total cropland and 60% of the total agricultural production of the state. The state has hot and dry climate and it is divided into three agro-climatic zones namely northern, central, and southern Telangana zones depicted in Fig II. Most of the soils in the state of Telangana fall under the alfisols, vertisols, and inceptisols soil orders [13]. The northern Telangana zone has 18.4 % black soils, 16.6 % deep calcareous soils, and 15.2 % red clayey soils. Central Telangana zone has 54 % red soils, 13 % calcareous soils, 8 % colluvial soils, and 6 % black soils. The southern Telangana zone has 54.8 % red soils with various textures and depths followed by 11.2 % of colluvial soils and calcareous soils [1]. The average annual rainfall is 906.3 mm with 62 rainy days. Southwest monsoons contribute 80 % of the total annual rainfall. The average annual Maximum temperature is 34.2 ^{o}C and the average annual minimum temperature is 21.6 ^{o}C.

The state has a gross cropped area spanning 62.88 lakh hectares and a net cropped area covering 49.61 lakh hectares in 2021-22. Its agricultural sector is strongly supported by a robust irrigation infrastructure, primarily sourced from the Godavari and Krishna River basins. This infrastructure enables a substantial gross irrigated area of 131.64 lakh hectares and a net irrigated area of 22.5 lakh hectares (2021-22). Irrigation intensity of 138 % and a cropping intensity of 127% in Telangana demonstrates remarkable efficiency in utilizing its arable land. The plateau region has an average height of 500 meters,

with greater elevations in the west and southwest ranging from 300 to 600 meters and a slope that descends towards the east and northeast (Fig. I.) [1].

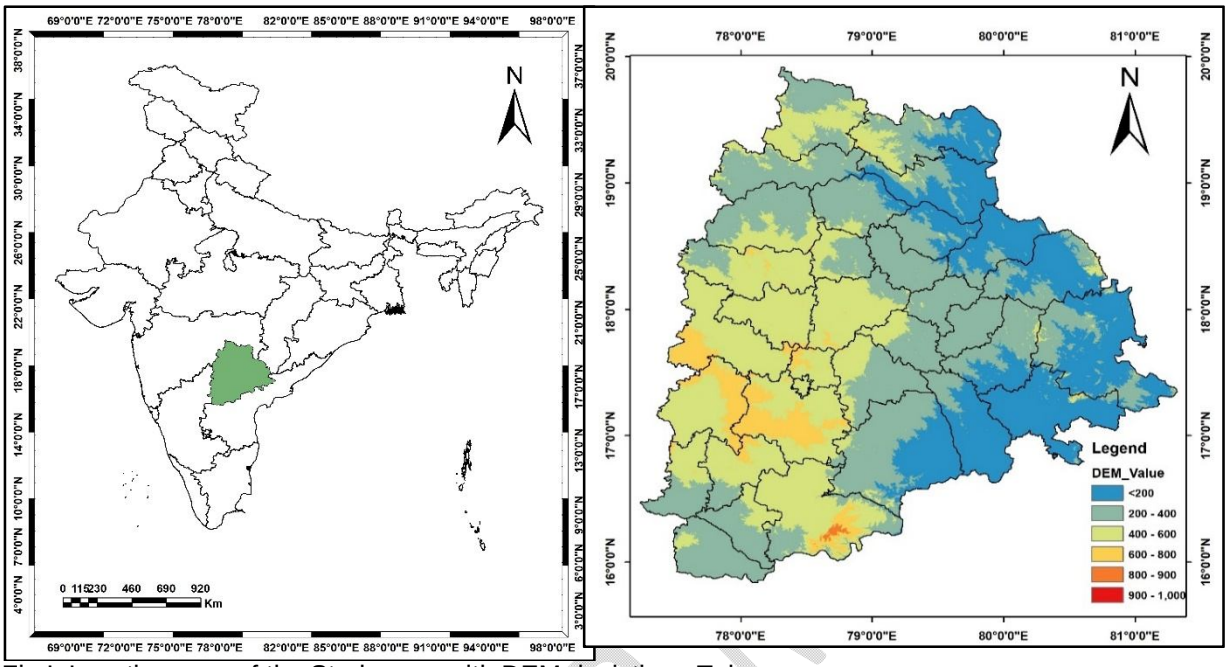


Fig I. Location map of the Study area with DEM depiction– Telangana

3. Materials and Methods

Google EarthEngine (GEE), ERDAS IMAGINE v 2014, and ArcGIS software applications were used for downloading satellite data, stacking, mosaicking, histogram matching, subsetting raster images, and mapping.

3.1. Reported Data on crop acreage

Telangana statistical abstract atlas published by DES-Telangana from 2017 to the 2022 year includes data on agricultural crop acreage that is compiled yearly at the district level. This database is used to confirm the classification of crops in the study area. However, this information available at the district level was compiled by field surveyors through sample surveys of farmers, therefore it does not provide accuracy of the cultivated crop at the village level/ mandal level.

3.2. Ground truth data

A field survey was taken up in the study area, to collect ground truth data for Rabi crops.A mobile app named google mapswas used to gather ground truth field data. Random samplingtechnique was practiced forground truth point selection due to unequal distribution of crop fields, variations in one crop's growth phases, a lack of suitable road infrastructure, the crop field's inaccessibility, and time and cost constraints.Collected ground truth points were widely distributed throughout the study area, covering various crop conditions and crop management practices.A database composed of 856 ground truth points associated with specific crop types and other points like forests, settlements, water bodies etc. were mapped in Fig II.

Ground truth point collected from crop field survey was overlaid ontoa season maximum false color composite image. Using ArcGIS software, crop-specific polygons were constructed around 856 ground truth points. These polygons encompassed areas of similar red pixel color within each field boundary to ensure the capture of pure crop pixels. These ground truth polygons with pure crop pixels' data were utilized to extract time series NDVI values from fortnight interval time series NDVI composite images. The time series NDVI values (Fig III) illustrate thetemporal NDVI profile along with threshold values for various

phonological stages for eachcrop. If a crop field has low foliage density, the least NDVI value relates to reflectance that emanates from bare soil pixels, while the highest NDVI value is ascribed to the crop's increased NIR and red reflectance [14].

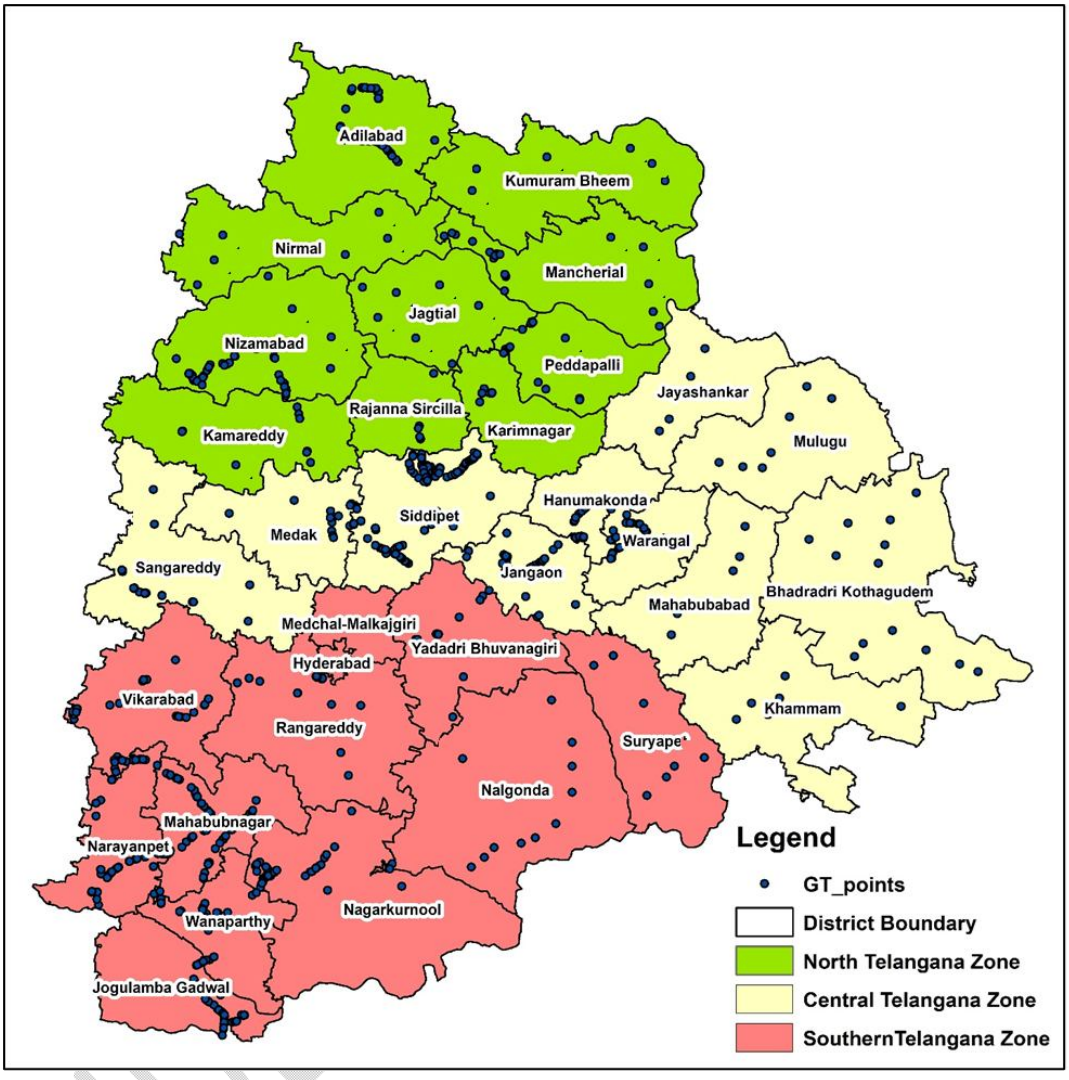


Fig II. Study area depicting the ground truth points distributionand three agro-climatic zone

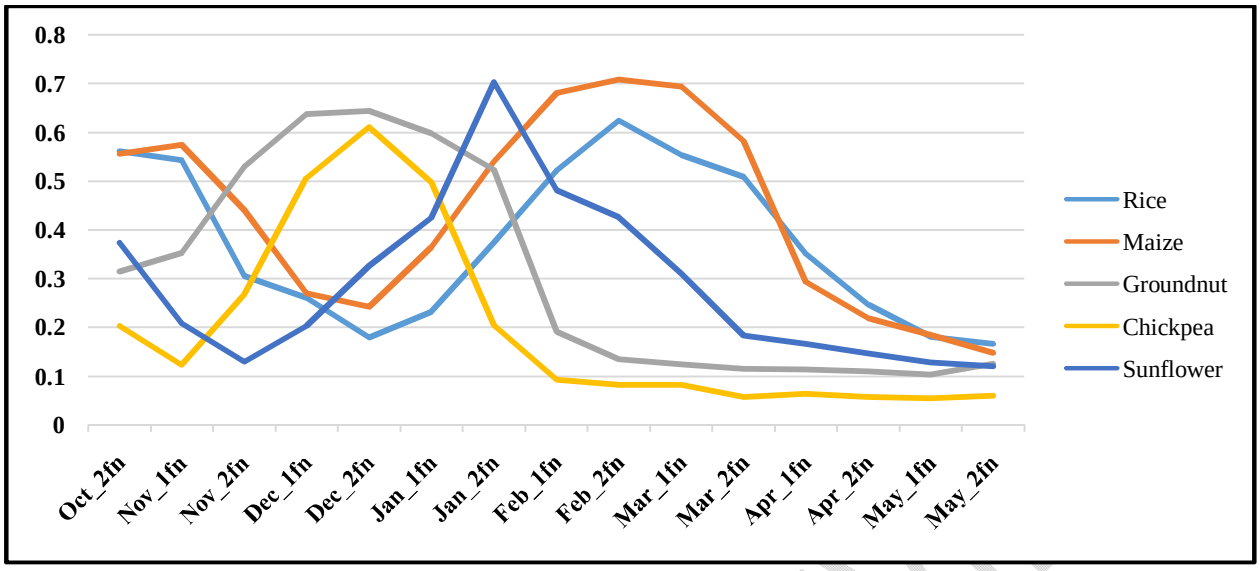


Fig III. NDVI-based crop growth profiles for Rice, Mize, Groundnut, chickpea, and sunflower

Sentinel 2A and 2B MSI L2A productscomprise radiance value metric that is used to compute NDVI (normalized difference vegetation index) values [15]. NDVI is frequently used in many applications for monitoring vegetation and agricultural crops[16, 17]. NDVI values were calculated using [18] NDVI concept.

$$NDVI = \frac{NIR-R}{NIR+R}$$

Where, NIR and R area the reflectance in Near-infrared and red band region.

NDVI value shows a strong correlation with the green biomass of crops at various growing stages in the growth cycle. Early in the crop cycle, when the crop is in its initial stage with a lesser green leaf area and more background effects due to tillage, crop residue, or moisture records minimum NDVI values[19, 20]. Whereas the peak flowering stage of the crop with a higher leaf area index and heavy crop density records higher NDVI values [19, 21]. The NDVI reading over time demonstrates that it is increasing with the rise of plant green biomass from the seedling stage to the peak vegetative stage, attaininga higher level of NDVI at the peak vegetation stage of the crop and twitching to decline gradually with the onset of the flowering stage with the decay of older leaves. Thus, NDVI temporal values portraythe exclusive spectral signature of each crop and enable to discriminate different crops during the Rabi cropping season (Fig III). So, this index serves to discriminate and estimate cultivated areas under various crops [15, 22].

3.3. Image processing on the GEE platform

The entire methodology's workflow is shown in FigIV. In the Google Earth engine using sentinel 2 MSI L2A product, the NDVI composite image was developed by using the NDVI formula over red and NIR bands [23]. The time series maximum NDVI composite images were developed at fortnightintervals, from September to Mayfor all the districts in the state from 2017-18 to 2021-22 years. Agriculture crop mask was applied to time series NDVI composite image to get only agricultural area for efficient crop type identification and to remove forest areas, waste lands and settlement areas. Cluster images were developed from NDVI composite images using ISOCLASS - K means clusters algorithm with 30 iterations and 0.90 convergence threshold to create 75 spectral classes [24].

3.4. Crop-specific area delineation

Zonal mean values were extracted for 75 spectral classes using NDVI composite image and cluster image at the district level for Telangana state. These 75 spectral classes with time series NDVI profiles represent existing cropped and non-cropped areas. Each crop has a distinct crop growth profile despitethe same geo-climatic conditions under the Rabi season. Each spectral class was thoroughly examined to identify the NDVI threshold values and distinctive NDVI time series profiles that align with the NDVI time series crop growth profiles produced from ground truth polygons (Fig III). The corresponding spectral classes, which match with specific Rabi crop growth profiles and NDVI thresholds were recoded and reclassified as individual specific crops (Gumma et al., 2014). The reclassified raster image contains five classes namely Paddy, Maize, Groundnut, Chickpea, and Sunflower. This is a hybrid method that uses phenology-based decision rules and unsupervised classification. The reclassified raster images are the thematic Rabi crop maps of Telanganafrom 2017-18 to 2021-22, which were mapped and presented in Fig. V.

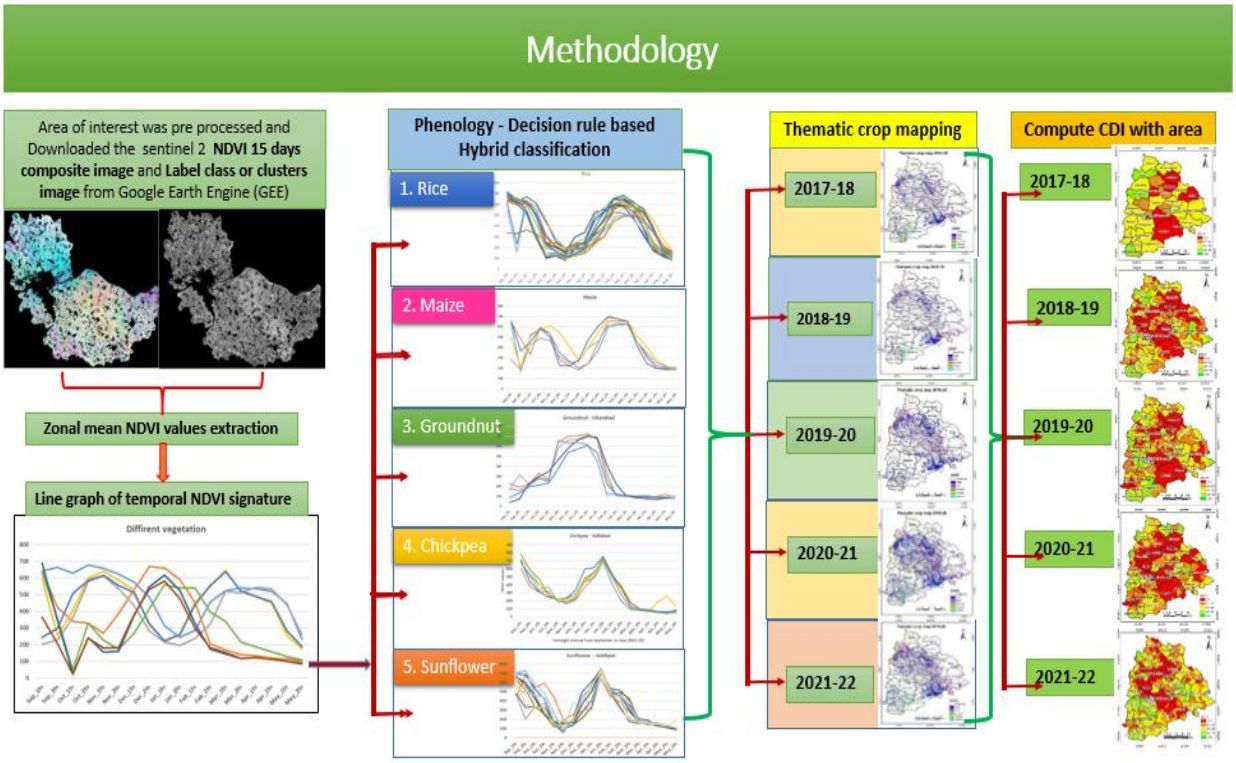


Fig. IV. Flowchart outlining the steps involved in mapping crop types, estimating their area using remote sensing and GIS, and creating crop diversity index

3.5. Accuracy assessment of thematic raster crop imagery

The overall accuracy and kappa coefficient were 85.6% and 0.81, respectively, which indicates that the classified result is satisfactory (Table I).

Table I. Confusion matrices with producer's accuracy and user's accuracy

Ground truth / Predicted	Paddy	Maize	Groundnut	Chickpea	Sunflower	others	Total reference points	Users accuracy (%)
Paddy	258	13	11	1	0	7	290	88.97
Maize	2	146	3	11	0	3	165	88.48
Groundnut	0	8	85	1	2	6	102	83.33
Chickpea	2	5	3	68	3	8	89	76.40

Sunflower	0	2	0	0	20	0	22	90.91
Others	12	9	6	3	0	146	176	82.95
Total classified points	274	183	108	84	25	170	844	
Producers accuracy (%)	94.16	79.78	78.70	80.95	80.00	85.88		
Overall accuracy	85.66							
Kappa's coefficient	0.815							

Thematic raster crop image was used to work out the individual cropped area at the district level and mandal level for all dates in the Rabi season (Annexure I). Further, this computed cropped area at district level from remote sensing and reported cropped area at the district level had shown a good comparison of agreement (Annexure II). The following formula was used to determine the discrepancy of the remotely sensed cropped area from state department reported statistics.

Relative deviation (RD) % = (RS- DOA) / RS x 100

(1)

where RSstands for remote sensing crop area estimates, and DOA stands for crop area estimates from the Department ofAgriculture, Telangana [25].

Crop Diversity Index (CDI): The [26] formula for crop diversification shown below was used to determine the agricultural diversity index in a region.

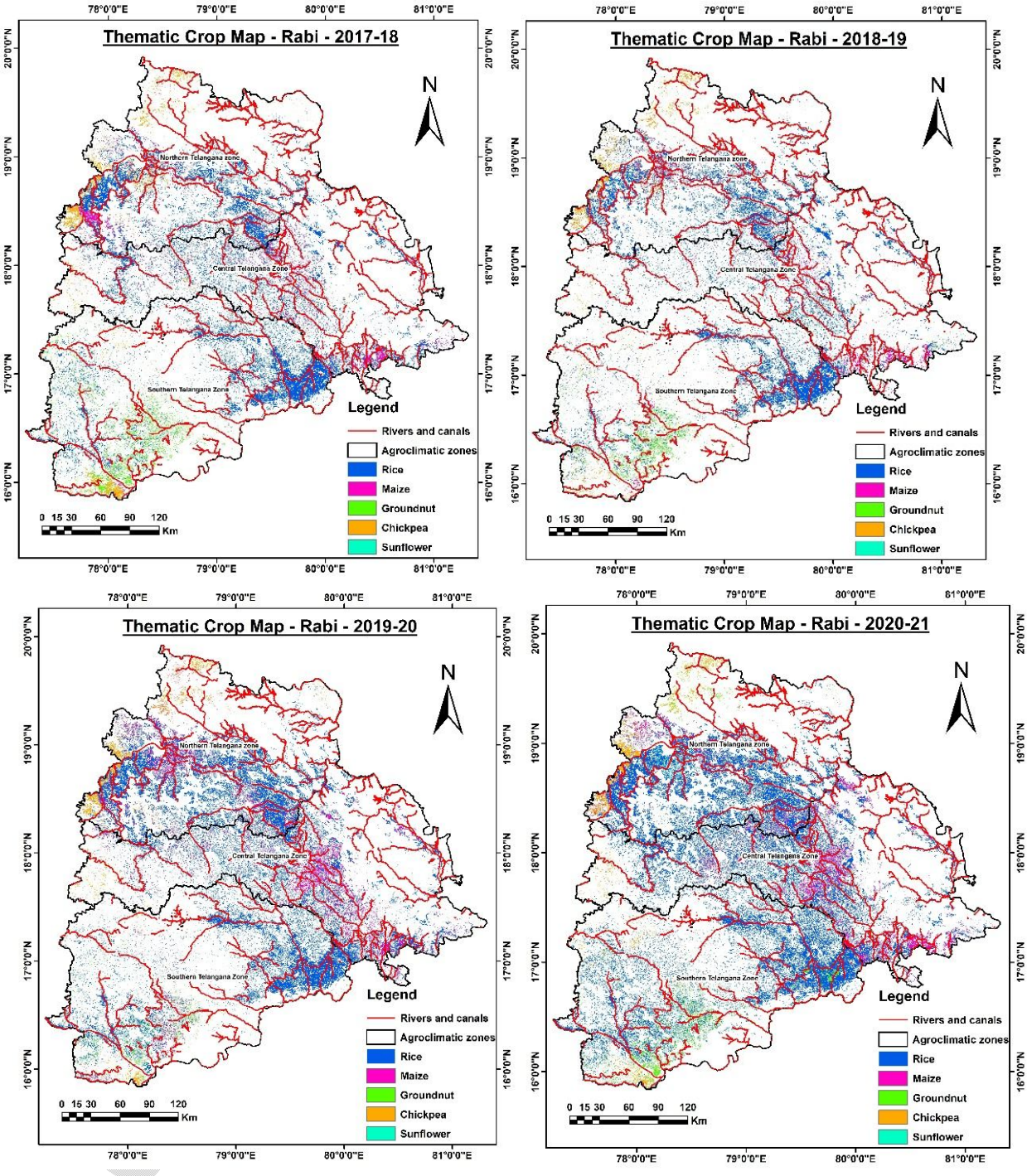
Crop diversity index $= 1 - \frac{\sum x^2}{\sum(x)^2}$ (2)

Where X is the percentage of the total cropped area occupied by each crop in a region.

The CDI ranges from 0.1 to 0.9, a higher value of CDI shows a higher magnitude of crop diversification and vice versa. The range was classified into four groups namely high (above 0. 65), medium (0.55 – 0.65), low (0.45 – 0.55), and very low (below 0.45)[27]. The crop diversity indexwas computed for all 5 years using remotely sensed crop areaestimates.

4. RESULTS AND DISCUSSION

In Telangana, the extended Rabi season known as the "*Yasangi*" season lasts from the first week of October till the end of May, encompassing both the winter and spring. The relative deviation percentage between estimated crop acreage using remote sensing and reported crop acreage by DES-Telangana was 17.88 % in the 2017–18, 21.96 % in2018–19, -0.77 % in2019, 2.92 % in2020–21 year and 8.08 % in2021–22. The large differences in2017-18 and 2018-19, may be attributed to change in district and mandal boundaries used for remote sensing of 2021-22, which were updated in the year 2020-21. Additionally, omission and commission could be significant factors contributing to discrepancies between remote sensing based and reported crop area statistics.


Thematic Crop Map - Rabi - 2017-18
Thematic Crop Map - Rabi - 2018-19
Thematic Crop Map - Rabi - 2019-20
Thematic Crop Map - Rabi - 2020-21
N
Northern Telangana zone
Central Telangana Zone
Southern Telangana Zone
Legend
Rivers and canals
Agroclimatic zones
Rice
Maize
Groundnut
Chickpea
Sunflower
0 15 30 60 90 120
Km
78°0'0"E
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80°0'0"E
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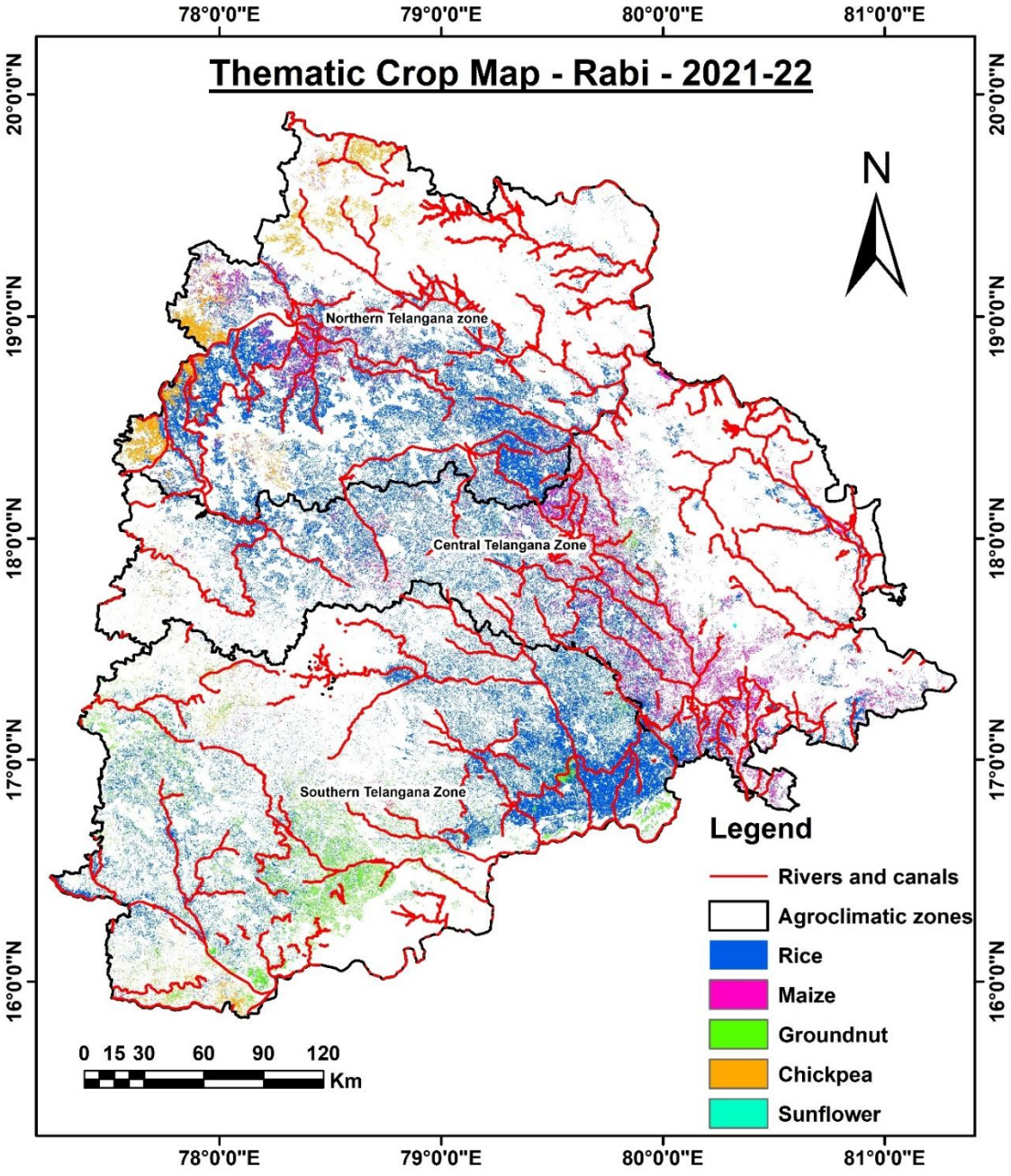


Fig V. Crop maps of Rice, Maize, Groundnut, Chickpea, and Sunflower crops from 2017-18 to 2021-22

Thematic raster crop maps for Telangana's Rabi *(Yasangi)* season from 2017-18 to 2021-22 are displayed in Fig V. In Telangana, the major field crops cultivated during the *Rabi* season, listed in descending order of crop area predominance, are Paddy, Maize, Groundnut, Chickpea, and Sunflower. Paddy crops account for 70 to 83% of the total *Rabi*area. As a semi-aquatic plant, paddy is primarily grown in the regions with good irrigation infrastructure under Krishna and Godavari rivers and their tributaries. The blue color in FigureV represents the paddy crop, which dominates in north and central Telangana, as well as indistricts such as Nalgonda, Suryapet, and Mahabubnagar districts in the southern

Telangana zone. These regions benefit from better irrigation infrastructure facilities like canal irrigation and lift irrigation projects. The pink pixels in the map indicate area where maize is grown, primarily found in the Warangal, Hanumakonda, Khammam, Kamareddy, and Nizamabad districts. These regions have improved irrigation systems and well-drained, light soils ideal for maize cultivation. Groundnut crops are represented by green pixels, predominating in the southern Telangana zone. This crop is favored by farmers in semi-arid districts like Nagarkurnool, Wanaparthy, Narayanpet, and Mahabubnagar due to its drought resistance and lower water requirements.

Chickpea crops are depicted with orange pixels and are significant in the northwest region of Telangana. This area typically records the lowest temperatures in the state, which are crucial for chickpea biomass development and flowering. Additionally, chickpea utilizes atmospheric dew water during winter for growth and development, as it is traditionally grown in black soils under residual moisture from the southwest monsoon [28].

Crop diversity index:

The Crop Diversity Index (CDI) values in Telangana from 2017-18 to 2021-22 (Fig VI and VII) are low due to paddy mono-cropping. Irrigation projects often result in paddy monocropping due to a variety of factors. The high-water demand of paddy, combined with the availability of irrigation facilities, makes it a convenient and economically secure choice for farmers [29]. Market supply chain and other economic benefits through policies and schemes from government driven farmers towards rice mono cropping[30]. However, this monoculture can lead to environmental degradation, including soil depletion and increased pest infestation [31].

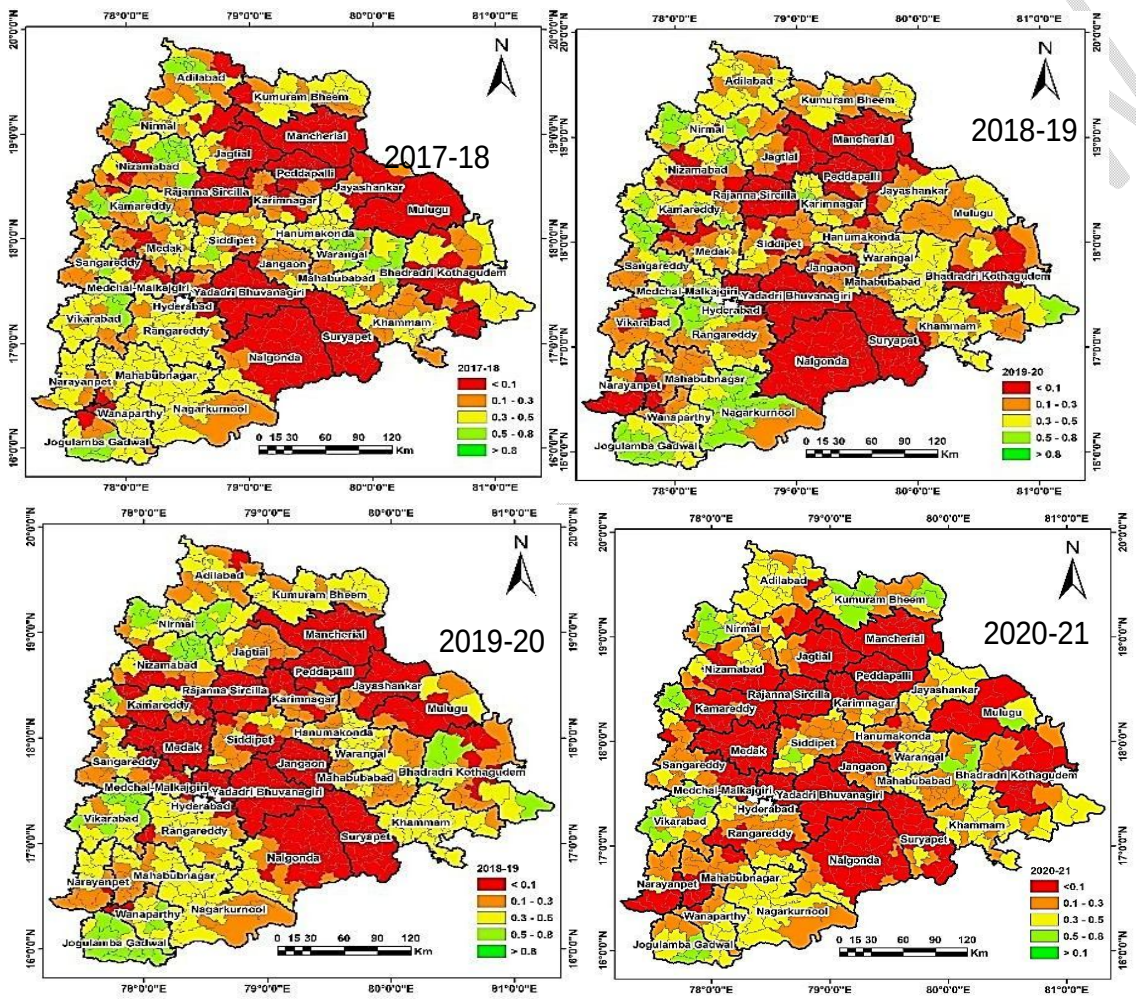
Crop diversity declination pose a considerable strain on the natural resources, environment, labor, market, machinery availability, and socioeconomic conditions of farmers[32]. The CDI maps in Fig VI and VII indicates low diversity in northern Telangana zone (0.28–0.31), attributed to better irrigation facilities promoting rice cultivation and reducing other crop cultivation. Central Telangana also shows low CDI values (0.361–0.445) due to extensive canal and tube well irrigation, with over 50% of the area dominated by Rice and 10% by Maize (Fig V). but the CDI values arebetter than the northern Telangana zone due to deep loamy soil and floodplain topography facilitated cultivation Maize crop. In contrast, southern Telangana has medium CDI values (0.461-0.582) driven by lower regional development, undulating topography, lack of irrigation infrastructure, and less monsoon rainfall. Farmers in the southern Telangana region prefer to grow various irrigated dry crops to mitigate risk from natural disasters.

In most of the districts, the crop diversity gradually reduced from 2017-18 to 2020-21 from 0.47 to 0.36, before rising to 0.41 in 2021-2 due to restriction on paddy crop cultivation and government campaignspromoting crop diversity. The CDI spatial distribution remained consistent at district level from 2017-18 to 2018-19 with minor variations at the mandal level.In2019 -20 and 2020-21 also had similar cropdiversityindexdistributionexceptlowCDI inthedistrictsofNagarkurnoolandSangareddydistrictsinthe2020-21year.The southernTelanganazonehad higher CDI values in in 2021-22 and 2017-18, encompassingJogulambaGadwall,Narayanpet,Wanaparthy,Mahbubnagar,NagarkurnoolandRangareddy districts. Eastern Telangana zone also had a good crop diversity index, which comprises Nirmaland Kamareddy, Vikarabaddistricts due to higher elevations and well drained soils.

Table II. Correlation (r) between crop diversity index and percent of area occupied by individual crop.

Crops	2017-18	2018-19	2019-20	2020-21	2021-22
Paddy	-0.75	-0.74	-0.77	-0.83	-0.69
Maize	0.42	0.35	0.56	0.49	0.49
Groundnut	0.94	0.94	0.97	0.97	0.92
Chickpea	0.39	0.43	0.41	0.51	0.15
Sunflower	0.03	0.00	0.00	-0.03	0.03

In every year from 2017-18 to 2021-22, the Crop diversity index demonstrateda strong positively correlation with the percentage of groundnut crop area (r = 0.92 to 0.97) followed by Maize (r = 0.35 to 0.56) and Chickpea (r - 0.15 to 0.51). Conversely, there was negative correlation with the percentage of Paddy crop area (r = – 0.69 to -0.75) (Table II). The influence of sunflower crop area on CDI was minimal due to its limited cultivation.Paddy and Maize are commonly grown across majority of the districts.However, the inclusion of groundnut cropssignificantly increased in specific districts, resulting in a high positive correlation with CDI. The negative correlation with paddy crops tosubmerged field conditionsand increased availability of irrigation water, which may reduce the cultivation of waterlogging sensitive cropssuch as Groundnut, Maize, and Chickpea crops.Thisindicates that an abundance irrigation water createsan unfavorable condition for crop diversity in Telangana.



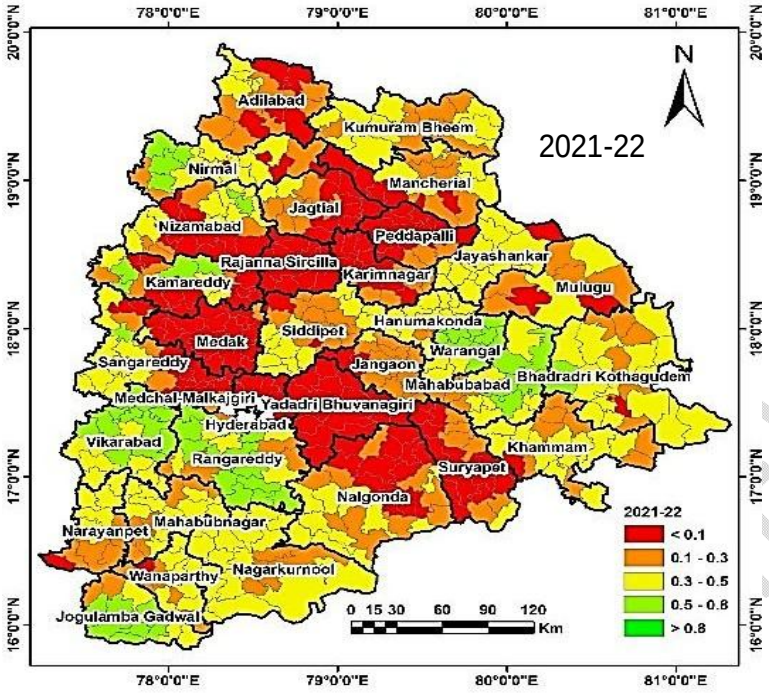


Fig VI. Mandal level crop diversity index maps for 5 years.

Paddy crop specialization is increasing with the increase in irrigated areas,decreasing crop diversity. The irrigated Rabi area in Telangana grew by 50.75 % from 2017–18 and 2020–21 years, due to lift irrigation projects and Mission Kakatiya programs, making paddya preferred crop for it's staple food status, low maintenance and favorable marketing conditions. However, this crop specialization pressures natural resources and farmer'ssocio-economic conditions by relying on single income source and increasing vulnerability to natural calamities[33].

Farmers of the north and central Telangana practice less crop diversification compared tothe southern zone, primarily due tointensive paddy cultivation innorth. In the Southern Telangana zone, crop diversification is practiced primarily as a preventive measure or contingency planning strategy for crop failure from unpredictable monsoons.Diversified cropping, particularly with legumes like gram and groundnut, iseconomically viable option for the semi-arid, less irrigated region due to their drought tolerance and nitrogen-fixing capacity to improve soil fertility. This approach provides continuous monetary benefits throughout the cropping season, unlike the limited income from monocropping[15].

These remotely sensed thematic crop maps, area estimates, and CDI maps at the Mandal level can be utilized by scientists and policymakers in various models to improve target effective technologies and increase productivity at the mandal level [34].

CDI	2017-18	2018-19	2019-20	2020-21	2021-22
Adilabad	0.34	0.26	0.36	0.46	0.18
Bhadradri Kothagudem	0.35	0.34	0.22	0.19	0.49
Hanumakonda	0.45	0.32	0.27	0.14	0.48
Jagtial	0.15	0.29	0.18	0.10	0.15
Jangaon	0.21	0.00	0.17	0.11	0.18
Jayashankar	0.32	0.09	0.26	0.43	0.50
Jogulamba Gadwal	0.68	0.69	0.67	0.60	0.69
Kamareddy	0.64	0.41	0.49	0.30	0.44
Karimnagar	0.17	0.08	0.34	0.18	0.09

Khammam	0.41	0.50	0.38	0.49	0.49
Kumuram Bheem	0.43	0.35	0.43	0.47	0.35
Mahabubabad	0.43	0.32	0.44	0.31	0.50
Mahabubnagar	0.46	0.29	0.18	0.13	0.36
Mancherial	0.00	0.00	0.00	0.00	0.16
Medak	0.24	0.00	0.24	0.00	0.06
Medchal-Malkajgiri	0.11	0.00	0.00	0.00	0.00
Mulugu	0.00	0.07	0.38	0.28	0.26
Nagarkurnool	0.40	0.42	0.64	0.49	0.43
Nalgonda	0.04	0.04	0.00	0.09	0.21
Narayanpet	0.37	0.34	0.15	0.15	0.33
Nirmal	0.55	0.57	0.57	0.62	0.62
Nizamabad	0.38	0.38	0.33	0.22	0.34
Peddapalli	0.05	0.03	0.03	0.00	0.06
Rajanna Sircilla	0.00	0.00	0.00	0.00	0.00
Rangareddy	0.45	0.42	0.42	0.24	0.64
Sangareddy	0.42	0.44	0.64	0.32	0.27
Siddipet	0.34	0.21	0.21	0.29	0.28
Suryapet	0.00	0.00	0.00	0.09	0.10
Vikarabad	0.50	0.51	0.29	0.43	0.59
Wanaparthy	0.50	0.53	0.36	0.41	0.44
Warangal	0.49	0.39	0.44	0.50	0.59
Yadadri Bhuvanagiri	0.00	0.00	0.00	0.00	0.00
Telangana	0.40	0.36	0.35	0.31	0.41

Fig. VII. District-level crop diversity index heat map for 5 years

5. CONCLUSION

The analysis of crop diversity and acreage in Telangana during the Yasangi season from 2017-18 to 2021-22 reveals significant agricultural patterns. Comparing remote sensing-based crop acreage estimates with data from DES-Telangana shows discrepancies, with deviations from -0.77% to 21.96%. These are primarily due to changes in district and mandal boundaries. The thematic raster crop maps highlight paddy's dominance, accounting for 70 to 83% of the total Rabi area. Paddy is mainly grown in regions with robust irrigation infrastructure under the Krishna and Godavari River basins. The Crop Diversity Index (CDI) values indicate low diversity due to paddy monocropping. This monoculture, driven by paddy's high-water demand and irrigation facilities. CDI maps show lower diversity in northern Telangana (0.28–0.31) and central Telangana (0.361–0.445) due to extensive irrigation infrastructure, while southern Telangana has medium CDI values (0.461-0.582) due to lower regional development and lack of irrigation infrastructure. From 2017-18 to 2021-22, CDI showed a strong positive correlation with the percentage of groundnut (r = 0.92 to 0.97), followed by maize (r = 0.35 to 0.56) and chickpea (r = 0.15 to 0.51). Conversely, there was a negative correlation with paddy (r = -0.69 to -0.75). The inclusion of groundnut significantly increased crop diversity in specific districts.

The specialization in paddy cultivation, driven by irrigation projects and government policies, pressures natural resources and farmers' socio-economic conditions, making them reliant on a single income source and more vulnerable to abiotic and biotic natural calamities. In contrast, southern

Telangana farmers practice crop diversification as a risk mitigation strategy to drought by growing legumes crops such as gram and groundnut.

In conclusion, thematic crop maps, area estimates, and CDI maps provide valuable tools for scientists and policymakers to develop targeted technologies and strategies to improve agricultural productivity and sustainability at the mandal level. Promoting crop diversity and supporting diverse crop irrigation infrastructure can mitigate the adverse effects of monocropping and enhance the resilience of Telangana's agricultural sector.

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Authors' Contributions: Ammaladinne Tharun Kumar was responsible for the acquisition of ground truth data and the calculation of the crop diversity index. Anima Biswal conducted image processing using Google Earth Engine. Gade Sreenivas and M. Venkataraman undertook the reclassification of rabi crop maps. The manuscript preparation was carried out collaboratively by Ammaladinne Tharun Kumar, A. Madhavi, and R. Vijay Kumari. All the authors read and approved the final manuscript.

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Annexure I – District wise estimated crop area using remote sensing (Area in hectares)

Paddy	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Bhadradri Kothagudem	24803	23394	37675	39928	24240
Jagtial	55053	50463	96073	106486	75804
Jogulamba Gadwal	13355	8820	18479	27878	13238
Kamareddy	36703	37403	62419	91117	68211
Karimnagar	70112	68058	86246	103366	97426
Khammam	60855	32245	97799	74089	73046
Kumuram Bheem	3029	4894	5766	6087	5481
Mahabubabad	32105	54506	56479	78831	55265
Mancherial	28441	35307	42331	46223	18180
Medak	32245	18382	32298	79814	64149
Medchal-Malkajgiri	5099	2964	4150	7493	379
Nagarkurnool	20473	19146	32218	63655	29673
Nalgonda	129512	124496	149500	197822	176085
Nirmal	25313	29420	46669	42345	42086
Nizamabad	110384	102232	149549	171737	149899
Peddapalli	49320	61903	76657	81458	63797
Rajanna Sircilla	28247	22858	51739	66362	46295
Rangareddy	8795	9566	14831	35382	14538
Sangareddy	25585	8905	13262	35345	17906
Siddipet	54134	29170	65641	109725	82858
Suryapet	149902	130177	147080	173419	169118
Wanaparthy	23806	23862	48285	58452	28587
Jayashankar	22265	27358	34865	41315	15883
Mulugu	22754	25692	16474	22999	10546
Narayanpet	25605	15141	27912	41163	34571
Yadadri Bhuvanagiri	55507	39899	68283	94193	56224
Jangaon	33020	18323	50987	63386	44818
Mahabubnagar	16660	15021	19366	46526	34263
Vikarabad	19867	9133	16546	31285	22575
Hanumakonda	21156	25654	41762	64040	35016
Warangal	23734	19512	24202	42774	32869

Toatal	1227837	1093902	1635541	2144695	1603027

Maize	2017-18	2018-19	2019-20	2020-21	2021-22
Adilabad	1906	1729	7040	0	2557
Bhadradri Kothagudem	7382	2839	3614	4595	17258
Jagtial	4877	8661	10732	6206	7010
Jogulamba Gadwal	1821	1197	3411	0	1433
Kamareddy	25623	2318	10950	4323	3142
Karimnagar	5022	3147	19718	11421	4621
Khammam	24405	36577	32821	53555	53020
Kumuram Bheem	0	0	0	838	0
Mahabubabad	8583	3851	26738	15291	28873
Mancherial	0	0	0	0	1687
Medak	5096	0	5101	1	2027
Medchal-Malkajgiri	328	0	0	0	0
Nagarkurnool	0	2	16695	0	1
Nirmal	6915	5794	18262	18927	16227
Nizamabad	6747	9381	26399	2099	23131
Peddapalli	1219	1029	1042	0	2029
Rangareddy	0	0	2784	0	3877
Sangareddy	2240	0	6198	0	2
Siddipet	8548	2774	9105	16622	10008
Wanaparthy	0	1646	2	0	0
Jayashankar	5605	1387	6475	18812	14175
Mulugu	1	984	5779	3470	1941
Jangaon	3223	1	5445	3906	3602
Mahabubnagar	0	3267	1	0	0
Hanumakonda	10801	6475	7845	3665	23639
Warangal	11868	7190	48569	44621	20178
Toatal	142211	100251	274728	208353	240439

Groundnut	2017-18	2018-19	2019-20	2020-21	2021-22
Adilabad	2066	1352	0	10325	772
Bhadradri Kothagudem	1	3098	1700	0	1
Jagtial	0	1623	0	0	0
Jogulamba Gadwal	14641	6294	9746	11549	9242
Karimnagar	1919	0	2646	0	0

Mahabubabad	3802	8535	0	2660	4187
Nagarkurnool	54309	44490	18791	45619	67106
Nalgonda	2989	2792	1	9230	23272
Rangareddy	7	1	5	4	5890
Suryapet	0	1	0	8456	9229
Wanaparthy	25548	19585	15234	23510	14079
Mulugu	0	0	0	894	1
Narayanpet	8527	4270	2458	3684	9262
Jangaon	1093	0	0	0	1270
Mahabubnagar	9545	0	2167	3615	10446
Vikarabad	9877	1369	1540	3336	17286
Hanumakonda	1	0	0	1365	1
Warangal	1777	1	0	1	8420
Total area	136102	93412	54287	124249	180466
Chickpea	2017-18	2018-19	2019-20	2020-21	2021-22
Adilabad	16106	17859	23044	18652	31581
Jogulamba Gadwal	19987	8803	8008	11276	11114
Kamareddy	18644	11491	18970	14591	27051
Kumuram Bheem	1369	1398	2616	1937	1619
Nirmal	9111	20177	14202	22775	25058
Nizamabad	28031	22331	9247	9237	14737
Rangareddy	4550	4075	2391	5759	3191
Sangareddy	7383	4295	9880	8766	3473
Siddipet	3425	1032	0	5581	2939
Vikarabad	1783	3813	1667	8823	5472
	110389	95272	90024	107399	126234
Sunflower	2017-18	2020-21	2021-22		
Nizamabad	0	11721	0		
Siddipet	1607	0	3733		

2 Annexure II – District wise reported area of Telangana from DES – Telangana (Area in hectares)

Area in hectares	Paddy					Maize				
	2017-18	2018-19	2019-20	2020-21	2021-22	2017-18	2018-19	2019-20	2020-21	2021-22
Adilabad	15	42	197	172	0	1125	1004	3121	1427	2550.384
Bhadradri_Kothegudem	7601	7064	22711	11079	8485	4213	3877	6434	1677	10699.72
Hanumakonda	18146	13316	30042	42982	37889	13648	10674	16887	12689	22325.37
Hyderabad				0	0				0	0
Jagtial	48935	48087	102546	120379	74746	9611	8933	7865	2561	5726.022
Jangaon	25116	18949	46799	64689	57059	5215	2109	4405	2389	3945.771
Jayshankar	24906	11331	25912	32290	19783	5686	1898	6924	7381	6696.074
Jogulamba	8373	6277	17810	23550	13904	2043	857	2193	2220	4610.279
Kamareddy	39332	23451	74463	99344	62329	17350	4874	14951	7517	16255.36
Karimnagar	55178	48707	89721	107050	85974	8416	7859	13396	9648	9536.625
Khammam	51130	31843	82093	91221	37167	23875	13736	36149	31743	33048.97
Kumurum_bheem	2263	2737	5026	6626	2198	543	288	621	465	497.7742
Mahabubad	16660	14264	46056	64079	36123	5897	4118	20686	10113	12176.85
Mahabubnagar	27990	6839	17109	48981	29344	182	27	177	412	1061.514
Mancherial	17437	20738	38616	44711	25313	642	420	557	376	665.7224
Medak	32224	11881	31649	85575	57415	5985	2086	3494	566	2581.141

Medchal_malkajgiri	4552	2702	3877	5501	1997	127	93	48	32	150.951
Mulugu		13416	16336	21607	6724		2394	2631	2019	1627.681
Nagarkurnool	17634	16758	36066	59783	23506	537	260	2798	3226	4346.418
Nalgonda	97074	86191	148819	186204	175242	40	16	26	31	126.2647
Narayanpet		10892	26102	41127	24775			32	27	107.6487
Nirmal	15877	17119	40684	38408	23247	17768	15269	33025	19381	29437.07
Nizambad	81531	67088	130653	155994	134577	6361	6149	13340	2143	5055.443
Peddpalli	38596	40312	77967	79966	67681	3813	3434	3704	3851	4943.343
Rajanna	22901	19023	53823	67651	48113	415	405	525	307	875.7588
Rangareddy	12099	6552	16222	40218	6573	2057	924	952	1097	4105.625
Sangareddy	18317	5968	9494	32973	8779	1977	880	1114	628	2018.616
Siddipet	45375	29250	65196	111273	98594	9836	7306	9085	3753	6982.193
Suryapet	87908	82472	152048	174696	177238	153	68	85	94	43.30231
Vikarabad	10641	4954	13303	28362	6924	574	385	2436	1896	2338.729
Wanaparthy	21826	19105	46626	58937	18147	138	10	153	119	106.0299
Warangal	17903	16052	36696	47917	23518	18983	16340	44730	42952	34085.39
Yadadri	47849	39128	80400	99701	57112	44	31	17	9	95.1032

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hactrea- Area	Groundnut					Chickpea				
	2017-	2018-	2019-	2020-	2021-	2017-	2018-	2019-	2020-	2021-

	18	19	20	21	22	18	19	20	21	22
Adilabad	1010	606	404	1042	516	15873	25311	34397	31005	36353
Bhadradri_Kothegudem	986	1194	1007	618	955	1			4	17
Hanumakonda	494	440	716	598	809	266	313	229	136	167
Hyderabad				0	0				0	0
Jagtial	936	876	220	249	444	191	125	480	404	310
Jangaon	1557	1033	701	1258	1113	189	219	113	121	134
Jayshankar	710	95	51	290	108	258	229	72	34	10
Jogulamba	9578	8718	5008	8936	8637	15551	13653	7113	6427	7968
Kamareddy	158	85	34	481	1833	19688	16960	26618	40123	41460
Karimnagar	1509	1373	1839	584	1404	199	291	140	89	166
Khammam	1728	1196	585	1619	760	17	22	10	33	48
Kumurum_bheem			27	75	147	1392	1310	2545	2545	2991
Mahabubad	9131	5588	1758	2338	1031		5		7	13
Mahabubnagar	18335	2530	3900	3861	8980	649		5	20	66
Mancherial	214	182	83	149	259	152	212	159	104	172
Medak	116	41	36	152	1480	656	281	418	384	738
Medchal_malkajgiri				0	5	78	66	24	6	7
Mulugu		364	378	416	257			4	4	14
Nagarkurnool	52575	45651	49722	54775	60541	205	229	188	96	128

Nalgonda	4965	3529	4592	7476	15035	99	125	114	54	85
Narayanpet		5354	2360	3377	6556		453	94	110	155
Nirmal	231	328	146	416	540	9920	12936	24485	22504	27428
Nizambad	165	81	16	18	746	10737	11181	12170	10630	9648
Peddpalli		29	38	93	231	110	205	60	28	81
Rajanna	166	149	32	47	264	341	330	303	244	365
Rangareddy	1335	538	624	1870	4102	2686	2233	2788	3429	2907
Sangareddy	110	113	31	214	1320	7103	7156	9477	12121	17086
Siddipet	1087	1206	651	723	1178	3746	2009	2235	2808	2448
Suryapet	5934	3541	1485	1415	1540	99	45	47	127	67
Vikarabad	5105	3614	3114	3293	7758	3242	2587	3501	8414	7261
Wanaparthy	24056	21732	17556	13548	12757	2974	4926	1639	403	676
Warangal	3802	3103	1450	1957	785	929	888	423	380	196
Yadadri	35	57	47	27	757	86	86	96	17	114

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Sunflower	2017-18	2018-19	2019-20
Nizambad	61	1189	3282
Siddipet	2503	928	956