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

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Authors' contributions

This work was carried out in collaboration among all authors. Author ATK was responsible for the acquisition of ground truth data and the calculation of the crop diversity index. Author AB conducted image processing using google earth engine. Authors GS and MV undertook the reclassification of rabi crop maps. The manuscript preparation was carried out collaboratively by Authors ATK, AM and RVK. All authors read and approved the final manuscript.

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ABSTRACT

Aim: In this study, crop diversity in Telangana during the Yasangi season (October to May) from 2017 to 2022 was assessed at the mandal level using crop area data resultant from remote sensing.
Place and Duration of Study: Telangana, from 2017-18 to 2021-22.

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Methodology: Sentinel 2A and 2B MSI L2A satellite 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 includes temporal profiling of NDVI values over time. A hybrid method, combining phenology-based decision rules and unsupervised classification, was employed to demarcate rabi crop area.

Results: 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. The Crop Diversity Index (CDI) values reveal low diversity in Telangana, primarily due to paddy monocropping. This reliance on a single crop can lead to soil depletion and increased pest problems.

Conclusion: Our findings underscore the environmental and economic impacts of monoculture. Policymakers should encourage farmers to diversify their crops, incorporating less water-intensive options like groundnut, sunflower and chickpea to improve yields, soil fertility and reduce environmental impact. Enhancing irrigation infrastructure to support diverse crops and ensuring equitable water distribution can help reduce the dominance of paddy and promote sustainable agriculture. Supporting research and development in crop diversity and sustainable farming techniques, along with educational campaigns, can lead to more resilient and economically viable farming practices.

Keywords: Remote sensing; sentinel 2A and 2B MSI L2A; crop area maps; crop diversity index.

1. INTRODUCTION

India is primarily an agrarian economy, contributing 17% of its gross domestic product (GDP) and involving around 70% of its working population in agriculture 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 development of 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 demonstrates the relative areal strength of a region. Crop diversification takes place because 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 ensures avoiding glut in the production of paddy grains and encourages the 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 helps scientists and policymakers to understand the Telangana 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.

1.1 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. 1). 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. 2. 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 °C and the average annual minimum temperature is 21.6 °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.

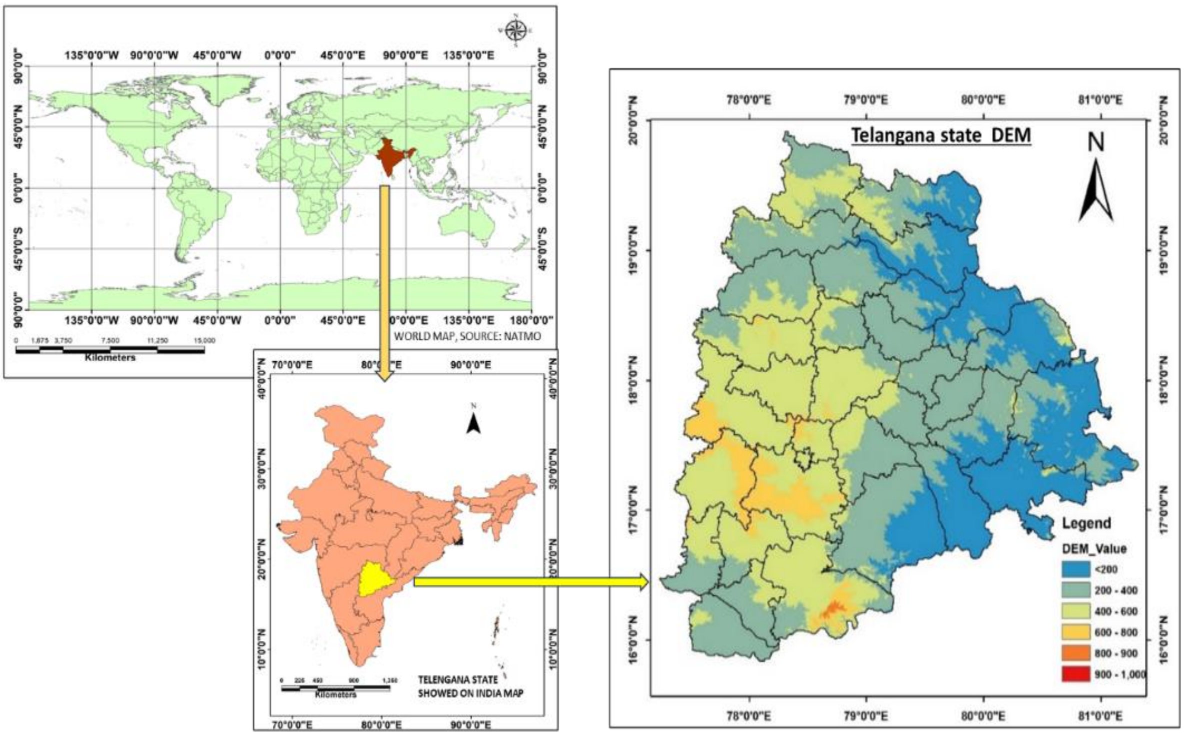


Fig. 1. Location map of the Study area with DEM depiction – Telangana

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. 1.) [1].

2. MATERIALS AND METHODS

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

2.1 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.

2.2 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 maps was used to gather ground truth field data. Random sampling technique was practiced for ground 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. 2.

Ground truth point collected from crop field survey was overlaid onto a 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. 3) illustrate the temporal NDVI profile along with threshold values for various phonological stages for each crop. 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].

Sentinel 2A and 2B MSI L2A products comprise 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, attaining a 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 portray the exclusive spectral signature of each crop and enable to discriminate different crops during the Rabi cropping season (Fig. 3). So, this index serves to discriminate and estimate cultivated areas under various crops [15,22].

2.3 Image Processing on the GEE Platform

The entire methodology's workflow is shown in Fig. 4. In Google Earth engine using sentinel 2

MSI L2A product, 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 fortnight intervals, from September to May for 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].

2.4 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 despite the 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. 3). 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 Telangana from 2017-18 to 2021-22, which were mapped and presented in Fig. 5.

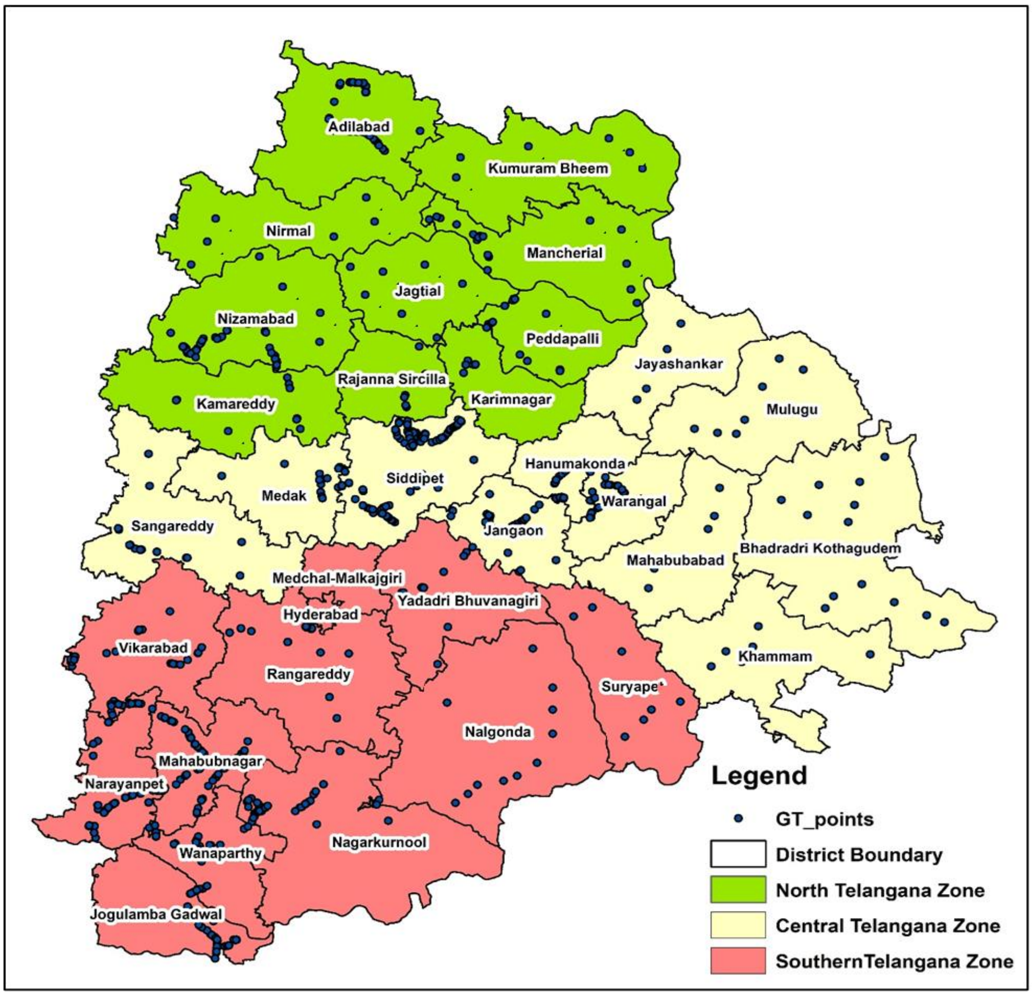


Fig. 2. Study area depicting the ground truth points distribution and three agro-climatic zone

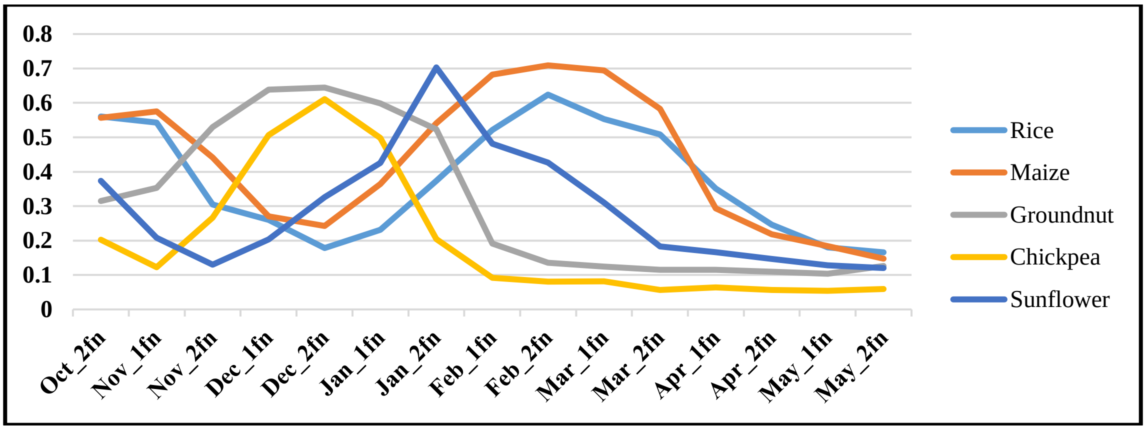


Fig. 3. NDVI-based crop growth profiles for Rice, Maize, Groundnut, chickpea, and sunflower

2.5 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 1).

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 RS stands for remote sensing crop area estimates, and DOA stands for crop area estimates from the Department of Agriculture, Telangana [25].

2.6 Crop Diversity Index (CDI)

The [26] formula for crop diversification shown below was used to determine the agricultural diversity index in a region.

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

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

Table 1. 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							

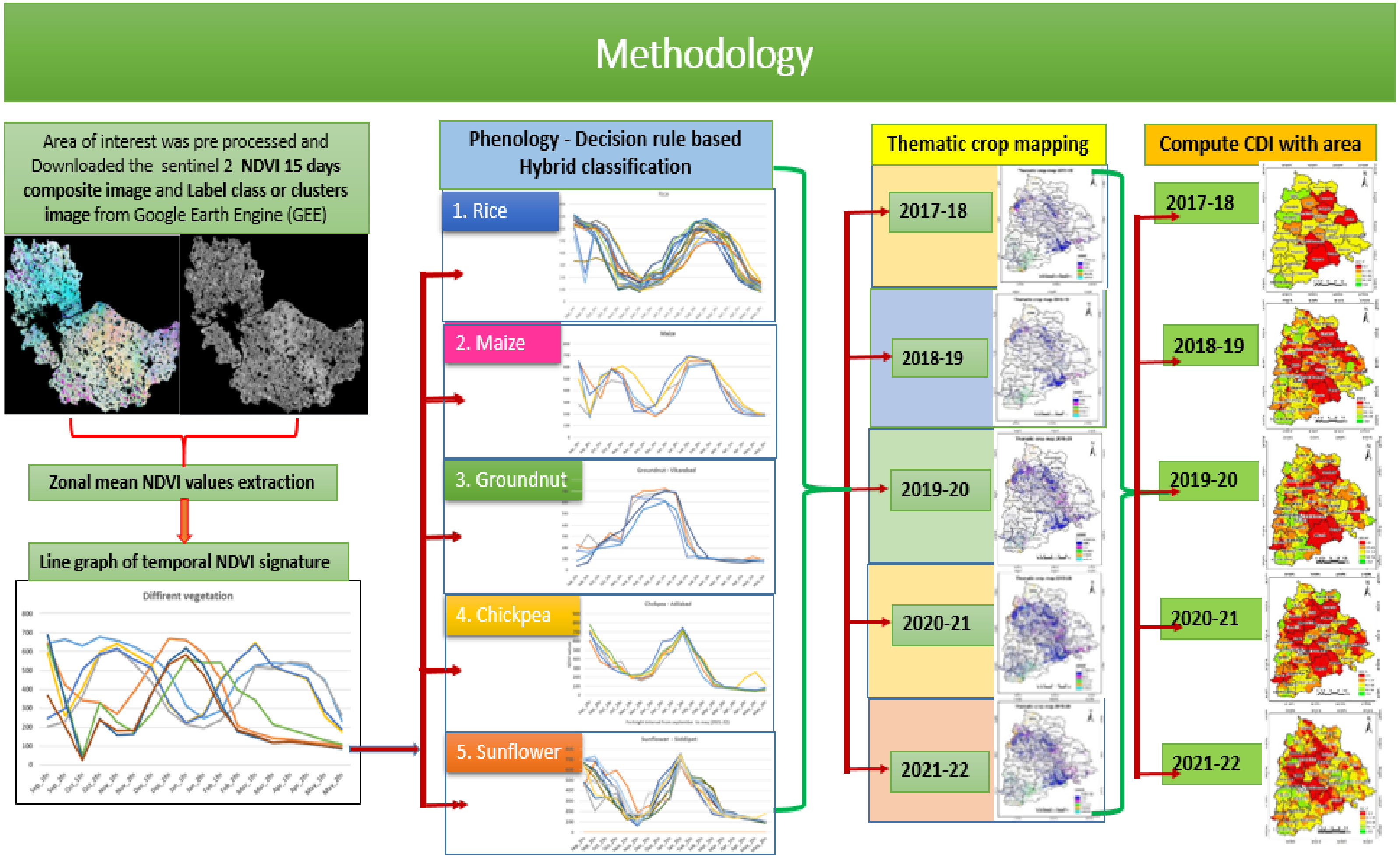


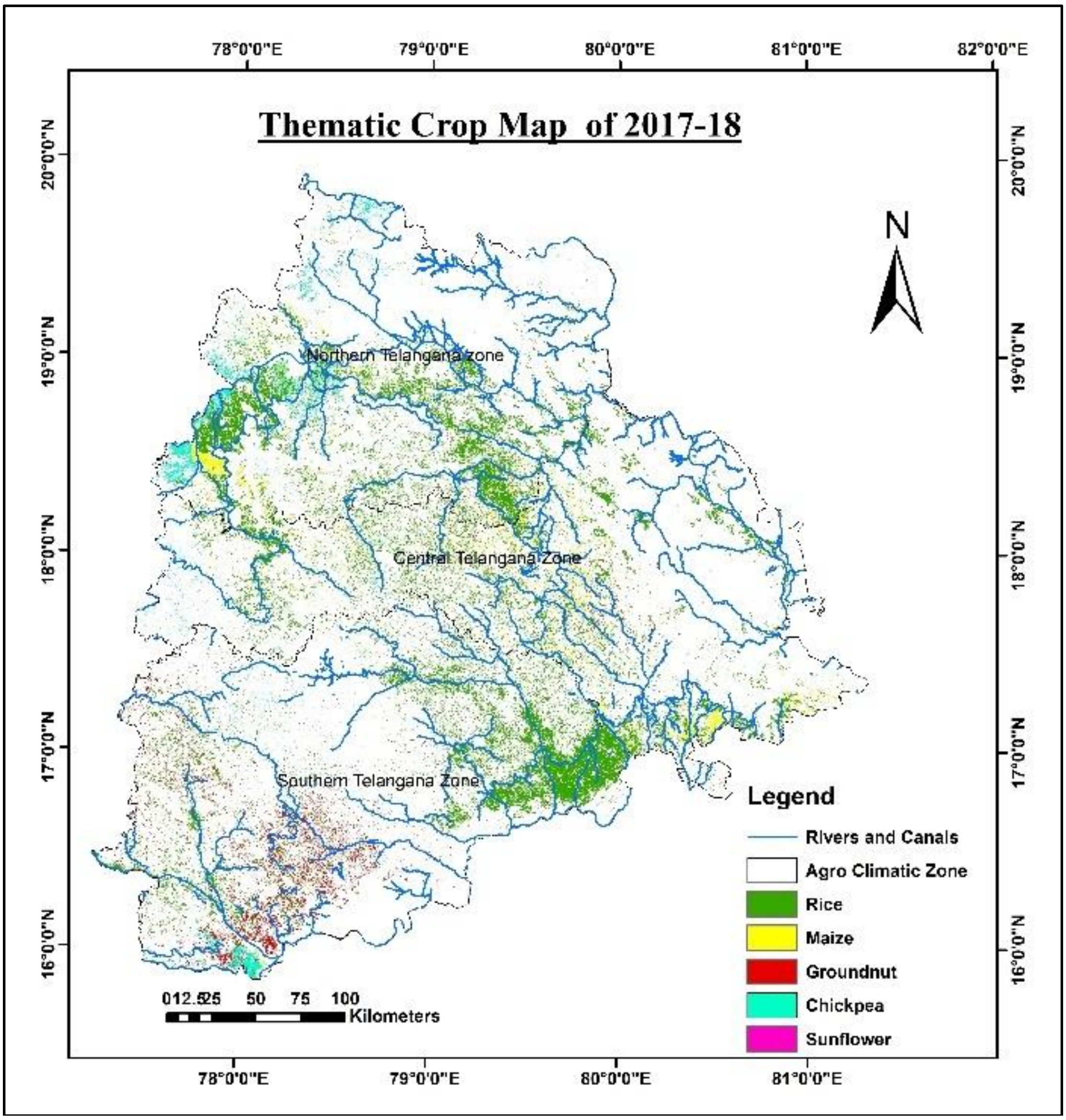
Fig. 4. Flowchart outlining the steps involved in mapping crop types, estimating their area using remote sensing and GIS, and creating crop diversity index

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 index was computed for all 5 years using remotely sensed crop area estimates.

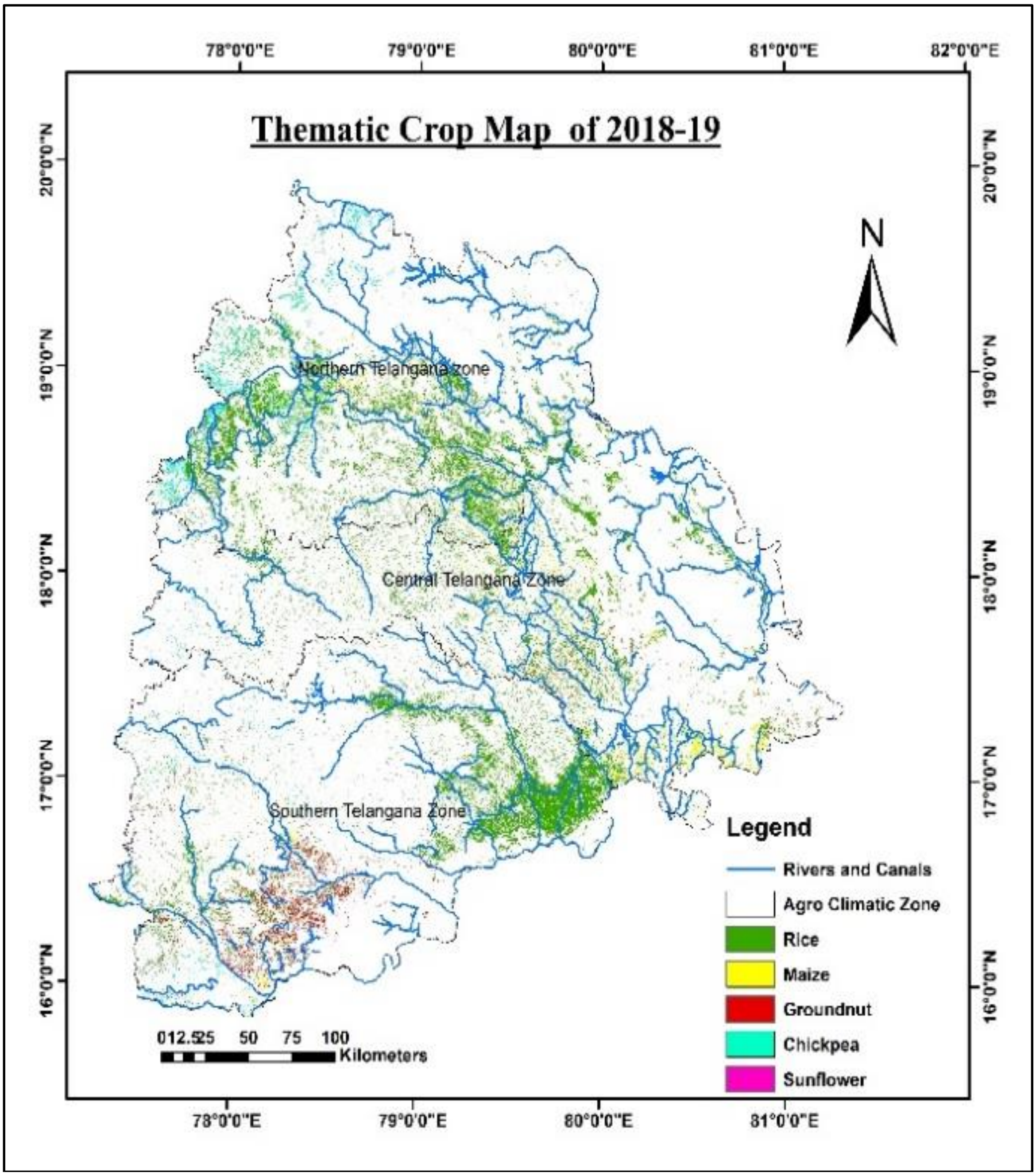
3. RESULTS AND DISCUSSION

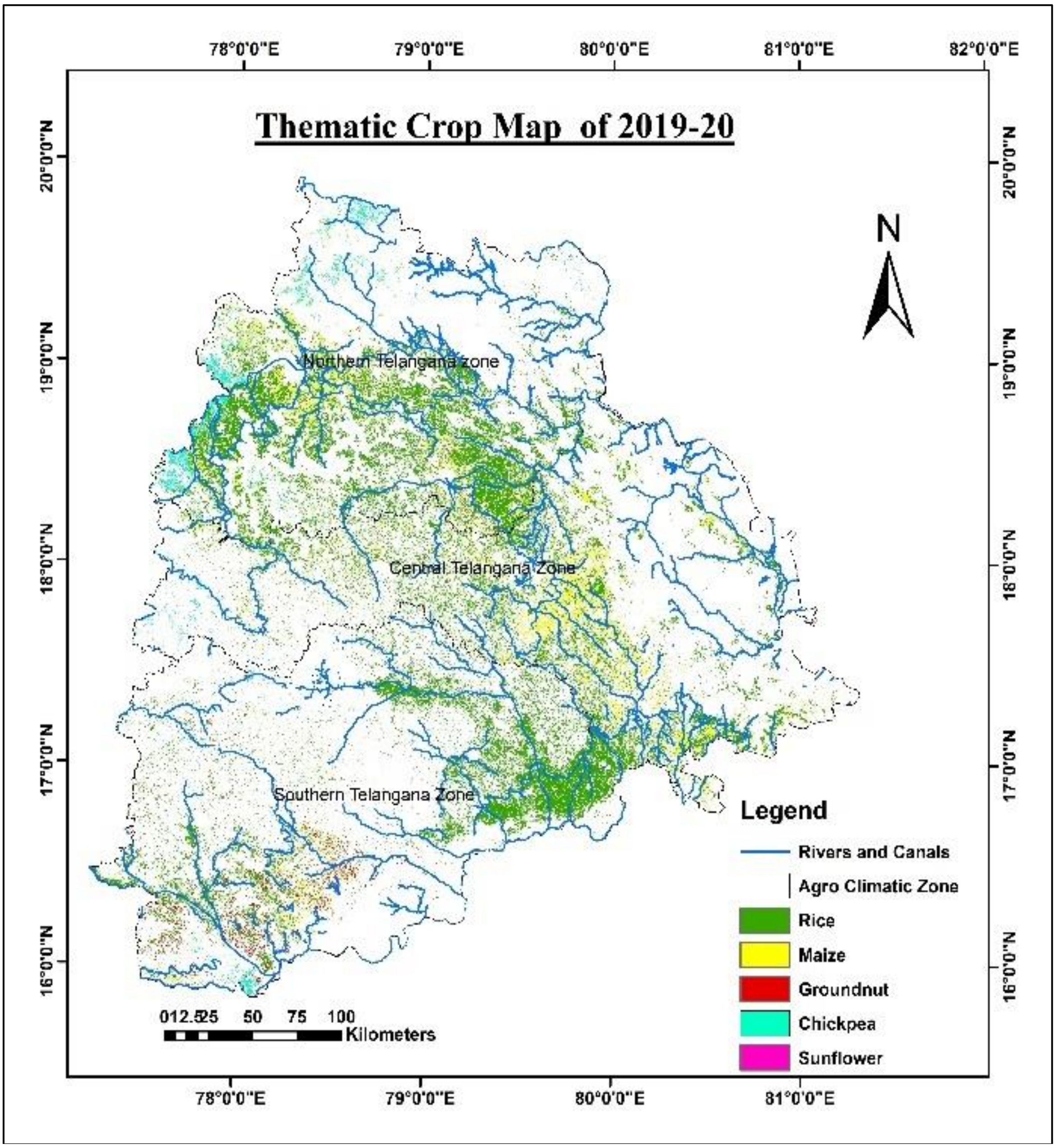
In Telangana, the extended Rabi season known as the "*Yasangi*" season lasts from the first week of October till the end of May, encompassing both the winter and spring. The relative deviation percentage between estimated crop acreage using remote sensing and reported crop acreage by DES-Telangana was 17.88 % in the 2017–18, 21.96 % in 2018–19, -0.77 % in 2019, 2.92 % in 2020–21 year and 8.08 % in 2021–22. The large differences in 2017-18 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 raster crop maps for Telangana's Rabi *(Yasangi)* season from 2017-18 to 2021-22 are displayed in Fig. 5. 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 green color in Fig. 5 represents the paddy crop, which dominates in north and central Telangana, as well as in districts 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 yellow 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 red 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.



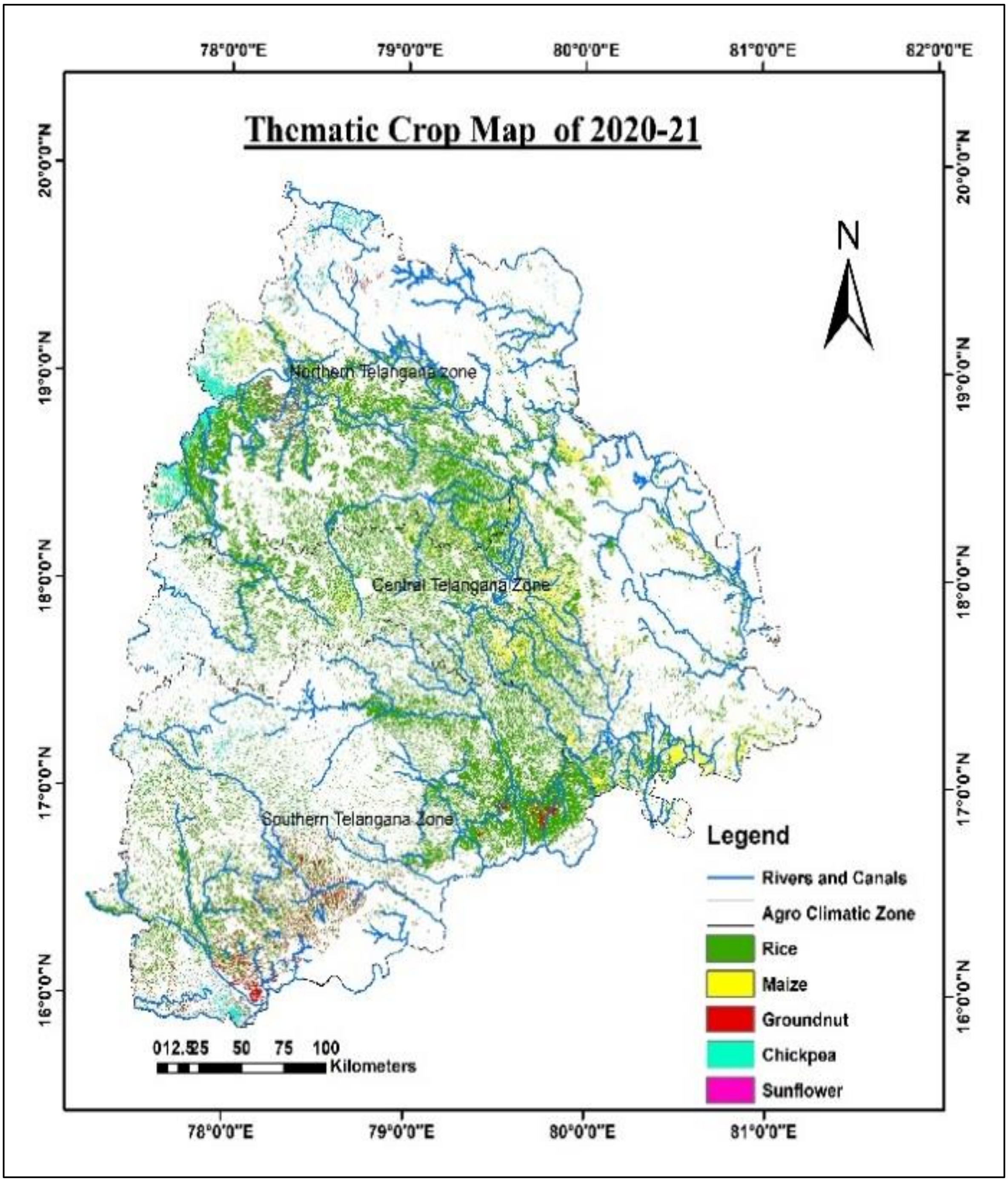


Chickpea crops are depicted with cyan blue pixels and are significant in the northwest region of Telangana. This area typically records the lowest temperatures in the state, which are crucial for chickpea biomass development and flowering. Additionally, chickpea utilizes atmospheric dew water during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

3.1 Crop Diversity Index

The Crop Diversity Index (CDI) values in Telangana from 2017-18 to 2021-22 (Fig. 6 and 7) 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. 6 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. 5). but the CDI values are better 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.



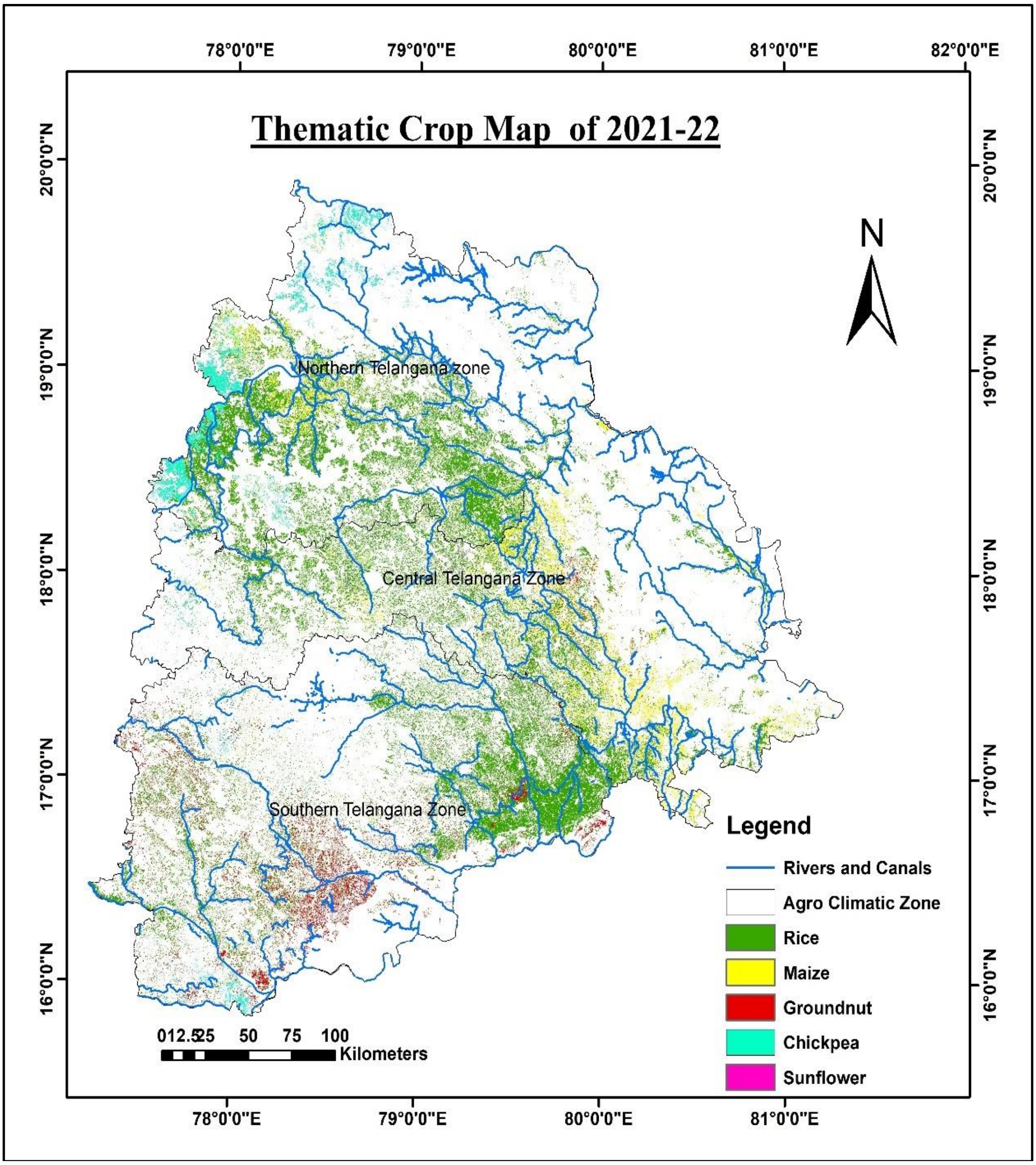
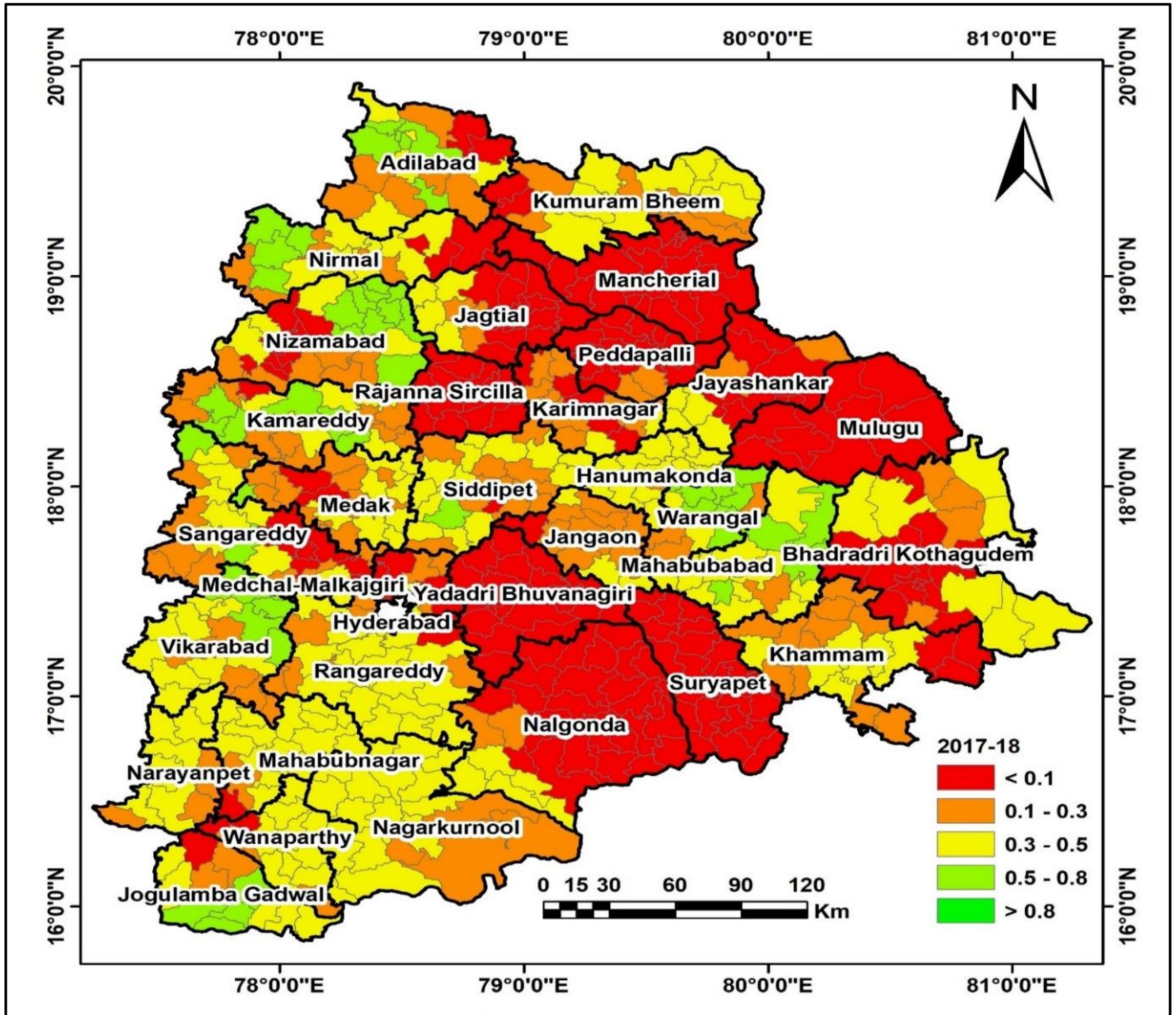
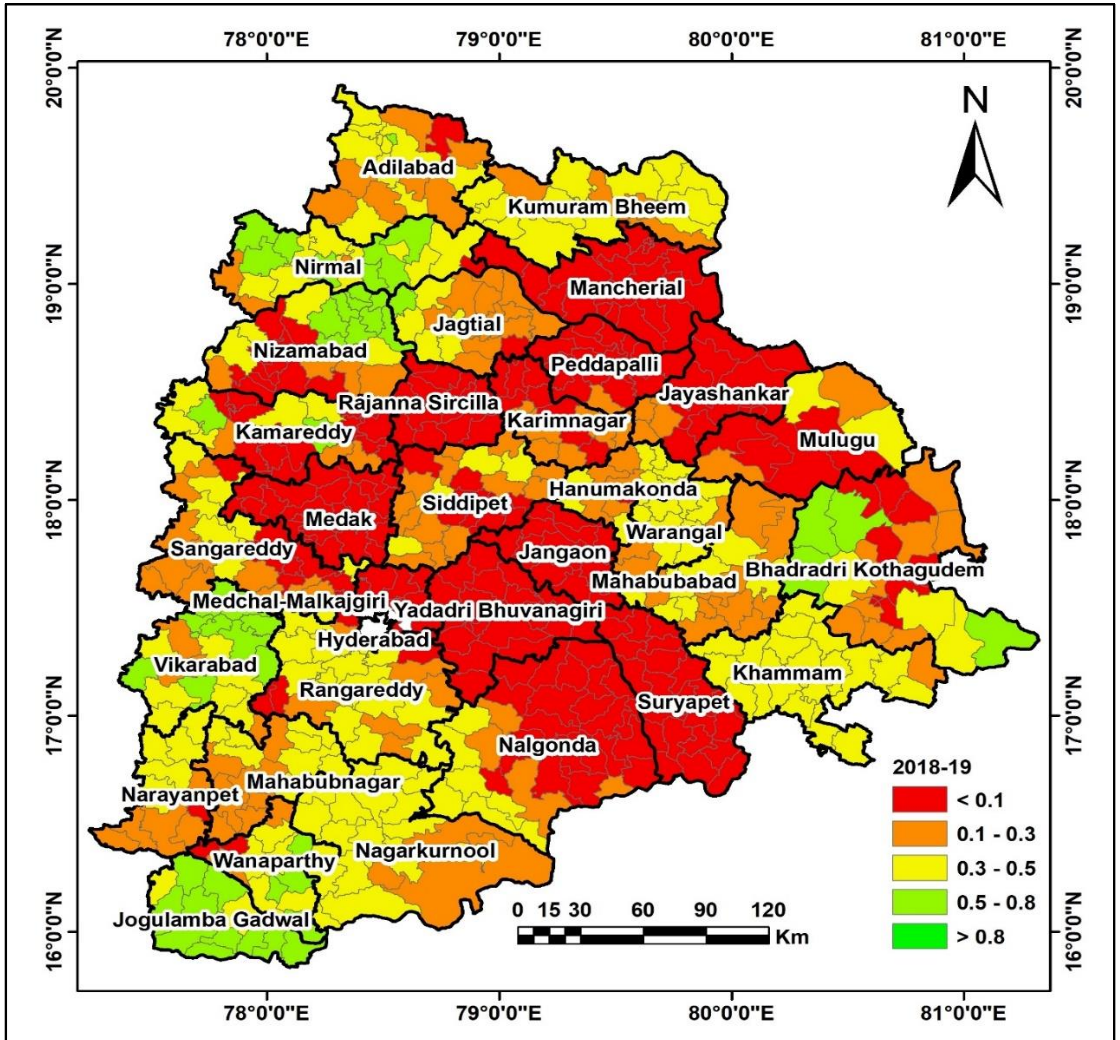


Fig. 5. Crop maps of Rice, Maize, Groundnut, Chickpea, and Sunflower crops from 2017-18 to 2021-22

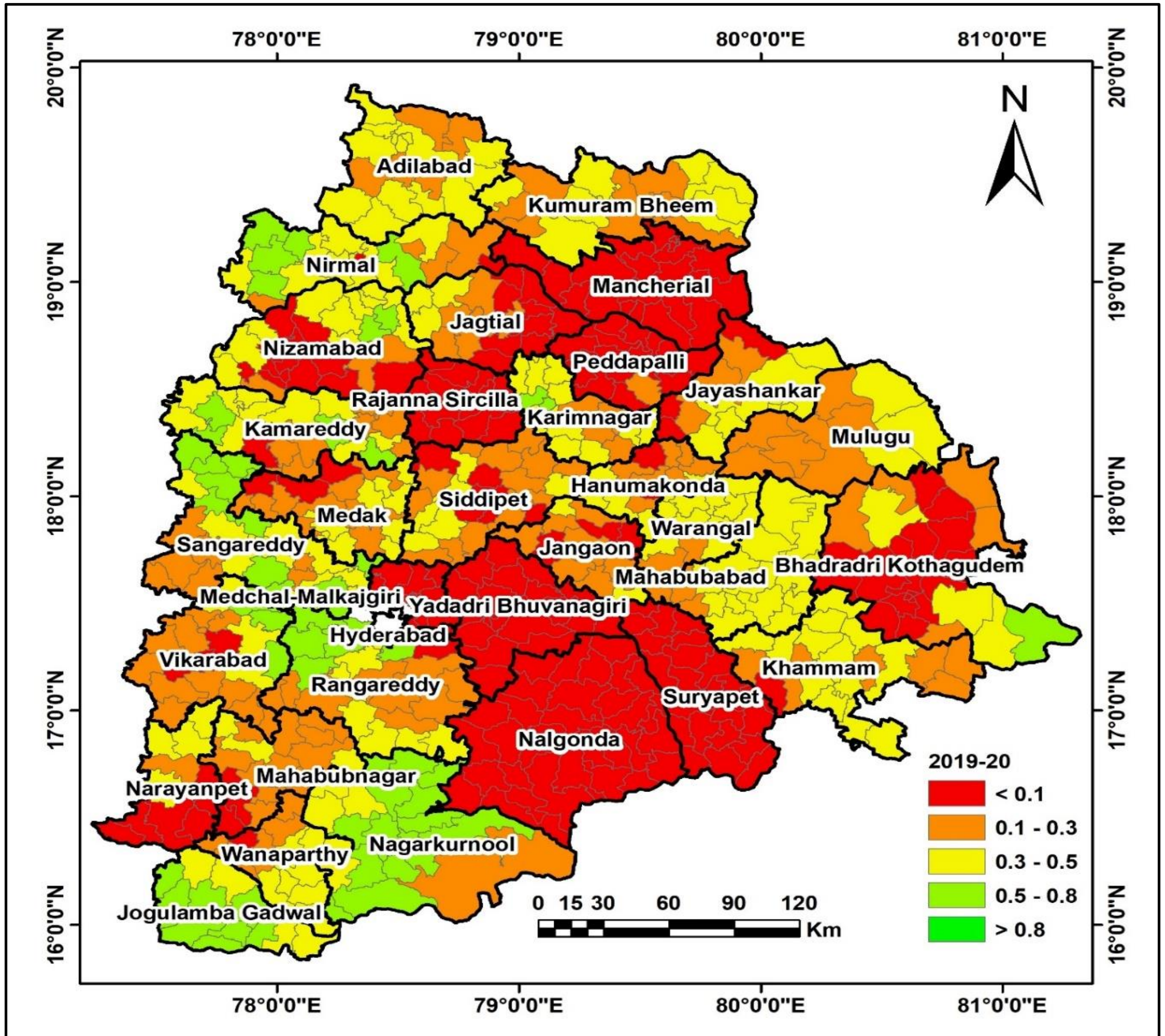
In most of the districts, the crop diversity gradually reduced from 2017-18 to 2020-21 from 0.47 to 0.36, before rising to 0.41 in 2021-2 due to restriction on paddy crop cultivation and government campaigns promoting crop diversity. The CDI spatial distribution remained consistent at district level from 2017-18 to 2018-19 with minor variations at the mandal level. In 2019 -20 and 2020-21 also had similar crop diversity index distribution except low CDI in the districts of Nagarkurnool and Sangareddy districts in the 2020-21 year. The southern Telangana zone had higher CDI values in in 2021-22 and 2017-18, encompassing Jogulamba Gadwall, Narayanpet, Wanaparthy, Mahbubnagar, Nagarkurnool and Rangareddy districts. Eastern Telangana zone also had a good crop diversity index, which comprises Nirmal and Kamareddy, Vikarabad districts due to higher elevations and well drained soils.



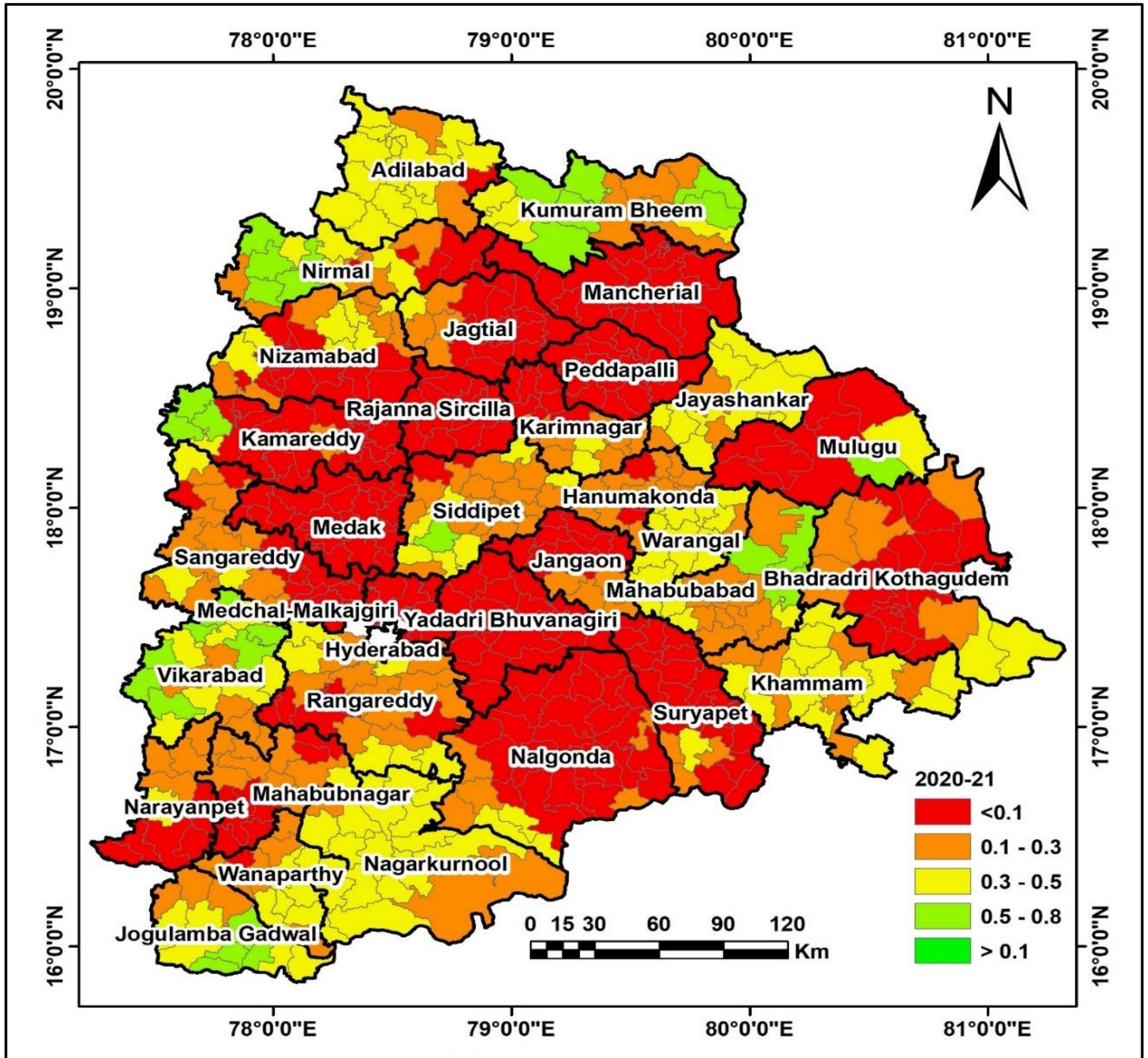
(a) Mandal Level CDI of 2017-18



(b) Mandal Level CDI of 2018-19



(c) Mandal Level CDI of 2019-20



(d) Mandal Level CDI of 2020-21

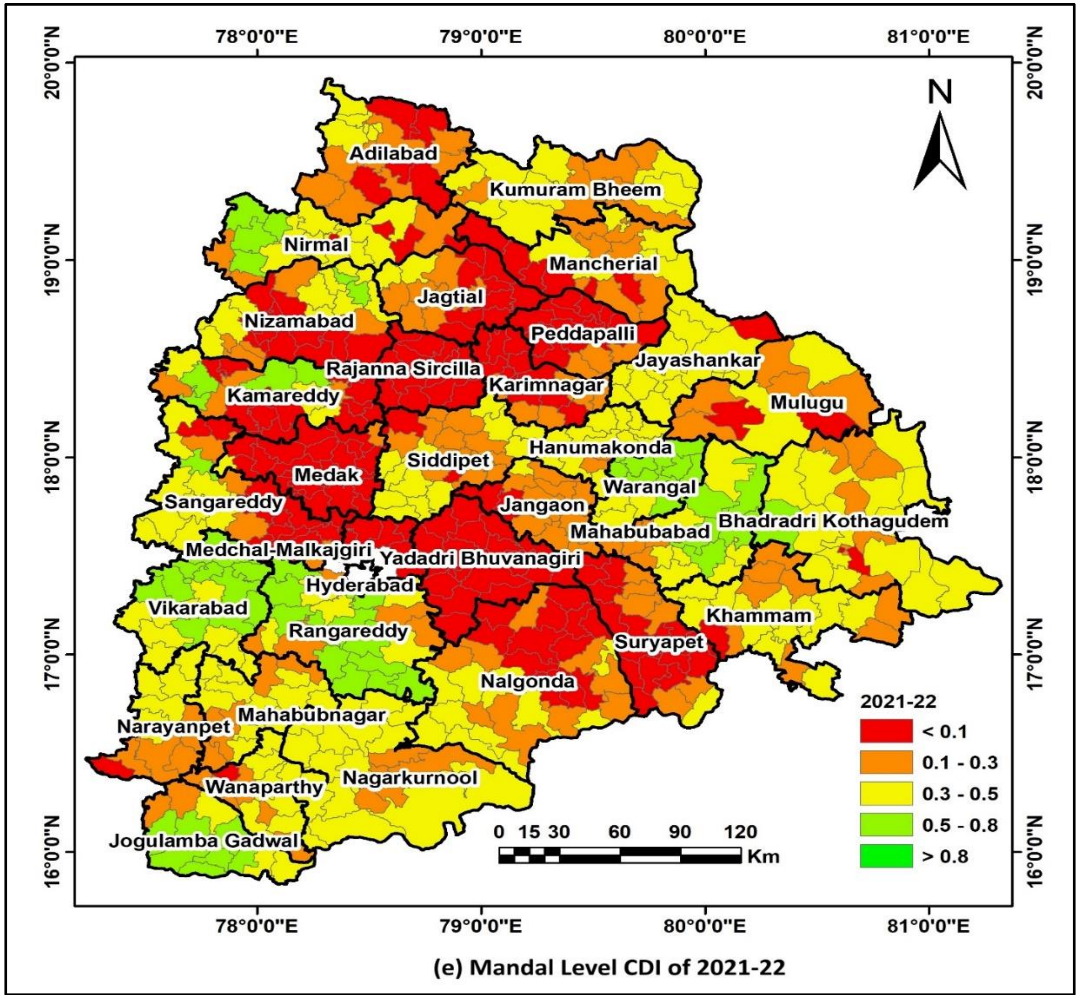


Fig. 6. Mandal level crop diversity index maps for 5 years (a) Mandal level CDI of 2017-18, (b) Mandal level CDI of 2018-19, (c) Mandal level CDI of 2019-20, (d) Mandal level CDI of 2020-21 and (e) Mandal level CDI of 2021-22 years

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

In every year from 2017-18 to 2021-22, the Crop diversity index demonstrated a 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 2). 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 crops significantly increased in specific districts, resulting in a high positive correlation with CDI. The negative correlation with paddy crops to submerged field conditions and increased availability of irrigation water, which may reduce the cultivation of waterlogging sensitive crops such as Groundnut, Maize, and Chickpea crops. This indicates that an abundance irrigation water creates an unfavorable condition for crop diversity in Telangana.

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Table 2. 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

waterlogging sensitive crops such as Groundnut, Maize, and Chickpea crops. This indicates that an abundance irrigation water creates an unfavorable condition for crop diversity in Telangana.

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 paddy a preferred crop for its staple food status, low maintenance and favorable marketing conditions. However, this crop specialization pressures natural resources and farmer’s socio-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 to the southern zone, primarily due to intensive paddy cultivation in north. 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, is economically 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].

4. 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. Maize is grown mainly in well drained soils with good irrigation infrastructure. Groundnut was predominant in semi-arid regions with lesser irrigation infrastructure. Chickpea thrives in Northwest part region, benefitting from cooler temperature and residual moisture in black soils.

The Crop Diversity Index (CDI) values in reveals low diversity in Telangana, primarily due to paddy monocropping. Northern Telangana (0.28–0.31) and central Telangana (0.361–0.445) regions show low CDI values, because of extensive irrigation infrastructure supporting paddy cultivation. This dependency on a single crop can lead to soil depletion and increased vulnerability to pest and disease. Conversely, southern Telangana has medium CDI values (0.461-0.582), where mix of crops cultivated to mitigate drought. 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.

Our findings underscore the environmental and economic impacts of monoculture. Hence, Policy maker should encourage farmers to diversify their crops by incorporating less water-intensive options like sunflower, groundnut and chickpea to improve yields and reduce environmental impact. Efficient water use through practices like drip irrigation can also support a wider range of crops.

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 for Telangana. The study suggest promoting crop diversification through educational campaigns, policies and incentives promote sustainable agriculture and improve the socio-economic conditions of farmers in Telangana.

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AVAILABILITY OF DATA AND MATERIAL

The satellite images used in this study are freely available in the public domain.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that generative AI technologies – openAi, 2024 -Chatgpt (June 20 version) has been used during for editing manuscripts. The prompt we have used is "provide any Grammer correction for the text given ()"

Appendix is available in the following link

https://journaljsrr.com/index.php/JSRR/libraryFiles/downloadPublic/24

COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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