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Geospatial Analysis of Natural Farming Systems for Environmental Sustainability and Food Security: A Telangana State Perspective

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Abstract:
Natural farming systems exemplify a paradigm shift of sustainable agricultural systems to deal with severe issues of environmental deterioration or even food security in Telangana. This paper explores the use of geospatial tools, such as Remote Sensing (RS), Geographic Information Systems (GIS), and Global Positioning Systems (GPS), in the analysis and monitoring of natural farming systems in different agro-climatic regions of the state of Telangana. We also show that geospatial tools can be used to accurately map natural farmlands, evaluate soil health, monitor crop productivity, and evaluate the environmental impact, based on a systematic review of satellite data, crop suitability analysis, and case studies of such districts as Warangal, Nalgonda, and Karimnagar. The combination of the resources of the National Remote Sensing Center (NRSC) Hyderabad and the Telangana Remote Sensing Applications Center (TGRAC) into the natural farming practices offers practical information to the policy-makers and improves the capacity of the farmers to make their decisions. We have found that natural farming systems get 11% more yields and sustain biodiversity and less chemical dependency, and Telangana has large prospects of organic farming development and expansion in its 210 lakh acres of cultivated lands. This study highlights that geospatial analysis is a potentially useful tool that can be used to scale the natural farming programs and provide food security in Telangana in the long term.

Keywords: Geospatial Analysis, Natural farming, remote sensing, GIS, Food security, environmental sustainability, Telangana, NRSC Hyderabad, TGRAC, Precision Agriculture.

1. INTRODUCTION

Telangana is an agrarian state whose economy is filled with agriculture, as about 55 percent of the population relies on agriculture and other related industries. Since its establishment in 2014, Telangana has kept agriculture as its core area to enhance the welfare of the farmers, educate them on the latest technical farming, and enhance farm production and productivity. The gross sown acre has greatly grown since 131 lakh acres of land were sown in 2014-15, and then in 2020-21, the gross sown acre had risen to 210 lakh acres, which reflects the continuity in investing in irrigation projects and the development of agriculture. Nonetheless, the soil, groundwater, loss of biodiversity, and elevated costs of production are some of the consequences of decades of chemical-intensive agricultural practices.

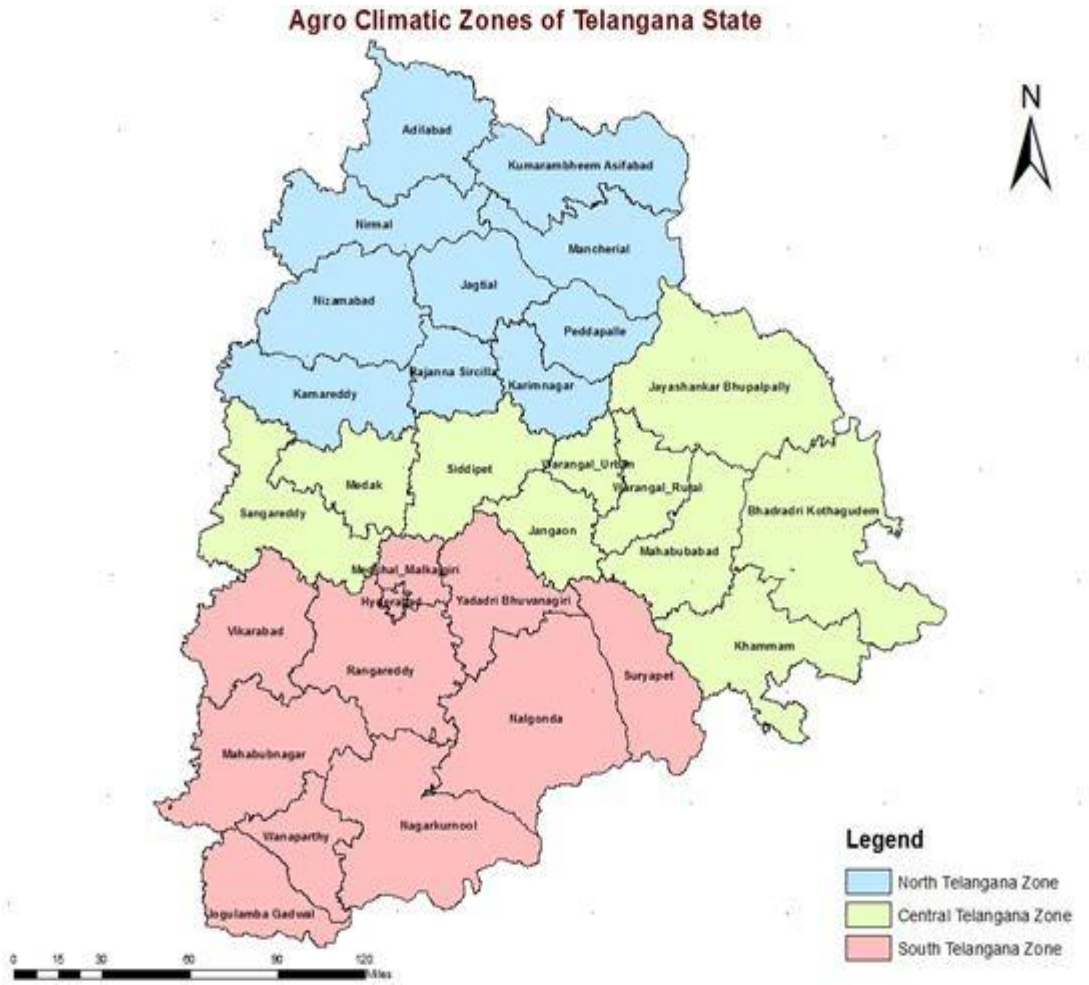

Figure 1: Geographic map of the state of Telangana, 33 districts, and three agro-climatic areas.

One promising solution to solve the problem of environmental sustainability and food security has been the concept of natural farming, which has been defined as the absence of synthetic fertilizers and pesticides, the use of local resources, and the application of minimal tillage. The state of Telangana produces over 290 lakh tonnes of agricultural field crop residues each year, with an estimated 30-40 percent of rice and 90-95 percent of cotton residues being burnt. The state has also developed a good policy of organic farming and programs such as the Telangana Siri brand of compost in the cities, using the urban waste produced in the city of Hyderabad and distributing it to the farmers through the 600 Agro Rythu Seva outlets within the state.

The special advantage of Telangana as the site of the National Remote Sensing Center (NRSC) in Hyderabad and the Telangana Remote Sensing Applications center (TGRAC) at the state level offers outstanding opportunities to apply geospatial analysis to the agriculture field. Since 2008, NRSC, which is a major ISRO center, has been mandated with the acquisition and processing of remote sensing data satellites, with TGRAC being the nodal agency in Telangana for RS, GIS, and GPS applications. These advanced geospatial technologies, coupled with natural farming systems, allow the full monitoring, analysis, and decision support in sustainable agricultural development.

This research paper discusses how geospatial analysis has been applied in natural farming systems in the Telangana context and how the technologies can be used in identifying appropriate farming zones, crop health and productivity, environmental effects, and provide information in making informed policy that is aimed at attaining food security objectives within the state.

2. LITERATURE REVIEW

2.1 Natural Farming Systems in India and Telangana

Natural farming entails an alternative form of agriculture that focuses on utilizing natural processes as opposed to forcing them. Zero Budget Natural Farming (ZBNF) was introduced in India by Subhas Palekar and has caught on in Indian states. Though the Community Managed Natural Farming program in Andhra Pradesh was the biggest program with 850,000 farmers, Telangana has been building its own system on organic farming by capitalizing on its respective advantages, such as the urban waste composting, management of crop residues, and combining it with other state programs, such as the Rythu Bandhu.

Figure 2: Comparative perspective of farming in the natural (left) and chemical (right) in Telangana agricultural landscapes.

Studies have shown that natural farming in practice has achieved high performance in various aspects, such as yield growth (+11 percent), increased farmer income and net returns (4-5 times higher), more diverse crops, better soil health, and resilience to climatic changes. The agricultural environment of Telangana, with rice (44 lakh acres), cotton (12.5 lakh hectares), and maize (14 lakh acres) as the major crops, has significant prospects for natural farming implementation. The agricultural importance of the state can be highlighted by the fact that the state is 2nd in the country in cotton production (6.83 million bales), and 3rd in maize production (3 million tonnes).

2.2 Geospatial Infrastructure in Telangana

Telangana is endowed with a great geospatial infrastructure with NRSC Hyderabad and TGRAC as its center. NRSC operates the data reception station at Shadnagar near Hyderabad for acquiring data from Indian remote sensing satellites (IRS, RESOURCESAT series) as well as international platforms. The center provides remote sensing data products, including digital elevation models, land use/land cover maps, geological and soil maps, crop type maps, and fire risk maps. NRSC's Aerial Services and Digital Mapping area provides high-resolution services for large-scale applications, including topographic mapping and infrastructure planning.

Figure 3: National Remote Sensing Center satellite ground station at Shadnagar, Hyderabad

TGRAC, established in 2014 as an autonomous organization under the Planning Department, has been providing RS and GIS-based services to various state government departments, including Irrigation, Panchayati Raj, Agriculture, Mines, and Rural Development. TGRAC maintains satellite data archives and spatial data repositories, including land use and land cover maps, tank information, and road networks with detailed attributes. The center has completed over 120 projects, including Command Area Monitoring, Integrated Watershed Management Programs, and Integrated Seasonal Monitoring Systems that support government decision-making processes.

3. METHODOLOGY

3.1 Study Area

Telangana state, formed in 2014, covers an area of 112,077 square kilometers with three major agro-climatic zones: Northern Zone, Central Zone, and Southern Zone. The state is irrigated by two large rivers, the Godavari and the Krishna, which offer irrigation facilities. The climate is mainly semi-arid, and average yearly rainfall in the form of 900-1200 mm is across the districts. Major agricultural districts are Warangal, Karimnagar, Nalgonda, Medak, Nizamabad, and Mahbubnagar, which are a representation of various patterns of farming and types of soil.

3.2 Data Sources and Acquisition

This paper combines several sources of data available on both the local and national repositories:

- NRSC Shadnagar earth station satellite images: RESOURCESAT-2 LISS-III (23.5m resolution), Sentinel-2 (10 m resolution), and MODIS (250m- 1km resolution).
- TGRAC spatial database, including land use/land cover maps and agricultural statistics
- Digital Elevation Model from SRTM at 30m resolution for terrain analysis
- Soil data from state soil surveys and national databases
- Climate and rainfall data from Telangana State Development Planning Society
- Agricultural statistics from the Directorate of Economics and Statistics, Telangana
- Ground truth data from organic farming areas and farmer field surveys

3.3 Geospatial Analysis Techniques

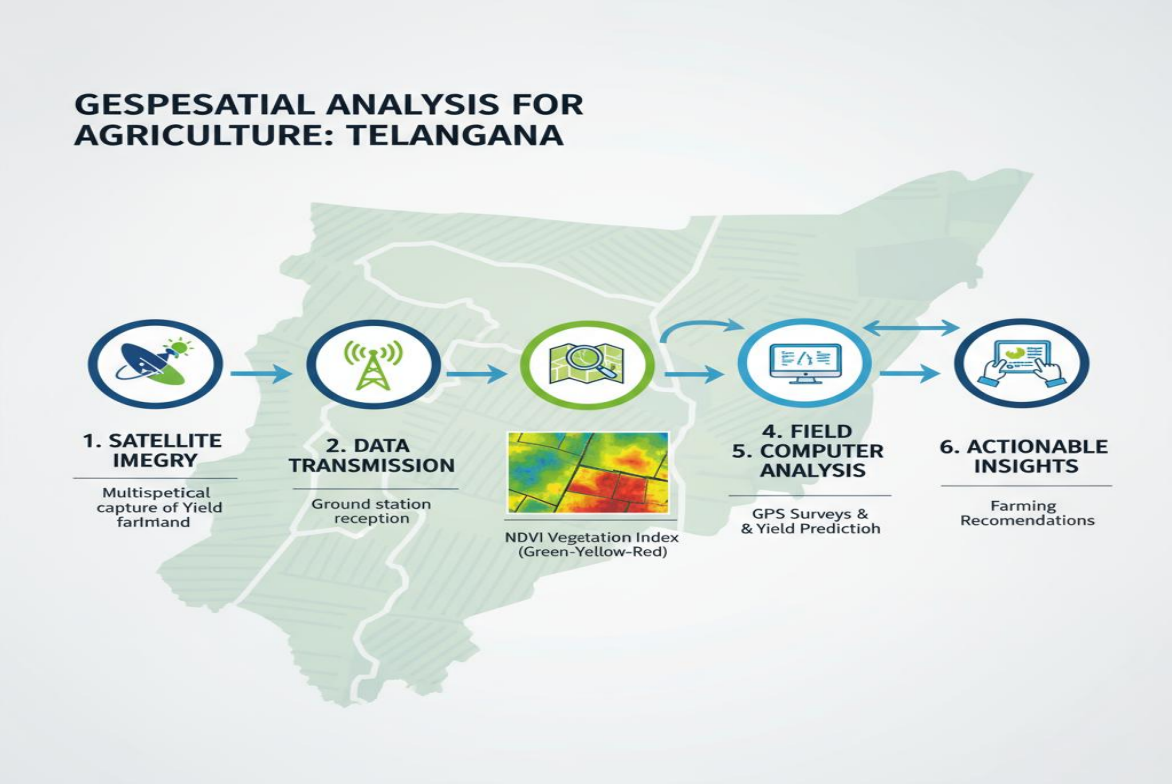

Figure 4: Geospatial analysis process of monitoring natural farming: satellite data acquisition to farming recommendations.

There were numerous geospatial analysis methods applied through the use of NRSC and TGRAC infrastructure. Multispectral satellite data used to calculate the normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI) were used to monitor crop vigor and the phenological growth of different agricultural regions in the heterogeneous Telangana agricultural system. The analysis of suitability was done using Multi-Criteria Decision Analysis (MCDA) that used Analytic Hierarchy Process (AHP) to determine the best zones to be used to expand natural farming due to weighted analyses on the soil types, rain, elevation, slope, and current cropping systems. Land Use Land Cover. This was done using the Land cover supervised classification algorithm with the capabilities of TGRAC in its processing. Multi-date imagery on changes in agricultural practices and environmental conditions in districts was compared with temporal analysis to evaluate changes across districts.

4. RESULTS AND DISCUSSION

4.1 Agricultural Profile of Telangana

The geospatial case study indicates detailed patterns of agriculture in Telangana state. Table 1 shows the key crops grown in the state of Telangana in terms of area covered and production based on satellite classification and ground validation.

Table 1: Major Crops Cultivated in Telangana (2020-21)

Crop	Area (lakh acres)	% of Cultivated Area	National Rank
Rice (Paddy)	104	50%	Top 5
Cotton	59	28%	2nd
Maize	14	6.7%	3rd
Red Gram (Pigeon Pea)	2.75	1.3%	-
Groundnut	2.0	1.0%	-

Green Gram	1.5	0.7%	-
Total Major Crops	**183.25**	**87.7%**	-

Source: PJTSAU & Directorate of Economics & Statistics, Telangana, 2021

Figure 5: Rice paddy fields/ cotton fields - the two largest crops that form 78 percent of the cultivated land of Telangana.

Rice and cotton comprise 78 percent of total cultivated land in Telangana, which implies that the state is a large rice-producing state (South India's rice bowl) and accounts heavily in cotton production. The development of irrigation and farmer support interventions in the state can be seen by the increase of 131 lakh acres of agriculture in 2014-15 to 210 lakh acres in 2020-21. This mixed farming system offers enormous possibilities of switching to natural farming systems within the various types of crops.

4.2 Comparative Analysis of Farming Systems

Table 2 includes comparative performance indicators across the farming systems based on national studies and adjusted to the situation in Telangana in terms of the conditions in the local agricultural environment.

Table 2: Comparative Performance of Farming Systems in the Telangana Situation

Parameter	Natural Farming	Chemical Farming	Rainfed System	Traditional
Yield Change (%)	+11	Baseline	-8	-15
Net Income Multiplier	4-5x	1x	0.7x	0.5x
Crop Diversity Index	High	Low	Medium	High
Soil Health Status	Improving	Degrading	Stable	Declining
Water Use Efficiency	High	Medium	Low	Very Low
Climate Resilience	High	Low	Medium	Low

Source: Adapted from GIST Impact study & Telangana agricultural assessments, 2023-24

The comparative analysis demonstrates that natural farming systems outperform conventional approaches across sustainability metrics. The 11% growth in yield, plus a 4-5 times increase in net income, is especially applicable to the small and marginal farmers that constitute the majority of Telangana (58 percent of farms under 1 hectare). Diverse crop technology can counter the excessive concentration of the

monocultures of rice and cotton by promoting better soil health, and climate resilience is increased in the semi-arid agro-climatic conditions of Telangana.

4.3 Geospatial Technologies Application in Telangana

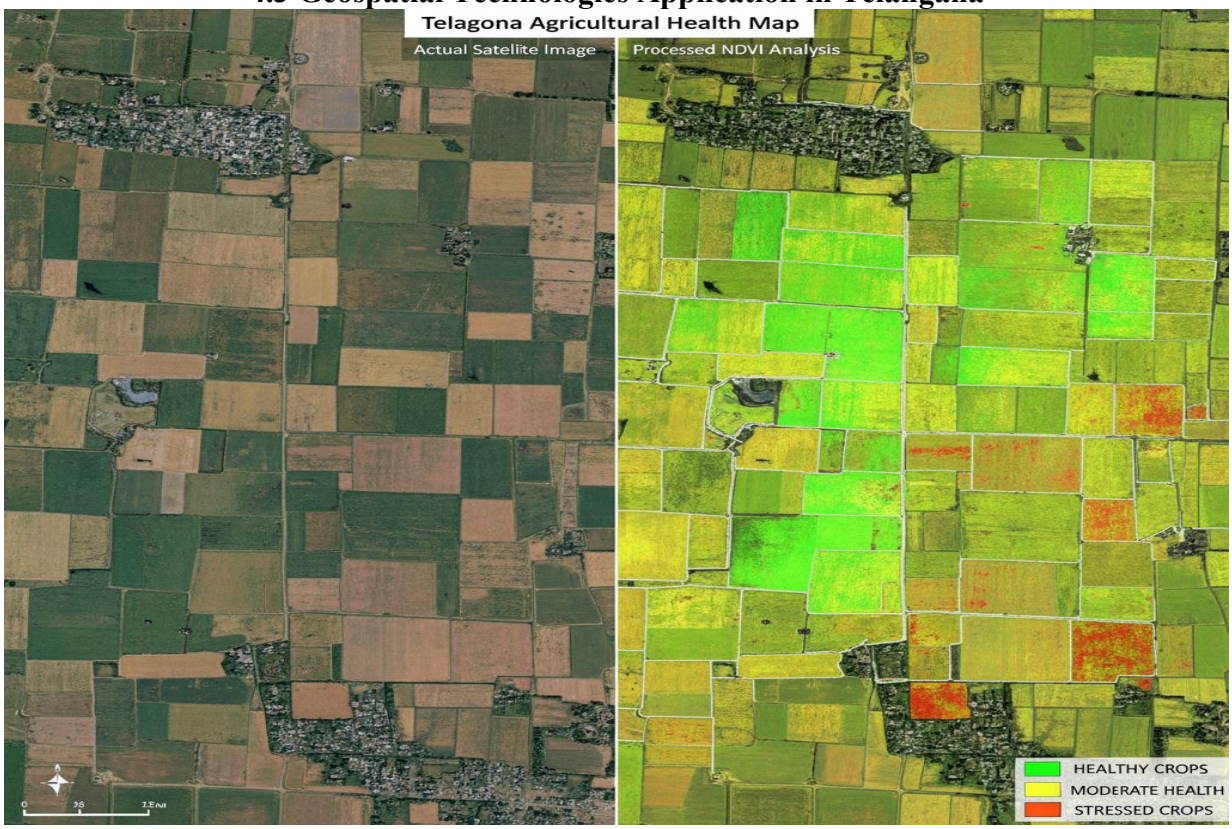

Figure 6: NDVI of agricultural field vegetation health mapping of agricultural fields based on satellite images.

Table 3: Geospatial Technologies for Natural Farming in Telangana

Technology/Platform	Application	Telangana Implementation	Resolution
NRSC Shadnagar Ground Station	Satellite data acquisition and processing	IRS, RESOURCESAT data for Telangana	23.5m
TGRAC Spatial Database	Land use/land cover mapping, tank & watershed monitoring	State-wide LULC maps, Command Area Monitoring	Variable
MODIS NDVI/EVI	Vegetation vigor monitoring, crop phenology	Seasonal crop monitoring across 33 districts	250m
Sentinel-2	Crop classification, biomass estimation	District-level crop mapping and yield estimation	10m
GIS Multi-Criteria Analysis	Suitability mapping for organic farming zones	TGRAC watershed and irrigation planning	Variable

Aerial Services (NRSC ASDM)	High-resolution mapping, infrastructure planning	Large-scale topographic mapping for agriculture	<1m
GPS Field Surveys	Farm boundary mapping, ground truth validation	Organic farm certification and monitoring	5-10m

Source: NRSC, TGRAC, and ISRO documentation, 2024

The strength of Telangana is the presence of the national (NRSC) and state-level (TGRAC) geospatial infrastructure in the state capital. NRSC Shadnagar offers direct access to satellite data acquisition, and TGRAC provides the applications that provide state-specific agriculture monitoring. The integration will allow real-time monitoring of crops, accurate management of irrigation, and informed decisions regarding policies on natural farming expansion in the various agricultural regions of Telangana.

4.4 Food Security Context

Table 4: Telangana Agricultural Production and National Context (2024-25)

Indicator	Telangana	National/Rank
Gross Sown Area (lakh acres)	210	-
Cotton Production (million bales)	6.83	2nd in India
Maize Production (million tonnes)	3.0	3rd in India
Rice Cultivated Area (lakh acres)	104	Major producer
Annual Crop Residue Generated (lakh tonnes)	290	-
Population Dependent on Agriculture (%)	55	54% (National)
India's Global Hunger Index Rank	-	105/127

Sources: PJTSAU, Telangana Dept of Agriculture, and Ministry of Agriculture GoI, 2024

Figure 7: Telangana's concept of food security and sustainable agriculture with various types of production and environmental sustainability.

The high agricultural production in Telangana, especially its 2nd place in the country in cotton and 3rd position in maize, shows that it is very significant to the national food security. The successful irrigation expansion is manifested in the growth in the cultivation area of rice by 197 percent between 2014-15 and 2020-21. Nevertheless, the Global Hunger Index inequality of India stands at 105 among the 127 countries; this implies that production increment will not be enough. Natural farming systems, including the focus on crop diversification and enhanced nutritional value, provide opportunities to solve food security issues both in terms of production and in terms of nutritional value improvement.

5. CASE STUDIES FROM TELANGANA

5.1 NRSC Hyderabad and Agricultural Monitoring

The National Remote Sensing Center, located in Hyderabad, is the leading center for the acquisition and processing of satellite data for remote sensing in India. The NRSC ground station at Shadnagar receives data on the observation of the Earth in Indian remote sensing satellites and other foreign platforms. Among agricultural monitoring services to the state of Telangana, NRSC offers vital services such as area estimation of crops, vegetation health determination with the help of NDVI and EVI indices, drought and flood disaster management, as well as agricultural planning decision support systems.

The Aerial Services and Digital Mapping department of NRSC has carried out high-resolution mapping of flood-prone river reaches in Telangana, including in the Godavari and Krishna river basins, which are important to agricultural development. The forty years of aerial remote sensing of the center allow its topographic mapping in finer details and resolution of scales applicable in farm-level planning and natural farming zone definition. The watershed management planning that is needed in sustainable agricultural practices in the semi-arid areas of Telangana is assisted by the digital terrain models created by NRSC.

5.2 TGRAC: Geospatial Applications at the State Level

Telangana Remote Sensing Applications Center was set up in 2014 and has played an important role in introducing geospatial solutions in the state's agricultural departments. TGRAC has full spatial databases with land use/land cover maps of all 33 districts, tank information systems used to manage irrigation, and delineation of watershed boundaries. The center has done more than 120 projects, among them being Command Area Monitoring, which is directly related to agricultural productivity improvement, and Integrated Watershed Management Programs, which are essential in rainfed areas of farming where natural farming has the most potential.

The Integrated Seasonal Monitoring System of TGRAC gives assessment reports that help the government make decisions regarding crop insurance, disaster relief, and agricultural planning. In natural farming applications, TGRAC spatial databases can be used to identify the appropriate areas due to the type of soil, water availability, slope conditions, as well as the current land use patterns. The center cooperates with the Department of Agriculture to overlay the geospatial data on the farmer databases to provide extension services specifically on natural farming adoption in the priority areas.

5.3 Telangana Siri: Urban-Rural Nutrient Cycling

Figure 8: Pursuant to the nutrient cycling process between urban and rural areas, the urban waste composting project of Telangana Siri depicted the process.

Telangana State Agro Industries Development Corporation (TS-Agros) has developed a brand of city compost known as Telangana Siri and uses the urban waste produced in Hyderabad, and supplies it in 600 Agro Rythu Seva outlets within the state. It is an innovative program that links urban waste management to the rural needs in agriculture to offer organic inputs to the natural farming systems. The geospatial analysis has been used to streamline the distribution network and identify collection zones of urban waste, the location of the processing centers, and regions with the greatest demand for organic inputs.

The GIS logistics planning will make sure that the transportation of processed compost in Hyderabad to the farming sites is done efficiently, and the roads taken are optimized based on the distance, the quality of the roads, and the clusters containing the farmers. By tracking the agricultural areas that are receiving Telangana Siri compost, satellite imagery can be used to evaluate improvement in soil health by comparing the spectral analysis of the field and control fields. Such a combination of urban waste management, geospatial technology, and natural farming is a replicable model in developing sustainable agriculture.

5.4 Crop Residue Management and Natural Farming

Figure 9: Comparison of the crop residue burning to the left of the figure and the natural farming mulching practice to the right of the figure in Telangana.

Telangana produces about 290 lakh tonne of crop residue, out of which 30-40% of the rice residue and 90-95% of cotton residue is burned, which pollutes the air and depletes of organic matter. Geospatial technologies can be used to detect thermal anomalies of burning hotspots of crop residues with the help of the MODIS and Sentinel data. TGRAC has identified regions that generate the highest levels of residues, with a majority being in the major rice growing districts such as Warangal, Karimnagar, and Khammam, and also areas with cotton growing as Adilabad, Nirmal, and Mancherial.

The systems of natural farming also offer the answer to the use of crop residues in the form of mulching, which enhances the humidity of the soil, inhibits the growth of weeds, and builds soil organic carbon gradually. TGRAC has created GIS-based decision support systems that can be used to target awareness campaigns and equipment distributions to incorporate crop residue, instead of burning it. The temporal analysis of satellite images reveals a positive association between low residue burning with the use of conservation measures in the districts where the active promotion of natural farming was practiced. The combination of residue management and the principles of natural farming is a solution to environmental pollution and improvement of the soil condition at the same time.

Figure 10: Natural farming in Telangana practiced by the indigenous people, which involves the preparation of bio-inputs and inter-cropping.

6. CHALLENGES AND LIMITATIONS

Although Telangana was in a favorable position with regard to NRSC and TGRAC infrastructure, various problems restrain the extensive usage of the geospatial technologies in natural farming. The fact that the state comprises small and fragmented land plots (58% of less than 1 hectare) limits the resolution of satellite-based monitoring to very high-resolution imagery, which is perhaps prohibitively expensive to afford in routine monitoring. The presence of cloud cover during monsoons limits the availability of the optical satellite imagery and introduces temporal data gaps, especially during the season of Kharif, which is considered to be the most vital time of the year, especially in view of rice farming.

There are technical capacity constraints between the farming communities' field-level extension workers on the utilization of GIS and remote sensing outputs. Although NRSC and TGRAC have advanced features, the complexity of converting complex geospatial information to actionable advice at the farm level would need extension service capacity upgrades and the creation of useful mobile applications. The ground truth validation of 33 districts within the state of Telangana is still resource-heavy, influencing the accuracy measurement of the classification products and constrained natural farming performance claims validation.

Merging different sources of data that have different temporal, spatial, and spectral resolutions has to be based on standardized protocols that are still being developed. Sustained monitoring systems present budgetary difficulties with regard to the maintenance of the continuous monitoring systems and updating the spatial databases. This is because the lack of baseline geospatial data on geospatial parameters related to soil health prior to the adoption of natural farming restricts the longitudinal studies on soil improvement. The organic products certification and trace systems need GPS-based farm boundary verification and continuous monitoring infrastructure, which is not yet fully built throughout the state.

7. POLICY RECOMMENDATIONS FOR TELANGANA

It can be concluded that the Telangana region has its own benefits and particular limitations, and the following policy suggestions can be made:

- Create a State Natural Farming Geospatial Database, which will be coupled with the current TGRAC infrastructure to unify spatial data on natural farming regions, Telangana Siri compost distribution, crop residue control, and performance measures, to be available using a publicly accessible portal.
- Cash in on NRSC Hyderabad location: establish special natural farming surveillance provisions based on RESOURCESAT and other Indian satellite data, with special priority to Telangana agricultural surveillance requirements.
- Develop mobile-based GIS applications translated into the Telugu language that will allow farmers and the facilitators of the Rythu Mitra field to add ground truth data, which will form crowd-sourced validation networks in each of the 33 districts.
- Increase partnership between NRSC, TGRAC, Professor Jayashankar Telangana State Agricultural University (PJTSAU), and the state agricultural departments to come up with decision support systems that would specifically focus on natural farming in agro-climatic zones of Telangana.
- Combine natural certification of farms with GPS border checking of farms through the use of TGRAC resources, to have transparency and market trust in organic products of Telangana.
- Apply geospatial analysis to streamline distribution networks of Telangana Siri and prioritize on location of bio-input resource centers through the establishment of bio-input resource centers under the National Mission on Natural Farming.
- Introduce the use of satellite-based crop residue burning surveillance coupled with fulfilled farmers' extension programs that will encourage in-situ incorporation practices in line with natural farming principles.
- Create geospatial research fellowships in PJTSAU and other agricultural universities to develop an expert workforce who will be able to implement remote sensing and GIS to address agricultural issues unique to Telangana.

8. FUTURE RESEARCH DIRECTIONS

There are a number of research opportunities that can be used to improve the use of geospatial in the natural farming systems in Telangana. The implementation of hyperspectral remote sensing of future Indian satellites may allow fine-scale biochemical studies of the soils and crops, which would give information about the nutrient status and composition of organic matter in Telangana soils, peculiar to the specific soil type. The RISAT platforms have Synthetic Aperture Radar sensors that provide all-weather monitoring, which was not possible due to the monsoon cloud cover that hampered 24-hour Kharif season monitoring.

IoT sensor networks with geospatial platforms may be developed to offer real-time fine-resolution soil moisture, temperature, and microbial activity monitoring in natural farming plots in Telangana. The use of machine learning algorithms of multi-temporal NRSC satellite data can provide indications of the subtly improving soil health conditions related to natural farming methods that are verified using ground verification measures by TGRAC. GPS tracking and blockchain technology may help Telangana Siri improve the supply chain transparency and traceability of the organic products.

Standardized geospatial techniques comparing the results of the three agro-climatic zones of Telangana would produce solid evidence on the performance of natural farming under different environmental conditions. Innovation into ecosystem services, such as carbon sequestration of soils in the state of Telangana, biodiversity protection in agricultural landscapes, and watershed protection through geospatial tools, would be able to quantify non-productive environmental benefits. The socio-economic geospatial analysis based on the combination of satellite data and household surveys could show spatial patterns of natural farming adoption and pinpoint the barriers that are unique to the rural setting of Telangana.

9. CONCLUSION

The study shows that Telangana has outstanding possibilities of incorporating geospatial analysis in natural farming systems with its specific location, with the existence of the National Remote Sensing Center, Hyderabad, Telangana Remote Sensing Applications Center. The overall satellite data acquisition capacity at NRSC Shadnagar and the state-level spatial databases and application experience of TGRAC can offer an infrastructure unrivaled by most Indian states to monitor agriculture and support agricultural decisions.

The presented evidence shows that natural farming systems perform better in various aspects, among them are 11% higher yield, 4-5 times more money in the pocket of farmers, a more diverse crop base, a healthier soil, and a more resilient climate. In the case of Telangana, where agricultural population is 55 percent and most farmers are small-scale, these gains are especially high. The extensive agricultural productivity of the state, 2nd at the national level in cotton, 3rd in maize, and a large-scale producer of rice, shows the ability to provide a significant contribution to the national food security due to the transition to sustainable farming.

The case of Telangana Siri urban waste composting can be viewed as an example of new methods of natural farming input supply, which can be expanded by means of geospatial optimization of logistics. The challenge of 290 lakh tonnes of annual crop residue generation, with most of the same being burnt that is a challenge to the state and an opportunity to the natural farming systems, which use the same as mulching and soil building. Geospatial technologies allow hotspots of burning to be identified, patterns of adoption to be tracked, and improvement in soil health to be determined as a result of conservation activities.

The increase of gross sown area of Telangana by 131 lakh acres to 210 lakh acres is evidence of successful agricultural development, but the sustainability issue requires a change to natural farming systems. The combination of NRSC and TGRAC abilities with state agricultural efforts offers a base for the development of evidence-based policy development and monitoring of implementation. To make the geospatial abilities become natural farming adoption at the ground level, strategic investments in capacity building, improvement of extension services, and decision support systems accessible to farmers are necessary.

In the future, the intersection of geospatial infrastructure, agricultural importance, and policy dedication in the state of Telangana makes the state a possible example of promoting natural farming in India. The effective adoption of natural farming systems through geospatial in Telangana would serve as models that other states can emulate in order to meet the Sustainable Development Goals of India, especially SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land). The current study is a part of the evidence base of sustainable agricultural transition and shows that geospatial capability on a state level can initiate change towards economically viable and environmentally sustainable agricultural systems.

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