Space technology support for development of agriculture in the North Eastern Region of India – scope and challenges

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The North Eastern Region of India (NER) has tremendous scope for accelerating its growth in agriculture and allied areas through advanced data acquisition, interpretation and dissemination methods with geospatial technology. For several thematic applications, geospatial tools and techniques are being used to provide synoptic, cost-efficient and timely information for effective crop planning and monitoring in the region. A review of space applications in agriculture, horticulture, sericulture, land-use suitability, shifting cultivation, groundwater prospecting, soil resources management, etc. has been made, highlighting the scope and limitation of using these advanced technologies. Satellite remote sensing has several limitations in NER, viz. small and fragmented farmlands, persistent clouds during monsoon, mixed farming, steep hills, etc. Considering these facts, unmanned aerial vehicles (UAVs) are used as an alternative for satellite remote sensing applications in agriculture. The increased availability of very high resolution satellite and UAV data will offer opportunities for innovative solutions to fulfil specific user needs of agriculture and allied sectors in NER.

Keywords: Agriculture, crop production, geospatial technology, remote sensing, unmanned aerial vehicles.

THE North Eastern Region of India (NER) comprises the states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Mizoram, Nagaland, Sikkim and Tripura, encompassing an area of about 262,179 sq. km, which is nearly 8% of the total land mass of the country. In the delicate ecosystems of the region, over 70% of the population relies upon marginal, input-intensive, low gainful farming activities for livelihood, which is a significant segment in the economy of the region[1,2]. The agrarian practices of NER are of two types: (i) shifting cultivation and (ii) settled or plains agriculture. As a large part of the region is hilly and inhabited by different tribal groups, shifting cultivation is the rudimentary life-supportive subsistence-intensive agriculture[3,4]. On the other hand, the plain or settled agriculture is practised in the fertile alluvial plains of Assam, and parts of Arunachal Pradesh, Manipur, Meghalaya Nagaland and Tripura. Figure 1 depicts the area under major crops in NER.

Growth of agriculture in NER is interrupted by the availability of quality inputs, inadequate farm mechanization and limited information communication technology (ICT) interventions. Also, in changing climatic scenarios, effective agricultural planning needs precise spatio-temporal information for accurate crop forecasting, irrigation scheduling, crop stress management and disaster preparedness. The methodology for acreage estimation of major crops in NER is yet to be established. This is because of inherent problems such as undulating topography and the inaccessibility of most agricultural fields. Acreage of major crops in such conditions is reported based on eye estimation, which accounts for about 5% of the reporting area[5]. This results in statistics that is erroneous and not reliable; at the same time, they are labour-intensive and time-consuming. In this context, geospatial technologies combining remote sensing (RS), geographical information system (GIS) and global positioning system (GPS) have gained relevance for providing spatial as well as temporal information on crop and weather parameters to complement the traditional methods[6–9]. Many studies have been carried out on the application of space technology in agriculture and allied sectors (Table 1). However, these are limited to a few areas of space application, with the scope for new areas to be analysed with geospatial tools and techniques in NER.

In this study, we discuss some important areas having the potential of using geospatial technology along with the challenges associated with such technologies.

Crop acreage and production estimation

During the initial period of the satellite remote sensing applications, the focus was on the delineation of land use land cover (LULC), with special emphasis on crop discrimination. However, the current trend of remote sensing applications in agriculture has emphasized plant biophysical characteristics and their relation to crop production and stress detection. The phenology and crop health influence the reflection from a crop field and thus multispectral sensors can be used to monitor these parameters[10–13].

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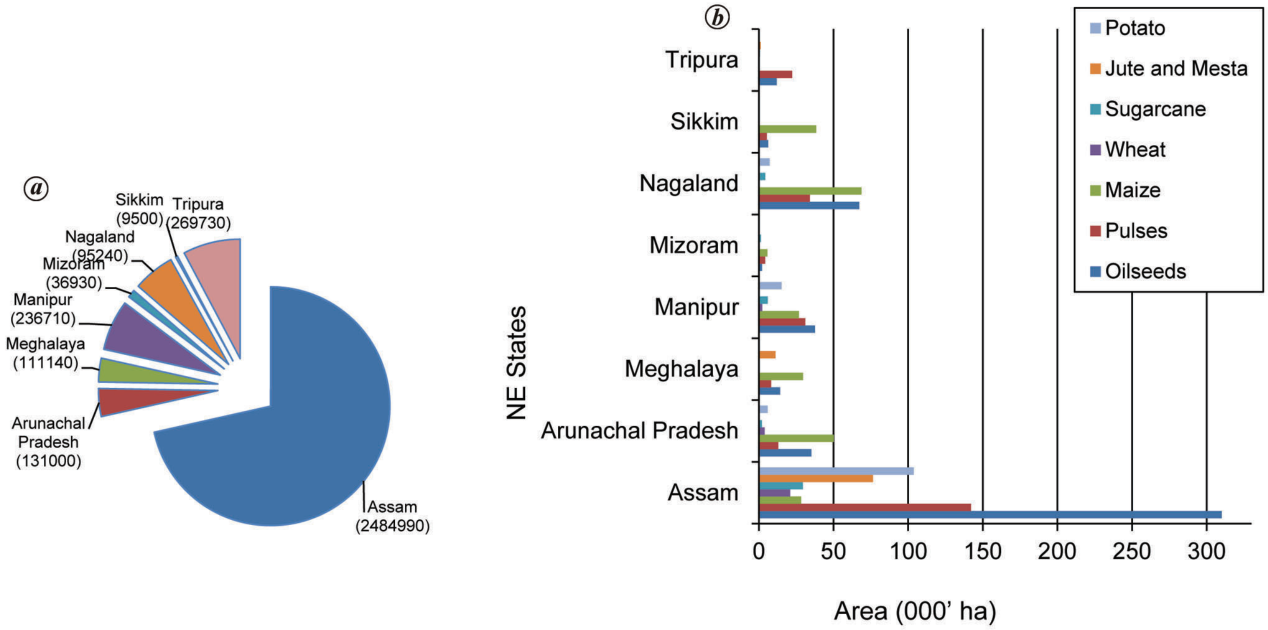

Figure 1. Area (ha) under (***a***) paddy and (***b***) other major crops of North eastern region (NER). Source: Directorate of Economics and Statistics of the NE states. 2014–15: Mizoram, Nagaland; 2015–16: Assam, Tripura; 2016–17: Arunachal Pradesh and 2017–18: Meghalaya, Manipur, Sikkim.

Owing to the undulating topography, scattered and small landholdings, a specific sampling method for collecting agri-statistics using RS data combining ground truthing was undertaken to estimate rice crop acreage in Ri Bhoi district, Meghalaya, employing Maximum Likelihood Classifier (MXL)[5]. This approach assumes that values of a class for a band are normally distributed and the probability of a given pixel belonging to a specific class is calculated. A class is assigned to the pixel based on maximum likelihood[14]. In addition to MXL, other supervised approaches that are commonly used in crop classification are the minimum distance (MD), Mahalanobis distance (MD), *k*-nearest neighbour (KNN), etc. Advanced classification techniques such as artificial neural network (ANN), classification trees (CTs), support vector machines (SVMs) and spectral angle mapper (SAM) are found to outperform conventional crop classifiers[15]. In a study conducted at IARI, New Delhi, it has been reported that machine learning classification algorithms, viz. Random Forest (RF) and Classification and Regression Trees (CART) showed better accuracy than SVM[16].

The capability of synthetic aperture radar (SAR) has been explored in delineating rice crops in NER[17]. In Kharupetia, Assam, a study was conducted to differentiate minor crops (maize and cauliflower) using time-series Sentinel-1 data[18]. Mixed and multistorey cropping patterns in the undulating terrain of the region prevented improved crop classification by microwave remote sensing. An integrated sampling approach adopted for acreage estimation of rice crops in Meghalaya using remote sensing, GIS and ground data produced encouraging results[19]. The combination of optical and radar data has been found to be useful in crop discrimination since it harnesses the advantages of both the sensors, viz. vegetation structure and biochemical properties. Multi-temporal satellite imageries are found to be useful for crop discrimination, where the variations in reflectance are a function of plant phenology[20]. Time-series multispectral and multi-temporal data from Moderate Resolution Imaging Spectrometer (MODIS), Advanced Very High-Resolution Radiometer (AVHRR), Landsat, Indian Remote Sensing Satellite (IRS), Satellite Pour l'Observation de la Terre (SPOT) and Chinese HJ-1A/B have been used at the national and regional scale for rice mapping[21–24].

Rice mapping in five districts of Assam had been done with reasonable accuracy using MODIS NDVI time-series data and HJ-1A/B multi-spectral satellite data[25]. A supervised classification approach was found to provide good results using Landsat data for acreage estimation of summer rice (*Boro* paddy) in Assam[26].

The LULC map prepared under the Natural Resources Census (NRC) programme of the National Remote Sensing Centre (NRSC), Hyderabad, identified crop classes up to level-3. The exercise carried out in a five-year time interval has provided the required baseline information for land use and agriculture planning. However, it is not sufficient to meet the demand for agricultural planning on a regular basis and yearly updation of the map is required specifically for the agricultural classes. Figure 2 gives an updated LULC map prepared using IRS LISS-III satellite data for 2020 and 2021. A total of 10 classes under agriculture are given, where shifting cultivation areas are given under two classes, viz. (i) shifting cultivation – current and (ii) shifting cultivation – abandoned. Seasonal variation of crop distribution is covered under three classes, viz. *kharif* (winter crop), *rabi* (summer crop) and *zaid* (autumn crop). Area under

Table 1. Applications of remote sensing and geographical information system in agriculture and allied areas in north eastern region

Thematic area	Applications of geo-spatial technology	Satellite/sensor used	Spatial resolution (m)	Reference
Agriculture and horticulture development	Crop damage due to abiotic stress	Radarsat-SAR	5.2–17.3 × 7.6	35–37
		MODIS	250	
		Multispectral UAV	0.05	
		IRS P6 LISS III	23.5	
	Crop insurance	Landsat 5 and 8,	30	38
		Sentinel 1,	20 × 22	
		Cartosat 1 and	2.5	
		Proba V NDVI	100	
	Crop damage due to biotic stress	UAV (multispectral)	0.5	40
	Crop acreage estimation	IRS 1D/P6LISS III	23.5	61, 99, 100
		HJ-1A and 1B (CCD1 and 2)	30	
		MODIS (Terra)	250	
		Landsat 5 TM	30	
		Hyperion	30	
		RapidEye	5	
		Sentinel 1 SAR	10	
	Cropping system analysis	IRS LISS III,	23.5	100–102
		Worldview 2	2	
	Site suitability analysis	Resourcesat-2 LISS-III	23.5	103–105
	Crop yield	UAV (Multispectral)	0.05	106
Land-use planning	Action plan for alternate land use planning	IRS 1A/1B LISS II	36.25	107–110
		IRS-1D LISS III	23.5	
		Resourcesat-1: LISS-III	23.5	
		Cartosat 1	2.5	
Shifting cultivation	Study of spatial and temporal dynamics of shifting cultivation	Landsat TM, ETM+, OLI IRS	30	111–113
		LISS-III	23.5	
		Multi-temporal AWiFS	56	
		SRTM-DEM	30	
Ground water	Ground water prospecting, preparation of water quality map	Resourcesat-1 LISS III	23.5	114–116
		Cartosat-I	2.5	
Soil	Soil resource mapping, soil fertility mapping, assessment of soil erosion	IRS LISS III	23.5	117, 118
		Landsat 4 MSS	30	
		Survey of India Topographical maps		
Agro forestry and plantation crops	Acreage estimation, site-suitability analysis	LISS III	23.5	119, 120
		LISS IV	5.8	
		Cartosat 1	2.5	
Sericulture	Site suitability analysis	Resourcesat-2: LISS-III/	23.5	121
		LISS-IV	5.8	
		CARTO-DEM	10	

these three categories is estimated to be 25.16 lakh ha for *kharif*, 1.43 lakh ha for *rabi* and 1.45 lakh ha for *zaid* for NER. Area under double crop is estimated to be 4.89 lakh ha, which is only about 12% of the net cropped area in the region, suggesting that there is tremendous scope for increasing cropping intensity in NER.

Acreage estimation of rice, jute and mustard crop in Assam was taken up under Forecasting Agricultural output using Space Agro-meteorology and Land-based observations (FASAL) programme of the Ministry of Agriculture and Farmers' Welfare, Government of India[27,28]. Under this programme, efforts were made to develop a remote sensing-based methodology for collecting agricultural statistics for other hilly states. While acreage estimation of rice could be made with acceptable accuracy, for other selected crops, viz. maize, potato, ginger, pineapple and cashew nut, estimation errors were higher and would require more studies[19]. Under the Space technology Utilization for Food security, AgriculturaL Assessment and Monitoring (SUFALAM) project coordinated by Space Applications Centre (SAC), Ahmedabad, maize acreage and production estimation is being made with satellite remote sensing on a pilot basis. There is still a long way to go in terms of acreage estimation of other important crops in the region.

Crop stress assessment

Remote sensing can provide critical spectral properties of the biophysical indicators of plant health[29–32]. Stress induces physiological changes in the plant, which in turn changes its spectral response. Thus, crop stress can be detected using remote sensing techniques. The growth and development of crops are hindered by several factors such as abiotic (temperature extremes, drought, frost, flood, Salinity, heavy metals, etc.) and biotic (diseases, pests, stress, etc.).

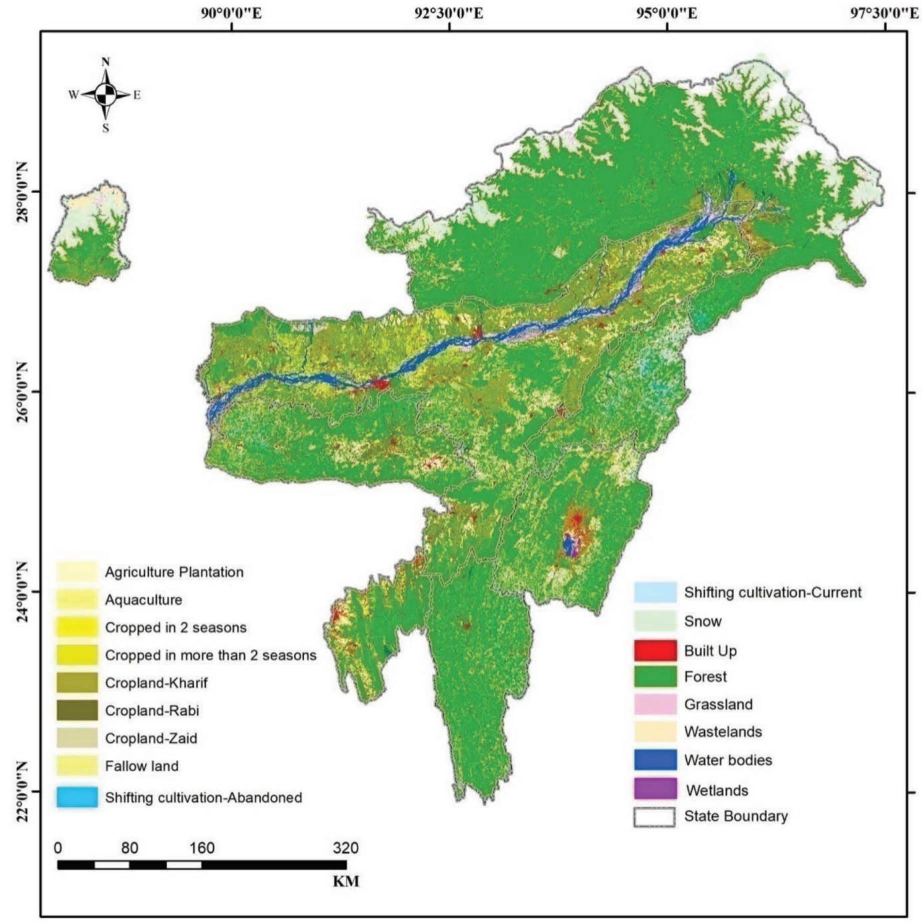

Figure 2. Land use land cover map of NER updated with LISS-III satellite data of 2020 and 2021.

A number of studies have revealed the sensitivity of maize yield to frost[33,34]. There was a decline in normalized difference vegetation index (NDVI) from 0.36 to 0.13 (derived from spectroradiometer data) and 0.5 to 0.31 (derived from UAV-borne multispectral sensor). The yield was reduced by 870 kg ha^{-1} than the previous frost-free year[35,36]. Agricultural productivity in NER is affected due to a lack of precipitation, particularly in winter. The use of satellite-derived products such as NDVI, land surface temperature (LST) and evapotranspiration (ET) to measure water and vegetation stress helps determine priority areas for irrigation for effective crop management[37]. Early warning and forecasting based on spectral response properties provide adequate time for managing pest infestation resulting in minimal crop damage, optimal pest management, reduced cost of cultivation and increased benefit : cost ratio.

Crop damage due to floods is a major issue of concern in the Brahmaputra and Barak Valley of Assam, and a few other valley areas in Arunachal Pradesh, Manipur and Meghalaya. Remote sensing data play a key role in retrieving flood information, viz. flood duration and water inundated areas, and the dynamics of waterlogging. A number of remote sensing-based studies carried out in two of the most flood-affected districts of Assam, namely Morigaon and Nagaon, have shown the effectiveness of the technology in quickly assessing crop loss due to floods[38]. Remote sensing techniques can also be used to assess the flood risk vulnerability and categorize the extent of damages[39].

UAV remote sensing applications have been found effective in quantitative estimation of brown plant hopper (*Nilaparvata lugens*, Stal) infestation in *boro* paddy in Morigaon district, Assam. This helped the farmers in taking immediate interventions to save their crops[40]. Following the recommendation of NITI Aayog's Task Force meeting held on 25 October 2016 on the use of space technologies for agricultural insurance, a number of new initiatives are expected to be taken up in NER, which will protect farmers against crop loss owing to natural disasters, viz. droughts, hailstorms, floods, cyclones, pest attacks, etc.[41].

Space technology support for horticulture development in NER

Horticultural crops play an important role in enhancing land productivity, employment generation, tapping export potential, uplifting the economic conditions of farmers and enabling food and nutritional security. The diverse agro-climatic

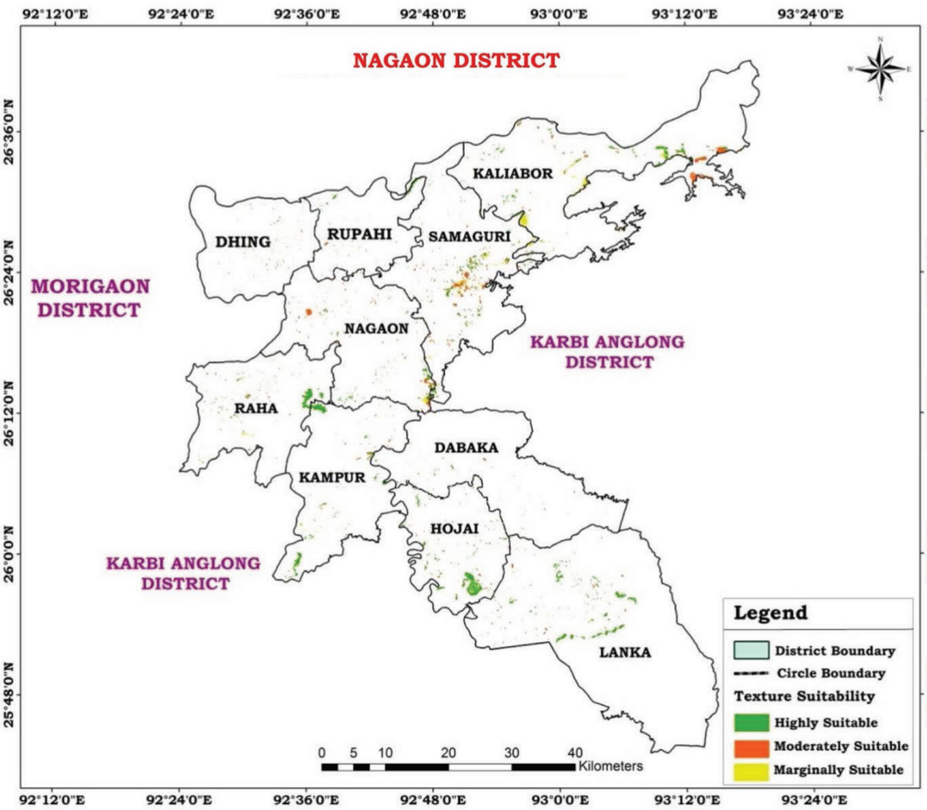

Figure 3. Suitable areas for growing Assam lemon in Nagaon district, Assam, NE India.

conditions and arable soil enable the growth of innumerous horticultural crops in NER. Total production of fruits in the region is estimated to be about 2.34 million tonnes, which is about 5.1% of the total production of the country. Similarly, the contribution of vegetable production in the region is about 4.5% of the total production in India[42]. Remote sensing aids horticultural crop inventory and site suitability analysis for area expansion. Under the Coordinated Horticulture Assessment and MAnagement using geoiNformatics (CHAMAN) project, coordinated by Mahalanobis National Crop Forecast Centre (MNCFC), mapping suitable areas for expansion of economically important horticultural crops in 24 selected districts of NER has been carried out. Figure 3 shows suitable areas identified for the expansion of Assam lemon cultivation in Nagaon district, Assam.

There is also a need for large-scale horticultural crop inventory, crop condition assessment, planning for marketing and post-harvest infrastructure, etc. A few studies have been carried out in the region with respect to citrus decline[43,44], agro-climatic planning for horticultural crops, etc. Delineation of horticultural crops grown on the slopes has challenges for remote sensing scientists due to hill shade and crop types such as multi-storey, inter-cropping and mixed cropping patterns. However, an integrated approach using high-resolution remote sensing data in conjunction with ground surveys may be expected to provide horticultural crop inventory with reasonable accuracy.

Soil resources mapping and management

In-depth, intimate knowledge of soil resources and their potential, limitation and capabilities is necessary for a variety of purposes such as developing optimum land-use plans for agriculture, irrigation and drainage, crop suitability analysis, soil conservation in catchment areas, watershed prioritization, reclamation of degraded lands, etc.[45–47]. The data obtained from remote sensing satellites are interpreted as a function of soil properties. A good number of studies have been carried out to testify the role of RS and GIS in soil-related studies, and this has been extensively used for soil resource mapping in India[47,48]. The National Bureau of Soil Survey & Land Use Planning (NBSS & LUP) has mapped the soils of the entire country on 1 : 250,000 scale. Similarly, the Soil and Land Use Survey of India (SLUSI) has prepared a soil map at 1 : 50,000 scale in collaboration with different organizations and institutions. In NER, the 1 : 50,000 scale soil map is now available for all the states, except Manipur, where the mapping is being done by the North Eastern Space Applications Centre (NESAC) and SLUSI. Inceptisols (recent soils) are the most dominant soil in NER, followed by Entisols (very recent soils), occupying 51.7% and 20.4% of the total geographical area, respectively. A number of studies on soil resource and soil fertility mapping, mapping of spatial variability of soil organic carbon and micronutrient, etc. have been carried out

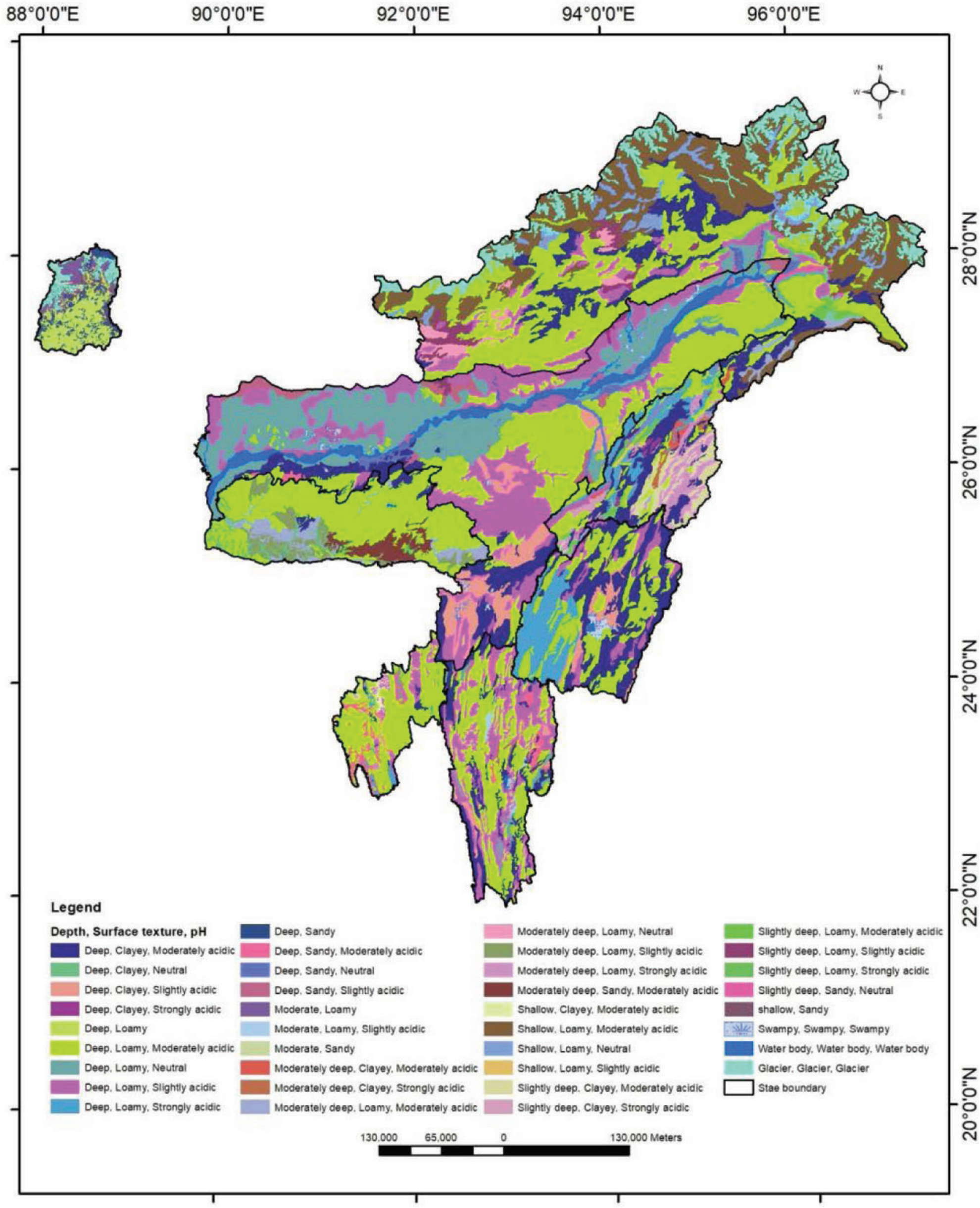

Figure 4. Soil map of NER.

in NER[49,50]. Figure 4 is a soil map of NER. The emerging methods and technologies bear immense potential in large-scale soil resource mapping and characterization in NER. This will facilitate the land-use planners to categorize lands parcel into different management zones.

Remote sensing inputs in land-use suitability and cropping system analysis

The knowledge of land suitability for growing crops is essential to suggest appropriate cropping systems based on suitable soils for various crops[51]. For the preparation of the soil site suitability map, the criteria outlined in the Food and Agriculture Organization of the United Nations (FAO) guidelines on the land evaluation system have been widely used in many studies[52–54]. Some other criteria, including environmental, social and economic factors, also play an important role in site suitability studies[55].

In NER, land suitability analysis is mainly confined to selected agricultural and horticultural crops. The analysis was carried out in a rice-based wetland ecosystem in Majuli river-island to study the relationship between soils and geomorphic units and propose a land-use plan suitable for crops and migratory birds[56]. In Mizoram, a study was carried out to identify the additional potential areas for wet rice cultivation based on slope, water availability, land-use pattern and environmental aspects using LISS-III and Cartosat-I data[57]. Studies were also conducted on assessing physical land suitability for seasonal summer paddy crop in Kamrup district of Assam[31] and multi-criteria evaluation for identifying potential areas for the cultivation of turmeric in the Jaintia Hills of Meghalaya[58]. There was also an effort to develop a spatial decision support system using a fused product of Hyperion and RapidEye red edge bands in the Dhemaji and Lakhimpur districts of Assam[59].

Mapping and monitoring of shifting cultivation areas

Shifting cultivation (also known as 'slash and burn agriculture' or 'jhum') is an agricultural system where plots of land are temporarily cultivated, then abandoned and allowed to revert to their natural vegetation as the cultivator shifts to another location[60]. This land use is usually the only way to ensure food security for the poorest inhabitants in rural hilly areas[61]. Although this form of cultivation is dominant in the highlands of the hilly states of NER, data on the spatial and temporal dynamics of shifting cultivation are inadequate.

Two categories of shifting cultivation are mapped as a part of the NRC LULC 50,000 scale mapping – current and abandoned. There are also remote sensing-based studies on different aspects of jhum cultivation in NER, such as on prevailing jhum cycles and their change dynamics[62], government policies and social impact[63,64], trend analysis on spatial and temporal dynamics of jhum cultivation[65], etc. In recent times advanced methods such as decision tree-based multi-step thresholds are being used for consistent and long-term mapping of shifting cultivation in the region[66].

There has been a need for a common repository of the geospatial database in NER to avoid confusion among users. The Northeastern Spatial Data Repository (NeSDR) developed by NESAC in collaboration with the State Remote Sensing Application Centres (SRSACs) of the NE states is fulfiling this requirement. NeSDR is supplemented with a large number of data, web services, applications and external data links, which can be accessed through a single-window platform for data visualization, interactive analysis, search and identification of spatial-based user interest[67].

Geospatial application in agroforestry

Agroforestry is a significant land-use system in NER that has been utilized by the locals for millennia[68,69]. This system covered 3.68 lakh ha area in NER, accounting for 2.1% of the total agroforestry area in the country[70]. Agroforestry has the potential to prevent and adapt to climate change[71], in addition to improving soil fertility and conserving biodiversity[72,73]. It also helps in employment generation, improvement of agro-ecosystem quality and attainment of food security[74–76]. Geospatial technology supports accurate estimation of area under agroforestry across the country, while saving time and money over traditional methods. The ICAR-Central Agroforestry Research Institute, Jhansi, in collaboration with the International Centre for Research in Agroforestry's South Asia Regional Programme, has developed a remote sensing-based methodology to map the area under agroforestry and trees outside forests (TOF) for the entire country[77]. Through land suitability assessments, space technology supports the expansion of area under agroforestry. A study conducted to analyse appropriate land for agroforestry in the Eastern Indian Himalayan Region revealed that 29% and 60% of the assigned land (non-forest, scrub and open forest land) were in the very good and good category respectively[78].

Potential applications of microwave, thermal and hyperspectral remote sensing

Microwave remote sensing offers the benefit of providing information under all weather conditions, avoiding the recurrent problem of cloud cover in optical satellite images. The technology can be used for crop yield forecasting, irrigation management as well as issuing drought early warnings[79].

Thermal remote sensing deals with data acquired primarily in the thermal infrared region of the electromagnetic (EM) spectrum[80]. Thermal remote sensing may have potential applications in NER for assessing canopy temperature, evapotranspiration rate, soil texture, soil moisture and land surface temperature[81,82].

There is also a tremendous scope for using hyperspectral remote sensing tools and techniques for spectral discrimination of crops and estimation of biochemical parameters using empirical and physical models[83]. By utilizing hyperspectral remote sensing, it is possible to obtain precise estimates of physiological parameters, including growth and morphology, water content, biochemical reactions, physiological processes, etc. Response of rice genotypes to elevated carbon dioxide, temperature and nitrogen stress was studied by adopting hyperspectral remote sensing techniques. The study revealed that the red edge position of wavebands might provide a real-time crop stress detection tool, reducing the yield losses associated with these stresses[84].

UAV remote sensing for crop planning in NER

The use of UAVs has added new possibilities for very high-resolution mapping and monitoring crops at the farm level. Satellite remote sensing has several limitations in NER, viz. small and fragmented farmlands, persistent clouds during the monsoon season, mixed farming, steep hills, etc. Considering these facts, UAVs are used as an alternative for satellite remote sensing applications in agriculture. Spectral sensors in optical, microwave and thermal regions of the EM spectrum have the added advantage of studying within-field variations.

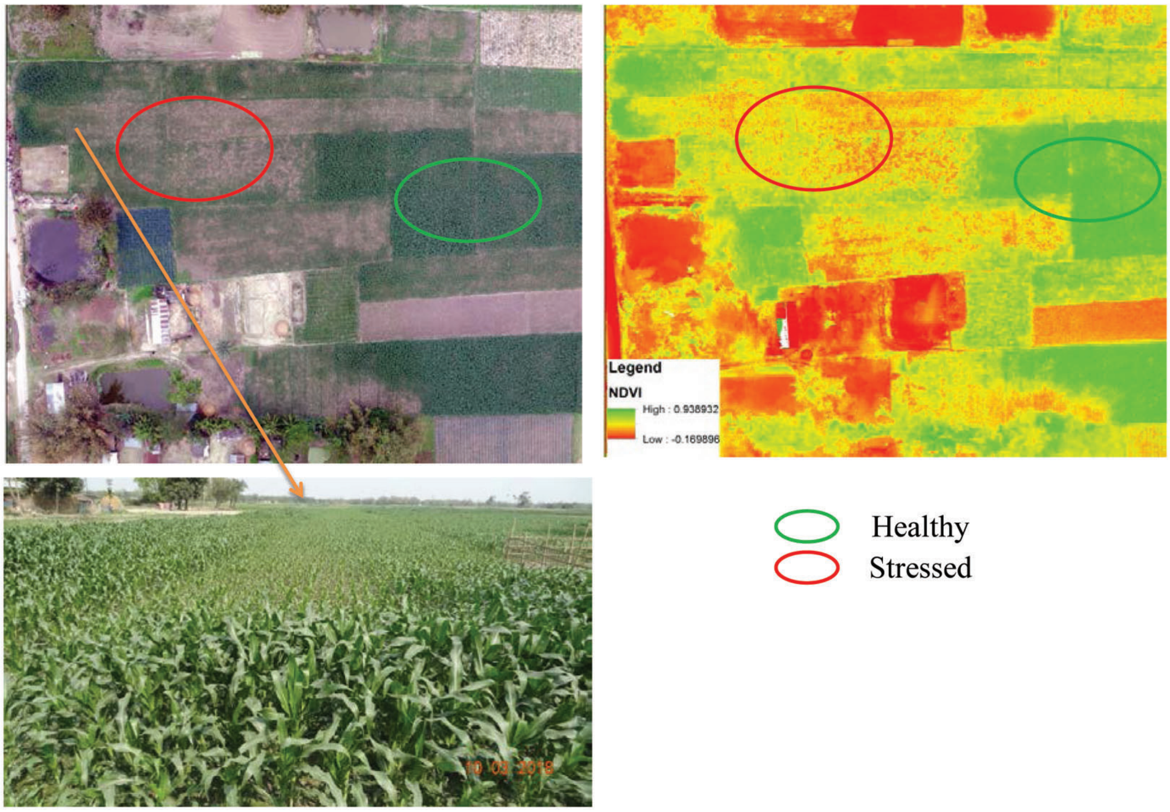

Figure 5. Maize crop condition assessment at Kharupetia, Darrang district, Assam.

Studies were carried out for crop discrimination, crop damage assessment and crop stress detection with RGB and multispectral sensors on-board UAVs. The Parrot Sequoia sensor having four bands was effective in crop discrimination and crop damage assessment at the farm level based on variation in spectral response. An analysis was carried out at Laskein development block in the West Jaintia Hills district of Meghalaya, for discrimination of horticultural crops considering the presence of multiple crops and mixed cropping in nature. Using Object-Based Image Analysis (OBIA), a hierarchical classification approach was used for delineating the target crops. With the aid of segmentation technique, one class was assigned to all pixels within a segment. Four vegetation indices were used, viz. NDVI, normalized difference red edge index (NDRE), green normalized difference vegetation index (GNDVI) and green-red vegetation index (GRVI) to discriminate different crops and other associated features[85]. Figure 5 shows the discrimination of stressed maize crops from healthy ones using NDVI in Kharupetia village of Darrang district, Assam. A study was carried out to discriminate acidity-induced abiotic stresses (toxicity of exchangeable Al and Fe and deficiency of P_2O_5) in maize crops grown in the hill agro-ecosystem of NER. The plants which were subjected to treatment with nitrogen/phosphorus deficiency showed poor NDVI compared to those subjected to balanced fertilization of NPK along with lime in the initial stages.

Constraints of remote sensing in NER (satellite and UAV remote sensing)

While the benefits outweigh the drawbacks, it is prudent to consider the limitations of satellite remote sensing before capitalizing on this technology in NER. The primary challenge is to develop tools and techniques to deal with the problems that have arisen as a result of satellite remote sensing experiments conducted over the last five decades[86].

Although satellite remote sensing provides a synoptic view of an area, limitations of freely available satellite data are also evident[87]. For instance, the 16-day Landsat revisit cycle has limited use for monitoring rapid surface changes like intraseasonal ecosystem variation and crop-growth monitoring[88,89]. Low Earth Orbit satellites offer useful sensors since the time lag is minimal. Moreover, their global coverage is around 1–3 days. Even though they can offer very high resolution (0.30 m GSD for Pléiades Neo), cost constraints have limited the utilization of such images. Geostationary satellites supply frequent daytime data; however, spatial resolution of the data is very low. Therefore, balancing resolution and coverage while maintaining an affordable price is the need of the hour.

Novel approaches like the fusion of very high-resolution satellite imagery and freely available satellite imagery of Sentinel-2 can be adopted to obtain high-resolution daily surface reflectance products for crop monitoring.

Hilly terrain, subsistence agriculture and fragmented landholdings are common in NER[3]. On the whole, the satellite remote sensing technique is a fairly expensive method of farm-level analysis and monitoring. Moreover, the acquisition of cloud-free optical images is one of the biggest challenges for this region. Cloud shadow affects the accuracy of vegetation estimates[90]. Due to the all-weather capability of microwave sensors, their utility has been demonstrated for applications that are limited because of weather conditions, such as agricultural crop monitoring. They can also provide temporal data of crop canopies at regular intervals during the cloudy monsoon period[91].

Although satellite remote sensing can provide data from very remote and inaccessible regions of NER, the final cross verification with ground (field) survey data is essential[92].

The shortage of trained workforce and expertise in RS and GIS has also hindered the extensive use of technology in crop assessment and monitoring. NESAC has played a crucial role in promoting capacity building in the field of geospatial technology in NER. The Centre has a state-of-the-art infrastructure facility for training programmes on various domains of satellite and UAV remote sensing[93]. Apart from this, there might be technical glitches like distortions in the imagery due to the relative motion of the sensor and the source, which can finally impact the output. Also, uncalibrated instruments may lead to uncalibrated remote sensing data[94].

Thermal and hyperspectral remote sensing data hold a promise to future remote sensing technology solutions for NER. Hyperspectral remote sensing data need to be specifically enhanced for spatial resolution to obtain better results. At the same time, storage and processing of large volumes of hyperspectral data have always remained a matter of concern.

In recent years, UAVs or drones have emerged as potential alternatives to traditional space-borne and airborne platforms. UAVs are competing with satellites and aircraft because of their lower initial investment, higher flexibility of flying and diversified applications. The use of drones in NER has cut down the leg work that ground surveyors had to take up[95]. With the developments of UAV technology and data analytics, it has been emphasized to refine the satellite-based estimates[96]. However, the usage of this technology has been hindered due to legal, safety and ethical concerns[97]. Some technical difficulties include requiring more flights to cover large areas, and large rotational and angular variations in the acquired imagery which limit their usage.

In addition, UAV platforms depend heavily on good weather conditions, as it is not advisable to fly drones under rainy or windy weather conditions[98]. Processing the acquired imagery also demands a powerful set-up as the volume of the acquired data can be very large.

Conclusion

Space technology can be instrumental for obtaining fast and unbiased information about crop conditions in a challenging area like NER. Giving a synoptic view, it can provide images of the whole region in a very short duration. The digital data can be harnessed for various programmes, which need information on crop type, acreage, condition assessment, etc. NESAC, since its establishment in 2000, has been proactive in using space technology in agriculture and allied areas of NER. It has a huge geospatial database (NeSDR) which can be of great value to farmers, agronomists, food manufacturers and agricultural policymakers for enhancing crop production as well as profitability. Spatial information can also help in estimating agricultural produce and thus contingency plans can be made for mitigating extreme weather and climatic conditions, which are becoming evident with time. NER has specific requirements, which can be addressed by possible space technology interventions by taking the probable challenges into consideration. Though various studies on agriculture, horticulture, sericulture, land-use suitability, shifting cultivation, groundwater, soil and plantation crops of NER have been carried out with the aid of space technologies, the scope of further research is unlimited with the tremendous growth in geospatial technologies. The unprecedented combination of temporal and spatial resolution of high-resolution satellite data will offer new opportunities for innovative solutions to fulfil specific user needs in agriculture and allied sectors in NER. The diversity and cost-effectiveness of remote-sensing solutions to monitor agricultural systems are increasing worldwide. Therefore individuals and institutions engaged in RS and GIS domain in NER should leverage these advanced technologies for a holistic development of agriculture and allied sectors in the region.

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