Geospatial Technologies for Transforming Agricultural Scenario in Assam

(APART experience)

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GOVERNMENT OF ASSAM

ARIAS Society
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Assam Rural Infrastructure and Agricultural Services Society

ASSAM AGRICULTURAL UNIVERSITY

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Introduction

The Assam Agribusiness and Rural Transformation Project (APART) is a World Bank-funded project that focuses on climate-resilient, market-led production, post-harvest management, agro-processing, and agribusiness with its effectiveness from January 17, 2018. APART is being administered and coordinated by the Assam Rural Infrastructure and Agricultural Services (ARIAS) Society. The ARIAS Society is an autonomous body of the Govt. of Assam and acts as the Project Coordination Unit (PCU) for APART. The project is adopting a value-chain and cluster approach. The Project Development Objective (PDO) of APART is to 'add value to and improve resilience of selected agriculture value-chains, focusing on smallholder farmers and agro-entrepreneurs in targeted districts of Assam'.

IRRI is providing technical assistance to the Department of Agriculture-Agricultural Technology Management Agency (DoA-ATMA) and Assam Agricultural University (AAU) for implementation of the project activities in Assam for 'Increasing productivity and profitability of small and marginal farmers in rice-based cropping systems'. Within the rice-based cropping systems, four distinct objectives were identified for achieving the targets. The first objective is focusing on strengthening seed systems and the adoption of high-yielding stress-tolerant rice varieties (STRVs) through various field demonstrations, rice varietal cafeterias, training, and awareness activities for upscaling STRV adoption. The second objective is targeting to increase the productivity, profitability and resource-use efficiencies with alternate crop establishment methods in rice-based cropping systems. Strengthening postharvest management and rice value chain is the third objective for IRRI-supported activities.

The fourth objective under IRRI supported activities of APART is developing extrapolation domain of cropping systems or identifying geographical areas by Remote Sensing (RS) and Geographic Information System (GIS) for efficient targeting of technologies in low-productivity, rice-fallows, and stress-prone areas. To achieve the primary goal of increasing the cropping intensity and improving yield of prevailing low-productivity rice-based cropping systems in Assam, geospatial technologies play an important role. Detailed characterization of present cropping pattern and resource profiles including biotic and abiotic stresses is required to understand the potential opportunities and constraints in the cropping systems.

Geospatial technology including RS which has the advantage of synoptic and repetitive spatial coverage through satellites/ aerial platforms, and GIS which can integrate this technology to create maps, statistics and spatial database is the appropriate tool for taking decisions regarding target areas to bring a significant increase in agricultural outputs in low productivity areas and enhance system productivity.

Under this objective, to efficiently target the potential areas of Assam with available technologies and to improve the cropping intensity, characterization of existing cropping systems was achieved by mapping cropping systems, cropping intensity, rice area, rice-fallow and soil moisture suitability maps using remote sensing satellite data. For characterization of existing stress-prone areas, RS technology was used to map areas inundated by flood in Assam. In addition, duration of submergence in the frequently flooded areas, was also extracted. Primary data was collected from ground surveys carried out during different cropping seasons, and secondary data were also collected from various sources for value-addition and validation of maps.

1. Geographic scenario of Assam

1.1 Location

Assam, with a geographical area of around 78,438 km^2, lies in the northeastern region of India comprising largely of the flood plain region of the Brahmaputra and Barak rivers. It is the most important economic and administrative hub of the northeastern region providing access to all other states excluding Sikkim because of its connectivity with mainland India. It is situated in south of the eastern Himalayas and comprises of three broad physical divisions: Brahmaputra valley in the north, Barak valley in the south, and the hill region in central part which is a continuation of the Shillong Plateau in the southwest and the Naga-Patkai hills in the southeast. Arunachal Pradesh lies to the north, Nagaland and Manipur in the southeast, Mizoram is in the south and Tripura and Meghalaya are in the southwest of the state. Assam shares international boundaries with Bhutan in the northwest and Bangladesh in the southwest.

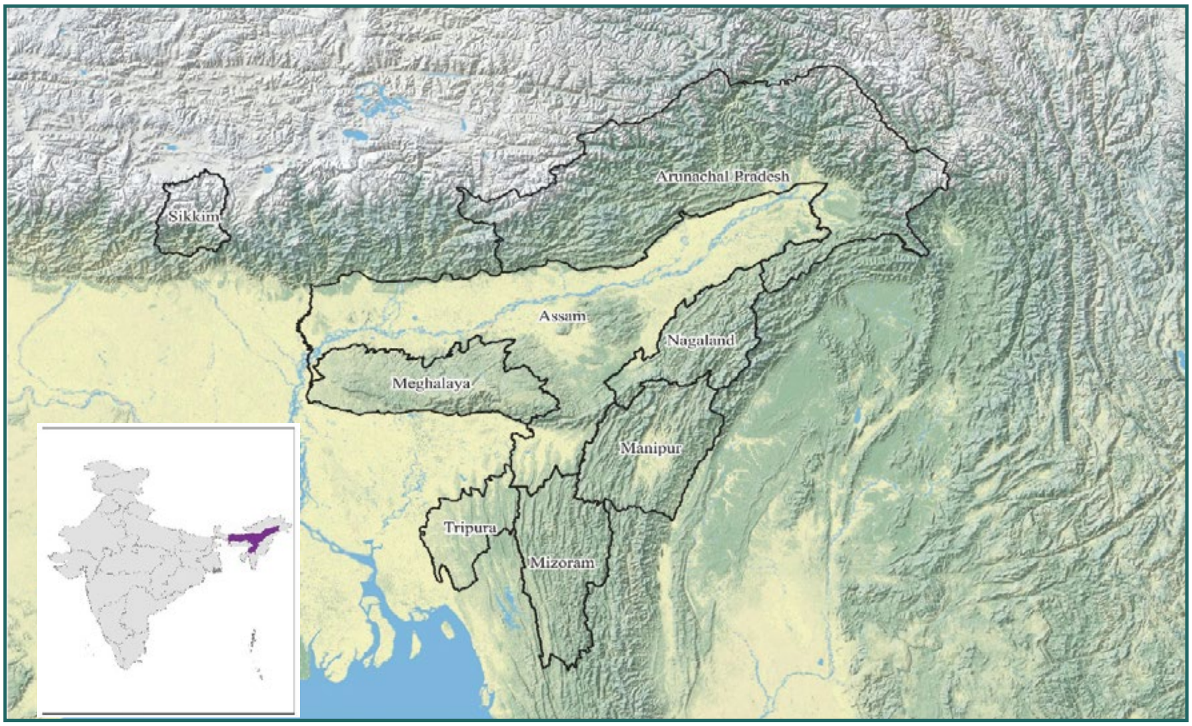

Fig.1: Location of Assam showing terrain relief

1.2 Administrative details

Assam is divided into 34 districts including Bajali district lately formed in 2021. The administrative districts are further divided into 80 sub-divisions. For revenue purpose, the districts are divided into revenue circles and *mouzas*; for the developmental projects, the districts are divided into 219 development-blocks. The local governance system is organized under 2202 *Gaon Panchayats* covering 26395 villages.

The Brahmaputra Valley consists of North Bank Plain Zone (NBPZ), Upper Brahmaputra valley Zone (UBVZ), Central Brahmaputra Valley Zone (CBVZ) and Lower Brahmaputra Valley Zone (LBVZ), the Barak Valley Zone (BVZ) mainly consists of three districts, viz. Cachar, Karimganj and Hailakandi, and the Hill Zone (HZ) consists of Karbi Anglong, West Karbi Anglong and Dima Hasao (Fig. 2).

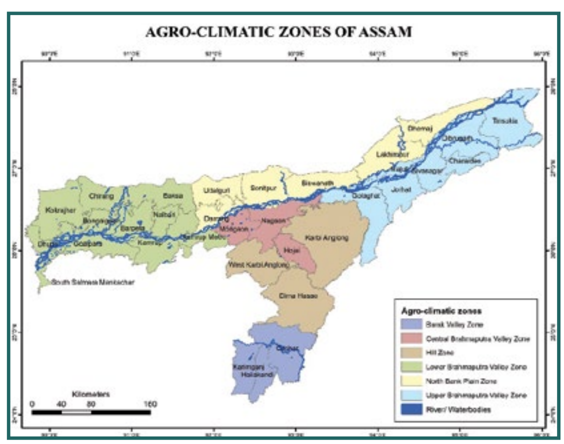

Fig. 2: Districts of Assam in different Agro-climatic zones

1.3 Climate

The climate of Assam is typically 'Tropical Monsoon Climate', with high levels of humidity and heavy rainfall. People here enjoy a moderate climate all throughout the year, with warm summers and mild winters. The temperature varies from a maximum of 35°C-38°C in summer to a minimum of 6°C-8°C in winter. Assam receives around 1500 – 2000 mm rainfall during the monsoon season (June to September) and the normal annual rainfall is around 2273 mm as estimated by IMD. The state is severely affected by floods during monsoon season causing enormous damage to the crops, livestock, land and property. Both the Brahmaputra and Barak valleys witness devastating floods every year.

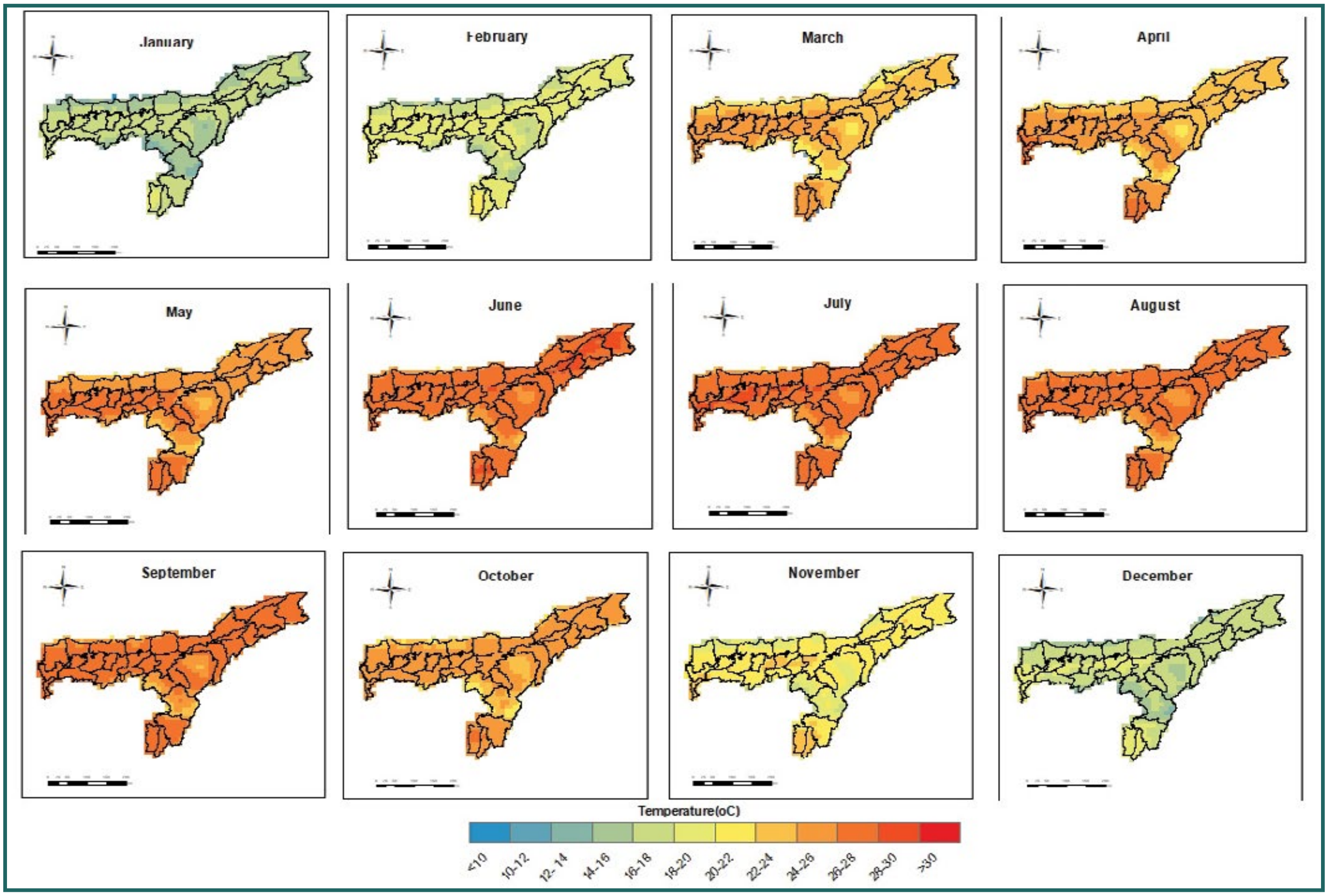

Fig. 3: Monthly average temperatures (2011-2021) for Assam (Source: ECMWF)

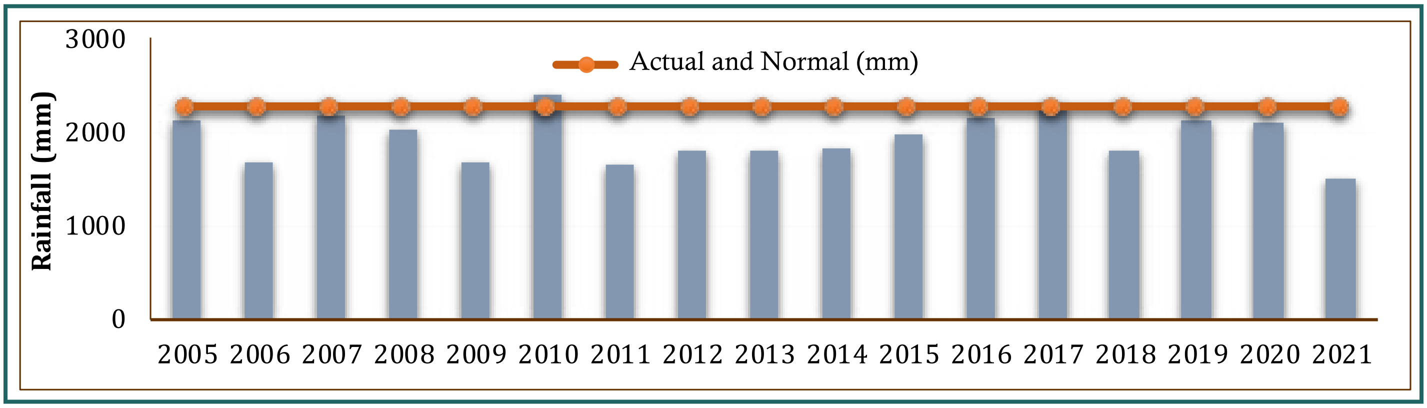

Fig. 4: Yearly rainfall trends for Assam,2005 to 2021 (Source: IMD)

1.4 Natural resources and drainage

Assam is rich in natural resources. The state is one of the richest biodiversity zones in the world and consists of tropical rainforests, deciduous forests, riverine grasslands, bamboo orchards, and numerous wetland ecosystems abundant with valuable flora and fauna. Assam has several national parks and wildlife sanctuaries, the most prominent of which are two UNESCO World Heritage sites - the Kaziranga National Park, and the Manas Wildlife Sanctuary. It also has abundant mineral resources; coal, petroleum, limestone, and natural gas are the principal mineral resources. It is also the largest producer of crude oil in India.

The soils of Assam are predominantly fertile alluvial soils of the Brahmaputra and Barak floodplains except the hill zone which is mostly covered with red soils. The Brahmaputra River runs through the entire length of the state flowing from the east to the west before entering Bangladesh. Innumerable small and large tributaries of the river flow from the north originating in the Arunachal and Bhutan Himalayas, and from the south originating in the Hill Zone of Assam or Naga-Patkai Hills crisscrossing the Brahmaputra floodplains causing devastating floods during monsoon. The major tributaries of the Brahmaputra are Aie, Manas-Beki, Jia-Bharali, Subansiri, Burhidehing and Kopili. The Barak River flows from the east towards west in the south part of the state.

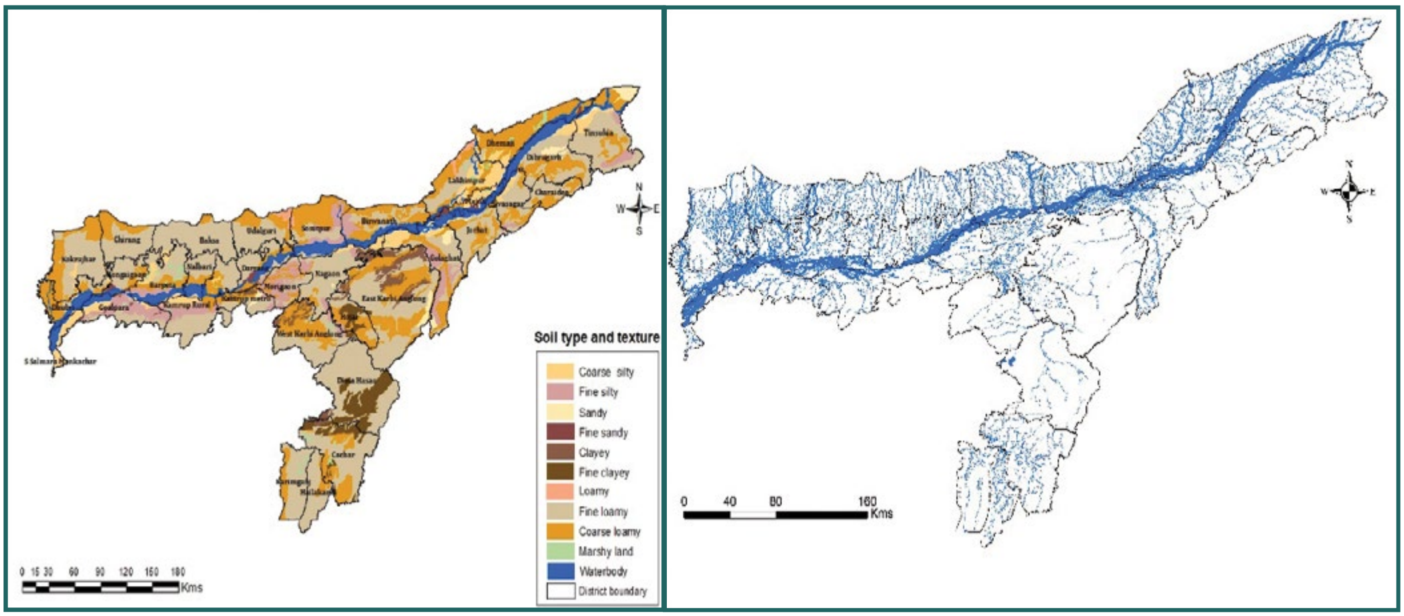

Fig. 5: Soil types of Assam based on texture and drainage map of Assam (Source: NESAC)

1.5 Land use and land cover

In the past two centuries, the impact of human activities on the land has grown remarkably, changing the entire landscape of Assam. According to the land use and land cover mapping of the state prepared using satellite images of 2015-16 by NESAC, it is estimated that around 41.4% of the total area of the state is agricultural land, 24.3% is covered by forests, and around 11% area is tree-clad which includes agricultural as well as homestead plantations (Fig. 6 & Fig. 7).

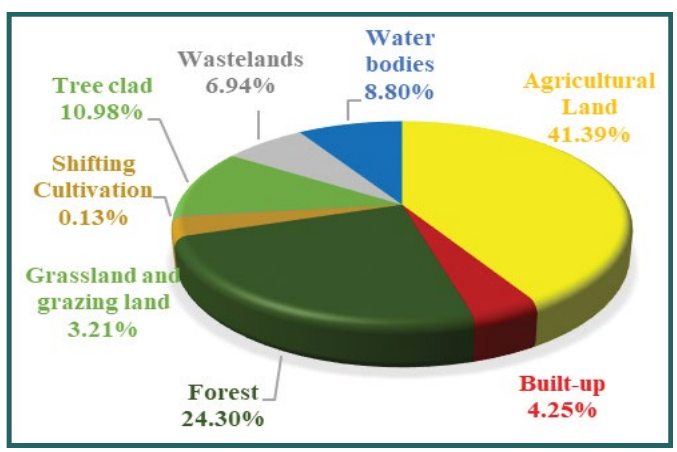

Fig. 6: Percentage area under different land use categories

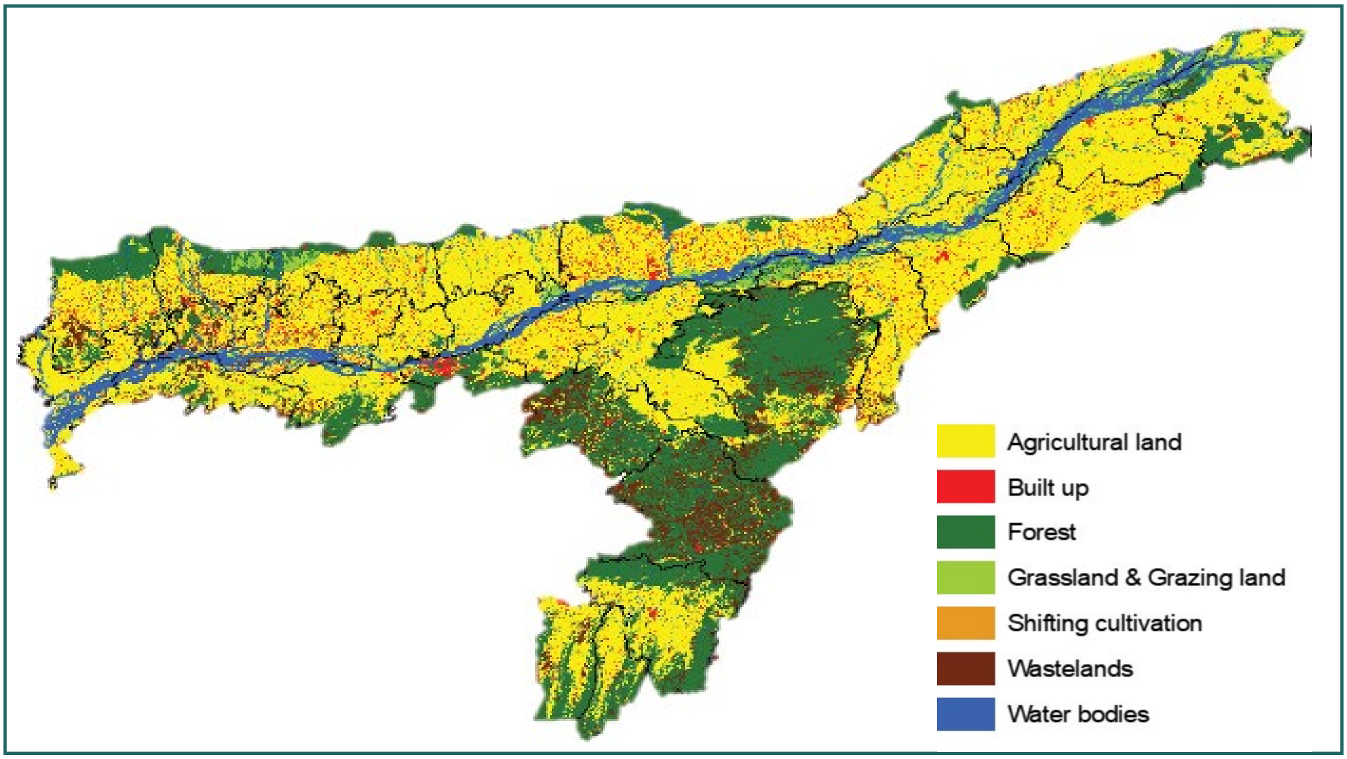

Fig. 7: Land use and land cover map of Assam (2015-16) (Source: NESAC)

1.6 Agriculture

Agriculture is the backbone of Assam's economy accounting for more than a third of Assam's income and employing about 69% of the workforce. Assam has the single largest tea growing area in the world, constituting around one-seventh of the global tea production and 50% of the country's overall tea production. Rice is one of the major field crops. Assam has an estimated 25 lakh hectares area under paddy cultivation which accounts for almost 83% of the total cultivable land of the state, and approximately 86% of small and marginal farmers of the state are engaged in rice production. In the Brahmaputra Valley, rice is largely cultivated during the *kharif* season, while other crops, such as mustard, black gram, lentil, and vegetables are the major crops grown during *rabi* season besides *boro* paddy. Apart from rice, Barak Valley practices *kharif* crops such as sugarcane, jute, cotton, maize; and *rabi* crops such as rapeseed-mustard, pulses and vegetables. In the hill districts of Karbi Anglong and Dima Hasao, jhum or shifting cultivation is practiced.

Paddy cultivation area in Assam

Rabi vegetables cultivation area in Assam

2. Introduction to geospatial technologies

Geospatial technologies include remote sensing (RS), geographical information systems (GIS) and satellite navigation systems (SNS). Geospatial technologies have the advantage of synoptic and repetitive spatial coverage of the earth's surface through satellites/ aerial platforms and analyse earth observation data to develop maps and spatial statistics.

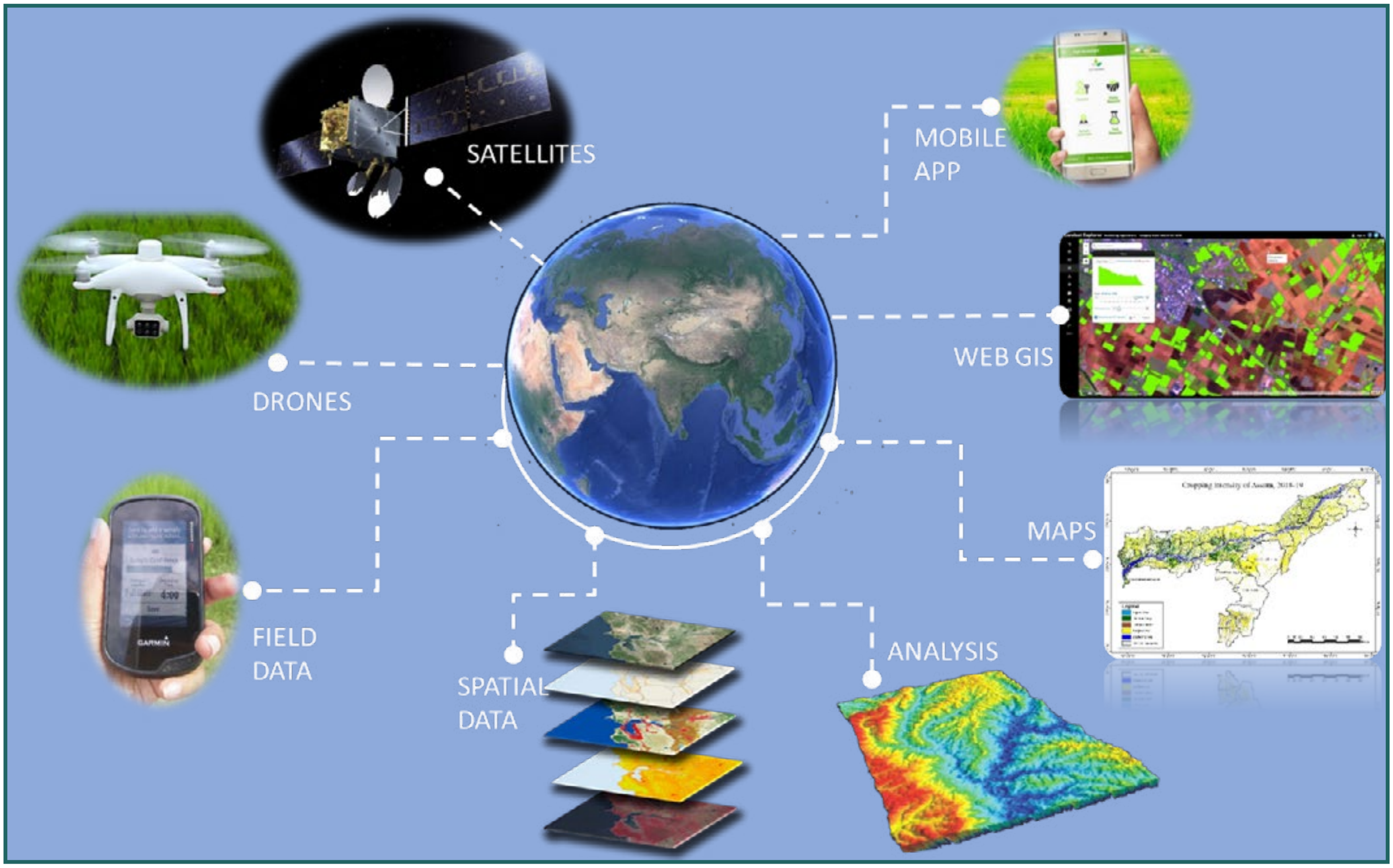

Fig. 8: Major components of geospatial technologies

2.1 Remote sensing

Remote sensing is the science of acquiring information about objects without being in contact with the object. This is done by sensing and recording reflected or emitted energy, and processing, analyzing, and applying that information. Every object on the earth's surface has a unique characteristic wavelength reflected or emitted by it which can be detected with the help of sensors that record them from a distance. Just like our eyes, there are different sensors that may be on-board different platforms (satellites/ aircrafts/ UAVs) for detection of different wavelengths of energy.

The process of remote sensing essentially comprises of different components as shown in the Fig. 9. A refers to the energy source or illumination which provides electromagnetic radiation to the target. B refers to the radiation that travels from the source to the target (C) on the earth's surface through the atmosphere. In the process, it interacts with the atmosphere which may affect the radiation that reaches the target or the sensor that records it. D refers to the sensor on a platform that collects and records the radiation scattered by or emitted from the target. E is the transmission and processing of energy recorded by the sensor, which is transmitted with the help of communication satellites, often in electronic form, to a receiving and processing station where the data are processed into an image. F refers to the processed image that can be interpreted visually or digitally to extract information about the targets.

G is the final output of the remote sensing process or the information about the targets that can be used to better understand it, reveal some new information, or assist in solving a particular problem.

Types of remote sensing

Based on the source of energy, remote sensing can be categorized into two types: passive remote sensing and active remote sensing. Remote sensing which involves measuring energy that is naturally available, like the sun's reflected and emitted radiations from the target, is called **passive remote sensing**. **Active remote sensing** is use of radiations from an energy source and detection and measurement of the reflected radiation. This has the advantage of obtaining measurements anytime, regardless of the time of day or season. Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. Examples of active remote sensor are Radio Detection and Ranging (RADAR) and Light Detection and Ranging (LIDAR).

By measuring the energy that is reflected (or emitted) by targets on the Earth's surface over a variety of different wavelengths, we can build up a spectral response for that object. This is known as the **spectral signature** of the object, as it is unique for different materials and can be used for identifying it. For example, water and vegetation may reflect somewhat similarly in the visible wavelengths but are almost always separable in the infrared. Spectral responses of three major land features – soil, vegetation and water are shown in the Fig. 10.

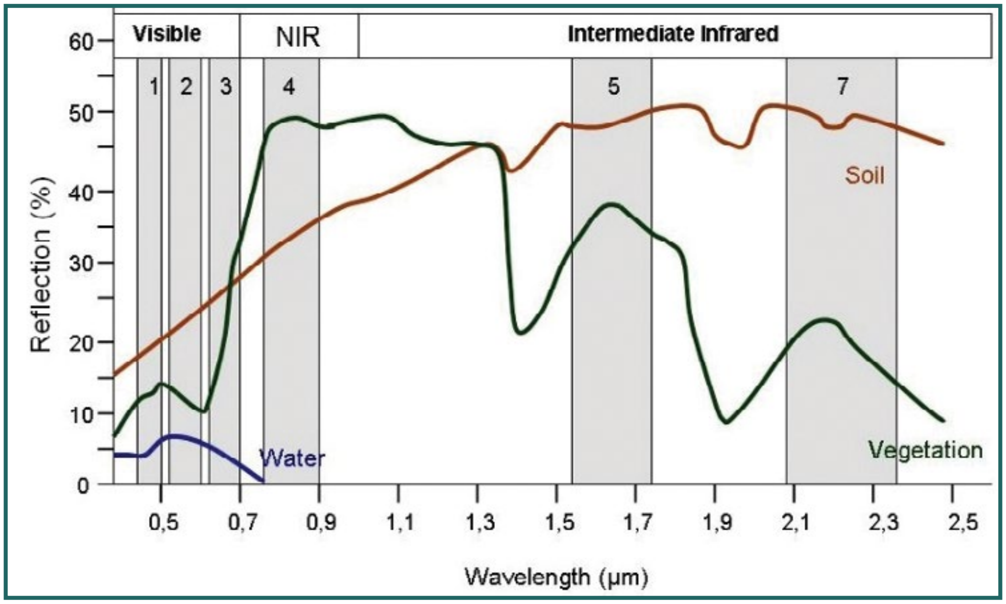

Fig. 10: Spectral signatures of land features

Remote sensing platforms and orbits

The sensors that record electromagnetic radiation are placed on stable platforms away from the target or surface being observed. Platforms for remote sensors may be situated on the ground, on an aircraft or balloon (or other platforms within the Earth's atmosphere) or on a spacecraft or satellite.

Satellites are the most common platform used for remote sensing, communication, and telemetry (location and navigation) purposes. Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis. The path followed by a satellite is referred to as its **orbit**. When a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the **swath.** Sensors record the reflected radiation or **reflectance** of the target objects or surface in an image format. Remotely sensed images are made up of reflectance values. The resulting reflectance values translate into discrete **digital numbers (DN)** which are recorded in equal-sized and shaped areas, called picture elements or **pixels.**

Image resolutions

Spatial resolution refers to the size of the smallest possible feature on the ground that can be detected. If a sensor has a spatial resolution of 20 metres and an image from that sensor is displayed at full resolution, each pixel represents an area of 20m x 20m on the ground. Spatial resolution increases when pixels become smaller (Fig. 11). Images where only large features are visible are said to have coarse or low resolution. In fine or high-resolution images, small objects can be detected.

Fig. 11: Spatial resolutions: Google earth, Sentinel-2 and Landsat 8 images of the same area in 30 cm, 10 m and 30 m resolutions, respectively

Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. It increases when number of bands increase. Remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as multi-spectral sensors. Hyperspectral sensors can detect hundreds of very narrow spectral bands throughout the visible, near infrared, and mid-infrared portions of the electromagnetic spectrum. Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands.

The **radiometric resolution** of an imaging system describes its ability to discriminate very slight differences in energy. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy. Imagery data are represented by positive digital numbers which vary from 0 to a selected power of 2. This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of power 2 (e.g. 1 bit=2^1=2). The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be 2^8=256 digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only 2^4=16 values ranging from 0 to 15 would be available (Fig. 12).

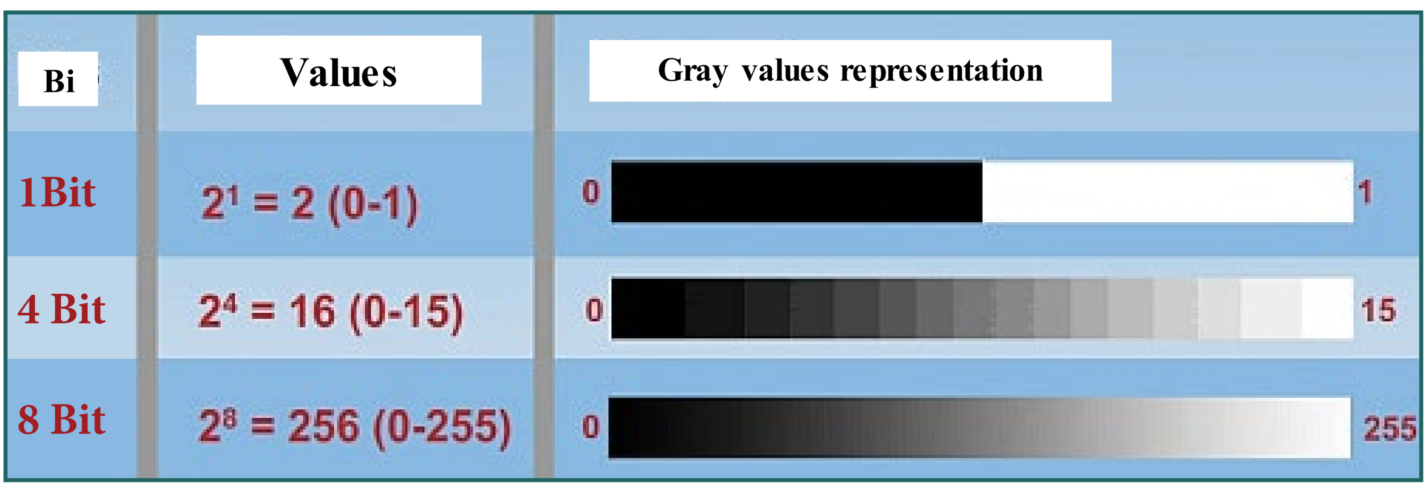

Fig. 12: Radiometric resolution

Temporal resolution is a measure of how often data are obtained for the same area (i.e., how often an area can be revisited). The temporal resolution varies from hours for some systems to about 20 days to others. The ability to collect imagery of the same area of the Earth's surface at different periods of time is one of the most important elements for applying remote sensing data. Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing multi-temporal imagery.

2.2 Geographical information systems (GIS)

GIS is defined as an integrated tool, capable of mapping, analyzing, manipulating and storing geographical data in order to provide solutions to real world problems and help in planning for the future. Burrough (1998) defined GIS as "a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes". According to Aronoff (1989), a GIS is a computer-based system that provides the following four sets of capabilities to handle geo-referenced data:

- Data capture and preparation
- Data management, including storage and maintenance
- Data manipulation and analysis
- Data presentation

Some of the major objectives of GIS are

- Maximizing the efficiency of planning and decision making
- Integrating information from multiple sources
- Facilitating complex querying and analysis
- Eliminating redundant data and minimizing duplication

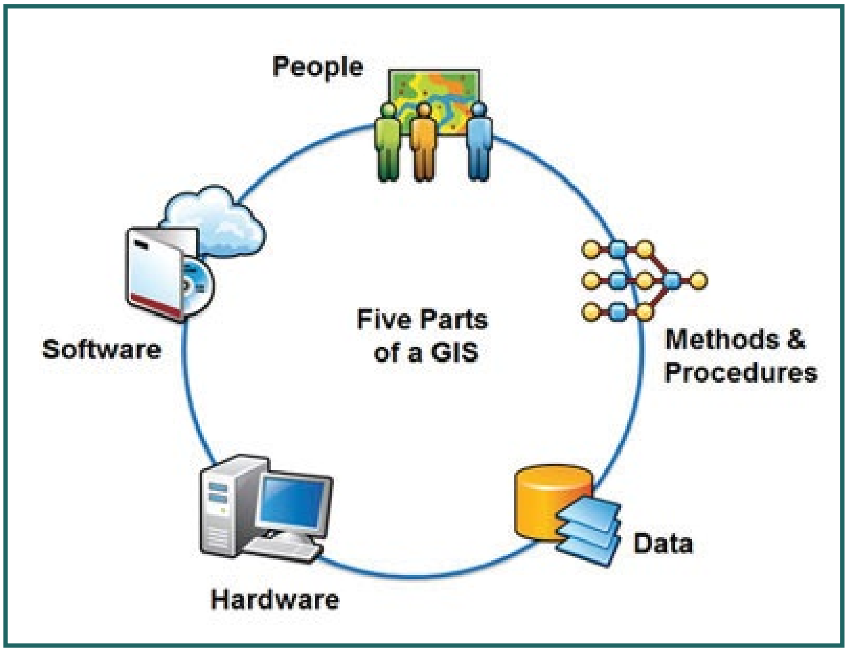

Fig. 13: Components of GIS

Components of GIS

GIS is made up of five components: hardware, software, data, methods and people (Fig. 13). Hardware consists of the equipment and support devices that are required to capture, store, process and visualize geographic information including high end workstations and servers with storage, scanners, printers, plotters etc. GIS software are specialized for working with spatial data and belong to either of the category – proprietary or open source. ArcGIS by ESRI is the most widely used proprietary GIS software. QGIS (Quantum GIS) is the most popular open-source software for GIS. Data in GIS refers to geospatial data which can be obtained from different sources such as maps, field observations, aerial photos, satellite images, etc. Methods comprise of standard procedures that need to be followed to process geospatial data. The most important component of GIS are the qualified people such as developers, GIS analysts, programmers and modelers who can use the GIS services, applications and tools.

GIS data models

All geographic data are represented and stored in GIS as geospatial data which comprises of a geometry and its associated attributes. All real-world features on the Earth's surface can be represented in GIS in two different formats associated with co-ordinates providing with its location: raster and vector (Fig. 14). Raster data are those which are composed of pixels (images), whereas vector data are composed of points which can be used to create lines and polygons. All data have a tabular data associated with it known as the attribute table.

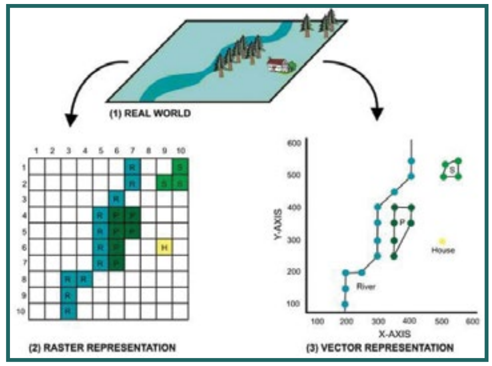

Fig. 14: GIS data models

2.3 Satellite navigation systems

Satellite navigation systems are a technology that uses multiple communication satellites to provide precise geospatial positioning. They use the concept of multi-lateration for position and time solution. Precise timing is fundamental for realizing high performance from satellite navigation systems. A typical receiver provides user position estimates accurate to a few meters by measuring the range (signal delay) between the user and multiple communication satellites. Global Navigation Satellite Systems (GNSS) is the satellite constellation used for positioning on a global scale (Fig. 15). Examples of GNSS are Global Positioning System (GPS) from USA, Galileo from European Union (EU), GLONASS from Russia, and Beidou or Compass from China. GPS is the most popular and widely used GNSS in the world for civilian purposes. The first GPS satellite was launched in 1978 and it was fully operational from 1994 onwards. A total of 24 satellites are covering the entire globe designed to have at least 4 satellites visible from any location for precise location and navigation.

Regional satellite navigation systems are also developed by a few countries for defence purposes. India has its own navigation system, the Indian Regional Navigation Satellite System (IRNSS) with an operational name of NavIC (Navigation by Indian Constellation) which covers India and a region extending 1,500 km around it, with plans for further extension (Fig. 16). There are currently 7 satellites in orbit with the first launch in 2013.

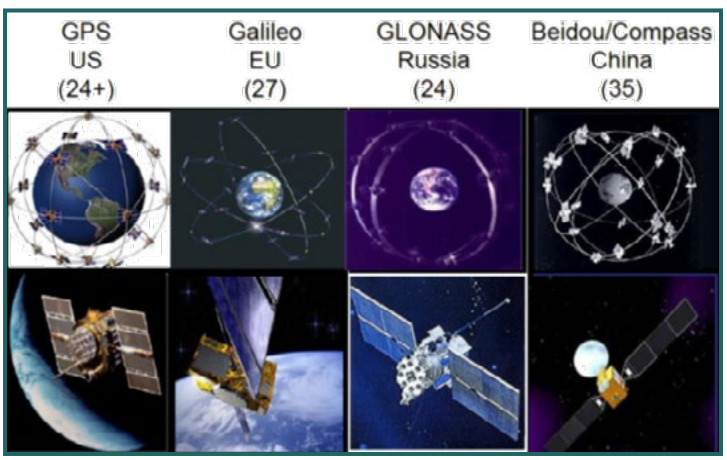

Fig. 15: Global GNSS constellations

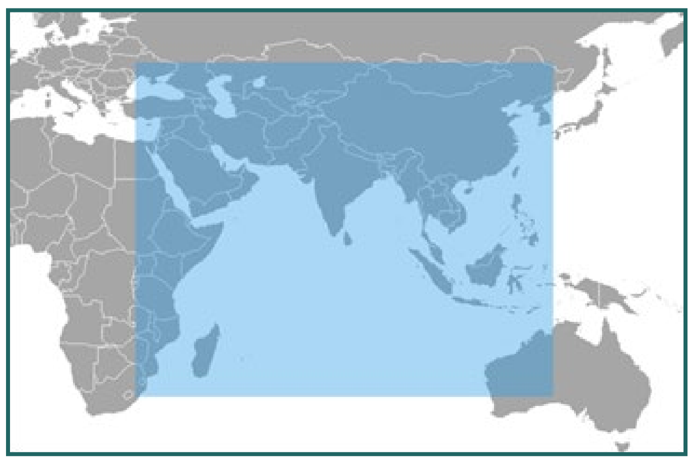

Fig. 16: NavIC coverage (300S – 500N latitudes and 300E – 1300E longitudes)

2.4 Applications of geospatial technologies in agriculture

GIS works with the concept of multiple layers to form a spatial database. Overlaying layers of data on base maps to analyze things geographically has been into existence much longer than the introduction of computers to the geographical world. The representation of geographical data in the form of maps has been done as early as 1000 B.C. in the Middle East. The earliest use of GIS during 1960s was as an area measuring tool and to produce tabular information rather than for creating maps. Since the launch of the first commercial GIS software in 1981 (ArcInfo) till the present, GIS has been widely used for a number of applications from cartography to insurance. GIS has been most commonly used for natural resource management, agriculture, disaster management, geology, urban planning, navigation, network and telecom services, and site suitability analysis.

In agriculture, GIS can be used to create more effective and efficient farming techniques. It can also be used to analyze soil data and to determine what are the best crops to plant and where? How to maintain nutrition levels to best benefit crop to be planted? It is a fully integrated and widely accepted tool for helping government agencies to manage programs that support farmers and protect the environment.

Some of the major applications of geospatial technologies in agriculture are:

- Cropping System Analysis (Derivation of cropping pattern and intensity, land utilisation and change metrics, identification of fallow areas)
- Crop suitability analysis (Crop-specific suitable areas for intensification and diversification)
- Crop phenology assessment (sowing and harvesting dates, crop duration patterns and variability across the landscape, crop growth simulation, generation of crop phenology metrics, onset of greening, photosynthetic duration, crop health, crop vigour at peak vegetative stage, maturity date, etc.)
- Mapping and monitoring environmental variables necessary for crop growth (temperature, precipitation, humidity, wind direction and speed, soil moisture, soil type, topography, etc.)
- Studies on effects of changing temperatures and precipitation regimes on crop phenology
- Yield estimates (Correlation between satellites-derived vegetation indices and crop parameters)
- Mapping agricultural stresses (Damaged area assessment after floods, drought, cyclones, hailstorms, biotic stresses, identification of stressed crop, identification of susceptible areas, forecasting and early warning)
- Digital and precision agriculture (Use of IOT sensors, drones, satellite) derived data, using ML and AI algorithms for farm automation, near real-time farm monitoring, etc.

Fig. 17: Illustration of GIS data being used in Precision Agriculture (Source: http://www.cavalieragrow.ca/ifarm)

Usage of geospatial technology in rice-ecosystems

Farmers rely on rainfall to produce crops during the monsoon (*kharif*) season, and droughts and floods often arise as a direct consequence of variations in monsoon rainfall. The state is plagued with the uncertainty of monsoon rainfall, and remote sensing methods can be used to predict weather parameters so that appropriate management and planning can be done.

The usage of geospatial technology provides leverage to effectively monitor and map the rice growing areas. Rice being majorly a *kharif* crop is usually obscured by clouds, and therefore both radar and optical remote sensing play a major role in providing temporal details of rice areas. Remote sensing is capable of providing timely and reliable information for various purposes related to rice agricultural systems. Mapping rice areas will provide important information to planners, decision makers, and scientists on where exactly rice is cultivated, its intensities, and changes over space and time. High temporal and spectral images are capable in providing near real-time information in rice phenological analytics. Knowledge of rice plant physiology and growth stages is indispensable to the success of applications and the planning stages of remote-sensing projects. Growth stages such as start of the season, crop duration and end of the season at landscape level are very important in understanding the spatio-temporal dynamics of rice.

Optimizing rice production can be achieved through sustainable agriculture. For sustainable agriculture, identification of suitable land is one of the prime requirements. Suitable land is the function of crop requirement, land and environmental characteristics. Remote sensing with the combination of geographical information system (GIS) and other ancillary data has proven to be valuable for spatial decision support in farm management as well as identifying the site suitability for the specific crops. Distinct methods and models have been applied for land evaluation, such as Linear Combination, Simple limitation, fuzzy-logic modelling, the use of Artificial Neural Networks, and the Analytical Hierarchy Process.

Fig. 18: Use of drones for precision agriculture

3. Geospatial activities under APART

The major geospatial activity under APART was developing a geospatial database for the state from satellite data, and field observation data to achieve the primary goal of increasing the cropping intensity and improving yield of prevailing low productivity rice-based cropping systems in Assam. Satellite data and field data were used to characterize the existing cropping system of the state of Assam and to identify the major stress-prone areas. A fully equipped GIS facility was established at AAU, Jorhat with high-performance workstations and Remote Sensing (RS) and Geographical Information System (GIS) software and a team of Project Scientists, Assistant Project Scientists and Research Technicians who were trained and equipped with all the available tools and methodologies for efficiently using geospatial technologies. Stress-prone areas, cropping system, cropping intensity, rice and rice-fallow areas as well as suitable areas for crop intensification and diversification were mapped using multi-temporal satellite data. The potential areas for paddy-fish farming, paddy-potato/maize/mustard/pulse/vegetables were identified using multi-criteria evaluation tools. Atlases for the year 2018-19, 2019-20, 2020-21 and webGIS portal with all geospatial outputs have also been developed for sharing data with different stakeholders. Field-level demonstrations in suitable rice-fallow areas were carried out with black gram and maize crops. The suitable cropping system trials were conducted with potato, mustard, pea and lentil after rice harvest in selected districts. A total of 402 persons were trained on the usage of geospatial technologies through various training programs and workshops.

3.1 Mapping existing cropping systems

Substantial area of potential productive land in Assam remains fallow during the winter *(rabi*) season, after the harvest of *Sali*/monsoon (*kharif*) rice crop due to different factors, such as lack of irrigation facilities, unsuitable soil type and frequently occurring natural disasters such as floods and droughts. Increasing the productivity and profitability of these low-productive areas is a major challenge to the state. To efficiently target these potential fallows, detailed characterization of the resource profile is needed to systematically understand the potential opportunities and constraints. High-resolution satellite images were utilized to identify the rice-fallow areas and the stress-prone areas using advanced RS and GIS technologies.

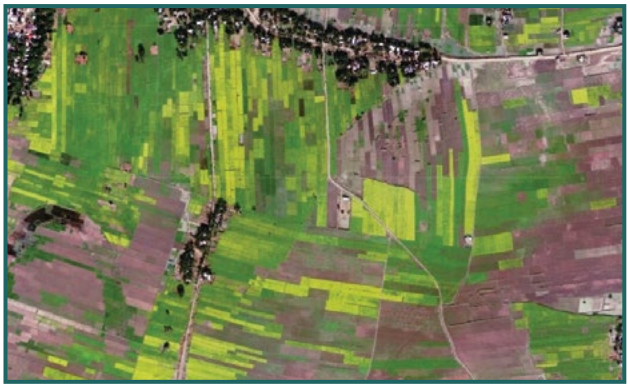


Fig. 19: Multi-spectral Landsat satellite data (NASA) and Synthetic Aperture Radar (SAR) Sentinel-1 satellite data (ESA) showing agricultural areas

3.1.1 Rice mapping

Usually, Assam gets heavy rains during the *kharif* season; hence the availability of cloud-free optical satellite images, especially during the monsoon, is rare. Therefore, Sentinel-1 Synthetic Aperture Radar (SAR) data, which have the ability to penetrate clouds, were used for the preparation of rice area maps for *kharif* season. Rice area maps for *kharif* were prepared for 2018 and 2019 by rice classification done in MAPScape-RICE software which uses specialized algorithms customized for rice area extraction. Rice area mapping for 2020 and 2021 was done using Sentinel-1 SAR images in the Google Earth Engine (GEE) platform. GEE was used to generate SAR temporal stacked images for each district of Assam from the start of paddy sowing season in June up to the harvest in November/December.

The temporal images were used to generate rice area using the random forest algorithm in R. More than 3000 field data points collected during *kharif* 2020, were used to train and validate the classified outputs. The overall accuracy of the rice map prepared for 2020-21 is approximately 87%.

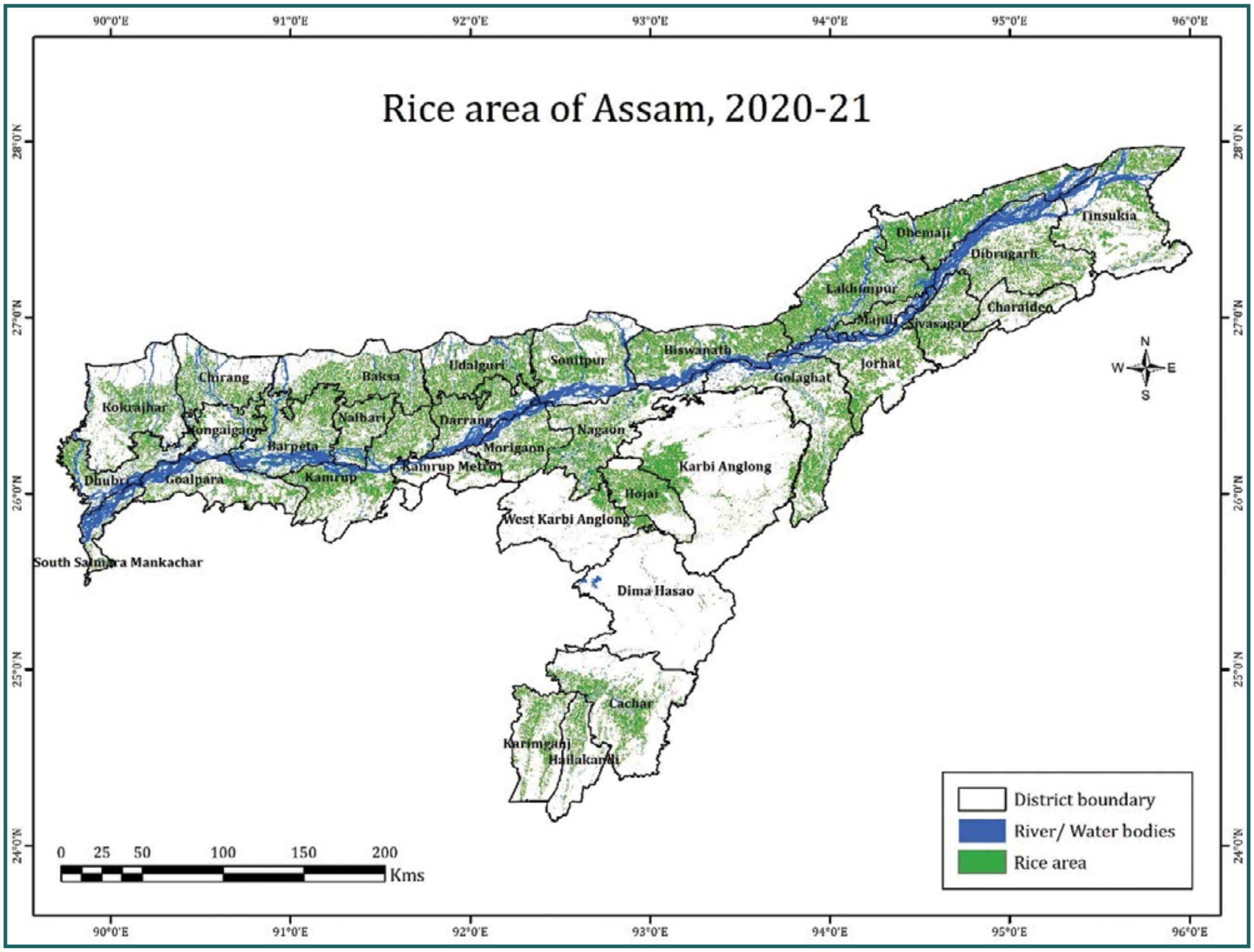

Fig. 20: Mapping of rice growing areas in Assam during kharif season

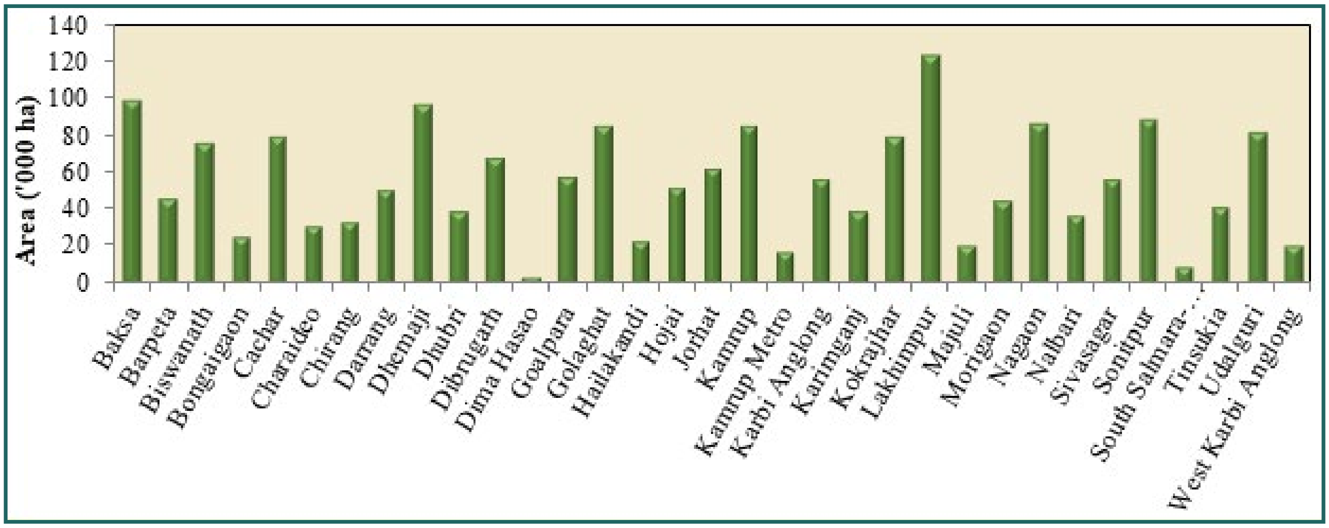

Fig. 21: District-wise rice area during kharif 2020-21

Apart from the hill districts of Dima Hasao, Karbi Anglong, and West Karbi Anglong, which have hill topography, all 30 districts practice *kharif* rice cultivation. Hence, a large area in the Brahmaputra plains stretching from the east to west of the state, and a smaller region in the Barak valley, is recognised as the high rice production zone of the state, as seen in the maps. The green colour indicates the rice area and approximately 18.3 lakh ha of agricultural land in the state is under rice cultivation during *kharif* season.

3.1.2 Cropping system/ intensity mapping

For the characterization of existing cropping systems of Assam, geospatial technologies have been used to create cropping intensity maps using time-series satellite data. A standard methodology approach has been used for processing and analysing the time-series remote sensing datasets of Optical and Microwave (SAR) imageries to identify the rice-fallow areas in Assam. Multi-temporal Landsat-8 OLI (Optical Land Imager) has been used to map the cropping system and cropping intensity. Three cropping seasons: *kharif* (June-November), *rabi* (December-February), and *zaid* (March-June) have been combined to generate the cropping system map of Assam for 2018-19, 2019-20 and 2020-21. Broadly, five cropping systems have been identified in Assam: *kharif-rabi* (double-cropped areas or the areas where the crop is sown in both *kharif* and *rabi* seasons), *kharif*-fallow (single cropped area where crop exists only in *kharif* season), fallow-*rabi* (single cropped area where crop exists only in *rabi* season), fallow-fallow (areas remains fallow in all seasons during the year) and Aqua-*Boro* (aquaculture areas with crop cultivation during *rabi* season in the same areas). Along with these, other land use/land cover classes such as water, sand bar, settlement, forest, vegetation, and barren areas were also mapped.

Cropping intensity maps were derived through reclassification of the generated cropping system maps. The agricultural classes and their patterns were extracted and combined to generate the cropping intensity map. *Kharif-rabi* was termed as a double-crop class/category; single crop consisted of *kharif*-fallow, *rabi*-fallow and Aqua-*Boro*; fallow-fallow remained as a separate class. Cropping intensity maps have been classified into three classes: single crop, double crop and fallow.

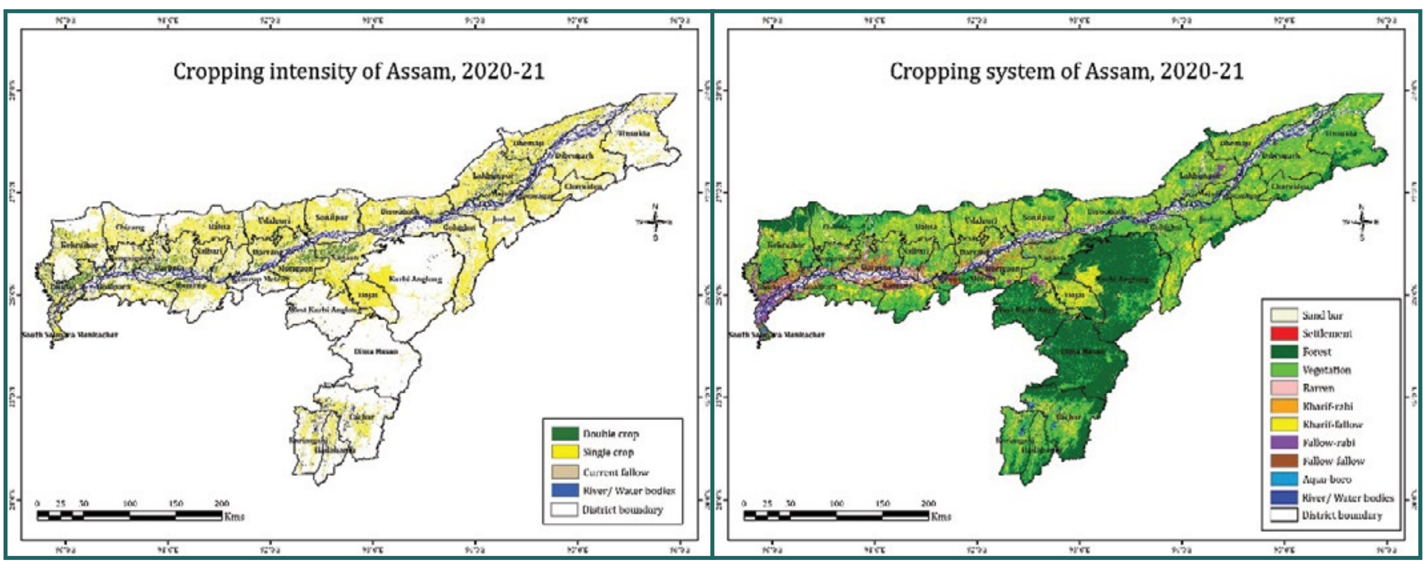

Fig. 22: Cropping system and intensity maps for Assam

Since agriculture in Assam is mainly rainfed, *kharif* crops have the highest area under cultivation, whereas *rabi* crops are observed only in 25% of the total agricultural area. Rice is the major *kharif* crop in the state, cultivated in almost all districts, while *rabi* crops are mostly cultivated in the Lower Assam districts of Barpeta, Dhubri, Nalbari, Kamrup, Morigaon and Nagaon. Single cropped area in the state is approximately 20-21 lakh ha, while double cropped area ranges between 2.6 and 2.9 lakh ha. The cropping intensity is around 110% as estimated from satellite data. This does not include triple cropped areas and areas with plantation crops, hence the cropping intensity is estimated lower than the official records.

Classification with the above methodology was able to accurately capture the broad spatial distribution of crop cycle across the state with average accuracies above 80% when validated with the collected ground truth points. Unique samples collected from random locations were further used to verify the crop cycles generated with satellite data with the crop combinations occurring on the actual ground.

3.1.3 Rice-fallow mapping

Rice-fallow maps for *rabi* season were prepared for 2018-19, 2019-20 and 2020-21 so that these areas can be targeted for increasing cropping intensity and substantially improve the food supply and enhance livelihoods of marginalized farmers of Assam. Rice-fallow area maps help in targeting the interventions for increasing cropping intensity, substantially improving the food supply and enhance livelihoods in the state of Assam. Rice-fallow maps for 2018-19, 2019-20 and 2020-21 were generated using the cropping intensity and rice area layers prepared in the same years.

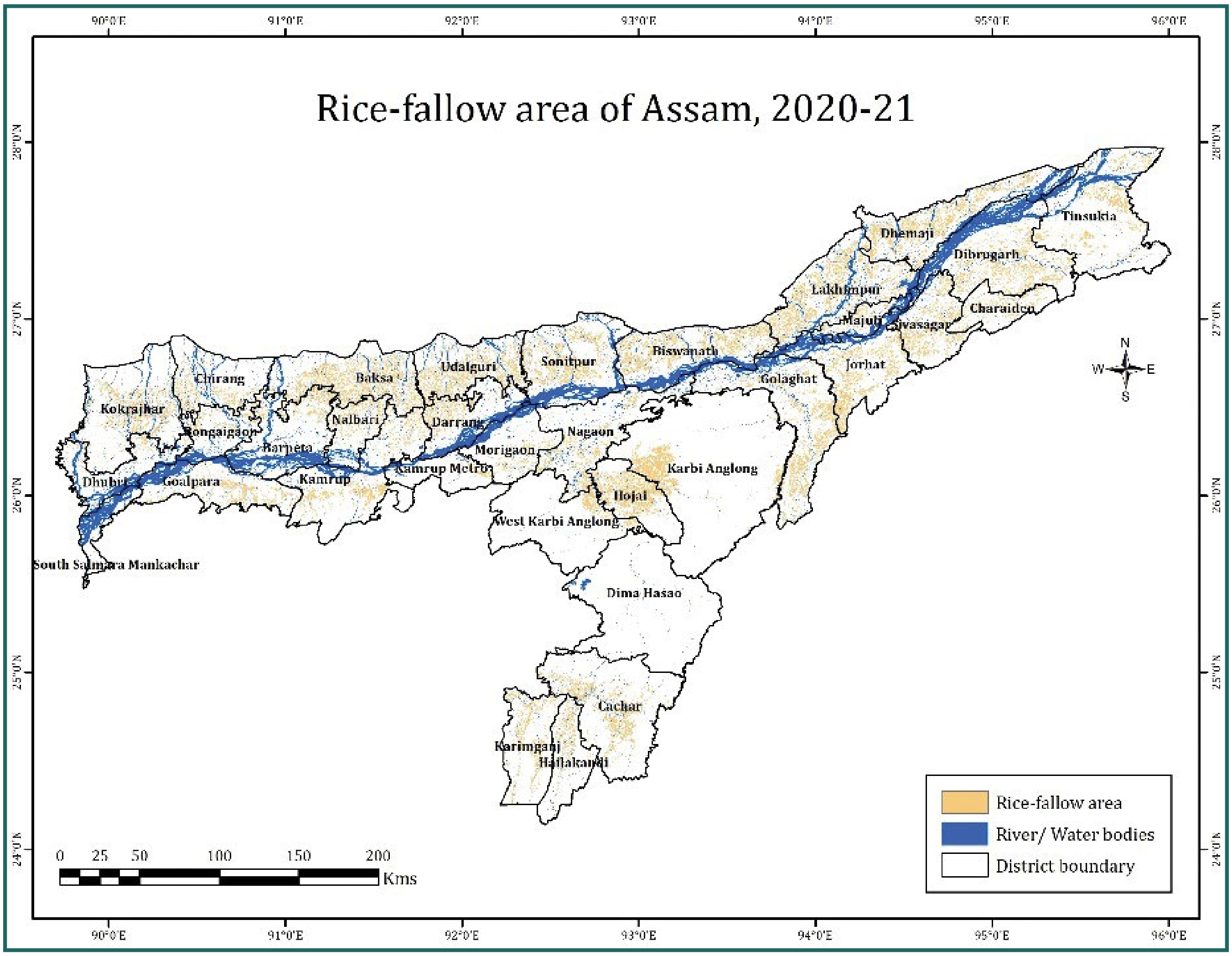

Fig. 23: Rice-fallow map for Assam

Approximately 10 lakh ha area is estimated to remain as rice-fallow during *rabi* season from this analysis. It is observed that most rice-growing areas of Upper Assam districts remain largely fallow during *rabi* season. Approximately 56% of the *kharif* rice area was estimated to be rice-fallow during *rabi* 2020-21. District-wise statistics were generated for rice and rice-fallow areas.

3.1.4 Soil-moisture suitability

Targeting of water-efficient crops (e.g., pulses) in rice-fallow areas not only helps intensify the cropping system and enhance crop diversification but also contributes to soil fertility. Evidently, the soil-moisture has high depleting rates in Assam which eventually becomes a deciding factor for the suitability of pulse or any other suitable crop cultivation, as most of the areas during the *rabi* season are not irrigated. Therefore, images have been processed to extract soil moisture availability to target potential areas for a second crop.

Residual soil moisture after rice harvest in deep alluvial soils, such that in Brahmaputra plains of Assam, are often sufficient to raise short-duration crops, such as pulses and oilseeds in rainfed cropping systems. During the *rabi* season, due to scanty and irregular rainfall over an area, the soil moisture depletes rapidly, however, depletion rates vary in accordance with multiple biophysical characteristics of the land. With time-series remote sensing data, these areas were identified to plan short-duration and high-yielding varieties (HYVs) of different crops.

Soil moisture suitability maps for rice-fallow areas in 2018-19, 2019-20 and 2020-21 were prepared to precisely target and utilize the narrow residual soil moisture window. The daily SMAP soil moisture product from November to April obtained from NASA, was analysed to get the monthly average soil moisture which was used to generate soil moisture suitability maps for Assam. The rice-fallow areas have been classified into four categories, viz., less suitable, moderately suitable, suitable and highly suitable, based on the optimum soil moisture availability from November to April.

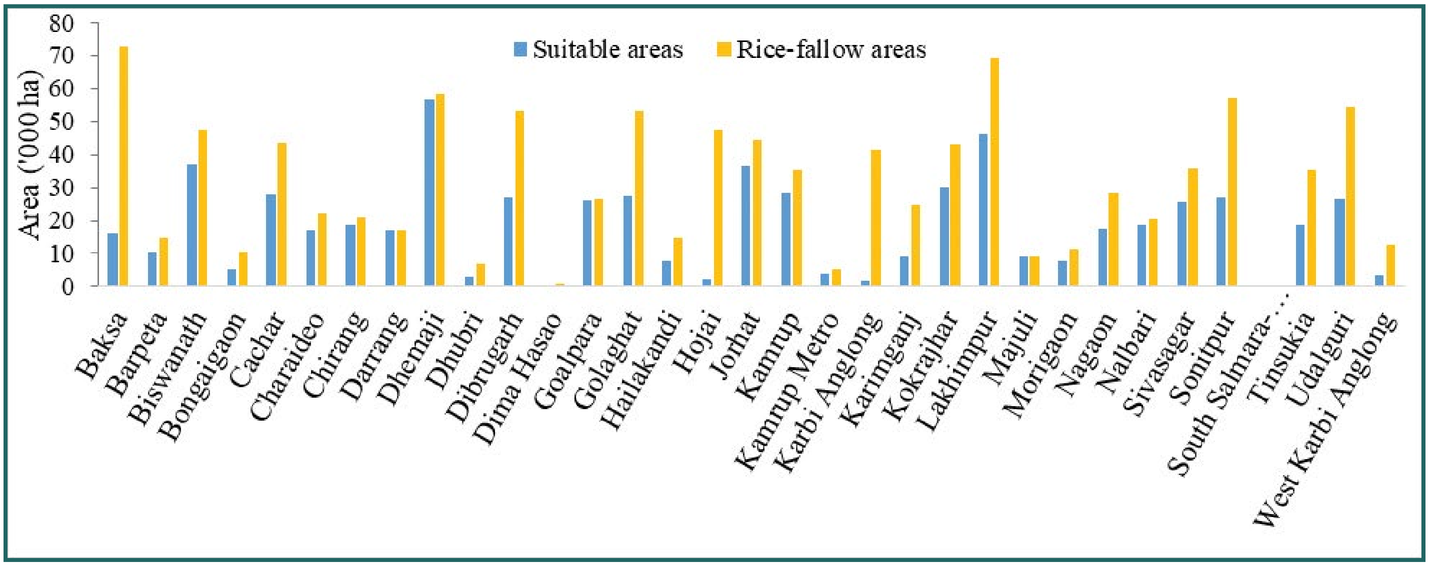

Fig. 24: District-wise rice-fallow areas during rabi 2020-21 with suitable soil moisture areas

Based on the soil moisture suitability maps, it was observed that some parts of districts like Hojai, Karbi Anglong, and lower parts of Golaghat district are prone to severe stress, thereby less suitable for even short-duration crops. While parts of districts, such as Nagaon, Morigaon, Tinsukia, Karimganj and Hailakandi, are highly suitable for short-duration crops with sufficient soil moisture available throughout the season. All other districts have rice-fallow areas under moderately suitable, and suitable soil moisture categories. Based on the soil moisture suitability assessment, approximately 59% of the total rice-fallow areas in the state fall under the suitable and highly suitable categories, 27% under moderately suitable and only 14% area does not have sufficient soil moisture for adopting a second crop. The districts with large area under suitable soil moisture category can be selected for intensification of cropping systems.

3.2 Mapping stress-prone areas

3.2.1 Flood mapping

Since Assam is one of the chronic flood-prone states, a detailed characterization of the flood-inundated area is required for identifying the suitable area to target submergence-tolerant rice cultivars, so that loss in rice production due to flood-submergence can be minimized. Remote sensing technology using synthetic aperture radar (SAR) data with cloud-penetration capabilities was used to map flood inundation areas over Assam during 2017-2021 for each flood event. In addition, the duration of submergence in the frequently flood-prone area was also extracted.

Assam is one of the most flood-prone states of the country, and it is common to have at least two or more flood waves in the state during the monsoon which results in loss of lives and property including heavy crop losses, affecting livelihoods every year. Delineation of flood-prone areas, and thereby identifying the areas vulnerable to such hazard, is very important for introducing the suitable flood-tolerant varieties for these low productivity zones.

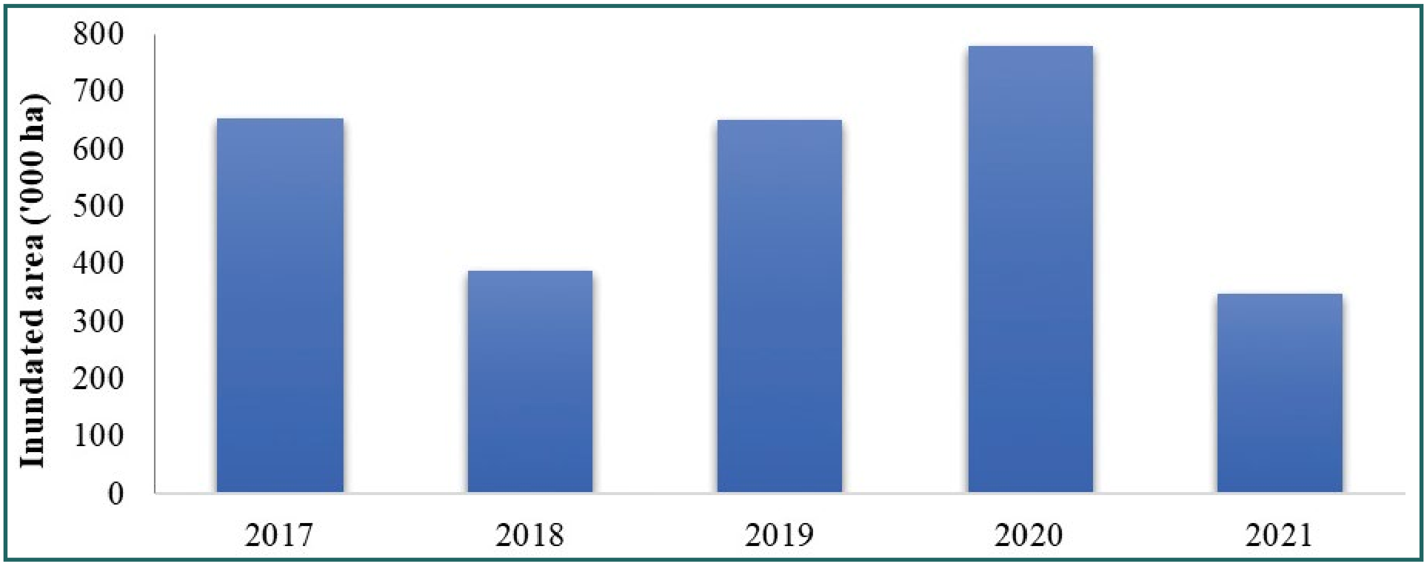

Fig. 25: Flood inundated areas during 2017-2021

Sentinel-1 SAR images were used to delineate inundated areas on occurrence of a flood event. SAR data has the advantage of cloud penetration as the entire monsoon season is heavily cloud-covered over Assam, and it is difficult to acquire an optical satellite image. Images were processed for inundation area using a flood-detection algorithm in GEE. The inundated areas were extracted and analysed for district-wise statistics, and maps were generated.

In a normal year, around 6-7 lakh ha area is inundated in the state with more than one flood events, but during the years 2018 and 2021, only one flood event occurred, with the inundated area of around 3-4 lakh ha. In the year 2020, Assam was worst affected by floods with more than 5 flood events and 7.8 lakh ha area affected, of which around 4 lakh ha was paddy cultivated area. In addition, duration of submergence in the frequently flood-prone areas, was also extracted to identify the suitable areas for targeting submergence-tolerant rice cultivars. It was observed that most of the flood inundated areas in the districts of Kamrup, Morigaon, Goalpara, Barpeta, Golaghat, Biswanath, Dhemaji, Jorhat and Cachar retain water (in >3000 ha) for more than 24 days, after the occurrence of flood.

Flood inundation layers were extracted using Sentinel-1 SAR images in Google Earth Engine for the last few years. Monthly inundation areas due to flood in the monsoon season were extracted from June to October for the last 6 years (2015-2020). The monthly inundation layers were used to estimate the annual flood inundated areas; and on the basis of these areas, the frequently flooded areas were mapped for the state of Assam. These areas can be targeted for suitable interventions and flood-tolerant rice cultivars to increase productivity and flood resilience.

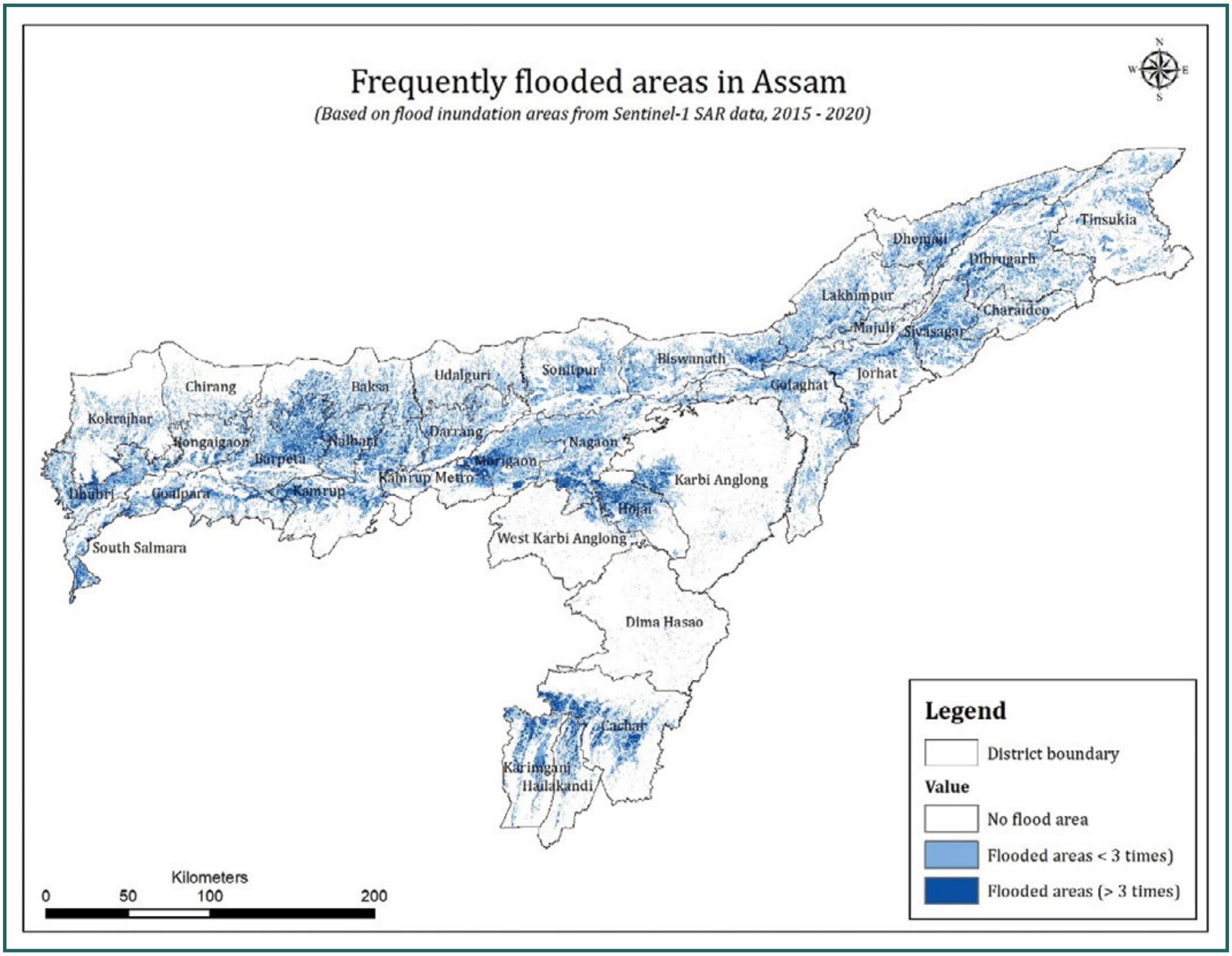

Fig. 26: Mapping of flood frequency during 2015-2020

Around 26% of the total state area was flooded during the last 6 years, of which approximately 5% (~3.8 lakh ha) area was flooded every year. Nagaon, Dibrugarh, Lakhimpur, Dhemaji, Barpeta, Kamrup and Golaghat districts have the highest areas under flood inundation (>70,000 ha), and districts of Barpeta, Kamrup, Cachar, Nagaon, Morigaon, Hojai and Dhubri have the largest areas under chronic floods (> 20,000 ha) every year.

Flood-prone areas of Assam were delineated from various outputs derived from satellite data and Digital Elevation Model (DEM) of Assam procured from NESAC. Six different criteria were selected for categorizing the entire state into different flood hazard classes using GIS. The criteria used for mapping flood-prone areas of Assam are; flood frequency (derived from flood inundation layers of last 6 years using Sentinel-1 SAR data), elevation, slope, flow accumulation (derived from DEM), land use and land cover, and proximity to waterbodies. The analysis categorizes approximately 5.18 lakh hectares as severely flood-prone and 21 lakh hectares as flood-prone. A total area of around 26.2 lakh hectares, which accounts for around 33% of the total geographical area of the state, is categorized as flood-prone in the state according to this analysis.

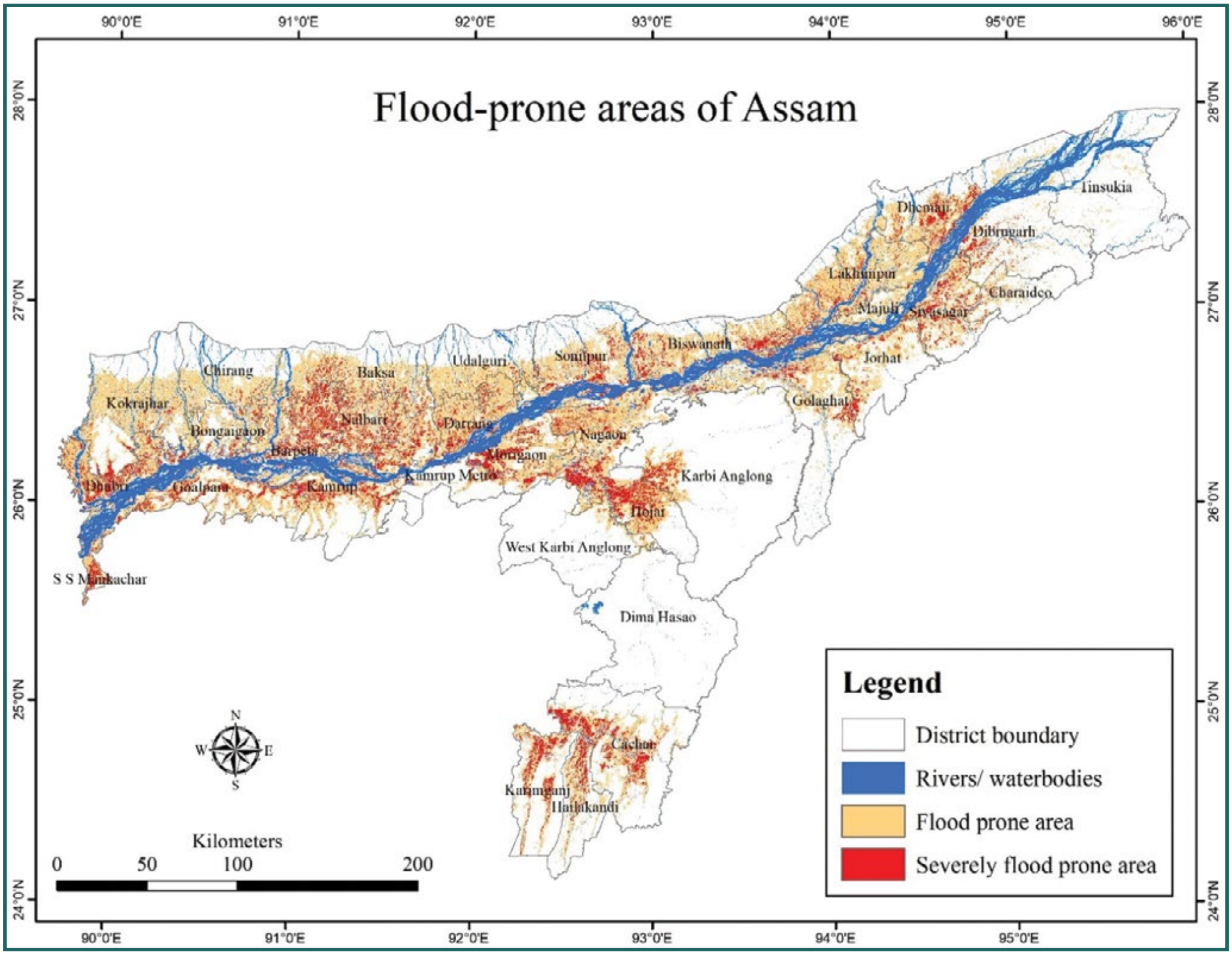

Fig. 27: Mapping of flood prone areas of Assam

3.2.2 Drought mapping

Agricultural drought basically refers to stressed and declined crop growth condition over a period of time due to shortage of precipitation, increasing surface temperature and deficit in soil moisture. A satellite-based remote sensing study was carried out to develop an integrated drought stress index based on historical satellite-measured climatic and bio-physical variables in order to identify the drought-prone areas of Assam. Subsequently, the agriculture areas with crop stress were identified with a range of severe, moderate, normal and healthy indicators. The study was carried out for 2017-18 when moderate crop stress due to drought was observed in parts of Kokrajhar, Dhubri, Sonitpur, Lakhimpur, Nagaon, Golaghat, Jorhat and Sivasagar.

Satellite images were used to identify crop stress areas during the kharif season in the last 12 years (2010-2021). Spectral vegetation indices are among the most used satellite data products for evaluation, monitoring, and measurement of vegetation cover, condition, biophysical processes, and changes. A multi-temporal analysis of satellite-based Vegetation Health Index (VHI) in GEE was done to delineate probable drought-affected areas in the state during the months of June-November. The VHI, which is a combination of the Vegetation Condition Index (VCI) and Temperature Condition Index (TCI), is used effectively for drought assessment. The VHI images were analysed and categorized into drought risk classes as high, moderate, and no risk for the agricultural areas of the state. Fig. 28 shows the drought-prone agricultural areas of Assam which can be utilized for planning suitable agricultural interventions.

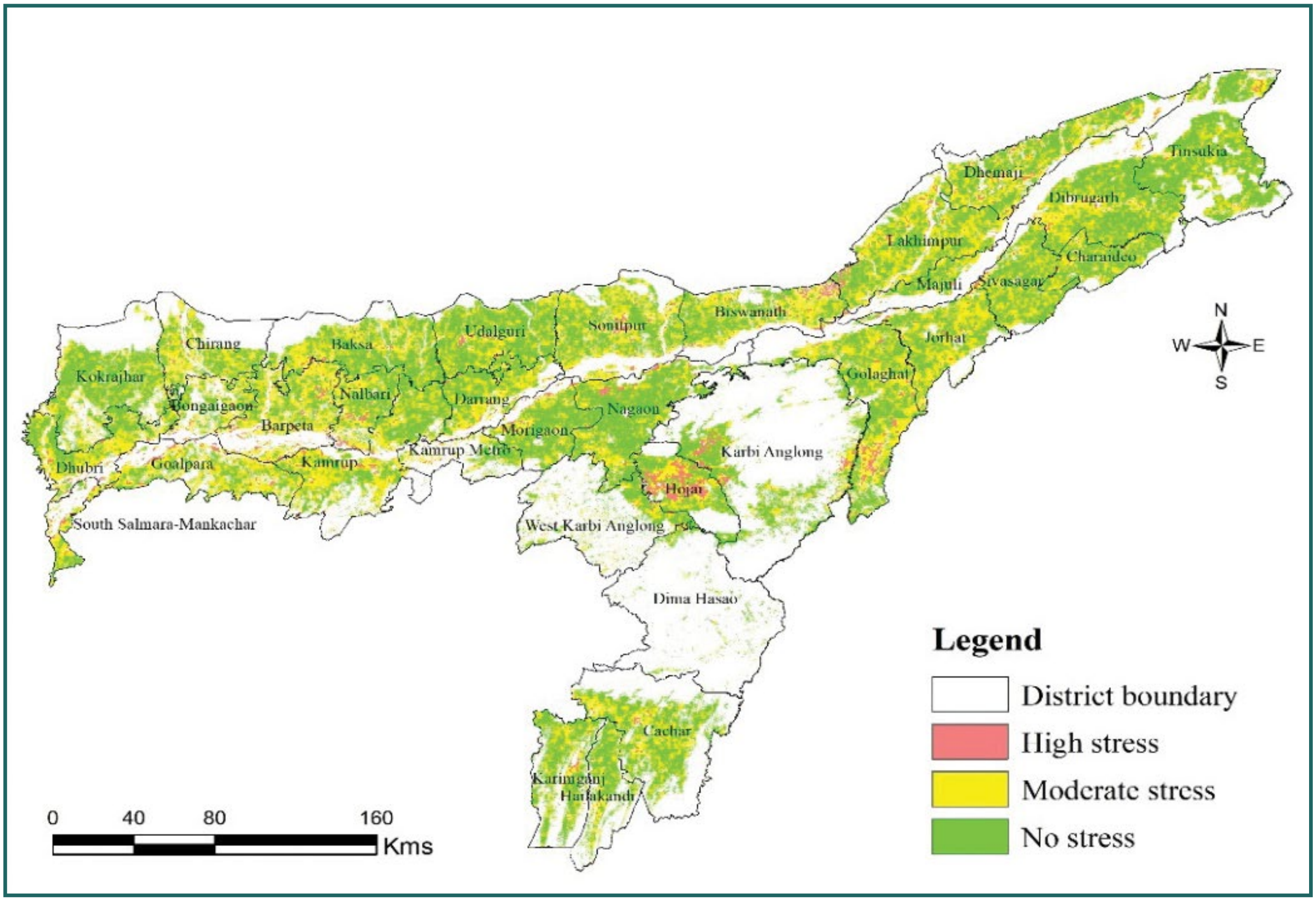

Fig. 28: Mapping of drought prone areas of Assam

3.2.3 Biotic stress mapping

Diseases naturally occur as a part of any plant ecosystem. In human-managed cropping systems, the environment created by the farmer influences disease development and impacts the natural environment. To understand the spatial distribution of insect-pest and disease infestations, information was collected from the paddy fields during 2018-19, 2019-20 and 2020-21. At a total of 2,363 locations, insect-pest and disease occurrence were recorded during different crop growth stages and this data was spatially plotted to analyse patterns and trends. The hotspots for insect-pests and disease occurrence were mapped using kernel density tool in GIS for visualizing the density of occurrence per unit area. Large areas in Morigaon, Golaghat, Nalbari, Barpeta, Kokrajhar and Dhubri are hotspots for pest and disease attack, and parts of Lakhimpur, Sonitpur, Dhemaji, Kamrup, Nagaon, Hojai, Bongaigaon, Goalpara and Cachar also have areas with high insect-pest and disease incidence in paddy.

The incidence of major insects-pests and diseases was observed in different districts of APART, which was not uniform across the agro-ecological zones of Assam. Weather/ climatic factors including temperature, rainfall, relative humidity, soil characteristics and management practices influence the level of occurrence and damage by the insect-pests and diseases. Mapping of biotic stress helps the local growers/ farmers to implement management strategies and provide an opportunity for the experts to design more targeted programs of pest management, including sustainable IPM components. The pest management interventions should be targeted in different districts according to the type of insect-pests and diseases prevalent in the area. The major insect-pests observed in different districts of Assam on the basis of field data and the district-wise damage percentage in paddy crop due to five different types of insect-pests and diseases: blast, brown spot, *gundhi* bug, leaf folder and stem borer, were mapped. The percentage of damage was calculated using the field data collected from infected areas in different districts.

Crop damage assessment due to pest attack using UAV

During *kharif* 2020, pest attack due to rice hispa was reported from few locations in Lakhimpur district of Assam. An unmanned aerial vehicle (UAV) survey was carried out at one of the locations in Khanajan Ahom gaon. The paddy varieties attacked by rice hispa were Swarna, Mahsuri, Ranjit and Biroi dhan, which were transplanted during the end of July. Survey was carried out in a total plot area of 5.6 ha during September 2020. Since the images were captured in RGB (Red, Green and Blue) spectrum, an RGB index named Visible Atmospherically Resistant Index (VARI) was estimated to extract the paddy areas damaged due to rice hispa. VARI is a vegetation index which gives an estimate of the fraction of green vegetation on ground. The entire field was categorised into healthy crop, crop with low stress, moderate stress and damaged crop areas, based on the VARI values (Fig. 29). An area of approximately 0.3 ha was estimated to be totally damaged within the plot and around 1.15 ha area was under moderate stress due to rice hispa attack.

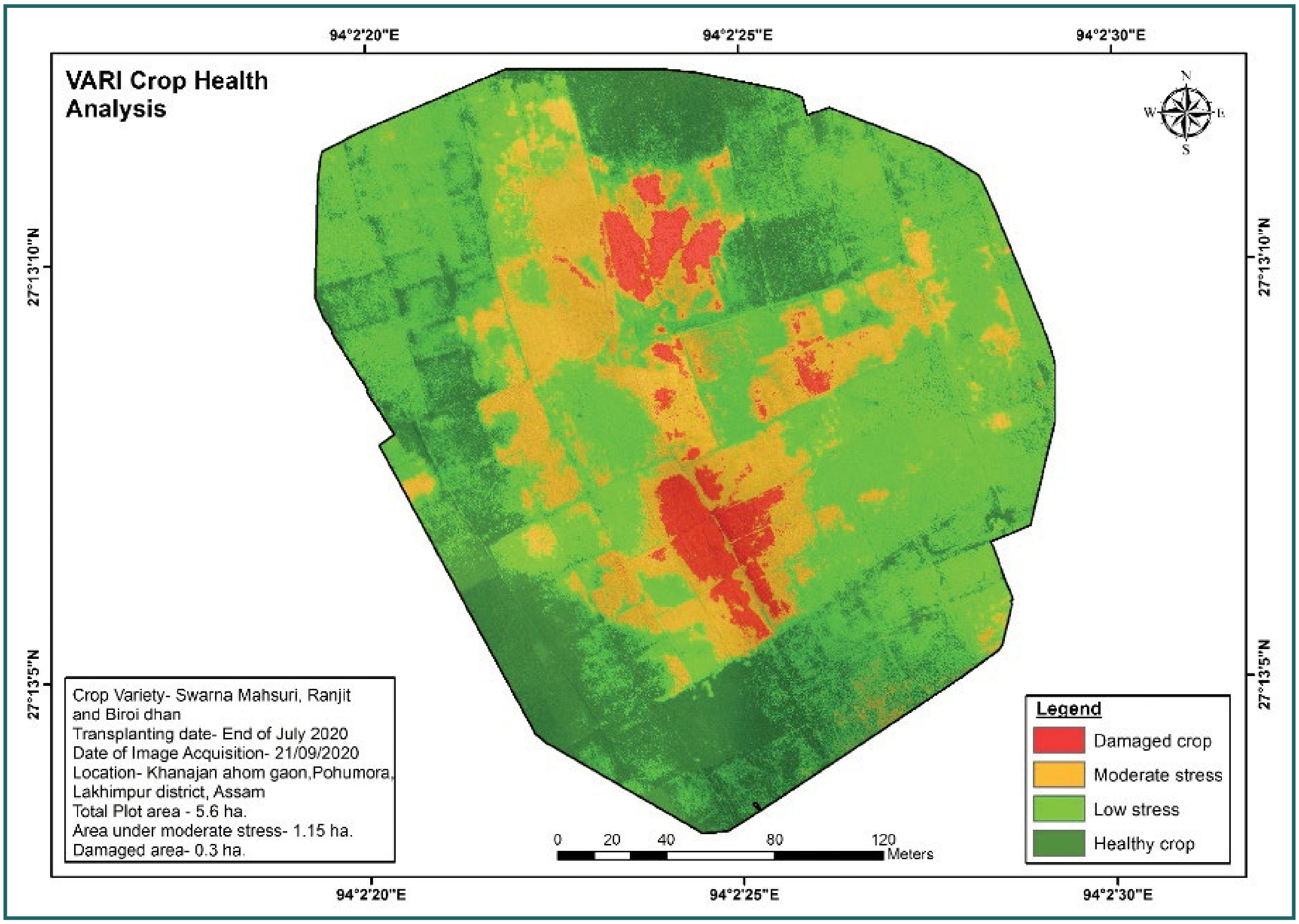

Fig. 29: Mapping of areas damaged due to biotic stress

3.3 Mapping suitability domains of different cropping systems

Extrapolation domain maps include mapping of suitable areas for system intensification/diversification specific to certain crops and efficient technologies using geospatial database were targeted during the project. A decision-tree was developed for each cropping system/technology using the decision rules developed, based on land-use requirements. Using the logical integration and geospatial modelling approach, extrapolation domain maps were prepared.

Suitability mapping of different crops require the understanding of various parameters. Remote sensing and GIS technology was used to map these parameters so that they can be used to map suitable areas for different crops. The crop suitability areas were mapped using a multi-criteria decision-based method where various parameters were incorporated in a GIS environment.

3.3.1 Paddy-fish

Mapping of potential areas for paddy-fish farming was carried out with the recommendations from WorldFish. Initially, 31 blocks in 11 districts of Assam were selected for paddy-fish farming, and maps for each of these blocks were prepared using geospatial data. Data on water bodies, roads and existing pisciculture locations procured from NESAC and paddy areas mapped from Sentinel-1 SAR data, and the perennial water bodies associated with paddy areas, were used for mapping of paddy-fish areas. Water bodies falling within 2 km buffer of roads, signifying accessibility, were considered suitable for pisciculture. Block maps for all the 31 selected blocks were prepared and shared with WorldFish and Dept. of Fisheries, Govt. of Assam. Around 7,600 ha of potential pisciculture locations were mapped in these 31 blocks of 11 districts. Field validation of the prepared maps was suggested to be carried out by the user departments and advised to plan the activities in appropriate locations.

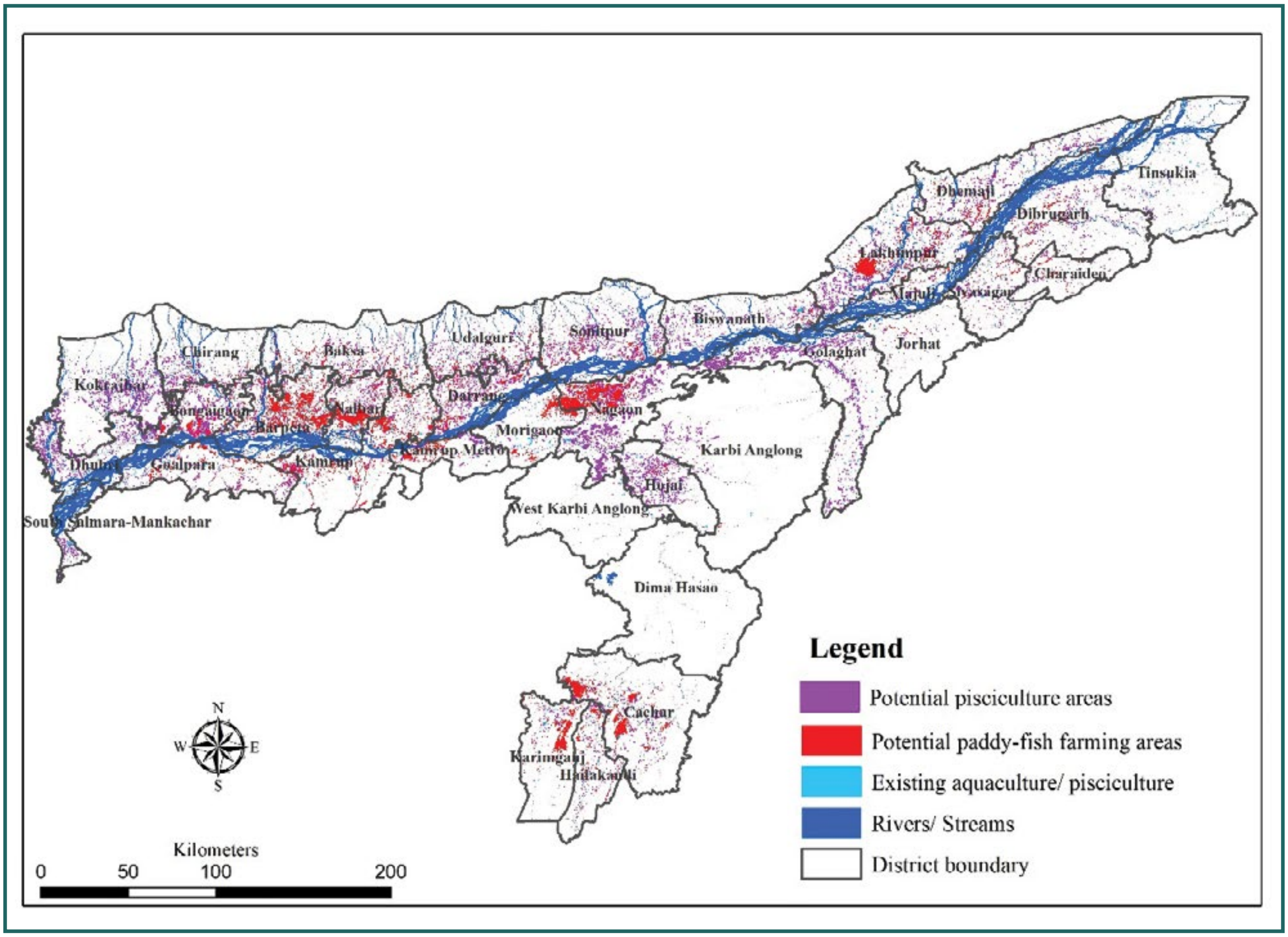

Fig. 30: Mapping of areas suitable for pisciculture and paddy-fish farming

Later on, potential sites for pisciculture were identified for the whole state based on areas that had water for more than 9 months, and at least 6 months (for paddy-fish) in a year and were subsequently used for *Boro* paddy cultivation in Assam. Cropping system maps developed under APART for 2018-19, 2019-20 and 2020-21 were utilized to extract the areas under water during the *kharif* season but utilized for paddy cultivation during the *rabi* season. An estimated area of approximately 38,000 ha has availability of water for more than 9 months and can be explored for pisciculture. Approximately 21,600 ha area in the state under water during *kharif* season, where paddy is cultivated during *rabi,* can be used as potential sites for paddy-fish farming based on these maps.

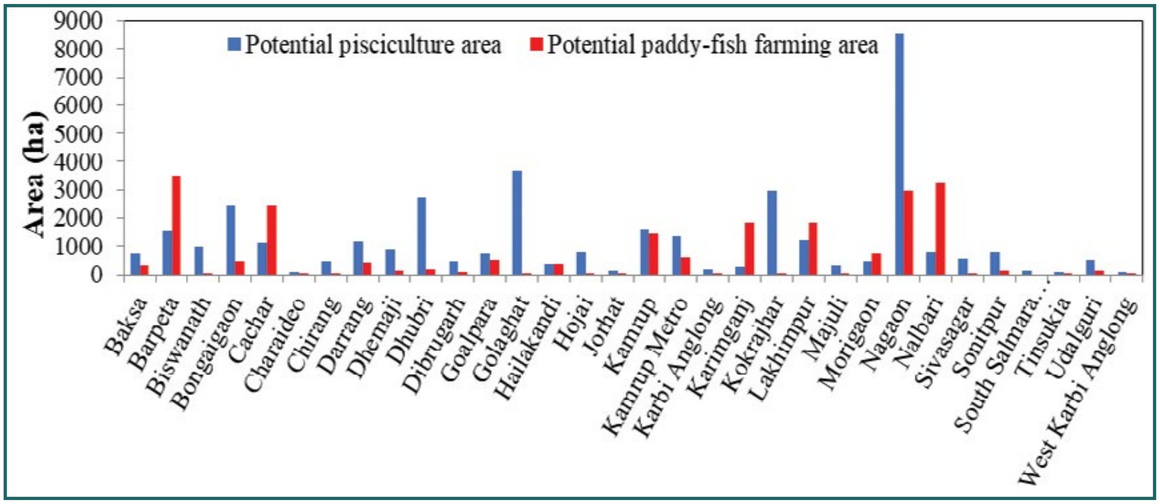

Fig. 31: District-wise areas suitable for pisciculture and paddy-fish farming

3.3.2 Paddy-potato

For mapping areas suitable for potato crop in *rabi* season after the harvest of *kharif* paddy, multi-criteria analysis was carried out in 'R' analysis software, based on different criteria for several relevant parameters. The parameters used for identifying suitable areas for potato in rice-fallow areas include sowing time, meteorological parameters such as rainfall, temperature, soil moisture, other soil characteristics, such as texture, drainage, depth, pH, CEC, organic matter content, and terrain conditions, such as slope, landform type, water stagnation status and time of rice harvesting in previous season. From this analysis, it was estimated that approximately 2.18 lakh ha area of rice-fallow is suitable for cultivation of potato in the entire state, after harvest of *kharif* season rice. Upper Assam districts of Lakhimpur, Dibrugarh, Dhemaji and Sivasagar have the highest potential areas (>15,000 ha) for potato cultivation. Considerable suitable areas (>8000 ha) are also available in districts of Sonitpur, Biswanath, Golaghat, Tinsukia, Jorhat, Charaideo, Kamrup, Karbi Anglong and Kokrajhar.

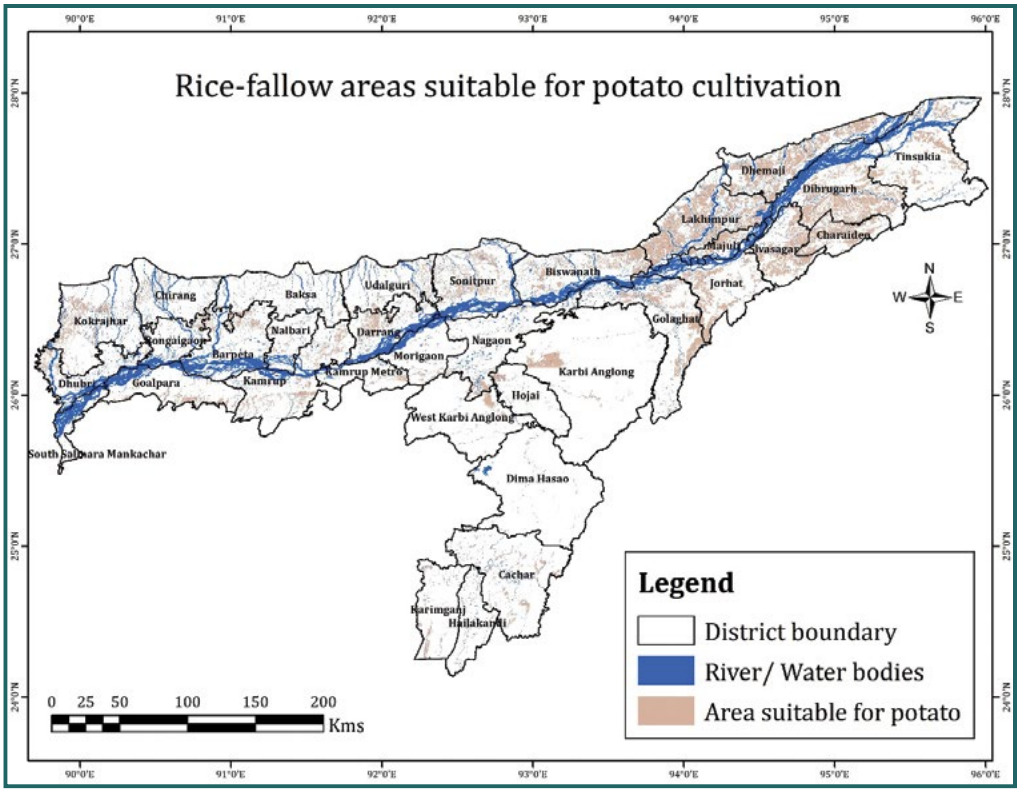

Fig. 32: Mapping of areas suitable for potato cultivation after paddy

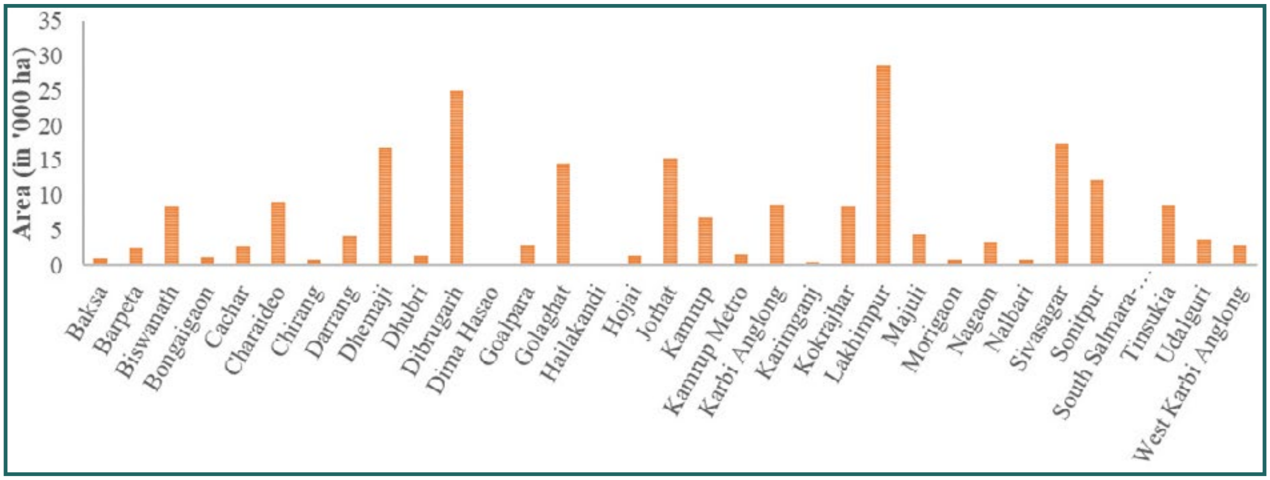

Fig. 33: District-wise areas suitable for potato cultivation after paddy

3.3.3 Paddy-mustard

Suitable criteria were selected for each of the parameters (time of sowing, rainfall, temperature, soil moisture, soil texture, drainage, depth, pH, CEC, organic matter content, and terrain conditions, such as slope, landform type, water stagnation status and time of rice harvesting in previous season) to identify potential areas for mustard cultivation after kharif paddy. Rice-fallow area of approximately 2.17 lakh ha is suitable for cultivation of mustard. The upper Assam districts of Dibrugarh, Lakhimpur, Sivasagar, Dhemaji, Jorhat, Golaghat and Sonitpur has considerable areas (>10,000 ha) identified as potential areas for mustard cultivation.

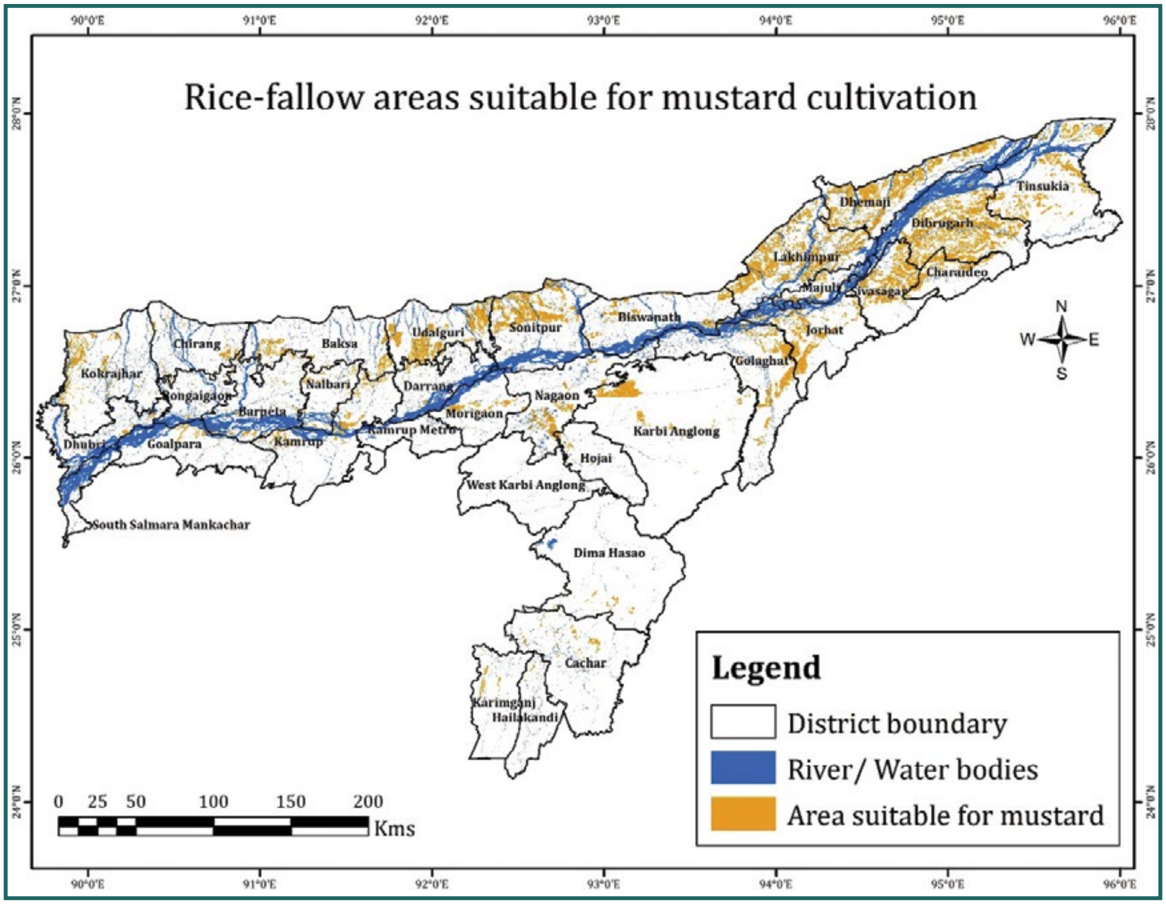

Fig. 34: Mapping of areas suitable for mustard cultivation after paddy

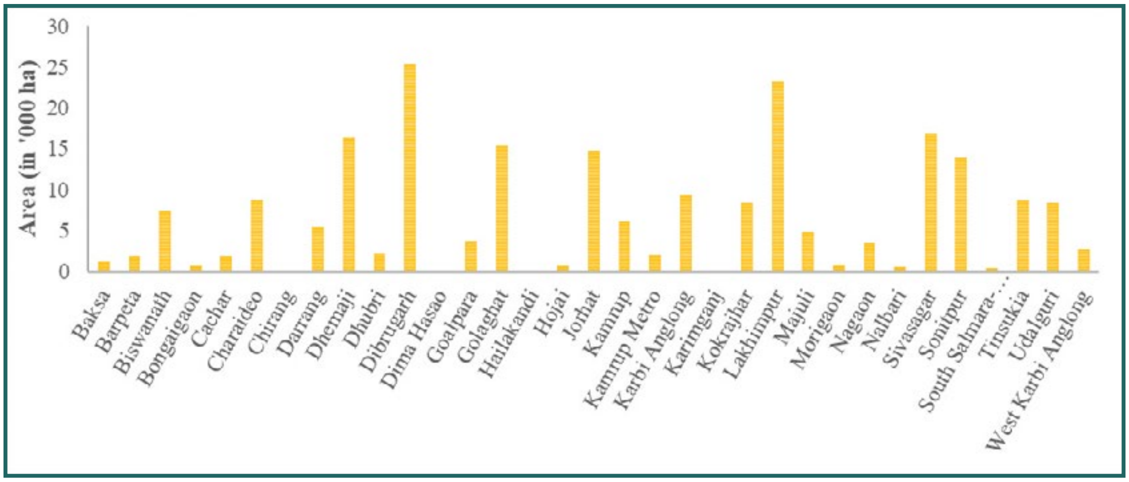

Fig. 35: District-wise areas suitable for mustard cultivation after paddy

3.3.4 Paddy-maize

Maize is cultivated in two different time periods and the potential areas for cultivating both in the state were estimated from the specified suitability criteria. *Rabi* maize (Sowing time: November-December) and Spring maize (sowing time: February-March) areas were estimated to be approximately 2 lakh ha and 3.72 lakh ha, respectively. Districts of Lakhimpur, Dibrugarh, Sivasagar, Jorhat, Dhemaji, Sonitpur, Golaghat and Karbi Anglong have the highest potential areas (>10,000 ha) for *rabi* maize, whereas Dhemaji, Lakhimpur, Dibrugarh, Sonitpur, Sivasagar, Charaideo, Tinsukia, Jorhat, Biswanath, Udalguri and Golaghat are the districts with high potential areas (>10,000 ha) for spring maize. Potential areas for spring maize are higher than *rabi* maize owing to the late harvest of long duration paddy varieties in the *kharif* season.

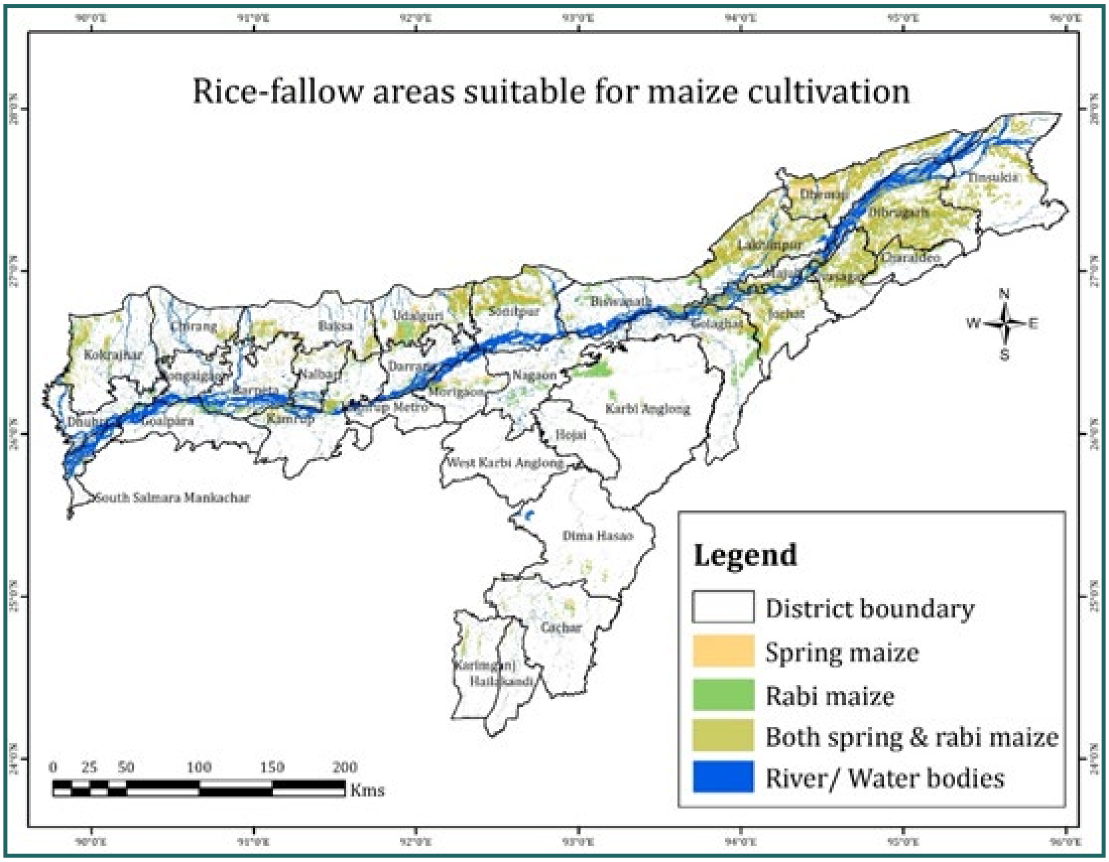

Fig. 36: Mapping of areas suitable for maize cultivation after paddy

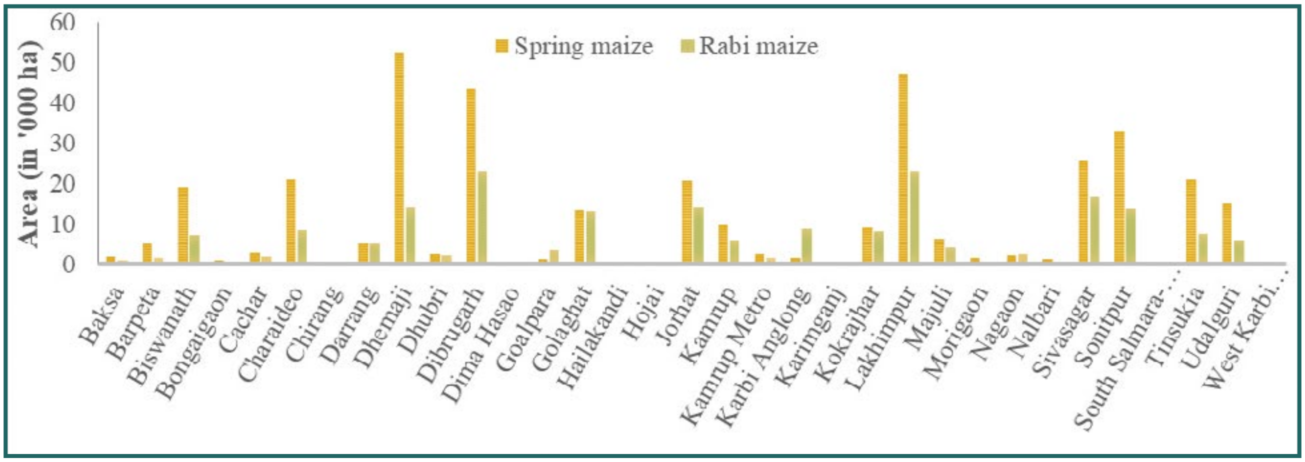

Fig. 37: District-wise areas suitable for rabi and spring maize cultivation after paddy

3.3.5 Paddy-pulses

Based on criteria selected for suitability parameters, an estimated area of approximately 3.4 lakh ha is suitable for cultivation of summer pulses after harvesting of *kharif* paddy. Dibrugarh, Lakhimpur, Dhemaji, Sonitpur, Sivasagar, Tinsukia, Charaideo, Jorhat, Biswanath, Golaghat, Kokrajhar and Udalguri have more than 10,000 ha of rice-fallow areas suitable for summer pulses.

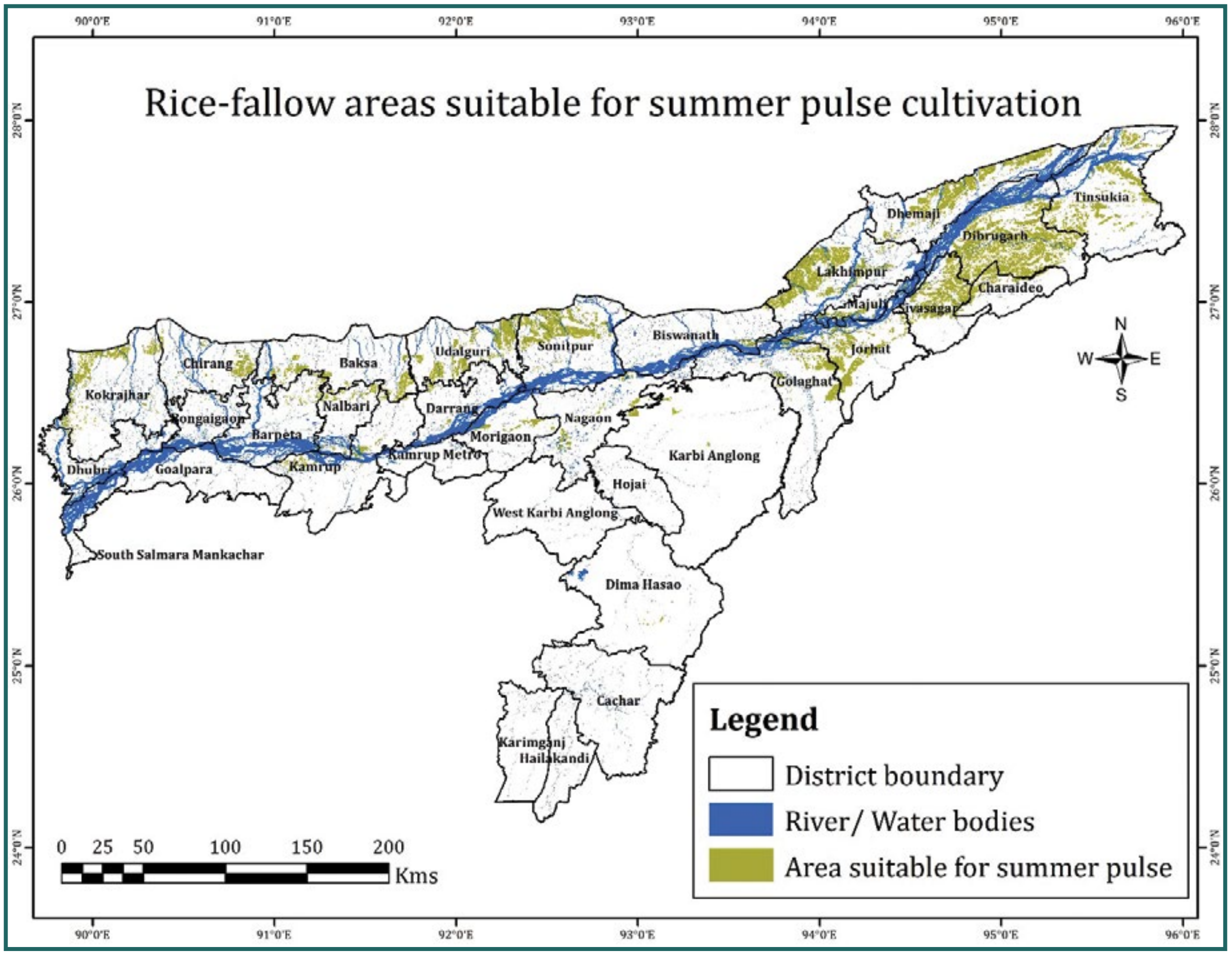

Fig. 38: Mapping of areas suitable for summer pulses cultivation after paddy

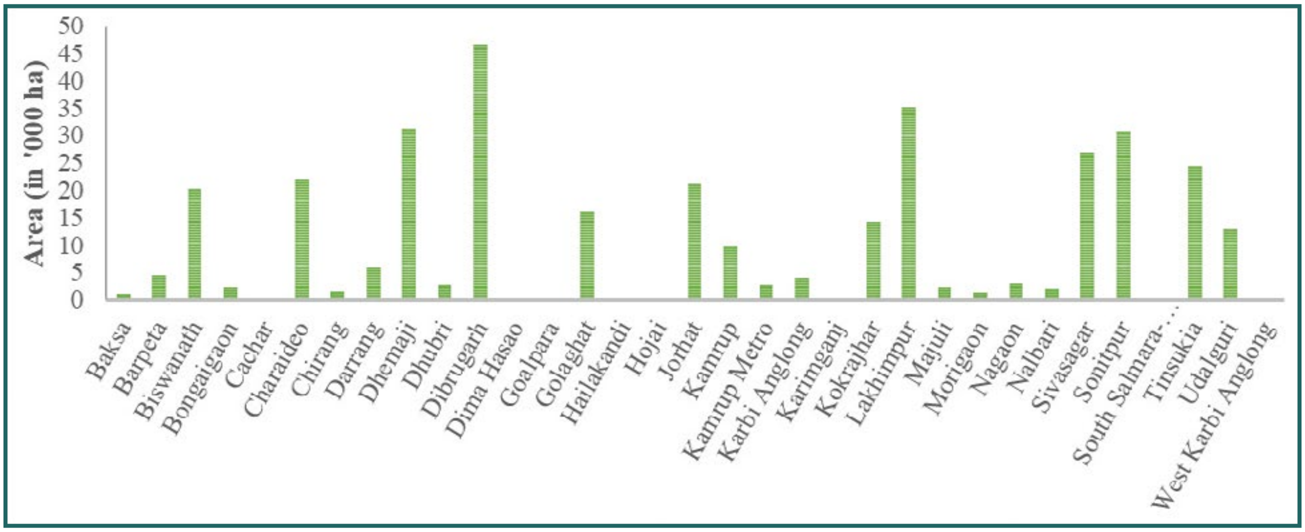

Fig. 39: District-wise areas suitable for summer pulses cultivation after paddy

3.3.6 Paddy-vegetables

Suitable criteria based on four common vegetables (cabbage, green pea, carrot and tomato) cultivated in Assam were grouped together to identify the potential rice-fallow areas for cultivation of vegetables after *kharif* paddy. An approximate area of around 2.18 lakh ha was estimated to be potential for cultivation of *rabi* vegetables. Lakhimpur, Dibrugarh, Sivasagar, Jorhat, Sonitpur, Golaghat and Kokrajhar are the districts with highest potential area (>10,000 ha) for *rabi* vegetables.

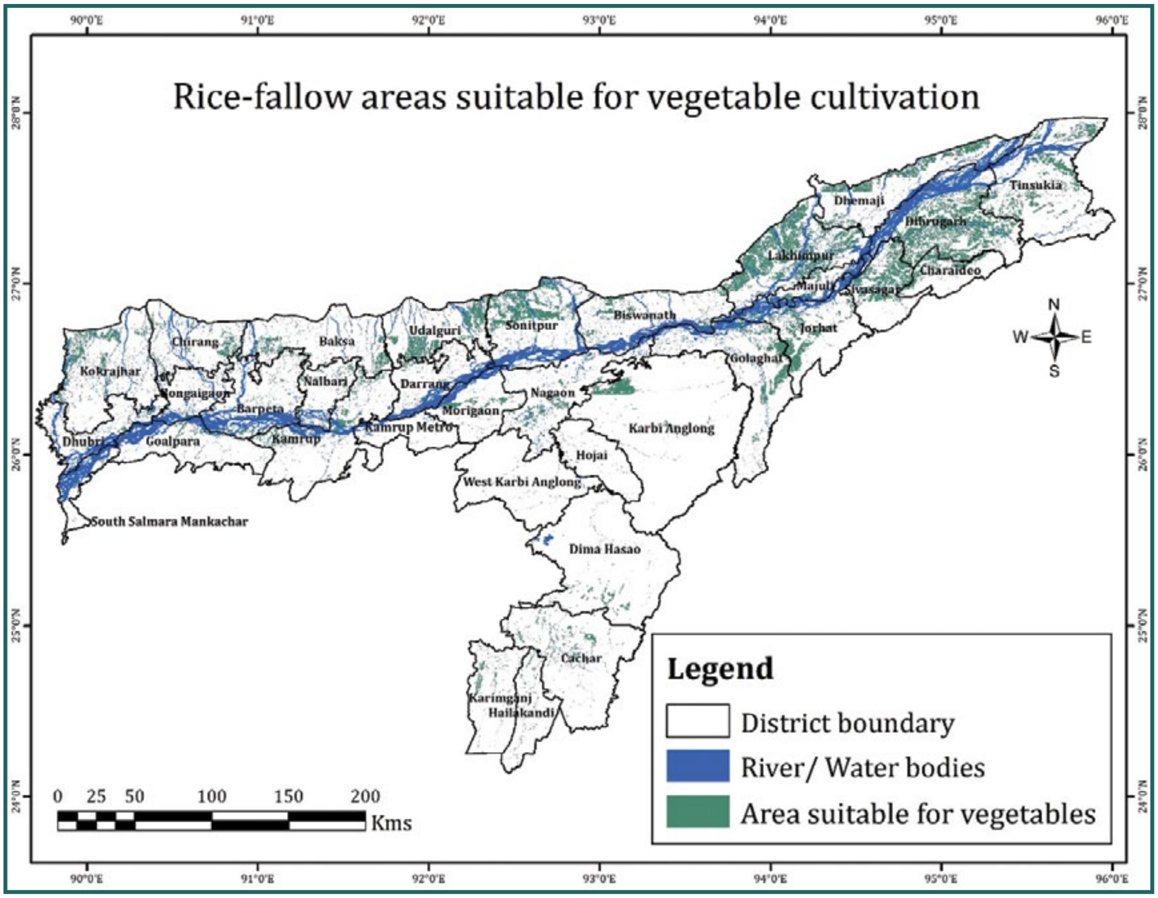

Fig. 40: Mapping of areas suitable for vegetables cultivation after paddy

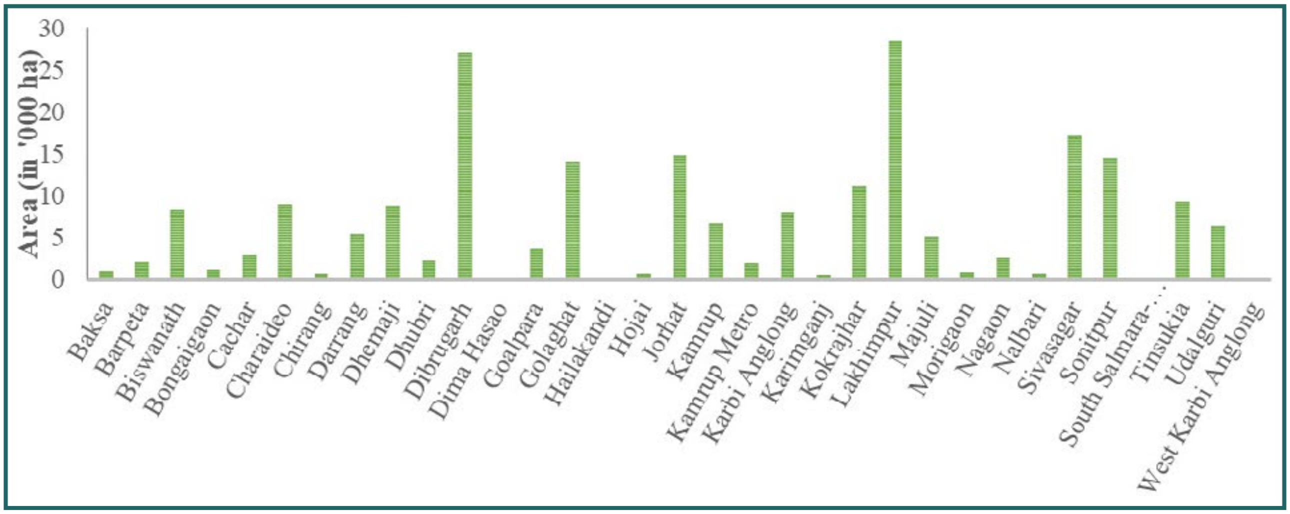

Fig. 41: District-wise areas suitable for vegetables cultivation after paddy

4. Cropping system trials

Field testing to evaluate four different innovative cropping systems: rice-potato, rice-lentil, rice-mustard and rice-green pea after harvesting the *Sali* rice crop at few representative sites of rice-fallow areas was carried out during *rabi* 2020-21 and 2021-22. Based on soil moisture availability in rice-fallow areas, the crops requiring minimum quantity of water were identified and grown in sequence at the farmers' field after rice. A total of 30.4 ha area including all four crops was put under trials in 6 districts. The crops were grown to increase the system productivity and farmers' net return, and to identify the cropping systems having highest return in the long run, which could be recommended for the adoption at large scale in the potentially suitable areas of rice-fallow. Some of the selected crops in sequence to rice were grown under conservation agriculture using zero tillage and straw mulch.

Fig. 42: Cropping system trial location in Kamrup district

The crop-cut data from all the cropping system trial sites were collected through KoboCollect and analysed to evaluate the district-wise performance of different crops, including grain yield and crop-wise net return with B:C ratio. The yield of mustard crop ranged from 0.6 t/ha in Nagaon to 1.43 t/ha in Kamrup district. The maximum grain yield for green pea was recorded 3.9 t/ha in Nagaon district and minimum of 1.06 t/ha was in Kamrup. For lentil, the grain yield ranged from 0.56 t/ha in Lakhimpur to 1.13 t/ha in Kamrup. Potato was observed to have the highest yield of 23.88 t/ha in Lakhimpur district and the lowest of 18.31 t/ha in the Golaghat district. The overall average grain yields of mustard, green pea, lentil and potato in the four districts of Assam, representing four different agro-climatic zones of the state, were 1.04, 2.18, 0.82 and 21.74 t/ha, respectively. The net profit to the farmers by growing four different crops in the rice-fallow areas ranged between Rs. 13,800 for green pea to Rs. 71,400 for potato per ha. Across districts, the benefit-cost ratio of crops varied from 1.29 for potato to 2.17 for mustard, depending on the productivity, market price and cultivation cost per hectare.

Table 1: Details of cropping system trials in specific rice environments of Assam (2020-2022)

District	Area targeted (bigha)	Beneficiaries (Number)
Lakhimpur	6.3	9
Sonitpur	2.6	2
Kamrup	6.3	5
Nagaon	6.3	14
Golaghat	6.3	16
Barpeta	2.6	2
Total	**30.4**	**48**
Number of trials: 2 in each district		

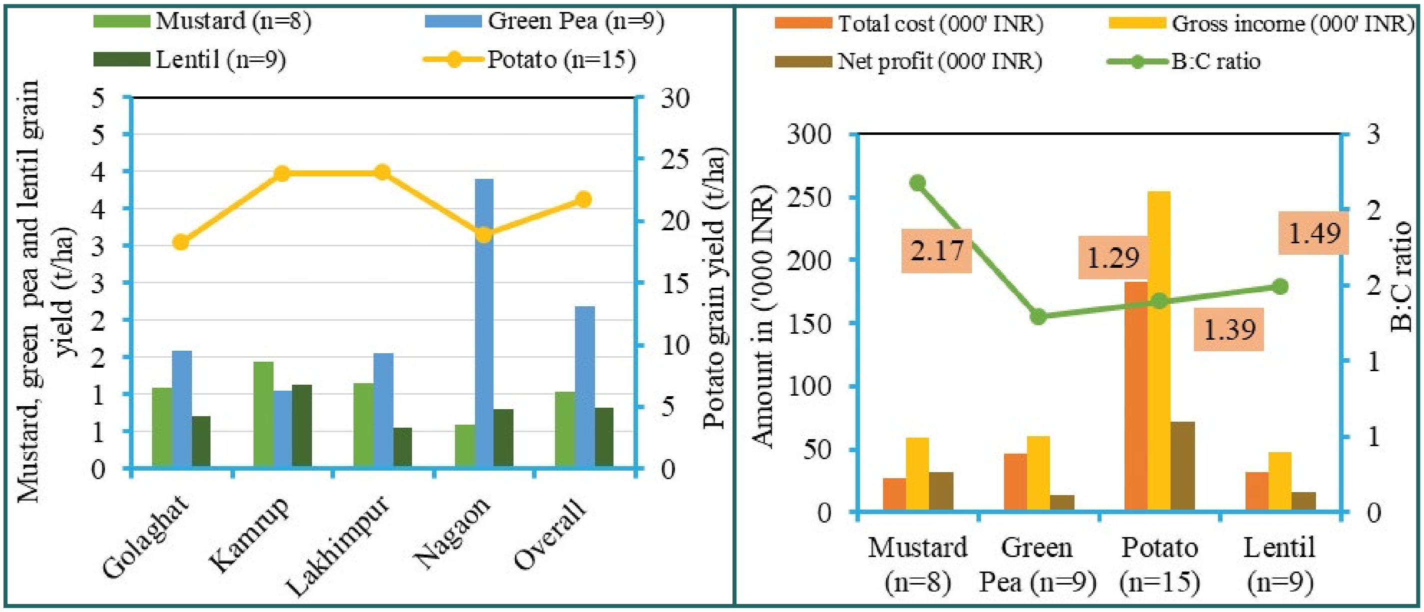

Fig. 43: Grain yield, net return and B:C ratio for cropping system demonstrations during rabi 2020-21 in different districts of Assam

Plot size: Each crop of mustard, green pea, potato and lentil had 0.33 ha; Total area per trial = 1.3 ha

5. Demonstrations in suitable rice-fallow areas

Rice is the most important crop of Assam, grown extensively throughout the state mainly in the *kharif* season. However, production on these lands does not meet the full potential as they are kept fallow in the succeeding cropping season. Utilization of these rice-fallow areas with suitable crops is essential for the upliftment of the socio-economic condition of the farmers as well as to harness the full potential of these areas. Based on the availability of soil moisture in rice-fallow areas, a total area of 100 ha in each year was chosen in few districts for pulse demonstrations during 2018-19 and 2019-2020, and for maize demonstrations during 2020-21 and 2021-22. The primary objective was to increase the cropping intensity in areas where farmers are cultivating only a single crop (paddy) during the *kharif* season. IRRI has shared the best management practices with its implementing partner organization, AAU, for conducting these demonstrations through the KVKs in selected districts. A total of 16 districts were selected in last four years for demonstrations during the *rabi* season and the details are given in the table below:

Table 2: Details of pulse and maize demonstrations in rice-fallow areas (2018-2022)

Sl. No.	District	No. of beneficiaries	Area targeted (ha)
1	Barpeta	70	31
2	Goalpara	11	11
3	Golaghat	85	50
4	Kamrup	49	33
5	Nagaon	81	61
6	Sivasagar	11	18
7	Morigaon	71	45
8	Darrang	10	10
9	Sonitpur	19	22
10	Biswanath	39	29
11	Jorhat	25	26
12	Majuli	15	20
13	Dhubri	68	25
14	Lakhimpur	8	8
15	Kokrajhar	6	6
16	Nalbari	5	5
	Total	573	400

The highest yield of black gram (0.98 t/ha) was observed in Jorhat district followed by Golaghat (0.86 t/ha) and Nagaon (0.81 t/ha) during 2019-2020 demonstrations. The overall average grain yield of black gram was 0.79 t/ha during that year. The net return to the farmers by growing black gram in the rice-fallow areas ranged between Rs 5,000 and Rs 29,000 per ha. The benefit-cost ratio also varied between the districts from 1.2 to 2.1, depending on the productivity. In the year 2020, early rains caused flood in the month of May, which damaged the pulse crop in some of the districts. The crop cut data from many fields could not be collected due to COVID-19 lockdown and restrictions on the physical movements.

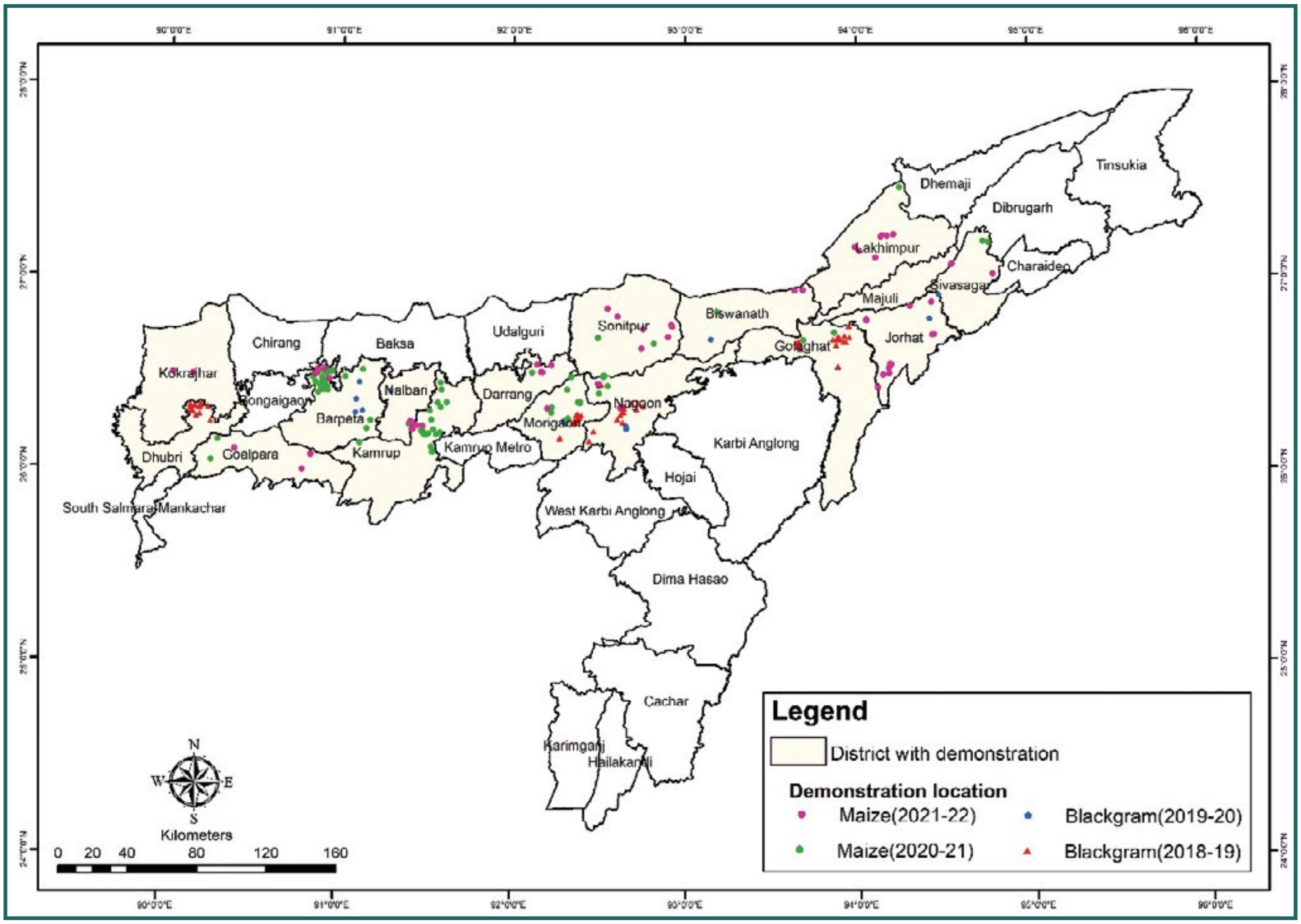

Fig. 44: Locations of field demonstrations in rice-fallow areas of Assam (2018-2022)

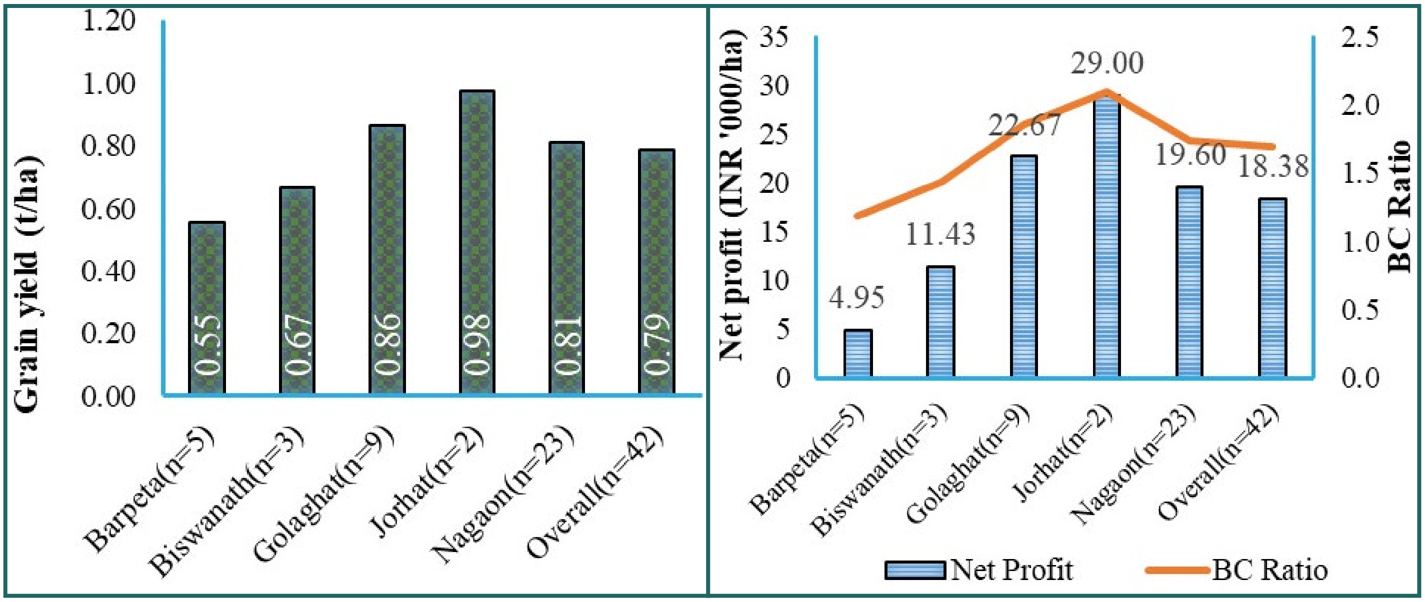

Fig. 45: District-wise black gram grain yield and net return with B:C ratio for demonstrations in rabi 2019-20

Crop-cut data was analysed for grain yield and net return with B:C ratio for maize demonstrations at different locations. Fig. 46 shows the maize grain yield in each agro-climatic zone and the district-wise net return with B:C ratio. The highest yield of 6.85 t/ha was observed in the North Bank Plain Zone (NBPZ) comprising of Sonitpur and Biswanath districts followed by 6.21 t/ha in the Lower Brahmaputra Valley Zone (LBVZ) comprising of Goalpara and Barpeta districts. District-wise grain yield of maize was highest in Goalpara with 8.87 t/ha followed by Biswanath with an average yield of 7.4 t/ha. The overall average grain yield of maize was 6.2 t/ha. Maize demonstrations in rice-fallow areas show that maize can be profitably adopted as a second crop during *rabi* season in areas with sufficient residual soil moisture.

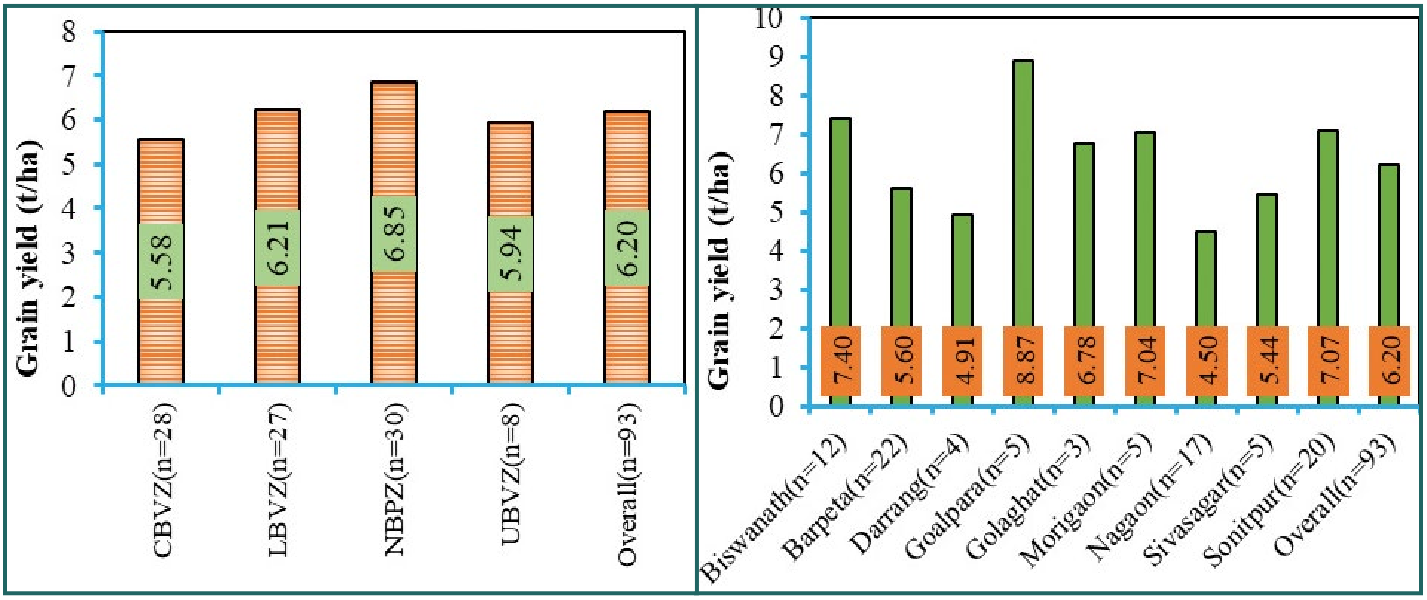

Fig. 46: Grain yield of maize demonstrations during rabi 2020-21 in different agro-climatic zones and districts of Assam

Line sowing with seed drill machine at Auniati Kheraj, Nagaon

Maize demonstration at Balabhita, Barpeta

6. Success stories under APART

Maize cultivation for additional income in rice-fallow areas of Titabar

The floodplains of Assam are endowed with rich and fertile soil which can host several crops in a year. However, rice cultivation is essentially finished in summer (*kharif*) and the fields stay neglected during winter (*rabi*). These areas can be efficiently put to use by utilization of the residual soil moisture after rice harvest, timely seeding, and improved best management practices.

In APART, geospatial technologies have been effectively used to monitor and map the rice-fallow areas and estimate the soil moisture suitability for the cultivation of the second crop for the entire state from 2018-2022. In *rabi* 2020-21, maize was chosen as the subsequent crop after rice in several districts of Assam. Jorhat and Sivasagar were two such districts.

In Jorhat, Titabar was chosen as one of the blocks where this demonstration was carried out. Located in the southwestern corner of Jorhat, the Titabar subdivision is renowned for its high rice production. With a large number of marginal farmers, the region was estimated to have around 13,000 hectares of rice-fallow area during *rabi* 2020-21. Based on soil moisture suitability locations, APART started working with RARS Titabar for maize farming in the identified rice-fallow areas. Appropriate best management practices using the seed drill and judicious nutrient application were done in the selected farmer's field.

Jiba Chutia, a 67-year-old marginal farmer from Dihingia village of Titabar with a land holding of 1 hectare, decided to grow maize crop in the rice-fallow area for the first time in *rabi* 2021. Maize variety DMRH - 1301 was sown in lines using seed-cum-fertilizer drill/multi-crop planter. The demonstration was successfully conducted by the implementing partner organization, AAU through RARS Titabar with the best management practices shared by IRRI. Mr. Chutia says, "Realizing the fact that *rabi* cultivation is possible after *kharif* paddy gave new cropping insights for the farmers of Titabar". Towards the end of May, the crop was harvested, and recorded a yield of 5.77 tons/ha which was more remunerative than keeping the land fallow during *rabi* season.

Photograph from Jiba Chutia's maize field, Titabar

This initiative and support from APART is an example application of geospatial technology in agriculture to achieve the dream of doubling farmer's income. The added maize production, will help Jiba Chutia to uplift the living standard of his family.

Encouraging farmers from Sivasagar through maize cultivation with geospatial technology

Sivasagar is situated in the Upper Brahmaputra Valley Zone of Assam. With a total number of 531 villages (Statistical Handbook of Assam 2021), the district recorded a cropping intensity of only 109% (Statistical Handbook of Assam 2021). The district was estimated to have around 39,992 hectares of rice-fallow area during *rabi* 2020-21. Based on soil moisture suitability locations, in 2020-2021, APART started working with KVK Sivasagar for maize farming in the identified rice-fallow areas.

Rituraj Chetia is a young farmer from Dissang Chapori of Sivasagar district. He is a marginal farmer with a land holding of 1.5 hectare. In 2020-21, Mr. Chetia decided to grow maize crop in the fallow area for the first time. After discussing with his fellow farmers, he decided to go for maize cultivation on a total land of 3 hectares of rice-fallow area. Bio-9637(Maharaja) variety was selected for sowing in lines with seed-cum-fertilizer drill/multi-crop planter. IRRI has shared the best management practices with its implementing partner organization, AAU, for conducting the demonstration through KVK Sivasagar.

Photograph from Rituraj Chetia's maize field

Mr. Chetia said that "Other farmers are also wishing to cultivate maize crop from next season. In fact, farmers are interacting with him regarding this matter. This initiative and support from APART are encouraging farmers to go for maize in Dissangmukh.

Knowledge Management Committee

Sl. No	Name	Designation	Department
Assam Agricultural University			
1	Dr. Ashok Bhattacharyya	Director	Directorate of Research (Agri.), AAU, Jorhat
2	Dr. Mrinal Saikia	Associate Director of Research	Directorate of Research (Agri.), AAU, Jorhat
3	Dr. Rupam Borgohain	Principal Scientist and Nodal officer	Directorate of Research (Agri.) and OPIU,_AAU, Jorhat
4	Dr. Debanand Das	Principal Scientist and Alternate Nodal officer	Directorate of Research (Agri.), AAU, Jorhat
5	Dr. Ranjit Kr. Saud	Associate Director of Extension Education (P&I)	Directorate of Extension Education, AAU, Jorhat
6	Dr. Ramani Kanta Thakuria	Principal Scientist	Horticulture Research Station, Kahikuchi, AAU, Jorhat
7	Dr. Kalyan Pathak	Professor and Head	Department of Agronomy, AAU, Jorhat
8	Dr. Kulendra Nath Das	Professor	Department of Soil Science, AAU, Jorhat
9	Dr. Bipul Deka	Principal Scientist	AICRP on Water Management, Department of Soil Science, AAU, Jorhat
10	Dr. Khagen Kurmi	Principal Scientist	AICRP on Weed Management, Department of Agronomy, AAU, Jorhat
11	Dr. Phuleshwar Nath	Senior Extension Specialist	Directorate of Extension Education, AAU, Jorhat
12	Dr. Sanjay Kumar Chetia	Chief Scientist	RARS, Titabar, AAU
13	Dr. Pulin Patgiri	Principal Scientist	AICRP on Postharvest Technology, Department of Agriculture Engineering, AAU, Jorhat
14	Dr. Sailen Gogoi	Principal Scientist	AICRP on Vegetables, Department of Horticulture, AAU, Jorhat
15	Dr. Surajit Kalita	Junior Scientist	Directorate of Research (Agri.)
16	Er. Manash Jyoti Barooah	Assistant Professor	AICRP on Farm Mechanization, Department of Agriculture Engineering, AAU, Jorhat
17	Dr. Sundar Barman	Assistant Professor	Department of Extension Education, AAU, Jorhat
18	Mr. Apurba Das	Assistant Professor	Department of Plant Pathology, College of Sericulture, AAU, Jorhat
International Rice Research Institute			
19	Dr. Kanwar Singh	Senior Associate Scientist II - Precision Agronomist & Resident Project Coordinator	
20	Dr. Virendar Kumar Yadav	Consultant	
21	Dr. Suryakanta Khandai	Associate Scientist (Postharvest & Rice Value Chain)	
22	Ms. Suranjana Bhaswati Borah	Senior Specialist - GIS & Remote Sensing	
23	Mr. Jyoti Bikash Nath	Specialist - Agriculture Research & Development (Agriculture Extension)	
24	Mr. Vipin Kumar	Specialist - Agriculture Research & Development (Crop & Natural Resource Management)	
25	Mr. Vivek Kumar	Specialist - Agriculture Research & Development (Agriculture Extension)	
26	Dr. Lisa Mariam Varkey	Specialist: Socio-Economics	
27	Dr. Rahul Priyadarshi	Specialist - Agriculture Research & Development	
Assam Rural Infrastructure and Agricultural Services (ARIAS) Society			
28	Mr. Baljeet Singh	Market Analyst-cum-Operations Specialist	
29	Dr. Pranab Mahanta	Agri Adviser, APART	
Department of Agriculture, Govt. of Assam			
30	Mr. Madhuram Patiri	Nodal Officer, APART	

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