APPLICATION OF REMOTE SENSING AND CROP MODELING FOR RICE IN ANDHRA PRADESH, INDIA

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ABSTRACT: The Satellite based Rice Monitoring System for Andhra Pradesh (APSRMS) project aims to support capacity development by establishing and maintaining a rice monitoring system that provides regular crop condition updates to the state government and rapid damage assessment in the event of extreme climate conditions to support intervention by government and relevant stakeholders. The project utilizes freely available Synthetic Aperture Radar (SAR) from Sentinel-1A (C-band, vv and vh polarization SAR with 20 m spatial resolution and 12 days temporal resolution) and Sentinel-2 (multispectral optical data with 10 m spatial resolution and 5 days temporal resolution) from the Copernicus Programme of European Space Agency (ESA), and LANDSAT-8 (multispectral optical data with 30 m spatial resolution and 16 days temporal resolution) from the National Aeronautics and Space Administration (NASA) for rice area and start of season estimation and ORYZA crop growth model for yield estimation. MAPscape-RICE, a fully automated software for generation of rice area, start of season, and leaf area index (LAI) estimates from multi-temporal SAR and optical data was used in conjunction with Rice-YES, a software linking remote sensing derived information with ORYZA crop growth model. The project started in two districts (Nellore and West Godavari) in 2016/17 *Rabi* (dry) season, followed by expansion of monitoring activities to four districts (East Godavari, West Godavari, Guntur, and Krishna) in 2017 *Kharif* (rainy) season, and to seven districts (East Godavari, West Godavari, Nellore, Chitoor, Kadapa, Prakasam, and Kurnool) in 2017/18 *Rab*i season, and to the entire 13 districts of Andhra Pradesh by 2018 *Kharif* season. The project involved a rigorous rice classification validation exercise through physical field verification visits to ensure rice area products at district, block, and village granularity were at acceptable accuracy of 85% or more. Rice area and yield estimates were also compared against values obtained from government source. Mitigating rice farmers' production loss thru implementation of crop insurance is a key area of use case of this Satellite based rice monitoring system with the goal of timely rice production provision to be used by crop insurance companies to validate farmer's claims for insurance payouts in case of loss triggered by drought, floods, or cyclones. This study demonstrates the utility of remote sensing and crop modeling technologies to support the government of Andhra Pradesh, India in near-real time rice production monitoring and conducting damage assessment in case of unfavorable climate events such as drought, floods, or cyclones affecting small-holder rice farmers. Likewise, it demonstrates the importance of regular and timely rice area monitoring and pre-harvest yield forecast as critical requirements to prepare for extreme climate events with a case study involving damage assessment from cyclone Titli that affected rice production in Srikakulam district during 2018 *Kharif* season.

1. INTRODUCTION

Rice remains to be the major food crops and staple in Andhra Pradesh (AP) with top rice producing districts relying on irrigation system supported by two main rivers- Godavari and Krishna (Andhra Pradesh Agricultural Status, 2019). Given the share of agricultural activities of the state, large portion of the population depends on it and its related activities. Due to its coastal location, AP is prone to natural disasters such as floods, drought, and cyclone putting the agricultural sector at risk.

The Satellite based Rice Monitoring System for Andhra Pradesh (APSRMS) project is a collaborative project between International Rice Research Institute (IRRI, Department of Agriculture (DOA), Acharya N.G. Ranga Agricultural University (ANGRAU) and sarmap. The main objective of the project is to support national partners' capacity in monitoring rice using remote sensing and crop modeling technology and to conduct rapid damage assessment in the event of natural calamities. This paper describes the methodology used and presents data generated during the 2018 *Kharif* season

2. DATA AND METHODS

2.1 Study Area

Andhra Pradesh, the location of the APSRMS project is in the southeast of India. The project started in 2016/17 *Rabi* season with two districts (Nellore and West Godavari) being monitored. The following season, 2017 *Kharif*, the monitoring area was expanded to top four rice producing district – East and West Godavari, Guntur, and Krishna and then in 2017/18 *Rabi* some districts were retained and some additional districts were added in the monitoring (East Godavari, West Godavari, Nellore, Chitoor, Kadapa, Prakasam, and Kurnool). In 2018 *Kharif* season, the rice crop monitoring covers the whole state (total of 13 districts) of Andhra Pradesh.

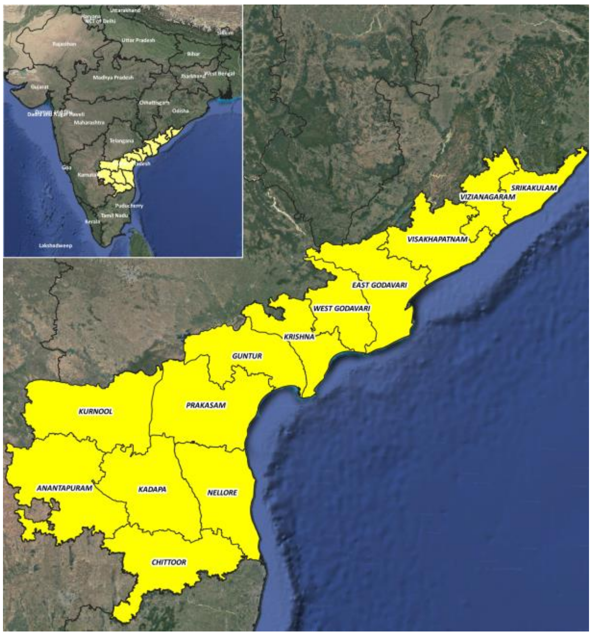


Figure 1. Location of the study sites.

2.2 Data

2.2.1 Satellite data

The study used multi-temporal Synthetic Aperture Radar (SAR) images from Sentinel-1A (C-band, VV and VH polarization ,20 meter spatial resolution, 12 days temporal resolution) and Sentinel-2 (multispectral optical data, 10 meter spatial resolution, 5 days temporal resolution) from the Copernicus Programme of European Space Agency (ESA), and LANDSAT-8 (multispectral optical data, 30 meter spatial resolution, 16 days temporal resolution) from the National Aeronautics and Space Administration (NASA) for rice area and rice seasonality and for yield estimation.

2.2.2 Field data

Field data were collected twice within the season at random locations across the study area. First field data collection was conducted during the early part of the cropping season to collect information on start of season of rice and other seasonal crops. Start of season for rice characterizes a flooded field which signals the start of the season. This is done primarily to validate the start of season and to calibrate the rice detection algorithm. Another field data collection was conducted towards the end of the season to validate and determine the accuracy of the rice map derived from rice detection algorithm of remote sensing data. Information such as field coordinates, planting dates, crop establishment methods (for rice), crop stage, types of crops, expected time of harvest, ecosystem, and geotagged photos were collected. In 2018 *Kharif* season covering the entire state of AP, total of 850 (418 rice and 433 non-rice points) ground truth points were collected for the classification of the start of season. For rice and non-rice validation, a total of 3,013 ground truth points (1,865 rice and 1,148 non-rice points) were collected at the district (1,221), mandal (1,322) and village (472) levels.

2.2.3 Other data

Daily weather information, varietal characteristics, and crop management information were collected as input to the rice yield model. The weather data includes solar radiation, wind speed, and vapor pressure, minimum and maximum temperature and rainfall. The first three variables comes from NASA Prediction of Worldwide Energy Resources (POWER) dataset (a publicly available global weather data produced by NASA Langley Research Center Power Project) while minimum and maximum temperature and rainfall comes from local weather stations of Andhra Pradesh, upon availability. The NASA POWER weather data were downscaled to 15 arc-minute resolutions and corrected using reported data from local stations before it can be use in the crop model. Another input is the soil information which was obtained from the World Inventory of Soil Emission potential (WISE) dataset and Harmonized World Soil Database (HWSD). Similarly, field information particularly crop management practices (amount nitrogen fertilizer application per hectare, irrigation management, and crop establishment) were also used in the model. Likewise, maturity duration and phenological characteristics of the popularly grown varieties in the area was also used in the model.

2.3 Methods

2.3.1 Rice area and start of season

For rice area and rice seasonality (SoS), SAR images from April to December were used in the analysis for the 2018 *Kharif* season. Initial steps include automated pre-processing in MAPscape-RICE® software for rice classification. The process includes automatic grouping of multi-temporal SAR data (belonging to the same acquisition geometry), slant range strip-wise mosaicking, multi-looking, multi-temporal image co-registration, time-series speckle filtering, terrain geocoding and Anisotropic Non-Linear Diffusion (ANLD) filtering (for smoothening the homogeneous area). Through MAPscape-RICE®, Sentinel-1 GRD time series SAR data is automatically converted into terrain-geocoded backscattering (σ^0) values. The multi-temporal, decision rule-based rice classification algorithm was then applied to ANLD filtered σ^0 images for multi-season rice crop detection and identification of start of season (date) based on lowest backscattered (σ^0) values. Detailed description of the rice mapping processes are described in Nelson, *et al.* (2014).

Flood damage assessment was generated in MAPscape-RICE® using images from Sentinel-1A C-band (pre-cyclone) and TerraSAR-X X-band (post-cyclone) SAR data sets together with the digital elevation model. Flood mapping is based on decreasing trend of the backscatter values between pre- and post-cyclone event. The rule-based classification was used to determine the effect of flood on rice crops. Focusing on post-flowering to maturity segment of rice growing cycle which was the crop stages of rice at the time when cyclone Titli landed and that are most likely to be affected.

2.3.2 Rice area accuracy assessment

A total of 1,221 ground observations in 2018 *Kharif* distributed within each of the 13 districts were collected to assess the accuracy of the rice classification. The validation points were classified into two types: rice and non-rice. Land cover types other than rice were grouped into one single non-rice class. The accuracy by district was calculated using a standard confusion matrix table and the kappa statistic was estimated (Congalton, 2001). Rice area map validation was conducted at the district level and presented in the results section.

2.3.3 Yield estimation

Yield estimation involves several processes and used different software- MAPscape-RICE®, ORYZA, Rice-Yield Estimation System (Rice-YES) and QGIS. The operational diagram as shown in Figure 2, illustrates the processes of the remote sensing-based yield estimation system starting from the satellite acquisitions to integration of SAR data into ORYZA model until the generation of yield forecast or estimates, and the final yield map. Rice-YES serves as an interface that connects the remote sensing information and ORYZA model and coordinates all inputs to generate yield estimates (Setiyono, *et al*, 2017). ORYZA crop model is a process-based rice growth and yield estimation model that captures complex and dynamic interactions among weather, agronomic management, crop characteristics, and soil properties (Boumant, *et al*, 2001). Leaf area index (LAI) acquired from SAR signature analysis is the main input that comes from remote sensing together with the start of season. The computation of the LAI is based on water cloud model (Attema and Ulaby, 1978) and it is done automatically in MAPscape-RICE®.

For rice the LAI values ranges from near zero (seedling stage) to a maximum of 10 at flowering stage (possible for hybrid rice varieties), although maximum LAI values closer to 6 are the typical. Setiyono *et al.* (2018) provided a detailed explanation on how the system operates from assimilation of SoS and LAI data from multi-temporal SAR images until the aggregation of yield estimates. Yield estimates obtained were aggregated into desired administrative level and compared with the government's reported yield using root mean square error (RMSE) and normalized root mean square error (NRMSE).

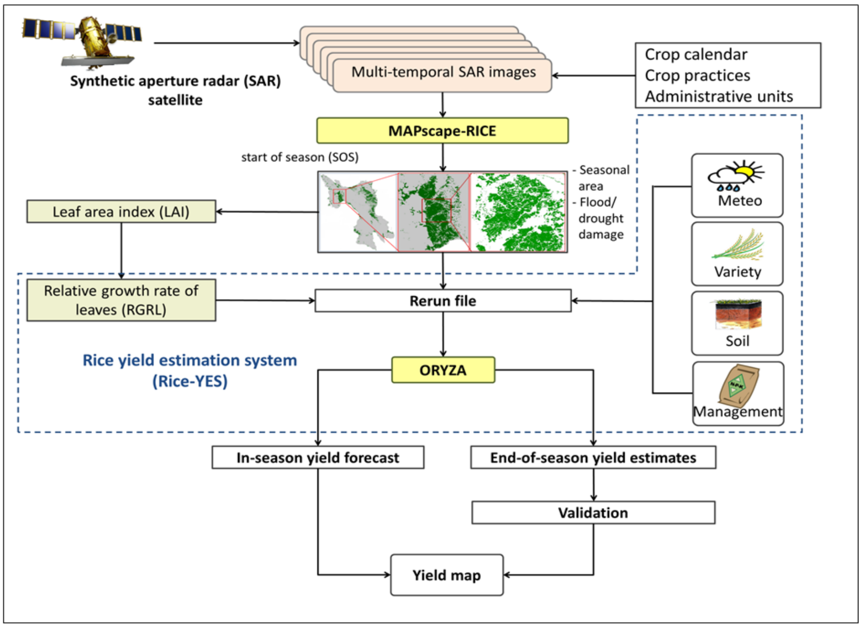
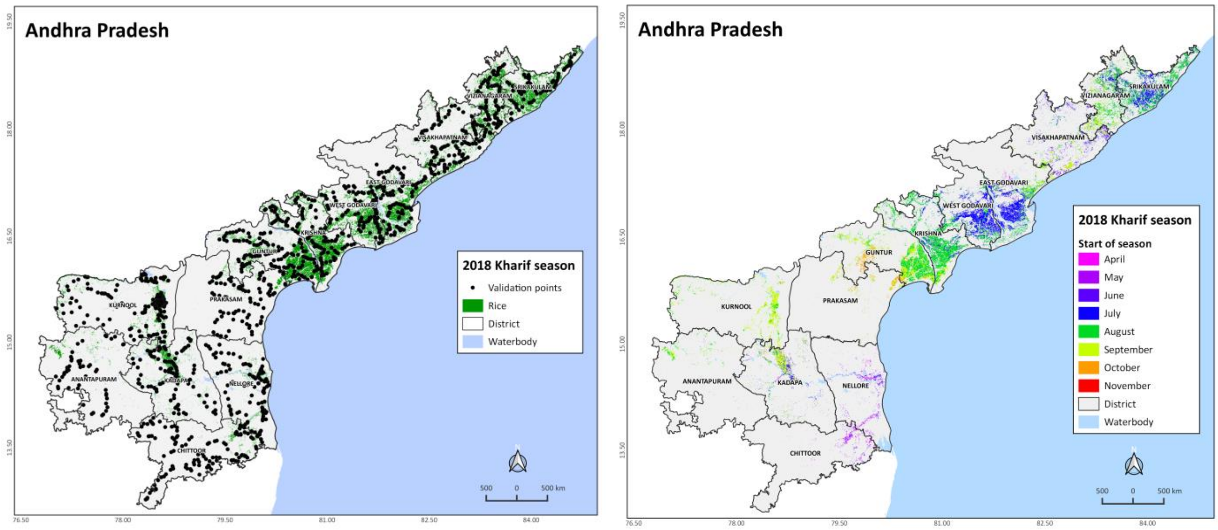


Figure 2. Process diagram of yield estimates using SAR and ORYZA crop growth model.

3. RESULTS AND DISCUSSION

3.1 Rice area and start of season

Using the satellite images from Sentinel-1 and Sentinel-2 together with LANDSAT-8, rice area and start of season maps, respectively were generated for the 2018 *Kharif* season (Figure 3). Accuracy assessment of the rice area map (using ground data points for each district), shows that most of the districts have >90% accuracy and with kappa value that ranges from 0.70 to 0.95 (Table 1). The estimated rice area in Andhra Pradesh during the 2018 *Kharif* season was recorded at 1.6 million hectare with Krishna district as having the most cultivated area for rice, followed by Guntur, West Godavari and East Godavari. The start of season map was derived based on the lowest backscatter value of the multi-temporal SAR signature, which marks the start of the agronomic flooding in the field (Nelson, *et al*, 2014). As shown in the map, peak of rice cultivation happened in July and August in four major rice producing districts which are mainly irrigated and transplanted. Likewise, Srikakulam and Vizianagaram's peak of cultivation also happened in July and August. In these two districts, majority of rice are direct seeded and are in rainfed system, hence farmers start cultivation in July and August in time for the monsoon rains. On the other hand, in Chittoor and Nellore, start of season begins in April to May (early *Kharif*). The wide variation in start of cultivation depends on the availability of water release from irrigation canal or the expected monsoon rains in particular districts. Farmers in general used 130-140 days duration rice varieties.



(a) (b)

Figure 3. Rice area map with validation points (a) and start of season map (b), 2018 *Kharif* season, Andhra Pradesh.

Table 1. Summary of validation points and accuracy assessment, by district, Andhra Pradesh, 2018 *Kharif* season.

District	Validation Points	Average Accuracy (%)	Average Reliability (%)	Overall Accuracy (%)	Kappa Index
Chittoor	86	88.3	93.6	93.0	0.86
East Godavari	102	94.8	92.9	94.1	0.88
Guntur	118	94.2	94.0	94.1	0.88
Krishna	110	96.6	97.3	97.3	0.95
Kurnool	111	95.9	95.0	95.5	0.91
Prakasam	89	89.7	93.3	92.1	0.84
Nellore	126	92.9	92.7	92.9	0.86
Srikakulam	76	78.6	97.9	96.1	0.92
Visakhapatnam	101	85.2	85.3	85.1	0.70
Vizianagaram	91	95.0	93.5	94.5	0.89
West Godavari	103	97.9	84.6	96.1	0.92
Kadapa (YSR)	108	94.4	94.4	94.4	0.89

3.2 Yield estimates

Figure 4 shows the end-of-season yield estimates for Andhra Pradesh for 2018 *Kharif* with district level aggregation. Based on the yield map, large rice patches in Guntur, Krishna, East and West Godavari exhibits high rice productivity. The high yields in these districts were expected given the relatively good crop management as well as presence of necessary irrigation supply throughout the growing season of the rice crop. On the other hand, districts located in the Northeastern portion of the state demonstrate low yield as these areas are mostly rainfed system. Given the variability in yield, policy makers, extension workers, and other stakeholders can easily assess the spatial yield distribution across specific area of interest and provide interventions if needed.

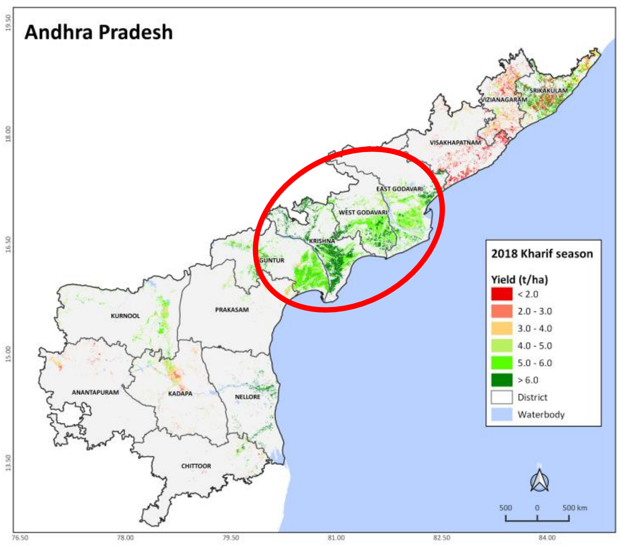


Figure 4. Spatial distribution of end-of-season yield estimates for Andhra Pradesh, 2018 *Kharif*.

Table 2 provides the agreement of the 2018 *Kharif* season estimated yield compared to the governments' reported yield. District level aggregation shows that yield ranges from 2.27 t ha^{-1} (Visakhapatnam) to 7.27 t ha^{-1} (Nellore). Yield estimates RMSE ranges from 0.07 t ha^{-1} (Kadapa) to 1.03 t ha^{-1} (Nellore). In terms of yield agreement between the estimates and reported, it shows that seven districts have agreement of more than 90%. This shows that yield generated based on the SAR data complemented well with the government statistics. Unlike the reported yield wherein it takes a while before information can be made available, yield estimates (mid-season or end-of-season) can be process quickly and can be provided to policymakers and other stakeholders earlier so that it can be used in their policy intervention or technology targeting.

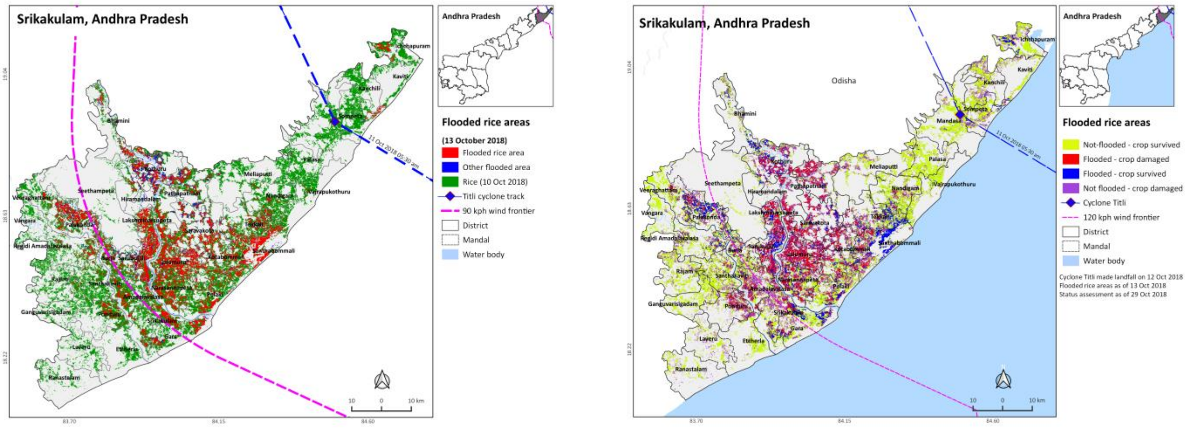
Table 2. Comparison of end-of-season yield estimates and reported yield, 2018 *Kharif* season.

DISTRICT	Estimated yield (t ha^{-1})	Reported yield* (t ha^{-1})	RMSE (t ha^{-1})	NRMSE (%)	Agreement (%)
Anantapur	3.95	4.33	0.38	9	91
Chittoor	4.11	5.11	1.00	20	80
East Godavari	5.61	5.23	0.38	7	93
Guntur	6.20	6.29	0.09	1	99
Krishna	5.77	5.03	0.74	15	85
Kurnool	5.06	5.53	0.47	8	92
Nellore	7.27	6.24	1.03	17	83
Prakasam	4.28	4.82	0.54	11	89
Srikakulam	3.51	4.38	0.87	20	80
Visakhapatnam	2.27	2.83	0.56	20	80
Vizianagaram	3.93	4.29	0.36	8	92
West Godavari	5.64	5.43	0.21	4	96
YSR (Kadapa)	3.61	3.54	0.07	2	98

* Source: Department of Agriculture, Andhra Pradesh. Provisional data

3.3 Flood Damage Assessment

Flood damage assessment was conducted in Srikakulam district having been directly hit by cyclone Titli on October 11, 2018. Cyclone Titli caused a lot of damage to the agricultural sector particularly on rice wherein at that time most of the rice crop is at maximum tillering to maturity stage. Post-cyclone analysis was conducted using acquired satellite image (TERRASAR-X) on October 13. SAR-based monitoring estimated the rice area in Srikakulam district at 205,174 hectares prior to the event. Post-cyclone assessment indicated that 52,312 hectares or 26% of the rice area were flooded. Figure 5 shows the rice area flooded (a) and rice area damaged (b) as of October 13. This was further validated by farmers during the focus group discussion conducted from 6-11 February 2019. As per the farmers, most of the rice areas were flooded due to heavy downpour on October 11 and due to river overflow (from 13 October onwards). Heavy downpour was experienced particularly in the northern mandals of Srikakulam while the river overflow was confined in the central mandals. Depending on rice variety planted by farmers, short duration varieties were mostly in grain filling stage while the long duration varieties were still on the panicle initiation to flowering stages. As per the district Depart of Agriculture, reduction in yield was estimated at 33% of their normal yield. Palasa, Ichchapuram, Mandasa, Vajrapukoturu and Santhabommali mandals were severely affected by cyclone Titli.



(a) (b)

Figure 5. Rice area affected by flood (a) and flood damage assessment maps (b), Srikakulam district, 2018 *Kharif*.

3.4 Capacity Building

In 2018, IRRI and sarmap conducted a series of training-workshops on protocols for field data collection, rice mapping and monitoring, and yield estimation. Continues capacity building is being done to the staff of Geospatial Technology Center (GTC) of ANGRAU by involving them in the field data collection, rice area mapping and analysis. As capacity building is one of the major objective of the project, technical support to national partners are continuously being conducted.

Table 3. List of trainings participated by national partners.

Training Title	Date	Place of Training	No. of participants
Field data collection	Feb	ANGRAU	3
MAPScape-Rice	24 Sep-12 Oct	sarmap, Switzerland	2
Quantum GIS	22-27 Oct	ANGRAU	13
Basic MAPscape-RICE	16-24 Nov	ANGRAU	9
Intermediate MAPscape-RICE	26 Nov-3 Dec	ANGRAU	9
Rice-YES	4-8 Dec	ANGRAU	8
Smartphone-based Field Data Collection	10-14 Dec	ANGRAU	6
Basic ORYZA	22-26 Apr	IRRI-HQ	4

4. CONCLUSION

The study demonstrates the utilization of freely available SAR data for crop monitoring, rapid yield estimation, and damage assessment with high accuracy and throughput data. Based on several seasons of generating rice products, we have seen that results generated for Andhra Pradesh are very promising given the high accuracy assessment for some of the districts. However, continued improvement of the processing chain- particularly in delivering the outputs (timeliness), commitment of existing partners in project implementation, engagement of emerging partners and potential users of the system including to support crop insurance program, and continues capacity building are crucial for sustaining the activities.

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