



Application of Multi-dated Sentinel-2 Imageries to Assess the Cropping System in Gosaba Island of Indian Sundarbans

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Application of satellite based remote sensing in agriculture has reached a new level with introduction of medium to high resolution earth observation satellites like Landsat series, SPOT, Sentinel-2, etc. This study assesses the cropping system and the spatio-temporal variability of crops and fallow land particularly during the post-monsoon season, at the Gosaba island of Indian Sundarbans using multi-dated Sentinel-2 data. Sentinel-2 data offers 10-20 m spatial resolution, 5-day revisit frequency, global coverage and compatibility to the Landsat missions and provides new opportunities for regional to global agriculture monitoring. Monitoring of crop conditions, soil properties and mapping tillage activities help to assess land use, predict harvests, monitor seasonal changes and assist in implementing policy for sustainable development. Indian Sundarbans is considered to be one of the most endangered regions in the world from climatological and biodiversity view point. The low cropping intensity of Sundarbans forces the people to unscientifically explore forest resources leading to degradation of natural biodiversity. Cropping system intensification is a promising and sustainable approach to support the livelihood of the people and to save the biodiversity of Sundarbans region. In this study, multi-dated Sentinel-2 data were classified by following supervised classification to generate thematic map for determination of the spatiotemporal variability of cropped and fallow land during the period of November, 2017 to March, 2018. The overall accuracy of the study was 72 to 85%. The periodical ground observations revealed five predominant cropping systems viz. rice-fallow, rice-fallow-rice, rice-grass pea-fallow, rice-fallow-chilli, rice-fallow-green gram in the area. Temporal profile of reflectance was generated for each cropping system using the multi-spectral response of crop surfaces in Visible and Near Infrared (VNIR) bands. Temporal profile of Normalized Difference Vegetation Index (NDVI) and Visible Atmospheric Resistant Index (VARI) were generated to determine the crop duration. NDVI reached its maximum during the peak growth stages of each crop. The present research is helpful to have a complete understanding of the in-season temporal changes in land use and land cover using Sentinel-2 imageries.

(*Key words:* Cropping system, Image classification, NDVI, Sentinel-2, VARI)

In order to cope up with the increasing population pressure and rising global food demand, it is necessary to effectively plan and manage the use of natural resources like soils, vegetation, water, etc. Successful crop planning requires proper information on natural resources on regional and global scale (Bauer and Black, 1981).

Satellite based remote sensing can effectively be used for continuous monitoring of agricultural activities because satellites provide cost effective and precise information with a wide field of view at regular frequent interval. Application of remote sensing in agriculture has increased to a greater extent with the launching of Sentinel-2 by European Space Agency (ESA) as a part

of Copernicus program. Sentinel-2 is a constellation of satellites that includes Sentinel-2A and Sentinel-2B with an overall revisiting time of about 5 days (Main-Knorn *et al.*, 2018). It is a sun synchronous satellite equipped with an optical imaging sensor MSI (Multi-Spectral Instrument) which measures reflectance in 13 spectral bands ranging from Visible and Near Infrared (VNIR) to the Short Wave Infra-Red (SWIR). The high spatial resolution of 10 m in VNIR bands and 20 m in red edge, narrow NIR and SWIR makes it a highly suitable for periodic crop monitoring. The Sentinel-2 data have been used for wide range of applications in agriculture (Ramoelo *et al.*, 2015; Zhang *et al.*, 2017; Mandal *et al.*, 2018; Veloso *et al.*, 2017; Ghosh *et al.*, 2018).

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Indian Sundarbans is a part of the coastal saline zone of West Bengal. The coastal ecosystems are highly disturbed and very much threatened (Ghosh *et al.*, 2015), encountering problems like pollution, siltation, erosion, flooding saltwater intrusion, storm surges and other activities due to ever expanding human settlements (Mahadevia and Vikas, 2012). Though agriculture is the major activity of this region, people are increasingly being engaged in unscientific fishing, wood cutting, illegal honey collection in the forest for their livelihood which lead to deterioration of forest biodiversity. The crop productivity severely constrained by soil salinity build up particularly in the post-monsoon season. Mono-cropping practice is being followed in major parts of this region which is inadequate to support the livelihood of the farmers especially during the lean period (Mahadevia and Vikas, 2012). So, cropping system intensification (increasing cropping intensity) is the best way to sustainably improve the level of their livelihood. The objective of the present study was to carry out the seasonal fallow mapping during post monsoon season

and cropping system analysis of Rangabelia island of Gosaba block of Indian Sundarbans using multi-dated Sentinel-2 imageries.

MATERIALS AND METHODS

Site description

The present study was conducted in Gosaba Island (Rangabelia) of South 24 Parganas district in the coastal saline zone of West Bengal, India (Fig. 1). The island is located in latitude $22^{\circ} 06.414' N$ to $22^{\circ} 12.570' N$ and longitude, $88^{\circ} 46.326' E$ to $88^{\circ} 52.152' E$ with a geographical area of about 3,599 ha. The climate of Gosaba is sub humid tropical with an average annual rainfall is 1,677 mm. Major part of the rainfall occurs during June to September. The average monthly temperature varies from $19.7^{\circ}C$ in January to more than $30.1^{\circ}C$ in May. Daily rainfall during the study period *i.e.* from November, 2017 to April, 2018 as recorded from the automatic weather station installed in the Gosaba island (Fig.2) shows that the second week of December (2017) received unexpectedly high amount of rainfall (47 mm) due to local depression.

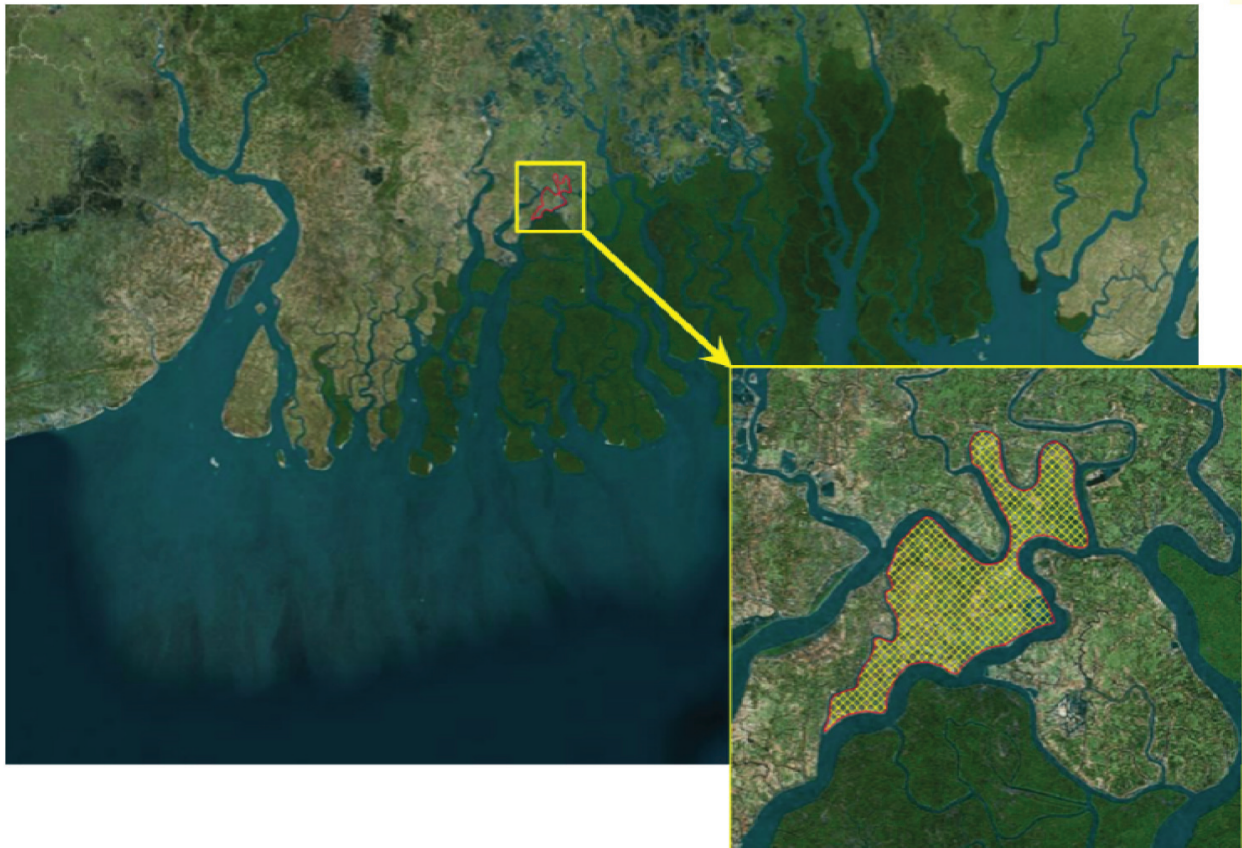


Fig. 1. Study site - Gosaba Island of Indian Sundarban

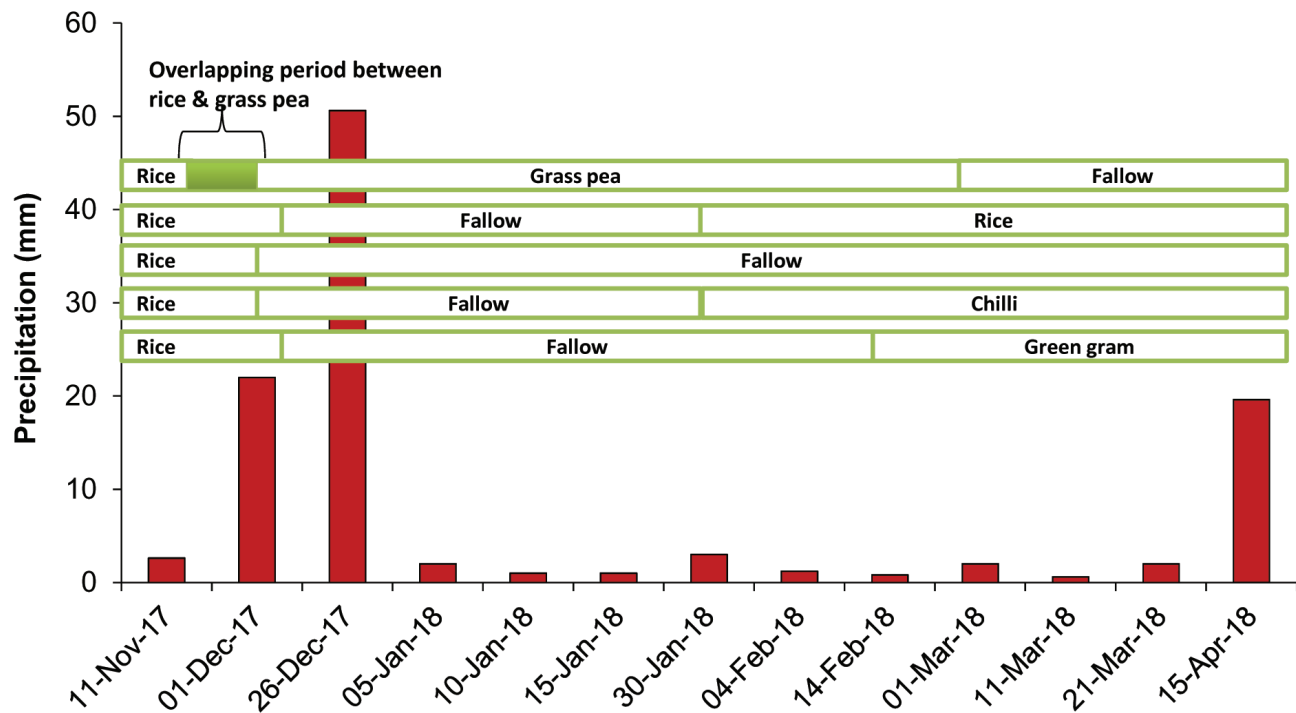


Fig. 2. Daily rainfall pattern with respect to crop calendar during study period

Study period

The study was carried out during the period from November 2017 to March 2018 to assess the diversity of the cropping pattern. This period was chosen because rice is the major crop of the region during monsoon period and thus there is not much spatial variation of cropping pattern during this period. On the other hand, during the post-monsoon season there is wide crop diversity according to land situation, salinity as well as availability of surface water resources.

Satellite data and source

Sentinel-2 data are collected from the data archive of European Space Agency as available in free domain for scientific applications. The clear sky (<20% cloud cover) imageries acquired for the entire post-monsoon period starting from November to March (Table 1) have been used in the current study.

Ground truth survey

The survey was done for training sample collection and also for ground truth analysis through transect walk across the Gosaba island. The GPS based survey was done for different types of land use systems e.g., a) tree + settlement, b) water body, c) fallow-1, d) fallow-2, e)

crop-1 and f) crop-2. In the study area, trees are generally associated with settlement areas (as homestead plants) as well as with the mangroves and the settlement areas are scattered. As the focus of our study is cropping system analysis, we have put settlement and trees under one class. The fallow lands are subdivided as fallow-1 and fallow-2 and the croplands are subdivided as crop-1 and crop-2 based on the tonal variation in false colour composite (FCC). The dates of ground truth are given in Table 1.

Image processing and classification

The uncorrected raw images (Level-1) of Sentinel-2 were pre-processed for atmospheric correction (haze removal) and radiometric correction using in-built pre-processing menu in the Semi-Automatic Classification Plugin of Quantum GIS (QGIS 2.18). The geometric correction was done for the processed images with reference to Survey of India toposheet. The corrected images were used for generating spectral profile of different cropping systems with respect to Visible (blue, green and red) and Near Infrared (NIR) bands with reference to the ground truth survey coverage over the post-monsoon season. For the purpose of mapping of the crop coverage areas at different dates over the

Sl. No.	Satellite Passage Date	Suitability for use	Ground Truth Survey Date
1	11-Nov-2017	√	15-Nov-2017
2	01-Dec-2017	√	12-Dec-2017
3	26-Dec-2017	√	25-Jan-2018
4	05-Jan-2018	*	21-Feb-2018
5	10-Jan-2018	*	30-Mar-2018
6	15-Jan-2018	√	Note
7	30-Jan-2018	√	
8	04-Feb-2018	*	√- Good quality image used in the present study * Poor image quality (cloud and haze)
9	14-Feb-2018	√	
10	01-Mar-2018	√	
11	11-Mar-2018	*	
12	21-Mar-2018	√	
13	15-Apr-2018	*	

Table 1. Satellite imageries (Sentinel-2) analyzed for cropping system study and ground observation dates

target cropping period (post-monsoon) supervised classification following maximum likelihood approach was carried out in Semi-Automatic Classification Plugin

of QGIS. The flow chart of the methodology has been presented in Fig.3.

Computation of vegetation indices

Profiles of Normalized Deviation Vegetation Index (NDVI) and Visible Atmospheric Resistant Index (VARI) were computed from the reflectance in visible and NIR bands for different cropping systems over the post-monsoon period using the following empirical formula-

$$NDVI = \frac{R_{NIR} - R_R}{R_{NIR} + R_R} \quad (\text{Rouse } et al., 1973)$$

$$VARI = \frac{R_G - R_R}{R_G + R_R + R_B} \quad (\text{Gitelson } et al., 2002)$$

where, R refers to reflectance and the subscript R, G, B and NIR refer to red, green, blue and near infrared bands respectively.

RESULTS AND DISCUSSION

Spectral profile of cropping systems

From the ground survey during the study period, five distinct cropping systems were identified. They were a) Rice - fallow - fallow (monocrop), b) Rice

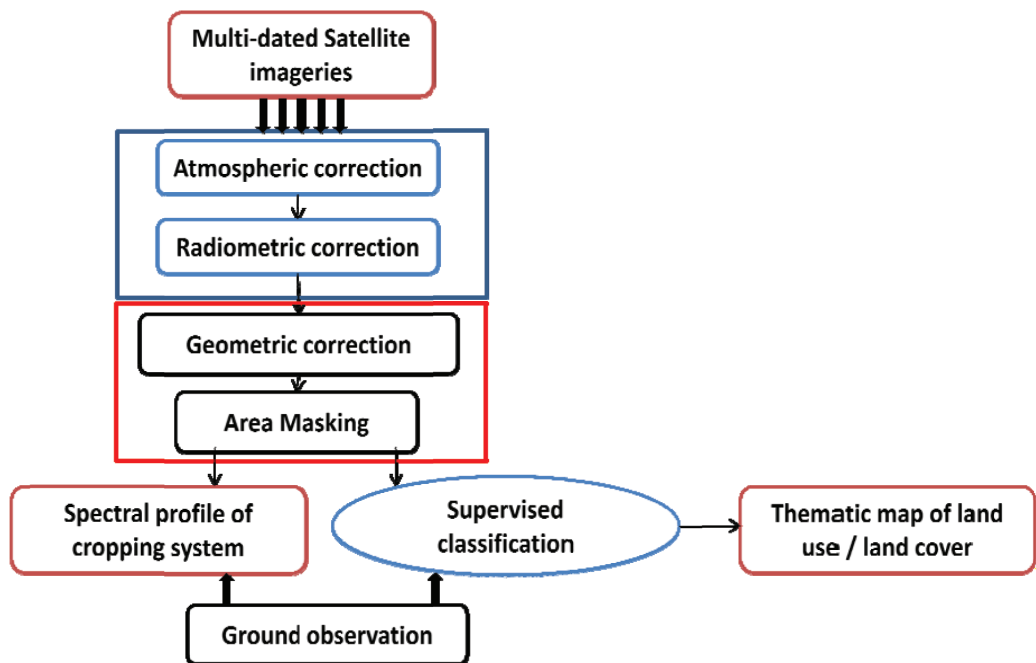


Fig. 3. Model flow chart for spatiotemporal analysis of land use/land cover pattern using satellite data

(*kharif*) - fallow - rice (*boro*), c) Rice - fallow - Chilli, d) Rice - grass pea, and e) Rice - fallow - green gram. Though, there were other crops like potato, cabbage, cauliflower, tomato and some other vegetables grown by farmers in Gosaba island, they were in small patches and most of them are grown in kitchen gardens and narrow field bunds.

The spectral profile of five different cropping systems in VNIR bands as derived from multi-dated satellite imageries, (Figs. 4 to 8) showed clear distinctions among themselves. The rice-fallow system (Fig. 4) showed high reflectance in visible region after January as compared to that of the rice crop whereas the rice - fallow - rice system (Fig. 5) showed decrease in reflectance in visible bands after February while the NIR reflectance showed a sharp increase during March-April. There were few patches of chilli crop recorded during the ground survey and the spectral profile of those areas has been presented in Fig. 6. The pattern of spectral profile for rice - fallow - chilli system was similar to that of rice - fallow - rice system. However, the NIR reflectance of rice was much higher than that of chilli during April owing to its higher vegetative growth. The rice - grass pea - fallow system (Fig. 7) was clearly distinguishable from others due to its peak NIR reflectance during February when the grass pea was at its active vegetative phase of growth. The rice - fallow - green gram system (Fig. 8) showed a sharp increase in NIR reflectance during March - April. The pattern was similar to that of rice - fallow - rice system with the difference that the NIR reflectance was very low during early growth of rice when there was standing water in the field.

The comparison of five predominant cropping systems was also done on the basis of two vegetation indices namely, Normalized Difference Vegetation Index (NDVI) and Visible Atmospheric Resistant Index (VARI). The rice - fallow - rice system (Fig. 9) showed a sharp decrease in NDVI during end of January to mid of February corresponding to the puddling and standing water condition during crop establishment phase followed by rapid increase during early March and April that coincided with active vegetative growth phase of rice. The two other systems e.g., rice - fallow - green gram and rice - fallow - chilli also recorded

similar pattern though the peak value of NDVI was comparatively less than that of rice - fallow - rice. The rice - grass pea system, on the other hand showed a different pattern of NDVI. The peak NDVI was reached during the end of January corresponding to the active vegetative phase of grass pea and lowest NDVI was recorded during the mid of March (Fig. 9) that coincided with the harvesting of grass pea.

Spectral profile of cropping systems gave the dynamics of growth and development of different crops through the variation in the spectral properties of the crops (Hatfield and Prueger, 2010). Temporal NDVI profile attained its peak during the maximum vegetative stage of each crop in the corresponding cropping systems (Kundu *et al.*, 2018). Katsoulas *et al.* (2016) opined that NDVI is a good indicator of plant nitrogen content, biomass, chlorophyll and leaf area index at leaf and canopy level.

The Visible Atmospheric Resistant Index (VARI) profile (Fig. 10) also showed clear distinctions among different systems at their peak vegetative stage. It was evident that rice - grass pea system recorded higher VARI than all others during the period of mid-December to end of February. Unlike NDVI, VARI decreased when the rice and chilli reached at reproductive stage. It was also observed that VARI profile showed less influence by the intermittent rainfall whereas NDVI values reflected the periodically varying moisture status of different crops due to the post monsoon rainfall. Gitelson *et al.* (2002) suggested using VARI for study of vegetation fraction for wheat and corn.

Image classification for crop coverage mapping

The land use map of 11 November, 2017 (Fig. 11) showed large proportion of land under crop vegetation. This coincides with growing period of rice. The fallow land during this period was very less. However, the classified image showed that some of the perennial tree areas are being classified as crop areas. This problem has occurred because the crop condition during this period was too good and the crop coverage area is too large to be distinguished from thinly populated perennial crop areas. The high vegetation coverage on 11 November (Fig. 11) implied the *kharif* rice which was at grain filling stage because long duration rice cultivars were grown in this region as a general practice. Only in small

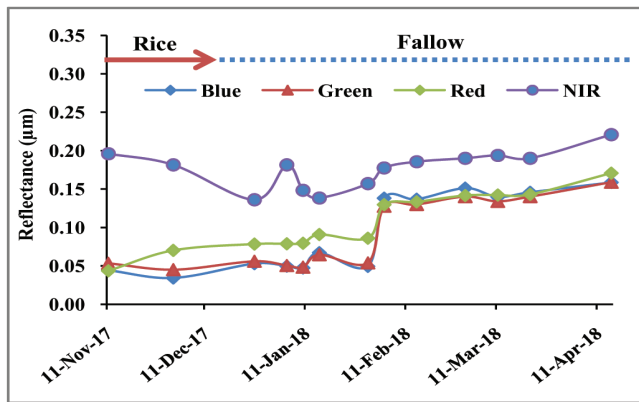


Fig. 4. Temporal variation in visible and near infrared (VNIR) reflectance of rice-fallow system

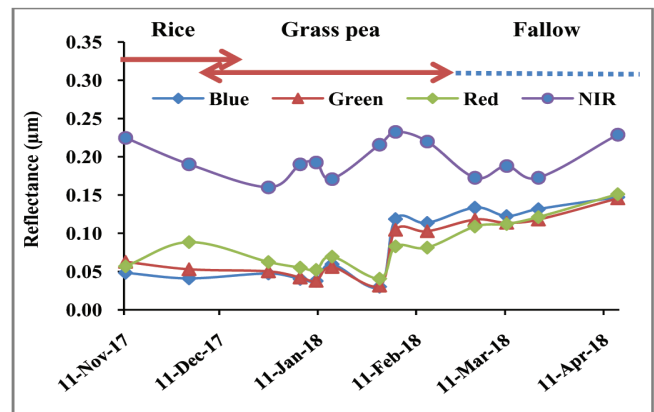


Fig. 7. Temporal variation in visible and near infrared (VNIR) reflectance of rice-grasspea-fallow system

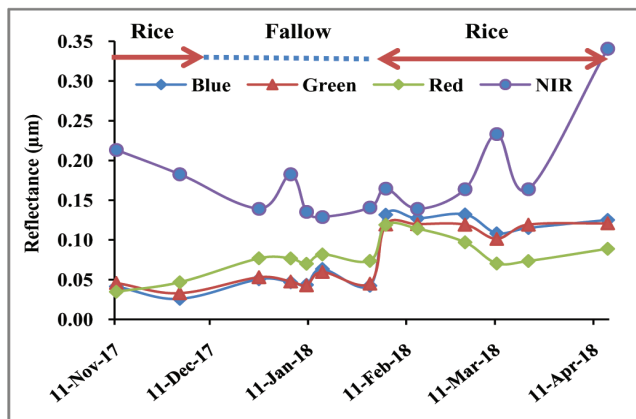


Fig. 5. Temporal variation in visible and near infrared (VNIR) reflectance of rice-fallow-rice system

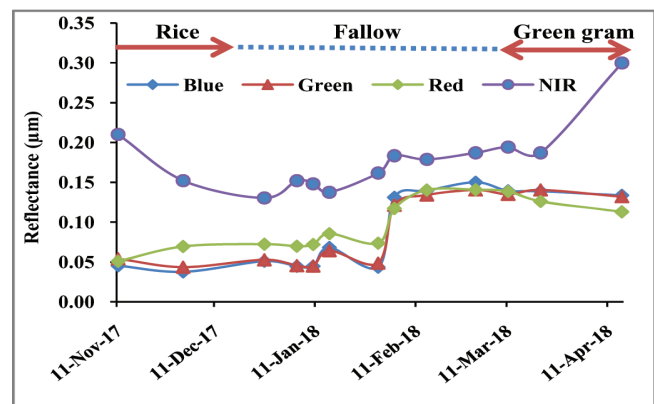


Fig. 8. Temporal variation in visible and near infrared (VNIR) reflectance of rice-fallow-green gram system

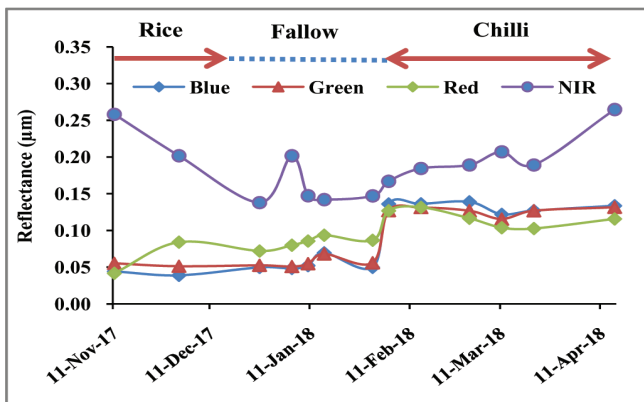


Fig. 6. Temporal variation in visible and near infrared (VNIR) reflectance of rice-fallow-chilli system

regions there were fallow lands. Those are the areas where either rice was not cultivated or these would be uplands where medium duration rice could have been harvested.

The classified image of 1 December, 2017

(Fig. 12) showed that there was sizeable proportion of fallow lands. Fallow lands were classified into two types based on the appearance in the false colour composites (FCC). The fallow-1 were characterized by lighter patches whereas, the fallow-2 were darker patches in the FCC. The tonal variation could be attributed to the difference in moisture status or development of salinity.

The careful observation of FCC of the image acquired on 26 December, 2017 implied that the fallow land had three distinct classes (Fig. 13). The first one was dry patch (fallow-1), the second one, *i.e.*, the fallow-2 was darker patches as discussed earlier. The third class (wet land) was ever darker characterized by blackish colour in the FCC. This was also well supported by ground truth observation. It was found from the ground truth study that some of the areas represented by darker patches in the FCC were later cultivated with *boro* rice (nursery or main field) in the following days. However, there was some mixing among fallow-2 and wetland

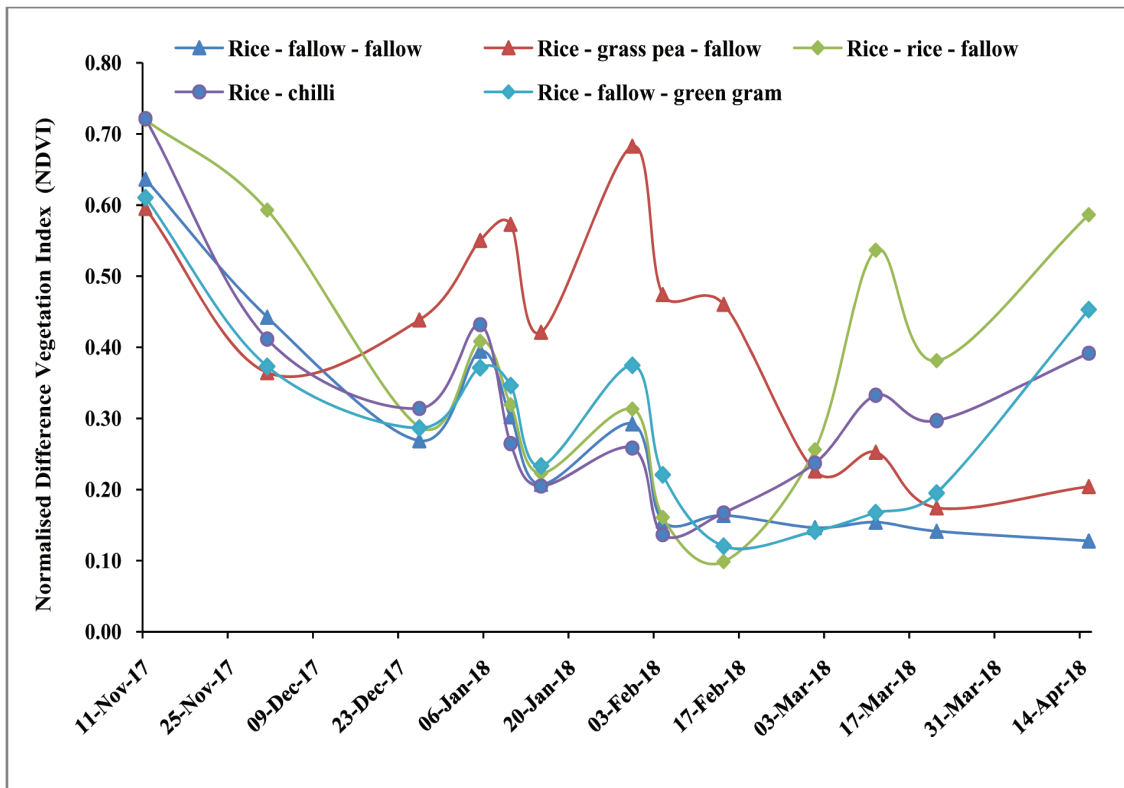


Fig. 9. Comparison of seasonal Normalized Difference Vegetation Index (NDVI) dynamics of different cropping systems

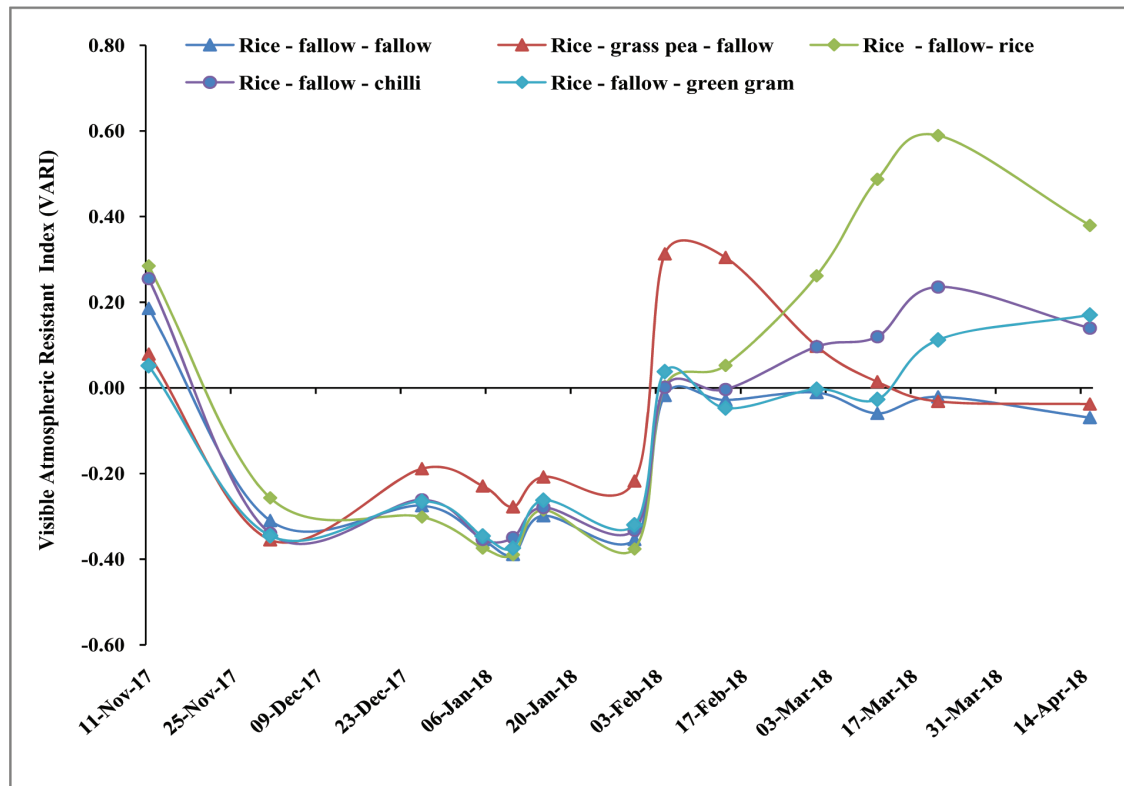


Fig. 10. Comparison of seasonal Visible Atmospheric Resistant Index (VARI) dynamics of different cropping systems

and *boro* rice area in the island. The rainfall due to low pressure during December might have led to water stagnation in some fallow lands that were shown as wet lands in the classified image. In the classified image of 15 January, 2018 (Fig. 14) and 30 January, 2018 (Fig. 15), we found small part of crop land representing the grass pea grown while the fallow-1 and fallow-2 covered major part of the study area.

The classified image of 14 February, 2018 (Fig. 16) showed some patches of wetland which were subsequently covered by *boro* rice classified as crop-2 in the classified image of 1 March, 2018 (Fig. 17) and 21 March, 2018 (Fig. 18). This was also supported by ground truth observations. The crop-1 in these images might be predominantly green gram or other vegetable

crops like chilli because grass pea was completely harvested.

The temporal changes in the areas under different types of land use and land cover as presented in Table 2 showed that the area under dry fallow (fallow-1) increased from December end (703 ha) to middle of February (1400 ha) while areas under wet fallow (fallow-2) decreased during this period. Cropped areas decreased in December as *kharif* rice was harvested and there were some little pockets of grass pea which gradually increased till January (680 ha). Grass pea was harvested during February which was clearly indicated by the reduction in areas under crop in 14-February (466 ha). After February cropped area showed slight increase due to summer (*boro*) rice and green gram which was marked as crop-2 and crop-1, respectively.

Table 2. Temporal changes in the area (ha) under different land use/land cover types over the study period

Date	LU class	Area	Date	LU class	Area
11-Nov-17	Fallow	692.5	30-Jan-18	Fallow-1	956.7
	Crop	1417.6		Fallow-2	1065.6
	Tree/settlement	1301.3		Crop	680.2
	Water	187.8		Tree/settlement	791.7
01-Dec-17			14-Feb-18	Water	105.1
	Fallow-1	874.8		Fallow-1	1400.4
	Fallow-2	1149.3		Fallow-2	500.5
	Crop	553.3		Wet land	245.4
	Tree/settlement	907.2		Crop	466.3
26-Dec-17	Water	114.7	01-Mar-18	Tree/settlement	857.6
	Fallow-1	703.1		Fallow-1	737.6
	Fallow-2	1104.6		Fallow-2	865.4
	Wet land	309.7		Crop-1	152.7
	Crop	408.3		Crop-2	881.5
	Tree/settlement	950.8		Tree/settlement	809.0
15-Jan-18	Water	122.8	21-Mar-18	Water	153.0
	Fallow-1	923.5		Fallow-1	218.0
	Fallow-2	1301.6		Fallow-2	1016.1
	Crop	440.9		Crop-1	171.7
	Tree/settlement	784.9		Crop-2	1018.42
			Tree/settlement	1006.62	
			Water	168.39	

Fallow-1: Dry fallow. Lighter patches in conventional FCC; Fallow-2: Wet fallow. Darker patches in conventional FCC
 Crop-1: Early growth stage. Light pink/red in conventional FCC; Crop-2: Dense crop. Deep reddish patches in FCC

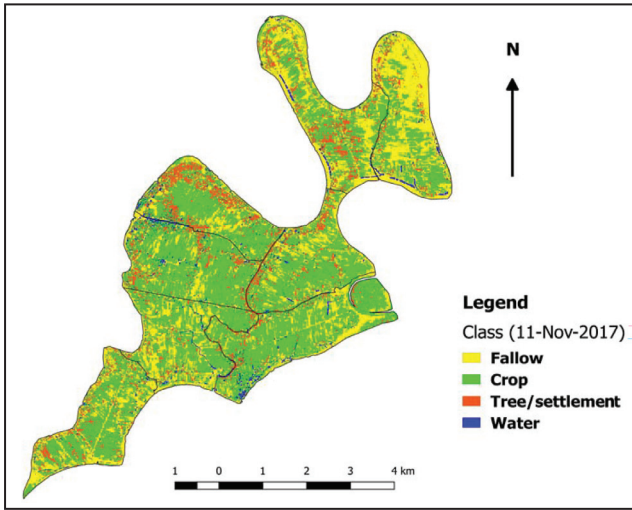


Fig. 11. Land use map of 11 November, 2017

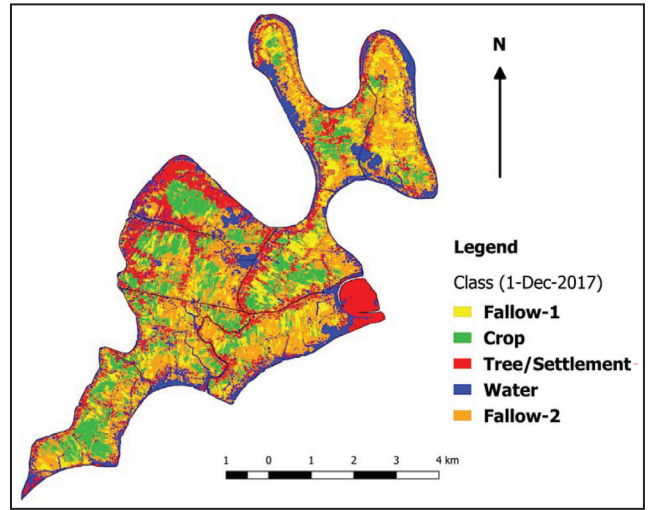


Fig. 12. Land use map of 1 December, 2017

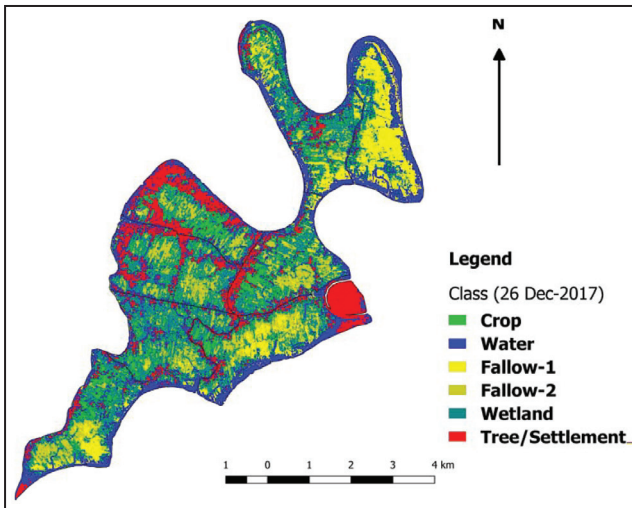


Fig. 13. Land use map of 26 December, 2017

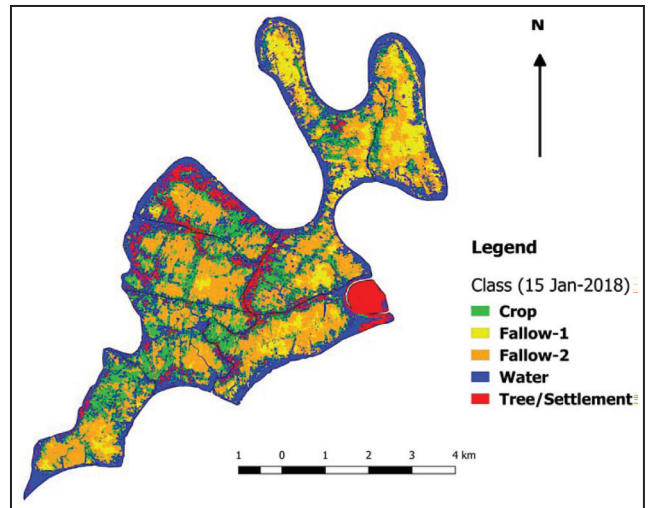


Fig. 14. Land use map of 15 January, 2018

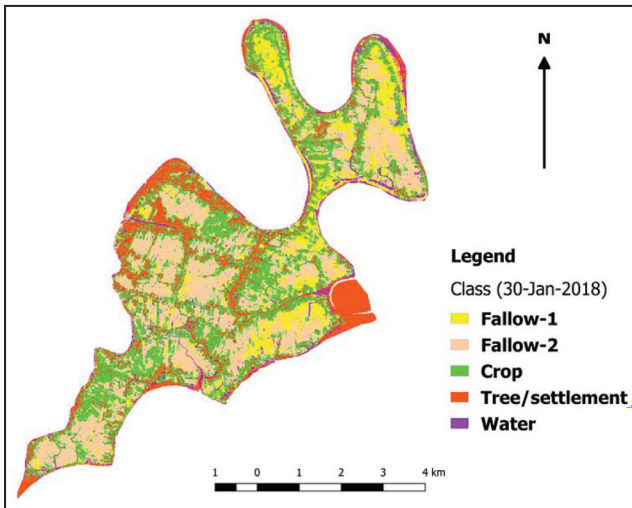


Fig. 15. Land use map of 30 January, 2018

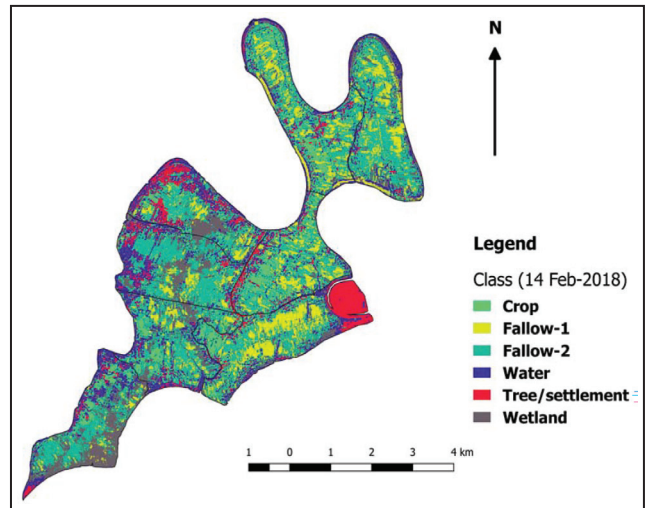


Fig. 16. Land use map of 14 February, 2018

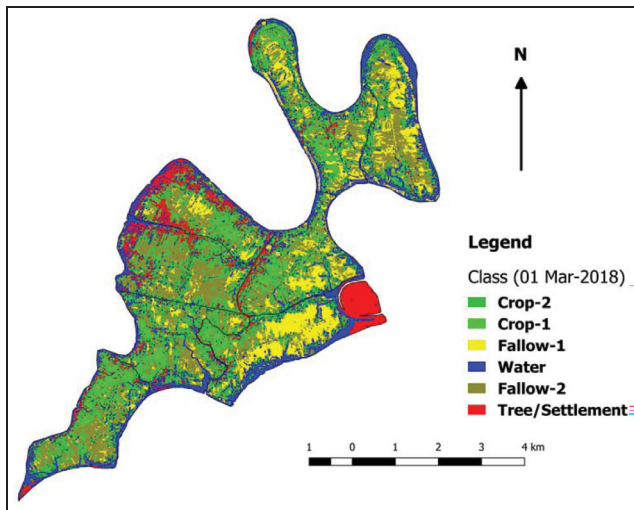


Fig. 17. Land use map of 1 March, 2018

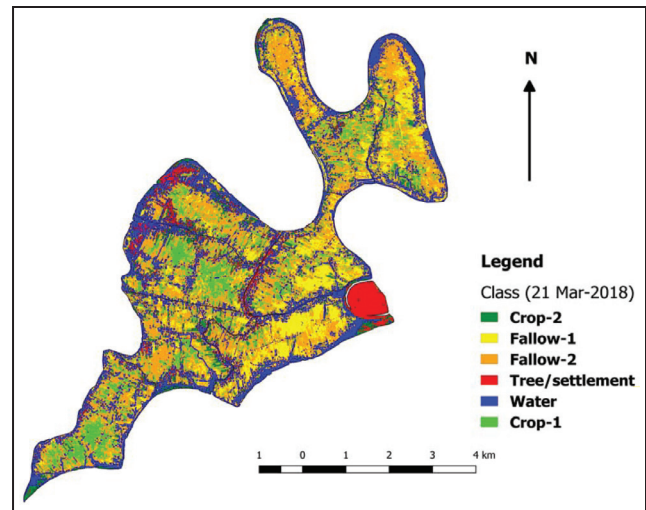


Fig. 18. Land use map of 21 March, 2018

Accuracy of classification

The commission/omission matrix for the image classification was prepared using the procedure of Barrett *et al.* (2000). Results (Table 3) showed that overall accuracy of the land use/ land cover classification gradually increased for the island from the image for 11-November, 2017 (72.22 %) to the image for 15-January, 2018 (84.85%) and after that overall accuracy decreased slightly in 30-January, 2018 (81.82 %) and 14-February, 2018 (77.78 %). The highest accuracy was found in 1-March, 2018 (85.19 %). The producer's accuracy of fallow-1 and fallow-2 were less in 1-December, 2017 (Table 3) due to the confusion between the dry fallow lands and very little moistened fallow lands after harvesting of *kharif* rice. Grass pea was grown under *utera* condition and due to this fact grass pea seeds were broadcasted in the rice field before harvesting of rice crop. When rice was harvested, grass pea was at vegetative stage. This made confusion with the regrowth from the rice stubble in the fallow area which appeared as light pinkish patches in the conventional FCC. During the end of January and in March less accuracy of the classification of cropped area were estimated. During this period grass pea was at its reproductive and maturity phase *i.e.* maximum growth stage and at the end of March summer rice exhibited vigorous growth as confirmed by the ground truth survey. For these reasons the areas under crop and tree/settlements were mixed in the classified outputs.

For monitoring of crop growth and development

using satellite based remote sensing, satellite data is to be collected at frequent interval throughout the entire crop growing phase. Satellite remote sensing has lot of promise in studying cropping systems even at smaller spatial scale with high quality of Sentinel-2 data being available at frequent periodicity as open source. This helps to overcome the difficulties of assessing crop phenology using SPOT or Landsat data with the low temporal frequency (Faivre and Fischer, 1997). The Sentinel-2 imageries with high spatial and temporal resolution can be used successfully to continuously monitor the growth and development of crop (Mandal *et al.*, 2018). Tricht *et al.* (2018) have obtained high overall accuracy for classification using Sentinel-2 data.

Satellite based remote sensing has great potential for application in cropping system analysis. Sentinel-2 imageries with its high temporal frequencies and fine spatial resolution particularly in VNIR bands are able to determine gradual changes in the crop field. Band width of Sentinel-2A and Sentinel-2B are narrow which makes them suitable for obtaining spectral response of crops in different spectral ranges. Phenological development as well as overall crop duration of crops can be successfully assessed by analysing temporal profile of reflectance and vegetation indices. We have identified some gaps in the present study. There was intermixing of tree vegetation, settlement areas and sometimes the small water bodies associated with the settlement areas. In some cases, there was mixing of very actively growing crop vegetation with tree vegetation which reduced the overall accuracy

Table 3. Temporal changes in the area (ha) under different land use/land cover types over the study period

Dates	Land use types	Producer's accuracy (%)	User's accuracy (%)	Overall accuracy (%)
11 Nov 2017	Fallow	83.33	71.43	72.22
	Crop	72.73	66.67	
	Tree/ Settlement	63.64	70.00	
	Water	75.00	85.71	
01-Dec, 17	Fallow-1	75.0	85.71	79.31
	Fallow-2	62.5	62.5	
	Crop	83.33	71.4	
	Tree/Settlement	100.0	100.0	
	Water	100.0	100.0	
26-Dec, 2017	Fallow-1	83.33	100.0	80.95
	Fallow-2	70.0	70.0	
	Wetland	66.67	66.67	
	Crop	90.0	100.0	
	Tree/Settlement	100.0	80.0	
	Water	100.0	75.0	
15-Jan, 18	Fallow-1	80.0	100.0	84.85
	Fallow-2	100.0	75.0	
	Crop	78.57	91.67	
	Tree/Settlement	85.71	66.67	
	Water	100.0	100.0	
30-Jan, 18	Fallow-1	100.0	100.0	81.82
	Fallow-2	83.33	62.5	
	Crop	66.67	80.0	
	Tree/Settlement	83.33	83.33	
	Water	100.0	100.0	
14-Feb, 18	Fallow-1	100.0	100.0	83.33
	Fallow-2	83.33	83.33	
	Wetland	85.71	75.0	
	Crop	85.71	75.0	
	Tree/Settlement	71.43	83.33	
	Water	80.0	100.0	
1-Mar, 18	Fallow-1	100.0	100.0	85.29
	Fallow-2	83.33	71.43	
	Crop-1	72.73	88.89	
	Crop-2	75.00	85.71	
	Tree/Settlement	100.0	80.0	
	Water	100.0	100.0	
21-Mar, 18	Fallow-1	80.0	100.0	84.62
	Fallow-2	85.71	66.67	
	Crop-1	75.0	81.82	
	Crop-2	80.0	88.89	
	Tree/Settlement	83.33	83.33	
	Water	100.0	100.00	

to 72%. However, this study demonstrated the potential of multi-dated Sentinel-2 imageries in analysing the cropping systems and delineating the different cropping systems with an overall accuracy of 79 to 85% during different dates in the post monsoon season.

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