Seasonal Compositing of Multi-dated Satellite Images for Cropping Intensity Mapping of Indian Sundarban Region

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ABSTRACT

Accurate assessment of seasonal crop coverage and cropping intensity is important for crop planning. The traditional approach of cropping area mapping relied on statistical reports, inventory records, as well as extensive field observations. The satellite based remote sensing provides ample opportunity for continuous monitoring of agricultural activities in a cost-effective way at regular frequent interval. The present study demonstrates application of seasonal image compositing technique with Sentinel-2 satellite images in open-source cloud computing portal, Google Earth Engine for assessing cropping sequence of 19 coastal blocks of Indian Sundarbans for 2019-20 and 2020-21.The block wise cropping system assessment showed that the *kharif* rice area showed minor change during the study period whereas the Haora and Hasnabad C.D. Blocks showed noticeable decrease in *rabi* crop area from 2019-20 to 2020-21 cropping year. In general the summer crop areas including *boro* rice decreased in almost all the blocks during this period. The cropping sequence analysis showed that the area under crop-fallow-fallow sequence (mono cropping *kharif* rice) increased from 49% to 61% of total crop lands while the area under crop-fallow-crop sequence decreased from 46% to 33%. The area under crop-crop-crop (300% cropping system) and crop-crop-fallow (cropping in *kharif* and *rabi* seasons) constituted only a small part of the total cropland in coastal Sundarban blocks.

Keywords : Cropping Intensity, Remote sensing, Seasonal image composite, Random Forest classification, Decision Tree Classification

Introduction :

Seasonal crop coverage is an important aspect of agricultural land use mapping. Accurate assessment of crop coverage, seasonality and cropping intensity can have great implication for policy makers, investors, development officials, insurance agencies, statistical bodies, trading companies, food production enterprises as well as the humanitarian aid organizations. The traditional approach of croppingarea mapping relied on statistical reports, inventory records, as well as extensive field observations.

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Since last few decades satellite remote sensing has been proved to be a reliable tool for assessment and continuous monitoring of agricultural activities in a cost-effective way (Dadhwal *et al.*, 2002 ; Ghosh *et al.,* 2018; Ennouri and Kallel, 2019; Mohammady, 2021), as the satellites provide precise information with a wide field of view at regular frequent interval.

The popularly used satellite based remote sensing tools work in three different domains namely, optical, thermal and microwave. Optical remote sensing that relies on the spectral reflectance of the target surface mainly in visible and near infrared (VNIR) wavelength range, is useful for monitoring different characteristics of crops including area of coverage, phenological development, biotic and abiotic stress which may help in simulating crop yield at regional and national scale. On the other hand, thermal remote sensing captures land surface features in the thermal infrared band which is relevant to forest fire, crop moisture stress, evapotranspiration etc. Microwave remote sensing with its high penetrating ability may be more useful under cloudy condition. In agriculture domain the microwave data are popularly used for soil moisture studies, flood area mapping etc. Several researchers have used optimally sampled temporal profiles of the satellite derived Normalized Difference Vegetation Index (NDVI) to determine the crop growth and developmental pattern (Sakamoto *et al.,* 2005; Tong *et al.* 2017; Kundu *et al.*, 2018; Ghosh *et al.,* 2021; Kundu *et al.,* 2021). The major constraint that limits application of remote sensing methods particularly in the optical range is cloud cover which occurs very frequently in the tropical countries like India. The problem is more serious during the monsoon (*kharif*) season. Even during the pre- and post-monsoon season the probability of occurrence of patchy cloud during satellite passage over a region cannot be ruled out.

The present study aims at assessing the seasonality of cropping areas by using image compositing technique for the coastal region of Indian Sundarbans. The Sundarbans region is environmentally sensitive. Besides being the biodiversity hotspot, the area around the Sundarbans is densely populated. As of 2011, the Indian Sundarbans hosts a population of 4.37 million with a staggering density of 957 people per square km spreading over 19 Community Development Blocks (Anonymous, 2014). The crop production in this region is constrained by number of hydrometeorological disasters like tropical cyclones, storm surge, frequent water logging as well as seasonal salinity build-up (Mainuddin *et al.,* 2019).

The present study aims at assessment of seasonal cropping areas of 19 coastal blocks of Indian Sundarbans for *kharif, rabi* and *pre-kharif* seasons of 2019-20 and 2020-21 using seasonal composites of Sentinel-2 satellite images in open source cloud computing portal, Google Earth Engine.

Materials and methods :

Study area and the period of study :

The present study was conducted in 2019-2020 and 2020-2021 cropping years for the Indian Sundarbans region (21° 30’ to 22° 40’ N, 88° 05’ to 89° 55’ E) which occupies around 4000 km^2 area at the estuary of the Hugli-Matla-Ichhamati river system along the coast of the Bay of Bengal. Indian Sundarbans region (Figure 1) constitutes of nineteen Coastal Developmental (CD) Blocks - thirteen blocksof South 24 Parganas and six blocks of North 24 Parganas districts of West Bengal. The region belongs to the coastal saline agro-climatic zone of West Bengal. People primarily depend on agriculture to sustain their livelihood. Mono-cropping of *kharif* paddy is the general practice here. The dry season crop production is limited by erratic rainfall, cyclonic disturbances, waterlogging, soil salinity build-up, unavailability of suitable irrigation water, etc. (Ghosh *et al.,* 2019; Mainuddin *et al.,* 2019; Sarkar *et al.,* 2019).

Data used :

Satellite imageries : Multi-temporal Sentinel-2 data were used in the present study to develop seasonal cloud-free composites. The Sentinel-2 mission European Space Agency comprises of a constellation of satellites aimed at earth surface monitoring at 290 km swath width of and high revisit time of 5 days at equator and in 2-3 days at mid-latitudes. Sentinel-2 delivers images in 13 spectral bands ranging from 10 to 60-meter pixel size. The blue, green, red, and near-infrared (B8) channels have a 10-meter resolution. The red edge, near-infrared NIR, and short-wave infrared SWIR are of 20 meters. The coastal aerosol and cirrus band have a 60-meter pixel size. The data are available open source for public use. The acquisition dates of the Sentinel-2 data for the present study are mentioned in the Table1.

Field survey : In order to generate the training dataset for land use classification, ground data for the study period were collected through GPS survey with support from the Agromet Field Unit (AMFU) of Regional Research Station, Kakdwip, BCKV.

Data processing steps :

The data processing in this study involved seasonal compositing of multi-dated satellite image followed by season wise land use classification for surface feature extraction. The land use classes are re-grouped into three classes namely, a) Cropped b) Fallow and c) Non-cropped (or other land use). The cropping intensity classification was done in the next step considering the regrouped classes. The schematic diagram of the model flow chart adopted in the presented study has been presented by the Figure 2.

Image compositing : Image compositing is a process in which the time series of multi-dated satellite images of the specific period are put together to obtain a synthetic image. The synthetic image is composed of pixel wise statistical aggregate of image values (Digital Numbers) for each location. Generally, the mean, maximum, minimum, median or any other aggregate values of the image series are considered for each pixel location are considered for image compositing. For example, the mean composite results an output consisting array of the mean all pixel values in the image series for each pixel location. In the present study we prepared the median composite with the assumption that the median value of the time series represents the overall vegetation condition irrespective of crop species and thus, the cropping area as a whole can be estimated. Another objective of image compositing is to avoid the cloudy pixels. As there is always a probability of patchy cloud throughout the year, more so during kharif season, we prepared the cloud free image for each date by masking out the cloud pixels. The cloud free images are thus patchy with holes of 'no data' replacing the cloud pixels. By compositing the multiple layers of image, the resultant image gives the median of whatever pixel values available in the series for each pixel location. The seasonal cloud-free Sentinel-2 composites were compiled using the threshold parameters (described in Table-2).

Parameters for seasonal image composite : The seasonal cloud-free composites were prepared by removing the cloud pixels of each image representing the peak vegetative growth period of major crops of the corresponding season and taking their median composite. The image acquisition dates and respective cloud cover percentage for each season are presented in Table-1. Unlike *kharif* and *rabi* seasons, we have prepared two image composites for summer season, one for the month of February to represent the transplanting and seedling stage of *boro* rice and the other for March-April to capture the vegetative growth stages of *boro* rice as well as other summer crops like green gram which covers large area in the Indian Sundarban region. The dates considered for seasonal image compositing varied from year to year depending on the availability of cloud free images covering the growth phase of the crop. The synthetic images so obtained were used for the present study. The parameters and thresholds considered for developing cloud composite has been given in the Table 2.

The image-composite generation process involved the following steps,

i) The images with cloud percentage of more than 80% (fully cloudy) are not considered for image composite development

ii) The cloud pixels from the partially cloudy images (<80% cloud cover) were removedby imposing reflectance threshold. As the clouds have a high reflectivity, the pixels with reflectance more than the threshold value that represents cloud pixels are masked with no data value.

iii) Removal of cloud shadow was done by selecting pixels of above 35 percentile of reflectance. This will not affect water pixels which have low reflectivity throughout the season.

iv) Bit wise median composite is done for rejecting no-data pixels and choosing overall vegetation condition of the season.

Image classification : The visible (blue, green and red) and near-infrared bands (VNIR bands) of the image composite of the study area were stacked season wise and used for supervised classification. Image classification is the process of clustering the pixels of an image based on the digital numbers of multiple bands. Each cluster represents a class comprising of pixels of similar spectral characteristics. The process is used for land use land cover (LULC) assessment in which the areas under similar features are put under one class. In supervised classification the ground survey data are used as training sets for the system to run the in-built classification algorithm. In the present study we used machine learning based Random Forest Classification (RFC) and rule-based Decision Tree (DT) classification for seasonal LULC mapping. The different LULC classes considered in the present study are presented in table-3.

A) Random Forest classification : The seasonal composite images were used for the Random Forest classification (RFC) to produce seasonal land use maps. The RFC algorithmis a supervised classification algorithm. The RF relies on many self-learning decision trees (i.e."Forest"). The idea behind using multiple decision trees (DT) is that many base learners can come to one strong and robust decision compared to a single DT (Breimann 2001). Different land use classes, separated by RFC during different seasons under study are given in the Table-3.

B) Rule based Decision Tree classification : Decision Tree (DT) is asupervised learning techniquethat is preferred for solving classification problems. It is a tree-structured classifier, whereinternal nodes represent the features of a dataset, branches represent the decision rulesandeach leaf node represents the outcome. In the present study, DT classifier was used for land use mapping of *kharif* season as well as for cropping system classification. The classification was done on the basis of class values of different classes. At each node, images acquired from different seasons were taken for further decision making to get an accurate cropping pattern. The non-crop area was not taken into consideration and assigned as 'Others'.

The decision tree classification was focussed on crop-fallow dynamics. Four possible cropping systems, viz. crop-fallow-fallow, crop-fallow-crop, crop-crop-fallow and crop-crop-crop were identified in the study area. The DT classifier rules followed in the present study is presented in the Figure 2. While doing classification, we found many seasonal water bodies in the study area. The land adjacent to the rivers are also flooded during *kharif* season. Thus, a part of the water class showed seasonal transition as water to vegetation or water to fallow. The lands which are categorized as water on one or two seasons and vegetation in other seasons are put under crop land class considering seasonal water as fallow.

We have considered three spectral bands viz. Blue, Green, Red and near infrared of the seasonal composite images for classification purpose. The land use classes obtained as a result of image classification for each cropping season are enlisted in Table 3.

Tools and software used :

In the present study the cloud computing platform, Google Earth Engine (GEE) was used for generating seasonal cloud-free composites of Sentinel-2 data. Open-source Remote Sensing and GIS software, SAGA 6.4.0 (System for Automated Geoscientific Analysis) was used for image classification and QGIS 3.16 (Quantum Geographic Information System) for map generation.

Results :

Seasonal land use dynamics :

The thematic land use maps of *kharif*, *rabi* and summer seasons for 2019-20 and 2020-21 are presented in the Figure 4.

It was observed from land cover classification that tree or perennial vegetation and Mangrove occupied about 44% (195977 ha) of the total study region in both 2019-20 and 2020-21 while the water class that included creeks canals and ponds constituted about 4-7% of the total study region. The water class and the submerged lands are mainly present in the northern blocks and they are seasonally variable. About 16% of the study area are submerged land during 2019-20 which reduced to about 10% in the following summer season. During 2020-21, the submerged land remained almost constant (at 12%) throughout the year.

The satellite-based observations showed that the crop coverage area was highly variable over the study region. The results revealed that about 38% and 37% of the total study region are covered by crop during the monsoon season of 2019-20 and 2020-21, respectively. There was practically no fallow land and the *kharif* rice was widely cultivated in all types of land. The crop coverage drastically reduced to 6% and 5% of the total study area during *rabi* season of 2019-20 and 2020-21 respectively. In the summer seasons the crop land increased to about 22% and 17% of the total study region during the same period.

The block wise crop land areas during different seasons are shown in Figures 5 to 8. The largest area under *kharif* rice was recorded in Patharpratima block followed by Gosaba and Basanti block (Figure 5) whereas during *rabi* season Hasnabad and Haroa blocks of North 24 Parganas which are away from the coast line, recorded higher *rabi* crop coverage (Figure 6). The area under *rabi* crops was very low in Sandeshkhali-1 and 2 blocks. In the summer seasons, the largest area under *boro* rice was found in the Kultali block (7558 ha in 2019-20 and 8284 ha in 2020-21) while Gosaba block constituted the largest area covered by non-rice summer crops (6710 ha 2019-20 and 3295 ha 2020-21).

As *kharif* rice is the major crop over the Sundarban region, there is no abrupt change in rice acreage during *kharif* season between 2019-20 and 2020-21. The general trend shows that the *kharif* rice area was slightly decreased in the larger blocks like Patharpratima, Gosaba, Basanti, Hingalganj and Kultali whereas in Sagar and Canning-2 there was slight increment in the *kharif* rice growing area (Figure 5). However, the change was very minor and that might be due to the inherent inaccuracy of the satellite-based estimation.Unlike the *kharif* season the cropping areas in *rabi* season showed noticeable variations in crop coverage area in the coastal blocks of Indian Sundarban region during the two years of study (Figure 6). In *rabi* season maximum decrease of cropping area was found in Haroa followed by Hasnabad. Other blocks like Canning-1, Canning-2, Jaynagar-1, Jaynagar-2, Kakdwip etc. also showed decrease in cropping areas. The increment in rabi crop area was also found only in few blocks, like Namkhana, Sagar, Kultali, Mathurapur-2 block etc.

Figure 7 shows that the area coverage under *boro* rice was higher than the non-rice crops in Kultali, Mathurapur-2, Canning-2, Jaynagar-2 and Mathurapur-1 blocks whereas in blocks like, Namkhana, Hingalganj, Sagar, Gosaba, Pathar Pratima, Kakdwip and Basanti other summer crops were widely grown. Unlike *kharif* season there was wide year to year variation in summer crop coverage in the coastal blocks. The *boro* rice coverage increased in Mathurapur-1, Mathurapur-2, Haroa, Sandeshkhali-2, Kultali and Canning-1 blocks whereas the area decreased in Basanti, Canning-2, Sandeshkhali-1 and Kakdwip blocks. The non-rice summer crop coverage in almost all the blocks decreased from 2019-20 to 2020-21 except Hasnabad, Haroa, Mathurapur-1 and Sandeshkhali-2.

Cropping system :

Rule-based decision tree classifier was followed to distinguish different cropping system classes e.g. crop-fallow-fallow, crop-fallow-crop, crop-crop-fallow, crop-crop-crop. The analysis (Figure 8) showed that in 2019-20 about 49% (50477 ha) of the total cropped areas were mono-cropped (crop-fallow-fallow) while in 46% (47260 ha) areas crop-fallow-crop system was followed. The crop-crop-fallow practice was followed in 3% of the total crop areas. Only 2% of the total crop lands were intensively cultivated with 300% cropping intensity. In the second cropping year (2021-21), mono cropping system (crop-fallow-fallow)was found to occupy about 61 % (97836 ha) of the total cultivated land. The crop-fallow-crop and crop-crop-fallow systems covered about 33% (52329 ha) and 2% (3392 ha) of total cultivated land, respectively. The crop-crop-crop system i.e., the 300% intensity was found in 4% (6220 ha) of total cultivated land in the study region.

The block-wise distribution of different cropping system classes (Figure 9) suggests that the mono-cropping system (crop-fallow-fallow) occupied major part of the cropping areas in Sagar, Patharpratima, Namkhana and Hingalganj blocks whereas in Kultali, and Mathurapur-1 and 2 blocks the summer crops are grown in larger areas (crop-fallow-crop system) in both the years of study. The Haora and Hasnabad blocks have very low cropping areas. But the rabi crop cultivation are more prevalent in these two blocks (crop-crop-fallow system). The study further shows that in most of the C D Blocksthe total cropping areas and particularly the monocropping areas (with *kharif* rice) increased from 2019-20 to 2020-21.

Conclusion :

The cloud free seasonal image compositing process yielded a single image representing vegetation coverage of each season irrespective of the growing window of crop by considering threshold percentiles of the available VNIR values (after cloud filtering) against each pixel location. The open-source satellite images like Sentinel-2 that gives global coverage at five days interval may be used for generating cloud free composite images that can be very useful for season wise overall cropping area mapping. The use of open-source cloud computing platform, Google Earth Engine can be explored for easy processing of multi dated satellite images which otherwise requires high end computing systems.

The Sundarban region is constrained by several factors like, adverse weather condition, high salinity, frequent seasonal inundation etc. The blocks where comparatively higher proportion of upland exists can harvest kharif rice earlier. There is a scope of increasing cropping intensity by appropriate agronomic and engineering interventions like paira cropping, introduction of salt tolerant crops and varieties, facilitating drainage methods.

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Table 1 : Acquisition dates of Sentinel-2 data used for seasonal cloud-free composites

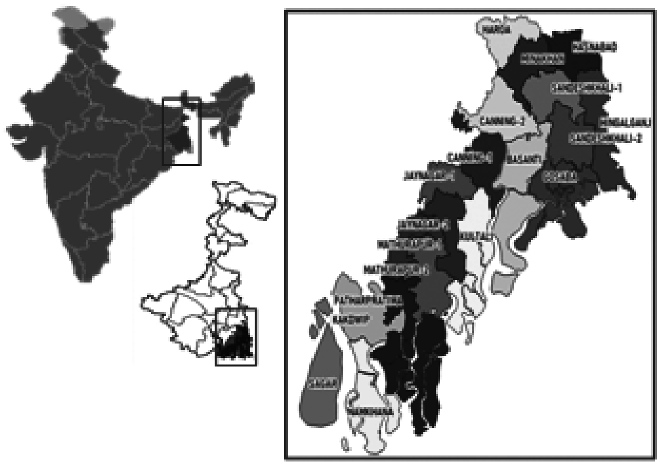
Cropping years	Seasons	Period of composites and Number of images	Dates of image acquisition and cloud cover percentage (in parenthesis)
2019-20	*Kharif*	15 Sep - 15 Nov 6 images)	17-Sep (23%); 12-(Oct12%); 17-Oct (11%); 22-Oct (23%) 27-Oct (41%); 01-Nov (31%);
	Rabi	25 Dec to 20 Jan (3 images)	31-Dec (0%); 10-Jan (68%); 15-Jan (0%)
	Summer-I	1 Feb to 15 Feb (3 images)	01-Feb (0%); 06-Feb (80%); 11-Feb (0%)
	Summer-II	1 Mar to1 Apr (6 images)	02-Mar (76%); 12-Mar (24%); 17-Mar (40%); 22-Mar (74%); 27-Mar (2%); 01-Apr (0%)
2020-21	*Kharif*	15 Jul to 15 Nov (6 images)	06-Oct (70%); 16-Oct (25%); 26-Oct (21%); 05-Nov (0%); 10-Nov (42%); 15-Nov (0%)
	Rabi	25 Dec to 10 Jan (3 images)	27-Dec (0%); 01-Jan (0%); 06-Jan (0%)
	Summer-I	1 Feb to 28 Feb (6 images)	03-Feb (0%); 08-Feb (0%); 13-Feb (3%) 18-Feb (4%); 23-Feb (0%); 28Feb (8%)
	Summer-II	15 Mar to 20 Apr (6 images)	15-Mar (0%); 20-Mar (4%); 25-Mar (69%) 30-Mar (54%); 09-Apr (62%); 19-Apr (65%)

Table 2 : Parameters and thresholds taken for developing cloud composite

Parameter	Threshold	Purpose
Cloud threshold	80	For filtering images cloud less than 80 percent
VNIR threshold	0.3	Cut-off for unmasked cloud
VNIR percentile	35	For selecting pixels at vegetative growth stages

Table 3 : Image classification methods and classes for different seasons

Season	Method	Classes
Kharif	Random Forest Classification (RFC)	1. Kharif rice 2. Tree + Settlement + Mangrove 3. Water 4. Submerged
Rabi	Random Forest Classification (RFC)	1. Fallow, 2. Tree + Settlement + Mangrove, 3. Other crops, 4. Water, 5. Submerged
Pre-kharif / Boro	Random Forest Classification (RFC)	1. Fallow 2. Tree + Settlement + Mangrove 3. Other crop 4. Water 5. Submerged 6. Boro rice
Cropping sequence (Kharif-Rabi-Summer/ Boro)	Rule-based Decision Tree Classification (DT)	1. Crop-Crop-Crop 2. Crop-Fallow-Crop 3. Crop -Crop-Fallow 4. Crop-Fallow-Fallow 5. Other Classes



Sl. No.	Block_Name	District name	Sl. No.	Block_Name	District name
1	Basanti	South 24 Parganas	14	Haroa	North 24 Parganas
2	Canning-1		15	Hasnabad	
3	Canning-2		16	Hingalganj	
4	Gosaba		17	Minakhan	
5	Jaynagar-1		18	Sandeshkhali-1	
6	Jaynagar-2		19	Sandeshkhali-2	
7	Kakdwip				
8	Kultali				
9	Mathurapur-1				
10	Mathurapur-2				
11	Namkhana				
12	Patharpratima				
13	Sagar				

Figure 1. Geographical location of the study area

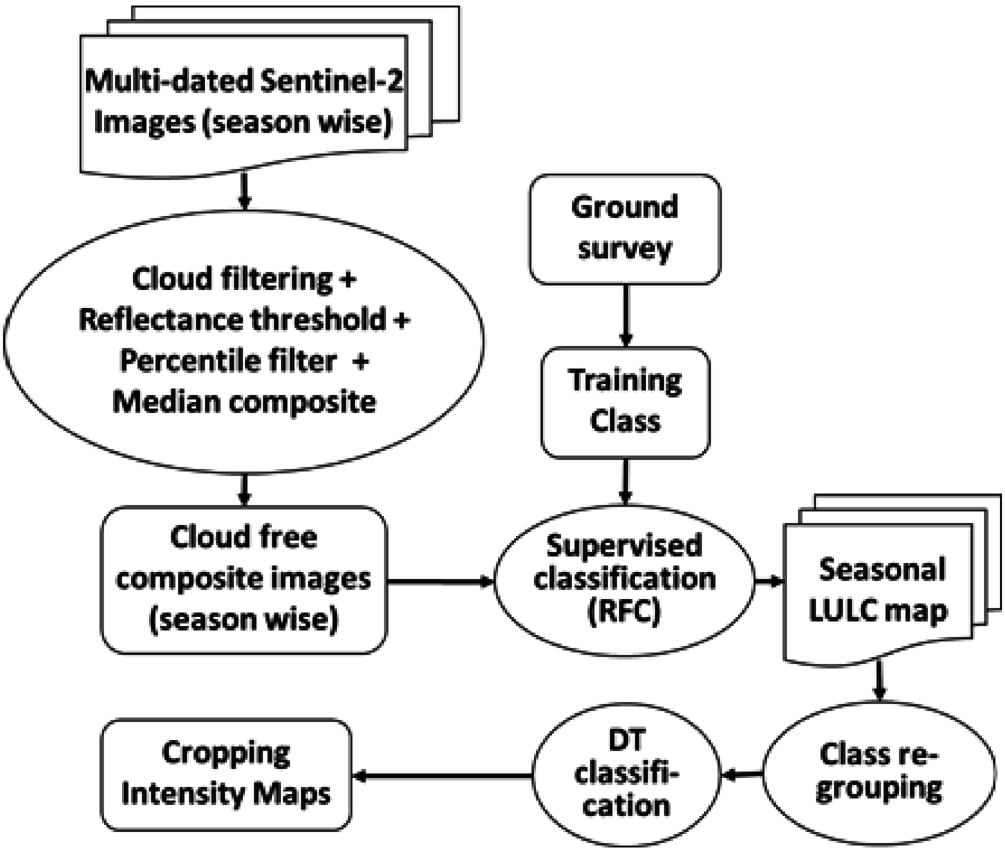


Figure 2. The model flowchart adopted in the presented study

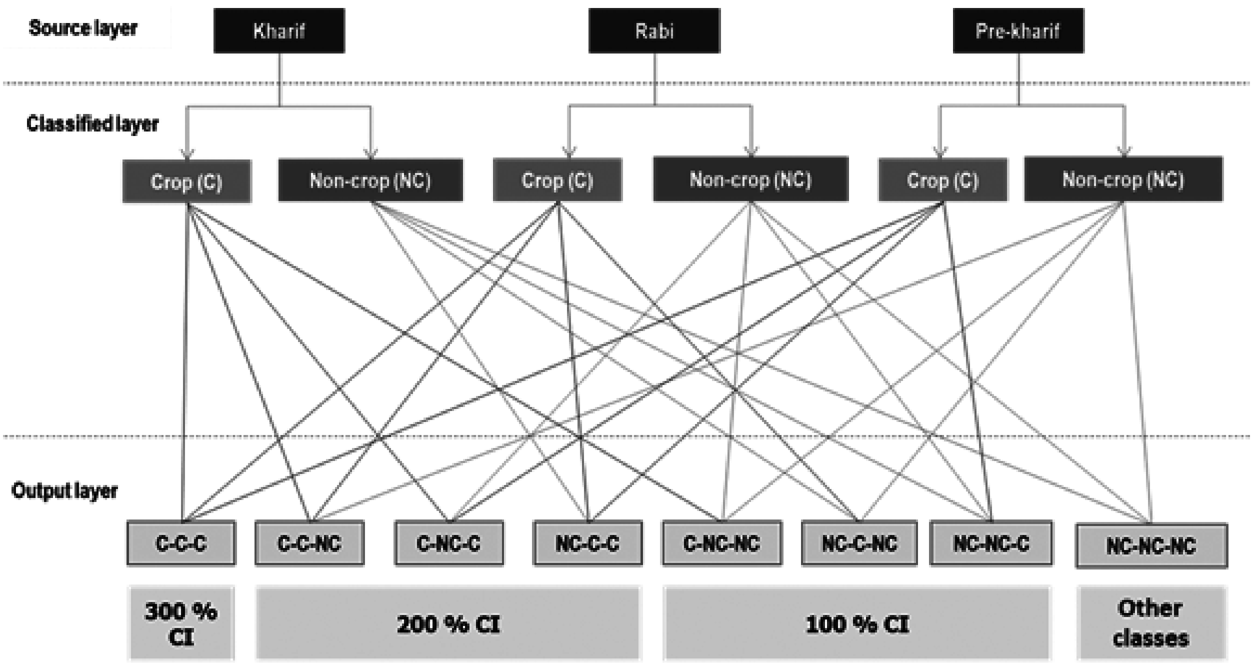
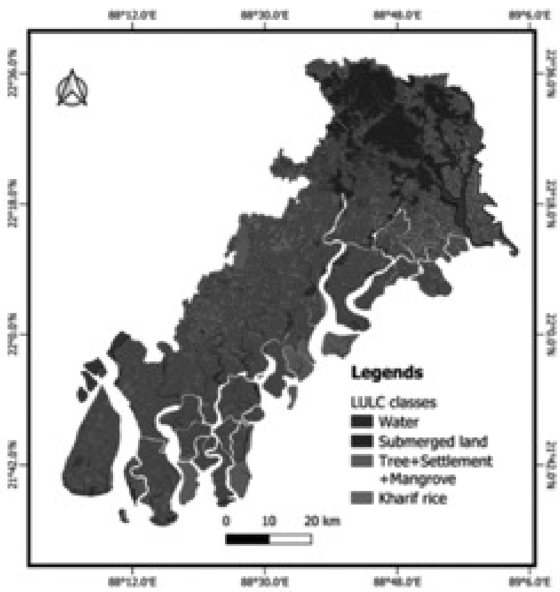
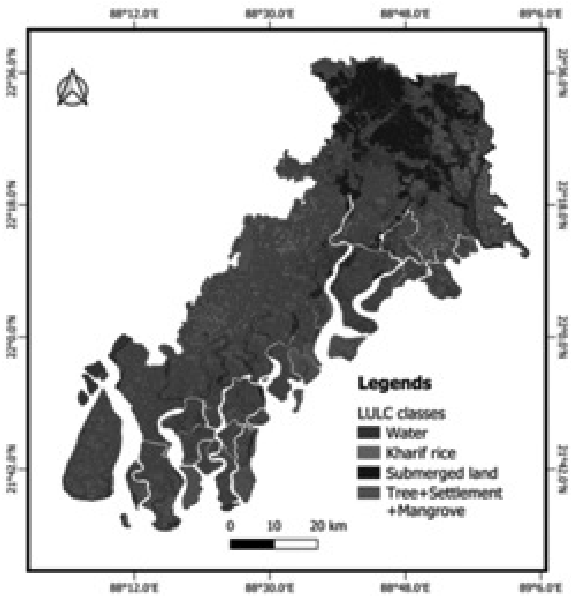


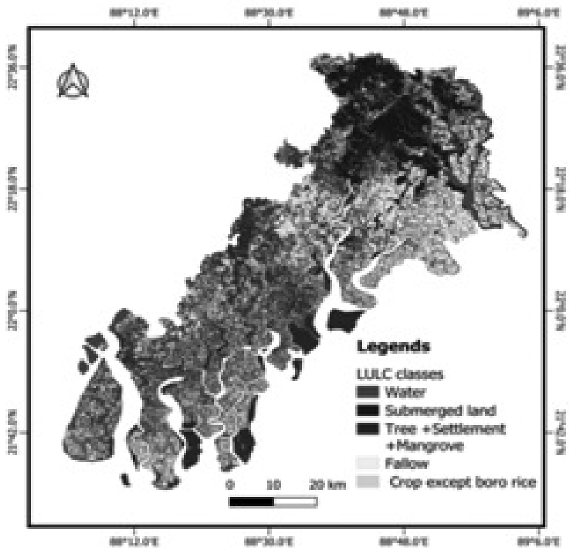
Figure 3. Decision Tree classification frame work for cropping intensity mapping



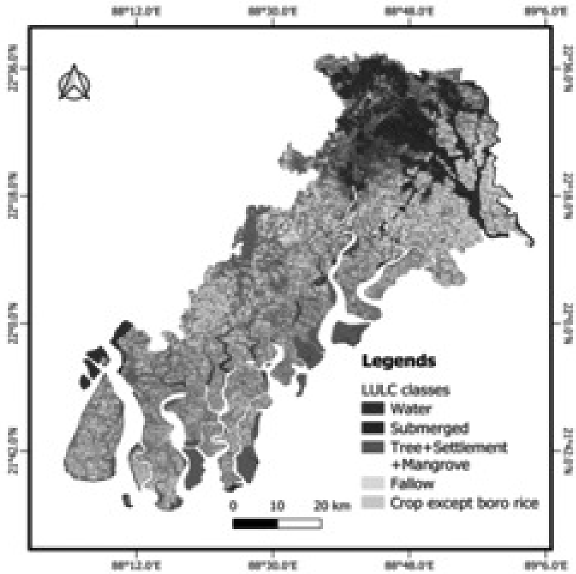
Kharif **Season 2019-20**



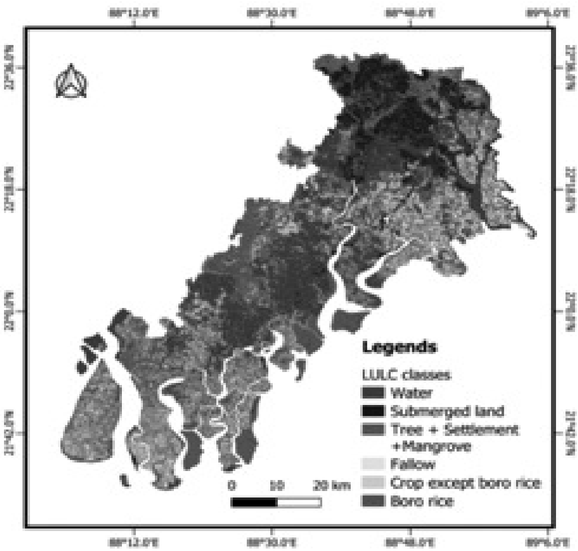
Kharif **Season 2020-21**



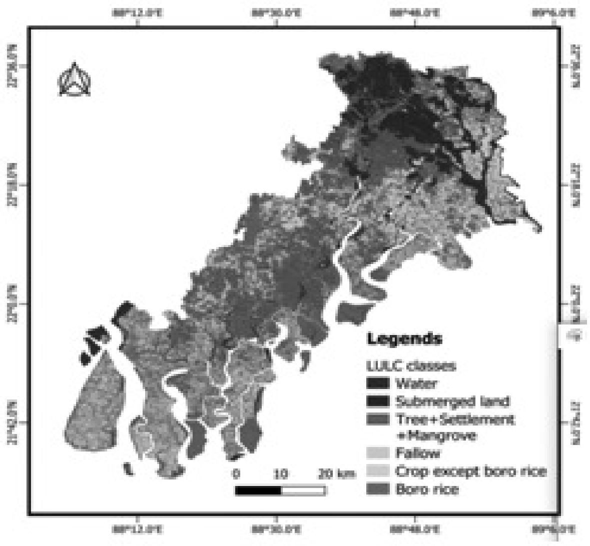
Rabi **Season 2019-20**



Rabi **Season 2020-21**



Summer Season 2019-20



Summer Season 2020-21

Figure 4. Land use maps of coastal blocks of Indian Sundarbans during 2019-20 and 2020-21

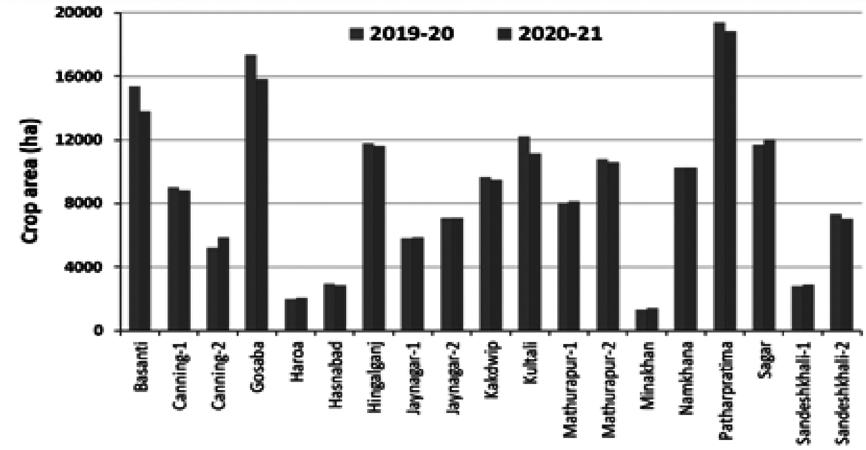


Figure 5. ***Kharif*** **rice area of coastal blocks of Indian Sundarbans during 2019-20 and 2020-21**

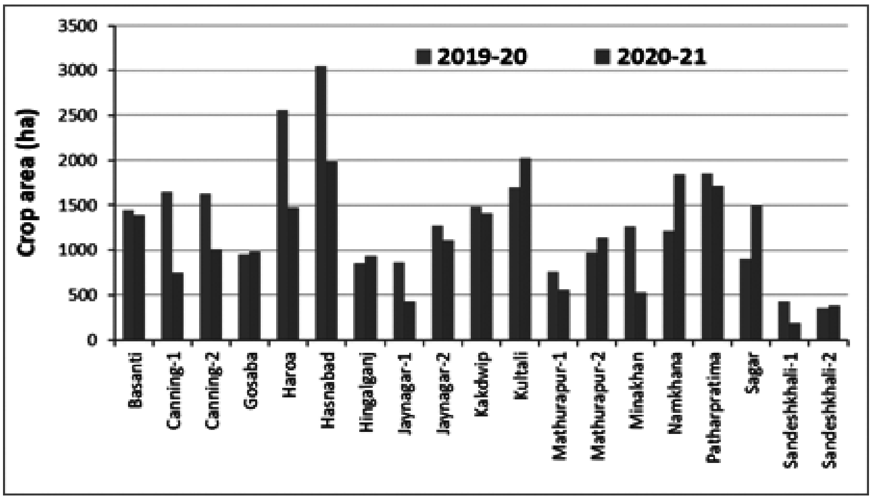


Figure 6. ***Rabi*** **crop area of coastal blocks of Indian Sundarbans during 2019-20 and 2020-21**

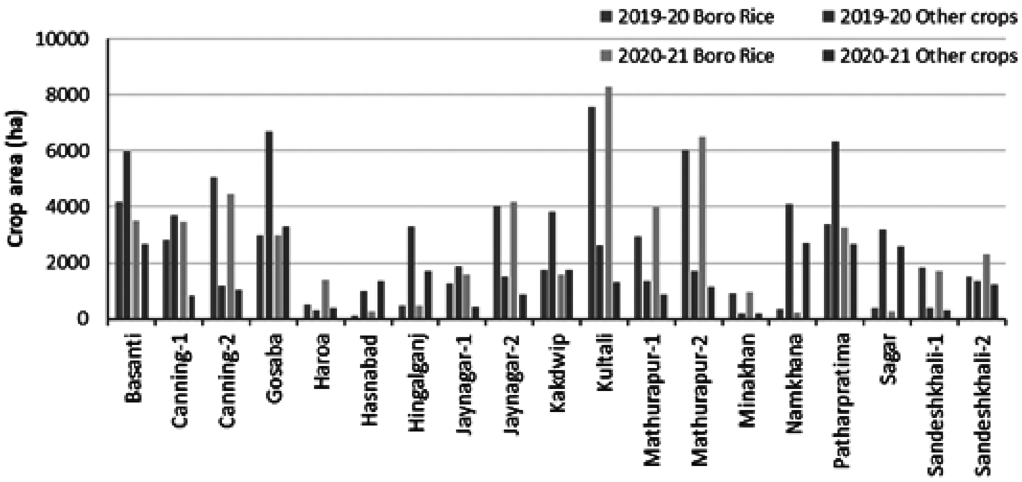


Figure 7. ***Boro*** **rice area of coastal blocks of Indian Sundarbans during 2019-20 and 2020-21**

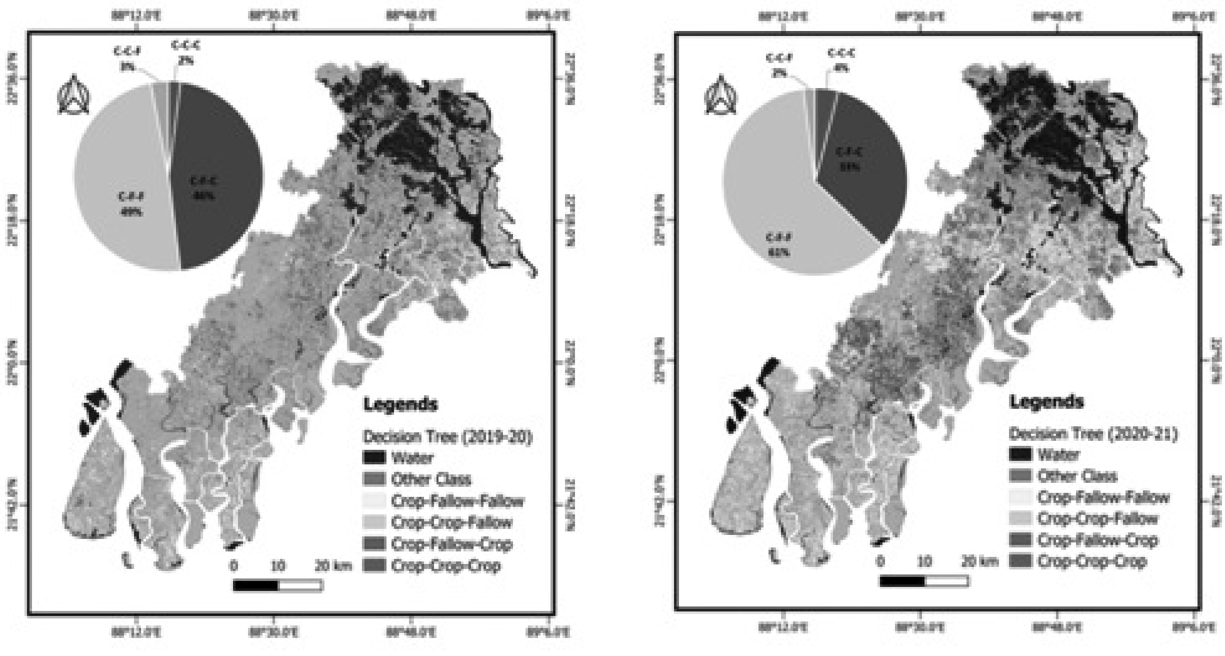
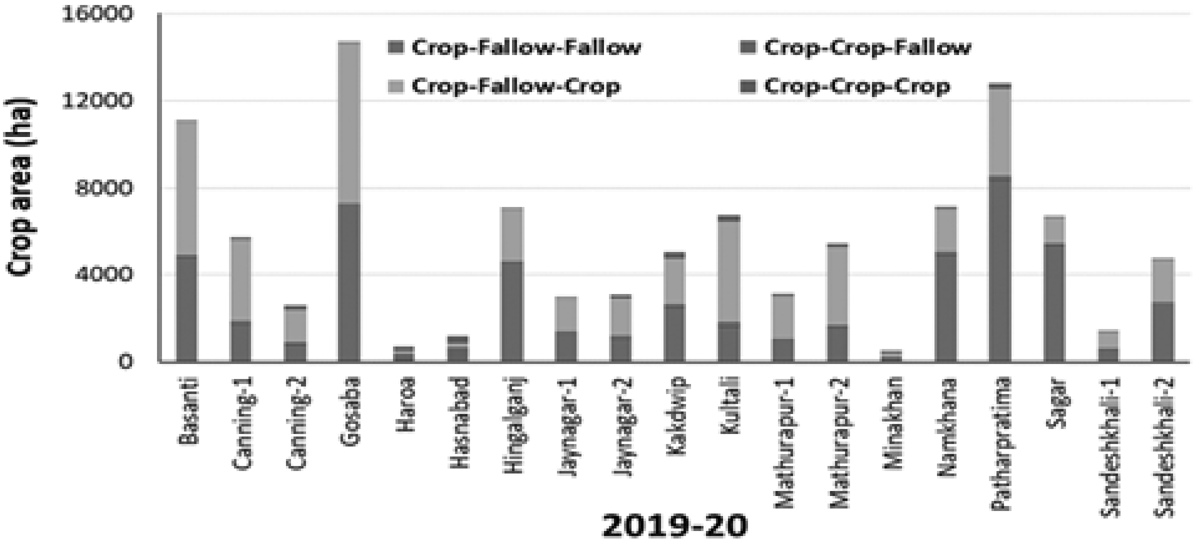


Figure 8. Cropping system map of coastal Sundarban blocks during 2019-20 and 2020-21



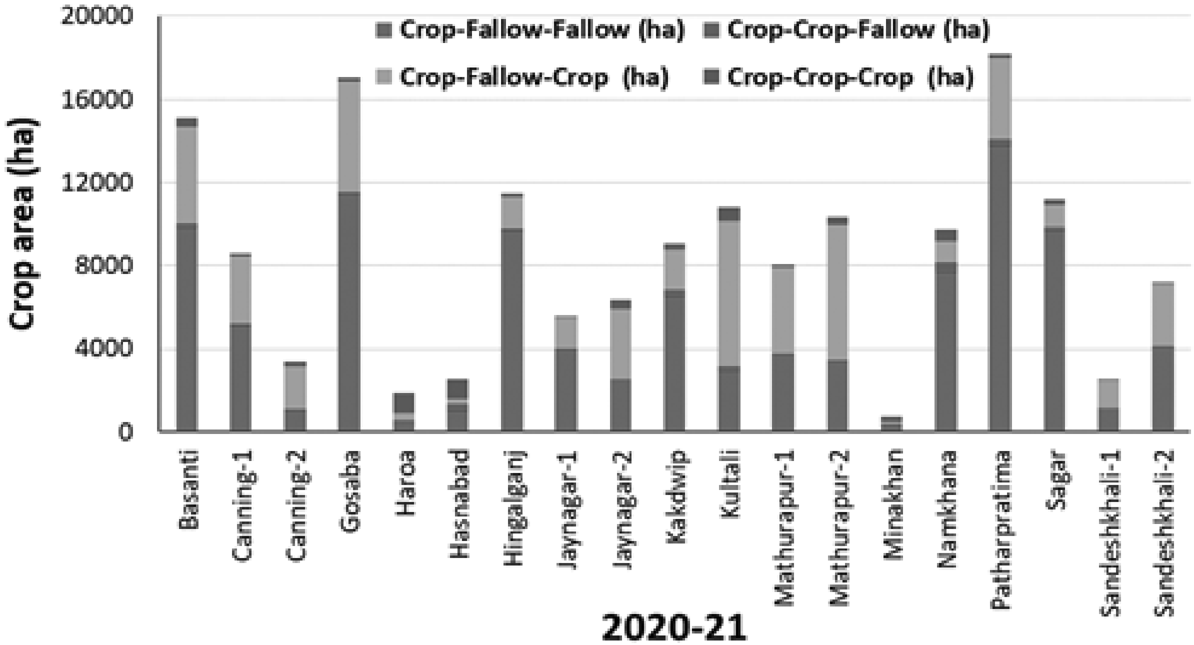


Figure 9. Estimated areas under different cropping sequences in coastal Sundarban blocks during 2019-20 and 2020-21