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Mapping Rice Paddy Cropping Patterns with MODIS and ALOS-2 ScanSAR Over Bangladesh from 2001 to 2018s

Md RahedulIslam[1]*, Wataru Takeuchi [1,] Kei Oyoshi[2]

1 Institute of Industrial Science, The University of Tokyo, Meguro, Tokyo 153-8505, Japan; wataru@iis.u-tokyo.ac.jp

2 Earth Observation Research Center, Japan Aerospace Exploration Agency (JAXA), Tsukuba, Ibaraki, 305-8505, Japan

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Abstract

Bangladesh is one of the largest rice producer, importer, and consumer's country in the world. The food security of the country depends on rice production. But the rice production of the country is facing several challenges like climate change, arable land loss, water scarcity and methane emission. The remote sensing-based rice area mapping of the country challenging due to the seasonal cloud contamination, fragmented field size, high cropping intensity and diversity. The objective of this study to mapped rice seasonal rice area as dry season boro, post-monsoon season amon and rainy season aus rice area from 2001 to 2018. The global positing system (GPS) field data on cropping pattern, ALOS-2 ScanSAR HH and HV backscattering coefficient and moderate resolution imaging spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) dataset uses for this study. In methodology, firstly we use multi date ALOS-2 ScanSAR and GPS field data with unsupervised k-means ++ clustering for identifying seasonal rice area in 2018. Secondly, ALOS-2 ScanSAR rice paddy information and MODIS Kalman's NDVI data uses for seasonal rice paddy area map in 2018 and extended it from 2001 to 2018. Thirdly, the ALOS-2 ScanSAR rice area map compared with GPS field data for validation and ALOS-2 ScanSAR map used for validating MODIS rice area map. Finally, the rice area compared with the national statistical data and relevant studies over the country. The result shows that the boro rice area increases (30.44%), amon (4.65%) and aus (11.90%) rice area decrease from 2001 to 2018. ALOS-2 ScanSAR seasonal rice area and GPS field data overall accuracy 78.65% and kappa value 0.76. The ALOS-2 ScanSAR and MODIS seasonal rice area show an overall accuracy of 83.5% with kappa value 0.77. The ALOS-2 and MODIS based estimated rice area compared with national statistics reported area and found R2 value 0.98 (boro), 0.87 (amon) and 0.62 (aus). Furthermore, we compared our result with the relevant studies and found very strong agreement.

***Corresponding Author:** Md Rahedul Islam, Email: rahe@iis.u-tokyo.ac.jp

Introduction

1.1 *Background of this Research*

Rice is the staple food for more than half of the global people and sources of 40% of total calorie intake(Mosleh and Hassan 2014). About 90% of total global rice is cultivated in Asia. Bangladesh is the 4th largest rice producer and top rice consumer (annual 172 kg per capita) country in the world (FAOSTAT: FAO Statistical Databases (Food and Agriculture Organization of the United Nations) Databases 2019). Agriculture contributes to 19.2% of the country's total Gross Domestic Product (GDP) and 40% of the labor force engaged in this sector(BBS 2018c). The 75% of the total arable land of the country is used for rice cultivation and produced 56.8 million ton rice in 2018 (BBS 2018c). Due to technological development (irrigation, high yield varieties, management), rice production increased drastically. But the country is still not self-sufficient to rice production and frequently imported rice (RAHMAN and PARVIN 2009). The country needs to produce 70% more food to extend 300 million people in 2050 (Government et al. 2018). To increase rice production, the country intensively using the arable land, irrigation water, chemical fertilizer, and pesticide. But, the rice production is facing several challenges likes; high demand of rice for drastic population growth(Mosleh and Hassan 2014) the arable land losses (Rai et al. 2017), climate change impacts(Kumar et al. 2017), water scarcity (Hasan et al. 2018), arsenic contamination(Carrijo et al. 2018), diseases transmissions(Gilbert et al. 2008), and salinity intrusion in the coastal area. At the end of 2025, 15 to 20 million hectares of irrigated rice will suffer extreme water scarcity(RAHMAN and PARVIN 2009). Intergovernmental Panel on Climate Change (IPCC) predicts that the country will possibly decline rice production 8% by 2050 (Cancelliere et al. 2007). To ensure food security, the country needs to adapt policy for sustainable rice management. As a result, proper information on rice paddy especially the spatial distribution, seasonal extended, long term dynamics are very important for the country.

The conventional ways of rice mapping are field visit, farmer interviews, household survey, and expert opinion to collect data and represent with Geographic Information System (GIS) and statistical application at the national or sub-national level. Although, it provides historical trends of rice area but unable to provide the exact location of the rice paddy field. Moreover, the traditional method is time-consuming, inconsistent, and laborious. There is a discrepancy between conventional rice area statistics and actual rice production and frequently unstable the country's rice market. As a result, sometimes the country shows enough rice production but at the end need to import rice(Gumma et al. 2014). Accurate and timely spatio-temporal information on rice paddy field could overcome the problem. The remote sensing application is one of the most appropriate solutions for rice area mapping.

Remote sensing application for rice area monitoring and mapping is already proven as an efficient and dependable tool for precise and timely information on rice phenology and vegetation development (Mosleh, Hassan, and Chowdhury 2015). The remote sensing-based rice mapping studies mostly used optical sensor and Synthetic Aperture Radar (SAR) sensor data. The optical single sensor-based Lands at, Advanced Very High Resolution (AVHRR) and MODIS data derived indices are the most commonly used at global and regional scale(Abatzoglou, J.T., S.Z.

Dobrowski, S.A. Parks 2018). The rice and others land used mix pixel classification is one of the disadvantages for single sensor application. Multi-temporal and high-resolution sensor data have been used to overcome such problem(Long et al. 2013). The multi-temporal Landsat 8 Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) data with Convolution Neural Network (CNN) algorithm were used for mapping rice area in China with very high accuracy(M. Zhang et al. 2018). The Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) data from 1993 to 2016 with NDVI, Modified Normalized Difference Water Index (MNDWI) and masking method have been used for rice area mapping in Southern China region(Liao et al. 2018). The Moderate Resolution Imaging Spectroradio meter (MODIS) derived NDVI, intensive field data and spectral matching techniques used rice mapping in Bangladesh with 90% accuracy(Gumma et al. 2014). Although, the global coverage, high temporal resolution and long time series are advantages of using optical data for rice mapping. But, the main challenges of the optical remote sensing data are cloud contamination and coarse spatial resolution especially for cloud prone country like as Bangladesh.

Synthetic Aperture Radar (SAR) sensor based data have been used to complement the cloud problems of optical sensor images because SAR data are not influenced by weather conditions (Zhu et al. 2012). Several studies used L-band SAR data for mapping seasonal rice at the national and subnational scale(Wang et al. 2015; Mosleh, Hassan, and Chowdhury 2015; Kuenzer and Knauer 2013). The advantage of SAR data is its ability to penetrate through canopies and sensitive to vegetation structure in any weather condition. The synthetic aperture radar (SAR) ALOS/PALSAR data derived multidate variation of horizontal-horizontal polarization and support vector machine (SVM) classifier has been used in south-east China (Y. Zhang et al. 2009). The operational near real-time rice area mapping with Sentinel-1 data on GEE platforms with random forest classifier with the classification accuracy of 0.84% found in India (Mohite et al. 2018). The study found 90% overall accuracy of rice classification in Bangladesh and Northeast India with SAR imagery and random forest classification at GEE platform (Singha et al. 2019). High spatial resolution, less weather affects, and polarized data are the advantages of SAR sensors remote sensing. But, the wide-area coverage, short time series, available data are the limitation for SAR dataset.

It is a dilemma between optical and SAR sensor-based rice mapping. Although, the optical remote sensing has long time series with high temporal resolution but the coarse spatial resolution and cloud contamination. On the other hand, SAR sensor has high spatial resolution and less cloud effects but short time series and data availability. Combinedly, SAR and optical sensor application for rice area mapping is potential solutions. Multisensory; Land sat, MODIS and PALSAR data derived Vegetation Indices have been used for rice mapping in Thailand(Guan et al. 2018). MODIS NDVI and AMSR-E Land Surface Water Coverage (LSWC) with Fast Fourier Transformation (FFT) techniques has been used for rice crop pattern and intensity recognition in global scale (Jonai and Takeuchi, 2012). The MODIS derived Enhanced Vegetation Index (EVI) and Land Surface Water Index (LSWI) indices along with Phased Array L-band Synthetic Aperture Radar (PALSAR) data with decision tree classification techniques has been used for rice mapping in Sacramento Valley, USA and found 85-94% agreement between PALSAR flood products and MODIS hydroperiods (Torbick et al. 2011). As a result, to leverage such spatial features continuous time series of remote sensing images covering the same region is very important.

In Bangladesh, along with seasonal cloud contamination, the high cropping intensity, crop diversity and land fragmentation are the challenges to map rice area. Due to the favorable environment for rice cultivation through the year, fertile land and high market demand of rice, rice cultivated three times in a year as single, double, and triple crops. Moreover, the small farm size, high cropping intensity and frequently changes the rice cultivated field. This study takes advantage of both optical sensors long time series and L-band SAR radiometric sensitivity to rice bio-geophysical properties. We used Geographical Positioning System (GPS) field data, high spatial resolution Phased Array-type L-band Synthetic Aperture Radar-2 (PALSAR-2) sensor onboard the Advanced Land Observing Satellite-2 (ALOS-2) data and MOD13A2 NDVI Kalman's filtered data from 2001-2018 used to overcome the rice mapping challenges over Bangladesh.

1.2 *Objectives of this Research*

The main objective of this study is rice paddy mapping with ALOS-2 ScanSAR and MODIS dataset over Bangladesh from 2001 to 2018. The dynamic changes of rice paddy cropping pattern, intensity, and area very important for the country. The long time series observation of rice paddy dynamics is also investigated in this study. The detailed objectives of this study have been set as follows.

(i) To produce seasonal rice area map with ALOS-2 ScanSAR images and GPS field data over selected tiles in 2018,

(ii) To delineate the seasonal rice area with ALOS-2 and MO13A2 data from 2001 to 2018, and

(iii) To evaluate the result with field data, relevant studies and national statistical data.

2. Methodology

This section consists of (1) field data collection; (2) ALOS-2/PALSAR-2 data processing and seasonal rice paddy detection; and (3) ALOS-2 ScanSAR data and MODIS data used rice mapping in the study area. The overall flowchart of this study is illustrated in Figure 1.

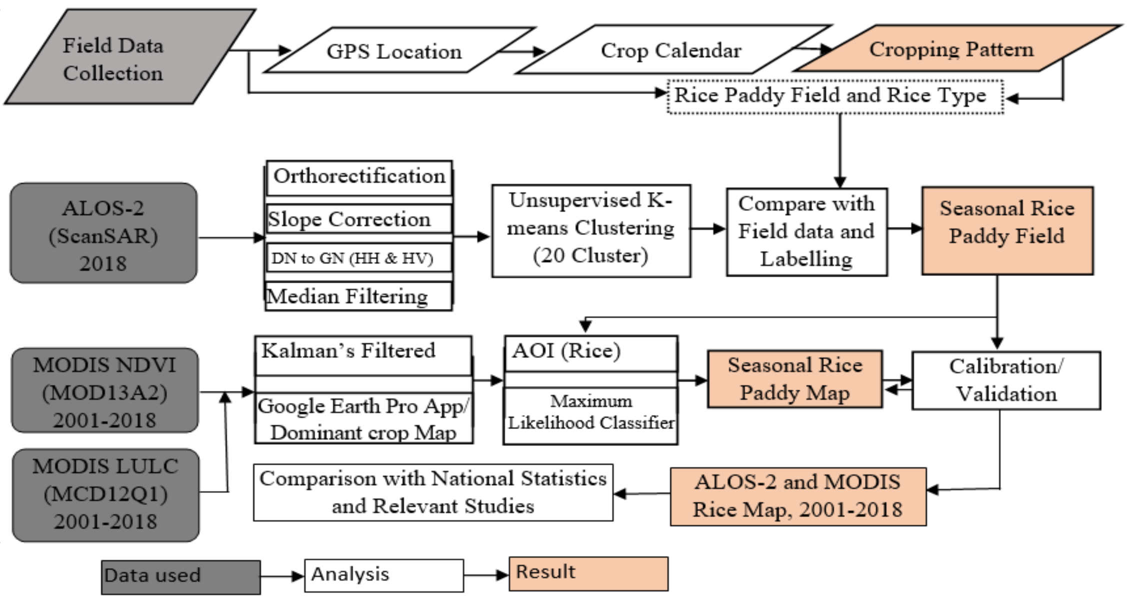


Figure 1. Overview of the rice paddy mapping framework. Geographical position system (GPS) location of rice paddy field with its cropping pattern, multi-dated PALSAR-2 HH and HV backscattered coefficient value with k-means clustering and rice area mapping MOD13A2 Kalman's filtered NDVI data used maximum likelihood classification techniques over Bangladesh from 2001 to 2018. The flowchart illustrated the data, analysis, and result of this study.

2.1 *Study Area*

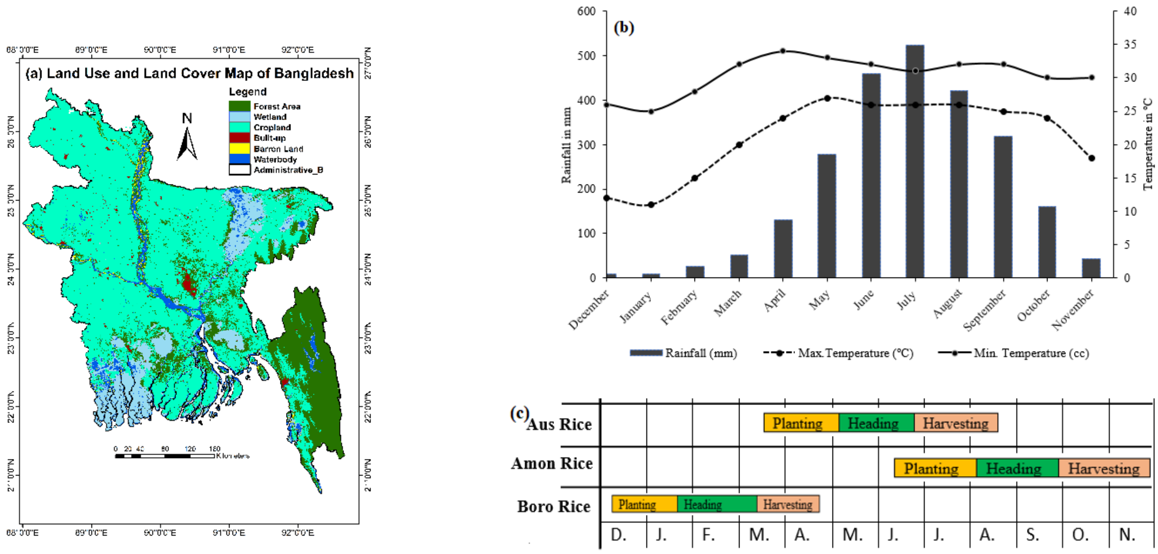
Bangladesh is one of the largest rice-growing countries in South Asia. It extends from 20º44´00″ to 26º37´51″ N latitude and from 88º00´14″ to 92º40´08″ E longitude and covered 148,450 km2 (figure 2.a). Physically the country is almost low altitude, relatively flat except the north-eastern and south-eastern hill tracts. Administratively, the country divided into major seven division: Dhaka, Rajshahi, Chittagong, Rangpur, Sylhet, Barisal, and Khulna. Climatically, average annual rainfall varies from 1,200 mm in the extreme west to over 4,000 mm in the northeast and temperature 4º C in January to 42º C in April (BMD (Bangladesh Meterological Department) 2017). The country's mean annual lake evaporation is approximately 1040 mm, which is about 45% of the mean annual rainfall (Kirby et al. 2014). The lowest average monthly precipitation is 4 mm in December to highest 560 mm in July 2017. The minimum monthly average temperature is 11º in January and maximum in April 35º in the same year (BMD, 2017). There is a huge seasonal variation of the weather parameters especially the temperature and rainfall (figure 2.b). Based on the crop calendar of Bangladesh, there are three major rice-growing seasons in the country (Kirby et al. 2014). The boro rice season (December/ January to March/April) is the second largest by cultivated area and largest by production, accounts for 50% (4.84 million hectares) of total rice production of the country. It is cultivated in dry winter and summer times with fully irrigation and high fertilizer inputs. Aus rice (April/May to July) season is the smallest cultivated area, accounts for 9% (1.04 million hectares) of total production. The Aus is cultivated under almost rainfed condition but a great uncertainty due to the flood. Amon rice (July/August to November) is the largest (5.53 million hectares) rice-growing season by area and second largest by production, accounts for 41% of total rice production (BBS 2018b). This rice season is a very critical growing period due to the flood in the early growing stage and frequent drought in the later growth stage. The detailed rice crop calendar showed in figure 2.c. The rice production in the country is seriously affected by climate change impacts.

Figure 2. (a) Geographical location and generalized land use and land cover (LULC) map-207 of the study area from MCD12Q1, (b) Monthly average minimum and maximum temperature, and rainfall over Bangladesh (BMD (Bangladesh Meterological Department) 2017), (c) Rice paddy crop calendar in the study area.

2.2 Dataset Used in This Study

2.2.1 Field Data Collection

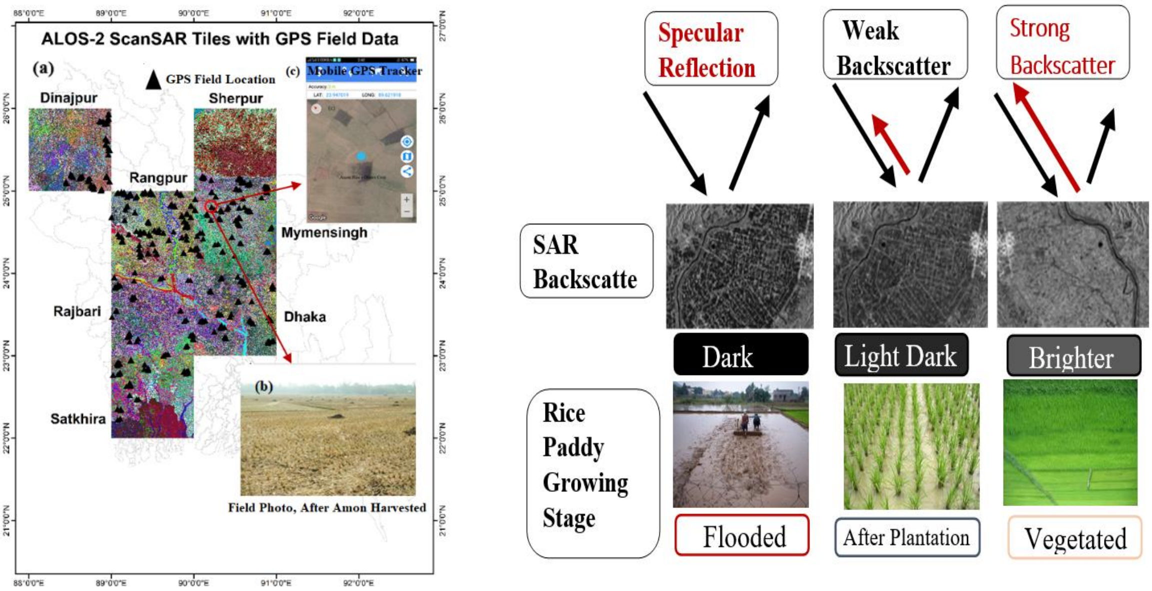
The Global Positioning System (GPS) location of sample field plots were collected from 267 locations during October to December 2018. The field data were collectedby local agricultural officers, journalist, and local expert through social media (Facebook messenger, IMO, What's app, Viber) on request volunteer basis.



The response person visited the field and gathered the GPS location with mobile GPS tracker, cropping pattern and crops season (Boro-Aus-Amon) information from the farmer's. Three basic questions provided to the volunteer, (i) Waht is the GPS location of the paddy field? (ii) How many times the rice paddy cultivated on this field in 2018? (iii) What are the plantation and harvested dates (tentative) of the cultivated rice paddy in 2018? We tried to select the large size field (> 3 hectares) for the better spatial resolution representation. They collected 48 GPS point on boro rice, 35 on amon rice, 32 on aus rice paddy field. The 71 points on the field where boro and amon rice cultivated as double rice crops, 21 points on field where rice cultivated in boro and aus rice season, 25 on fields where aus and amon rice cultivated and 35 points on fields where boro rice, aus rice and amon rice cultivated as tripple rice crops. The number of collected sample filed-plot data varied due to boro-amon rice cropping pattern is the most common cropping system and aus-amon, boro-aus rice cropping pattern is not so familiar rice cropping pattern in Bangladesh. The GPS field plot location with rice cropping pattern were used for seasonal rice paddy delineation with ALOS-2 ScanSAR data.

2.2.2 ALOS-2 ScanSAR Dataset

The ALOS-2/(PALSAR-2) was launched in 2014 and it's equipped with enhanced phased array L-band Synthetic Aperture Radar-2 sensor (PALSAR-2). The ALOS-2 ScanSAR used in this study were tiled ortho-slope corrected ALOS-2 Scan SAR data as an analysis ready data (ARD) provided by Japan Aerospace Exploration Agency (JAXA) and Japan International Cooperation Agency (JICA) in JICA-JAXA Forest Early Warning System in the Tropics (JJ-FAST). The dataset on selected tiles and date used for this study. In this study uses nine images of the ALOS-2 ScanSAR mode backscatter coefficient product of both HV and HH polarization (18 scenes) data at 50-m grid size. The L-bands ALOS-2 ScanSAR HH and HV backscattering value are very sensitive to the surface inundation condition even in vegetated stage(Arai et al. 2018). The L-band backscattering characteristics are very helpful to detect rice paddy field (figure 3.d). The ALOS-2 ScanSAR revisit time is 14 days and this study covering the image on the following months January, February, March, May, June, July, September, October and November in 2018. Although, the dataset missing April, August and December month's image but based on the crop calendar, these months are harvesting season for boro, aus and amon rice, respectively. As a result, the missing dataset not affected for this analysis. We used total of 7 tiles on the study area and rename the tiles as the major administrative coverage area. The used tiles are N26E090_RSP045 (Sherpur), N26E088_RSP046 (Dinajpur), N25E090_RSP045 (Mymensingh), N25E089_RSP045 (Rangpur), N24E090_RSP045 (Dhaka), N24E089_RSP045 (Rajbari) and N23E089_RSP045 (Satkhira). The geographical area coverage of the tiles along with the GPS field-plot location shown figure-3.



(d)

Figure 3. (a) Selected ALOS-2 ScanSAR tiles on the study area with the administrative coverage, (b) Field photo of a selected field after amon rice harvested and preparing for the boro rice plantation, (c) Mobile GPS tracker location of the field; (d) ALOS-2 ScanSAR backscattering characteristics in different rice-growing stages.

2.2.3 MODIS Dataset

Moderate-resolution imaging spectroradio meter (MODIS) imagery was downloaded from the Land Processes Distributed Active Archive Center (LP DAAC) (https:// lpdaac. usgs.gov/l pdaac/get_data/data_pool). The MOD13A2, which is referred to as the continuity index to the existing National Oceanic and Atmospheric Administration-Advanced Very High-Resolution Radiometer (NOAA-AVHRR) derived NDVI (Didan 2015). MOD13A2 version 6 products are derived by compositing two MOD09A1 8-day surface reflectance data in 16 days periods. The dataset already used atmospheric correction and cloud screening. Annual 23 scene and altogether 411 scenes for 18 years composite uses for analysis. We used MOD13A2 NDVI data with 1km spatial resolution and 16 days temporal resolution over the study area from 2001 to 2018. The MCD12Q1 LULC dataset provides a suite of science data sets (SDSs) at an annual time step for six different land cover legends (Friedl, MFriedl, M., Sulla-Menashe, D. ., Sulla-Menashe 2019). This study used MCD12Q1 500-m spatial resolution data from 2001 to 2018 supplementary dataset.

2.2.4 National Rice Area Statistics and Others Data

Bangladesh Bureau of Statistics (BBS) is a government organization under the Ministry of Planning (MoP) and responsible for data collection, analysis and published. The national and major administrative boundary level rice area statistics were obtained from BBS. The BBS collected data from the field level by household survey and reports the annual rice area and estimated the production. This study uses the annual statistical report from 2001 to 2018 on rice cultivated area in Bangladesh. The dominant crop calendar map produced by the Bangladesh Agriculture Research Council (BARC, 1998) and Very High Resolution (VHR) images visualization of Google earth pro app (Google earth V 7.3., 2010) used to extract the seasonal rice area. Moreover, the remote sensing based relavant studies result also use for comparision the result of this study.

2.3 Rice Cropping Pattern Mapping With ALOS-2 ScanSAR and Field Data 2018

The rice crop cultivation is a unique physical environment which distinguishable from other crops. Before plantation, the cultivated land plough with water and makes muddy and flooded for a few days. This flooding period for one week or more, ALOS-2 backscattered shows a specular reflection, after plantation and growing stage showed weak backscattered. In the well growing vegetated period, the strong backscatter appears in the rice paddy field. After harvesting, the fallow straw field also demonstrates distinguish backscatter value.The multi-dated ALOS-2 ScanSAR dual polarized (HH and HV) images use for the rice paddy identification. In image pre-processing, orthorectified and slope corrected by Sigma SAR (Shimada 2010). The digital number (DN) value of the images converted into backscattered coefficient (Gamma-naught). The median filtering (3×3 window) applied for HH and HV gamma naught. The unsupervised classification (K-means++) run with 20 categories and 100 iterations for image clustering. The rice paddy growing condition is difference from others crop condition. The flooded condition of rice paddy field shows the homogenic backscattering signal and almost similar cluster classes into a K-means class. We trial different K-means number classes and found 20 cluster classes are satisfactory result. By using the GPS field information of rice paddy field, the K-means classes are compared with the field data. Initially, we distinguish the rice and non-rice class. Within the rice class, the K-means cluster value extracts for confusion matrix. With the confusion matrix, we select which K-means classes are matches with the field cropping pattern (boro, aus, and amon and other pattern of rice). Then, we labelled the K-means class according to the seasonal rice cropping pattern. Finally, we prepared the boro, aus and amon season rice map over the selected ALOS-2 ScanSAR tiles. This rice paddy map further used for MODIS based rice area mapping. We compared our result with field data and national statistical data.

2.4 Rice Paddy Mapping with ALOS-2 ScanSAR and MODIS Data from 2001 to 2018

In Bangladesh, the most challenging to use optical data is seasonal uncertainty especially cloud contamination, missing values and atmospheric noise. The cloud contamination is a severe problem especially during the aus rice-growing season (June to August). To overcome the problem, we used local maximizing fit Kalman filter (KF), is a recursive extrapolation algorithm that integrates observations and their respective uncertainties to estimate the state of a process minimizing the mean of the squared errors[37]. The maximum and minimum NDVI values used for Kalman's filtering and smoothing. The Kalman filters make the NDVI time series smooth and continuous time series of NDVI values from 2001 to 2018. The 16 days Kalman's filtered MOD13A2 NDVI dataset composed as annual image.

The MCD12Q1 land use and land cover (LULC) data resampled and reclassified as the agricultural and non-agricultural land class. The agricultural land area masked out from annual MOD_NDVI annual data to reduce the data volume and prepared annual agricultural land MOD_NDVI data layer from 2001 to 2018. The NDVI temporal signature of annual Kalman filtered NDVI values shows various patterns. We used the annual rice crop calendar of Bangladesh fixed out the rice planting, development, and harvested period. At the land preparation and plantation season, the NDVI spectra for rice paddy is very low. During the growing and development stage, the NDVI value increased and reached to the peak. After the peak, the temporal value decreased at harvesting season. The entire growing period rice spectra demonstrated as a fold. In double and triple rice case, it is illustrated double and triple fold, respectively. Based on these NDVI temporal signature similarity characteristics (Gumma et al. 2014; Mosleh and Hassan 2014), the annual Kalman's filtered MODIS data used for the rice spectral signature extraction.

Based on the distinguish rice phenology development temporal extend, we selected various location for rice paddy temporal signature extraction. In this stage, ALOS-2 ScanSAR based seasonal rice area map of 2018 used as the base map for the different rice paddy pattern temporal signature extraction. Moreover, the very high resolution google earth pro app and dominant cropping pattern map used to select the area of interest (AOI). Based on ALOS-2 ScanSAR rice paddy map and spectral similarity technique (SMT) (Sakamoto et al. 2009), we extracted the standard NDVI signature of various rice pattern in 2018. The temporal signature of a rice paddy in 2018 used as a standard spectrum for rice pattern recognition for other years. The 2018 ALOS-2 based MODIS rice area map used as based map and applied for the rest of the year rice area mapping. The temporal signature has been collected as; Boro rice-other crops, Amon rice-other crops, Boro-Amon rice, Aus rice-others crop, Aus-amon rice, and Boro-aus-amon rice. At least 100 AOI has been selected for each cropping pattern and set a threshold value for each class. More than 700 AOIs for each year selected for temporal signature extraction. Among the various classification, the maximum likelihood classification (MLC) is commonly used for rice crop mapping with good performance (Defries and Townshend 1994; Hubert-Moy et al. 2001). The MLC presumes that signatures class of the pixels are normally distributed and evaluated the probabilities of a given pixel belong to each class. The pixel is assigned to the class with the highest probability (D. Zhang et al. 2014). In this study used the supervised classification with maximum likelihood classifier (MLC) for rice area identification. The three major rice-growing seasons (Boro, Aus and Amon) rice area map prepared from the various rice cropping pattern. Then, we estimated the rice area statistics in the major seven administrative division level in the study area. Finally, the rice area is extracted and prepared the annual seasonal rice area map of each year and seasons from 2001 to 2018. The overall research flowchart is shown in figure 1.

2.5 Accuracy Assessment and Area Validation

The field data, the government reported national statistics and relevant data used for accuracy assessment and validation the result from this study. Firstly, the GPS filed data used for ALOS-2 ScanSAR seasonal rice area maps accuracy assessment. The government reported annual rice area statistics have been used for the ALOS-2 ScanSAR rice area validation. Secondly, the ALOS-2 ScanSAR rice area data used for the MODIS based rice map validation and accuracy assessment. Finally, the published report from the Bangladesh Bureau of Statistics (BBS) annual reported rice area from 2001 to 2018 used for MODIS based rice area map comparison. Moreover, the relevant studies from the literature review also used for the comparison of the result from this study.

3. Results

3.1 ALOS-2 ScanSAR Rice Paddy Map

The ALOS-2 ScanSAR rice area map over the selected tiles in the study area was compared with the GPS field data and statistically reported rice area. The boro rice area is the dominant rice area in the selected tiles 10,28,036 ha (47.14% of total rice area), followed by amon rice 10,17,983 ha (46.64%) and aus rice area 135543 ha (6.21%), respectively. In major district boundary coverage of the selected tiles on the study area are estimated the seasonal rice area statistics shown in table 2. The Mymensingh and Gazipur districts are the prominent boro rice cultivated area in the study area. In percentage of the total rice cultivated area, Gazipur (54.80%), Munshigonj (54.81%), Tangail (53.59%), Sirajgonj (53.63%) of the total rice area estimated as boro rice area. The Faridpur (32.22%), Rajbari (33.70%) and Pabna (38.50%) districts are the lowest boro rice cultivating area in the study area. The estimated amon rice is the second largest rice cultivated area followed by the boro rice area in the study sites. The Mymensingh and Tangail districts are the leading estimated amon rice producing area is 2,57,157 ha (45.13%) and 1,22,680 ha (42.92%), respectively. Faridpur (60.50%), Rajbari (58.00%) and Magura (53.85%) districts are the top amon rice production area by the percentage of the total rice cultivated area. The aus rice area is the lowest estimated rice planted season in the study area. The Mymensingh (41,233 ha) and Pabna (24,759 ha) districts are the major aus rice cultivated area. The details seasonal rice distribution map shown in figure 4.

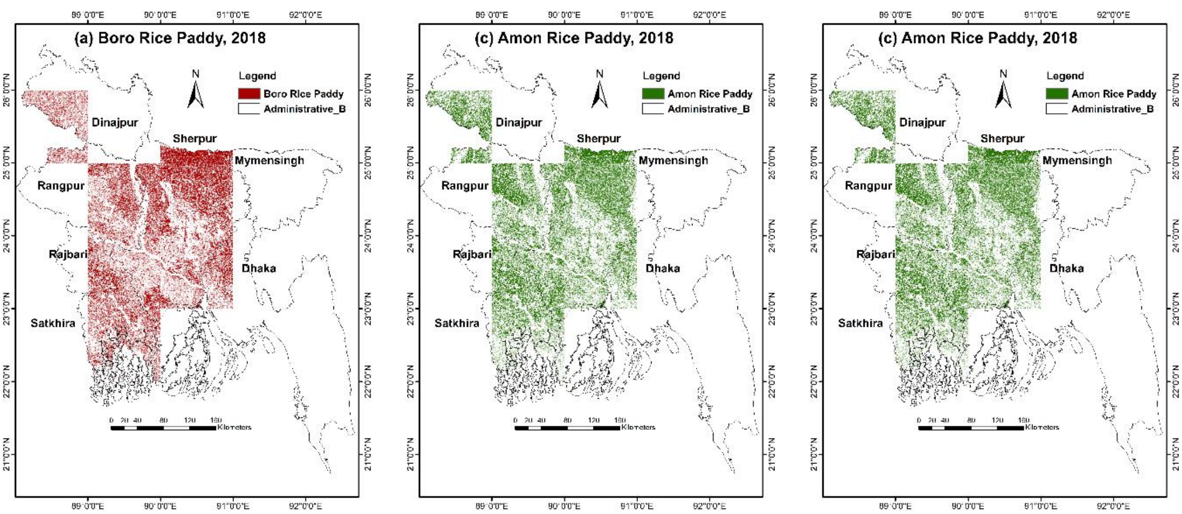


Figure 4. ALOS-2 ScanSAR backscattered coefficient unsupervised k-means class and GPS field data used seasonal rice area map over selected tiles on Bangladesh in 2018, (a) Seasonal boro rice area distribution map, (b) aus rice paddy field distribution map and (c) Amon rice paddy field map.

3.1.1 *ALOS-2 ScanSAR Rice Area Map Validation with Field Data and National Statistics*

The ALOS-2 ScanSAR derived seasonal rice area map of selected seven tiles validated with the collected GPS filed data. The field data point compared with the ALOS-2 ScanSAR based rice area map. Among the 35 GPS points of amon rice field data, 27 pointsclassified amon rice paddy field, 2 fields are misclassified asboro and amon rice, 3 fields as aus rice and 3 fields as aus and amon rice crop field in ALOS-2 ScanSAR rice map. The probable misclassification between amon and aus rice class is late amon and early aus planted rice paddy field. The single amon to double boro and amon rice paddy fields and aus and amon rice field misclassified is mainly due to the field size change in the different season. Among the total 48 points of boro rice paddy field data, 38 GPS points on boro rice identified as boro and 2 points misclassified as boro and amon rice field, 3 points as aus rice field, 4 points as boro and ausrice and 1 point as amon rice paddy field. Among the 32 GPS point on aus rice field data, 24 points classified asausrice field and other points are misclassified as amon rice, bororice, and boro and amonrice field in ALOS-2 ScanSAR rice paddy map. Among the 71 points on boro and amon rice paddy field, 61 points identified as amon and misclassified 3 of them as boro rice, 2 as amon rice, 3 as boro, amon and aus rice paddy field. The higher user's and producer's accuracy found at boro-amon rice pattern are 84.72% and 85.91% respectively. The more GPS point, the most common rice cropping pattern are the probable causes of higher accuracy. The lower producer's and user's accuracy in the boro-aus rice cropping pattern and the probable causes are the rarely cultivated pattern and fragmented small field size. The aus rice paddy also shows lower accuracy (70.59%) as the fluctuated planting date in between boro and amon rice growing season and misclassified as boro and amon rice paddy field. The double and triple rice cropping pattern also illustrated comparatively lower accuracy mostly due to the changing field size from one season to another. The overall accuracy between the GPS field data and ALOS-2 ScanSAR rice paddy map is 78.65% with the kappa value 0.76. Table 1 demonstrated the detail error matrix.

Table 1. Accuracy assessment of GPS field plot data and ALOS-2 ScanSAR based seasonal rice paddy map over the study area, 2018.

Classified Data	Reference Data								
	Amon	Boro	B-A	Aus	A-A	B-A	B-A-A	Classified Total	User's Accuracy
Amon	27	1	2	2	0	2	0	34	79.41
Boro	0	38	3	2	0	2	0	45	84.44
B-A	2	2	61	2	3	1	1	72	84.72
Aus	3	3		24	1	3	0	34	70.59
A-A	3	0	1	0	16		2	22	72.73
B-A	0	4	1	2	1	13	1	22	59.09
B-A-A	0	0	3	0	4	0	31	38	81.57
Reference Total	35	48	71	32	25	21	35	267	
Producer's Accuracy	77.14	79.17	85.91	75.00	64.00	61.90	88.57	Overall Accuracy=.7865, Kappa=.7622	

(Here, B-A= Boro-Amon Rice, A-A= Aus-Amon Rice, B-A= Boro-Aus Rice, B-A-A= Boro-Aus-Amon Rice)

Moreover, the ALOS-2 ScanSAR seasonal rice area in major administrative boundary level compared with the Bangladesh Bureau of Statistics (BBS) reported rice area statistics(BBS 2018c). Among the administrative boundary, the Mymensingh district is the top rice producing area. The estimated amon rice area and reported amon and boro rice area are almost same, whereas the estimated aus rice area is overestimated in the district. Similarly, in case of other district, the estimated and reported amon and boro rice area showed higher agreement. But, the estimated and reported aus rice area demonstrated overvalued and higher discrepancy. The ALOS-2 ScanSAR amon rice area and the BBS reported rice area are shown very good agreement (R^2= 0.98) followed by boro (R^2= 0.94) and aus (R^2= 0.71) in the selected administrative district level. The total estimated and reported amon rice area is 10,17,983 ha and 9,95,505 ha, respectively in the study area. The boro area also showed good agreement whereas reported area is 11,01,538 ha and estimated area 10,29,036 ha. The aus rice area shows higher descripancy between the reported and estimated area (table 2).

Table 2. Comparision of seasonal ALOS-2 ScanSAR estinmated rice area with national statistics by administrative districs.

District	ALOS-2 Estimated rice area (ha)				BBS Reported rice area (ha)			
	Boro Rice	Aus Rice	Amon Rice	Total	Boro Rice	Aus Rice	Amon Rice	Total
Dhaka	35361	5448	32986	73795	47156	747	16716	64619
Faridpur	44309	9997	83172	137478	27804	6580	82090	116474
Gazipur	48218	2796	36963	87977	54316	1356	42502	98174
Madaripur	26218	2813	31631	60662	33677	1525	26511	61713
Manikgonj	36481	1752	43652	81885	46533	142	38891	85566
Munshigonj	36377	845	29138	66360	26450	940	20745	48135
Narayangonj	25106	4578	20361	50045	26018	690	10883	37591
Narshingdi	43892	6127	42720	92739	50213	331	41483	92027
Mymensingh	271349	41233	257157	569739	266243	16626	259040	541909
Rajbari	22488	5539	38712	66739	12664	1310	46256	60230
Shariatpur	34911	4634	26610	66155	21172	9180	17689	48041
Tangail	153148	9931	122680	285759	191878	837	116482	309197
Magura	40850	3075	51254	95179	42696	3310	58715	104721
Narail	43826	5561	37737	87124	59063	5459	39975	104497
Pabna	68888	24759	85268	178915	56317	16974	94727	168018
Sirajgonj	97614	6455	77942	182011	139338	4725	82800	226863
Total	1029036	135543	1017983	2182562	1101538	70732	995505	2167775

3.1.2 *MODIS Based Rice Map Calibration with ALOS-2 ScanSAR Rice Data*

The ALOS-2 ScanSAR seasonal rice area map was used for calibrating the MODIS derived seasonal rice area map in 2018. The higher spatial resolution and field data validated ALOS-2 rice area map used as the base map for the MODIS rice area mapping. The region of interest (ROI) have been selected from ALOS-2 ScanSAR rice area map and the MODIS NDVI spectral singnatures of that ROI extracted (figure 5). The ALOS-2 ScanSAR derived ROI's spectral signature of MODIS NDVI value observed and adjusted over the study area for seasonal rice area mapping.

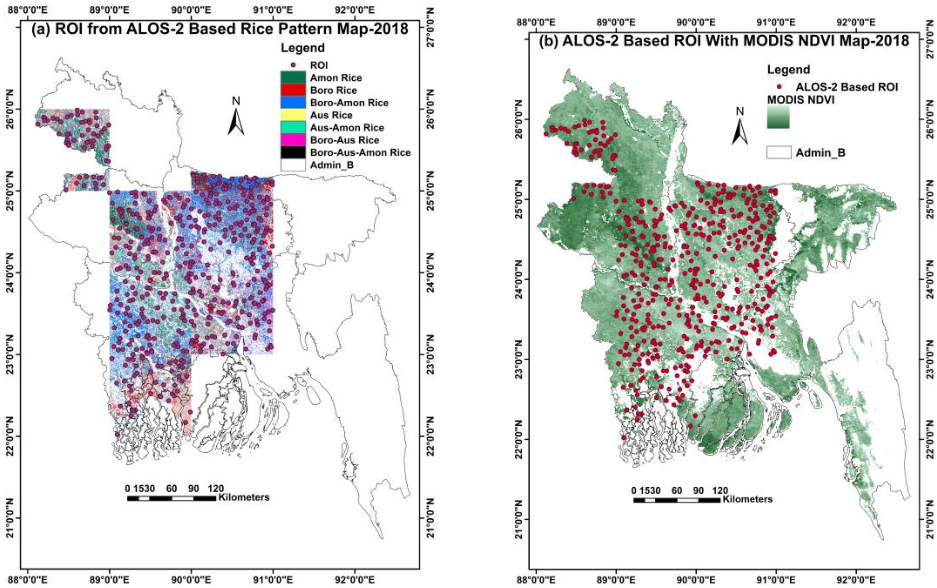


Figure 5. (a) ALOS-2 ScanSAR seasonal rice area map used region of interest (ROI) selection over the selected tiles, (b) ALOS-2 ScanSAR derived ROI used to extract the MODIS NDVI spectral value over the selected region in 2018.

Due to the high spatial resolution and atmospheric noise-free ALOS-ScanSAR data, even the smaller rice area could detect efficiently. In pixel level, the low spatial resoution MODIS NDVI one pixel represent almost twenty (20) pixel of ALOS-2 ScanSAR data. As a result, the ALOS-2 SacanSAR derived and MODIS adjusted NDVI ROI value represent better classification result for the seasonal rice area map. The ALOS-2 ScanSAR and MODIS data used maximum likelihood classified seasonal rice area map compared over the study area. Randomly, 600 points selected in ALOS-2 ScanSAR rice map and extracted the raster value from the MODIS seasonal rice area map. The result is compared as the confusion matrix of ALOS-2 and MODIS map (table 3). The amon rice area demonstrated 84.08% user's and 84.50% producer's accuracy. There is 30 points classified as aus rice and 2 points as boro rice. The commission and omission error also lower (16%) in ALOS-2 and MODIS amon class. The boro rice paddy illustrated the higher produce's accuracy (90%) and user's accuracy (86.54%) with lest commission (6.98%) and omission (13.5%) error. The boro planting date is distinguishably different than amon rice planting date but late boro and early aus plantation date in some region are very close. As a result, there is some misclassification between boro and aus rice class. The aus rice is the lowest user's and producer's accuracy 76.00% and 79.58%, respectively. The commission (23.83%) and omission (18.5%) error are also higher in aus rice class. The probable causes of this dicrepancy are – i) difference between ALOS-2 ScanSAR (50-m) and MODIS (1000-m) spatial resolution, ii) smaller cultivated area (almost 10%), and iii) fluctuation of planting date of aus rice area. Moreover, the data acquisition process of ALOS-2 ScanSAR and MODIS are also different. The error matrix of ALOS-2 ScanSAR and MODIS seasonal rice area map showed in table 3. This calibrated MODIS rice area map used for updated the rice area map from 2001 to 2017 and finally produced the MODIS seasonal rice area map from 2001 to 2018 over Bangladesh.

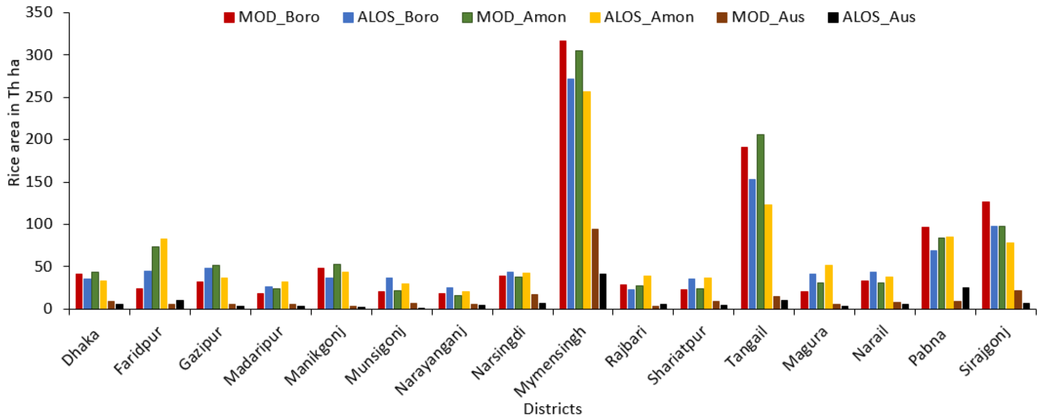
Table 3. Confusion marix between ALOS-2 ScanSAR based seasonal rice and MODIS based seasonal rice paddy map in 2018.

MODIS/ Classified Data	**PALSAR-2/Reference Data**				
	Amon Rice	Boro Rice	Aus Rice	Classified Total	User's Accuracy
Amon Rice	169	2	30	201	84.08
Boro Rice	10	180	18	208	86.54
Aus Rice	21	18	152	191	79.58
Reference Total	200	200	200	600	
Producer's Accuracy	84.5	90.00	76.00		Kappa .77

3.2 *Comparisopn of ALOS-2 ScanSAR Rice Area and MODIS Rice Area-2018*

The ALOS-2 ScanSAR seasonal rice area and ALOS-2 ScanSAR derived MODIS seasonal rice area in 2018 compared. Among the administrative 16 district coverage of ALOS-2 ScanSAR rice area statistics and the MODIS estimated rice area show very good agreement (figure 6). The ALOS-2 boro rice area and MODIS estamated boro rice area demonstrated the highest agreement (R2 value 0.97). In Dhaka, Mymensingh, Manikgonj, Rajbari, Tangail, Pabna and Sirajgonj district MODIS derived boro rice area is a bit of over-estimated from ALOS-2 rice area and rest of the case are underestimated. In amon rice area case also showed very good agreement in MODIS and ALOS-2 estimated rice area (R2 value 0.93). In Dhaka, Gazipur, Mymensingh, Manikgonj, Tangail and Sirajgonj district MODIS derived amon rice area is comparatively over-estimated from ALOS-2 rice area and rest of the case are slightly underestimated. The probable cause of this dicrepancy is the variation of MODIS and ALOS-2 SacanSAR spatial resolution. As the larger cultivated rice area are leading the overestimation. The higher disagreement shown in between the ALOS-2 and MODIS estimated aus cultivated rice area (R2 value 0.72). As the comparison of ALOS-2 ScanSAR rice area and national statistics reported aus rice area also showed the similar lowest agreemnt. In the study area, most of the district case the result showed fluctuation. The overall result of ALOS-2 ScanSAR and MODIS rice area showed very agreement.

Figure 6. The ALOS-2 ScanSAR seasonal rice area statistics and MODIS rice area staistices on Boro, aus and amon rice season over the seleected 16 administrative districts in 2018.



3.3 *MODIS Rice Area Map 2001-2018*

The MOD13A2 NDVI time-series data demonstrated uncertainty and missing value over the year especially during the rainy season. The aus and amon rice planting season (June to August) the cloud affects are optimum and there is huge missing data. The most challenging part of using optical data is to solve cloud contamination problem. The Kalman's filtered recursion methods filled the missing data to smooth the NDVI spectral signature. The smoothed spectral signature of NDVI indices used for the rice crop pattern identification. In figure 7 showed the MOD13A2 NDVI spectral signature with and without Kalman filter.

(a) *Before filtering*

(b) After filtering

(c)

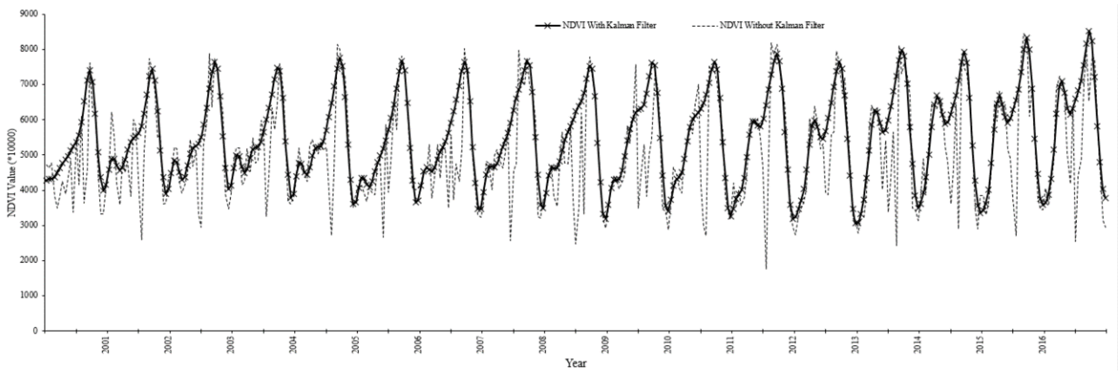


Figure 7. (a) MOD13A2 NDVI data from 2001 to 2018 before Kalman's filtered, (b) the images after filtering and (c) the temporal NDVI signature of a selected point in the study area with Kalman's filtered and without Kalman's filtered data.

The temporal variation of NDVI spectral signature in different rice growing stage evaluate for the distinguish rice paddy field from the non-rice field as well as the seasonal rice. The rice paddy NDVI signature shows very low value in the transplanting season (0-20 days after transplanting) and start to increase up to the peak (80-100 days) in growing and maximum greenness stage. After the peak, the rice greenness value as well as the spectral signature values start to decrease and become very low in harvesting (110-120) and fallow season. The boro, aus and amon single rice crop pattern shows the single fold in their growing period. In case of double and triple rice paddy, the spectral signature value starts to increase followed the fallow season to transplanting season. The value again shows the similar pattern as the previous cycle. The boro-amon, boro-aus and aus-amon double rice cropping pattern demonstrated the double fold and the boro-aus-amon triple rice paddy showed the triple-fold in a single year. The single or double rice along with the non-rice cropping pattern shows single rice or double rice fold and others pattern. In figure 8 illustrated the selected ROI for various rice cropping pattern and ideal NDVI spectral signature for the rice cropping pattern over the study area.

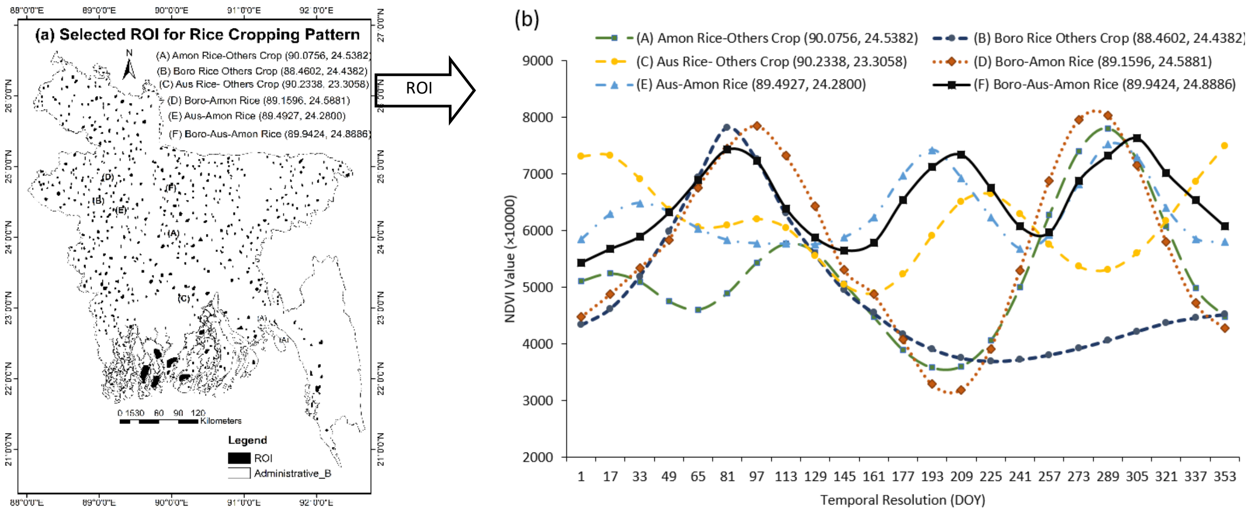


Figure 8. (a) ALOS-2 ScanSAR, dominant rice crop map and Very high resolution google earth pro used selected rice paddy field area of interest (AOI); (b) the ideal spectral signature for the different rice cropping pattern over the study area, (A) Amon single rice and others crop, (B) Boro-Amon double rice paddy field, (C) Boro single rice paddy and other crop field, (D) Aus single rice paddy and others crop, (E) Aus-Amon double crop rice paddy field, and (F) Boro-Aus-Amon triple rice paddy field spectral signature.

3.3.1 Boro Rice Paddy Mapping Result

The estimate dbororice area of the country gradually increased from 37,27,600 ha (34.43%) in 2001 to 48,62,500 ha (42.09%) in 2018. The area grew by 30.44% from 2001 to 2018. Although, the boro rice cultivated under fully irrigated condition and required more input but the high yield rate (4.42 tone/ha) and less disaster-prone makes it popular in the country. The boro rice area started to increase drastically from 2010 with the availability of deep and shallow irrigation pump (Kirby et al. 2014). In 2007, the boro rice area was 42,79,500 ha and in 2010 it suited 47,96,300 ha. The boro rice area becomes almost saturated from

2015 (48,03,200 ha) with slight fluctuation in later years (around 48,62,2200 ha). The central-northern part of the country especially Mymensingh and Rangpur district are the major boro rice cultivating region in the country. The southern coastal zone and north-western driest part of the country are the less boro rice farming regions. The detail boro rice distribution map shown in figure 9.

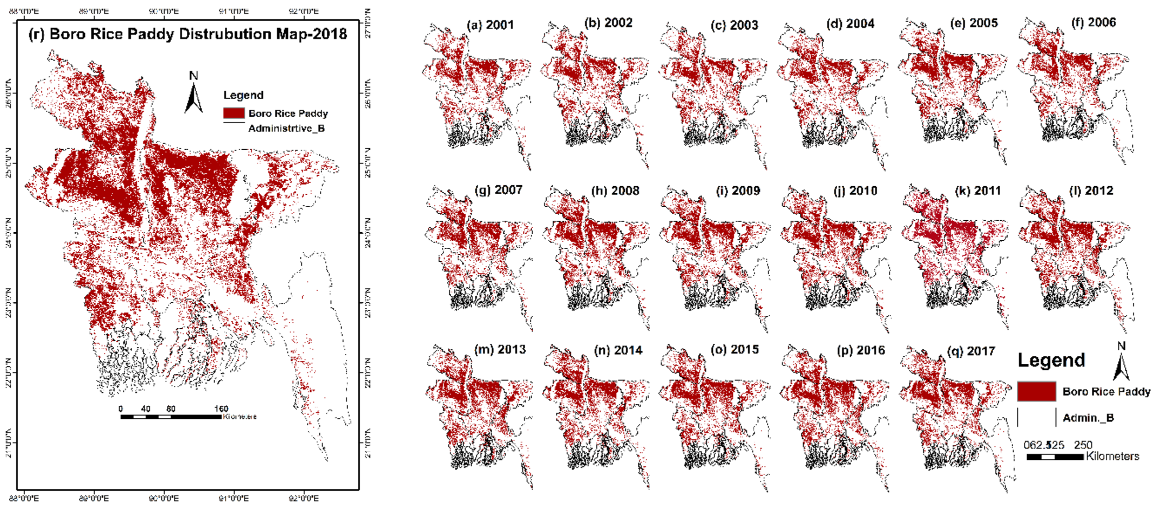


Figure 9. MODIS Kalman's filtered NDVI with maximum likelihood classifier used and ALOS-2 ScanSAR updated seasonal boro rice distribution map over the study area, (a) 2001, (b) 2002, (c) 2003, (d) 2004, (e) 2005, (f) 2006, (g) 2007, (h) 2008, (i) 2009, (j) 2010, (k) 2011, (l) 2012, (m) 2013, (n) 2014, (o) 2015, (p) 2016, (q) 2017 and (r) 2018.

3.3.2Aus Rice PaddyMapping Result

The aus rice area is the smallest amount of cultivated rice season in the country. Although, the aus rice cultivated under almost rainfed condition over the country. In the aus rice harvesting season, heavy rainfall and flood occurred and frequently faced disaster. Moreover, the low per unit yield (2.27 tone/ha) makes it rarely cultivated among the farmers. In 2001, the estimated aus rice area was 12,11,800 ha (11.19%) and becomes 10,67,500 ha (9.24%) in 2018. The area gradually decreasing over time with some fluctuation. The comparatively higher altitude central and south-central part of the country is the majoraus rice-farming area in the country. The details distribution of aus cultivated rice area over the study area shown in figure 10.

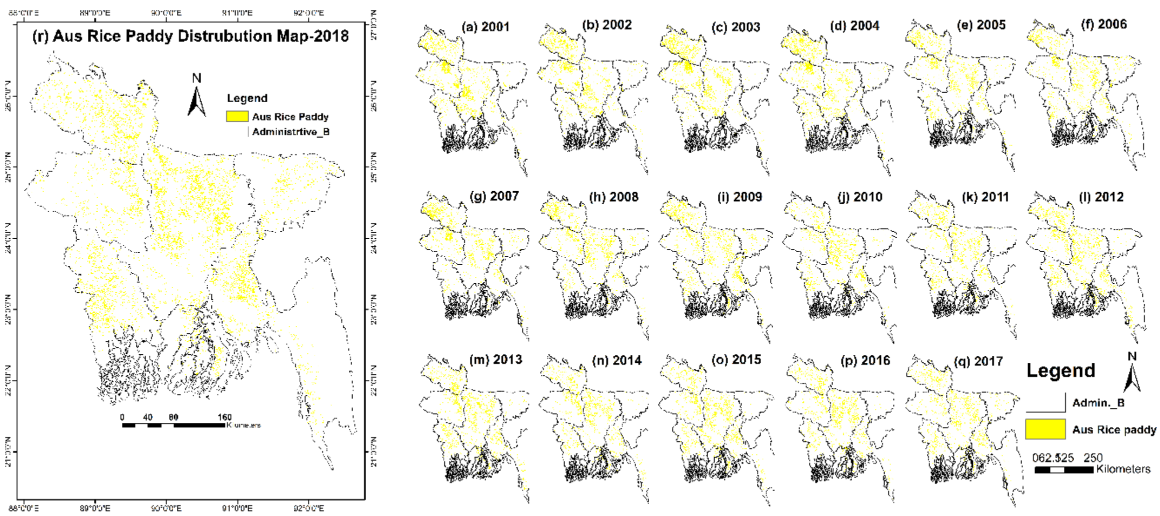


Figure 10. MODIS Kalman's filtered NDVI with maximum likelihood classifier used and ALOS-2 ScanSAR updated seasonal aus rice distribution map over the study area, (a) 2001, (b) 2002, (c) 2003, (d) 2004, (e) 2005, (f) 2006, (g) 2007, (h) 2008, (i) 2009, (j) 2010, (k) 2011, (l) 2012, (m) 2013, (n) 2014, (o) 2015, (p) 2016, (q) 2017 and (r) 2018.

3.3.3 Amon Rice PaddyMapping Result

The amon rice cultivated area decreasing over time but still it's the dominant rice-growing season in the country. The estimated amon rice produce area were 58,85,000 ha (54.37%) in 2001 and becomes 56,22,200 ha (48.67%) in 2018. The amon rice area in 2008 shows the lowest estimation similarly to the reported amon rice area (BBS 2018a). The flash flood leading damaged of amon rice is the probable cause of this year lower estimation of amon rice. The amon rice cultivated from July to November/December, which is the monsoon and post-monsoon season with plenty of rainfall. As a result, the amon rice area is mostly rainfed and supplementary irrigated and popular rice-growing season in the study area. But, the amon rice cultivated area decreasing (4.47%) due to the comparatively lower per unit yield (2.46 tone/ha) then boro rice and disaster risk in the harvested season. The central north and northwestern part of the county especially, Mymensingh, Rajshahi and Rangpur division is the major Amon rice growing zone in the country. Moreover, the boro-amon double rice cropping pattern is the most common cropping pattern in the study area. The details distribution of amon rice cultivated rice area shown in figure 11.

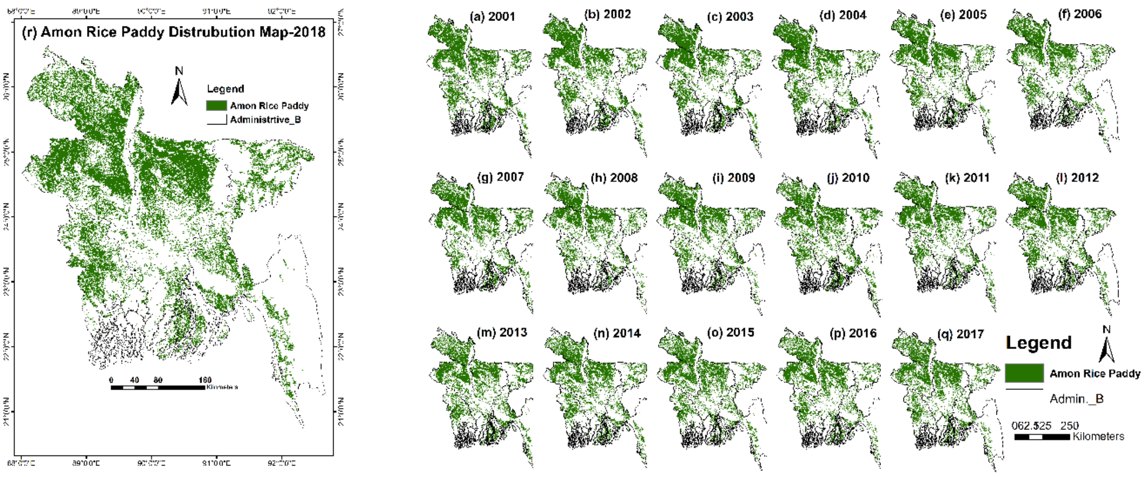


Figure 11. MODIS Kalman's filtered NDVI with maximum likelihood classifier used and ALOS-2 ScanSAR updated seasonal amon rice distribution map over the study area, (a) 2001, (b) 2002, (c) 2003, (d) 2004, (e) 2005, (f) 2006, (g) 2007, (h) 2008, (i) 2009, (j) 2010, (k) 2011, (l) 2012, (m) 2013, (n) 2014, (o) 2015, (p) 2016, (q) 2017 and (r) 2018.

3.3.4 *MODIS Rice Area in Major Administrative Division Level*

The MODIS derived rice area in greater seven (7) administrative divisional scale were estimated from 2001 to 2018. The greater Dhaka division is the largest rice cultivated division as it's also greater by area. The amon (45.48%) and boro(45.73%) rice as single and double cropping pattern is the dominant crop. Currently, Dhaka division divided as Dhaka and Mymensingh division and especially the Mymensingh division is the major rice-growing region in the country. The aus rice is cultivated in very small area (8.78%) in this division. The flat physiographic condition, fertile land, better agricultural infrastructure, and less disaster driving the rice crop expansion in this region. The second largest division Chittagong is dominant by amon rice (47.92%) and followed by boro(37.44%) and aus rice (14.63%). Although the coastal and mountainous physiography and blooming of non-agricultural economic leading declined of the rice area in this division. The Khulna division is another coastal region and recently aquaculture practice increased, and saline intrusion is the major constraint for rice cultivation. But the development of salinity tolerates rice verities and mix cultivation practices of fish and rice becoming popular in this region(Chowdhury et al. 2011). The leading rice crop is amon (50.40%) and trailed by boro (35.40%) and aus (14.65%) rice. The riverine Barishal division's major rice crop is amon(65.55%), boro (20.70%) and aus (14.14%). The less rainfall and higher temperature leading drought prone Rajshahi division's leading estimated rice crop area amon (46.54%), boro (45.60%) and aus rice (7.84%). The Rangpur division also showed similar rice cropping pattern as the amon (54.25%), boro (40.82%) and aus rice (4.85%). All over the country, Amon is the main rice crop (48.67%) followed by boro rice (42.09%) and aus rice (9.24%). In figure-12 shows, the division wise estimated different types of the rice area in Bangladesh from 2001 to 2018.

Figure 12. Boro, Aus and Amon rice area in seven division in Bangladesh (a) Dhaka division, (b) Rajshahi division, (c) Rangpur division, (d) Chittagong division, (e) Barisal division, (f) Sylhet division, (g) Khulna division and (h) over Bangladesh from 2001 to 2018.

3.4 *MODIS Rice Area Comparision with Relavent Studies*

International rice research institute (IRRI) produced and published seasonal rice area map on Bangladesh, 2010(Gumma et al. 2014). The study used MODIS 500m spatial resolution, 8-days composite and spectral matching techniques with intensive field data. The IRRI seasonal rice area map compared with this result of this analysis. The result illustrated the higher user's accuracy in boro rice class (85.89%) similar to ALOS-2 MODIS comparison. The overall accuracy is 0.70 and kappa value 0.664. The highest comission error occur in boro-amon (46.15) rice pattern and lowest in case of boro-aus-amon (8.06) rice pattern. The higer comission error of boro and amon double rice cropping patterns most probable cause is the boro-aus and aus-amon rice pattern misclassification. The early aus rice sometimes classified as boro rice and late planted aus misclassified as amon rice. The maximum omission error in aus-amon rice (45) cropping pattern and minimum in boro rice (15) case. The aus rice and amon rice plantation seasons are mostly overlapped in some regions. Especially, the single aus rice cropping pattern planted in early and aus as double or tripple rice cropping pattern planted in comparatvely late season, which are the probable causes of higher omission error. The boro rice as single crop mostly cultivated in low land of the study area and there is no others rice or crop cultivated in the cropping year is the causes of minimum omission error.

Table 4.Confusion matrix between MODIS analysis rice map of this study with the IRRI produced seasonal rice area map on Bangladesh, 2010.

Classified/PALSA R-2 Data	**Reference/IRRI Data**							
	Amon	Boro	B-A	Aus	A-A	B-A-A	Classified Total	User's Accuracy
Amon	82	1	8	24	8	5	128	80.00
Boro	1	85	7	16	7	4	120	85.89
B-A	9	4	83		27	32	155	70.37
Aus	5	10	0	60	0	0	75	70.58
A-A	3				55	2	60	61.29
B-A-A	0	0	2	0	3	57	62	82.35
Reference Total	100	100	100	100	100	100	600	
Producer's Accuracy	82.0	85.0	83.0	60.00	50.0	57.00	Overall Accuracy=.7033, Kappa=.644	

(Here, B-A= Boro-Amon Rice, A-A= Aus-Amon Rice, B-A-A= Boro-Aus-Amon Rice)

We compared the result from this study with sentinel-1 images, field photo and random forest classifier use seasoanal paddy rice mapping in Bangladesh with 90% overall accuracy in 2017 (Mohite et al. 2018). Although, there is spatial resolution difference between the ALOS-2 ScanSAR and MODIS dataset with the sentinel-1 (10-m) data but the result shows overall accuracy 76% and kappa value 0.70. A significant number of the random point were selected as no data value in MODIS rice map especially in aus, boro-aus and aus-amon rice cropping pattern due to the spatial resolution differences. With higher spatial resolution data it's possible to identify even small size field but in low spatial resolution, it's challenging.

4.Discussion

4.1 MODIS Rice Area Comparision with Reported Government Statistical Data

The annual rice area estimated from this study compared with the reported statistics of Bangladesh Bureau of Statistics (BBS) published "Yearbook of Agricultural Statistics" from 2001 to 2018(BBS 2018c). Although, the BBS data collection methodology is the quite different from the remote sensing technology. The BBS data were collected by the household survey, field visit, and expert opinion on rice cultivated area and estimated the annual production. But, the comparison with the statistical data could be a viable source of validation of remote sensing data. The comparison was conducted at two stages- i) at the national level estimated seasonal boro, aus and amon over the study area from 2001-2018 with the BBS reported statistics, ii) major administrative division level within the same period. The estimated boro rice area in 2001 to 2004 shows slightly underestimated (2 to 3%) from the reported data and 2010 demonstrated the best agreement between two datasets and after that boro rice area somewhat (3 to 5%) overestimated compare to the statistical data.The estimated amon rice area and reported area shows some variation (2 to 5%) during some year. The estimated ausrice area and reported rice area show poor accuracy among the seasonal rice with 3-10%. The estimated and reported seasonal rice area (boro, aus and amon) and reported rice area from 2001 to 2018 illustrated in figure 11 with R^2 value 0.97 (boro rice), 0.76 (amon) and 0.27 (aus) rice. The comparison between remote sensing based estimation and statistical data similar relationship found in others studies, R^2 value 0.42 and 0.87 in South and Southeast Asia (Xiao, Xiangming & Boles, Stephen & Frolking, Steve & Li, Changsheng & Yeluripati, Jagadeesh & Salas, William & Moore 2006), 0.97 in Asian countries (Gumma 2011) and 0.84 to 0.91 (Mosleh and Hassan 2014) in Bangladesh.

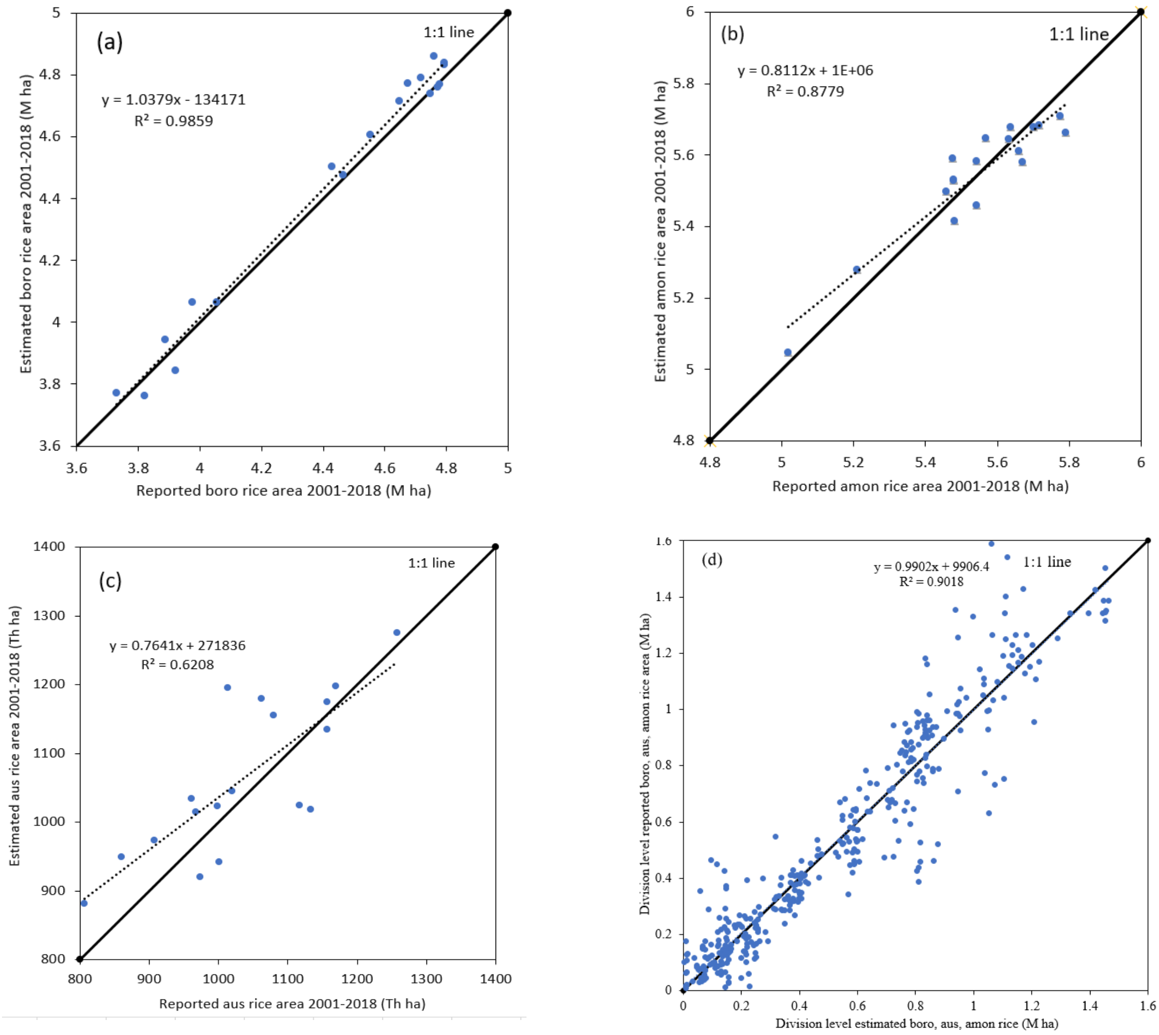


Figure 13.MODIS based rice area statistics comparison with national statistical rice area data; (a) MODIS estimated boro rice area vs national statistics reported boro rice area 2001 to 2018, (b) MODIS estimated amon rice area compare with reported statistical

amon rice area 2001 to 2018, (c) estimated aus rice area vs reported aus rice area from 2001 to 2018, and (d) estimated boro, Aus and amon rice area comparison with reported boro, aus and amon rice area by division from 2001 to 2018.

The estimated rice area competes with the division level reported rice area over the study area from 2001 to 2018 (figure 13). In Dhaka division, the 18 years average estimated amon rice (45.48%) area is slightly overestimated than the reported amon rice (43.19%), boro rice area also underestimated (5%) and aus rice area over estimated (2%). The estimated amon rice area in Chittagong division underrated (3%) than the reported amon area, boro rice area overestimated by 2% and aus rice area almost comparable the reported aus rice area(14.05%) of total rice. In Rajshahi division, the estimated boro (45.60%), amon (45.49%) and aus rice (7.84) almost like the reported rice area of this district. In Rangpur, estimated boro and amon rice area slightly underestimated, and aus rice area overestimated compare to the reported rice area in this division. In Barishal division, also show the similar result as like the Rangpur division. In Sylhet division, the estimated boro (45.57%) and reported boro (44.84%), estimated amon (42.11%) and aus (12.33%) almost like the reported area. In individual year basis division wise boro, amon and aus rice area show some fluctuation. In figure 13.d, shows the division wise estimated and reported boro, amon and aus rice correlation from 2001 to 2018.

We also compared our result with the United State Department of Agriculture (USDA) Foreign Agriculture Service (FAS) dataand found very good agreement with our estimation(USDA, 2019). As rice is the staple food, the country's staple market price of rice is a very important indicator for socio-economic stability. The government always try to keep the balance of rice market price and frequently import rice in case of insufficiency. The country still fighting to achieved self-sufficient to produce rice and there is no export of rice. The rice import statistics is an important indicator of rice production of the country. The result of this study compared with the rice import data (figure 14) of Bangladesh. The comparison found that the estimated rice area in 2008 (107,78,200 ha), 2010 (114,52,800 ha) and 2017 (111,34,600 ha) was comparatively lower estimation and higher amount of imported rice in 2007 (2,04,700 tones), 2010 (1,30,800 tones) and 2017 (3,20,000 tones). Which strongly support to the result of this analysis. But the statistical data shows similar trends as the earlier and previous year. Although the rice cultivated area not increasing that much but the overall rice production is increasing over Bangladesh due to the high yielded varieties, intensive agriculture input (fertilizer, pesticide, irrigation) but the rice area slightly decreased over the time(Kirby et al. 2014).

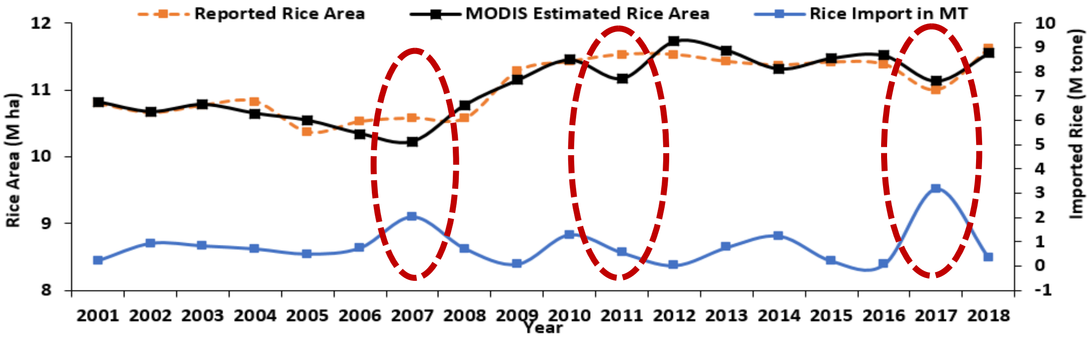


Figure 14. ALOS ScanSAR-MODIS estimated rice area compared with annual national imported rice statistics (USDA) reported from 2001 to 2018.

4.2 Uncertinity

Rice paddy mapping with remote sensing is challenging and there are some potential sources of uncertainties. The uncertainties sources could affect the result of the rice paddy map. All the stages from field data collection, image processing, classification and calculation could be possible sources of potential error. Although we try to collect field data in larger crop extend (>3 ha) but the co-exists of others vegetation and water body could be a potential source of uncertainty. The monthly temporal resolution of ALOS-2 ScanSARdata used for this study, but the rice planting season especially in aus and amon season varied region to region more than one month and lead to misclassifying of paddy rice. The ScanSAR backscattered coefficient data very sensitive to the surface water condition and during the rainy season the non-rice field also exist inundated condition. As a result, aus rice paddy detection shows the higher discrepancy. The MODIS data with 16 days temporal and 1 km spatial resolution and some paddy field area extend less than the spatial extends and influence the result. Although, the higher resolution ALOS-2 ScanSAR data for 2018 used to update the problem. The result compares with remote sensing-based study, but the spatio-temporal resolution and methodologies are the difference and potential error source of discrepancy. Moreover, the national statistics source data used for statistical comparison. The national statistical data collection and estimation process itself has some discrepancy and not always provides accurate measurement. In BBS rice paddy statistical data case, it's mentioned that the data avoided the fraction number and represent as the round figure. Moreover, it's very common that the national statistical data sometimes influenced by the government for political and socio-economic reason in the developing countries. So, the sources of uncertainties could occur on both resultant and compared parameters.

5. Conclusion

This study demonstrated the remote sensed based seasonal rice paddy mapping over Bangladesh from 2001 to 2018. The multi dated ALOS-2 ScanSAR data with unsupervised classification and supervised labelling used for seasonal rice paddy. The methodology shows very good accuracy (59% to 84%) to identify even the complex rice cropping pattern. Along with the high spatial resolution ALOS-2 ScanSAR, the low-resolution MODIS Kalman's filtered NDVI data with spectral similarity matching and maximum likelihood classifier used seasonal rice map with very good agreement. The comparison results between ALOS-2 ScanSAR rice map and MODIS rice area map shows very good agreement with overall accuracy of 84.04%, and kappa value 0.77. The MODIS rice map result compared with the national statistics and shows R2 value 0.97 for boro, 0.77 for amon and 0.28 for aus rice in national scale from 2001-2018. The compared result in major divisional level shows r2 value 0.90 from 2001-2018. The combinedly, high spatial resolution SAR sensor data and high spatial resolution of long time series optical sensor data could be potential tools for seasonal rice area mapping. The long time series spatial data on seasonal rice paddy area could be very important for the policymaker to ensure the food security and climate change mitigation.

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