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Scope of paddy harvesting technologies through cropland mapping using GIS tools and remote sensing

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ABSTRACT

Nowadays, modern agriculture has benefited from Precision Agriculture (PA) through incorporation of technological advances like the use of GIS (Geographic Information Systems), RS (Remote Sensing), GPS (Global Positioning System) and advanced information processing. Based on the GIS, RS and GPS, a study was conducted to develop a cropland map using GIS and remotely sensed unsupervised algorithm for suitability analysis of paddy harvester. The research was carried out at four selected locations such as Kulbaria-Baratia, Mundopasha, Charwapda, and Holdibaria villages of Dumuria, Wazirpur, Subarnachar and Kalapara upazilas of Khulna, Barishal, Noakhali Patuakhali districts, respectively in the southern Bangladesh. The satellite images for GIS mapping were captured at vegetation stage of Boro-2018 and Aman-2018 during March-April and October-November. Technical performances of reaper and combine harvester were used to determine the required number harvester based on the estimated cultivated area found through GIS maps. The calculated required number of (a) reaper, (b) mini combine and (c) medium combine to cover the estimated paddy area are (a) 17 and 16, 1 and 5, 38 and 127, 6 and 21, (b) 35 and 32, 3 and 10, 76 and 254, 13 and 42 and (c) 10 and 9, 1 and 3, 21 and 72, 4 and 12 during Boro and Aman seasons at Kulbaria-Baratia, Mundopasha, Charwabda and Holdibaria of Dumuria, Wazirpur, Subarnachar and Kalapara upazilas, respectively. The estimated results revealed that GIS tools and remote sensing are helping in simplification and visualization by incorporating data sets which can supports decision making for the implementation of paddy harvesting technologies in order to ensure the proper agricultural mechanization. Based on the accuracy assessment, GIS tool is found very useful to assess area to be harvested mechanically with specific type and number of harvester. It can be considered for formulating mechanized harvesting policy through further research in other areas.

Keywords: Precision agriculture, cropland mapping, GIS, remote sensing, LULC classification, paddy harvesting technologies

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1 Introduction

There is a significant role of agriculture in the gross domestic product (GDP) of Bangladesh. More than 70% of Bangladeshi people and 77% of its workforce lives in rural areas and earns their living from agriculture (World Bank, 2016). Paddy is the most important cereal crop in agriculture and timely harvesting of paddy is very important to reduce losses affecting the total yield. As per the United States Department of Agriculture (USDA), with a production of paddy Bangladesh stands in third position globally after China and India (Roy and Parvez, 2020). Due to unavailability of modern mechanical harvesting system, significant amount of field losses of paddy in every year has been occurred due to natural calamities and shortage of time during harvesting period (Noby et al., 2018). Timely harvesting of paddy is a big challenge due to shortage of labor and high wages during peak paddy harvesting season. Zhang et al. (2014) indicated that a progressive shrinking of rural labor availability, as workers migrate to cities or abroad to engage in more remunerative employment, particularly in the garments and construction sectors. To overcome the shortage of labor, mechanical harvesting are urgently needed (Keerti and Raghuveer, 2018). Technologies/mechanization can improve the timely harvesting of paddy (Jones et al., 2019). Projections also indicate that paddy and wheat production will need to increase by 0.4 and 2.17% per year, respectively, to keep pace with the additional two million population if added annually (Mainuddin and Kirby, 2015). There is no scope to extend the agricultural land frontier as crop land availability in Bangladesh has declined by 68,760 ha/year (0.73%) since 1976 (Hasan et al., 2013). In other words, Bangladesh needs to produce more food from the same land, while at the same time easing farm labor requirements resulting from the country's increasingly profitable alternative forms of employment (Zhang et al., 2014).

Appropriate farm mechanization has been emphasized as an important policy and development goal in Bangladesh (Mandal, 2002, 2014; Zhang et al., 2014). To promote the modern agricultural technology, resource planning is needed with proper information management infrastructure (Ahmed et al., 2003) that requires a systematic effort towards the proper planning of land use activities and appropriate use of modern agricultural technologies. Precision Agriculture (PA) can combine multiple technologies such as remote sensing (RS), Geographic Information Systems (GIS), Global Positioning System (GPS) and process control (Batte and Van Buren, 1999). PA techniques are employed to increase yield, reduce production costs and minimize negative impacts to the environment through using information technology, satellite positioning data, remote sensing and proximal data gathering (Zarco-Tejada et al., 2014; Zhang et al., 1999). Besides, digital agriculture takes advantages of PA techniques and information technologies to make the best decisions in agricultural resource planning.

Nowadays, the PA technologies (GIS, GPS, Global Navigation Satellite System (GNSS), etc.) are being adopted by farmers and farm managers around the world to evaluate machine performance precisely and to manage the farms in more economically (Hasan et al., 2021). Currently, GIS-GPS-RS technologies are used in combination for precision farming and site-specific crop management through land use land cover (LULC) along with land suitability mapping to convey information to the users. The farmers, policy makers and other decision makers will be benefited to know about how to accomplish sustainable agriculture over the wide variations in climate around the world. GIS is now emerging as a powerful set of tools and spatial decision support system and also uses to organize the data sets for analysis and decision making process. RS imagery is the most important data resources of GIS. Agricultural RS with GPS data is a useful tool for agricultural management and decision making (Schowengerdt, 2006) that produces spatially-varied data and information for agricultural planning and prescription for precision agricultural operations with GIS (Yao and Huang, 2013). Many studies employed remotely sensed data to build up thematic maps (Kapetsky and Nath, 1997; Salam et al., 2003; Hossain et al., 2007) of crop land use planning and a constructive tool for decision-making. The farmers, scientists and policy makers can work together to create more effective and efficient farming techniques through mapping of geographic and geologic features of current potential farmland (Das, 2003). Satellite remote sensing proved to be an important tool for crop mapping (Gallego et al., 2014) as it allows mapping the cropland area. Based on the cropland area, GIS has the capability to analyzed agricultural land use data from satellite based remote sensing and can be determined when and which type of machinery should be used and estimate the number of machinery to be needed in different farming systems practices for crop cultivation during a cropping season (Ahmed et al., 2003). The purpose of the acreage of agriculture land use map is to identify areas within a planning area that are best suited to particular land-use such as settlement, agriculture and other uses (Kaiser, 1998) that can be used to develop a land-use plan of an area (Steiner et al., 2000). To promote modern agricultural technology, resource planning is needed with proper information management infrastructure, planning of land use activities and appropriate use of modern agricultural technologies. So, GIS mapping is necessary to identify the land topography and scope of harvesting technologies in the Southern Delta of Bangladesh. Findings of the study will assist the development and management of sustainable agricultural mechanization especially in paddy harvesting in Bangladesh.

2 Materials and Methods

2.1 General features of the experiment

Based on the objective of the study, a resource mapping framework was developed utilizing Participatory Rural Appraisal (PRA) and Focus Group Discussion (FGD) with local communities and community leaders to improve the agricultural development with mechanized agriculture. ArcView GIS (Version 10.3.1) was used to digitize the resource maps as a Decision Support System (DSS). Also, FGD based interaction were conducted with community people at each village in an upazila of selected districts of Bangladesh (Fig. 1) to know stakeholders' opinions on agricultural land and water body management, cropping pattern and intensity relevant to paddy harvesting machinery. To know the scope of paddy harvesters accessibility, the study were also conducted to evaluate the technical performances of 2 reapers (Model: MR 120 and AR 120), a mini combine harvester (Model: 4LBZ-110) and 2 medium combine harvesters (Model: DR150Aand AG600A).

2.2 Study area

For GIS mapping and performance evaluation of selected paddy harvesters, the study was conducted at four selected locations such as Kulbaria-Baratia, Mundopasha, Charwapda, and Holdibaria villages of Dumuria, Wazirpur, Subarnachar and Kalapara upazilas of Khulna, Barishal, Noakhali and Patuakhali districts, respectively in the southern Bangladesh. These areas were selected purposively based on its some diverse topography (vegetable field, paddy field, hatchery, river, canal, etc.) and climatic conditions.

2.3 Major cropping systems

A detailed assessment and analysis of the quality, quantity and physical status of resources (settlement, water body, forestry, agricultural land etc.) were first mapped in the field and then digitized using GIS. Cyclone prone agro-ecology of southern region of Bangladesh is different from other areas. Generally, farmers are mostly dependent on climate sensitive crop production and cultivated their land during three seasons: (i) Kharif-1 (mid-March to mid-June, summer crops), (ii) Kharif-2 (mid-July to mid-October, monsoon crops), and (iii) Rabi (mid-October to mid-March, winter crops) in this region. From field survey, identified major cropping patterns of the selected study areas are presented in Table 1.

2.4 Materials used

Primary data were collected using survey questionnaire, face to face interview, KII (Key Informant Interview), PRA and FGD. On the other hand, secondary data were collected from books, journal articles, research report, etc. In addition, remote sensing, satellite imagery and GIS were also used in the study.

2.5 Data collection

In this study, two types of data were used, i.e., a) satellite data and b) ancillary data included ground truth data. Satellite data that comprised of two seasons multi- temporal satellite imageries (LANDSAT 7 imageries of Boro-2018 and Aman-2018) for the months of March-April and October-November that acquired from the USGS GLOVIS website (Table 2) and the ancillary data included the ground truth data for the land use and land cover (LULC) classes. The ground truth data was collected using GPS for image analysis, image classification and overall accuracy assessment of the classified results.

2.6 Data sources

Sentinel-2 is the most advanced and popular two satellite (Sentinel-2A, launched on 23rd June 2015, and Sentinel-2B, launched on 7th March 2017) launched by European Space Agency (ESA) with freely available data for long-term high-frequency remote sensing applications (Li and Roy, 2017). These satellites provide spatial resolution ranges from 10 m in VIS/NIR (visible/near-infrared), 20 m in red edge bands, up to 60 m in cirrus and UV bands. Spectral resolution in VIS/NIR ranges from 458 to 900 nm in 4 channels, but sensors provide at least 12 bands. Sentinel-2 satellites have a radiometric resolution of 16 bits/pixel, with a revisit time of 5 days. Among the 13 bands, Band 2 (green, 0.52–0.60 mm), Band 3 (red, 0.61–0.69 mm), Band 4 (near infrared, 0.76–0.89 mm) and Band 8 (near infrared blue, 0.42–0.50 mm), were chosen for this study due to the small spatial resolution (10 m) (Sozzi et al., 2021). Sentinel-2 provides more details in NIR band range and SWIR (short wave infrared) band range, which is helpful for agriculture, forest monitoring, and natural disaster management applications. The satellite images were freely acquired in between March to April for Boro season and October to November for Aman season from open-access hub USGS (United States Geological Survey) earth explorer website (https://earthexplorer.usgs.gov/) for each study areas during peak vegetative stage of crop for the time period of 2018 (Table 2). The acquired images were selected based on the temporal coverage with minimum to no cloud cover (less than 10%) and unwanted shade free conditions. Imagery having cloud and unwanted shade substantially reduces the accuracy of the image classification work. It should be noted that in Bangladesh, November to February is winter season and March to early April is the transi-

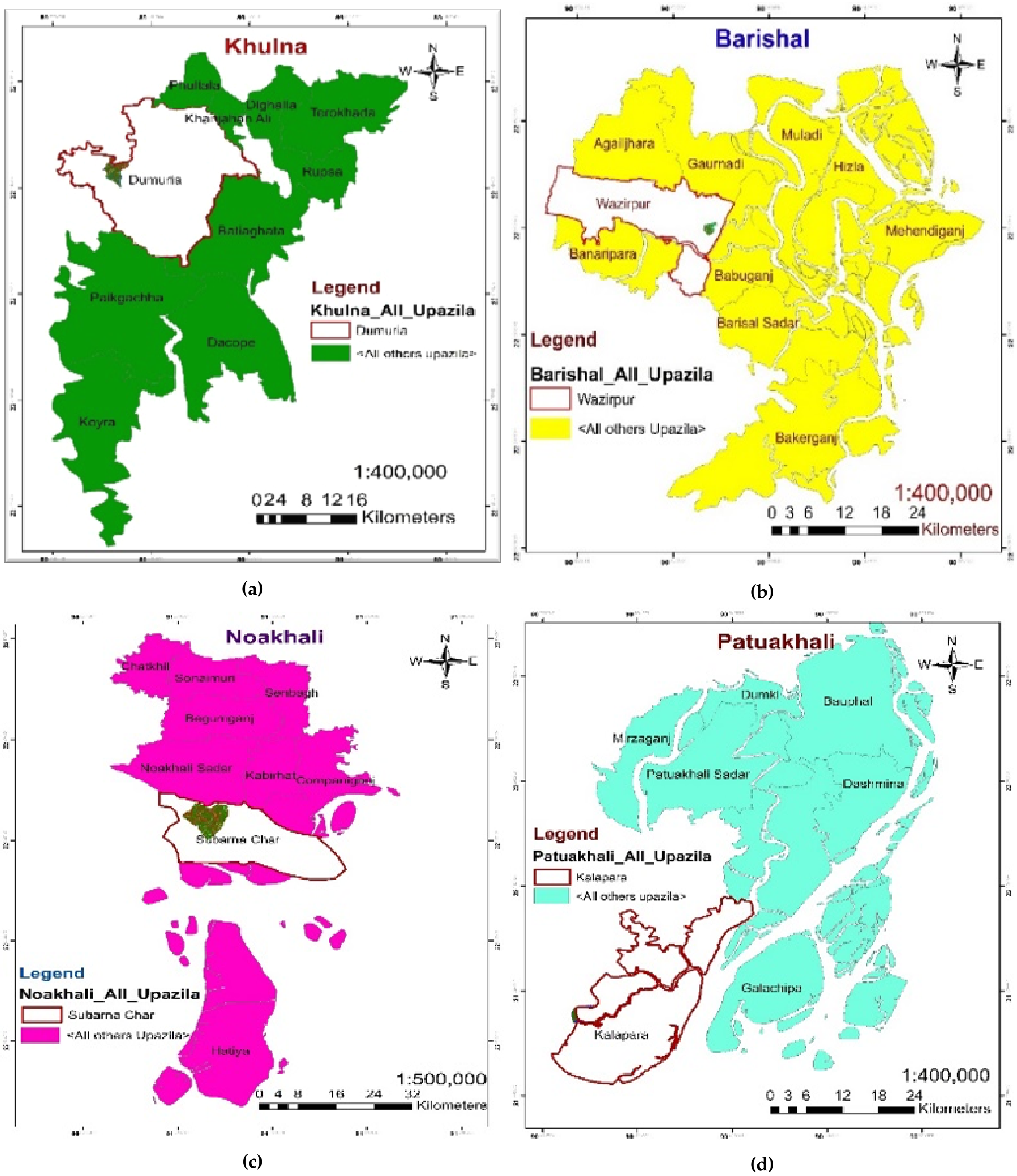

Figure 1. Selected four study locations are shown in district map: (a) Dumuria-Khulna, (b) Wazirpur-Barishal, (c) Subarnachar-Noakhali, and (d) Kalapara-Patuakhali

Table 1. Major cropping systems in the study areas

Study area	Major cropping pattern	Major crop
Kulbaria-Baratia	Boro/Wheat/Mustard - Jute/Fallow - T. Aman	Paddy
Mundopasha	Boro/Mungbean - Jute/Fallow - T. Aman	Paddy
Charwapda	Boro/Watermelon/Soybean - Aus/Fallow - T. Aman	Paddy
Holdibaria	Boro/Watermelon/Mungbean - Fallow- T. Aman	Paddy

Source: Author's field survey, 2017

Table 2. Data acquisition date with respective season in the study areas

Site	Season	Date
Kulbaria-Baratia, Dumuria	Boro	15th April 2018
	Aman	13th November 2018
Mundopasha, Wazirpur	Boro	12th April 2018
	Aman	24th October 2018
Charwapda, Subarnachar	Boro	18th March 2018
	Aman	13th November 2018
Holdibaria, Kalapara	Boro	08th March 2018
	Aman	24th October 2018

tional period of winter to summer. Again rainy season in Bangladesh is cloudy and days in the winter are most of the cases cloud free. For this reason, satellite imageries could not select of same month along the whole study period. GIS data including administrative boundary of mouza, union, upazila, district, division and country shape file of Bangladesh is now available and could be freely downloaded from the internet sources (https://www.diva-gis.org/Data). The mouza map boundary shape which contained one or two villages corresponding to a specific land area of each study area was clipped from Bangladesh administrative boundary shape file. This type of map is very important as it comprises the boundaries of all land parcels and contains methodically arranged information lie the ownership, land use and area details. The boundaries of all land parcels are on large scale which are generally 1.0 m equal to 3.96 km. Printed hard copy of mouza map was also collected from survey of Bangladesh (SoB) and geo-referenced to projection system of Universal Traverse Mercator (UTM), zone 45 and 46N, respectively with datum WGS 84 which was utilized throughout the analysis using the ArcGIS. Other related data sources such as topographical map and Google Earth were used as a base map to illustrate rural road network map, correct the study area (mouza) boundary and GPS co-ordinate (ground truth) point; as well as overly the generated land use map for identifying feature classes during classifying of image classification.

2.7 Data processing steps

After getting satellite images, it is necessary to undergo several processing steps. In this study, ArcGIS 10.3.1 software was used for image processing, classification, and its final analysis as well as development of thematic map. Prior to image classification, the satellite images were stacked to obtain multi-band composite images of selected band (2, 3, 4 and 8) into a single layer since they all have a similar spatial resolution of 10m in order to join together to form a single image file (`.tif`). From the layer file, each village features data was later clipped by using sub-set tool and shape file (mouza boundary) of each village that overlaid over the respective multi-band composite image to extract all features data during crop growing season of 2018 at each site. A false color composite (FCC) band combination of 4-3-2 (8, 4 and 3 image band respectively) was selected for RGB color composite, i.e. band 4 in the red, band 3 in the green and band 2 in the blue after literature review and lab examination. This type of color infrared composite (combination of near infrared, red and green) is displayed by placing the infrared, red, green in the red, green and blue frame buffer memory. The FCC was visually interpreted using on screen digitizing in order to delineate land cover classes that could be easily interpreted. Besides, the FCC format allows healthy vegetation to be detected readily in the image. The healthy vegetation showed in the shades of red because vegetation absorbs most of green and red energy but reflects approximately half of incident NIR energy in this type of color composite images.

2.8 Digital image classification

Selection of the most appropriate algorithm for land cover classification from satellite data is depended on specific circumstances and available resources (Fisher et al., 2005). The unsupervised—ISODATA algorithms were used for digital image classification through ArcGIS 10.3.1 software.

2.9 Unsupervised ISODATA classification

Unsupervised classification is more accurate than supervised classification (Borghuis et al., 2007). The number of classes is the most significant of the clustering parameters (Araya and Hergarten, 2008). If too small, relatively broad clusters may be generated which may not produce true results. If the number is too big, very pure clusters may be yielded with highly demanding computational resources and substantial increase in time required for cluster labeling (Ahmad et al., 1992). The final number of chosen classes for this study was 25. The other required parameters include the maximum percentage of pixels whose class values are allowed to remain unchanged between iterations and the minimum cluster size. A value of 100 was selected as the threshold value. This implies that the system is forced to assign every pixel in the image to one of the clusters. Duda et al. (2000) mentioned that a value of less than 100 results in some pixels not being assigned to clusters. The classification result arranges and assigns clusters in order of descending level of brightness. Lastly, a true color scheme resembling that of the original image was used to assign color to the different classes with the aid of digital vegetation, land use maps and ground truth data. For estimation of different classes after LULC image classification (land area, crops, fallow land, fisheries, water bodies, etc.), the essential base data were collected from each specific locations according to the cropping pattern as presented in Table 1.

2.10 Accuracy assessment

Accuracy assessment is an essential and crucial part of conducting image classification by LULC. A common tool to assess accuracy is the error matrix. Error matrices compare pixels or polygons in a classified image against ground reference data. The kappa index was calculated for each classification to estimate the accuracy of the land cover classifications. Rosenfield and Fitzpatrick-Lins (1986) advised for using the kappa index to measure classification accuracy. Several statistical analyses were used in the accuracy assessment of the obtained results. Also, the following equations were used for calculating the accuracy assessment during image classification in ArcGIS mapping (Miranda et al., 2018):

Classified Image Area (ha) = [Count (pixel) $\times$ 10 m $\times$ 10 m]/1000

Producer accuracy (%) = (Number of truth values in feature class/Sum of values of column in each feature class) $\times$ 100

Users accuracy (%) = (Number of truth values in feature class/Sum of values of rows in each feature class) $\times$ 100

Cohen's Kappa Coefficient (k) = (Sum of true values – Random accuracy)/(1 – Random accuracy)

Overall accuracy (%) = (Sum of true values in all feature class/Sum of sample values in all feature class) $\times$ 100

A set of about 80 GPS co-ordinate or georeferenced points from each study area were recorded by conducting various field trips using a smart phone (Model: Huawei P30Lite, Software: www.gps-coordinates.org) at the peak vegetative stage of crop. The samples were produced by calculating polygons around the GPS points and using aerial photographs for photo-interpretation. Generally, GPS-enabled smart-phones are typically accurate to within a 4.9 m (16 ft) radius under open sky (https://www.ion.org/). Recent research study revealed that an android smart-phone determined approximately 98% of its GPS points within 10 m of true positions and approximately 59% within 5 m (Merry and Bettinger, 2019). Therefore, a position correction algorithm was needed. The collected samples were also identified in high-resolution imagery using Google Earth pro (http://earth.google.com). Other various data sources such as topographical map and Google Earth were used as a base map to generate subsequent themes for decision making, illustrate rural road network map, rectify the study area (village) boundary and GPS co-ordinate (ground truth) points as well as exaggeratedly the generated LULC map for identifying feature classes.

2.11 Overall conceptual framework

There were three phases in conducting this research: (i) initial image processing, (ii) unsupervised classification with accuracy assessment, and (iii) identify the total number of necessary harvesting machinery. Complete work procedure is presented in Fig. 2. Every step including preliminary data collection source, analysis and find out the total number of necessary harvesting machinery are mentioned in this diagram. At a glance it is possible to understand the complete procedure of GIS mapping to find the suitable harvesting land and number of necessary harvesting machine.

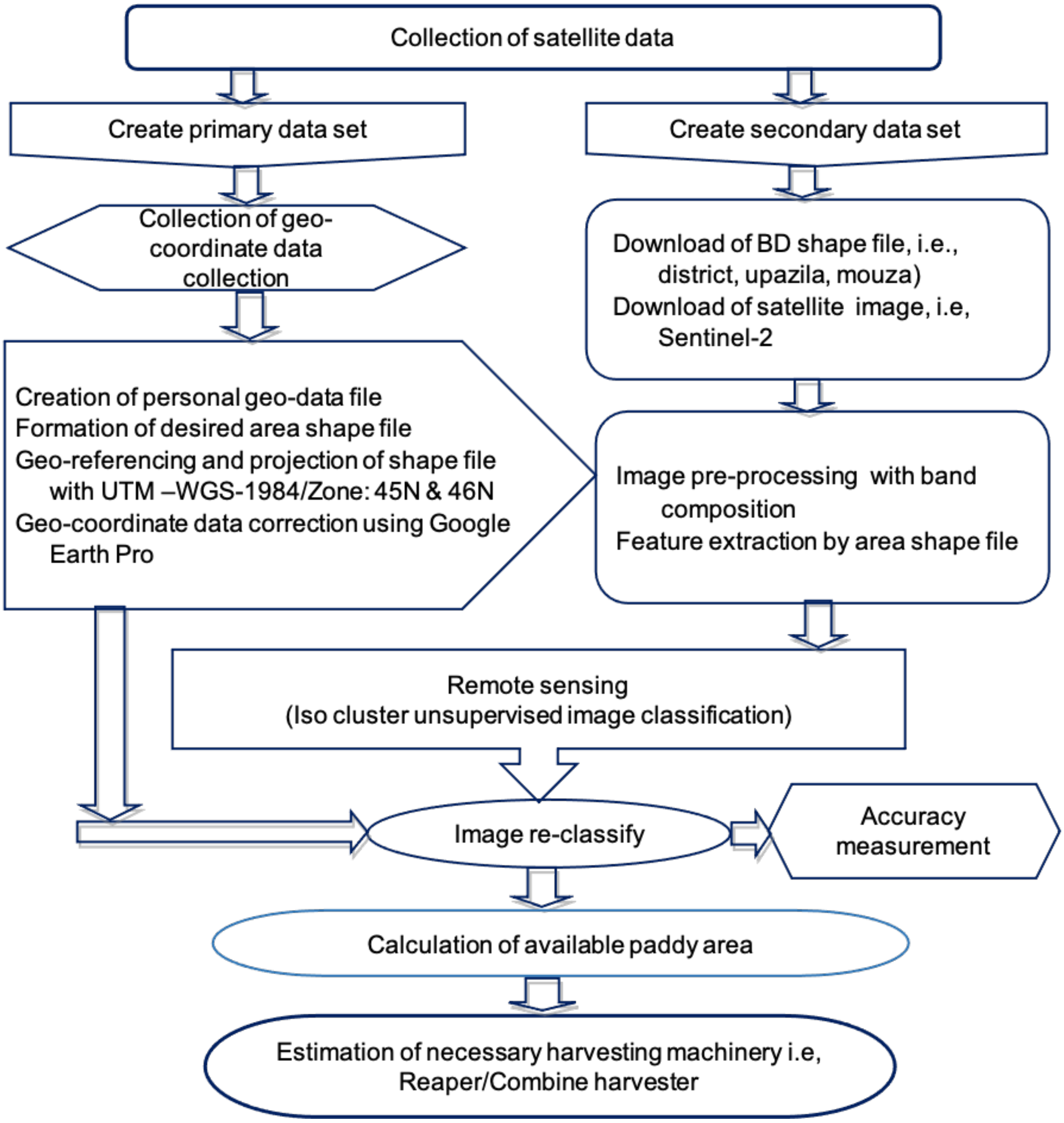

Figure 2. Flow diagram on the conceptual overview for the complete GIS Mapping

Table 3. Description of LULC classes

No.	Classes	Description
1	Settlement	Natural vegetation and planted trees, small houses, back/front yards, large space house, road and road side, playground, grass and bush vegetation, betel leaf yard
2	Water Bodies	River, river bank, ponds, canal, lakes, lowland, fisheries/gher, charland, water logged area, forested wetland
3	Paddy land	Boro, Aus and Aman paddy cultivation land
4	Other crops	Vegetable, Mungbean, Jute, Watermelon, Soybean etc
5	Forest	Forest plantation, scrub forest and degraded forest
6	Fallow land	Open space, bare and exposed soil, dry pond, canal, wet land, fodder crop field, seasonal agricultural fallow land (after paddy cultivation) mix barren land

Table 4. Classified LULC area during Boro season

Feature class	Area (ha)							
	Kulbaria-Baratia		Mundopasha		Charwabda		Holdibaria	
	Boro	Aman	Boro	Aman	Boro	Aman	Boro	Aman
Settlement with forest	278.60	295.90	82.34	71.41	1397.57	1163.84	385.60	443.99
Boro Paddy	457.86	428.68	34.03	127.89	1000.84	3349.15	168.11	560.01
Vegetable and others	131.57	69.37	76.71	42.20	2290.65	336.00	75.98	141.02
Water body†	127.36	201.44	30.10	26.11	415.44	255.51	432.07	449.89
Fallow	-	-	44.43		-	-	533.14	-
Total	995.39		267.61		5104.50		1594.90	

† Including gher and fishery

3 Results and Discussion

3.1 Spatial features data extraction using mouza boundary

Fig. 3 shows specific land area of each study areas which were clipped from Bangladesh administrative boundary shape file. This type of map is very important as it comprises the boundaries of all land parcels and contains methodically arranged information lie the ownership, land use and area details as well as shows the boundaries of all land parcels on large scale generally in 1 m: 3.96 km.

3.2 Classification of LULC

The maps were prepared using visual and digital image interpretation. The different LULC class areas were estimated based on a group of pixel counted and estimated on the pixel grid cell method. After applying the classification techniques, various LULC classes were identified in the study areas including crop land, forest, water bodies, fallow land and settlement which are described in the Table 3. Consequently, the distributions of each classified LULC class area are shown in Fig. 4.

3.3 Distributions of each classified LULC area

In this study, in addition to existing data and fieldwork, spatial and temporal remote sensing data have been extensively used and analyzed under a GIS environment. The visual interpretation gave a general idea about the forms of LULC of those areas. The analysis showed that most of the study areas are under agricultural crops areas. Area distribution under different land use categories has shown in Fig. 5. It illustrates the variation of crop cultivated area in the study areas. Consequently, the statistical results from each LULC on Boro and Aman paddy seasons of four selected study areas are presented in Table 4.

3.3.1 LULC of Kulbaria-Baratia

Table 4 represents the estimated area of the each LULC and Fig. 5 represents the percent of area covered by each LULC type, respectively in Boro and Aman seasons. Estimated total land area in Kulbaria-Baratia mouza of Dumuria in Khulna district is 995.39 ha. During the Boro season, paddy was cultivated in 457.86 ha (46%). During this season, vegetables area was 131.57 ha (13.2%) and rest of the area was water body and settlement with forest. Also, in Aman season, paddy was cultivated in 428.68 ha (43.07%) and vegetables area was 69.37 ha (6.97%). A new class named Gher/fisheries 145.26 ha (14.59%) was found in Aman season out of total 201.44 ha water body which is used as agricultural land in Boro season and rest of the area was water body and settlement with forest.

3.3.2 LULC of Mundopasha

Estimated total land area in Purbo-Mundupasha mouza of Wazirpur in Barishal district is 267.61 ha. During the Boro season, paddy was cultivated in only 34.03 ha (12.72%). During this season, vegetables and mugbean area was 76.71 ha (28.66%) and rest of the area was water body and settlement with forest and betel leaf. Also, in Aman season, paddy was cultivated in 127.89 ha (47.79%) and vegetables area was 42.2 ha (15.77%) and rest of the area was water body and settlement with forest.

3.3.3 LULC of Charwabda

Estimated total land area in Charwabda mouza of Subarnachar of Noakhali district is 5104.50 ha. During the Boro season, paddy was cultivated in 1000.84 ha (19.61%). Vegetables including watermelon and soybean area was 2290.65 ha (44.88%) and rest of the area was water body and settlement with forest. In Aman season, these areas were 3349.15 ha (65.61%) and 336.00 ha (6.58%), respectively and the rest of the area was water body and settlement with forest.

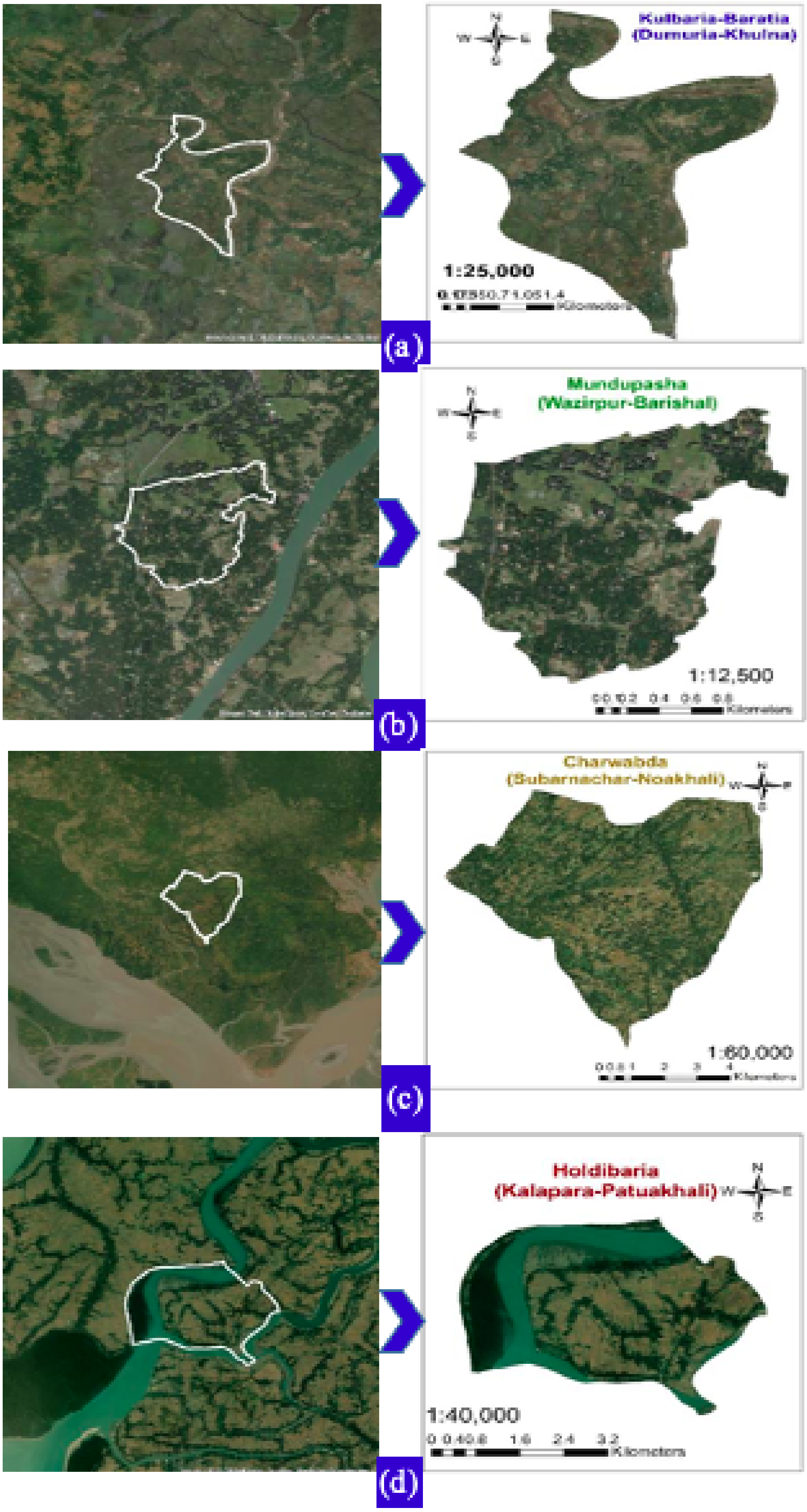

Figure 3. Spatial features data extraction using mouza boundary over composite satellite datasets: (a) Kulbaria-Baratia of Kalapara, (b) Mundupasha of Wazirpur, (c) Charwabda of Subarnachar, and (d) Holdibaria of Kalapara

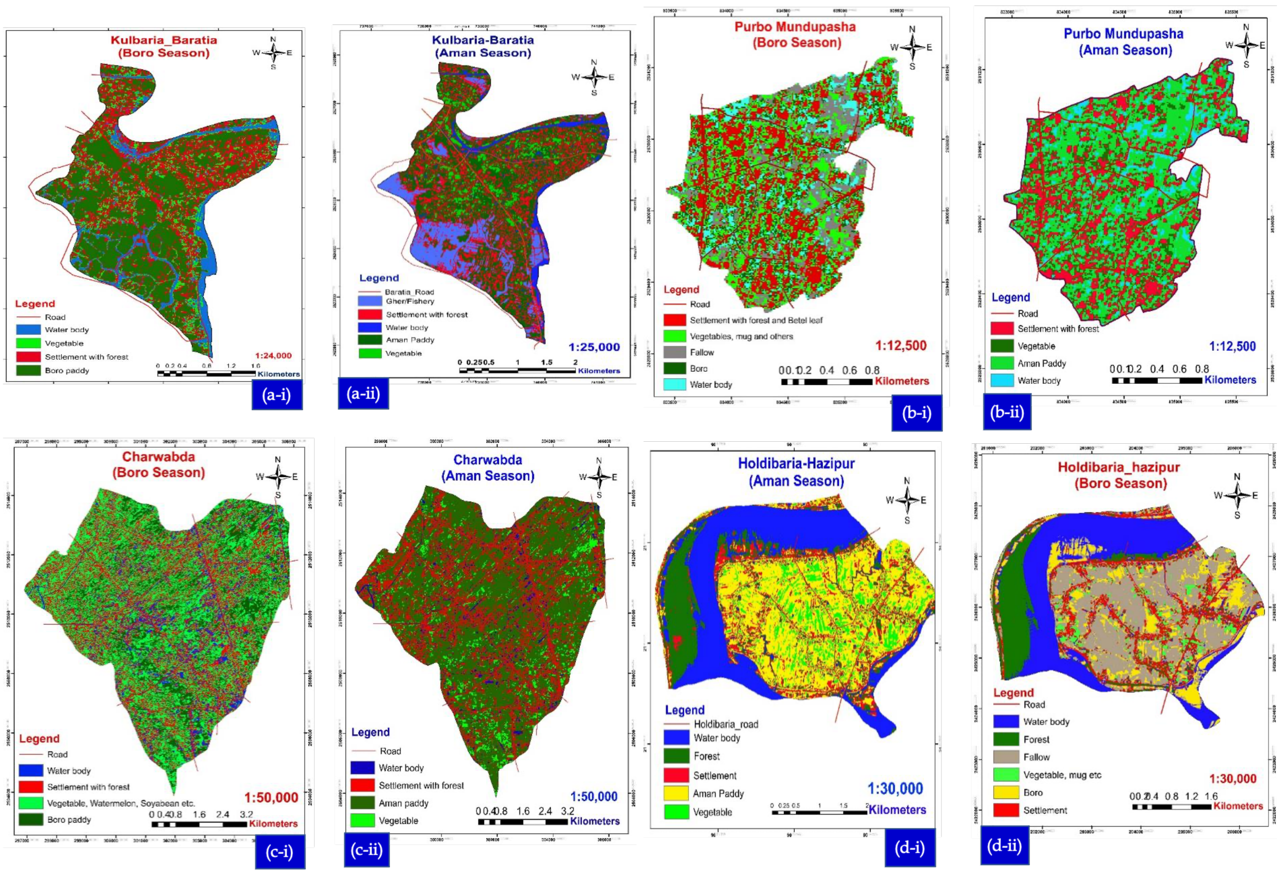

Figure 4. LULC classified maps: (a-i) Boro season of Kulbaria-Baratia, (a-ii) Aman season of Kulbaria-Baratia, (b-i) Boro season of Mundupasha, (b-ii) Aman season of Mundupasha, (c-i) Boro season of Charwabda, (c-ii) Aman season of Charwabda, (d-i) Aman season of Holdibaria, (d-ii) Boro season of Holdibaria

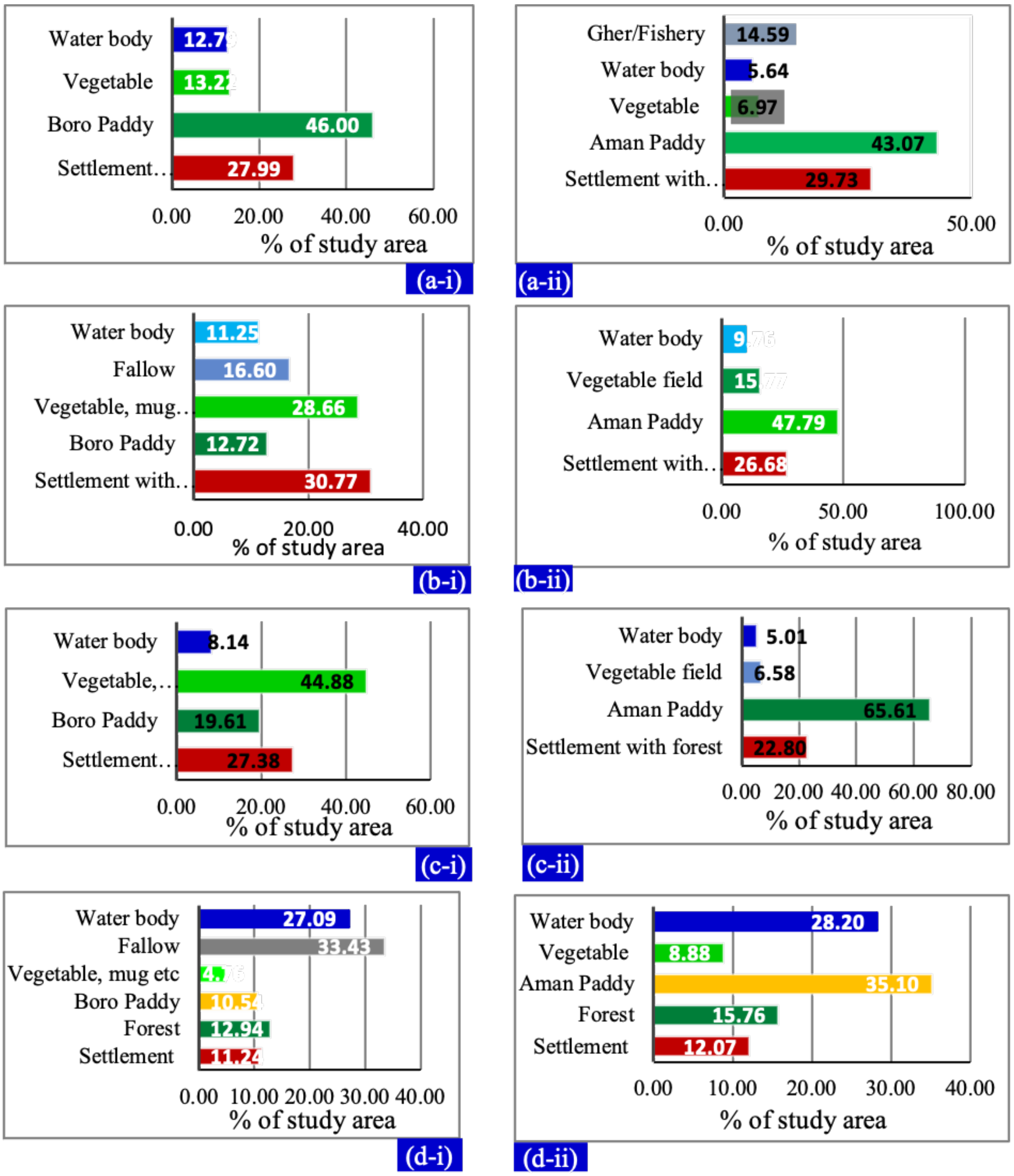

Figure 5. The graphical representation of the percent of area distribution under different land use categories: (a-i) Boro season of Kulbaria-Baratia, (a-ii) Aman season of Kulbaria-Baratia, (b-i) Boro season of Mundupasha, (b-ii) Aman season of Mundupasha, (c-i) Boro season of Charwabda, (c-ii) Aman season of Charwabda, (d-i) Boro season of Holdibaria, (d-ii) Aman season of Holdibaria

3.3.4 LULC of Holdibaria

Estimated total land area in Holdibaria-Hazipur mouza of Kalapra in Patuakhali district is 1594.9 ha. During the Boro season, paddy was cultivated in only 168.11 ha (10.54%), vegetables with mugbean area was 75.98 ha (4.7%), and rest of the area was water body, settlement with forest and fallow land. Due to water crisis, most of the area remains fallow in Boro season. But, in Aman season, paddy was cultivated in 560.01 ha (35.10%) and vegetables area was 141.60 ha (8.88%). A new class named distinct forest 206.31 ha (12.94%) and 251.42 ha (15.76%) were found in Boro and Aman seasons, respectively which are being protected the local people from natural calamities, i.e., cyclone, tidal, etc. and rest of the area was water body and settlement.

3.4 Accuracy assessment of LULC

A random stratified sampling method was used to prepare the ground reference data as shown in Fig. 6. After then the accuracy of the classified maps were analyzed and represented by estimating the Kappa value and overall accuracy. Statistical results from accuracy assessment on Boro and Aman paddy seasons of selected four study areas are presented in Table 5. The percentage of overall accuracy for the land cover classes were 85% and 87% of Kulbaria-Baratia in Dumuria, 79% and 82% of Mundopasha in Wazirpur, 80% and 78% of Charwabda in Subarnachar, 82% and 80% of Holdibaria in Kalapara, respectively from satellite image classification in Boro and Aman seasons. Sometimes misclassifications were happened. The major reason of lower accuracy of image is due to misclassification or poor performance of classification algorithm, overlapping and error in visual interpretation in distinguishing some LULC classes. For example, in Holdibaria and Mundopasha areas, the high misclassification rate was happened in paddy field due to the confusion with fallow land and settlement. Again, in Charwapda, misclassification was happened in between vegetable and watermelon fields as well as low land and dry fishing pond were showed as fallow land. Furthermore, in this study, the estimated average value of Kappa which was used to check the accuracy of LULC classification as 0.80 and 0.83 of Kulbaria-Baratia in Dumuria, 0.73 and 0.75 of Mundopasha in Wazirpur, 0.73 and 0.71 of Charwabda in Subarnachar, 0.79 and 0.75 of Holdibaria in Kalapara, respectively from satellite image classification in Boro and Aman seasons. The values of Kappa greater than 0.80 indicates strong agreement beyond chance, values in between 0.40 to 0.79 indicates fair to good, and values below 0.40 indicate poor agreement. Based on result, it can be noted that LULC mapping and area estimation of small crop area using unsupervised algorithm might be a better option for crop area identification.

3.5 Performances of paddy harvesters

The workable condition of reaper and combine harvesters is important for providing information to farmers and extensions service holders. To know the appropriate options for paddy harvesting, the performance indicators of harvesters were identified, determined and presented in Table 6. Average effective field capacity of the medium combine harvester was found 0.39 ha/h which is higher than that of mini-combine harvester (Model: 4LBZ-110) 0.09 ha/h and reaper (Model: AR 120 & MR 120) 0.22 ha/h. Based on climate, southern region of Bangladesh is a vulnerable area. Shattering of paddy at the matured stage is a common phenomena in this region due to early flood, storm and cyclone etc. Due to climate vulnerability, it is necessary to harvest large area of paddy within a short time. Considering the purchase price, harvesting quality and farmer's affordability, medium size combine harvester will definitely be most appropriate for Bangladesh. However, farmers in some areas also preferred to have paddy straw intact after harvesting and threshing, in that situation reapers also have valid ground to be promoted in some selected areas in the country.

3.6 Scope of harvesters' accessibility

To develop a mechanized farming, especially for mechanical paddy harvesting, it is essential to access the paddy harvesters to the crop field. However, in most of the rural Bangladesh have no adequate farm roads. Comparatively, reaper and mini combine harvester are easily transported to paddy field like power tiller and tractor but in case of medium combine harvesters need enough roads facilities for transporting to the paddy field. Considering the enough road facilities, required number of individual harvester were estimated and presented in Table 7. During this estimation, necessary harvesters were counted based on the seasonal paddy cultivated area and machine capacity. Also, to estimate the necessary harvester, separate LULC classified maps through GIS mapping for only paddy area were developed as shown in Fig. 7. This study would be helpful in future research for large areas such as upazila, district or country level agricultural mechanization related policy planning and application. With this study, a policy maker can take decision about how many and what type of paddy harvesting technology need to be introduced either by adoption or replacement for related crop cultivation in Bangladesh.

3.7 Sensitivity analysis on the scope of paddy harvesters

The sensitivity analyses were carried out with considering the variation of cultivated area and machine

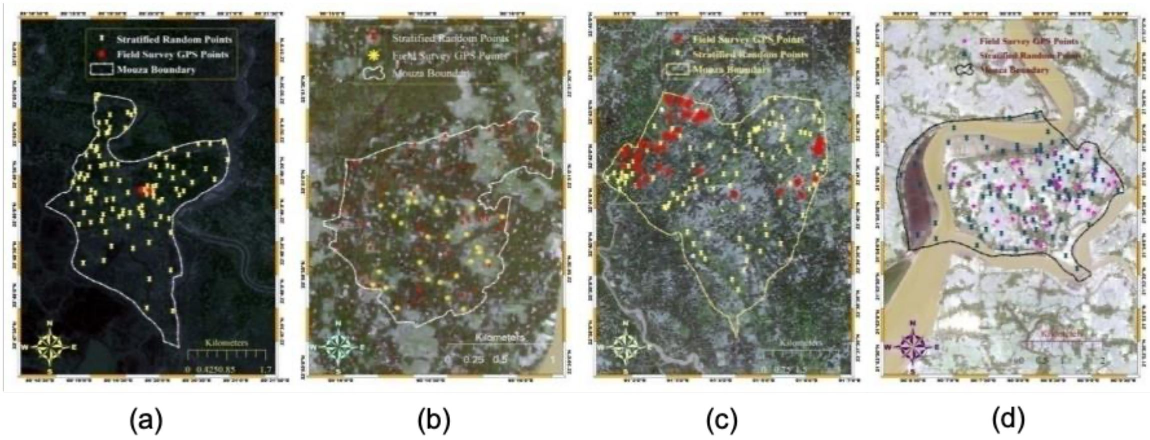

Figure 6. Plots of collected GPS points and stratified random points during accuracy assessment: (a) Kulbaria-Baratia, (b) Mundopasha, (c) Charwapda, and (d) Holdibaria

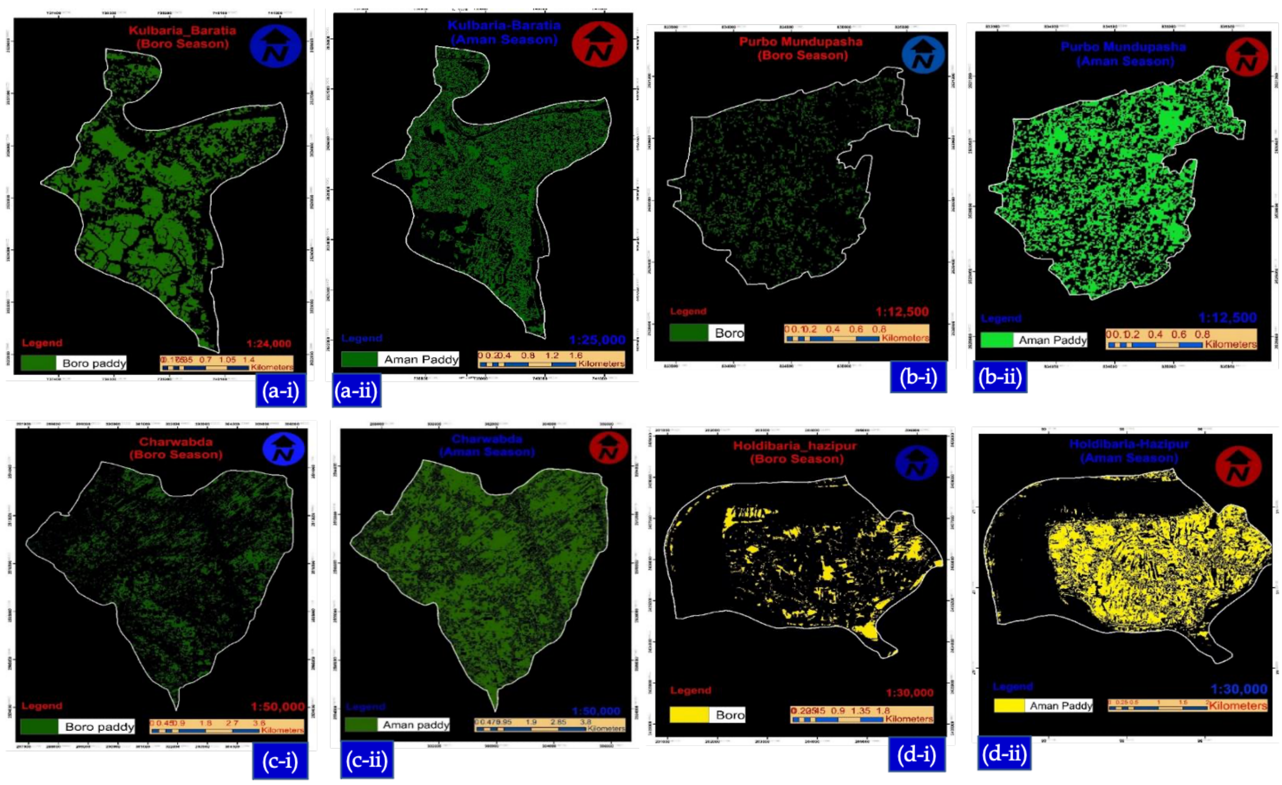

Figure 7. LULC classified maps for only paddy: (a-i) Boro of Kulbaria-Baratia, (a-ii) Aman of Kulbaria-Baratia, (b-i) Boro of Mundupasha, (b-ii) Aman of Mundupasha, (c-i) Boro of Charwabda, (c-ii) Aman of Charwabda, (d-i) Boro of Holdibaria, (d-ii) Aman of Holdibaria

Table 5. Accuracy assessment on LULC of study sites

Seasons	LULC class	Accuracy (%)			k	Agreement
		User	Producer	Overall		
Kulbaria-Baratia						
Boro	Settlement with forest	100	81	85	0.80	Strong
	Boro Paddy	80	75			
	Vegetable	82	100			
	Water body	80	86			
Aman	Settlement with forest	100	88	87	0.83	Strong
	Aman Paddy	86	86			
	Vegetable	82	88			
	Water body	92	73			
	Gher/Fishery	78	100			
Mundopasha						
Boro	Settlement with forest and betel leaf	67	71	79	0.73	Good
	Boro Paddy	81	87			
	Vegetable, mug bean and others	79	85			
	Fallow	85	73			
	Water body	86	80			
Aman	Settlement with forest and betel leaf	65	76	82	0.75	Good
	Aman Paddy	80	86			
	Vegetable field	100	100			
	Water body	92	71			
Charwabda						
Boro	Settlement with forest	80	80	80	0.73	Good
	Boro Paddy	81	81			
	Vegetable, Watermelon, Soybean etc	69	73			
	Water body	92	86			
Aman	Settlement with forest	79	79	78	0.71	Good
	Aman Paddy	80	80			
	Vegetable field	65	73			
	Water body	93	81			
Holdibaria						
Boro	Settlement	86	80	82	0.79	Good
	Forest	88	82			
	Boro Paddy	79	85			
	Vegetable, mug etc	91	56			
	Fallow	68	100			
	Water body	88	100			
Aman	Settlement	86	75	80	0.75	Good
	Forest	86	86			
	Aman Paddy	82	78			
	Vegetable	91	67			
	Water body	63	100			

k = Kappa co-efficient

Table 6. Average technical performance of different harvesters

Machine	Company	Model	Forward speed (km/h)	Fuel consumption (L/ha)	EFC (ha/h)	Field efficiency (%)
Reaper	ACI	AR 120	2.96	3.32	0.23	63.61
	Metal	MR 120	2.68	4.08	0.21	63.65
	Average		2.82	3.7	0.22	63.63
Mini combine	Glory	4LBZ-110	1.88	18.11	0.11	53.05
Medium combine	ACI	AG600GA	6.09	21.49	0.45	53.32
	Metal	DR150A	6.71	24.59	0.33	50.14
	Average		6.4	23.04	0.39	47.16

Table 7. Required number of individual harvester

	Cultivated area (ha)		Number required					
			Reaper		Mini combine		Medium combine	
	Boro	Aman	Boro	Aman	Boro	Aman	Boro	Aman
Kulbaria-Baratia	457.86	428.68	17	16	35	32	10	9
Mundopasha	34.03	127.89	1	5	3	10	1	3
Charwapda	1000.84	3349.15	38	127	76	254	21	72
Holdibaria	168.11	560.01	6	21	13	42	4	12

Table 8. Sensitive analysis on the scope of accessibility of different machines

Variables	Kulbaria-Baratia		Mundopasha		Charwapda		Holdibaria	
	Boro	Aman	Boro	Aman	Boro	Aman	Boro	Aman
Reaper								
All constant	17	16	1	5	38	127	6	21
CAI 10% and SUMC	19	18	1	5	42	140	7	23
CAD 10%and SUMC	16	15	1	4	34	114	6	19
CAI 10% and SUMD 10%	21	20	2	6	46	155	8	26
CAI 20% and SUMC	21	19	2	6	45	152	8	25
CAD 20% and SUMC	14	13	1	4	30	101	5	17
CAI 20% and SUMD 20%	26	24	2	7	57	190	10	32
Mini combine harvester								
All constant	35	32	3	10	76	254	13	42
CAI 10% and SUMC	38	36	3	11	83	279	14	47
CAD 10%and SUMC	31	29	2	9	68	228	11	38
CAI 10% and SUMD 10%	42	40	3	12	93	310	16	52
CAI 20% and SUMC	42	39	3	12	91	304	15	51
CAD 20% and SUMC	28	26	2	8	61	203	10	34
CAI 20% and SUMD 20%	52	49	4	15	114	381	19	64
Medium combine								
All constant	10	9	1	3	21	12	4	12
CAI 10% and SUMC	11	10	1	3	24	79	4	13
CAD 10%and SUMC	9	8	1	2	19	64	3	11
CAI 10% and SUMD 10%	12	11	1	3	26	87	4	15
CAI 20% and SUMC	12	11	1	3	26	86	4	14
CAD 20% and SUMC	8	7	1	2	17	57	3	10
CAI 20% and SUMD 20%	15	14	1	4	32	107	5	18

CAI= Crop area increase, CAD = Crop area decrease, SUMC= Seasonal use of machine constant, SUMD= Seasonal use of machine decrease capacity as shown in Table 8. To know the prediction of required power, the consequences of specified changes were determined between cultivated crop area and seasonal use of machine. The sensitivity analysis gives an indication of how changes would effect on machine estimation decision. Table 8 represents the scenarios on the harvester machine accessibility with the variation of total seasonal paddy cultivation area. In the sensitivity analysis, 7 different indicating criteria's were considered such as (a) all constant variable, (b) crop area increase 10% and seasonal use of machine remain constant, (c) crop area decrease 10% and seasonal use of machine remain constant, (d) crop area decrease 10% and seasonal use of machine decrease 10%, (e) crop area increase 20% and seasonal use of machine remain constant, (f) crop area decrease 20% and seasonal use of machine remain constant, and (g) crop area decrease 20% and seasonal use of machine decrease 20%. Sometimes machine use can be reduced with crop lodging and water logged due to heavy rain, early flood, cyclone and storm. Also, machine capacity can be reduced with the life of machine and machine accessibility to the field. On the other hand, seasonal cultivated area can be increased with the farmer's willingness of paddy transplanting by getting enough irrigating and others facilities.

4 Conclusion

GIS tool and remote sensing in agriculture have been found effective tools. Considering crop area, cropping pattern, land topography, road access to cropland, required number of harvesters were estimated through GIS and separate LULC classified mapping in four selected areas of southern delta of Bangladesh. Based on mechanical harvesting, estimated average effective field capacities were found 0.22 ha/h, 0.11 ha/h and 0.39 ha/h, respectively of reaper, mini-combine harvester and medium combine harvester. The calculated required number of (a) reaper, (b) mini combine, and (c) medium combine to cover the estimated paddy area are (a) 17 and 16, 1 and 5, 38 and 127, 6 and 21, (b) 35 and 32, 3 and 10, 76 and 254, 13 and 42, and (c) 10 and 9, 1 and 3, 21 and 72, 4 and 12 during Boro and Aman seasons at Kulbaria-Baratia, Mundopasha, Charwabda and Holdibaria of Dumuria, Wazirpur, Subarnachar and Kalapara upazilas, respectively. Based on the overall accuracy (78∼87) and Kappa coefficient (0.71∼0.83), the results of the study will be useful and the classified image technique can be considered for further research in other areas. The results of the study are also important to policy makers to formulate national mechanization strategies.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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