Monitoring Long-Term Wheat Cultivation and Climatic Drivers for Land Use Change: A Case Study Using Remote Sensing at Thakurgaon Sadar in Bangladesh

M. S. H. Siddiquee [1]*, M. G. Miah[2], H. M. Abdullah[2] and T. Afroz [3]

[1]Department of Agricultural Extension (DAE), Khamarbari, Dhaka
[2]Department of Agroforestry and Environment, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-1706
[3]Department of Agroforestry and Environmental Science, Sylhet Agricultural University, Sylhet
*Corresponding email: muhammadsiddiquee@gmail.com

Abstract

The present study uses Remote Sensing techniques to monitor long-term wheat cultivation in Thakurgaon Sadar *Upazila*. Multi-spectral Landsat images from 1999 to 2019 at five years intervals were collected at the maximum growth stage of wheat. The images were processed by QGIS, ArcGIS, and R software with the random forest supervised classification. The findings revealed that images were classified and separated the crops successfully due to cloud-free images and pure pixels. The results show that the wheat area was decreased from 1999 (16349 ha) to 2019 (9161 ha). It was due to the transformation of the wheat area into other crop areas. The shrinkage rate of wheat areas was much higher (10.93 %) in 1999-09 than in 2009-19. It was due to a sudden decline in blast disease during 2005-09 and increased again. The shrinkage of the wheat area has been driven mainly by climate change influencing profitability. Prolonged hydrological drought introduced maize and potato in the wheat area. The benefit-cost ratio decreased gradually in wheat but increased in maize and potato. The study demonstrates that remote sensing is an effective method for wheat crop area monitoring. This study will help us understand the status of long-term wheat cultivation.

Key words: Climate change, Drought index, Drivers, Remote sensing, Wheat

Introduction

Wheat (*Triticum aestivum* L.) is currently the second major human food crop after maize and rice in total global production (Mccormick, 2020). It belongs to the family Poaceae (previously known as Gramineae). China is the largest wheat producer (133.6 Mt), followed by India (103.6 Mt), Russia (73.61 Mt), and the United States (52.58 Mt) (FAOSTAT, 2020 and USDA, 2020). Wheat is ranked 3rd among the cereals produced in Bangladesh (Nazmul, 2021). In terms of food grains, wheat's demand is just slightly behind rice. The first reason for increasing wheat demand is the country's ever-growing population (Sarwar and Biswas, 2021). The second reason is the change in diet, which resulted in an awareness of human health. Wheat flour has long been a staple of the rich, middle, and emerging middle classes' diets. As a result, demand for wheat is rising. The third reason for increasing wheat demand is that wheat flour is cheaper than fine rice. Although wheat consumption continues to increase, production has decreased significantly since the late 1990s. The country produced 1.91 million tonnes of wheat in 1998-1999, but now it is 1.2 million tonnes (less than one-fifth of total demand). Currently, the country's yearly wheat demand is approximately 7.0 million tonnes (BBS, 2020a). The country has become almost entirely reliant on wheat imports. According to Mandal (2020), 6.43 million tonnes of wheat was imported in 2019-20. The country's northern region is the major wheat-growing area in Bangladesh, accounting for almost 68 percent of the total cultivated area and 70 percent of total production (BBS, 2020b). The shortage in our country is mainly because it is cultivated exclusively during the winter season and lacks accurate information. However,

wheat production needs to be at least at the stage of meeting demand or better. So there is no substitute for advanced monitoring to play a role in food security as an alternative to rice.

Conventionally, wheat cultivation is monitored using field-based site visits or eye-estimating. Such techniques are frequently subjective, relative, and expensive, resulting in highly imprecise crop data, even though they are crucial for export/import decisions (Noureldin *et al.*, 2013). Thus, policymakers lack access to accurate estimates and forecasts of total wheat data before harvest. Due to these information gaps in wheat production, unscrupulous traders artificially create a market crisis by stockpiling (Wion, 2020 and Faridi, 2020). However, one of the primary issues with imports is accurate data on demand and supply.

According to recent reports, remote sensing could play a vital role in accurately monitoring crop cultivation (Abdullah *et al.*, 2011). Additionally, the techniques may address the wheat production issues mentioned above by giving real-time information on crop areas. While remote sensing monitors crop cultivation in different countries, it is relatively new and limited in Bangladesh. As a result, Bangladeshi researchers require additional and extensive study in this sector.

In the past, Bangladesh has used remote sensing, particularly MODIS NDVI, to estimate and forecast crop cultivation for a few crops such as aman rice and potato (Bala *et al.*, 2007; Salam, 2014; Mosleh *et al.*, 2016 and Kalpoma *et al.*, 2019). Previous research on rice crops has proved that accurate area estimation and forecast before harvesting are crucial for food security, sustainable crop production, and farmers' profitability (Faisal *et al.*, 2020; Kalpoma *et al.*, 2020). Thus, this

type of research should be conducted on other priority crops, such as wheat, so that required measures can be made in advance to address any looming difficulties.

In Bangladesh, the first attempt was undertaken using multi-decadal Landsat imagery to monitor wheat cultivation areas, to validate with national crop statistics, and to determine the climatic drivers influencing wheat area changes in the research location.

Materials and Methods

Study Area

The northern region has a better environment for wheat production than other parts of the country. Considering the suitability, Thakurgaon Sadar *Upazila* was selected as the present study site (Figure 1). The geographical coordinates of *Upazila* are 26.0208 N latitude and 88.4667 E longitude. The total area was 683.45 square km or 68345 hectares. The maximum temperature of the study site was 33.5 °C, and the minimum was 10.5 °C. The annual average total rainfall was 2536 mm. Most of the land of *Upazila* was high, where low land was in the second position.

Characteristically, the soil of the study area was loamy textured and sandy mixed, with good structure and moderate water holding capacity, which is ideal for wheat cultivation (Singh, 2018 and BBS, 2020). *Upazila* was characterized by land areas of Tangon, Punarbhaba, Nagar, Tentulia, Kulik, Pathari rivers, *Ulir Beel,* and considerable numbers of *Deghee*. Due to the extensive cultivation of the wheat crop, there are pure pixels available, which is a prerequisite for accurate classification.

Crop Selection

Wheat is one of the major cereal crops produced in Bangladesh. Wheat ranks second in terms of production and demand. A significant amount of wheat was cultivated in the study area. The demand for wheat in the country is increasing, but the cultivation area and production decrease day by day. Hence wheat crop monitoring and yield forecasting are crucial to our decision-makers. Also, wheat crops are cultivated in winter when cloudless images are available, prerequisites for satellite image classification (Wardad, 2019). Therefore, the wheat crop was selected for the present study.
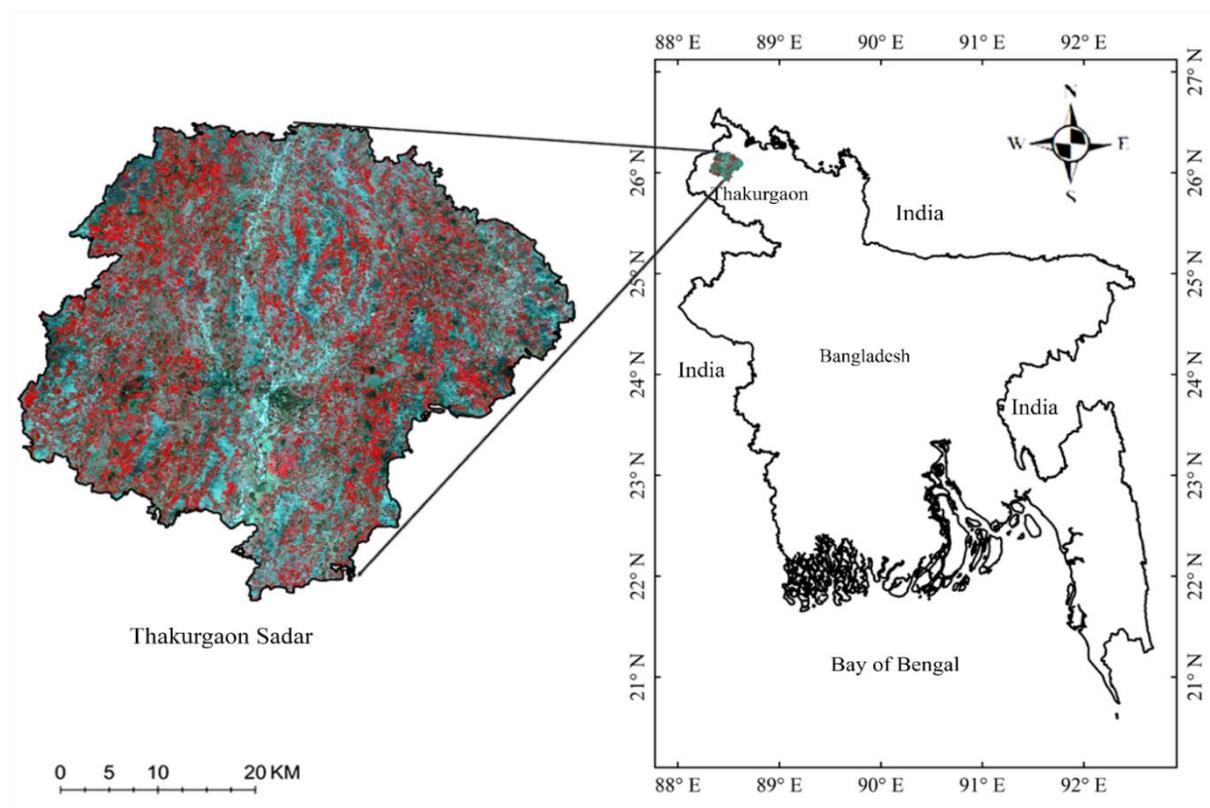

Fig. 1. Map showing the Thakurgaon Sadar *Upazila* and the locations of Bangladesh

Data collection

Crop data

Time-series (1999 to 2019) data of wheat, maize, potato, boro rice and mustard crops were collected in the form of acreage (ha), yield (ton ha^{-1}), production (MT),

production cost (Tk), and harvest time market price (Tk). Data were collected from the Bangladesh Bureau of Statistics (BBS), Department of Agricultural Marketing (DAM), and the office of *Upazila* Agriculture Officer of Thakurgaon Sadar.

GPS data

Global Positioning System (GPS) coordinates were collected from the wheat crop field of the Thakurgaon Sadar *Upazila*. GPS is a system of thirty-plus navigation satellites circling the earth. It is a United States maintained utility that provides users with positioning, navigation, and timing (PNT) services. We used a handheld GPS receiver, Google map, and mobile app of GPS tracker to collect the data. These data were then utilized to detect the exact location of the wheat crop fields during training data generation for satellite image classification, accuracy assessment, and validation.

Satellite images

Multi-spectral satellite imageries are the most crucial data in this research. Landsat images were selected due to the availability of multi-spectral data over a long period. Required images were downloaded from the United States Geological Survey (USGS) website. Temporal data from 1999 to 2019 at five years' intervals were collected during February when the wheat crop attained the maximum growth stage. Moreover, cloud-free images were available at that time. In Bangladesh, it should be noted that November-February was considered the dry season, while March-May is pre-monsoon and June-October is the rainy season. The main features of collected imageries are given in Table1.

Table 1. Main features of multispectral satellite imageries over the Thakurgaon Sadar

Name of sensors	Path and Row number	Date of acquisition	Spatial resolution	Coordinate Reference System
Landsat 4-5 (TM)	139 and 042	15-02-1999	30 m	EPSG:32645
Landsat 4-5 (TM)	139 and 042	13-02-2004	30 m	EPSG:32645
Landsat 4-5 (TM)	139 and 042	10-02-2009	30 m	EPSG:32645
Landsat 8 (OLI)	139 and 042	14-02-2016	30 m	EPSG:32645
Landsat 8 (OLI)	139 and 042	06-02-2019	30 m	EPSG:32645

Meteorological Data

Meteorological data includes daily total rainfall (mm), daily minimum, and daily maximum temperature (°C) that were purchased from Bangladesh Meteorological Department (BMD).

Methodology

Crop Data Processing

The benefit-cost ratio (BCR) was calculated from the present value of total revenue or benefit of the crops was divided by the present value of total cost. Since data were collected from the different dates, all the collected values were converted to the present worth of monetary value. For this, the following formula was used:

$FV = PV (1+r)^n$

PV = Present value, also known as a present discounted value, is the value on a given payment date.
FV = It is the projected amount of money in the future
r = the periodic rate of return, interest, or the inflation rate, also known as the discounting rate
n = number of years.

Satellite Images Processing

Atmospherical correction of downloaded images was done using the ESPA website. For Landsat images, surface reflectance data were generated from the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS), a specialized software initially developed by the National Aeronautics and Space Administration (NASA). Additionally, various vegetation indexes (VIs) were obtained. ArcGIS and QGIS software were used to merge the bands, including the VIs, to create multi-band images. Thakurgaon Sadar *Upazila's* shapefile was constructed as an administrative study area boundary. Multiband images were clipped by the study area boundary using QGIS software. Clipped images were assigned to the false-colored composite value. In the case of Landsat 0-4 TM images, RGB 4, 3, 2 and for Landsat 8 OLI images RGB 5, 4, 3 composites were used, respectively, to create false color. Objects have shown specific colors on false-colored images from which desirable features could be identified. Accurate training inputs from composite images using QGIS software were also generated. After generating training input data through QGIS software, selected images were classified with Random Forest (RF) algorithm using R Script. RF is a popular machine learning algorithm that belongs to the supervised learning technique. It is also one of the most used algorithms because of its simplicity and diversity (it can be used for both classification and regression tasks). Images were classified into four classes as wheat crop, other lands, vegetations, and water bodies. Other land classes included *char* of river, fallow lands, built up, homesteads, brickfields, bare soils, etc. Vegetations classes comprised other crops, water hyacinth, trees,

shrubs, grasses, etc. River, pond, canal, *beel, boropit,* lake water, etc., belonged to the water bodies. Reclassification of classified images was done for re-assigning one or more values in a raster dataset to new output values.

Wheat Area Estimation

Reclassified images were contained pixel numbers from which cultivated area was estimated in hectare using the following equation through ArcGIS software. Finally, the map was developed and exported for further use.

$$Area\ (ha) = pixel\ number * 0.09$$

$$Here,\ Pixel\ size = 30 \times 30 = 900\ m^2$$
$$= 0.09\ ha$$

Spectral Reflectance Curve

A spectral reflectance curve was prepared from selected images (Figure 4). At first, training input data were generated from false-colored composite imageries through QGIS software, and then the signature curve was developed from reflectance value through R software. This curve gives an insight into the spectral characteristics of different objects/ground cover. The spectral curve supports the probability of accurate image classification.

Meteorological Data processing

Monthly total rainfall, minimum, maximum, and average temperature were calculated from daily meteorological data. The drought index, known as standardized precipitation evapotranspiration index (SPEI), was calculated using monthly total rainfall, maximum (Tmax), minimum (Tmin), average temperature (Tavg), and coordinate (latitude) data. SPEI was then used to justify or validate the research results. The SPEI is designed to consider precipitation (PRCP) and potential evapotranspiration (PET) in determining drought (Katipoglu *et al.*, 2020). The SPEI accomplishes the requirements of a drought index as its multi-scalar character enables it to be used by different scientific disciplines to detect, monitor, and analyze droughts (Miah *et al.*, 2017 and Abdullah, 2014).

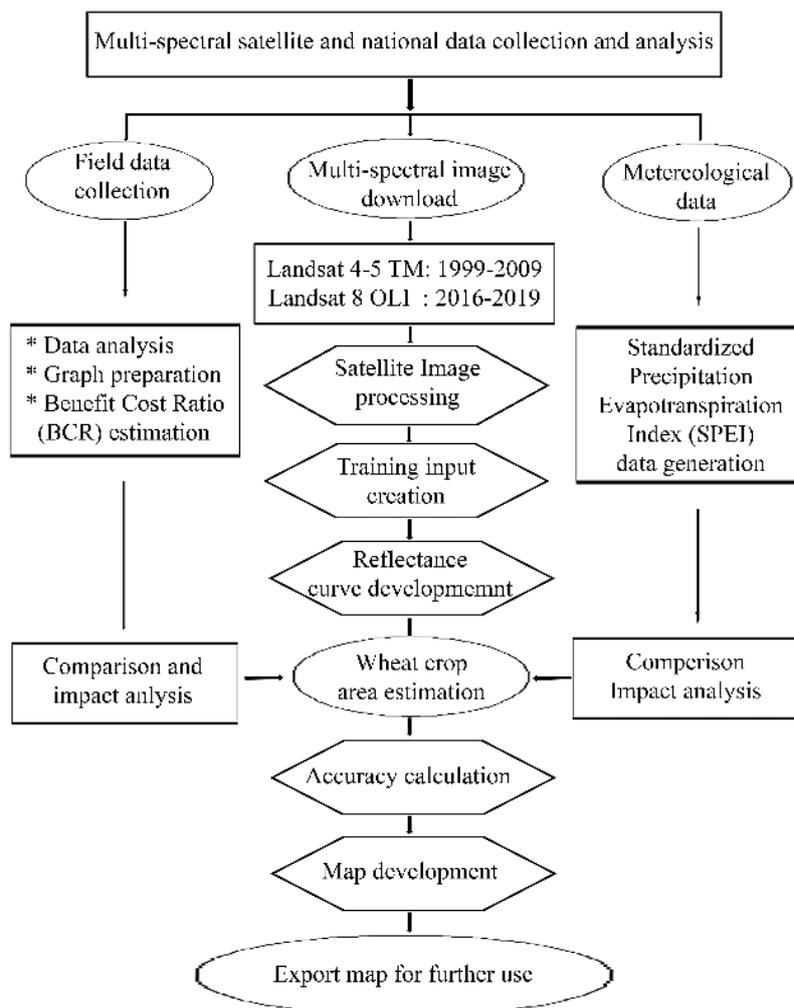### The overall process data collection and analysis

Fig. 2. The total procedure of data collection and analysis.

Results and Discussion

Monitoring of Wheat Cultivation Area

Separation and Identification of Wheat Area through Spectral Signature

Land cover land use (LULC) classes have presented in Figure 3. The distinguished four classes were wheat crop, other lands, vegetations, and water bodies. It is easy to identify the wheat crop in Figure 3 by looking at the green color. Yellow color denoting vegetations, light paste color showing other lands, and deep blue indicate water bodies. This research successfully distinguished wheat and estimated its cultivated area despite the challenges of assessing a single crop area from satellite images, such as tropical cloud effects, mixed cropping, smallholder farmlands, etc. Zhang *et al.* (2019) also described several challenges to separating a single crop area from satellite images using remote sensing technology, such as the tropical cloud effect, mixed

cropping, smallholder farming, and so on. This classification might be successful because wheat was cultivated in the winter, and cloud-free images were obtained. In addition, despite the small size of the wheat fields, the area was extensive and continuous. Our results are supported by a few other researchers (Su & Zhang, 2021 and Roy *et al.*, 2021). Pure pixels were created as a result, and this became a prerequisite for accurate image classification. Wheat crops, other crops, trees, lands, and water bodies in the study area had varying spectral reflectance besides the wheat crop. Land use and land cover features in the study area have variable spectral reflectance, which helps classify the images. Different LULC will have varying percent reflectance (Figure 4). The research findings of Sanchez *et al.* (2019) and Arias *et al.* (2020) supported the results. Using spectral signature curves and satellite image processing, they were able to distinguish boro rice crops.
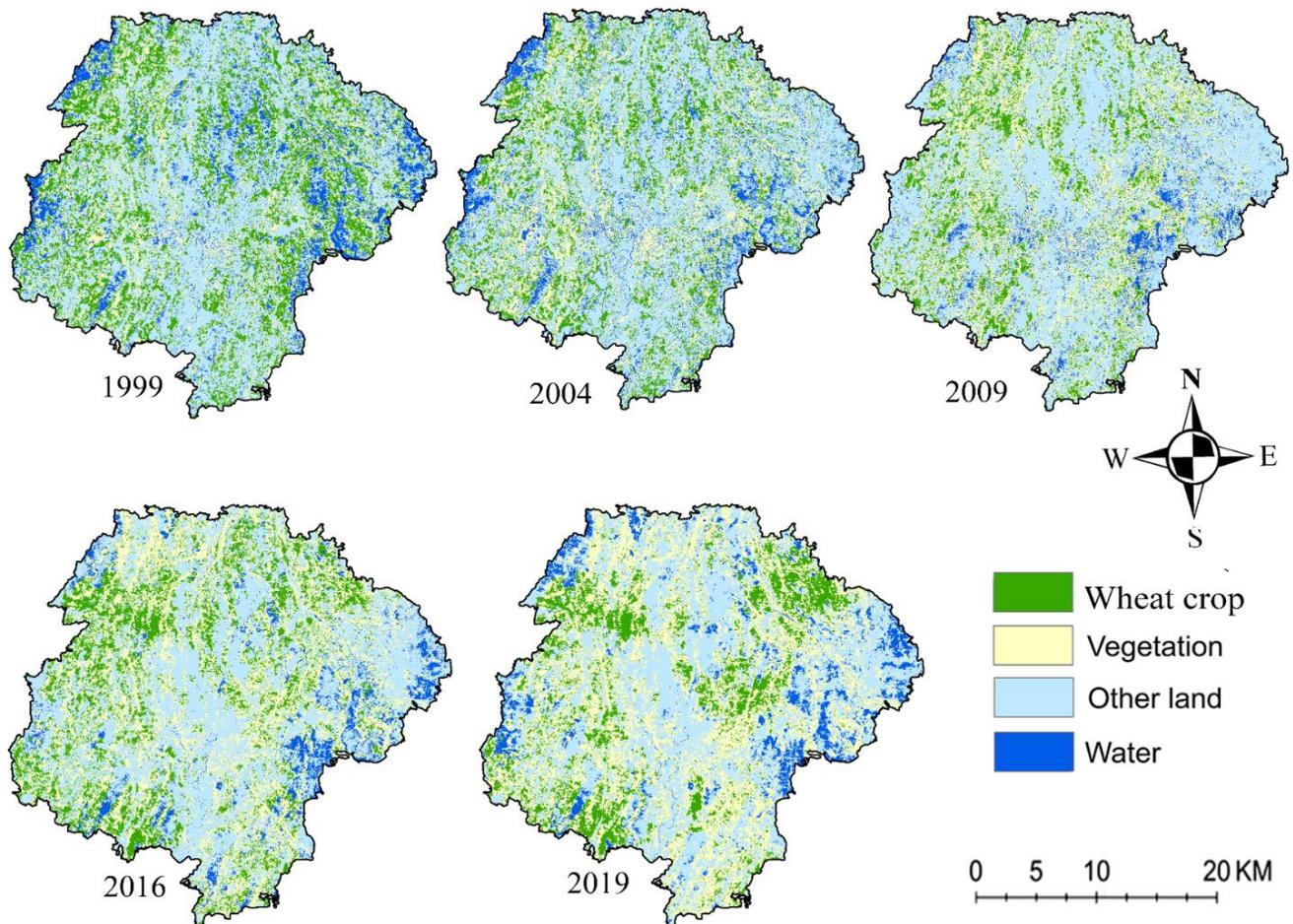

Fig. 3. Classified map of land use land cover classes showing the progressive increase of wheat-growing area from 1999 to 2019.
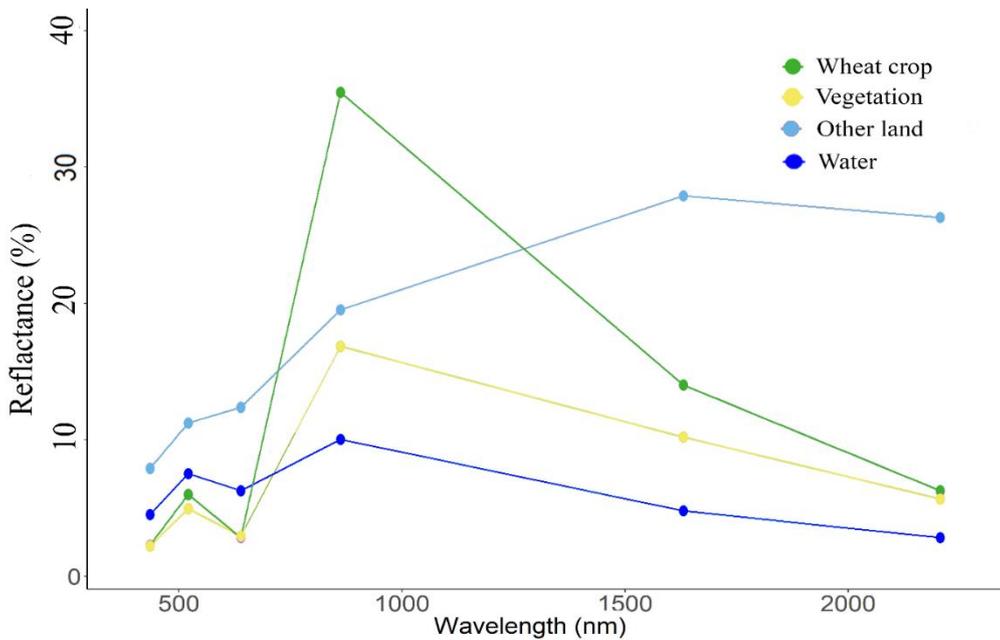
Fig. 4. A spectral signature curve showed the reflectance of different land use land cover (LULC) features that enhance the classification accuracy.

Area Estimation and Decadal Change Detection

Table 2 presents the estimated land use land cover (LULC) classes based on classified imagery. Table 2 shows that the wheat cultivation area was higher in 1999 (16349 ha), followed by 2016 (11511 ha). In contrast, the minimum wheat area was observed in 2009 (8772 ha), followed by 2019 (9160 ha). On the contrary, the maximum areas of vegetations (27585 ha) were observed in 2019, but other lands (32832 ha) and water (7685 ha) were maximum in 1999. In the present study, it was found that vegetation lands were increased where water bodies decreased gradually.

But other lands increased up to 2009 and again reduced up to 2019. This result indicates that lands covered by wheat, water, and other areas were transformed into vegetations.

In Figure 5, the masked wheat crop has shown for better visualization. It is shown in Figure 5 that wheat-growing areas were very high in 1999, but they are decreased significantly by 2019. In the study area, wheat is typically grown on medium-high land. Wheat cultivation is becoming less profitable as a result of climate change-induced high temperature and higher production costs. Due to these factors, the lands were being used to grow other crops instead of wheat. From 1999 to 2019, the study area's land use and land cover (LULC) changed shown in Figure 6. It shows how vast areas of wheat areas have been converted over time into other crop areas. In 1999-2009, the most noteworthy lands, 5740 and 5244 ha of wheat were transformed into vegetations and other lands. The transformation from wheat to other classes was much lower in 2009-2019 than in the previous decade. The Sankey diagram describes the transformations between the wheat crop and other classes. Although wheat cultivation has been declining continuously since 2004, it declined abnormally in 2009. Due to climate change, there was an outbreak of blast disease, so cultivation was greatly decreased. Thus, wheat is becoming an unpopular crop choice among farmers.

Table 2. Estimated area of land use and land cover classes by remote sensing techniques

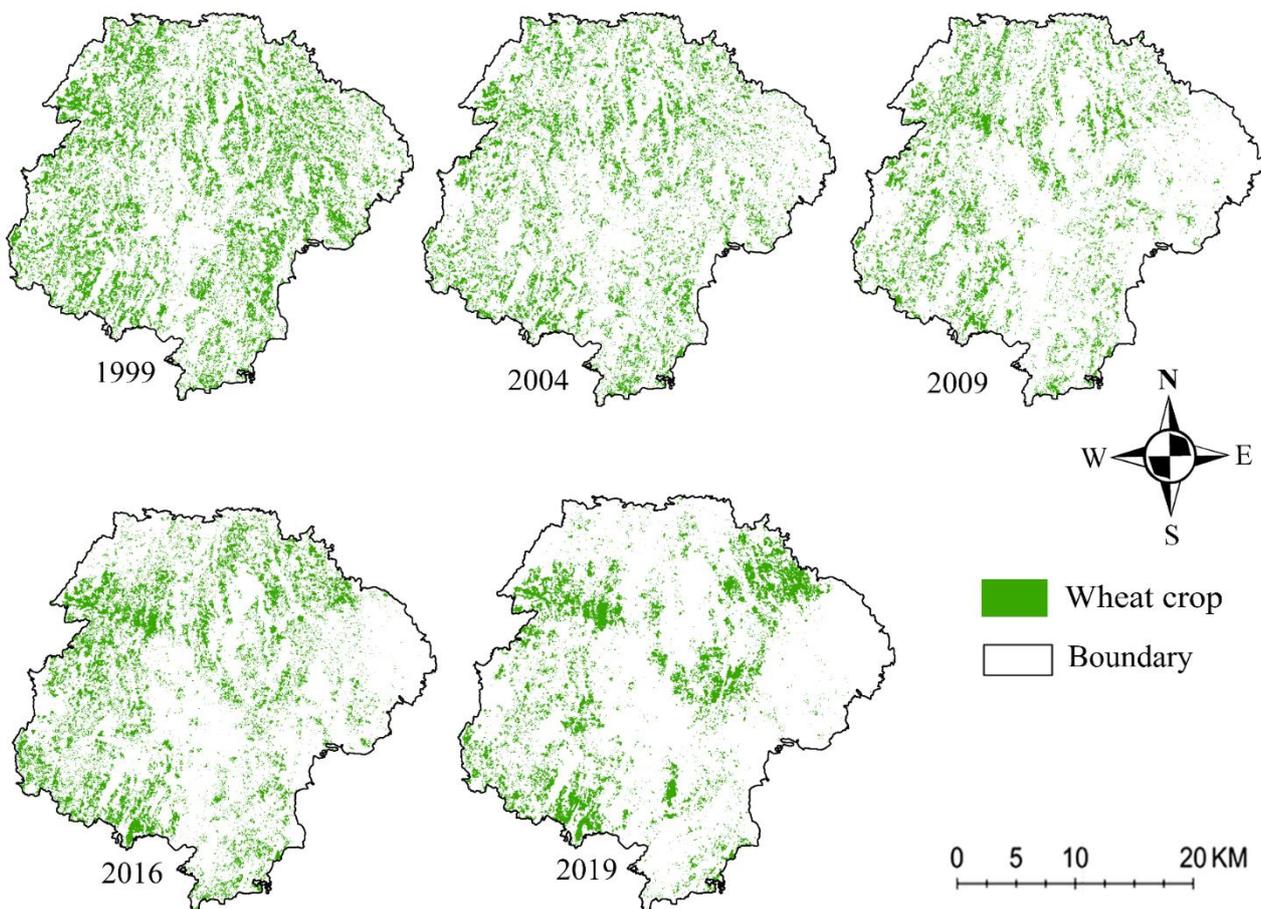| Year	Area in ha (%)				
	Wheat crop	Other lands	Vegetations	Water bodies	Total
1999	16349 (23.59%)	14323 (20.66%)	30954 (44.66%)	7685 (11.09%)	69311
2004	11177 (16.13%)	18705 (26.99%)	31774 (45.84%)	7655 (11.04%)	69311
2009	8772 (12.66%)	22357 (32.26%)	32832 (47.37%)	5350 (7.72%)	69311
2016	11511 (16.61%)	24003 (34.63%)	29636 (42.76%)	4161 (6.00%)	69311
2019	9161 (13.22%)	27585 (39.80%)	27502 (39.68%)	5063 (7.30%)	69311

Fig. 5. Masked wheat class for better visualization of the wheat cultivated area from the year 1999 to 2019.
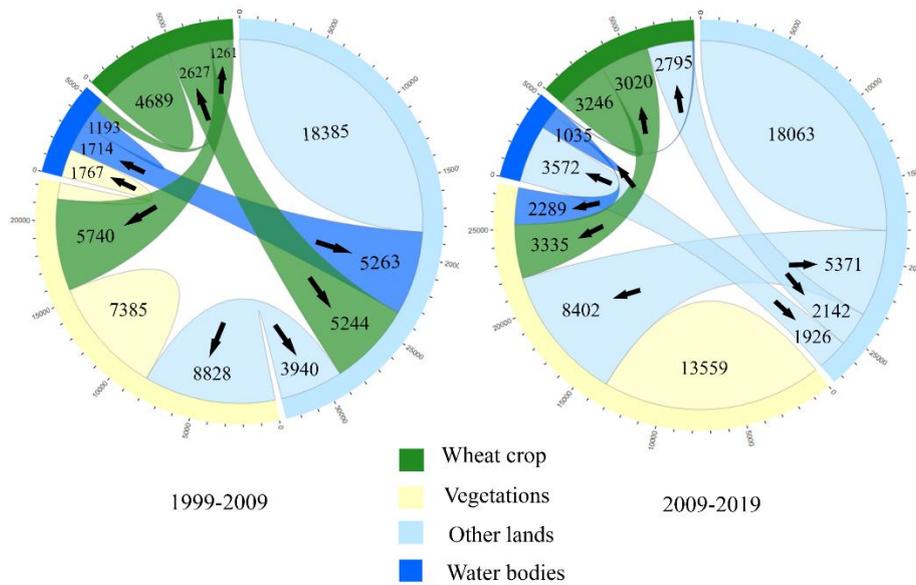
Fig. 6. Chord diagram showing the conversion of land use land cover (LULC) classes in the two decades 1999 to 2019. Persistent wheat class is prominent in the later ten years phase (2009-2019).

The wheat-growing areas changed for the worse during the research period (Table 3). The table shows 3 that wheat cultivation, other lands and water bodies were decreased in the last two decades, whereas vegetation areas were increased prominently. The most remarkable change in the wheat area occurred between 1999 and 2019 (10.37%). The area decreased by 10.93 percent between 1999 and 2009 and increased 0.56 percent in 2009-2019. Wheat cultivation has increased a bit in the last decade. In fact, after the widespread decline in wheat cultivation in 2009, it continued to increase until 2016. However, since 2016, wheat cultivation has been declining gradually up to 2019.

Table 3. Cultivation area changes under different classes from 1999 to 2019

Land cover and land use classes	Area changes (%) in the decade 1999-2009	Area changes (%) in the decade 1999-2009	Area changes (%) within 20 years (1999 to 2019)
Wheat crop	-10.93	0.56	-10.37
Vegetations	11.6	7.54	19.14
Other lands	2.71	-7.69	-4.98
Water bodies	-3.37	-0.42	-3.79

Validation of Remote Sensing Estimated Area with Traditional Data

The research shows a correlation between the remote sensing-estimated wheat area and the traditional methodology-estimated area (Figure 7). Figure 7 shows that the wheat cultivation areas were highest in 1999, based on remote sensing and traditional estimation methods. Both methods predict that wheat cultivation areas have decreased steadily since 2004 and will continue until 2019. The regression's R2 value was 0.96, indicating good agreement between the remote sensing and traditional estimates of the wheat area (Table 4). While land-use change has decreased from 28.10 percent to 16.09 percent using traditional approaches between 1999 and 2019, the wheat area has risen from 23.59 percent to 13.22 percent using remote sensing techniques. Both strategies show a decrease in the wheat crop while increasing the vegetations class.

Table 4. Percent land-use changes estimated by remote sensing and traditional techniques

Name of land use classes	Percent area changes in remote sensing technique		Percent area changes in traditional technique	
	2009	2019	2009	2019
Wheat crop	23.59	13.22	28.1	16.09
Vegetation	20.66	39.80	18.33	38.82
Other land	44.66	39.68	43.26	36.91
Water	11.09	7.30	10.31	8.18

Fig.7. Bar graph showing the Wheat area estimated by remote sensing and traditional techniques are well-matched.

Drivers of wheat cultivation area changes

The drought index, i.e., Standardized Precipitation Evapotranspiration Index (SPEI) from 1990 to 2019 (30 years) with a 12, 24, and 36-month lag has shown in figure 8. A value of -3 denotes a severe drought, +3 indicates an extreme wet, and 0 is close to normal. Figure 10 shows the hydrological drought in which, from 2007 to 2018, the dry spell was longer, which contributed to the decrease of wetlands. Salimi et al. (2021) also found similar results for wetland shrinkage. Thus, the lands that had water till December-January dried up 2-3 months earlier due to the impacts of prolonged drought (Abdullah et al., 2019). In this way, those lands became suitable for potato and maize cultivation. As a result, it was not possible to cultivate wheat in those lands, so that the land of the wheat area was gradually decreasing.

The results also revealed that rainfall in wheat-growing areas decreased, and the temperature increased according to SPEI. The changes of average, lower and upper limits of temperature from 1990 to 2019 at ten-year intervals have shown in figure 9. The figure shows that the lower-upper limit of temperature changed in the wheat-growing season (December-March) every ten years. The temperature has decreased slightly in December and January, but the change has increased in each case. Although the upper limit has been somewhat different, the average temperature has increased in most cases. Due to prolonged drought spell, increase in the lower limit, and average temperature, the seed sowing time of wheat has been delayed was the first reason. Secondly, there was a problem with pollination during wheat flowering. Third, the incidence of the disease-insect has increased. Due to these reasons, farmers are feeling discouraged in wheat cultivation. As a result, the wheat cultivation area was shrinkage day by day.

On the other hand, due to the impact of climate change, farmers are discouraged as the profit from wheat cultivation was less than other crops. The benefit-cost ratio (BCR) of different crops has shown in table 5. In the table, the BCR value of wheat was higher in 1999 (1.55), which decreased gradually up to 2019 (1.09). In contrast, the BCR of maize and potato was lower in 1999 (1.40 and 0.95), which increased significantly in

2019 (2.00 and 2.67). The results show that wheat was less profitable than maize and potato. As a result, farmers were losing interest in wheat cultivation. Since maize and potato can be grown in the same season as wheat cultivation and the weather favor, maize and potato cultivation increased instead of wheat (The

Financial Express, 2020; The Daily Bangladesh, 2021, and Abdullah, 2021).

Although the BCR of boro rice was comparatively much lower, the potato crop could be cultivated before boro. So that profit was increased. In this regard, boro rice was included in the cropping pattern (Rahman, 2021 and Eijck, 2021).

Table 5. The Benefit-Cost Ratio (BCR) value of several crops cultivated in the study site

Year	Benefit-Cost Ratio			
	Wheat	Maize	Potato	Boro rice
1999	1.55	1.40	0.95	1.02
2004	1.39	1.37	1.09	0.95
2009	0.99	1.24	2.06	0.80
2016	1.11	1.81	2.65	0.67
2019	1.09	2.00	2.67	0.95

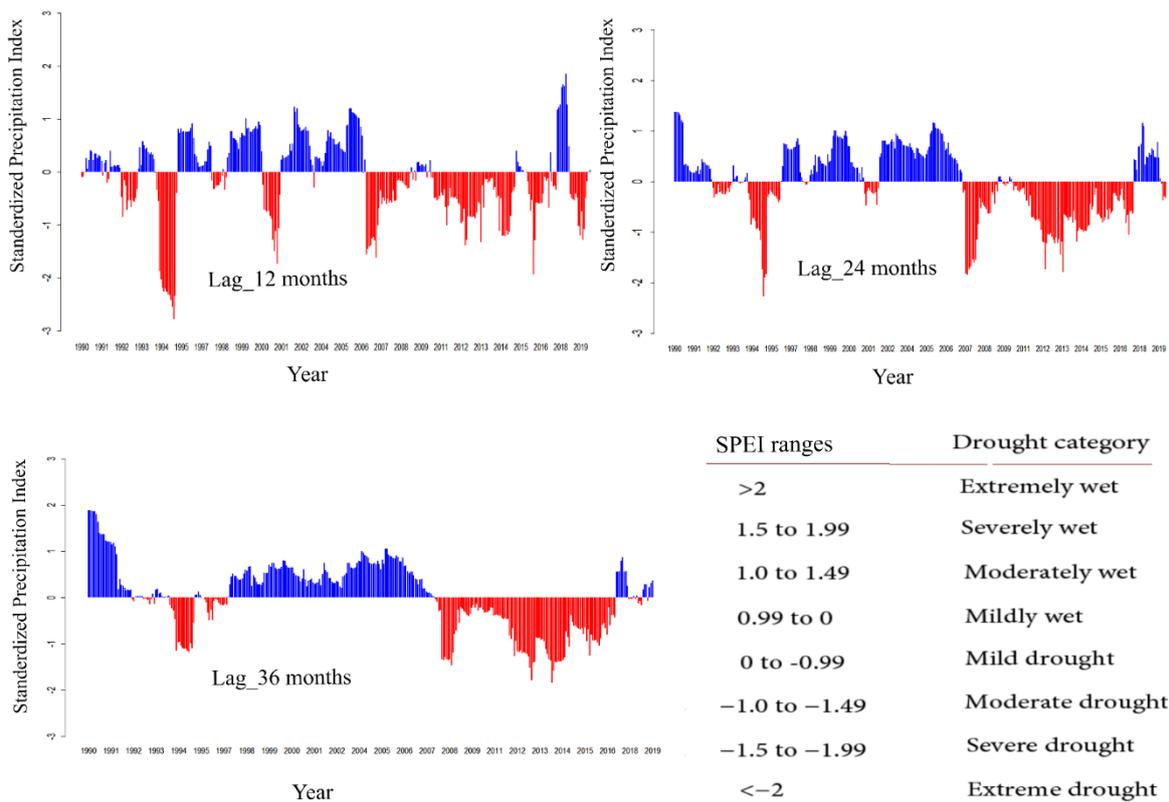| SPEI ranges	Drought category
>2	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.99 to 0	Mildly wet
0 to -0.99	Mild drought
−1.0 to −1.49	Moderate drought
−1.5 to −1.99	Severe drought
<−2	Extreme drought

Fig.8. Standardized precipitation Evaporation Index in 12, 24, 36, and 48 months lag from 1990 to 2019
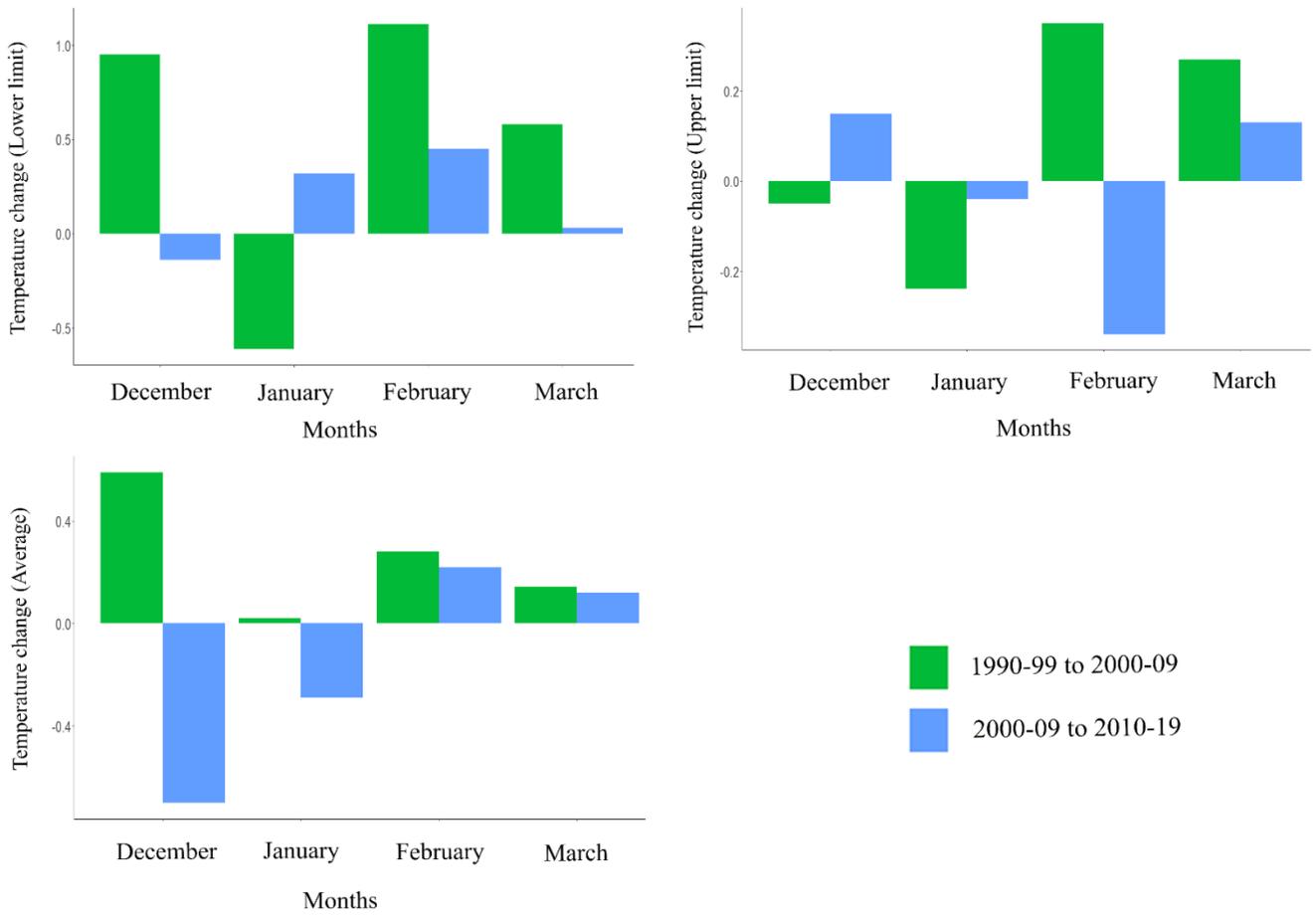
Fig. 9. Graph showing temperature (average, lower limit and upper limit) changes from 1990 to 2019 at ten years intervals.

Conclusion

Remote sensing techniques with random forest supervised classification of multi-spectral Landsat images effectively monitor wheat cultivation area. According to the study, the wheat crop area decreased from 1999 (16349 ha) to 2019 (9161 ha). In 1999-2009, large quantities of wheat crop area transformed into vegetations (5740 ha) and other lands (5244 ha) classes. On the contrary, in 2009-2019, the amount of transformation has decreased somewhat but continues. Wheat crop cultivation was reduced by 10.37 percent in 1999-2019 due to transformation. The results of the study show that the amount of wheat cultivation decreased drastically in 2005-2009. After 2009, however, the amount of wheat cultivation has increased slightly, but after 2016, it started declining again. The main drivers behind the transformation and the decrease in the wheat area were the impacts of climate change. The lands that had water till December-January dried up 2-3 months earlier due to the impacts of prolonged drought. In this way, those lands became suitable for potato, maize and other crops cultivation. As a result, it was not possible to cultivate wheat in those lands.

Rising temperatures have reduced yields and increased disease-insect infestation. The effect of which was noticed during 2005-2009. At that time, wheat cultivation was significantly reduced due to epidemic blast disease. On the other hand, due to the impact of climate change, farmers are discouraged as the profit from wheat cultivation was less than maize and potato. These remote sensing-based techniques could also be utilized to forecast yield and assess quality wheat crop and other crop cultivation monitoring.

Acknowledgements

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