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CHANGES IN AGRICULTURAL CROP SUITS AND LANDSCAPE: A TIME-SERIES STUDY USING MULTISPECTRAL IMAGERIES FROM RURAL BANGLADESH

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Abstract

Bangladesh is predominantly an agricultural country, so studying suitable land for crops and landscapes is essential. Substantial or detailed studies, particularly on this aspect of the landscape and crop suitability for different seasons, are limited. In this paper, an attempt has been made to analyze and evaluate the chronological changes in agricultural crop suits and landscapes along the river Titas, Bangladesh. For the study, the Brahmanbaria district was considered as a case study period from 2012 to 2022. Primary data were obtained from 384 Questionnaire surveys and 10 FGDs, whereas secondary data were collected from CEGIS and BBS. Sentinel 2 images were used for mapping and chronological changes in Land Use and Land Cover (LULC). Between the study periods, paddy cultivation declined from 31 to 18% in *Rabi*, leading to maximum winter vegetation. However, there were no significant changes in the *Kharif-I* season. Except for paddy farming, which declined from 22% to 18% in *Kharif-II*, changes are few. This study identified 12 driving variables demonstrating that labor and capital availability were more responsible, whereas farm size was less responsible for determining agricultural and landscape changes. *Rabi*, *Kharif-I*, and *Kharif-II* had an overall accuracy of 85.98, 82.13, and 89.52%, respectively, with a kappa coefficient of 84.90, 86.37, and 82.50%. All classes were over 83.87% in producer accuracy, while all classes except urban and industrial were above 86.00% in user accuracy.

Keywords: Agricultural Crops, Landscape, Remote Sensing, GIS, Rural Bangladesh.

Introduction

In Bangladesh, agriculture is the single largest productive sector, contributing roughly 20.83% of the country's total gross domestic product (GDP) in 2007–2008 and employing 48.4% of the country's workforce (Faroque *et al.*, 2013). Agricultural practices spread over three types of cropping seasons are prevailing: *Rabi*, *Kharif-I*, and *Kharif-II*. In contrast, the *Rabi* season is counted from mid-November to mid-march, *Kharif-I* from mid-March to mid-July, and *Kharif-II* from mid-July to mid-November (Banglapedia, 2021). The country's agricultural resources have yet to be adequately assessed (Miah and

Islam, 2011). It has been stated that, due to the overabundant food supply, a significant shift in land and water consumption has been seen in recent decades following the green revolution (Rahman, 2010).

On the contrary, agriculture is one of Bangladesh's most important occupations, significantly impacting the farmers and the country's economic conditions (Alam *et al.*, 2009). These activities directly or indirectly employ almost 87% of rural people, contribute 19.6% to the national GDP, and employ approximately 63% of the population. (BBS, 2015). It significantly reduced rural poverty from 48.9% in 2000 to 31.5% in 2010 (BBS, 2015). On the contrary, it also significantly impacts the natural landscape and environment of rural areas, which produce food, livestock, and raw materials for various agro-based businesses (Dewan and Yamaguchi, 2009). Changes in crops and combinations in any place are influenced by terrain, topography, slope, temperature, rainfall volume and reliability, soil, and irrigation water availability (Mallupattu and Reddy, 2013). Furthermore, agricultural crop changes are influenced by various factors such as infrastructure, socioeconomic conditions, and technological advancements.

Crop suitability depends on the climate, land level, soil lithology, drainage characteristics, and the facilities of the technological support provided by the government and non-government organizations. In this regard, crop suitability and physical landscape are strongly connected. For intance, low land has high moisture with single crops; medium land has medium moisture with double crops, and high land has low moisture with triple crops in a year. However, this study tries to delineate the land use classification using the high resolution of the latest satellite images, considering the maximum cropped area for three different crop calendars (*Rabi*, *Kharif-I*, and *Kharif-II*) and for the landscape of Brahmanbaria district, Bangladesh. Therefore, this research aims is to analyze and evaluate chronological changes in agricultural crop suits and landscape along the river Titas, Bangladesh. This study sets three objectives which are (i) map the chronological changes of agricultural crop suits and landscape from 2012 to 2022; (ii) investigate the factors behind the chronological changes in the agricultural landscape and crops; and finally, (iii) analyze the error matrix of three different crop calendars (*Rabi*, *Kharif-I*, and *Kharif-II*) and for the landscape of Brahmanbaria district, Bangladesh.

Methodology

Selection of the study area

Brahmanbaria district, with major rivers, has been used as a case study. The Titas River is a transboundary river that merges with the Meghna River and starts its journey from the

Tripura state. It is 98 kilometers (61 miles) long and joins the Meghna River near Ashuganj Brahmanbaria. It is bounded by Kishoreganj and Habiganj districts on the north, Comilla district on the south, Habiganj district and Tripura state of India on the east, Meghna River, Kishoreganj, Narsingdi, and Narayanganj districts on the west.

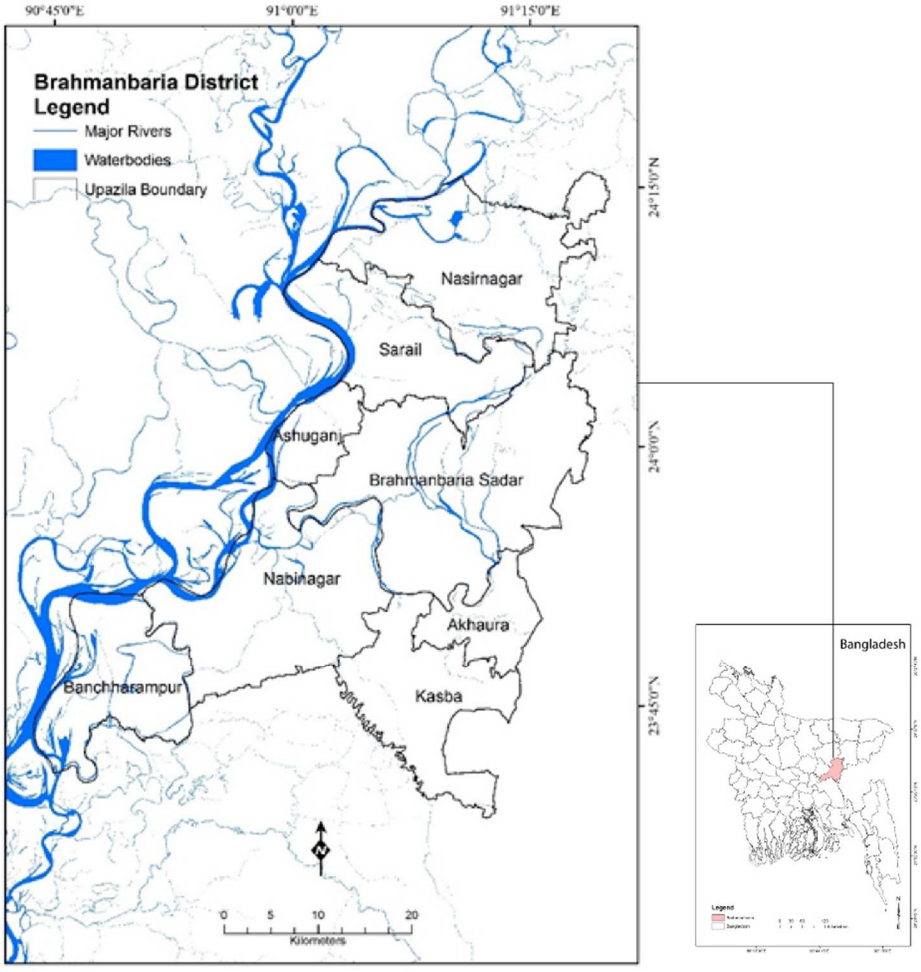


Fig. 1. Brahmanbaria district with major rivers, 2022
Source: Compiled by authors, 2023

Data and methods

This study used primary information gathered from the local community using a questionnaire. Total 384 questionnaires were administered with a confidence level of 95% and a margin of error of 5%. There were 10 FGDs chosen randomly. The preliminary information gathered includes respondents' information, landscape, and crop suit changes, occupation changes, sex, number of family members, driving forces responsible for affecting agriculture and landscape. Besides, secondary data were collected from different non-government organizations and government organizations such as CEGIS and BBS. Details of the images utilized are given in Table-1. Hereafter, data were analyzed using modern technological tools such as ArcGIS 10.2, SPSS 16.0, Excel 2013, and Google Earth.

This study included a wide range of image processing features accessible in the ERDAS IMAGINE, including layer stack (Band 2,3,4,8 of 10m resolution), data extraction, image enhancement, data merging, mosaicing, and geocoding. Then cloud masking, noise reduction, and haze reduction methods were used to reduce the radiometric correction of sentinel-2 images acquired at different seasons under diverse atmospheric circumstances.

This study also conducted an extensive field survey using the global positioning system (GPS) from October 2021 to April 2022 to verify the classification results. The paper used kappa statistics for a detailed validity assessment for three seasons, *Rabi*, *Kharif-I*, and *Kharif-II,* in 2021. The overall accuracy for said seasons was computed by dividing the properly classified pixels by the total number of pixels evaluated. The Kappa coefficient, unlike the overall accuracy, which is measured by the ratio of the sum of diagonal values to the total number of cell counts in the matrix, also considers non-diagonal elements (Foody 2020; Banko, 1998; Rosenfield and Fitzpatrick, 1986). With the help of Earth Explorer, the accuracy tables for the classification results from 2012 to 2022 were summarized using Kappa statistics.

Reclassify and Area Calculation with Percentages

A supervised classification scheme was applied with individual signature files to determine land features such as the percentage of water bodies, settlements, vegetables, and cropland, and then analyzed and evaluated the evolution of agricultural systems, crop suites, and landscape features over time.

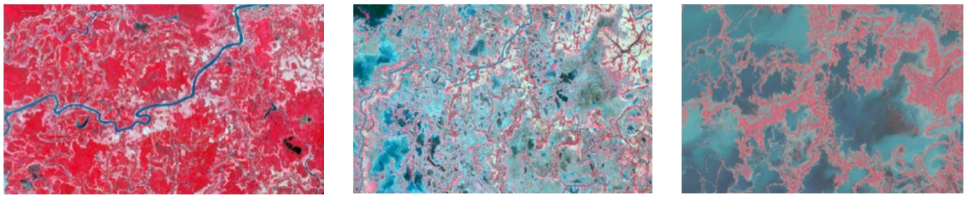
- % Waterbodies= {(ΣWp/n) *100}; whereas ΣWp= Total number of waterbodies pixels, n= total number of pixels.

- %Settlement= {(ΣVp/n) *100}; whereas ΣVp= Total number of settlement pixels, n= total number of pixels.
- % Vegetables= {(ΣHp/n) *100}; whereas ΣHp= Total number of vegetable pixels, n= total number of pixels.
- % Crop land= {(ΣCp/n) *100}; whereas ΣCp= Total number of crop land pixels, n= total number of pixels.

Table 1. Data acquisition for the three different seasons, namely *Rabi, Kharif-I,* and *Kharif-II*

Cropping Season	*Rabi* (Mid-November to mid-March)	*Kharif-I* (Mid-March to mid-July)	*Kharif-II* (Mid-July to mid-November)
Acquisition Time	January 28, 2022	April 13, 2022	October 13, 2021
Projection	UTM (Universal Transverse Mercator) Zone 45/46, Datum: WGS 1984	UTM (Universal Transverse Mercator) Zone 45/46, Datum: WGS 1984	UTM (Universal Transverse Mercator) Zone 45/46, Datum: WGS 1984
Spatial Resolution	10 meter (Band-2, Band-3, Band-4, Band-8)	10 meter (Band-2, Band-3, Band-4, Band-8)	10 meter (Band-2, Band-3, Band-4, Band-8)

Source: Compiled by authors, 2022



a. Rabi
Time Period: Mid-November to mid-March

b. Kharif-I
Time Period: Mid-March to mid-July

c. Kharif-II
Time Period: Mid-July to mid-November

Fig. 2. Same area with different seasons from 15th July 2021 to 14th July 2022
Source: Compiled by authors, 2023

Results and Discussion

Most of Bangladesh is covered in alluvial soil, which is rich in nutrients. Throughout the year, the land and atmosphere are ideal for various crops (Nasim *et al.*, 2018). The season of a crop refers to the time of year when that crop is typically cultivated. It shows how crops are distributed throughout the year based on climatic requirements, as different

seasons have varied climatic characteristics that affect crop germination, growth, flowering, and yield (Mohsenipour *et al*., 2018).

In Bangladesh, there are 3 major types of cropping seasons (Banglapedia, 2021) such as-

1. ***Kharif-I*:** Mid-March to mid-July.
2. ***Kharif-II*:** Mid-July to mid-November.
3. ***Rabi*:** Mid-November to mid-March.

Comparative characteristics of cropping seasons in Bangladesh

Based on the seasons, especially weather, precipitation, temperature, amount of evaporation, humidity, and irrigation facilities, these three major cropping seasons have their characteristics. The following Table 2 reflects the cropping seasonal variations.

Changes in agricultural crop suits and landscape in the *Rabi* seasons from 2012 to 2022

The Sentinel-02 and Landsat images of three different years (2012, 2016, and 2022) were used here to calculate the crop suits and landscape of Brahmanbaria District. A location's is diverse environmental and physiographic conditions significantly impact agriculture (Nasim *et al*., 2018). The agricultural crop suits and landscape maps for the *Rabi* season are classified into 13 classes based on the land use types.

Table 3, coupled with Figures 3 and 4, shows that among the 13 classes, paddy (*Boro*) land accounted for over 31% in 2012, but dropped to barely 18% in 2022. In contrast, in 2012, nearly 10% of the land was used to cultivate winter vegetation, whereas in 2022, almost 19% was converted to winter vegetation. This shows that nearly 9% of the land was converted to winter vegetation from other land classes. Except for paddy (*Boro*) and winter vegetation, the changes in other land classes are not significant and that means paddy (*Boro*) lands are mostly being converted to winter vegetation lands.

Changes in agricultural crop suits and landscape in the *Kharif-I* seasons from 2012 to 2022

The *Kharif-I* season runs from mid-March through mid-July. This season has medium rainfall, which is why it is known as the pre-monsoon season. Low-lying agricultural land is filled with water and turned into waterbodies due to moderate rain. Aside from that,

only this season is suitable for water-tolerant crops. As a result, there are fewer variations in crops and vegetation in this season than in the *Rabi* season. The agricultural crop suits and landscape types map of the *Kharif-I* season is classified into 11 classes based on crop variability and land use types. Figure 5 illustrates the classification maps for the *Kharif-I* season for the Brahmanbaria district.

Table 2. Comparative Characteristics of Cropping Seasons in Bangladesh.

Types	*Kharif-I*	*Kharif-II*	*Rabi*
Duration	Mid-March to mid-July.	Mid-July to mid-November.	Mid-November to mid-March.
Intensity of rainfall	Rainfall is medium and rain starts in the mid of the season.	The whole season is more or less rainy.	Rainfall is low at the beginning of the season.
Hailstorm	The possibility of a hailstorm is minimum.	There is a possibility of a hailstorm.	The possibility of a hailstorm is less.
Weather	Stormy weather prevails.	The weather is mild and rainy.	Mild weather with cool air.
Temperature	Temperature is high.	Temperature is high.	Temperature is low.
Cloud cover	The sky is cloudy, mainly in the late season.	The sky is cloudy.	Clear and cloud-free sunny day. But there is a little cloud in the early season.
Length of day and night	Day length increases with the advancement of the season.	The length of day and night is almost equal.	Day length decreases with the advancement of the season.
Irrigation	Irrigation is beneficial for crops.	Irrigation is not required.	Irrigation is essential.
Evaporation	Evaporation is high.	Evaporation is less.	Evaporation is high.
Atmospheric humidity	Atmospheric humidity is moderate.	Atmospheric humidity is high.	Atmospheric humidity is low.
Major crops	Major crops are *aus* rice, jute, groundnut, maize, and soybean.	Major crops are *aman* rice, sunflower, maize and soybean.	Major crops are *boro* rice, potato, tobacco, mustard, and groundnut.

Source: Compiled by authors from agriculturist Musa, 2018

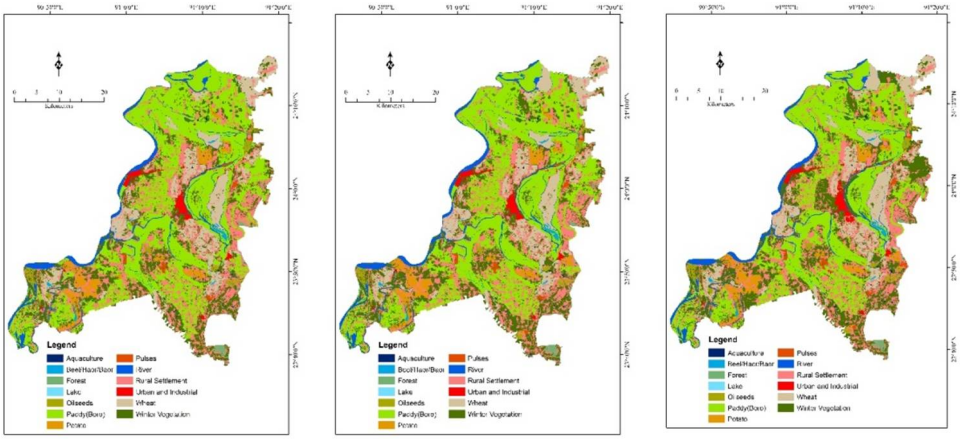


Fig. 3. Map the changes in agricultural crop suits and landscape in the *Rabi* seasons from 2012 to 2022 Brahmanbaria district, Bangladesh. Source: Compiled by authors, 2022

Table 3. Percentages of agricultural crop suits and landscape in the *Rabi* seasons from 2012 to 2022 of Brahmanbaria district, Bangladesh

Land class	Area in percentage, 2012	Area in percentage, 2016	Area in percentage, 2022
Aquaculture	2%	2%	1.5%
Beel/Haor/Baor	3%	3%	2%
Forest	6%	5%	5%
Lake	7%	6%	5.5%
Oilseeds	15%	16%	15%
Paddy(Boro)	31%	26%	18%
Potato	8%	8%	9%
Pulses	2%	2%	3%
River	6%	6%	6%
Rural Settlement	5%	5%	4%
Urban and Industrial	2%	3%	7%
Wheat	3%	3%	5%
Winter Vegetation	10%	15%	19%
Total	**100%**	**100%**	**100%**

Source: Compiled by authors, 2022

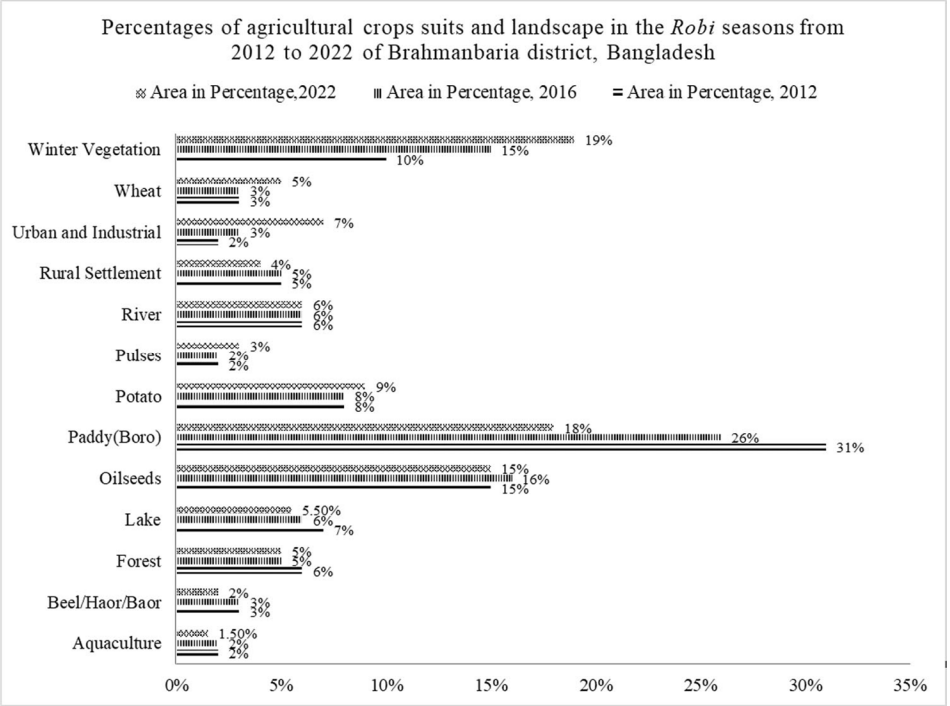


Fig. 4. Percentages of agricultural crop suits and landscape in the *Rabi* seasons from 2012 to 2022 Brahmanbaria district, Bangladesh. Source: Compiled by author, 2022

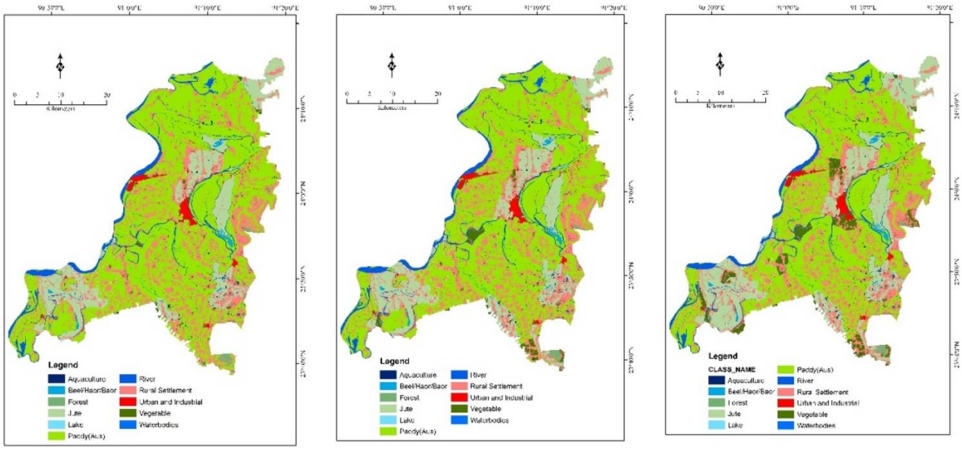


Fig. 5. Map the changes in agricultural crop suits and landscape in the *Kharif-I* seasons from 2012 to 2022 Brahmanbaria district, Bangladesh. Source: Compiled by authors, 2022

Table 4. Percentages of agricultural crop suits and landscape in the *Kharif-I* seasons from 2012 to 2022 Brahmanbaria district, Bangladesh

Land class	Area in percentage, 2012	Area in percentage, 2016	Area in percentage,2022
Aquaculture	4%	4%	5%
Beel/Haor/Baor	6%	6%	6%
Forest	6%	5%	5%
Jute	5%	7%	6%
Lake	17%	15%	14%
Paddy (Aus)	35%	29%	25%
River	10%	10%	10%
Rural settlement	2%	2%	2%
Urban and Industrial	6%	8%	10%
Vegetable	3%	6%	9%
Water bodies	6%	8%	8%
Total	**100%**	**100%**	**100%**

Source: Compiled by author, 2022

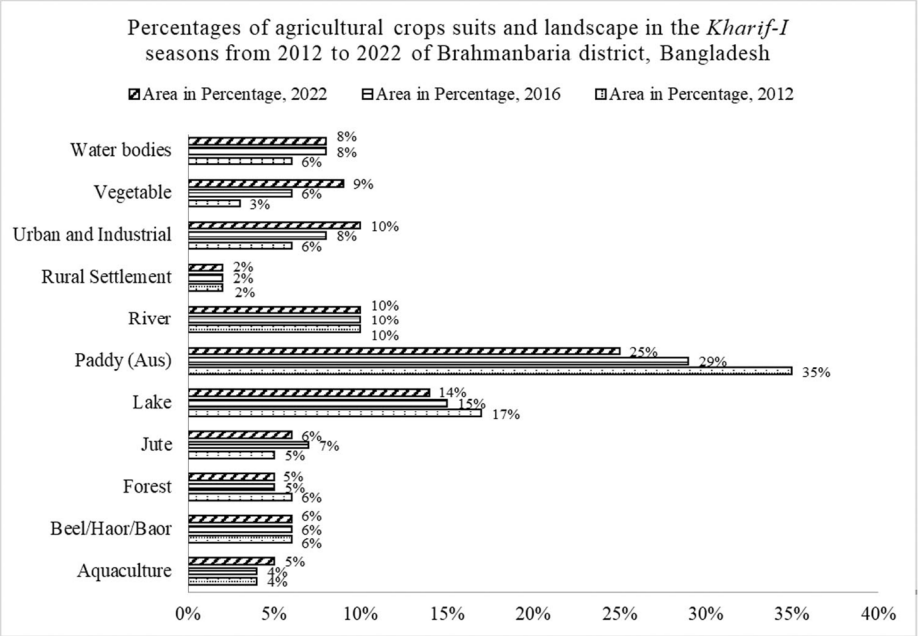


Fig. 6. Percentages of agricultural crop suits and landscape in the *Kharif-I* seasons from 2012 to 2022 Brahmanbaria district, Bangladesh. Source: Compiled by author, 2022

Table 4 and Figures 5 and 6 depict the crop suits and landscape for Brahmanbaria District's *Kharif-I* seasons. In 2012, water-related landscapes, such as rivers, lakes, and other bodies of water, covered over 33% of the study area in this season, but in 2022, this percentage was nearly the same. Rapid urbanization and land grabbing are the main reasons for declining waterbodies in other parts of Bangladesh, but similar incidents have not occurred in the study area over the last ten years.

In the case of paddy (*Aus*), the overall amount of paddy land was 35% in 2012, but by 2022, it had shrunk to 25 %, with nearly 10% of the area changed to other land types. As is well known, due to the huge amount of water, only a small amount of vegetation is cultivated in this season. In 2012, just 3% of areas where farmers produced vegetation in this season. However, in 2022, over 9% of the area is covered with vegetation, indicating a rising in vegetation cultivation, and about 6% of the land is converted to vegetation from other classes. Figure 5 shows that most agricultural lands were formerly farmed paddy but have now been converted to seasonal vegetation land.

Changes in agricultural crop suits and landscape in the *Kharif-II* seasons from 2012 to 2022

The *Kharif-II* season began in mid-July and ran through mid-November. The monsoon season is named for the large amount of rain that fell in Bangladesh during this time. Due to massive rainwater, almost all low-lying fields turned into water bodies. Most agricultural land is flooded, except high land, where significant cultivation occurs, and low land, where water-tolerant crops are cultivated.

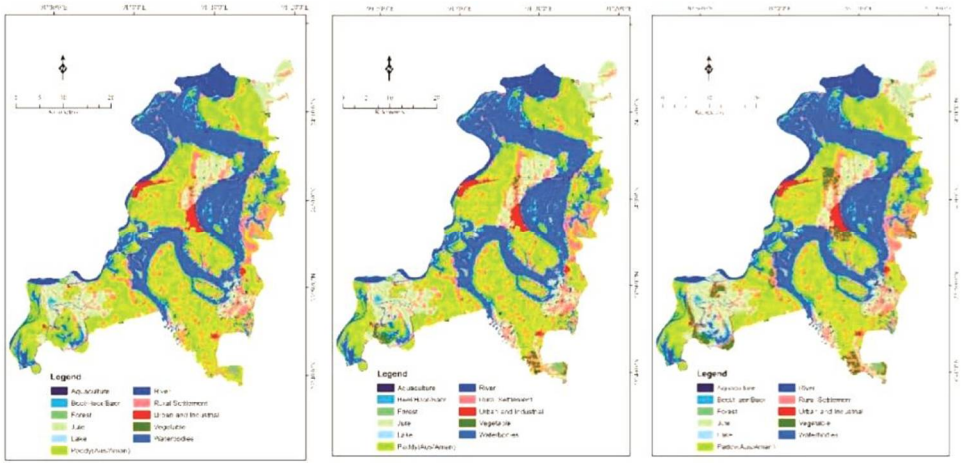


Fig. 7. Map the changes in agricultural crop suits and landscape in the *Kharif-II* seasons from 2012 to 2022 Brahmanbaria district, Bangladesh. Source: Compiled by authors, 2022.

Figure 7 depicts the majority of agricultural land becoming water bodies due to heavy rainfall, the primary cause of crop production rate reduction. Over 10% of the study area is flooded on average during this season. Rainwater fills all low-lying lands, including rivers, lakes, aquaculture, beel/haor/baro, and waterbodies. Water is also logged in a few highland areas where the drainage system isn't sufficiently maintained. There are a few advantages to cultivating crops this season as well. The cultivable ground was naturally irrigated, and the water carried a large amount of suspended sediment, making the land more fertile and assisting in growing crops for the following season.

Table 5. Percentages of agricultural crop suits and landscape in the *Kharif-II* seasons from 2012 to 2022 of Brahmanbaria district, Bangladesh

Land class	Area in percentage, 2012	Area in percentage, 2016	Area in percentage, 2022
Aquaculture	2%	2%	2%
Beel/Haor/Baor	4%	4%	4%
Forest	4%	3%	3%
Jute	6%	7%	9%
Lake	18%	17%	15%
Paddy (Aus/Aman)	22%	18%	18%
River	26%	26%	26%
Rural settlement	2%	2%	2%
Urban and Industrial	6%	8%	10%
Vegetable	1%	1%	1%
Water bodies	9%	12%	10%
Total	**100%**	**100%**	**100%**

Source: Compiled by authors, 2022

Percentages of agricultural crop suites and landscape in the *Kharif-I* seasons of Brahmanbaria district, Bangladesh, from 2012 to 2022 were clearly described in Table 5 and Figure 8. During this season, the river's water level rises rapidly and overflows into neighboring areas. Figure 8 demonstrates that the river area expanded in this season compared to the *Kharif-I* and *Rabi* seasons, with this class covering over 26% of the study region. This season, water covers approximately 58% of the study area, including rivers, lakes, aquaculture, beel/haor/baro, and waterbodies.

Paddy (*Aus/Aman*) production is also low compared to other seasons. In 2012, the area was 22 %, and by 2022, it is 18 %. In this season, vegetation output is also quite poor, covering barely 1% of the study area. In this season, in the case of jute production, a distinct scenario is visible. Even though jute is a water-tolerant crop that may grow in

water, a large amount of jute was produced in the research area this season. Jute was grown on over 9% of the study area's lands in 2012, but by 2022, it had dropped to only 6%.

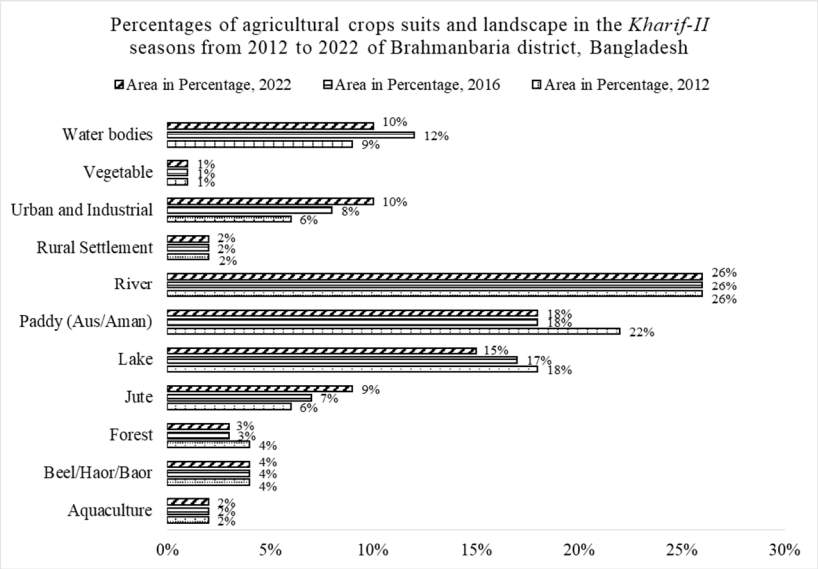


Fig. 8. Percentages of agricultural crop suits and landscape in the *Kharif-II* seasons from 2012 to 2022 Brahmanbaria district, Bangladesh. Source: Compiled by authors, 2022.

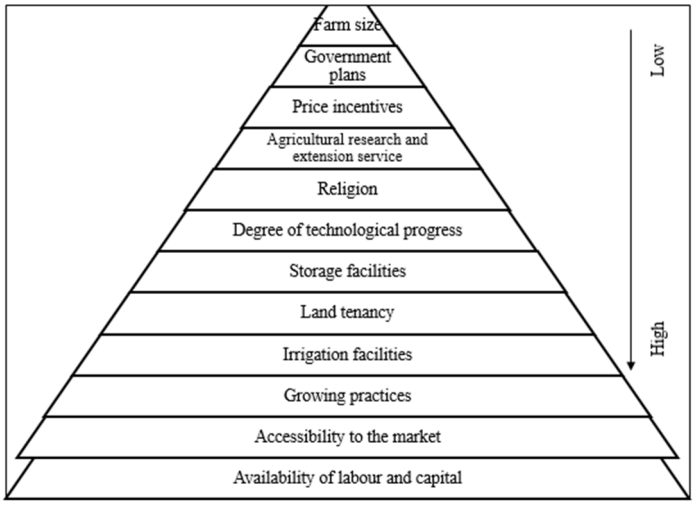


Fig. 9. Hierarchical triangle reflecting driving forces responsible for affecting agriculture and landscape. Source: Compiled by authors, 2022

Driving forces responsible for affecting agriculture and landscape

According to the data and analysis above, paddy productivity has been falling while vegetation production is expanding. It has also revealed that paddy and vegetation production is high in the *Rabi* and *Kharif-I* seasons and very low in the *Kharif-II* season. The research also identifies a few driving forces that affect the agriculture productivity and landscape of the study area based on local people's perceptions and the findings of the analysis section.

This study identified 12 driving forces and attempted to determine their impact on the study area's agriculture and landscape. Based on their impact, the factors are arranged in a hierarchical order (Figure 9). The forces that are most responsible for agriculture and landscape changes are depicted at the bottom of the hierarchical triangle, while those are least responsible at the top. The triangle shows that labor and capital availability are more responsible for agriculture and landscape changes, whereas farm size is less responsible.

Accuracy Assessment/Validation

Table 6. User's accuracy, producer accuracy, overall accuracy, and kappa statistics for *Rabi, Kharif-I, and Kharif-II* seasons from classifying Pixels

Features	Rabi		Kharif-I		Kharif-II	
	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy
Aquaculture	85.00%	81.73%	80.00%	83.33%	91.11%	95.35%
Beel/Haor/Baor	82.00%	85.42%	85.00%	86.73%	92.22%	90.22%
Forest	84.00%	84.00%	88.00%	83.81%	94.44%	91.40%
Lake	92.22%	83.84%	93.33%	86.60%	88.00%	91.67%
Oilseeds	93.33%	88.42%	88.89%	89.89%	92.22%	84.69%
Paddy (Boro)	82.00%	87.23%	91.11%	85.42%	88.00%	88.89%
Potato	88.89%	88.89%	86.67%	90.70%	86.67%	83.87%
Pulses	75.00%	89.55%	78.82%	94.37%	86.25%	93.24%
River	90.00%	97.30%	93.75%	92.59%	90.00%	91.14%
Rural settlement	83.00%	84.69%	87.00%	87.88%	86.00%	89.58%
Urban and Industrial	84.00%	89.36%	86.00%	90.53%	83.00%	94.32%
Wheat	90.00%	82.76%	93.75%	80.65%	97.50%	88.64%
Winter vegetation	90.00%	79.12%	90.00%	90.00%	90.00%	86.75%
Overall accuracy	85.98%		82.13%		89.52%	
Kappa statistics	84.90%		86.37%		82.50%	

Source: Compiled by authors, 2022

Table 6 below reveals the results obtained from the classified map of Sentinel images, where 3785 pixels were randomly selected for *Rabi*, *Kharif-I* and *Kharif-II* and checked using sentinel images, Google Earth Images, and local knowledge of the area. From the

data Table 6, the overall accuracy for *Rabi*, *Kharif-I*, and *Kharif-II* are, respectively 85.98%, 82.13%,89.52%, and kappa coefficients are 84.90%, 86.37%, and 82.50% were obtained. In terms of the producer's accuracy, all classes were above 83.87%, while for the user's accuracy, all the classes except urban and industrial were above 86.00%.

Conclusion

This study observed valuable insights into the changing agricultural crop suits and landscape in the Brahmanbaria district. The findings indicate that while paddy production has declined, vegetable production has increased rapidly. The rise in vegetable production could be because it requires less labor effort and cash than traditional paddy crop production. Also, farmers can earn liquid money, persuade them to turn their attention to vegetable farming. Also contributing to the shift toward vegetable farming may be the rising demand for vegetables as a food source. The driving variables affecting agriculture and landscape were also identified, and a hierarchical triangle based on their relative priority was established. This study highlights the potential for increased exports and marketing opportunities in the agriculture sector, particularly in light of the raised vegetable production. Additionally, the findings suggest the potential for developing phytosanitation products, which could offer a source of revenue for farmers. However, Government patronization and farmers' cooperation will be crucial to fully realize these opportunities. It will also be essential to ensure that prices at the grower level are fair, so that brokers cannot take advantage of the situation for profit. Moving forward, this research can inform agricultural policies and practices in Bangladesh and other countries facing similar challenges. Further research could explore the potential applications of remote sensing and GIS technologies for precision agriculture and developing more sustainable agricultural practices.

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