

Monitoring Land Use Dynamics and Agricultural Land Suitability in Samastipur District, Bihar Using Landsat Imagery and GIS

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Received September 21, 2024; revised and accepted October 23, 2024

Abstract: This study investigates land use and land cover (LULC) changes in Samastipur District, Bihar, from 2000 to 2020 using Landsat data and GIS techniques. Our analysis reveals a significant increase in agricultural land from 64.24% to 84.80%, amounting to a rise of 59,615 ha. During the same period, natural vegetation decreased sharply from 20.76% to 3.19%, and water bodies diminished from 2.72% to 1.82%. Settlement areas expanded by 38.30%, while barren land was reduced by 44.65%. Accuracy assessments showed substantial agreement, with Kappa values improving from 0.64 in 2000 to 0.88 in 2020, and overall accuracy rising from 71.62% to 90.74%. The Productivity Rating Index (PRI) for Pusa Farm indicates high suitability for major crops, with PRI values of 82.90% for wheat, 106.57% for sugarcane, and 137.14% for paddy. These findings underscore the dynamic changes in land use and the effectiveness of remote sensing for monitoring and managing agricultural resources, providing valuable insights for sustainable land management and policy-making.

Keywords: LULC; Landsat; Change detection; Productivity rating index; Land suitability.

Introduction

Land Use and Land Cover (LULC) change is a critical indicator of environmental transformation, directly influencing ecosystem services, biodiversity, and the hydrological cycle (Foley et al., 2005; Lambin et al., 2003). As human activities intensify, particularly in regions experiencing rapid agricultural expansion and urbanisation, monitoring LULC changes becomes essential for sustainable land management and

environmental conservation (Ellis & Ramankutty, 2008; Turner et al., 2007). Samastipur District in Bihar, India, represents a prime example of such a region, where extensive agricultural activities, coupled with population growth, have driven significant land cover transformations over the past few decades (Rai et al., 2018; Rajesh et al., 2024).

Remote sensing and Geographic Information System (GIS) technologies have emerged as powerful tools for detecting, analysing, and visualising LULC changes

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across various spatial and temporal scales (Lillesand et al., 2015; Lu et al., 2004; Rajesh & Prasad, 2024). These technologies enable a systematic assessment of land cover dynamics, offering critical insights into the patterns and drivers of change (Xiao et al., 2006; Weng, 2002; Singh, 2013). Numerous studies have demonstrated the efficacy of satellite imagery in monitoring LULC changes, particularly in agricultural and urban contexts (Saha et al., 2020; Seto et al., 2002). In the context of India, satellite-based LULC studies have revealed significant shifts in land use patterns, primarily driven by agricultural intensification, urban sprawl, and infrastructural development (Rawat & Kumar, 2015).

Bihar, with its predominantly agrarian economy, has witnessed substantial LULC changes over the last few decades, influenced by both natural and anthropogenic factors (Kumar et al., 2020; Chowdhury et al., 2009). However, despite the state's importance as an agricultural hub, there is a relative paucity of detailed studies focussing on specific districts such as Samastipur, which play a critical role in regional agricultural productivity (Das & Sinha, 2019; Kumar et al., 2023). Understanding the extent and nature of

LULC changes in these districts is crucial for informed decision-making and policy formulation aimed at achieving sustainable development goals (SDGs).

This study aims to bridge this gap by providing a comprehensive analysis of LULC changes in Samastipur District over a 20-year period (2000-2020) using Landsat satellite data and GIS-based methods (Tucker et al., 2006). The research also evaluates the implications of these changes on agricultural productivity, water resources, and land degradation, contributing valuable insights to the discourse on land management in Bihar (Verma et al., 2020; Kashinath, 2020). The findings of this study are expected to inform regional land use policies and strategies, supporting sustainable development in Bihar and similar regions experiencing rapid environmental change (Rai et al., 2018).

Study Area

Samastipur district, Bihar, covering approximately 2900 km², lies between 25°27' to 26°05' N latitude and 86°31' to 86°23' E longitude, with an elevation of 53 m (Figure 1). It is bounded by the Bagmati River to the north, Vaishali and Muzaffarpur districts to the west, the

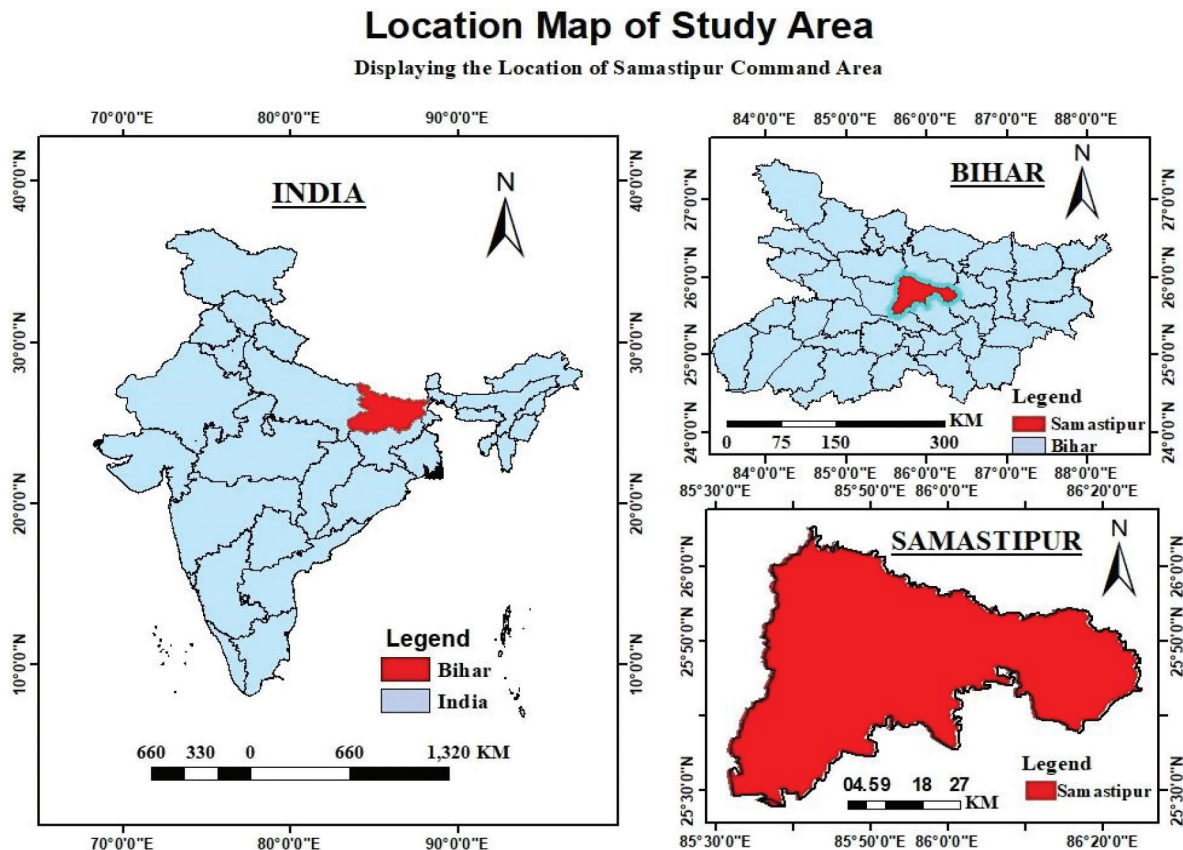


Figure 1: Location map of study area.

Ganga to the south, and Begusarai and Khagaria districts to the east. Major rivers include Burhi Gandak and the Ganga. The district features a monsoon tropical climate with temperatures ranging from 6°C in winter to 45°C in summer and an annual rainfall of 1142 mm (Rajesh and Prasad, 2024). The soil is sandy loam, with a pH of 7.0-8.5, ideal for cultivating crops such as rice, maize, wheat, pulses, oilseeds, tobacco, sugarcane, spices, and vegetables. Agriculture is the primary occupation, engaging 83% of the population, with the district being a key producer of tobacco, maize, rice, wheat, litchi, mango, and potatoes. There are over 20 cold storages for potato preservation.

Data Collection

LANDSAT-5 Thematic Mapper (TM) data from 2000 and 2010, along with LANDSAT-8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) data from 2020, were downloaded from the USGS Earth Explorer site (<https://earthexplorer.usgs.gov>) for analysing Land Use-Land Cover (LULC) changes. All datasets have a resolution of 30 m. The types of data collected for this study are listed in Table 1.

Table 1: Data collected for the present study

S. No.	Data	Path/row	Date	Resolution
1	LANDSAT 5 (TM)	140/42	24/01/2000	30 m
2	LANDSAT 5 (TM)	140/42	04/02/2010	30 m
3	LANDSAT 8 (OLI/TRIS)	140/42	03/03/2020	15 m

Google Earth Data

Google map and Google Earth are regularly used for the generation of ground truth data for accuracy assessment. It is well known that Google Maps is a free net mapping service application and technology supplied by Google. The present study considers Google Earth data as ground truth data.

Crop Yield Data

Crop yield data of Pusa farm for assessing land suitability for major crops has been collected from the office of Pusa Farm, RPCAU, Pusa, Samastipur.

Methodology

Development of Inventory and Map of Land Resources and Water Bodies

Inventory and map of land resources and water bodies

have been prepared by RS and GIS techniques using satellite data and ground truth data.

LULC Mapping

Land use land cover (LULC) is one of the maximum critical thematic inputs in any study as it provides the present status of land usage and its pattern. The change in LULC could be very dynamic; this is why satellite remote sensing is extensively used for its mapping. The images of LANDSAT-5 with Thematic Mapper (TM) and LANDSAT-8 with OLI/TRIS of the study area for the specific years were downloaded from on-line archive of the United States Geological Survey (USGS). False colour composite (FCC) were created for each year (Figure 2) and followed by land use classification using supervised classification algorithm. Five classes [agricultural land, settlement (build-up area), natural vegetation, waterbodies; and sand and barren land] of land use-land cover have been identified to develop LULC map using supervised classification.

Change Detection Technique

Many strategies of change detection have been developed in the recent past to detect land cover changes. Although the improvement of RS technology has been developed dramatically in the last few years, examples of powerful LULC alternate detection research continue to be relatively rare (Loveland et al., 2002; Rogan et al., 2004). After the Land Use Land Cover category of LANDSAT-5 and LANDSAT-8, characteristic tables (*Data > export data > file exported into .dbf format*) have been imported into MS Excel and changes in all five classes have been detected. The float chart used in the change detection is shown in Figure 3.

Accuracy Assessment of Classification

In the existing investigation, the accuracy assessment of class accuracy was done by computing overall accuracy and the Kappa coefficient. In the error matrix, the column indicates the reference statistics while the row gives the categorised generated satellite-derived statistics. Kappa's evaluation approach relies upon K statistic and it's been advocated as an appropriate degree of thematic class because it takes into account the entire mistakes matrix rather than the diagonal elements. The Kappa coefficient is the degree of affiliation of categorical variables.

The Kappa coefficient (K) is computed as below:

$$K = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^r (x_{i+} \times x_{+i})}$$

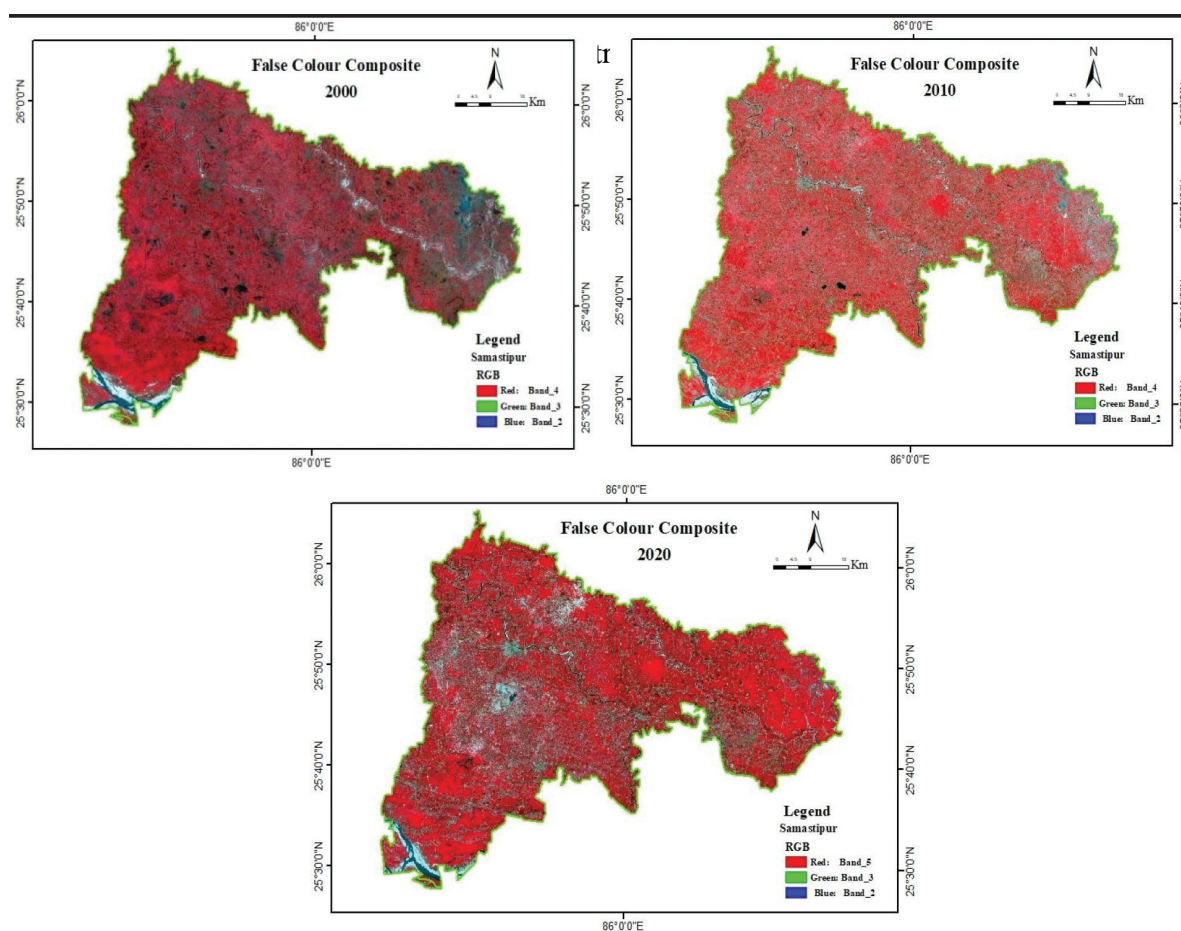


Figure 2: False colour composite of LANDSAT-5 (bands- 4, 3 and 2) and LANDSAT-8 (bands- 5, 3 and 2) of Samastipur district of Bihar.

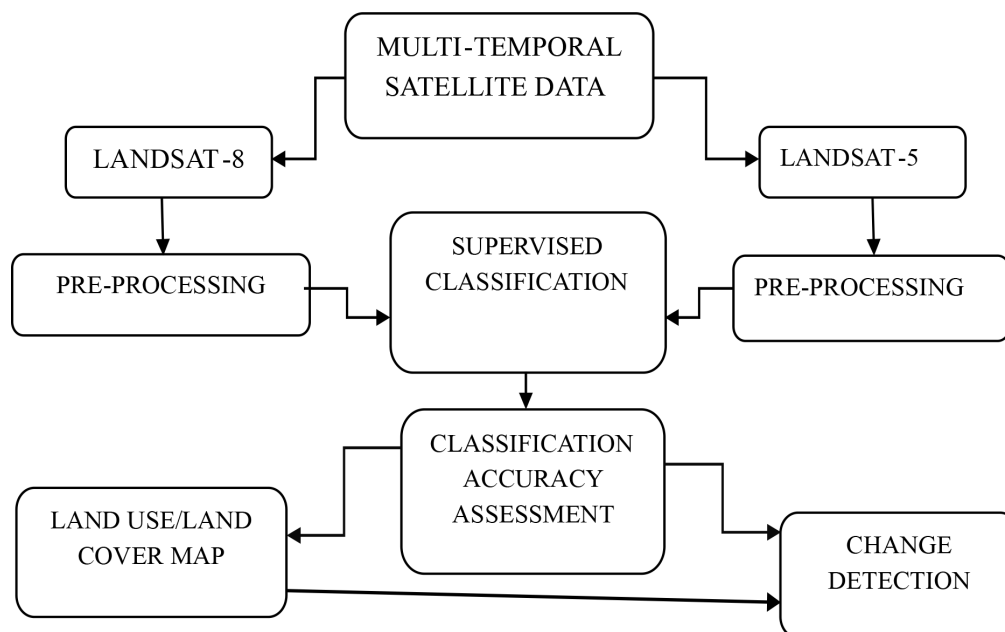


Figure 3: Flow chart used in the change detection.

where,

- r = number of rows in the error matrix
 x_{ii} = number of observations in row i and column i (on the major diagonal),
 x_{i+} = total number of observations in rows i (shown as marginal total to right of the matrix)
 x_{+i} = total number of observations in column i (shown as marginal total at bottom of the matrix)
 N = total number of observations included in matrix

K is a real dimensionless number between -1 to 1, the value close to 1 shows maximum agreement while the value of -1 is total disagreement. The ranges of K for different levels of agreement are presented in Table 2.

Table 2: Interpretation of Kappa value

<i>K-Value</i>	<i>Rating</i>	<i>Agreement</i>
≥ 0.81	Excellent	Almost perfect Agreement
0.81-0.61	Good	Substantial Agreement
0.61-0.41	Moderate	Moderate Agreement
0.41-0.21	Poor	Fair Agreement
0.21-0.0	Bad	Slight Agreement
<0.0	Very Bad	Less than chance Agreement

(Source: Landis & Koch (1997))

Assessment of Land Suitability at Pusa Farm

Land suitability for major crops grown in Pusa farm was assessed by computing the Productivity Rating Index Model (PRI) (Soil Survey Staff, 1951) using recent yield data of crops grown in the present study.

PRI was computed by the following formula.

$$PRI = \frac{\text{Expected or actual yield of crop per ha}}{\text{Standard yield of crop per ha}} \times 100$$

where

PRI = Productivity Rating Index (%)

Actual yield = Average actual yield of major crop (kg/ha)

Standard yield = Average national yield of major crop (kg/ha)

The major crops grown in Pusa farm are wheat, paddy and sugarcane. The data of the actual yield of the crops produced in the last three years were collected from the office of Pusa farm. In the present study, the national average yield of three crops has been taken as the standard yield.

The land suitability class based on PRI is presented in Table 3.

Table 3: Land suitability class based on PRI

<i>Suitability class</i>	<i>Class Name</i>	<i>PRI (%)</i>
S1	Highly suitable	>80
S2	Moderately suitable	40-80
S3	Marginal suitable	20-40
N	Not suitable	<20

Results and Discussion

Development of Inventory and Map of Land Resources and Water Bodies

Using the LANDSAT-8 (OLI/TRIS) image, the inventory and the map of the two classes- land resources and water bodies of the Samastipur district have been prepared using the supervised classification technique. The developed inventory map of the district for the year 2020 is shown in Figure 4 while the prepared inventory of land resources and waterbodies is presented in Table 4. From the classification of the image, it was identified that the study area consists of 98.17% land area and 1.83% water-bodies area (Table 4). The inventory of land resources and waterbodies indicates that the total area of Samastipur district has been estimated as 290000 ha. Out of this, 284689 ha has been occupied by land resources and 5311 ha by water bodies. Out of total land area, 245906 ha (84.80%) is occupied by agricultural land, 9238 ha (3.19%) by natural vegetation, 14779 ha (5.10%) by settlement, 14766 ha (5.09%) by sand and barren land while 5311 ha (1.83%) is occupied by water bodies (Table 4).

Table 4: Inventory of land resources and waterbodies in Samastipur district

<i>S.N.</i>	<i>Particular</i>	<i>Area covered</i>	
		<i>(ha)</i>	<i>%</i>
1.	Land resources	284689	98.17
	Agriculture land	245906	84.80
	Natural vegetation	9238	3.19 5.10
	Settlement	14779	5.09
	Sand and Barren land	14766	
2.	Waterbodies	5311	1.83
	Total	290000	100

Land Use-Land Cover (LULC) Classification

LULC Classification for Year 2000

The obtained LULC classification map of Samastipur district for the year 2000 is shown in Figure 5. This figure shows that in year 2000, the agricultural land coverage was highest followed by natural vegetation.

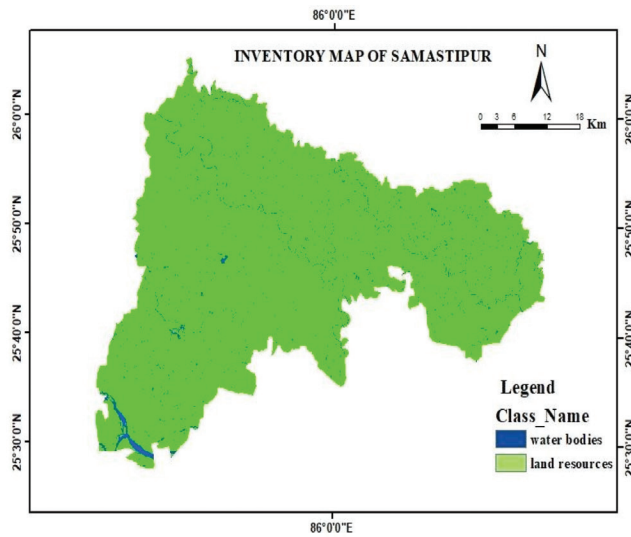


Figure 4: Inventory map of Samastipur district.

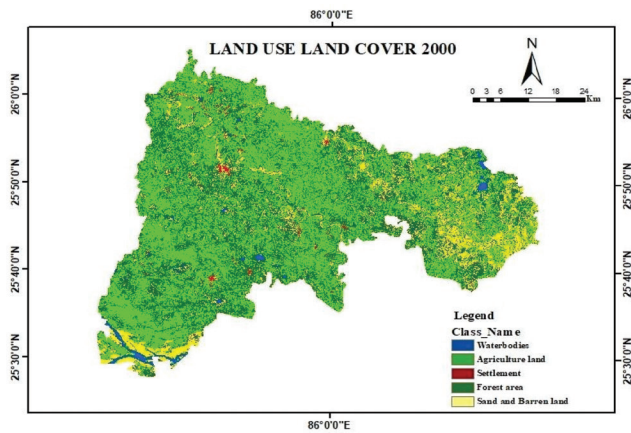


Figure 5: LULC map for year 2000.

The area covered (in terms of actual area and % area) by different LULC classes for this year is presented in Table 5. The table indicates that the total area under agricultural land use was 186291 ha which shares 64.24% of the total area. The total area under

the settlement was 9242 ha while natural vegetation coverage was 60219 ha this year. In addition, the water bodies were spread over 7889 ha. The area under sand and barren land was computed to be 26359 ha.

The accuracy of the classification was assessed category by category, with the reference data (ground truth) and the corresponding results of an automated classification were compared. After the accuracy data was collected in pixel form and combined into an error matrix, it was typically subjected to further statistical and detailed interpretation. The kappa statistic was computed to be 0.64 while the overall accuracy was calculated to be 71.62%. The value obtained from the kappa statistic indicates a substantial agreement match.

Table 5: Area of land use-land cover classes for the year 2000

S.No.	LULC	Area (ha)	Area (%)
1.	Waterbodies	7889	2.72
2.	Agriculture land	186291	64.24
3.	Sand And Barren Land	26359	9.09
4.	Natural vegetation	60219	20.76
5.	Settlement	9242	3.19
	Total	290000	100

LULC Classification for Year 2010

Figure 6. depicts the LULC classification map of the district obtained for the year 2010. These figures show that in year 2010, the agricultural land use was highest followed by natural vegetation, out of five land use classes. The computed areas and percentage area under different LULC classes for the year 2010 are presented in Table 7 which indicates that the total area under agriculture land use was 227586 ha sharing 78.48% of the total area. The total area under the settlement

Table 6: Error matrix of LULC classification for year 2000

Classified data	Reference data					
	LULC	Water bodies	Agriculture land	Sand and Barren Land	Natural Vegetation	Settlement
Waterbodies		5	5	1	0	0
Agriculture Land		0	17	0	1	0
Sand and Barren Land		0	3	12	1	0
Natural Vegetation		1	4	1	8	0
Settlement		0	2	1	1	11
Total		6	31	15	11	11

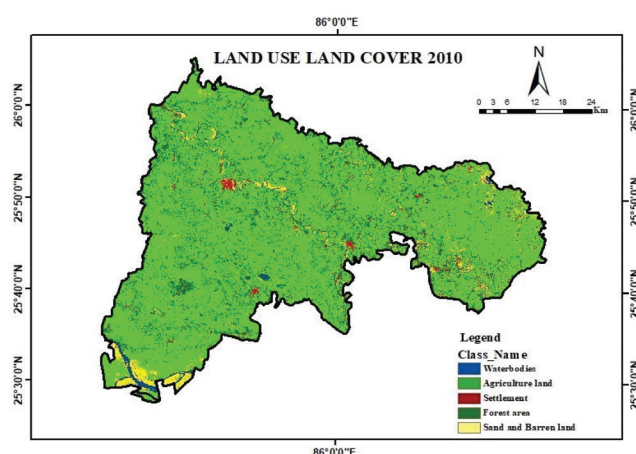


Figure 6: LULC map for year 2010.

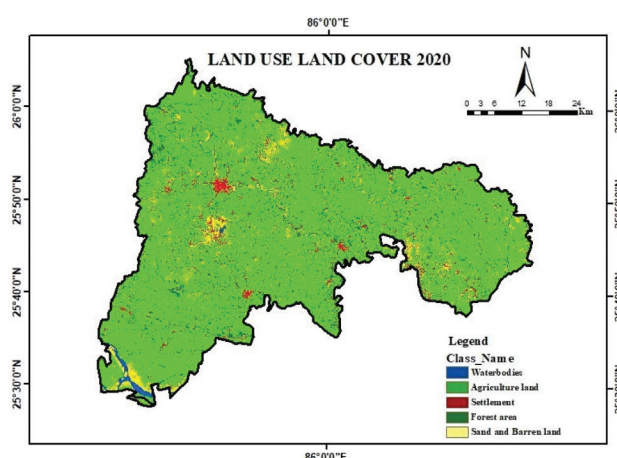


Figure 7: LULC map for year 2020.

was 10686 ha; under natural vegetation was 37314 ha; under the waterbodies was 4206 ha; and under sand and barren land was 10208 ha. For this year, 92 random samples were taken from the entire study area. The overall accuracy was found to be 81.52% and the kappa statistic was computed to be 0.76 (Table 8). The obtained value of kappa statistic indicates that there is substantial agreement.

Table 7: Area of land use-land cover classes for the year 2010

S.No.	LULC	Area (ha)	Area (%)
1.	Waterbodies	4206	1.45
2.	Agriculture land	227586	78.48
3.	Sand And Barren Land	10208	3.52
4.	Natural vegetation	37314	12.87
5.	Settlement	10686	3.68
	Total	290000	100

LULC Classification for Year 2020

For the year 2020, the generated LULC classification of the study area is shown in Figure 7. The areas covered under the various LULC classes this year are written in Table 9. It is obvious from this table that the study area consisted of 84.80% agricultural land, followed by 5.10% settlement, 5.09% sand and barren land, 3.19% natural vegetation and 1.82% waterbodies. The overall accuracy was computed to be 90.74% while the Kappa coefficient was found to be 0.88 (Table 10). The obtained value of the kappa statistic indicates that there is almost perfect agreement. The overall accuracy for this year is observed to be the highest among all three years.

Assessment of Land Use/Land Cover Changes

The comparison of the area covered by various LULC classes in the years 2000, 2010 and 2020 is presented in Table 11, while the graphical comparison is shown in Figure 8 respectively. It is obvious from Table 11 that considerable changes have occurred in many LULC classes during the period from year 2000 to year 2020.

LULC Change @ 10 Years During 2000-2020

The LULC changes that occurred @ 10 years and @ 20 years in the Samastipur district during the years 2000-2020 are summarised in Table 8. The table indicates significant changes in the LULC classes in the study area in three different time periods (2000-2010, 2010-2020 and 2000-2020).

Between 2000 and 2010, the agricultural land area expanded by 22.17%, corresponding to an increase of 41,295 hectares. In contrast, the area covered by natural vegetation decreased by 38.04%, representing a loss of 22,905 hectares. Additionally, water bodies saw a reduction of 46.69% (3,683 hectares), and the extent of sand and barren land shrank by 61.27% (16,151 hectares). During this same period, settlement areas expanded by 15.62%, adding 1,444 hectares. In the subsequent decade (2010-2020), the area devoted to agriculture continued to grow, increasing by 8.05% (18,320 hectares). Settlement areas experienced a significant rise of 38.30% (4,093 hectares), while the area of water bodies expanded by 26.27% (1,105 hectares), and sand and barren land grew by 44.65% (4,558 hectares). However, the area covered by natural vegetation experienced a sharp decline, decreasing by 75.24% (28,076 hectares).

A graphical comparison of LULC changes @ 10 years during the years 2000-2020 is shown in Figure 8. This figure shows that agricultural land area significantly

Table 8: Error matrix of LULC classification for year 2010

Classified data	LULC	Reference data					Total
		Water bodies	Agriculture Land	Sand and Barren Land	Natural Vegetation	Settlement	
Waterbodies		12	7	0	0	0	19
Agriculture Land		0	25	0	0	0	25
Sand and Barren Land		1	6	8	1	0	16
Natural Vegetation		0	1	0	16	0	17
Settlement		0	1	0	0	14	15
Total		13	40	8	17	14	92

Table 9: Area of land use-land cover classes for the year 2020

S.No.	LULC	Area (ha)	Area (%)
1.	Waterbodies	5311	1.82
2.	Agriculture land	245906	84.80
3.	Sand And Barren Land	14766	5.09
4.	Natural vegetation	9238	3.19
5.	Settlement	14779	5.10
	Total	290000	100

Table 10: Error matrix of LULC classification for year 2020

Classified data	LULC	Reference data					Total
		Water bodies	Agriculture Land	Sand and Barren Land	Natural Vegetation	Settlement	
Waterbodies		18	2	0	0	0	20
Agriculture Land		0	33	0	0	0	33
Sand and Barren Land		3	1	11	0	0	15
Natural Vegetation		0	1	0	17	0	18
Settlement		0	3	0	0	19	22
Total		21	40	11	17	19	108

Table 11: LULC changes in Samastipur district @ 10 years and @ 20 years from year 2000 to year 2020

LULC Class	Changes in area coverage					
	Changes @ 10 years				Changes @ 20 years	
	2000-2010		2010-2020		2000-2020	
	ha	%	ha	%	ha	%
Waterbodies	-3683	-46.69	1105	26.27	-2578	-32.68
Agriculture Land	41295	22.17	18320	8.05	59615	32.00
Sand and Barren Land	-16151	-61.27	4558	44.65	-11593	-43.98
Natural Vegetation	-22905	-38.04	-28076	-75.24	-50981	-84.66
Settlement	1444	15.62	4093	38.30	5537	59.91

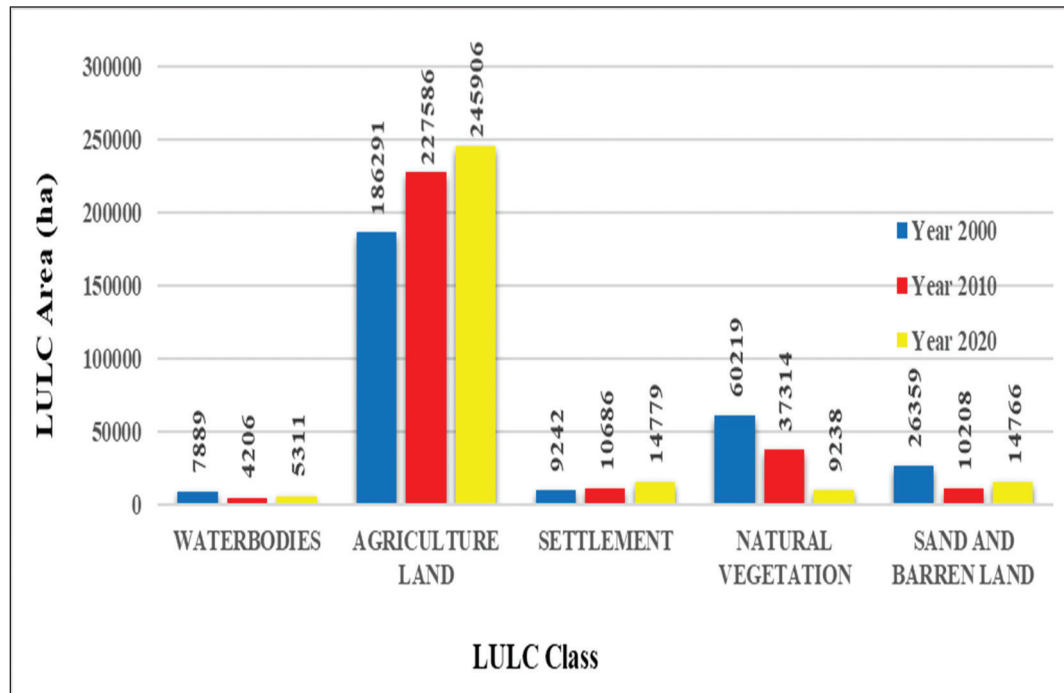


Figure 8: Graphical comparison of LULC for the years 2000, 2010 and 2020.

increased during 2000-2010 while it slightly increased in the next 10 years (2010-2020). On the other hand, the natural vegetation coverage sharply decreased during 2010-2020 while settlement i.e., urbanisation sharply increased during this period.

The loss of vegetation and water bodies has significant environmental impacts, disrupting ecosystems, reducing biodiversity, and contributing to climate change by decreasing carbon sequestration. Vegetation loss leads to soil erosion and degradation, affecting agricultural productivity, while the disappearance of water bodies alters local hydrological cycles, reducing groundwater recharge and streamflow. This disruption can lead to local temperature extremes and alter precipitation patterns, affecting both regional climate and human livelihoods, especially in communities reliant on natural resources for agriculture and fisheries. These environmental changes not only threaten ecological balance but also increase vulnerability to food and water insecurity (Babaremu et al., 2024).

Assessment of Land Suitability at Pusa Farm

Land suitability for major crops has been assessed by computing Productivity Rating Index (PRI) values using the recent three years (2018-2020) data of major crops grown in Pusa Farm. Table 4.15 presents computed values of PRI for major crops grown in the Pusa farm. The PRI index was calculated for the major crops wheat, paddy, and sugarcane for the year 2018 to 2020. The actual yield data varied from 2792.23 kg/ha to 85471.42 kg/ha. The standard yield data varied from 2576 kg/ha to 80198 kg/ha and the computed PRI index values were found to vary in the range from 82.90% to 137.14% for the major crops.

Table 12 indicates that the PRI index values were computed to be 82.90 %, 106.57 % and 137.14 % for the wheat, sugarcane and paddy crops respectively. These values indicate that the land of Pusa farm comes under the S_1 class and hence is highly suitable for these crops.

Table 12: Computation of productivity rating index (PRI) for major crops at Pusa farm

Major Crops	Average Actual Yield (kg/ha)	Standard Yield (kg/ha)	PRI Index (%)	Suitability classes
Wheat	2792.23	3368	82.90%	S_1 (highly suitable)
Paddy	3532.83	2576	137.14%	S_1 (highly suitable)
Sugarcane	85471.42	80198	106.57%	S_1 (highly suitable)

Conclusion

Assessment of changes in land use/land cover (LULC) plays a vital role in planning land resources management. The spatial land cover information is necessary for proper management, planning and monitoring of natural resources in a particular area. The present study entitled “Assessment of Land Use/Land Cover Changes in Samastipur District of Bihar using RS and GIS” is conducted in the said district situated in Bihar state of India.

Between 2000 and 2010, the agricultural land area expanded by 22.17%, corresponding to an increase of 41,295 hectares. In contrast, the area covered by natural vegetation decreased by 38.04%, representing a loss of 22,905 hectares. Additionally, water bodies saw a reduction of 46.69% (3,683 hectares), and the extent of sand and barren land shrank by 61.27% (16,151 hectares). During this same period, settlement areas expanded by 15.62%, adding 1,444 hectares. In the subsequent decade (2010-2020), the area devoted to agriculture continued to grow, increasing by 8.05% (18,320 hectares). Settlement areas experienced a significant rise of 38.30% (4,093 hectares), while the area of water bodies expanded by 26.27% (1,105 hectares), and sand and barren land grew by 44.65% (4,558 hectares). However, the area covered by natural vegetation experienced a sharp decline, decreasing by 75.24% (28,076 hectares).

It indicates that agricultural land area significantly increased during 2000-2010 while it slightly increased in the next 10 years (2010-2020). On the other hand, the natural vegetation coverage sharply decreased during 2010-2020 while settlement i.e., urbanisation sharply increased during this period.

PRI index values for assessing land suitability at Pusa farm were computed to be 82.90 %, 106.57 % and 137.14 % for the wheat, sugarcane and paddy crops respectively. These values indicate that the land of Pusa farm comes under the S_1 class.

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Contents

<i>Editorial</i>	i
❑ <i>Snapshot</i>	ii
Evaluating Passive Housing Strategies in Extreme Climates: A Case Study of Dubai Using PHPP and IESVE Models <i>Mohamed Mahgoub and Pankaj Kumar</i>	1
Alder-Based Shifting Cultivation in Nagaland – A Theoretical Perspective <i>Bondita Saikia, Trinadh Nookathoti and Channaveerayya Hiremath</i>	19
Present Scenario of Ocean Warming (OW) and Ocean Acidification (OA) in the Coastal and Marine Waters of the Bay of Bengal, Bangladesh and Implications of OW and OA on Fisheries and Seafood of Bangladesh: A First Regional Review Study <i>Alam Pervez, Md. Shafiqul Islam, Md. Mostafa Monwar, Ataher Ali and Golam Kibria</i>	27
Enhancing Data Analytics in Environmental Sensing Through Cloud IoT Integration <i>Rohan Verma, Harsh Taneja, Kiran Deep Singh and Prabh Deep Singh</i>	41
Impact of Ocean Acidification on Plankton – A Short Review <i>Ishita Sharma, Dipanwita Das, Sayantika Mukherjee and Amrita Saha</i>	47
Climate Change Impact on Migration Situation in Coastal Delta Belt of Bangladesh: A Qualitative Explorative Study <i>Prabal Barua and Ashim Kumar Saha</i>	51
Enhancing Fuel Efficiency and Emission Control in Diesel Locomotives through Auxiliary Power Units (APUs) in Neutral Conditions <i>Pavani Siva Mallemoggala, Srinivasa Rao Gummadi, Swetha Vanapalli, BalaSheshasri Guttula and Jananika Katta</i>	69