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Spatio-Temporal Assessment of Land Use and Land Cover Change in a Hill District of Manipur Using Remote Sensing and GIS

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Abstract

Land use and land cover (LULC) change is a major driver of environmental transformation, particularly in ecologically fragile hill regions where human-environment interactions are intense. Understanding the nature, magnitude, and direction of these changes is essential for sustainable land management and regional planning. The present study examines the spatio-temporal dynamics of LULC in Churachandpur district, Manipur, Northeast India, over a 30-year period from 1994 to 2024 using remote sensing and GIS techniques. Multi-temporal Landsat data from Landsat 5 TM (1994 and 2009) and Landsat 8 OLI (2024) were employed to classify the study area into five major LULC categories: vegetation cover, fallow land, agricultural land, built-up area, and water body. Supervised classification using the maximum likelihood algorithm was applied, followed by accuracy assessment through confusion matrix analysis. The classified maps achieved satisfactory accuracy and corresponding kappa coefficients. The results reveal that vegetation cover remained the dominant land cover throughout the study period. Fallow land exhibited considerable fluctuations, reflecting shifting cultivation in the region. Agricultural land showed a gradual net decline, while built-up areas expanded rapidly, particularly after 2009, indicating accelerated urbanization and infrastructure development. Water bodies recorded a marginal but consistent increase over time. Change matrix analysis highlighted that the most dominant transitions occurred between vegetation cover and fallow land, underscoring dynamic land-use interactions in the district. The findings provide valuable baseline information to support informed decision-making, sustainable land management strategies, and balanced regional development in Churachandpur district and similar mountainous landscapes of Northeast India.

Keywords: LULC, Remote sensing, Spatio-temporal analysis, Change detection, Manipur.

Introduction

Land cover refers to the biophysical features of the Earth's surface, including vegetation, water bodies, soil, and human-made structures such as settlements (Foresman et al., 1997; Rawat and Kumar, 2015; Sohl and Sleeter, 2012). Simultaneously, land use refers to human activities that modify the biophysical characteristics of land cover (Roy and Roy, 2010). Land use and land cover (LULC) are closely related concepts and are usually studied together because the physical features on the Earth's surface and the way humans use them are interconnected (Rawat and Kumar, 2015; Turner and Ruscher, 1988). LULC plays a direct role in altering ecosystem structure and functions, making it a key concern for sustainable management (Hasan et al., 2020; Roy and Roy, 2010). Under current socio-economic conditions, rapid population growth, and increasing natural disasters, the world is experiencing significant changes in land use and land cover (Devi and Shimrah, 2022). Therefore, understanding the current status and trends of changes at the ground level is essential for effective ecosystem management.

Advanced tools like remote sensing and geographic information systems (GIS) are extensively applied in research to examine spatio-temporal LULC changes and their impacts on landscapes. Remote sensing provides synoptic data over short periods at low cost and with better accuracy (Kachhwala, 1985). Various LULC change detection studies using geospatial technologies have been carried out in different parts of the world. Juliev et al. (2019) examined LULC changes in the Bostanlik District of Tashkent, Uzbekistan, from 1989 to 2017. The study revealed significant changes in forest cover, built-up areas, bare soil, and snow cover over the 28-year period. Yang et al. (2017) conducted a study to detect LULC changes and their effects on the urban heat island in Changchun, China. Similarly, a study carried out in Islamabad, Pakistan, detected rapid urban expansion through the growth of impervious surfaces at the expense of forests and other natural land covers, resulting in increased urban heat island intensity and land surface temperature (Sadiq Khan et al., 2020). Tiwari and Saxena (2011) employed remote sensing and GIS techniques to detect LULC changes in and around the Mandideep and Obedullaganj regions. A study in the Rani Khola watershed of the Sikkim Himalaya assessed and monitored changes in LULC patterns using Landsat-5 TM and Sentinel-2 data (Mishra et al., 2020), while LULC changes due to coal exploitation in the Dhanbad district of India during 1987-2017 were evaluated in another study by Singh et al. (2018). Urban land use changes in Imphal, Manipur, over a 45-year period were investigated by Tungnung and Anand (2017). LULC changes and forest fragmentation in Ukhrul district, Manipur, using multi-temporal satellite data from 1991, 2005, and 2020 were analysed by Shimrah et al. (2022). Similarly, spatio-temporal changes in LULC, along with the net rate of deforestation and forest fragmentation, were examined in the traditional landscape of Senapati district, Manipur, Northeast India (Devi and Shimrah, 2022).

Among the hill districts of Manipur, Churachandpur district is characterized by a predominantly forested landscape. The population is dependent on forest resources and shifting cultivation for livelihoods (Haokip et al., 2025). In recent decades, the area has undergone significant LULC change. Despite its ecological and socio-economic importance, a systematic LULC change detection studies at the district level remain limited. Therefore, the present study aims to assess and analyse LULC changes in Churachandpur district using remote sensing and GIS-based techniques. The findings will help inform decision-makers in promoting sustainable land management and regional development.

Materials and Method

Study area

The Churachandpur district extends between 93°21′ E and 93°53′E longitudes and 23°56′N and 24°37′N latitudes (Fig. 1). It is one of the regions of Manipur Western Hills, located in the southern part of the state. Topographically, the region is rugged, characterized by low hills with a mean elevation ranging from 900 to 1000 metres and covered by dense forest. The region is well drained by the Khuga, Leimatak, Tuivai, Tuitha and Manipur rivers.

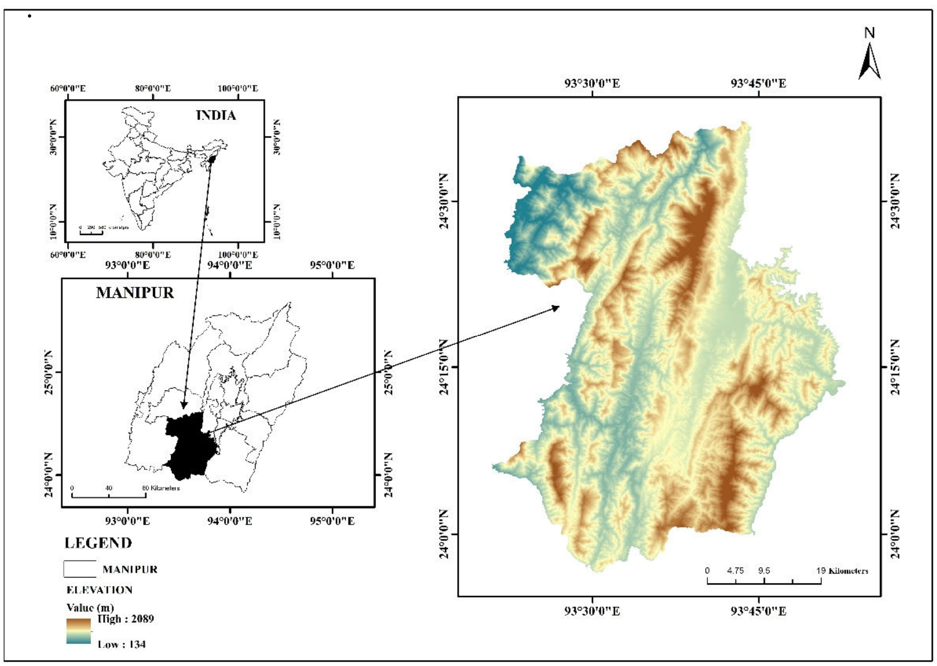

Fig. 1 Churachandpur district, Manipur

Demographically, the region has a population of 226,884 persons according to the 2011 Census, with a population density of 95 persons per km². It comprises a total of 396 villages and has a literacy rate of 82.78% and a sex ratio of 975 females per 1,000 males. Agriculture dominates the district's economy, engaging 59.61% of the total working population. Climatically, the region experiences a summer season from March to May, characterized by warm to hot and sunny weather. The rainy season extends from April to October, while the winter season lasts from November to February and is cool and dry. NH-150 (Imphal-Aizawl) and NH-150A (Churachandpur-Tuivai) pass through the region. Some of the important towns include Churachandpur, Rengkai, Zenhang Lamka and Hill town. Churachandpur serves as the regional headquarters.

Administratively, the district is divided into 10 sub-regions: Churachandpur region, Saikot region, Tuibong region, Mualnuam region, Singhat region, Henglep region, Kangvai region, Samulamlan region, Sangaikot and Luangthul Suangdoh region, based on sub-district administration demarcated by the sub-district boundaries (Nabakumar, 2026). The shapefile used for the study area is downloaded from Survey of India website (https://www.surveyofindia.gov.in/).

Data preparation and processing

Cloud-free (<10%) multi-spectral Landsat data from Landsat 5 TM and Landsat 8 OLI were used to analyse the LULC changes in Churachandpur district, Manipur. Landsat 5 TM images were used for the years 1994 and 2009, while a Landsat 8 OLI image was used for 2024. The images were downloaded from United States Geological Survey (USGS) Earth Resources Observation Systems Data Centre. The path and row of the satellite data are 135 and 43 respectively. Radiometric and atmospheric corrections were applied to enhance the accuracy of the satellite data. The spatial resolution of the downloaded imagery is 30 m. A detailed summary of the satellite datasets used in this study is presented in Table 1. And the detailed methodological flow chart of the study is given in Fig. 2.

Table 1 Details of data sources and datasets used in the study

Sl. No.	Satellite Data	Date of acquisition	Path	Row	Resolution(m)
1	Landsat 5 TM	21/Feb/1994	135	43	30
2	Landsat 5 TM	14/Feb/2009	135	43	30
3	Landsat 8 OLI	11/Mar/2024	135	43	30

Land use and land cover mapping

The corrected satellite imagery was imported into ArcGIS and band stacking was performed using the blue, green, red, near-infrared (NIR), and shortwave infrared (SWIR) bands. The area of interest was clipped. Standard false colour composites (FCC) were generated using the NIR, red, and green bands to classify the different features present in the study area. LULC classification was executed using the pre-processed imaged and change matrix analysis was performed.

The imagery was classified into five LULC classes- vegetation cover, fallow land, agricultural land, built-up area, and water body -for the years 1994, 2009, and

2024 using the supervised classification method viz. the maximum likelihood algorithm. The rate of change between the initial and final years was calculated using the formula provided in Eq. 1.

$$C = \frac{A2 - A1}{30} \quad (1)$$

Where, C = rate of change in LULC class

A2 = area covered by LULC class in recent year (2024)

A1 = area covered by LULC class in initial year of the study period (1994).

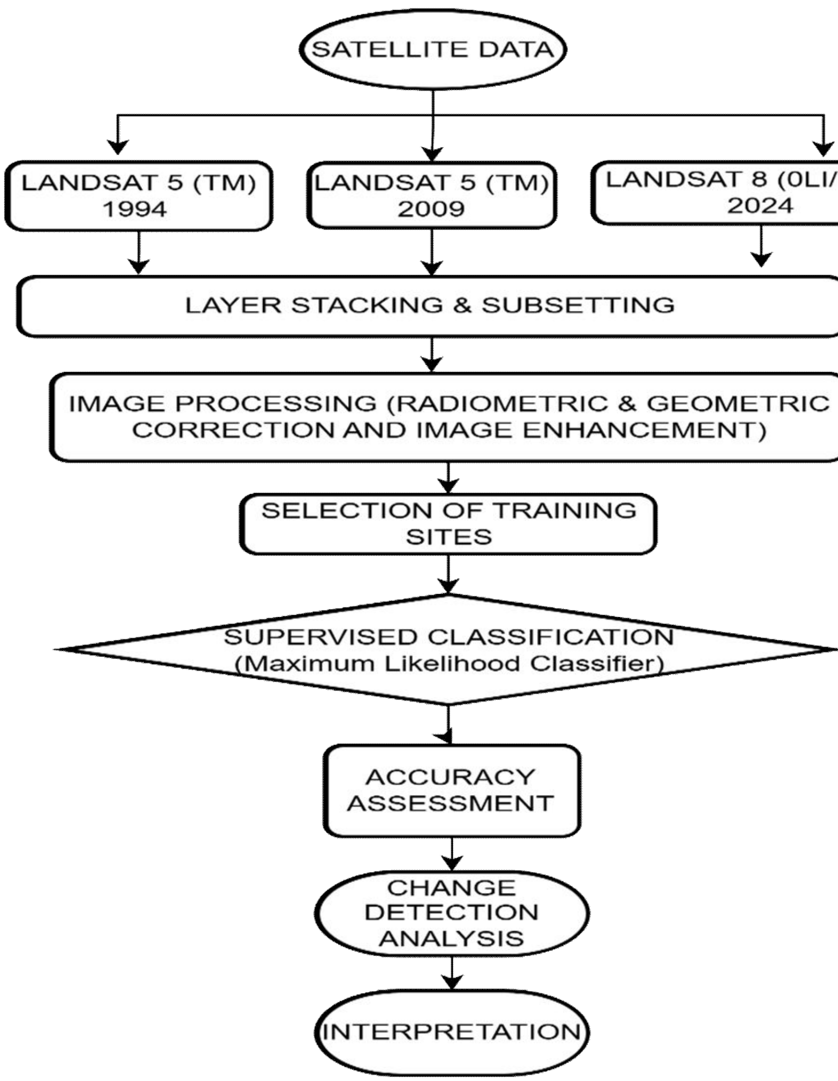

Fig. 2 Methodological flow chart of the study

Accuracy Assessment

Accuracy assessment and error matrix analysis are widely used to evaluate the correctness of results (Reis, 2008). To validate the classified LULC, we need to calculate accuracy assessment for each classified image (Devi and Shimrah, 2022). It is a fundamental component of most remotely sensed data mapping studies (Congalton, 2001), as it determines the quality of the result (Sharma et al., 2016). The overall accuracy represents the collective accuracy of all classes and indicates the proportion of pixels that are classified correctly (Anand, 2017). A "Confusion matrix" between reference and classified data is employed to examine the accuracy of the classification. High resolution images from Google Earth Pro were used as reference image.

The kappa coefficient and overall accuracy are calculated using Eq. 2 and Eq. 3 respectively. The overall accuracy of a classification map is calculated by dividing the total number of correctly classified pixels by the total number of reference pixels in the error matrix. The producer's accuracy (omission error) and user's accuracy (commission error) are calculated using the formula given in Eq.4 and Eq.5 (Shimrah et al., 2022).

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

Where, $\hat{K}$= kappa co-efficient

N = total number of samples

r = number of classes

X_{ii}= diagonal values in the matrix

x_{i+}= total samples in row i

x_{+i}= total samples in column i.

Overall Accuracy (OA),

$$\text{OA} = \frac{1}{\text{N}} \sum_{i=1}^{r} n_i \quad (3)$$

Where, N = total number of pixels

r = number of classes

n = correctly identified pixels in each class.

Producer accuracy (PA),

$$\text{PA} = \frac{n_i}{n_{i\ c_0 l}} \quad (4)$$

Where, n_i= correctly identified pixels in the class

$n_{i\ c_0 l}$ = column total for the considered class.

User accuracy (UA),

$$\text{UA} = \frac{n_i}{n_{irow}} \quad (5)$$

Where, n_i= correctly identified pixels in the class

n_{irow} = row total for the considered class.

Results and Discussion:

Accuracy Assessment

In the present study, the overall accuracy of the classified images of Churachandpur for the years 1994, 2009 and 2024 is 89.25%, 94.57% and 87.16% respectively. The kappa coefficients for the different periods of 1994, 2009 and 2024 are 0.85, 0.92 and 0.83 respectively (Table 2). Table 3 shows the user's and producer's accuracy for each LULC class in different years. These results demonstrate the reliability of our classified images and indicate that these images are acceptable.

Table 2 Overall accuracy and Kappa coefficient for the classified maps of 1994, 2009 and 2024.

Sl. No.	Year	Overall Accuracy	Kappa Coefficient
1	1994	89.25%	0.85
2	2009	94.57%	0.92
3	2024	87.16%	0.83

Table 3 Producer's and user's accuracy for the years 1994, 2009 and 2024.

LULC Classes	Producer accuracy			User accuracy		
	1994	2009	2024	1994	2009	2024
Vegetation Cover	82.61	96.55	67.07	95.96	95.73	100
Fallow Land	89.66	90.62	70.91	72.22	92.06	76.47
Agricultural Land	95.08	94.44	96.67	100	94.44	97.48
Built-up Area	95.45	90.91	100	91.3	90.91	59.74
Water Body	100	100	100	85.18	100	98.44

LULC Status in 1994, 2009 and 2024

In this study, multi-spectral Landsat satellite data were used to examine the spatio-temporal dynamics of LULC. To derive historical LULC patterns, Landsat 5 TM images were used for 1994 and 2009, and a Landsat 8 OLI TIRS image was used for 2024. The study area was classified into five different classes, viz. vegetation cover, fallow land, agricultural land, built-up area, and water body, for the analysis. The LULC classified maps of the Churachandpur district for the years 1994, 2009 and 2024 are shown in Fig. 3.

Table 4 shows the results of the classified data. The results from the 1994 classified image revealed that the area was predominantly characterized by vegetation cover, with 1722.2 sq. km (71.23%), indicating a largely natural landscape, followed by fallow land with 634.52 sq. km (26.25%). Agricultural land accounted for 49.81 sq. km (2.06%), while built up area covered 8.05 sq. km (0.33%). Water body occupied the lowest area with 3.09 sq. km (0.13%). In the year 2009, vegetation cover continued to dominate the study area with 1672.76 sq. km (69.19%) of the total area. Fallow land covered 687.32 sq. km (28.43%), followed by agricultural land with 31.88 sq. km (1.32%). Built up area constituted 18.37 sq. km (0.76%), while water body accounted for 7.34 sq. km (0.3%). The LULC classified image of 2024 showed that vegetation cover remained the predominant land use class, occupying 1756.81 sq. km (72.67%). Fallow land constituted 559.77 sq. km (23.15%), followed by agricultural land at 35.57 sq. km (1.47%). Built up area accounted for 57.56 sq. km (2.38%), and water body covered 7.96 sq. km (0.33%). Across all three study periods, the forest class occupied the largest proportion of the district, as the study area extends into the forested Eastern Himalayan region, whereas water body accounted for the least area coverage due to the mountainous terrain, which supports limited surface water.

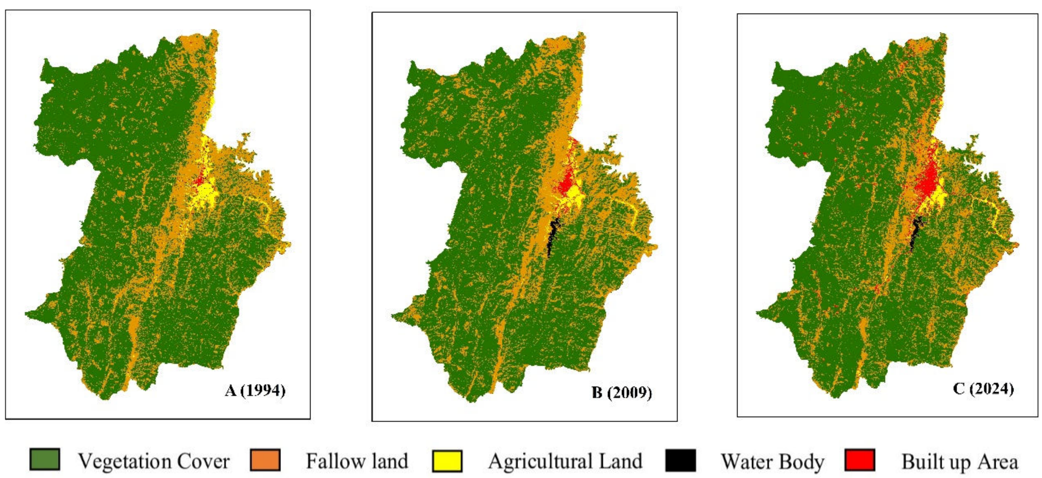

Fig. 3 LULC maps of Churachandpur district of Manipur, Northeast India

Table 4 Area of different LULC classes for different periods (1994, 2009 and 2024)

LULC Classes	**1994**		**2009**		**2024**	
	Area (sq. km)	**% of Area**	**Area (sq. km)**	**% of Area**	**Area (sq. km)**	**% of Area**
Vegetation Cover	1722.2	71.23	1672.76	69.19	1756.81	72.67
Fallow Land	634.52	26.25	687.32	28.43	559.77	23.15
Agricultural Land	49.81	2.06	31.88	1.32	35.57	1.47

Built-up Area	8.05	0.33	18.37	0.76	57.56	2.38
Water Body	3.09	0.13	7.34	0.3	7.96	0.33
Total	**2417.67**		**2417.67**		**2417.67**	

Change detection of LULC classes from 1994 to 2009, 2009 to 2024 and 1994 to 2024

The LULC change analysis demonstrates significant changes across the study period (1994, 2009, and 2024) as shown in Table 5 and Fig. 4. Vegetation cover experienced a significant decline during 1994-2009 (49.44sq. km; 2.04%), followed by a substantial increase during 2009-2024 (84.05 sq. km; 3.48%). However, it increased by a total of 34.61 sq. km (1.43%) from 1994 to 2024, with an annual change rate of 1.15 sq. km/year. Fallow land increased by 52.8 sq. km (2.18%) between 1994 and 2009, but declined significantly during 2009-2024 (127.55sq. km; 5.28%). Fallow land had an overall reduction of 74.75 sq. km (3.09%) over the entire period, at a rate of 2.49 sq. km/year. Agricultural land decreased during 1994-2009 (17.93 sq. km; 0.74%) but slightly increased during 2009-2024 (3.69 sq. km; 0.15%). However, the net change over 1994-2024 remained negative at 14.24 sq. km (0.59%), with an annual loss of 0.47 sq. km/year. On the other hand, the built up area recorded a consistent and noticeable expansion. It increased by 10.32 sq. km (0.43%) during 1994-2009 and 39.19 sq. km (1.62%) during 2009-2024. The total increase of 49.51 sq. km (2.05%) was observed for this land use class over the study period, with an average growth rate of 1.65 sq. km/year. Water bodies expanded significantly between 1994 and 2009 (4.25 sq. km; 0.18%), followed by a marginal increase during 2009-2024 (0.62 sq. km; 0.03%). They experienced a total increase of 4.87 sq. km (0.2%) from 1994 to 2024, with an annual change rate of 0.16 sq. km/year.

Table 5 LULC changes of Churachandpur district from 1994 to 2009, 2009 to 2024 and 1994 to 2024

LULC Classes	**Area Change (km^2)**			**Percentage Change (%)**			**Rate of Change (km^2/year) C**
	1994-2009	**2009-2024**	**1994-2024**	**1994-2009**	**2009-2024**	**1994-2024**	**1994-2024**
Vegetation Cover	-49.44	84.05	34.61	-2.04	3.48	1.43	1.15
Fallow Land	52.8	-127.55	-74.75	2.18	-5.28	-3.09	-2.49
Agricultural Land	-17.93	3.69	-14.24	-0.74	0.15	-0.59	-0.47

Built-up Area	10.32	39.19	49.51	0.43	1.62	2.05	1.65
Water Body	4.25	0.62	4.87	0.18	0.03	0.2	0.16

The positive (+) and negative (–) signs denote inter-period increases and decreases in values, respectively.

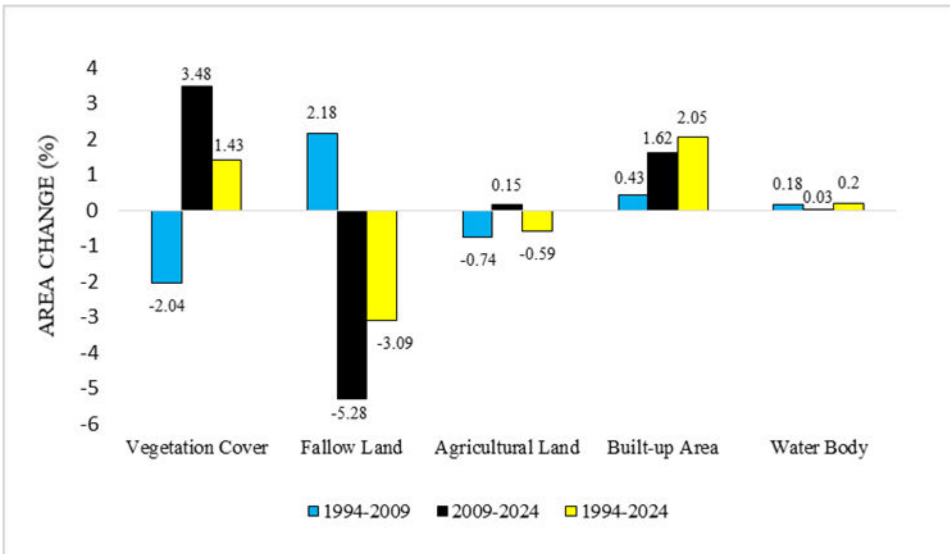

Fig. 4 Graphical representation of LULC change during the study period

During the study period, all five LULC classes in the district experienced inter class conversions. The LULC transitions for the periods 1994-2009 and 2009-2024 are presented in Tables 6 and Table 7, respectively. In the tables, the diagonal cells indicate areas that remained unchanged, whereas the remaining matrix cells represent conversions from one LULC class to another.

During 1994-2009, the most significant transition is observed between vegetation cover and fallow land. A substantial area of 255.35 km² of vegetation was converted into fallow land, while 205.65 km² of fallow land converted back into vegetation. The expansion of built-up areas is also evident, primarily sourced from agricultural land (7.74 km²) and fallow land (4.84 km²).

Table 6 LULC change matrix for the period 1994-2009

	Vegetation Cover	**Fallow Land**	**Agricultural Land**	**Built-up Area**	**Water Body**
Vegetation Cover	1466.04	255.35	0.09	0.09	0.31
Fallow Land	205.65	413.26	5.1	4.84	5.34

Agricultural Land	0.65	14.11	25.89	7.74	1.33
Built-up Area	0.06	2.48	0.41	4.97	0.11
Water Body	0.03	1.74	0.37	0.7	0.24

The change matrix indicates that during 2009-2024, the most dominant transition occurred between vegetation cover and fallow land. A substantial 197.06 km² of vegetation was converted into fallow land, while an even larger area of 285.94 km² of fallow land transitioned back into vegetation. A notable expansion of built-up areas is evident, primarily at the expense of fallow land (32.05 km²) and agricultural land (7.2 km²).

Table 7 LULC change matrix for the period 2009-2024

	Vegetation Cover	**Fallow Land**	**Agricultural Land**	**Built-up Area**	**Water Body**
Vegetation Cover	1470.1	197.06	0.28	4.67	0.35
Fallow Land	285.94	355.51	12.29	32.05	1.12
Agricultural Land	0.1	3.89	20.64	7.2	0.03
Built-up Area	0.07	2.2	2.32	13.59	0.17
Water Body	0.23	0.82	0.001	0.01	6.26

Conclusion

The present study assessed the spatio-temporal dynamics of LULC in Churachandpur district, Manipur, over a 30-year period (1994-2024) using multi-temporal Landsat satellite data and GIS-based techniques. The results reveal notable transformations in the district's landscape, driven by a combination of anthropogenic activities and natural processes. Vegetation cover remained the dominant LULC class throughout the study period. Fallow land exhibited significant fluctuations, reflecting the influence of shifting cultivation. Agricultural land showed a gradual overall decline, while built-up areas expanded consistently and rapidly, particularly after 2009, highlighting increasing urbanization and infrastructure development in the district. The sudden increase in water body from 1994 to 2009 was mainly due to the construction of Khuga Dam. Change matrix analysis revealed that the most dominant transitions occurred between vegetation cover and fallow land, emphasizing dynamic land-use interactions. The high overall accuracy and kappa coefficients confirm the reliability of the classification results. Overall, the findings underscore the growing pressure on land resources and the need for sustainable land management strategies.

The study provides valuable baseline information for planners and policymakers to promote environmentally balanced development and effective land-use planning in the district.

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