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Geospatial Assessment And Prediction Of Land Use Changes In Bikaner Urbanizable Area: A QGIS-Based Approach Using MOLUSCE Plugin

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Abstract
The current research explores the Spatio-temporal dynamics of land use/land cover (LULC) in Bikaner district, Rajasthan—a semi-arid district with high urbanization and changing land use trends. Multi-temporal satellite data for the years 2000, 2014, and 2024 were analyzed under supervised classification using the Maximum Likelihood Classification (MLC) method in QGIS. Five prominent LULC classes—Built-up, Agricultural Land, Forest, Grazing/Wasteland, and Water Bodies—were identified and analyzed. The classification accuracy of the outputs provided an overall accuracy of [insert]% with a Kappa value of [insert] reflecting high agreement between the classified results and the reference data. Transition matrix was produced to measure LULC dynamics over time.
The result showed a high growth in urban areas, along with high degradation of agricultural and grazing lands, due to the effects of urbanization and land degradation. To forecast future land cover configurations, the MOLUSCE plugin was utilized under Cellular Automata and Markov Chain modeling, following land cover changes witnessed between 2000 and 2014, to project the LULC scenario in 2044. The results highlight the extent and orientation of land change in the area and provide useful insights for sustainable urban design, resource administration, and policy formulation in arid and semi-arid environments.
Keywords: *LULC, Landsat data, QGIS, MOLUSCE, CA–ANN, Accuracy assessment*

RATIONALE OF THE STUDY:

The increasing population of the world in relation to the limited land resources of the world is increasingly putting countries across the globe under pressure. With only a fraction of the Earth's surface as land, the demand for these limited resources has intensified—especially because of fast-paced urbanization and land use pattern modifications. Land Use and Land Cover (LULC) changes have been a dominant research area in geography and environmental science over the past decades, and these provide critical information on the dynamics of human settlements and the natural environment. Urban areas, particularly, are expanding at a historic rate. Projections show that by the not-too-distant future, nearly half the world's population will be urban. This expansion is most evident at the fringes of cities, where land use land cover change processes are dynamic, rapid, and largely unregulated. As urban peripheries expand outward, productive agricultural land—essential for local food security and economic sustainability—is increasingly at risk. Understanding LULC change processes in peri-urban areas has therefore become an imperative for effective urban planning, sustainable development, and policy-making. In this global context, India faces similar challenges, especially in the arid state of Rajasthan. The present study focuses on Bikaner, a major district located in the Thar Desert, with specific attention to Bikaner city and its surrounding peri-urban areas. This region exemplifies the mounting pressure of urban expansion on limited land resources, particularly those used for agriculture, which play a crucial role in the local economy. The current study investigates the spatio-temporal trend of LULC between the years 2000 and 2024 and presents a comprehensive analysis of prevailing land use trends surrounding and within Bikaner city. The study also projects future LULC scenarios for the years 2034 and 2044 using the MOLUSCE (Modules for Land Use Change Simulation) plugin in QGIS. The potential futures of the study model have been made possible based on the analysis of historical LULC trends to allow for sustainable urban planning. The simulation also anticipates unutilized or vacant land areas that can be covered for future development and thus conserve fertile agricultural lands from unsustainable encroachment. With regional geographic sensitivity and the heightened need for city infrastructure, such studies of foresight become important in striking a balance between ecological conservation and developmental needs. Taking Notified Urban Area Limit – 2043 as the spatial boundary for the study offers an additional contextual dimension because it ties the study to themes of official planning. Using the MOLUSCE plugin in QGIS, a popular geospatial modeling software, this study generates graphic and analytical urban footprint projections of Bikaner in 2034 and 2044. These projections are intended to support data-informed, resilient, and inclusive urban development policies. The findings are generally applicable to semi-arid urban India, which is both economically important and ecologically vulnerable.

Lastly, this research not only detects historical and current trends of land use alteration but also provides a platform for predictive modeling and long-term spatial planning. It sheds light on the significance of geospatial technologies in tackling the challenges of urbanization in addition to enabling sustainable land management in rapidly expanding cities like Bikaner.

MATERIALS AND METHODS

Study Area

The present study focuses on the urban and peri-urban zones of **Bikaner city**, emphasizing land use and land cover (LULC) dynamics. Geographically, Bikaner is situated at approximately 28.0176° N latitude and 73.3149° E longitude. Bikaner is located in the northwestern arid region of Rajasthan, forming part of the Thar Desert's Golden Triangle. It serves as the administrative headquarters of both Bikaner district and Bikaner division. The total area of the city is approximately 270 km², and it lies at an elevation of 242 m above mean sea level. According to the 2011 Census of India, Bikaner had a population of 644,406, with a population density of about 24 persons/km². The city experiences a hot desert climate (BWh) under the Köppen classification, characterized by extremely hot summers with temperatures reaching up to 48°C, and cold winters with temperatures dropping to 0°C. The average annual rainfall is around 290 mm, mostly received during the monsoon season from late June to September, although this varies significantly from year to year.In contrast to traditional urban studies which are confined to municipal boundaries such as that of the Bikaner Municipal Corporation (BMC), the present research adopts the broader Notified Urban Area Limit – 2043 as defined by the Bikaner Development Authority (BDA). The Bikaner Master Plan 2043 draft covers an area of 108,749 hectares and includes 90 villages. This boundary has been selected because Bikaner's urban agglomeration has significantly expanded beyond the core city limits, and a substantial portion of recent land use/land cover transformations are occurring in these outer fringe areas.

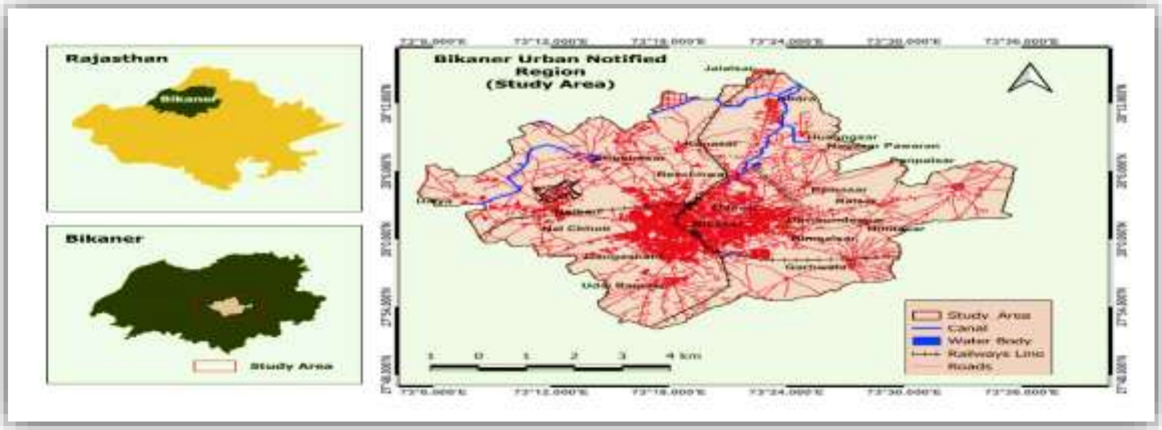

Figure 1. Location Map of Bikaner Urban Notified Area (Study Area).

Data acquisition and image pre processing

In the context of LULC change analysis for **Bikaner city,** Satellite images were selected with due consideration to phenological variations, seasonal consistency, and minimal cloud cover to ensure reliable land cover classification. Landsat TM 5 data for the year 2000 and Landsat 8 OLI data for the years 2014 and 2024 were acquired from the USGS Earth Explorer portal (https://earthexplorer.usgs.gov/), each with a spatial resolution of 30 × 30 meters. These images, corresponding to **path/row 149/41** and **149/40** with less than **1% cloud cover**, were downloaded from the **USGS Earth Explorer portal**.

The acquired satellite data were pre-processed using QGIS 3.40.7 software through a series of steps. First, the images were reprojected from the World Geodetic System 1984 (WGS84) to the Universal Transverse Mercator (UTM) Zone 44N. This was followed by layer stacking and mosaicking of the images. Subsequently, the study area was extracted from the mosaicked images.

S. No.	Landsat Scene Identifier	WRS Path/Row	Sensor Identifier	Date Acquired	Image Quality	Scene Cloud Cover
1	LT05_L2SP_149041_20001005_20200906_02_T1	149/41	L5_TM	2000-10-05	9	0.00
2	LC08_L1TP_149041_20141012_20200910_02_T1	149/41	LANDSAT_8OLI_TIRS	2014-10-12	9	0.00
3	LC08_L1TP_149041_20241023_20241109_02_T1	149/41	LANDSAT_8OLI_TIRS	2024-10-23	9	0.00

Table 1. List of Landsat satellite images with their specification, used during the study

LULC Classification System Adopted for Study Area

Selecting an appropriate land use/land cover (LULC) classification system is critical for ensuring the relevance and usability of spatial data in research. It is particularly important to maintain compatibility with previous classification standards, especially when comparing historical datasets across multiple timeframes or integrating data from adjacent jurisdictions. Harmonizing classification schemes allows for more accurate regional assessments and supports cross-boundary urban planning.

In India, the National Urban Information System (NUIS), initiated in March 2006 as a national Mission Mode Project by the Ministry of Urban Development in collaboration with the Survey of India, introduced a standardized framework for urban land classification. The NUIS classification system is designed for 1:10,000 scale mapping and is structured into a five-level hierarchical system. This system supports detailed mapping of urbanizable areas using high-resolution satellite imagery.

For the present study of Bikaner city, while the NUIS framework serves as an important national standard, the available data—derived from Landsat satellite imagery—lacks the spatial resolution required for implementing the full five-tier classification hierarchy. Therefore, a two-level classification approach has been adopted in this study, which is suitably adapted to medium-resolution data while still aligning broadly with NUIS categories. This modified system ensures both the usability of data for regional-scale LULC analysis and comparability with national-level datasets.

Level 1 Category	**Level 2 Sub-Categories (Grouped for Landsat-based classification)**	**Description**
Built-up Area	Urban settlements- Rural settlements-	Includes all man-made constructions, such as residential colonies, markets,

	Industrial/commercial area- Institutional area	administrative buildings, and urban/rural settlements.
Agricultural Land	Cropland (irrigated and unirrigated)- Fallow land	Cultivated fields used for agriculture including both seasonal and permanent crops.
Forest/Scrub	Forest cover- Scrubland, Forest Dept. Notified Area	Natural or semi-natural vegetation including sparse shrubs, tree cover, and degraded forest patches.
Grassland/Wasteland	Pastures- Recreational green spaces- Open barren land	Includes community parks, grazing fields, barren wasteland, and undeveloped urban open lands.
Water Bodies	Canals- Reservoirs- Lakes/Ponds	Natural and man-made water features including seasonal and perennial sources.

Table 2. NUIS LULC Classification System Adopted for Study

The land use/land cover (LULC) classification for the Bikaner region was carried out using the Maximum Likelihood Classification (MLC) method in QGIS. This supervised classification approach was applied to Landsat satellite imagery to map the spatial distribution of major land cover categories including Built-up, Agricultural Land, Forest, Grazing/Wasteland, and Water Bodies. The reclassification was validated through interpretation using high-resolution Google Earth imagery. To prepare the data for use in transition potential modeling, resampling techniques in QGIS were applied to standardize the spatial resolution between LULC layers and spatial variables.

Accuracy Assessment

Accuracy assessment was carried out on the post-classified LULC maps to evaluate the performance and reliability of classification outputs for the years 2000, 2014 and 2024 in the study area. This step is crucial to determine the number of pixels that were correctly classified, misclassified, or excluded from the classification process (Congalton & Green, 2019).

To evaluate the accuracy of the classified maps, a post-classification accuracy assessment was conducted. A stratified random sampling technique was used to select reference points across all land cover classes, ensuring unbiased representation. Reference data were obtained from a combination of high-resolution satellite imagery, Google Earth, and ground truthing where available.

The results of the accuracy assessment were summarized in a confusion matrix, from which the following area-based accuracy metrics were derived:

Year	2000	2014	2024
Overall accuracy [%]	82.0975	82.7841	75.1871
Kappa hat classification	0.6943	0.7195	0.6168

Table 2. Accuracy of LULC classification of supervised classification

These values indicate a substantial level of agreement and acceptable classification performance, with slightly lower accuracy in the 2024 dataset in Built up class due to some spectral signature inaccuracy, possibly due to increased landscape complexity or classification challenges.

Modelling process of future LULC scenarios and Model validation

The MOLUSCE plugin, integrated within QGIS, has emerged as a robust and versatile tool for predicting future Land Use/Land Cover (LULC) patterns based on historical spatial data. Known for its ability to simulate potential LULC scenarios, MOLUSCE incorporates various modeling techniques such as logistic regression (LR), multi-criteria evaluation (MCE), artificial neural networks (ANN), and weights of evidence (WoE). Its most advanced simulation capability involves combining Cellular Automata with Artificial Neural Networks (CA–ANN), making it a preferred tool in recent LULC change analysis studies.

In this study, a systematic modeling approach was used to project land cover changes for the years 2034 and 2044 through the MOLUSCE plugin. The process began by creating transition probability matrices from

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previous LULC maps to identify the likelihood of transitions between different land cover classes. These inputs, derived from LULC data for the years 2000, 2014, and 2024, were used to train an ANN model, which learned spatial patterns and trends to simulate future land cover changes.

Subsequently, the Cellular Automata model was applied to forecast the spatial distribution of LULC for 2034 and 2044. The model parameters were finalized as follows: 150 iterations, a neighborhood size of 0, momentum factor of 0.05, 10 hidden layers, and a learning rate of 0.001. The simulated outputs were then validated against the actual 2024 LULC map to assess spatial accuracy and consistency. Validation process employed several statistical metrics, including the correctness coefficient, overall kappa coefficient, historical kappa coefficient, and local kappa coefficient. This comprehensive modeling and validation process was carried out entirely using the MOLUSCE plugin in QGIS environment.

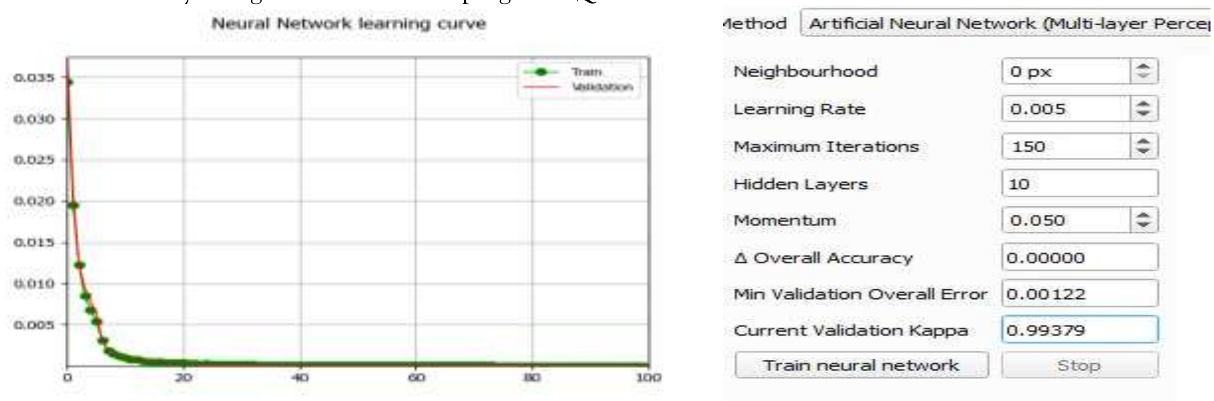

Figure 2. Artificial Neural Network (Multi-Layer perception) and Parameters for the Future Simulation Map of LULC

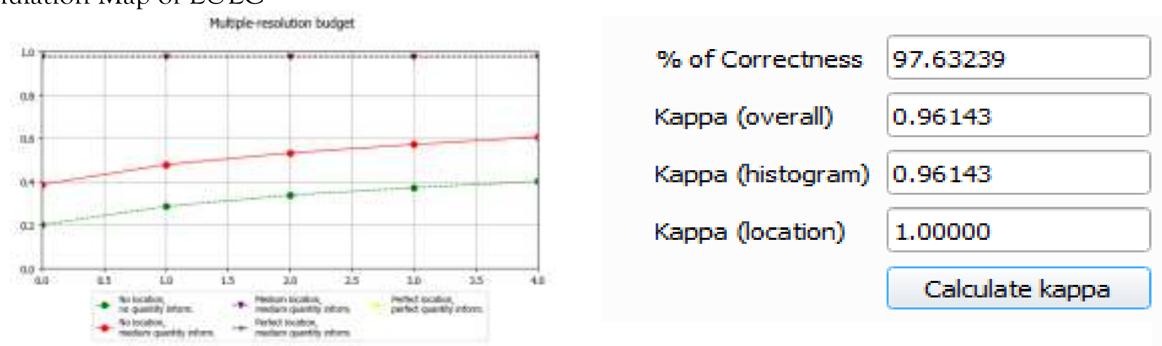

Figure 3. Validation graph between observed 2024 and predicted 2034 & 2044 LULC map of Study Area

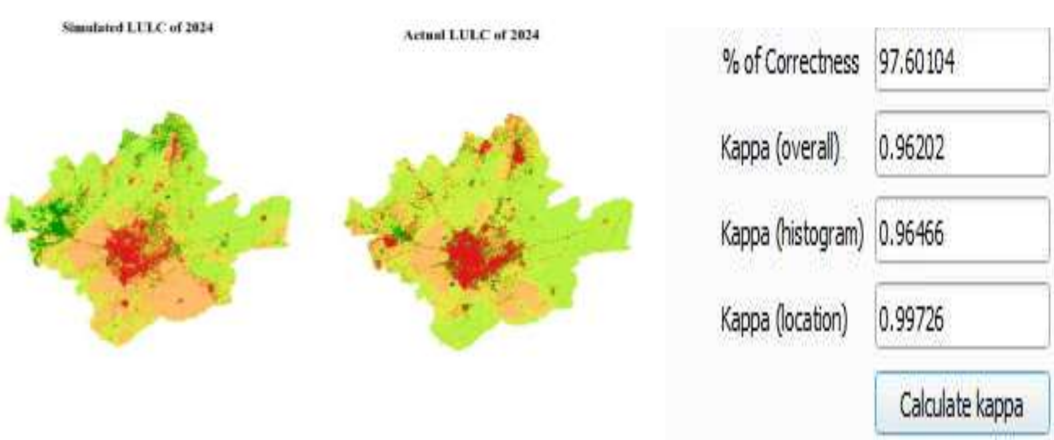

Figure 4. Actual and Projected LULC map of 2024 prepared in Model CA_ANN and respective Kappa values

LULC Classes	Actual 2024		Projected 2024		Accuracy
	Area in sq km	Area in %	Area in sq km	Area in %	
Built Up	127.7	11.88	117.78	10.96	Overall accuracy [%] = 59.6795
Agricultural Land	601.47	55.95	538.48	50.09	
Forest	68.21	6.34	96.22	8.95	Kappa hat classification = 0.3546
Grazing/Wasteland	273.97	25.48	321.97	29.95	
Water bodies	3.68	0.34	0.59	0.05	

Table 3. Actual and Projected LULC area of 2024 prepared in Model CA_ANN and respective Accuracy values

RESULTS AND DISCUSSION

LULC classification and change analysis of land use/cover from 2000 to 2024

The Land Use/Land Cover (LULC) classification of the Bikaner urbanizable area is distributed across five primary categories: Built-up area, Agricultural land, Forest, Grazing/Wasteland, and Water bodies. The total geographical area under analysis remains nearly constant across all three years, approximately 1075 square kilometers. In the **year 2000**, Agricultural land occupied the largest share with 605.52 sq. km, covering 56.33% of the total area. This was followed by Grazing/Wasteland at 285.61 sq. km (26.57%), Forest areas covering 126.54 sq. km (11.77%) (Note: - There is no reserved forest area in Bikaner district only protected and Un -classed forest area is in legal status according to Forest department of Rajasthan statistics 2021 so considering this in study area the area of forest is demarcated from Forest department Statistics) , Built-up areas at 56.07 sq. km (5.22%), and Water bodies accounting for the smallest area at 1.28 sq. km (0.12%).

By **2014**, the land cover distribution shows Agricultural land still as the dominant class with 558.29 sq. km (51.93%), followed by Grazing/Wasteland at 324.93 sq. km (30.23%), Forest at 92.04 sq. km (8.56%), Built-up area at 97.96 sq. km (9.11%), and Water bodies at 1.80 sq. km (0.17%).

In **2024**, Agricultural land continues to cover the largest area, amounting to 601.47 sq. km (55.95%). Grazing/Wasteland occupies 273.97 sq. km (25.48%), Forest area stands at 68.21 sq. km (6.34%), while Built-up areas have reached 127.7 sq. km (11.88%). Water bodies cover 3.68 sq. km (0.34%) of the total area.

	2000		**2014**		**2024**	
LULC Classes	Area in Sq km	% of Area Covered	Area in Sq km	% of Area Covered	Area in Sq km	% of Area Covered
1 - Built UP	56.07	5.22	97.96	9.11	127.7	11.88
2 - Agricultural Land	605.52	56.33	558.29	51.93	601.47	55.95
3 - Forest	126.54	11.77	92.04	8.56	68.21	6.34
4 - Grazing/ Wasteland	285.61	26.57	324.93	30.23	273.97	25.48
5 - Water Bodies	1.28	0.12	1.8	0.17	3.68	0.34
Total	**1075.02**	**100.00**	**1075.02**	**100.00**	**1075.02**	**100.00**

Table 4. LULC Classes Distribution over time from 2000 ,2014 and 2024

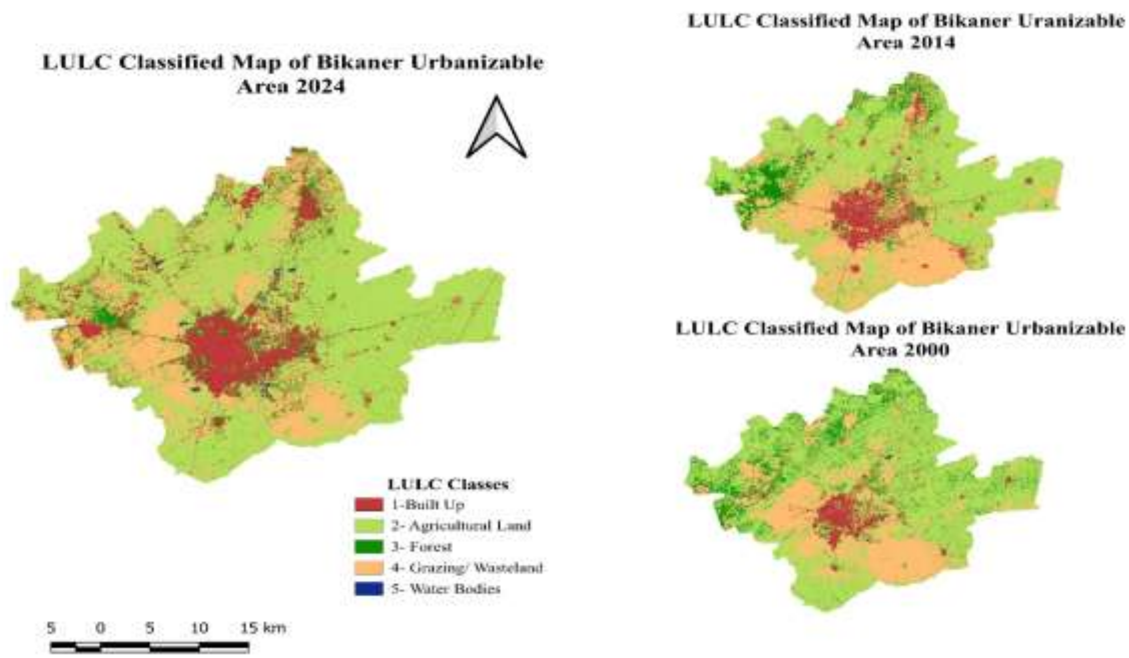

Figure 5. Classified LULC map of Bikaner Urbanizable area showing spatial distribution of various LULC classes in 2000,2014 &2024

Spatio-temporal changes in LULC classes

The analysis of Land Use/Land Cover (LULC) changes in Bikaner's urban area over the past three decades highlights a steady expansion of the built-up area, reflecting the broader trend of increasing urbanization worldwide. In 2000, agricultural land occupied the largest share of the urban landscape, followed by grazing or non-cultivable wasteland, forested areas, built-up land, and water bodies. By 2014, agricultural land had declined by approximately 47.23 square kilometers, while built-up areas, grazing land, and wastelands showed moderate growth. From 2014 to 2024, agricultural land surprisingly showed the highest increase, likely driven by the rising number of tube wells in peripheral areas. Meanwhile, grazing and wasteland areas continued to shrink. The growth rate of built-up land during this period was 2.7%, slightly lower than the 3.9% increase recorded in the previous decade. In forest LULC class is shows decreasing trends in three decades in study area, due to change in urban notified limit overall there is continuous increase rate in forest cover is visible.

Water bodies expanded from 1.28 square kilometers in 2000 to 1.80 square kilometers in 2014, primarily due to the construction of the Shobhasar reservoir. Between 2014 and 2024, further expansion was observed, attributed to new water storage tanks construction for fulfil the demand of increasing urban population, wastewater accumulation in the Karni Industrial Area and sewage collection near Vallabh Garden and various other places in city.

Overall, the LULC dynamics of Bikaner reflect shifting land priorities influenced by urban expansion, changing agricultural practices, and infrastructure development.

LULC Classes	2000-2014		2014-2024	
	Change	Change in %	Change	Change in %
1 - Built UP	41.89 sq. km.	3.90	29.75 sq. km.	2.77
2 - Agricultural Land	-47.23 sq. km.	-4.39	43.18 sq. km.	4.02
3 - Forest	-34.50 sq. km.	-3.21	-23.83 sq. km.	-2.22
4 - Grazing/ Wasteland	39.32 sq. km.	3.66	-50.96 sq. km.	-4.74
5 - Water Bodies	0.52 sq. km.	0.05	1.87 sq. km.	0.17

Table 5. Spatio-Temporal changes in LULC classes in 2000,2014 &2024

The transition matrix shows the probability values of land use/land cover (LULC) changes from 2000 to 2014 and 2014 to 2024. Each row represents the initial (2000 & 2014) LULC class, while each column indicates the final (2014 & 2024) LULC class. The values are probabilities (ranging from 0 to 1) of transition between the two time points. Here is the analysis of inter LULC class change during last two decades in Bikaner urbanizable area. Between 2000 and 2014, Land Use/Land Cover transitions in Bikaner reveal dynamic changes across all classes. About 72% of the built-up area remained unchanged, while significant expansion occurred through conversions from agricultural land (17%), grazing/wasteland (7%), and forest (3%), indicating urban sprawl. Agricultural land showed 69% stability, but experienced notable conversions into grazing/wasteland (19%), forest (6%), and built-up areas (5%), reflecting both land degradation and urban pressure. Forest areas were highly affected, with only 19% retention; the majority was transformed into agricultural land (56%) and grazing areas (20%), pointing to deforestation. Grazing/wasteland maintained 62% of its area, while the rest transitioned into agricultural (21%), forest (10%), and built-up land (7%), indicating mixed land-use pressures. Water bodies were the most vulnerable, with only 46% remaining intact, while the rest was lost to agricultural use (27%), built-up expansion (22%), and wasteland (5%), highlighting the encroachment and depletion of natural water resources.

	2014						
	LULC Classes	Built UP	Agricultural Land	Forest	Grazing/ Wasteland	Water Bodies	Total
	Built UP	0.72	0.17	0.03	0.07	0.00	1
	Agricultural Land	0.05	0.69	0.06	0.19	0.00	1
	Forest	0.05	0.56	0.19	0.20	0.00	1
	Grazing/ Wasteland	0.07	0.21	0.10	0.62	0.00	1
	Water Bodies	0.22	0.27	0.00	0.05	0.46	1
2000	**Total**	1.12	1.90	0.38	1.14	0.47	5

Table 6.From to Change 2000-2014

Between 2014 and 2024, the Land Use/Land Cover (LULC) transition matrix for Bikaner highlights continued land transformation across various categories. About 65% of the built-up area remained stable, while it expanded through conversions from agricultural land (16%), forest (10%), and grazing/wasteland (8%), indicating ongoing urban development. Agricultural land showed 76% retention, yet experienced changes to grazing/wasteland (14%), built-up area (5%), and forest (4%), suggesting moderate pressure from both land degradation and urban influence. Forest areas maintained only 19% of their 2014 extent, with substantial conversion into grazing land (43%) and agriculture (28%), underlining a continuing trend of deforestation. Grazing/wasteland showed 45% stability but underwent significant transformation into agricultural land (41%), as well as minor changes to built-up (8%) and forest (6%) categories, reflecting its flexible nature in land-use shifts. Water bodies displayed 70% persistence; however, 19% was converted into built-up areas, 7% to agriculture, and 4% to forest, pointing to encroachment and functional repurposing of aquatic zones.

	2024						
	LULC Classes	Built UP	Agricultural Land	Forest	Grazing/ Wasteland	Water Bodies	Total
	Built UP	0.65	0.16	0.10	0.08	0.00	1
	Agricultural Land	0.05	0.76	0.04	0.14	0.00	1
2014	**Forest**	0.10	0.28	0.19	0.43	0.00	1

	Grazing/ Wasteland	0.08	0.41	0.06	0.45	0.00	1
	Water Bodies	0.19	0.07	0.04	0.00	0.70	1
	Total	1.08	1.68	0.43	1.10	0.71	5

Table 7. From to Change 2014-2024

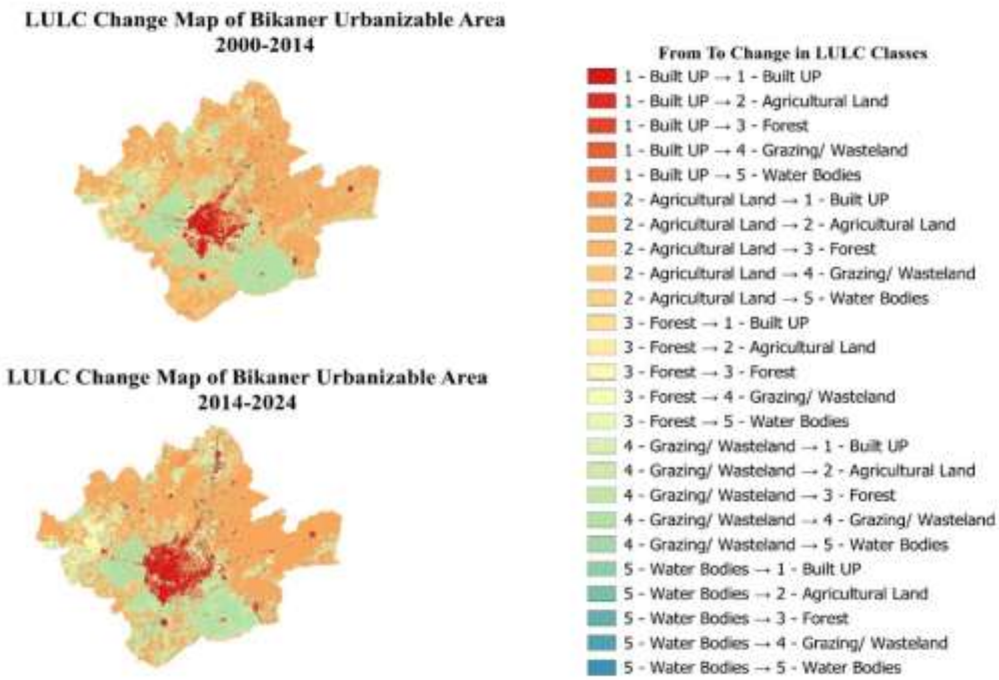

Figure 6. Maps represent change in LULC from 2000-2014 & 2014-2024

LULC Transition Analysis and Potential Modeling for Future

Predicated and projected LULC classification

After achieving satisfactory model validation results, LULC projections were carried out for the years 2034 and 2044. The prediction for 2034 was generated using the temporal LULC datasets of 2014 and 2024, incorporating relevant spatial variables and the corresponding transition probability matrix. The model yielded a Kappa coefficient of 0.99, indicating a perfect level of agreement. Subsequently, the LULC prediction for 2044 was performed using the same temporal inputs (2014 and 2024), supported by updated explanatory variables and transition probability values, resulting in a Kappa value of 0.96

Land Use/Land Cover (LULC) statistics for the years 2024, 2034, and 2044, detailing the spatial distribution (in square kilometers) across five major LULC classes: Built-Up Area, Agricultural Land, Forest, Grazing/Wasteland, and Water Bodies. The total geographical area for all three years remains relatively constant, around 1075 sq. km.

The **Built-Up Area** exhibits a significant increase from 127.7 sq. km in 2024 to 152.4 sq. km in 2034, reflecting a trend of rapid urban expansion. Interestingly, this value remains unchanged in 2044, suggesting a stabilization or saturation point in urban growth. **Agricultural Land** demonstrates a gradual decline over the same period, reducing from 601.47 sq. km in 2024 to 598.06 sq. km in 2034, and further to 576.8 sq. km in 2044. This indicates a steady conversion of agricultural zones, possibly into built-up or other land use categories.

The **Forest** category shows a sharp decline from 68.21 sq. km in 2024 to 46.97 sq. km in 2034, followed by a notable recovery to 68.23 sq. km in 2044. This trend suggests possible degradation due to land pressure in the intermediate period, with subsequent regeneration efforts or afforestation measures contributing to recovery. **Grazing/Wasteland** remains relatively stable, increasing slightly from 273.97 sq. km in 2024 to 276.4 sq. km in 2034, and then decreasing marginally to 274.76 sq. km in 2044, indicating minimal fluctuations in this category.

Lastly, **Water Bodies** decline significantly from 3.68 sq. km in 2024 to 1.26 sq. km in 2034, with a slight increase to 2.9 sq. km by 2044. These variations may reflect changing climatic conditions, groundwater table dynamics, or anthropogenic impacts on surface water resources.

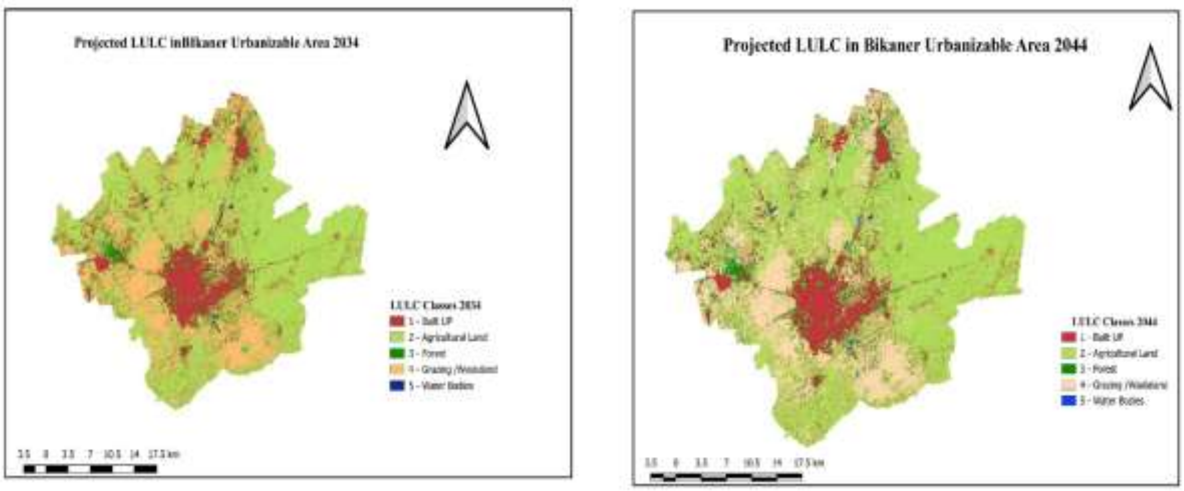

Figure 7.Projected LULC in 2034 and 2044 respectively

Prediction of Change

Land Use/Land Cover (LULC) of 2024 was taken as the base year to compute and forecast spatial and proportionate change in the dominant LULC classes for 2034 and 2044 over the study area of approximately 1075 sq. km. Future change under five dominant land types—Built-Up Area, Agricultural Land, Forest, Grazing/Wasteland, and Water Bodies—were assessed to identify land transformation trend direction and magnitude.

In comparison to the 2024 base, the Built-Up Area is observed to increase from 127.73 sq. km (at 11.88% increase) in 2024 to 152.40 sq. km (at 14.18% increase) in 2034, and no additional increase is projected by 2044, when it remains 152.40 sq. km (at 14.18% increase). This is a reflection of an ongoing urban expansion followed by a stabilization or regulation phase. Agricultural Land, however, reflects a downward trend in comparison to the 2024 base, from 601.47 sq. km (at 55.95% increase) to 598.06 sq. km (at 55.63% increase) in 2034 and further to 576.80 sq. km (at 53.65% increase) in 2044. This persistent downtrend is reportedly a reflection of ongoing land conversion due to increased urban pressure.

The Forest class exhibits a dramatic fluctuation from 2024 levels. It plummets dramatically from 68.23 sq. km (6.35%) in 2024 to 46.97 sq. km (4.37%) in 2034 only to return to 68.23 sq. km (6.35%) in 2044. This decline and recovery are seen to reflect a temporary decade of deforestation or land degradation, perhaps reversed by afforestation effort or increased conservation policy in the following decade. The Grazing/Wasteland classes are comparatively stable throughout the forecast period, fluctuating only slightly from 273.98 sq. km (25.48%) in 2024 to 276.40 sq. km (25.71%) in 2034 and 274.76 sq. km (25.56%) in 2044, indicating that this class is less affected by anthropogenic disturbance than others.

Water Bodies, relative to 2024, have a significant drop in 2034 from 3.68 sq. km (0.34%) to 1.26 sq. km (0.12%), and a moderate rise to 2.90 sq. km (0.27%) in 2044. All of these could be attributed to seasonality, declining water supply, or human intervention in the hydrological system.

LULC Classes	Area in Sq km 2024	Area in Sq km 2034	Change	% of Area Covered	% of Area Covered	Change in %
1-Built Up	127.73	152.40	24.67	11.88	14.18	2.29
2- Agricultural Land	601.47	598.06	-3.41	55.95	55.63	-0.32
3- Forest	68.23	46.97	-21.26	6.35	4.37	-1.98
4- Grazing/ Wasteland	273.98	276.40	2.42	25.48	25.71	0.22
5- Water Bodies	3.68	1.26	-2.42	0.34	0.12	-0.22

Table 8. Area change Matrix From 2024 to 2034.

LULC Classes	Area in Sq km 2034	Area in Sq km 2044	Change	% of Area Covered	% of Area Covered	Change in %
1 - Built UP	152.40	152.40	0.00	14.18	14.18	0.00
2 - Agricultural Land	598.06	576.80	-21.26	55.63	53.65	-1.98
3 - Forest	46.97	68.23	21.26	4.37	6.35	1.98
4 - Grazing /Wasteland	276.40	274.76	-1.64	25.71	25.56	-0.15
5 - Water Bodies	1.26	2.90	1.64	0.12	0.27	0.15

Table 9. Area change Matrix from 2034 to 2044

DISCUSSIONS

This research analyzed the Land Use/Land Cover (LULC) processes of Bikaner district with satellite classified data and model-based projections for base years 2000 2014 and 2024, 2034, and 2044. Five major land categories were recognized: Built-Up Area, Agricultural Land, Forest, Grazing/Wasteland, and Water Bodies. Based on the 2024 LULC dataset as the base, spatial change and future directions were evaluated by using transition probability modeling, which reflected the pressures and changes acting in the landscape of the area.

The trend analysis reveals a consistent and clear increase in urbanized land from 2024 to 2034, from 127.73 sq. km (11.88%) to 152.40 sq. km (14.18%). Surprisingly, this increase stabilizes at 2044, possibly due to urban saturation or regulation of spatial control. Agricultural land, on the other hand, continues to decline throughout the study period, indicating urban encroachment and land-use change. Grazing/Wasteland remains relatively stable, indicating minimal land-use changes in these Water bodies, on the other hand, show unusual fluctuations, with a precipitous decline in 2034 followed by some recovery at 2044, indicating environmental stressors and pressures of sustainable water management. In general, the Land Use Land Cover (LULC) trend of Bikaner district reflects the broader pattern of urbanization and agricultural decline commonly observed across India's arid and semi-arid regions. These findings highlight the urgent need for a balanced regional development policy that simultaneously promotes ecological sustainability, infrastructure growth, and economic development. Key strategies should include integrated land use planning, effective urban management, conservation of natural resources, and the implementation of climate-resilient policies to ensure long-term sustainability of Bikaner's landscape.

Ultimately, this research reveals a dynamic shift in the region's land use patterns—marked by increasing urbanization at the cost of agricultural and natural cover areas—emphasizing the critical need for robust environmental management and forward-looking sustainable planning.

Software Used

QGIS 3.40.7

Websites for Study Material

- **https://earthexplorer.usgs.gov/**
- **https://www.surveyofindia.gov.in/**
- **https://forest. rajasthan.gov.in/**
- **https://lsg.rajasthan.gov.in/**
- **https://earth.google.com/**
- **https://www.wikipedia.org/**

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