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AJMER CITY'S URBAN TRANSITION: A COMPREHENSIVE ANALYSIS OF LAND USE LAND COVER CHANGES (1991-2021) AND THEIR ENVIRONMENTAL IMPLICATIONS

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ABSTRACT

Urbanization, a global phenomenon, presents a complex interplay between human development and environmental sustainability. This research investigates the transformative LULC patterns in Ajmer City from 1991 to 2021, addressing the overarching research problem of understanding the dynamics of urbanization and how it has impacted our environment. The present research addresses how the LULC patterns have evolved over the period from 1991 to 2021 and the ensuing implications for environmental sustainability. The investigation aims to uncover the shifts in key land categories—Agricultural Land, Barren Land, Built-Up Areas, Vegetation, and Water Bodies—seeking to identify the overarching challenges and opportunities posed by the city's urbanization trends. The research adopts a comprehensive methodology entailing the scrutiny of LULC maps spanning the years 1991, 2001, 2011, and 2021. These maps intricately delineate the proportional distribution of diverse land types, unravelling the dynamic composition of Ajmer's terrain over time. Within this methodology, precise quantitative metrics are employed to calculate the percentage area occupied by each LULC category. This meticulous approach facilitates a systematic comparison across the four temporal junctures. Furthermore, the research integrates a change detection analysis, quantifying the nuanced shifts within each category throughout the thirty-year timeframe. The degree of accuracy, a critical facet in this study, gauges the proximity of the results to the true values and stands as a pivotal metric for assessing the reliability of information derived from remotely sensed data. To ascertain accuracy, the visual interpretation of images is undertaken, a process meticulously validated through the collection of ground truth data during on-site fieldwork. The study reveals substantial shifts in Ajmer's Land Use Land Cover (LULC) patterns. Agricultural Land decreased from 44.67% in 1991 to 27.06% in 2021, marking a significant relative decrease of 17.61%. Built-Up Areas expanded from 26.55% in 1991 to 60.05% in 2021, reflecting a notable relative increase of 33.50%. Barren Land and Vegetation witnessed noteworthy decreases, while Water Bodies experienced moderate changes, highlighting a clear trend towards increased urbanization. This research provides crucial insights into Ajmer's urban dynamics, emphasizing the pivotal role of geography in crafting informed strategies for sustainable development, urging policymakers to adopt resilient approaches that balance urban expansion with environmental well-being. The city has witnessed transformative urban development projects, propelled by national initiatives like the development of Smart Cities, , Augmentation Yojana Scheme ,Development of Heritage Cities, and, enhancing its historical, religious, educational, administrative, and tourism significance.

Keywords: *LULC, Urban Expansion, Environmental Sustainability, Smart City Mission.*

Introduction

In the never-ending evolution of our modern world, urbanisation is a driving force, transforming landscapes, cultures, and the very essence of human life. As the unrelenting tide of progress sweeps over the global arena, the disruptive impact of increasing urbanisation becomes an obvious feature of the

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twenty-first century. According to projections, urbanisation, or the steady migration of human populations from rural to urban regions, combined with global population growth, might result in an additional growth of 2.5 billion urban population by 2050. Surprisingly, approximately 90% of this rise is predicted to occur in Africa and Asia, according to a recently released United Nations data set (UN 2018). In India, urbanisation accelerated following independence, owing to the implementation of a mixed economy that encouraged private sector expansion.

The present research addresses how the LULC patterns have evolved over the period from 1991 to 2021 and the ensuing implications for environmental sustainability. The investigation aims to uncover the shifts in key land categories—Agricultural Land, Barren Land, Built-Up Areas, Vegetation, and Water Bodies—seeking to identify the overarching challenges and opportunities posed by the city's urbanization trends.

Present Study

The present research addresses how the LULC patterns have evolved over the period from 1991 to 2021 and the ensuing implications for environmental sustainability. The investigation aims to uncover the shifts in key land categories—Agricultural Land, Barren Land, Built-Up Areas, Vegetation, and Water Bodies—seeking to identify the overarching challenges and opportunities posed by the city's urbanization trends.

Changes in LULC are primarily influenced by population expansion, crucial for studying the intricate relationship between population growth and its environmental consequences. Urban expansion, a facet of urbanization, manifests in various forms, such as increased residential density, redevelopment of existing urban areas, and the conversion of non-urban land into new urban spaces. According to the 2011 census, approximately 40.08% of Ajmer's total population resides in urban areas, comprising 1,035,410 people, with 534,688 men and 500,722 women. The sex ratio in the urban parts of Ajmer district, based on the 2011 census, stands at 936.

Urban and Rural Population in Ajmer

In Ajmer City, you can find 85 villages and 4 towns. According to the Census of India in 2011, Ajmer Tehsil comprised 156,701 households with a total population of 798,454. Among this population, 410,711 were males, and 387,743 were females. Notably, there were 103,603 children aged 0-6, constituting 12.98% of the total population. The Tehsil boasts a literacy rate of 69.95%, with 76.95% of males and 62.53% of females being literate. Ajmer Tehsil covers a total area of 897.06 square kilometers, with a population density of 890 people per square kilometer. Inhabitants are distributed between urban and rural areas, with 27.63% residing in urban regions and 72.37% in rural areas. Additionally, the Tehsil includes 21.51% Scheduled Caste (SC) and 1.42% Scheduled Tribe (ST) populations within its total demographic composition (www.censusindia2011.com).

Population Density of Ajmer Municipal Region

Ajmer has a modest population density, but a congested inner core with over 5,000 people per square km. The Anasagar zone, including Anasagar, Vaishali Nagar, and Chaurasiyawas, has the lowest population density of under 2,000 people per square kilometre. Despite the gross

The city has an average density of 5,750 people per square kilometre.

The Inner City has the most densely populated wards. In places of high concentration, such as Ward Nos. 15, 16, 17, 19,20, 22, 29, 30, 32, the population density can reach 100,000 people per square kilometre, which is one of the causes of environmental degradation and low quality of life in these areas. (City Development Plan for Ajmer and Pushkar)

Table 1: Decadal Population Growth Rate

Decadal Population Growth Rate Ajmer City				
Census Year	Area in Square Kilometres	Population	Variation since the Preceding Census	
			Decadal Variation	Decadal Growth Rate
1901		73,839	---	---
1911		86,222	12,383	16.77
1921		1,13,512	27,290	31.65
1931		1,19,524	6,012	5.30
1941		1,47,258	27,734	23.20
1951		1,96,633	49,375	33.53

1961	55.76	2,31,240	34,607	17.60
1971	47.19	2,64,291	33,051	14.29
1981	262.64	3,75,593	1,11,302	42.11
1991	241.58	4,02,700	27,107	7.22
2001	223.48	4,90,520	87,820	21.81
2011	219.36	5,42,321	51,801	10.56

Source: Census 2011

Material and Methodology Used

We obtained LANDSAT OLI (Operational Land Imager) images for the project area from the USGS website. These images consist of 11 bands, including seven spectral bands (1, 2, 3, 4, 5, 6, and 7) covering the Blue, Green, Red, Near Infrared (NIR), SWIR 1, and SWIR 2 regions, each at a spatial resolution of 30 meters.

Table 2: Data Sources

Data	Purpose	Month & Year	Resolution	Sources
Landsat 5 TM	LULC	March-1991 March-2001 March-2011	30 m	USGS Earth Explorer
Landsat 8 OLI	LULC	March-2021	30m	USGS Earth Explorer

Land Use/Land Cover Classification System

"According to the NRSA (National Remote Sensing Agency) classification approach in 2006, the categorization system for land use and land cover comprises three hierarchical levels. The following table offers a comprehensive breakdown of land use and land cover categories at different hierarchical levels. The term 'classification' typically denotes the act of grouping similar entities, signifying the grouping of subjects or groups with analogous properties or characteristics."

Geospatial technologies have been discovered for use in evaluating land use/land cover changes. It entails multiple steps, including data gathering, pre-processing, classification, ground truth data collection and verification, accuracy assessment, product development, and documentation.

Image classification involves identifying real objects or land covers in remotely captured multispectral imagery with p-band bands. Each pixel is expressed as a vector, representing its spectral properties in these bands. The number of classes, like water bodies or forests, can be predetermined. Classification assigns land cover to pixels based on their spectral reflectance values, employing a classification rule. This process can be supervised or unsupervised, relying on labelled or unlabelled data. It aims to evaluate distinct land cover classes and label each class element numerically. Various algorithms use spectral features to categorize land cover categories in an image, offering insights into supervised or unsupervised techniques.

Supervised Image Classification

In a supervised classification system, known land cover categories, termed training sites, must be predetermined. Spectral values of pixel digital numbers within these categories generate multivariate statistical parameters. This per-pixel classification method, relying on measurable concepts, visualizes spectral distributions using scatter plots. Euclidean space represents features of interest, utilizing a distance measure to determine similarity. Visual interpretation identifies distinct bands in feature space, aiding in decision boundary placement. Supervised classifiers demand a predefined class count and prior knowledge of statistical characteristics, necessitating careful selection of training samples.

Maximum Likelihood Classification

Pre-processing of satellite images involved atmospheric and radiometric correction, band combination, layer stacking, and enhancements to remove distortions and enhance image quality. The focus was on Ajmer city, extracting its region of interest. Land Use and Land Cover (LULC) classification utilized the supervised maximum likelihood classification (MLC) algorithm. MLC computes the chance that each pixel belongs to a certain LULC class by comparing its spectral signature to known classes. The algorithm incorporates discriminant functions, determining likelihood based on spectral features. Classification was conducted using Erdas Imagine and ArcGIS 10.8, categorizing pixels into Bare Ground, built-up areas, agricultural land, water bodies, and rangeland.

Accuracy Assessment

- Accuracy, the proximity of results to real values, gauges information precision in remotely sensed data. Visual interpretation, validated by ground truth data from fieldwork, measures accuracy. Testing ground truth data, acquired through purposive sampling, forms two sets: one for training and one for testing image classification. An error matrix, aligning reference and classified data, quantifies the number of sample units assigned to categories, ensuring accuracy verification in scientific assessments.
- **User's and Producer's Accuracy**

Other error matrix-derived measurements include 'error of omission' (or producer accuracy) and 'error of commission' (or user accuracy). An omission error occurs when a pixel is added to a certain class that is not part of that class. A commission error is a pixel that should be part of a specific class but is not included.

The accuracy of this classification indicated that the method for selecting the training region, interpretation approaches, and the number of reference data used were critical to achieving superior classification results.

- **Overall Accuracy**

The accuracy is weighted by the number of samples (pixels) in each class, which is calculated as the sum of all diagonal samples divided by the total number of samples. However, as a single measure of accuracy, total accuracy (or percentage classified correctly) provides no information about how well the classifier performs in each of the other classifications. In particular, a classifier may perform well for a class that accounts for a high fraction of the test data, skewing the overall accuracy despite low class accuracies for other classes. As a result, the error matrix is insufficient for predicting the classification accuracy.

- **The Kappa Statistic**

The Kappa statistic was developed to include measures of class accuracy into a broader measure of classifier accuracy (Congalton 1999). It provides a better estimate of a classifier's accuracy than overall accuracy since it takes into account interclass agreement. Kappa analysis produces a Khat statistic, which is a measure of agreement or accuracy. The Khat statistic is computed as:

$$K_{\text{hat}} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+} * x_{+i})}$$

The kappa coefficient is computed based on the matrix's row count (k), where xii represents the number of observations in both row i and column i. Additionally, xi+ and x+i represent the marginal totals for row i and column i, respectively. N denotes the total number of observations. The kappa coefficient ranges from 0 to 1, with a negative value indicating poor categorization (Lillesand et al., 2000). The land use/land cover classification results were used to generate the Kappa statistic, as presented in the table. Landis and Koch (1987) established criteria for Kappa, defining weak agreement when K is less than 0.75.

Results & Discussion

LULC Map of Ajmer City 1991

In 1991, Ajmer City exhibited distinct LULC patterns, with various categories contributing to its overall composition. The largest portion of the city's landscape was dedicated to Agricultural Land, covering an expansive 30.3444 sq. km, accounting for 44.67% of the total area. Barren Land, comprising 12.142 sq. km, made up 17.87% of the landscape (Fig.). The Built-Up areas, representing urban development and infrastructure, occupied 18.0361 sq. km, equivalent to 26.55% of the city's area. Natural Vegetation covered 6.04836 sq. km, constituting 8.90% of the total land cover. Additionally, Water Bodies, encompassing 1.36488 sq. km, accounted for 2.01% of Ajmer city's composition. These diverse LULC categories collectively shaped the city's landscape, totalling 67.94 sq. km in 1991.

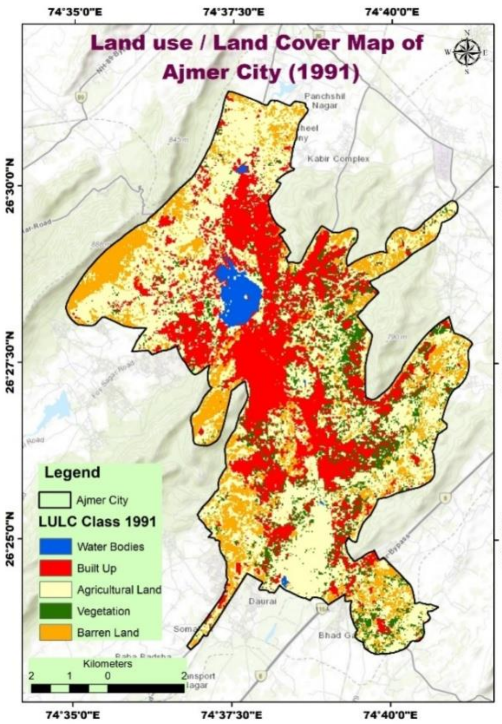


Figure 1: Land Use Land Cover of Ajmer City (1991)

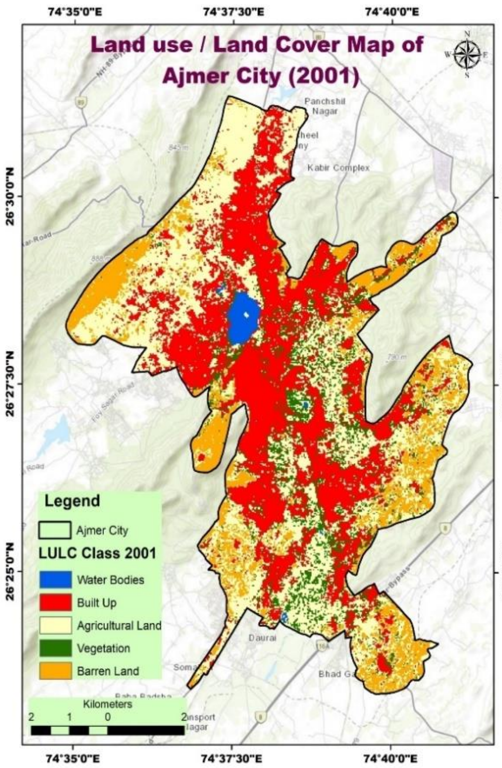
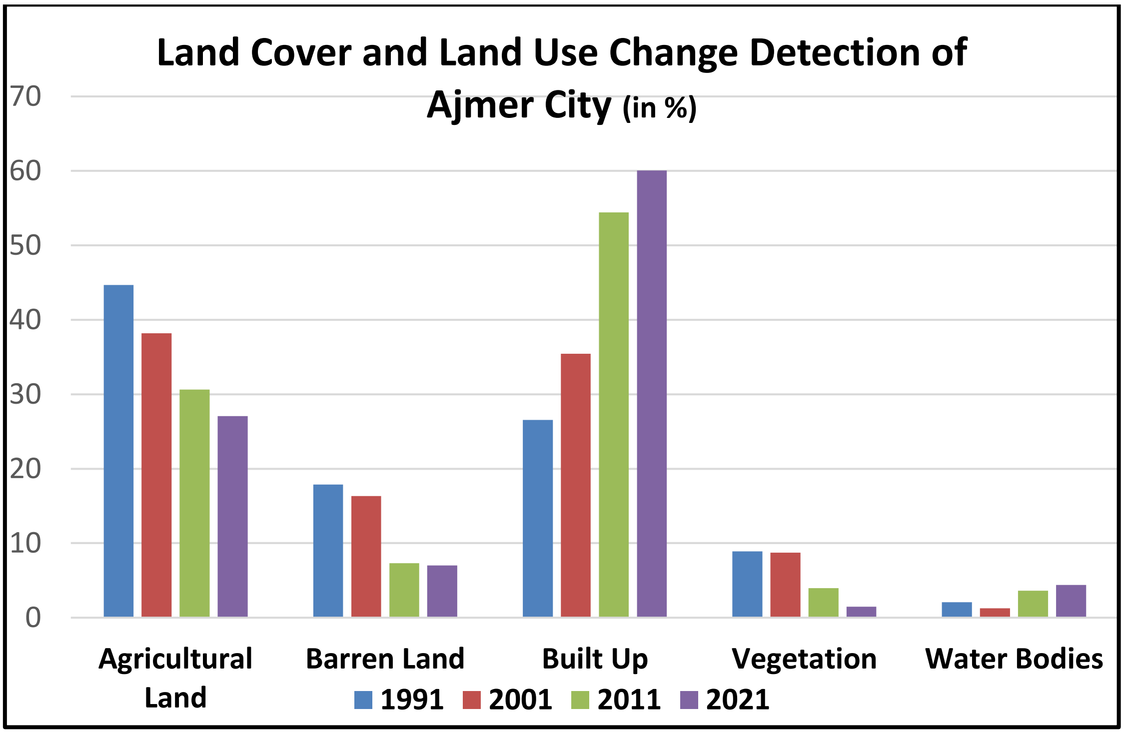


Figure 2: Land Use Land Cover of Ajmer City (1991)

Table 6: Results

Sr No	LULC Class	Area Sq. km 1991	% 1991	Area 2001	% 2001	Area 2011	% 2011	Area 2021	% 2021
1	Agricultural Land	30.34	44.66	25.95	38.19	20.80	30.62	18.37	27.05
2	Barren Land	12.14	17.87	11.10	16.34	4.98	7.33	4.77	7.02
3	Built Up	18.03	26.54	24.09	35.46	36.98	54.43	40.79	60.05
4	Vegetation	6.04	8.90	5.93	8.73	2.70	3.97	1.00	1.47
5	Water Bodies	1.36	2.09	0.86	1.26	2.46	3.63	2.98	4.38
	Total Area Sq. Km	67.93							



LULC Map of Ajmer City 2001

In 2001, The largest portion of the city's landscape was allocated to Agricultural Land, encompassing 25.9523 sq. km, constituting 38.19% of the total area. Barren Land, comprising 11.1031 sq. km, made up 16.34% of the landscape. The Built-Up areas, representative of urban development and infrastructure, covered 24.0954 sq. km, equivalent to 35.46% of the city's area. Natural Vegetation occupied 5.93459 sq. km, constituting 8.73% of the total land cover. Additionally, Water Bodies, encompassing 0.862838 sq. km, accounted for 1.27% of Ajmer city's composition. These diverse LULC categories collectively shaped the city's landscape, totaling 67.9482 sq. km in 2001.

LULC Map of Ajmer City 2011

In 2011, Agricultural Land, encompassing 20.8061 sq. km, constituted 30.62% of the total area. Barren Land, covering 4.98266 sq. km, accounted for 7.33% of the landscape. The Built-Up areas dominated with 36.9865 sq. km, equivalent to 54.44% of the city's expanse. Natural Vegetation occupied a modest 2.70018 sq. km, constituting 3.97% of the total land cover. Additionally, Water Bodies, spanning 2.4663 sq. km, contributed 3.63% to Ajmer city's overall composition. These diverse LULC categories collectively shaped the city's landscape, amounting to 67.94174 sq. km in 2011.

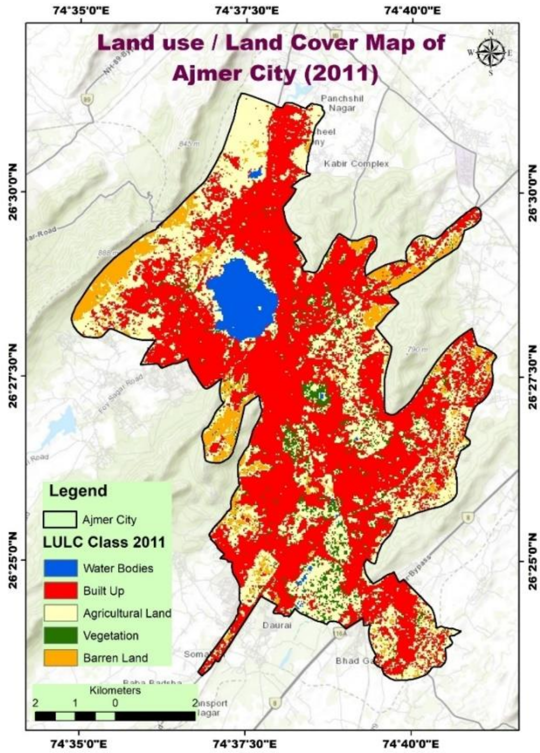


Figure 3 Land Use Land Cover of Ajmer City (2011)

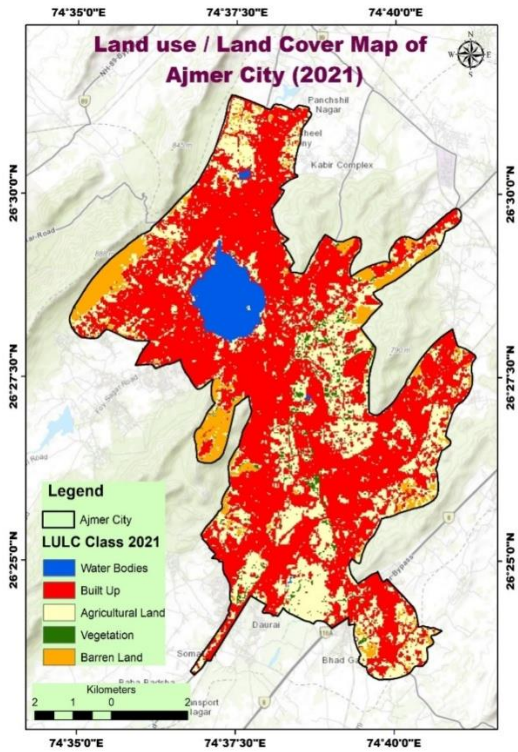


Figure 4: Land Use Land Cover of Ajmer City (2021)

LULC Map of Ajmer City 2021

Agricultural Land: Agricultural land covered approximately 18.38 Sq. Km, which is approximately 27.06% of the city's total area.

Barren Land: Barren land accounted for about 4.77 Sq. Km, making up approximately 7.03% of the total area.

Built-Up: Built-up areas, including urban and infrastructure development, comprised the largest portion, covering approximately 40.79 Sq. Km, which is approximately 60.05% of Ajmer City's total area.

Vegetation: Vegetation, including parks and green spaces, occupied a relatively small portion, at approximately 1.00 Sq. Km, representing about 1.48% of the total area.

Water Bodies: Water bodies, such as lakes and ponds, cover approximately 2.98 Sq. Km, which is approximately 4.39% of the city's total area. The total area of Ajmer City in 2021 was approximately 67.93 Sq. Km.

LULC Change Detection

Over the span of thirty years, from 1991 to 2021, Ajmer City underwent significant transformations in its LULC patterns. Notably:

Agricultural Land

In 1991, it covered 30.3444 sq. km, constituting 44.67% of the total area.

By 2021, it reduced to 18.3786 sq. km, accounting for 27.06%.

This represents a substantial decrease of 11.9658 sq. km and a relative decrease of 17.61%.

Barren Land

In 1991, it occupied 12.142 sq. km, making up 17.87% of the landscape.

By 2021, it diminished to 4.77214 sq. km, representing 7.03%.

This signifies a significant decrease of 7.36986 sq. km and a relative decrease of 10.84%.

Built-Up Areas

In 1991, they covered 18.0361 sq. km, constituting 26.55% of the city's area.

By 2021, they expanded to 40.7949 sq. km, dominating 60.05% of the landscape.

This demonstrates a substantial increase of 22.7588 sq. km and a relative increase of 33.50%.

Vegetation

In 1991, it occupied 6.04836 sq. km, representing 8.90% of the total area.

By 2021, it decreased to 1.00352 sq. km, constituting 1.48%.

This indicates a significant decrease of 5.04484 sq. km and a relative decrease of 7.42%.

Water Bodies

In 1991, they encompassed 1.36488 sq. km, accounting for 2.01% of the landscape.

By 2021, they slightly increased to 2.98115 sq. km, contributing 4.39%.

This shows a moderate increase of 1.61627 sq. km and a relative increase of 2.38%.

These changes highlight the urbanization and development trends in Ajmer city over the decades, with notable shifts from agricultural and vegetated areas to increased built-up urban areas, along with slight changes in barren land and water bodies.

Conclusion

The study of Ajmer City's demography, urban development, and land use patterns over the years provides valuable insights into the dynamic interplay between population growth, urbanization, and environmental changes. The urbanization process in Ajmer is influenced by various factors, including industrialization, commercialization, social benefits, employment opportunities, modernization, and urban-rural transformations. The city has witnessed significant urban development initiatives, influenced by national policies and schemes such as the Smart City Mission, Heritage City Development, and Augmentation Yojana Scheme, contributing to its historical, religious, educational, administrative, and tourism significance. The causes of urbanization, ranging from economic shifts to improved living standards and employment opportunities, have driven a substantial increase in the urban population. The detailed analysis of land use and land cover changes, as depicted in LULC maps from 1991 to 2021, underscores the transformative impact of urbanization on Ajmer's landscape. The substantial decrease in agricultural land and vegetation, coupled with a significant increase in built-up areas, reflects the city's shift towards urbanization and infrastructural development. These trends indicate the importance of comprehensive urban planning to address the challenges posed by rapid urbanization, ensuring sustainable development, environmental conservation, and improved quality of life for the residents. The data presented here can serve as a foundation for policymakers, urban planners, and researchers to make informed decisions and implement strategies that balance urban growth with environmental preservation in Ajmer City.

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