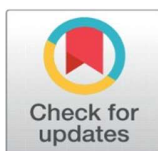
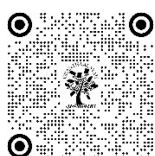


SPATIO-TEMPORAL ANALYSIS OF LAND USE LAND COVER CHANGES IN LEH TOWN, LADAKH: A GEOSPATIAL APPROACH

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ABSTRACT

Any geographical region of the planet earth must be well understood in terms of land use and land cover change. LULC is thought to be the topmost layer of the earth that is constantly being altered by both manmade and natural forces. The sensors on the remote sensing satellites sufficiently record and measure these changes. In one manner or another, the land cover is constantly changing. In order to address different viewpoints on resource management, ecosystem protection, sustainable development, and land use planning, among other issues, assessment of such changes is essential. The study area that was looked into for this study is 1770 hectares. Multi-temporal classified raster layers (1990, 2000, 2010, 2022) of Leh town were generated for estimation of LULC changes using Remote Sensing and GIS. The LULC structure of Leh town experienced significant changes in Built-up from the year 1990 to 2022 with a net increasing rate of 232.41%. Agriculture area in the study area decreased considerably from the year 1990-2022 with a net decreasing rate of -33.65%. However, vegetation category in the study area experienced a continuous increasing trend. It was covering an area of 66.77ha (3.77% of the total area) in the year 1990 which increased to 124ha (7% of the total area) in 2022 with a net positive increasing rate of 85.71%. But again, LULC categories Meadows and Barren depicted a decreasing trend with a net decreasing rate of -68.47% and -10.98% within the study period. According to the study, urban expansion is very swift, which might have a negative effect on the study area's delicate ecosystem. Because of the rapid LULC transition in the study region and the unplanned urban built-up expansion, several ecosystems will be under constant stress, which will further negatively affect Leh town's quality of life.

Keywords: Sustainable Ecosystem, Himalayas, Ladakh, Cold Desert, Remote Sensing and GIS.

INTRODUCTION

Land use/land cover change is one of the main drivers of global environmental transformations, significantly impacting people's lives. Understanding patterns of land use, changes therein, and the interplay between human activities and natural phenomena is crucial for effective land management and sustainable development (Middelkoop & Asselman 2003; Ganaie et al. 2021; Zhai et al. 2021; Zhang et al. 2023). Land, as a fundamental production factor, requires proper utilization to prevent degradation. Therefore, comprehending natural characteristics, productivity, quality, and limitations of various land uses is essential for sustainable resource management. While the broader issue of land use change has garnered attention, its implications in high mountain regions, particularly in the Himalayas often remain overlooked.

Changes in land use in the Himalayas poses significant environmental and socio-economic challenges, impacting biodiversity, water resources, and local communities dependent on these fragile ecosystems (Jamal & Ahmad 2020;

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Ahmad et al. 2024; Jamal et al. 2019; Wang et al. 2020). The region's diverse landscapes, from alpine meadows to high-altitude glaciers, are vulnerable to deforestation, agricultural expansion, and infrastructure development, exacerbated by climate change effects like glacier retreat and altered precipitation patterns (Shafiq et al. 2019; Saleem et al. 2024). These changes not only degrade ecosystem services crucial for global climate regulation and water provision but also increase the risk of natural disasters such as landslides. Sustainable land management strategies integrating conservation efforts, sustainable agriculture practices, and responsible tourism are essential (Tewabe & Fentahun 2020; Khursheed et al. 2022; Ahmad et al. 2024). International cooperation among Himalayan countries is vital to mitigate land use change impacts, preserve biodiversity, and ensure the resilience of these critical ecosystems for future generations.

With rapid economic growth, coupled with population expansion, urbanization and evolving socio-economic dynamics, land use/land cover in regions like Leh and Kargil towns has undergone significant transformations over recent decades. These trends have accelerated notably since the region was opened to outsiders in the 1970s and are expected to intensify further with Ladakh's status as a Union Territory. As a result, large swathes of agricultural land have been diverted to non-agricultural purposes due to substantial modern development, including burgeoning tourism and related infrastructure such as hotels, guest houses, and increased vehicular traffic. These changes have far-reaching implications, such as encroachment on productive land, loss of biodiversity, and degradation of land and water resources in the region. Moreover, the rapid economic growth, coupled with population expansion, urbanization, and the advent of tourism industry, exerts immense pressure on the already limited land resources of the region. This poses significant challenges not only to sustainable development but also to food security and livelihoods in the region. Therefore, continual monitoring of land use/land cover patterns over time is crucial for ensuring sustainable development, managing natural resources effectively, and monitoring environmental changes.

The transformation of land use and land cover has gained considerable attention among scholars in recent years. The focus has shifted from understanding the environmental impacts of such changes—such as earth system process deterioration—to exploring opportunities for ecological restoration through effective land management. Scholars have expressed concerns that land transformation contributes to climate change, reduces biodiversity through deforestation and desertification, and alters natural vegetation patterns. Therefore, conducting such analyses is instrumental in developing realistic models for understanding and managing land use change. Therefore, the present study aims to investigate how land degradation, climate change, and water scarcity impact agricultural activities and health security in the Ladakh region. Additionally, it seeks to elucidate the key drivers of environmental change in Ladakh and their repercussions on ecosystems, society, and the economy.

1. STUDY AREA

Leh Town, is located between 34°10'N to 34°35'N Latitude and 77°45'E to 78°15'E Longitude, situated in the northern part of the Indian union territory of Ladakh (Figure 1). At an altitude ranging from approximately 3,500 to 3,800 meters above mean sea level, Leh Town is nestled amidst the towering peaks of the Karakoram and Himalayan mountain ranges. Covering a relatively smaller area compared to the entire district, Leh Town spans approximately 24.01 square kilometres.

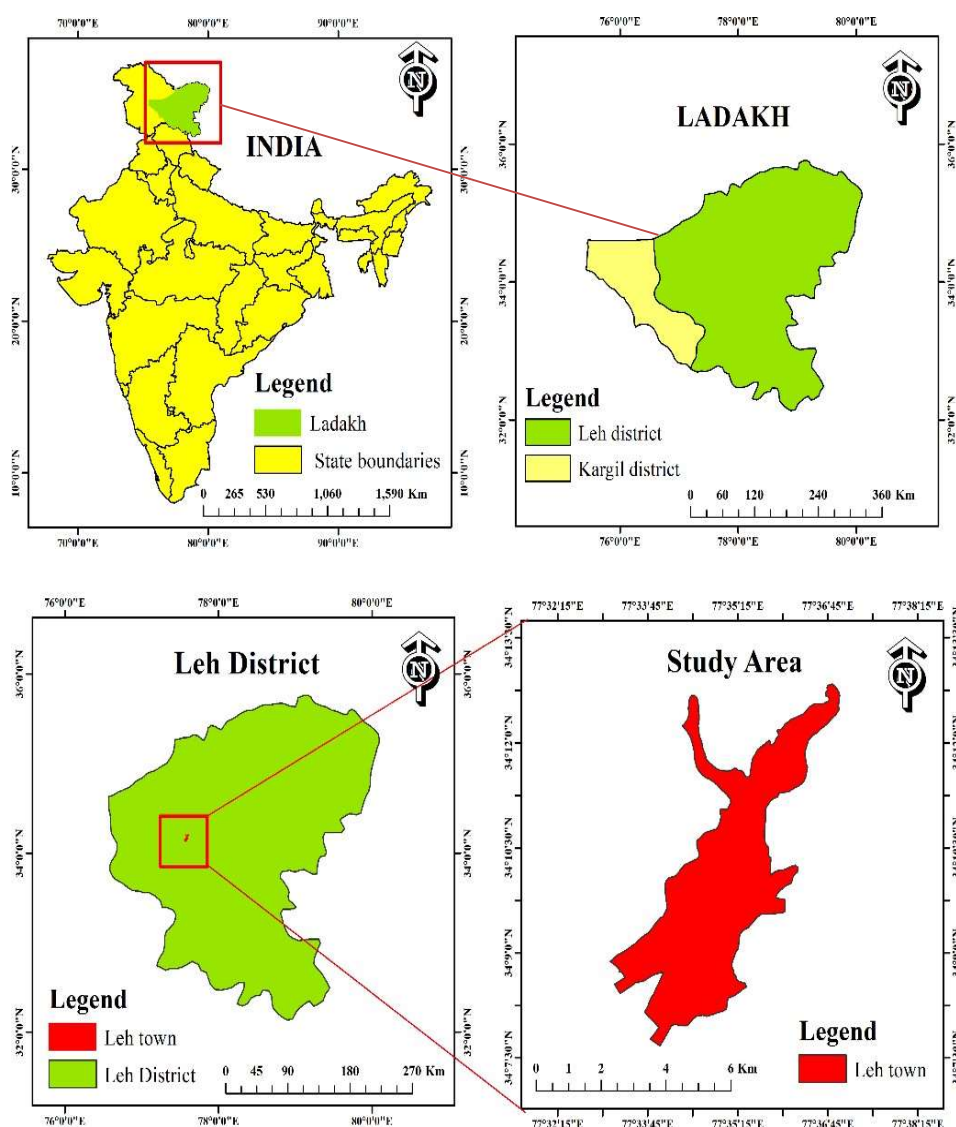


Figure 1: Location of the Study Area: Leh Town

Despite its smaller geographical size, Leh Town holds significant cultural and economic importance as a key hub in the Ladakh region. It serves as a major centre for commerce, administration, and tourism, attracting visitors from around the world due to its rich cultural heritage and stunning landscapes. The climate of Leh Town is characterized by its high altitude and arid conditions, falling within the cold desert climate zone. Annual precipitation is extremely low, averaging around 10 cm per year, with most of it occurring during the summer months in sporadic bursts of rainfall. The town experiences harsh winters with temperatures dropping well below freezing point, often resulting in heavy snowfall which further isolates the region. The socio-economic landscape of Leh Town is primarily shaped by its geographical constraints and climatic conditions. Agriculture, though challenging, is practiced in the fertile river valleys surrounding the town, where barley, wheat, and vegetables such as peas and potatoes are cultivated. Livestock rearing also plays a significant role in the economy, providing essential resources such as wool, milk, and meat. Due to its remote location and the rugged terrain of the surrounding mountains, Leh Town remains isolated for a significant part of the year. During the winter months, when road access is limited due to snowfall, air connectivity becomes crucial for both transportation and supplies. In recent years, Leh Town has witnessed rapid development in infrastructure and tourism facilities, aimed at accommodating the growing number of visitors while preserving its unique cultural identity.

2. DATABASE & METHODOLOGY

2.1 Database

The following spatial and non-spatial datasets will be used for the present study.

- Mostly spatial data from USGS will be used in this study. Satellite imagery was downloaded from USGS (United States Geological Survey). Multi temporal data of LANDSAT 4-5 TM, LANDSAT-7 ETM+ and LANDSAT-8,9 OLI were processed, classified and analyzed to detect analyze the change in land use and landcover in the study area.
- Secondary data such as population, climate, tourist arrivals etc. were collected from:
 - i. Census of India (2001, 2011)
 - ii. District Census Handbook Leh & Kargil (Ladakh): VILLAGE AND TOWN WISE PRIMARY CENSUS ABSTRACT (PCA)
 - iii. District Statistical Handbook.
 - iv. Tourism directories.

Table 1: Spatial data used in the present work

	Data type	Source	Data specifications	Time Period
LANDSAT 4-5 TM	Spatial	USGS	(30 m resolution) Path/Row 146/36	21 May 1990
LANDSAT 4-5 TM	Spatial	USGS	(30 m resolution) Path/Row 147/36	14 April 2000
LANDSAT-7 ETM+	Spatial	USGS	(30 m resolution) Path/Row 147/36	23 July 2010
LANDSAT-8,9 OLI	Spatial	USGS	(PAN 15 m, 30 m resolution) Path/Row 147/36	30 July 2020
Google Earth Pro				

The Landsat satellite series provides a valuable source of remote sensing data for land use and land cover change analysis. In this study, Landsat imagery will be obtained for the desired study area from USGS Earth Explorer (<https://earthexplorer.usgs.gov/>). The selection of the Landsat scenes will be based on their availability, cloud cover, and appropriate temporal resolution. The Landsat scenes cover the desired time period to capture the changes in land use and land cover accurately. The data sets from the LANDSAT 4-5, LANDSAT-7 ETM+ and LANDSAT-8,9 OLI with spatial resolution of 30 m and 15 m Panchromatic band were downloaded according to the required time period.

2.2 Methodology

The LANDSAT series provides a series of multispectral satellite imagery which can be used for different types of analyses and modelling. The data were downloaded and extracted in the form of zip files. These files were then layerstacked with ERDAS Imagine using 1 to 7 bands of the LANDSAT data and band-8 (Panchromatic) was added to the LANDSAT-8 OLI data to enhance the spatial resolution to 15m. The area of interest (AOI) was extracted using clip/subset with the shapefile of the study area which was manually digitized and extracted using a city map of Leh town provided by the Municipal Committee Leh. False colour images have the effect of rendering the visualization of land use land cover (LULC) patterns, particularly when the red, green, and blue channels are assigned different spectral bands thus making specific land cover classes or changes visible, further these images were converted in the form of FCC (False Colour Composition) for image visualization.

Survey of India Toposheets are invaluable sources for georeferencing, aiding in aligning spatial data with known coordinate systems. These elaborated topographic charts, which are skilfully done by the Survey of India, provide extensive information about different parts of the country including contour lines, water bodies and road networks and settlement areas. The Survey of India Toposheets have standardized grid lines, scale bar and legends making them very useful during georeferencing. It provides complete maps of control points as well ground features in order to make sure

that spatially correct data is being aligned. For the present study SOI Toposheet of 1:50000 scale was used for georeferencing and accurate spatially aligned maps.

Image classification is a crucial step in land use and land cover change analysis. This step involves assigning land cover categories to each pixel in the image based on their spectral characteristics. For image classification process, nonparametric methods have shown high accuracy rates. Thus, in the present study, rule-based maximum likelihood classification (MLC) algorithm was adopted using ERDAS IMAGINE software. Due to some similar spectral reflectance in some of the classes (build-up, barren, agricultural classes etc.) lead to potential misclassifications which has led to the low accuracy values, so to overcome these errors Google Earth Pro was used to manually digitize these classes. As Google Earth Pro provides a valuable tool for conducting such analyses due to its vast database of satellite imagery and its user-friendly interface.

The digitized polygons of different categories were then saved in (.kml) format. These files were then converted to shapefiles (.shp) format in Arc Map 10.8.1 using conversion tool. Further these files were selected using ERDAS Imagine software and recoded to the prior classified map, this enhanced the clarity and accuracy of the LULC classification maps. The classified maps were then processed in ArcMap 10.8.1 and title, legend, north arrow and grids will be added for the final output map.

Finally, multi-temporal classified raster layers (1990, 2000, 2010, 2020) LULC maps of Leh town were generated and for estimation of LULC change their corresponding statistics were compared. The rate of change and the land transformation from 1990 to 2022 for different LULC classes of the study area were obtained using the following equation.

$$R = \left[\frac{1}{t_1 - t_2} \right] \times \left[\ln \left(\frac{C_1}{C_2} \right) \right] \quad (i)$$

Where,

R = Rate of change

C_1 and C_2 = area under different land use categories

t_1 = Time period 1

t_2 = Time period 2

2.3 Ground Truthing

The technique of gathering information on-site to confirm or validate data from indirect methods, such as remote sensing, is known as "ground truthing." It entails obtaining information regarding the precise land cover types that are present in particular areas when it comes to LULC classification. For LULC classification, ground truthing is crucial since it guarantees the accuracy of the findings. Analysing the differences from real field data by satellite pictures, mistakes can be observed and fixed resulting in a higher quality of classification. For the present study field visits were carried out using GPS devices. The GPS coordinates were recorded at random locations in the study area and were analysed with the prepared LULC maps to enhance the accuracy of the maps.

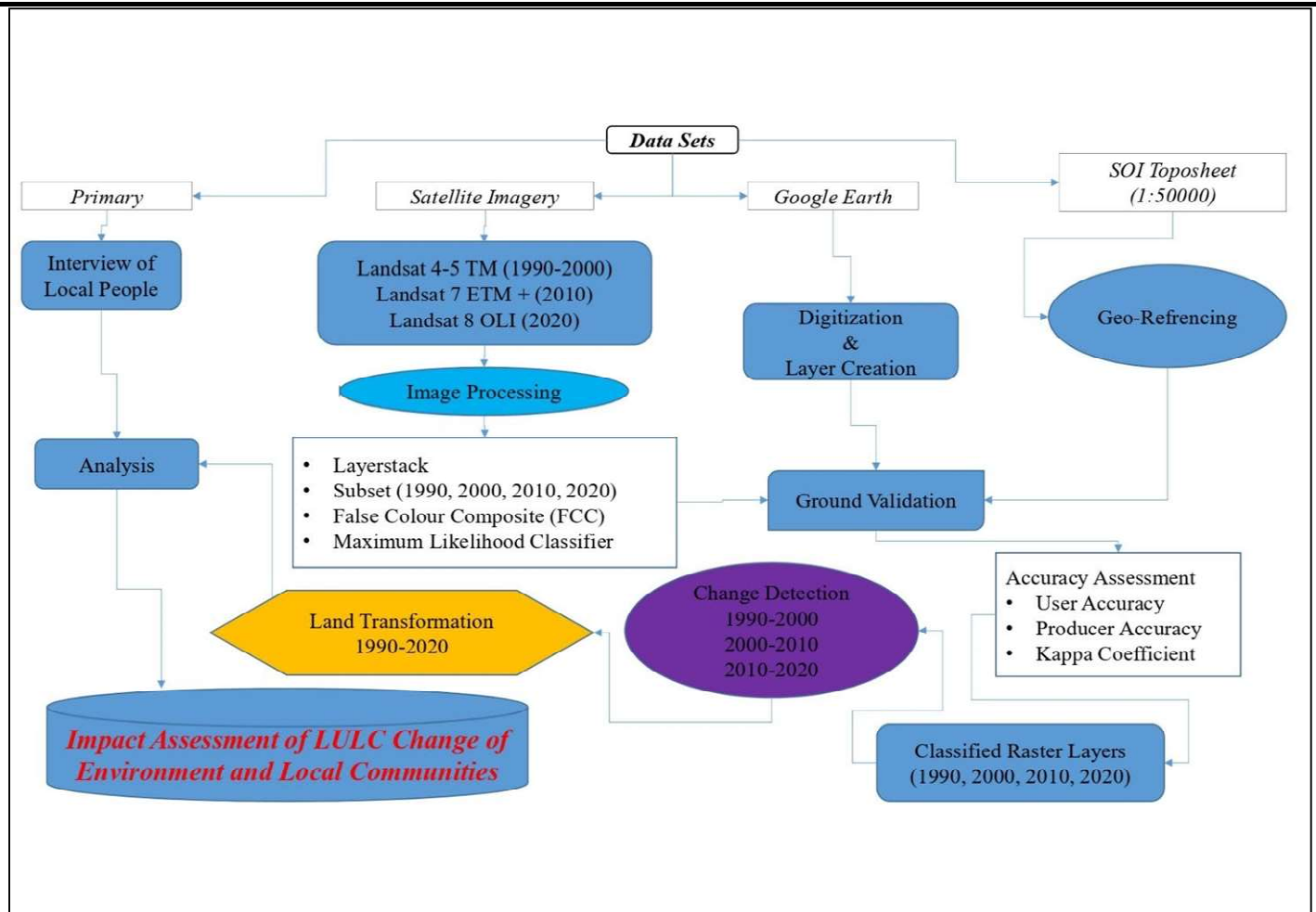


Figure 2: Methodology flowchart for the present study.

2.4 Accuracy Assessment

Accuracy assessment using Kappa coefficient is an important tool in the analysis of Land Cover/Land Use (LCC classification) algorithms that evaluates their performance and reliability. The Kappa coefficient, called Cohen's Kappa evaluates how well the observed classification matches the reference data. It considers both the expected chance accuracy and the actual accuracy, from the classification process. By assessing agreement beyond chance against agreement the Kappa coefficient offers a reliable measure of classification precision. This evaluation is especially valuable, in scenarios involving imbalanced class distributions or where relying solely on accuracy might be deceptive. The kappa coefficient ranges from -1 to 1, where 1 indicates perfect agreement, 0 indicates no agreement beyond chance, and negative values indicate less agreement than expected by chance (Congalton 2021).

For this study stratified random sampling technique was used to collect 50 samples from each category from the classified maps of 1990, 2000, 2010 & 2022. The Stratified random sampling technique is a systematic random sampling approach that ensures an unbiased representation of the study area. Thus, integrating the stratified random sampling technique to the assessment makes it more credible since it randomly samples the whole study area and provides a reliable estimate of the points that the classification has gotten right. The collected sample points serve as a reference location for collecting ground truth data. Subsequently, the Kappa coefficient is calculated between the LULC classification map derived from remote sensing data details and the ground truth details from the sample. The Overall Accuracy was calculated using the following formula (Behera et al. 2023):

$$\sum_{i=1}^r X_{ii} \quad (ii)$$

Where,
 xii=diagonal elements in the error matrix;
 x=total number of samples in the error matrix.

The Kappa Coefficient

$$\hat{K} = \frac{n \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_i + x_{+i})}{n^2 - \sum_{i=1}^r (x_i + x_{+i})} \quad (iii)$$

Where,

r = number of rows in the matrix;
 xii = number of observations in row i and column i.
 xi+ and x+i=marginal totals of row i and column i respectively and
 n=total number of observations (samples/pixels).

3. RESULTS AND DISCUSSION

Land use Land cover analysis, through the classification of the Landsat images of Leh town for the year 1990, 2000, 2010, 2022 has been done using Remote sensing and GIS. The total area of about 1770 hectares was mapped in which five categories were identified, namely built-up, agriculture, vegetation, meadows, and barren.

3.1 Land Use Land Cover Statistics of Leh Town (1990, 2000, 2010, 2022)

3.1.1. LULC Pattern of Leh Town: 1990

The 1990 LULC structure of the Leh town depicts the landscape was predominantly covered by barren area, out of the total area the barren category covered 72.88%, with a total area of 1293.6 ha. On this basis, it can be pointed out that due to the aridity of the region most of the area was not suitable for agriculture, residential purposes and any other recreational activities, the natural vegetation is also low because Ladakh classifies as a cold desert climatic region. This tends to suggest that a large proportion of the land was not being used for agriculture, for built-up or vegetation and was either left idle and could have been under some form of natural condition or was un-developed. The agriculture category was the second most dominant category on the study area. It accounts for 14% of the total area with total area of 248.71 ha. (Figure 3).

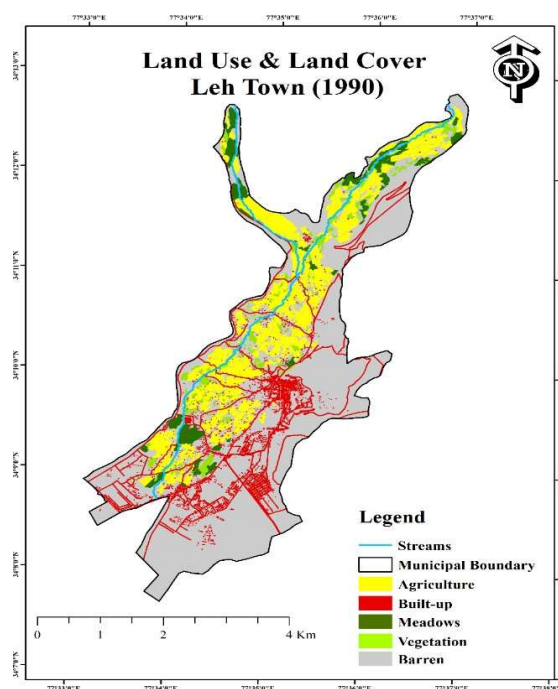


Figure 3: LULC Map of Leh Town: 1990

This proves that a significant amount of area was devoted to farming and such purposes, which indicated that the region was involved in farming. During 1990s the population was also low and the tourist influx was also low, due to which the economy of the study area was mainly dependent on agriculture so people were more into primary activities rather than secondary & tertiary. The buildup area mostly comprised of the residential areas; commercial government buildings were in little number. This category constituted 5.23% of the total town area covering 92.73 ha. This portrays a moderate level of urban development and infrastructure in the said period. Meadows accounted for 68.19 hectares and covered 3.85% of the total area. This category constituted mainly pastures grounds, grasses and shrubs. These were present mainly in areas like Gonpa, Gangles and Skara. They offered opportunities for nutrient-rich grasslands for feeding cattles for the local people. Vegetation is basically low in the region because of its harsh climatic conditions. It covered 3.77% of the total area with 66.77 ha in area. Most of this vegetation was natural, as there was no scope of plantation in the barren areas because of lack of resources to lift water in these areas. This category mainly includes trees like willow, poplar, fruit trees like apricots and apples etc.

3.1.2. LULC Pattern of Leh Town: 2000

In 2000, the LULC structure of Leh town experienced some noticeable changes compared to 1990. The barren land was still the dominating category covering 1,290.8 ha in area and 72.92% of the total area (Figure 4). Although there was a slight decrease from 1,293.6 hectares (72.88%) in 1990, it revealed that the most of land remained unused but some portion of these category was covered by the build-up and the vegetation classes due to various reasons such as increase in tourism, increase in population and more awareness towards plantation among the people.

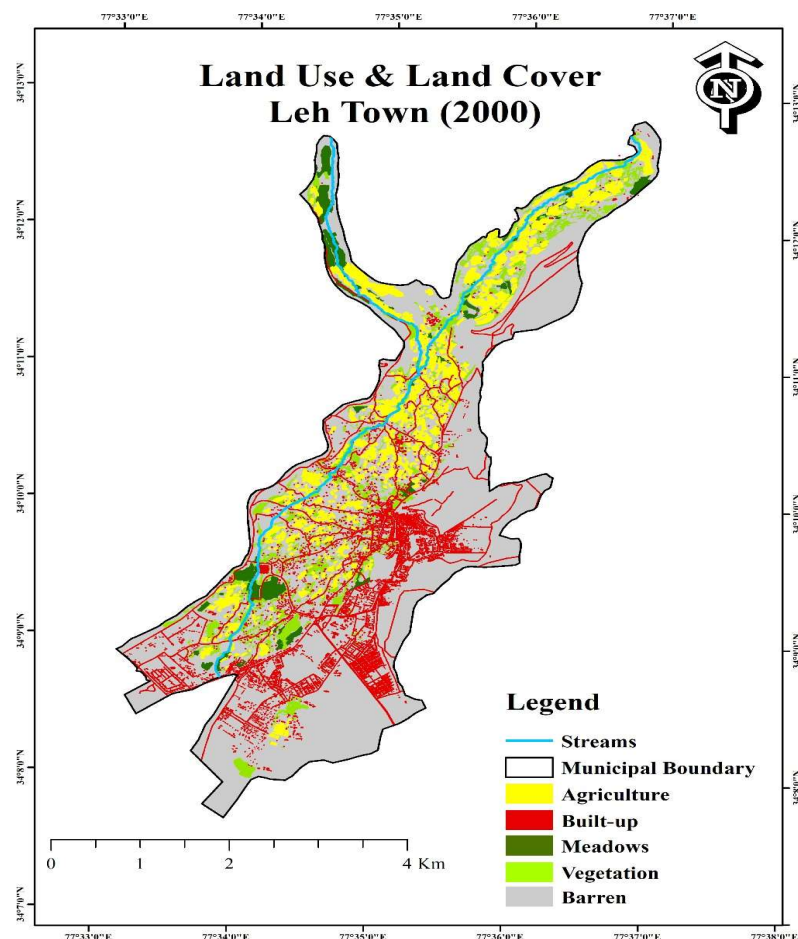


Figure 4: LULC Map of Leh Town: 2000

Agricultural category saw a significant decrease than the previous year, shrinking to 185.19 ha, accounting 10.45% of the total area, down from 248.71 ha (14.05% of the total area) in 1990. This decline can be due to the shifting of the

people from agriculture towards government jobs and other tertiary activities. The tourist influx has also contributed in beginning construction of hotels and guest houses in the areas like Changspa, Sankar, Chubi etc. which earlier used to be agricultural areas. On the other hand, built-up category has shown an increase in Leh town. In the year 2000, it covered 138.0 ha in area and 7.79% of the of the land from 92.73 hectares (5.23%) in 1990. This increase reflects the town's growth, with more people moving in and more residential areas, businesses setting up, construction of many government offices and residence were recorded during this period. These can likely be driven by the town's strategic importance and being getting known as a tourist destination. The vegetation category also showed a notable increase, it grew to 105 ha in area constituting 5.93% of the total area from 66.77 ha (3.77%) in 1990. This rise in this category could be due to the plantation activities and also because of the availability of water for irrigational purposes from construction of canals and borewells. Because of construction of some residential areas in the earlier barren lands people also started to plantation in those areas contributing to the increase in this category. However, meadows in the study area decreased to 51 ha, constituting 2.88% of the total area which was earlier 68.19 ha (3.85%) in 1990. This reduction can be due to land being converted for other uses, overgrazing and depleting water in the streams along which these meadows were located. The year 2000 brought about a number of notable changes to Leh town, including a modest drop in the area used for agriculture, an increase in the build-up area and a decrease in the area covered by meadows. Through these changes, we can imagine a community trying to regulate its expansion in accordance with environmental conditions and establishing a current outlook in terms of modern requirements.

3.1.3. LULC Pattern of Leh Town: 2010

The 2010 Land Use Land Cover (LULC) scenario of Leh town showed a further evolution in land utilization and development from previous years. Barren land, still being the largest category, witnessed a decreasing trend to 1,221.2 ha in area (68.99% of the total area) from 1,290.8 ha (72.92%) in 2000 (Figure 5). This decline indicates a gradual shift towards more productive land use and increasing tourist influx. Agricultural land continued to decrease and accounted for only 172.2 ha (9.72% of the total area), from 185.19 hectares (10.45%) in 2000, this highlights the continued shifting towards other economic activities other than farming only. Due to a greater number of tourists visiting the area more of the agricultural lands were being converted to tourist-oriented infrastructures like hotels and guesthouses. Meanwhile, the built-up area saw substantial growth, expanding to 231.3 ha (13.05% of the total area), a significant increase from 138.0 hectares (7.79%) in 2000. The expansion in this category reflects the increase in the residential, government infrastructures, tourism infrastructures etc. due to the rise in population of the area and also the increasing number of tourists visits due to the rising popularity of the study area as a tourist destination. The geo-strategic importance of the region can also be considered as one of the major reasons behind this change. Vegetation areas also increased, covering 114.8 ha (6.48% of the total area) from 105 hectares (5.93%) in 2000.

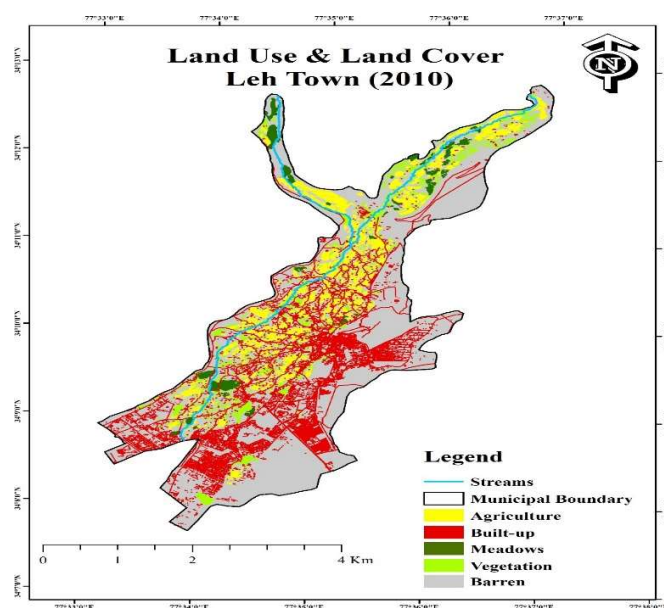


Figure 5: LULC Map of Leh Town: 2010

The growth in this category can be the increasing awareness among the people regarding the importance of vegetation, many plantation drives was observed in the areas like Lamdon, Skara etc. and also the availability of water for irrigation in the earlier barren areas can be a huge reason behind the increase in this category. However, meadows experienced a significant decrease to 30.45 ha (1.72% of the total area), from 51 hectares (2.88%) in 2000, indicating a further reduction in natural grasslands. The Himalayan meadows are rapidly depleting due to climate change and overgrazing, with studies showing significant reductions in vegetation cover over the past few decades (Körner, 2003; Pandey et al., 2018). Consequently, the 2010 LULC scenario of Leh Town indicates an emergence of a less barren dominated landscape with a significant reduction in agricultural areas and increase vegetative cover but degradation in the meadows. These trends highlights Leh's ongoing shift from an agrarian to a more urban and economically mixed settlement, highlighting the importance sustainable land management that can combine development with ecological conservation.

3.1.4. LULC Pattern of Leh Town: 2022

The Land Use Land Cover (LULC) structure of Leh town reflected a significant transformation in land use patterns over the past three decades. In the year 2022 the Barren category, while still occupying the largest portion of the area, declined further to 1,151.5 ha, covering 65.02% of the total area, from 1,221.2 hectares (68.99%) in 2010 (Figure 6).

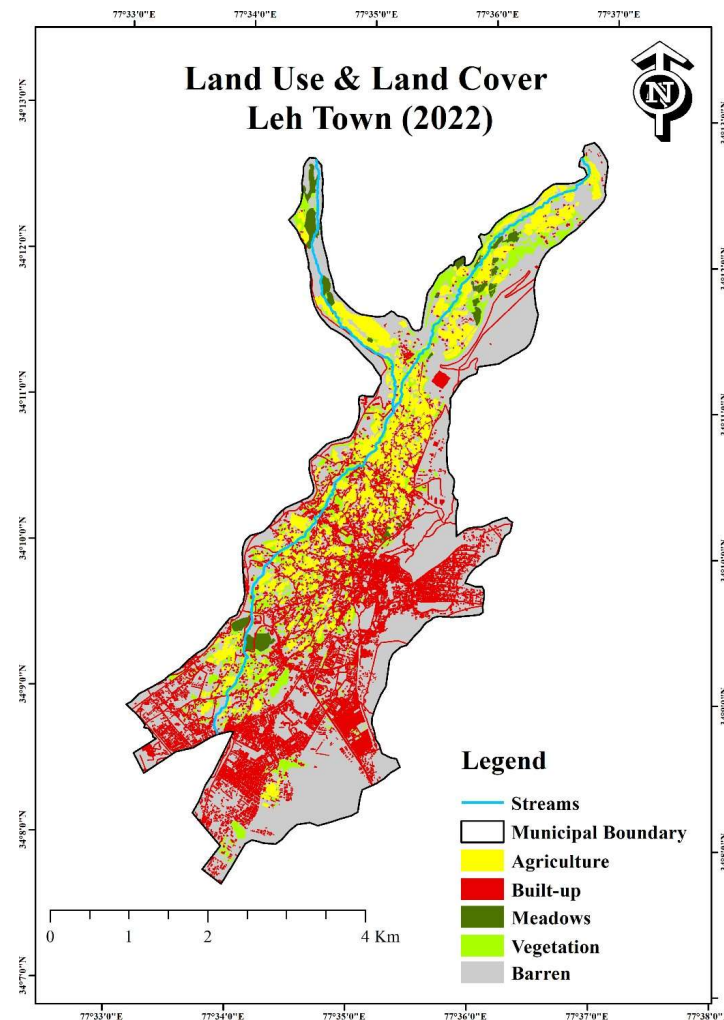


Figure 6: LULC Map of Leh Town: 2022

This continuous reduction in the category shows the regions continuous urbanization trend. This also signifies the utilization of previously barren areas like Skampari, Skalzangling, Ibex Colony etc. for residential and recreational purposes. The tourism oriented infrastructural shifts also remain a major reason for the decrease in this category and

increase in the Build-up category. The built-up area experienced the most significant increase among all the categories expanding to 308 ha constituting a total of 17.40% of the total area, a considerable rise from 92.73 ha (5.23% of the total area in 1990). This remarkable growth highlights Leh Town's rapid urbanization, influenced by the population growth, immigration of the people from far-flung areas, infrastructure development, and economic activities, particularly tourism. Leh's position as the capital of the district and geo-strategic importance of the area are also some major reasons behind the increase in this category. Agricultural land continued to show a decreasing trend, it decreased to 165 ha (9.32% of the total area) from 172.2 hectares (9.72%) in 2010 which reflects the further transformation of the agricultural lands towards residential and tourism oriented infrastructural areas, due to the increase tourist visits and also because of the shift the society towards nuclear family from joint family system. On the other hand, vegetation category continued to increase, covering 124 ha (7% of the total area), up from 114.8 hectares (6.48%) in 2010, reflecting more plantation activities in the area. However, meadows experienced a further decline to 21.5 ha (1.21% of the total area) from 30.45 hectares (1.72%) in 2010, indicating the impact of climate change and conversion of these natural grasslands into other land uses. One of the reasons behind decrease in this category can also be considered to the over extraction of the groundwater from the boring wells which are dug near these ecologically sensitive areas. In summary, based on the 2022 LULC of Leh town, it is inferred that this region is on the path of urbanization with the increase in built-up lands and with a consistent decrease in the agricultural lands, farther reduction in the barren land. Vegetation category increases identify a positive environmental project while the decrease in meadows depict a major problem of the organization in protecting natural grasslands.

3.1.5. Accuracy Assessment

When it comes to Land Use and Land Cover (LULC) classification, errors of accuracy can occur from many sources which can diminish the potential of the results. Due to spectral resemblance, a number of land covers for instance urban and bare soils can be haphazardly classified. There is also an issue of temporal variability, such as seasonal variation, which makes the matter even more complex. As with the identification of objects, the spatial resolution is critical here and low one can miss out on certain features. Inter-class noise, or the presence of mixed pixels, pixels that contain more than one type of land cover, also contribute to the errors. It is equally important to note that train data must of high quality to avoid incidences such as generalization of biased data. Mistakes made when processing the obtained information can also lead to errors. These problems can be solved by using high resolution image, better training data, better algorithms, and field checking for better LULC classification. To overcome these errors accuracy assessment through Kappa Coefficient assessment is among the widely used accuracy assessment processes for measuring the reliability of classification systems. The Kappa coefficient, called Cohen's Kappa evaluates how well the observed classification matches the reference data. It considers both the expected chance accuracy and the actual accuracy, from the classification process. By assessing agreement beyond chance against agreement the Kappa coefficient offers a reliable measure of classification precision. This evaluation is especially valuable, in scenarios involving imbalanced class distributions or where relying solely on accuracy might be deceptive. The kappa coefficient ranges from -1 to 1, where 1 indicates perfect agreement, 0 indicates no agreement beyond chance, and negative values indicate less agreement than expected by chance (Congalton & Green, 1999).

For this study stratified random sampling technique was used to collect 50 samples from each category from the classified maps of 1990, 2000, 2010 & 2022 (Table 2a). The Stratified random sampling technique is a systematic random sampling approach that ensures an unbiased representation of the study area. Thus, integrating the stratified random sampling technique to the assessment makes it more credible since it randomly samples the whole study area and provides a reliable estimate of the points that the classification has gotten right. The collected sample points serve as a reference location for collecting ground truth data. Subsequently, the Kappa coefficient is calculated between the LULC classification map derived from remote sensing data details and the ground truth details from the sample.

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Built-Up	63	62	47	75.60%	75.81%
Vegetation	32	29	19	59.38%	65.52%
Barren	71	71	57	80.28%	80.28%
Agriculture	24	19	10	41.67%	52.63%
Meadows	60	69	50	83.33%	72.46%
Totals	250	250	183		

Table 2a: Accuracy totals for the year 1990

Overall Classification Accuracy = 73.20%

Kappa (K) Statistics

Overall, Kappa Statistics = 0.6513

Table 2b: Conditional Kappa for each Category

Class Name	Kappa
Build-up	0.6766
Vegetation	0.6046
Barren	0.7246
Agriculture	0.4760
Meadows	0.6377

Table 3a: Accuracy totals for the year 2000

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Built-Up	63	62	50	79.37%	80.65%
Vegetation	31	29	21	67.74%	72.41%
Barren	71	71	60	84.51%	84.51%
Agriculture	23	19	11	47.83%	57.89%
Meadows	62	69	53	85.48%	76.81%
Totals	250	250	195		

Overall Classification Accuracy = 78.00%

Kappa (K) Statistics

Overall, Kappa Statistics = 0.7132

Table 3b: Conditional Kappa for each Category

Class Name	Kappa
Build-up	0.7412
Vegetation	0.6851
Barren	0.7836
Agriculture	0.5363
Meadows	0.6916

Table 4a: Accuracy totals for the year 2010

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Built-Up	64	62	53	82.81%	85.48%
Vegetation	29	29	22	75.86%	75.86%
Barren	72	71	62	86.11%	87.32%
Agriculture	19	19	11	57.89%	57.89%
Meadows	66	69	58	87.88%	84.06%
Totals	250	250	206		

Overall Classification Accuracy = 82.40%

Kappa (K) Statistics

Overall, Kappa Statistics = 0.7692

Table 4b: Conditional Kappa for each Category

Class Name	Kappa
Build-up	0.8049
Vegetation	0.7269
Barren	0.8220
Agriculture	0.5443
Meadows	0.7834

Table 5a: Accuracy totals for the year 2022

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Built-Up	64	62	56	87.50%	90.32%
Vegetation	32	29	22	68.75%	75.86%
Barren	71	71	64	90.14%	90.14%
Agriculture	17	19	11	64.71%	57.89%
Meadows	66	69	61	92.42%	88.41%
Totals	250	250	214		

Overall Classification Accuracy = 85.60%

Kappa (K) Statistics

Overall, Kappa Statistics = 0.8113

Table 5b: Conditional Kappa for each Category

Class Name	Kappa
Build-up	0.8699
Vegetation	0.7232
Barren	0.8623
Agriculture	0.5482
Meadows	0.8425

The accuracy assessment done for the classified maps (1990, 2000, 2010 & 2022) of Leh town reveals that the overall accuracy and the kappa coefficient increases with the increasing year, which means that accuracy of the 2022 classification is more than the 1990 classified map. The overall accuracy for the years (1990, 2000, 2010 & 2022) was computed (73.20%, 78.00%, 82.40% & 85.60%) and the Kappa Coefficient showed (0.65, 0.71, 0.76 & 0.81) respectively.

Through these accuracy values we can conclude that the accuracy values of the classified maps are acceptable, except for the year 1990. The overall accuracy of the 1990 classified map was 73.20% and the Kappa coefficient was 0.65 which is lower than the acceptable value. The reason behind this can be considered as the lack in high resolution data availability. For the LULC classification of the year 1990 only LANDSAT-5TM data was available which has a relatively low resolution due to which image visualization & interpretation was difficult and distinguishing between closely situated or classes with similar spectral reflectance became difficult, leading to potential misclassifications which has led to the low accuracy values. Other than this, the accuracy values of all other years (2000, 2010 & 2022) showed a good and acceptable accuracy values. The accuracy value of the year 2022 was greatest among all other years, from this it can be pointed out that with the greater resolution datasets more accuracy can be expected. Also, the accuracy values of the years 2000, 2010 & 2022 were good because of the manual digitization done using Google Earth Pro to overcome the errors due to the similarity in the spectral reflectance of some classes (built-up, barren, vegetation etc). Overall, all the classified maps of Leh town have shown a good accuracy except for the year 1990 for which the reasons have been quoted above.

3.2. Land Use Land Cover Change Detection of Leh Town (1990-2022)

3.2.1. LULC Change in Leh Town (1990-2000)

The LULC structure of Leh town experienced significant changes from the year 1990 to 2000.

Buildup: This category showed an increasing trend, it accounted for 92.73ha in the year 1990 which increased to 138ha in the year 2000 with percentage change of 48.81%. The reasons behind this increase can be the growth of population of the Leh District which rose from 0.895 lakhs to 1.71 lakhs during this decade (1991-2001) (*Census of India*). The beginning of increased tourist visits can also be considered as another reason behind this change. As no. of tourist visiting the study area also increased from 6738 in 1990 to 18055 in 2000 (*Department of Tourism, Leh*) which has led to the construction of hotels and guest house in the study area. Another reason could be the migration of people remote areas to the city center in search of jobs and to avail more sound facilities like schooling, health etc., Some development can also be is the construction of military areas, because of the geo-strategic importance of the area contributing to the building area increase.

Table 6: LULC Statistics of Leh Town (1990-2022)

LULC Classes	Area in hectare (1990)	Area in % (1990)	Area in hectare (2000)	Area in % (2000)	Change (%) (1990-2000)	Area in hectare (2010)	Area in % (2010)	Change (%) (2000-2010)	Area in hectare (2022)	Area in % (2022)	Change (%) (2010-2022)	Change (%) (1990-2022)
Built-up	92.73	5.23	138.0	7.79	48.81	231.3	13.05	67.60	308	17.40	33.16	232.14
Agriculture	248.71	14.05	185.19	10.45	-25.53	172.2	9.72	-7.01	165	9.32	-4.18	-33.65
Vegetation	66.77	3.77	105	5.93	57.25	114.8	6.48	9.33	124	7	8.01	85.71
Meadows	68.19	3.85	51	2.88	-25.2	30.45	1.72	-40.2	21.5	1.21	-29.39	-68.47
Barren	1293.6	72.88	1290.8	72.92	-0.21	1221.2	68.99	-5.39	1151.5	65.02	-5.74	-10.98

Agriculture: The agriculture category showed a decreasing trend. Its total area was 24.71ha in the year 1990 which decreased to 185.19ha in 2000 with a net declining rate of -25.53% revealing the loss in the agricultural lands due to people shifting towards other economic activities. Many studies reveal that with advent of urbanization the agricultural trend gradually decreases. Most of the area with agricultural land like Changspa, Sankar, Chubi etc., were becoming residential areas for tourist due to its nearness to the market area, some of the hotels and guesthouses were getting constructed on the agricultural lands.

Vegetation: This category has showed net positive growth rate of 57.25%, the total area it covered in 1990 was 66.77ha which increased to 105ha by the year 2000. The increase in this category can be due to the increase in the water availability in the area which were earlier in the barren category, construction of canals and tubewells was led to the increase in vegetation in these areas, one other reason might be the increase in plantation in these areas.

Meadows: This category has shown a decreasing trend from the year 1990 to 2000. The meadows the study area has decreased from 68.19ha in 1990 to 51ha in 2000 with a declining rate of -25.2% within this decade. The reasons behind this decreasing trend can be considered the changing climate and overgrazing. This category consists of grazing grounds, small grasses and shrubs which the local people used as grazing lands for their cattle. During 1990s the people of Leh town were mostly indulged in primary activities and people used to have a decent number of cattle which used to graze in these grazing lands, so one other reason behind the decrease in this category can be overgrazing.

Barren: This category remained the largest category in the study area. Its area share in 1990 was about 1293.6ha which experienced a slight decrease to 1290.8ha till the year 2000 with a net declining rate of -0.21%. Due to Ladakh's harsh climatic conditions the soil here is not that much fertile and most of the land area in this region remains unused or they are mostly uncultivable. The reasons behind this slight decrease in this category can be due to the increase in the buildup area. Areas like Skampari, Skalzangling, and H.Colony etc., has started experiencing more construction work in the

current study period (1990-2000). The migration of people from the remote areas to the city center has led to the construction of residential areas in these barren areas leading to this decreasing trend in this category.

3.2.2. LULC change in Leh Town (2000-2010)

The Land Use Land Cover (LULC) scenario of Leh town showed some further evolution in land utilization and development from the year 2000 to 2010.

Built-up area saw substantial growth, it increased from 138.0 hectares (7.79%) in 2000 to 231.3 ha (13.05% of the total area) in 2010, with an increasing rate of 67.6%. The expansion in this category reflects the increase in the residential, government infrastructures, tourism infrastructures etc. due to the rise in population of the study area and also the increasing number of tourists visits due to the rising popularity of the study area as a tourist destination. The population of Leh Town increased from 21175 in 2001 to 30880 in 2011 (*Municipal Committee Leh Town*). The geo-strategic

importance of the region can also be considered as one of the major reasons behind this change, many army camps were also constructed in the area after the Indo-China & Indo-Pak wars.

Agricultural land continued to decrease from 185.19 hectares covering 10.45% of the total area in the year 2000 which only accounted for 172.2 ha covering 9.72% of the total area in the year 2010, with a declining rate of -7.01%, this highlights the continued shifting towards other economic activities other than farming only. The no. of tourist visiting the study increased from 8068 in 2002 to 77800 in 2010 (*District Statistical Handbook 2016-17*). Due to a greater number of tourists visiting the area more of the agricultural lands were being converted to tourist-oriented infrastructures like hotels and guesthouses.

Vegetation also experienced an increasing trend, covering 105 hectares (5.93% of the total area) in 2000 to 114.8 ha (6.48% covering of the total area) in 2010 with a net increasing rate of 9.33%. The growth in this category can be the increasing awareness among the people regarding the importance of vegetation, many plantation drives was observed in the areas like Lamdon, Skara etc. and also the availability of water for irrigation in the earlier barren areas can be a huge reason behind the increase in this category.

Meadows experienced a significant decrease from 51 hectares (covering 2.88% of the total area) in 2000 to 30.45 ha (1.72% covering of the total area), with a net decrease of -40.25% indicating a further reduction in natural grasslands. The Himalayan meadows are rapidly depleting due to climate change and overgrazing, with studies showing significant reductions in vegetation cover over the past few decades (Körner, 2003; Pandey et al., 2021). Consequently, the 2010 LULC scenario of Leh Town indicates an emergence of a less barren dominated landscape with a significant reduction in agricultural areas and increase vegetative cover but degradation in the meadows. These trends highlight Leh's ongoing shift from an agrarian to a more urban and economically mixed settlement, highlighting the importance sustainable land management that can combine development with ecological conservation.

Barren land, still being the largest category, witnessed a decreasing trend from 1290 ha covering 72.92% of the total area in 2000 to 1,221.2 ha covering 68.99% of the total area in the year 2010 with net decline rate of -5.39%. This decline indicates a gradual shift towards more productive land use and increasing tourist influx, the tourist visit increased from 8068 to 77800 within this decade, which led to the migration of people from other areas to the study area in search of new job opportunities.

3.2.3. LULC change in Leh Town (2010-2022)

Build-up area experienced the most significant increase among all the categories expanding from 231.3 ha (13.05% of the total area in 2010) to 308 ha constituting a total of 17.40% of the total area in 2022 with a net increasing rate of 33.16%. This remarkable growth highlights Leh Town's rapid urbanization, influenced by the population growth, immigration of the people from far-flung areas, infrastructure development, and economic activities, particularly tourism. The tourist visit increased from 77800 in 2010 to 235698 in 2016 (*District Statistical Handbook 2016-17*). Leh's position as the capital of the district and geo-strategic importance of the area are also some major reasons behind the increase in this category.

Agricultural land continued to show a decreasing trend, it decreased from 172.2 hectares (9.72% of the total area) in 2010 to 165 ha (9.32% of the total area) which reflects the further transformation of the agricultural lands towards residential and tourism oriented infrastructural areas, due to the increase tourist visits and also because of the shift the society towards nuclear family from joint family system. The no. of hotels and guesthouses increased from 190 in 2005 (*Thoma & Pasang, 2005*) to 650 in 2015 (*Department of Tourism, Leh*) contributing to further decrease in the agricultural lands in the study area.

Vegetation category continued to increase up from 114.8 ha (6.48% of the total area) in 2010 to 124 ha (7% of the total area) in 2022 with a net increasing rate of 8.01%, reflecting more plantation activities in the area. Due to the habitation in the areas like Skampari, Ibex Colony, Skalzangling etc. which were earlier in barren category people also started to plant trees in these areas due to the improved irrigation facilities, contributing to the increase in this category.

Barren category, while still occupying the largest portion of the area, declined further from 1,221.2 hectares (68.99%) in 2010 to 1,151.5 ha, covering 65.02% of the total area in 2022, with a net decreasing rate of (-5.75). The continuous reduction in the category shows the regions continuous urbanization trend. This also signifies the utilization of previously barren areas like Skampari, Skalzangling, Ibex Colony etc. for residential and recreational purposes. The tourism oriented infrastructural shifts also remain a major reason for the decrease in this category and increase in the Build-up category. The buildup increased from 2010 to 2022 with an increasing rate of 33.16% covering the previously barren area contributing to its decrease.

Meadows experienced a further decline from 30.45 ha (1.72% of the total area) in 2010 to 21.5 ha (1.21% of the total area) in 2022 with a net decreasing rate of (-5.74%), indicating the impact of climate change and conversion of these natural grasslands into other land uses. One of the reasons behind decrease in this category can also be considered to the over extraction of the groundwater from the boring wells which are dug near these ecologically sensitive areas. Some parts of these category were also destroyed and covered by mud during the flash-flood events during August 2010, which can also be considered as a reason for decrease in this category.

3.2.4 LULC change in Leh Town (1990-2022)

Build-up: This category witnessed the most significant change among all other categories. The build- up are in the region increased from 93.73ha, which was 5.23% of the total area in 1990 to an astonishing 308 (ha) about 17.40% of the total area in 2022. With a net increasing rate of 232.41%. The reason behind increase in this category are, increase in the population of the study area, increase in the tourist visits, migration of the people from far flung areas, and also the geo-strategic importance of the study area. The population of Leh Town increased from 21175 in 2001 to 30880 in 2011 (Municipal Committee Leh) which led to the construction of new houses and residential areas. Tourist visits also increase from 8068 (2002) to 235689 (2016) (*District Statistical Handbook 2016-17*) leading to the construction of hotels and guesthouses, many army camps were also developed considering the geo-strategic importance of the area. Due to Leh's position as district capital many people from the remote areas of Leh district like Nubra, Changthang, Sham region also migrated to the Leh Town to avail urban amenities like, schooling, health facilities, and all other public amenities which were better in Leh Town compared to their region. All the above factors contributed in the substantial increase in the buildup category which has led the Trend of urbanization in the Leh Town.

Agriculture: Agriculture area in the study area decreased considering from the year 1990-2022 with a net deceasing rate of -33.65%. It covered a total area of 248.72ha (14.05%) in the year 1990 which came down to 165ha (9.32%) till the year 2022. Many reasons are responsible for the decrease in this category, but most important one can be considered the tourist influx, the increased tourist visits change the whole land use scenario of the study area. During the early 90s people were mostly engaged in agricultural activities because it was the main source of livelihood but due to the increased tourist visits people started shifting towards tourism industry which was giving more income. Due to this the agricultural lands were left un-cultivated contributing to the decreasing trend of this category. Another reason can be considered the construction of hotels and guesthouses in the agricultural lands, the no. of hotels and guesthouses increased from about 30 in 1974 (*Schettler & Schettler 1977*) to approximately 190 in 2005 (*Thoma & Passang, 2005*), and further to about 650 in 2015 (*Department of Tourism, Leh*). The change in the socio-cultural lifestyle of people is also one of the reasons for the decreasing agricultural category, people started to shift to nuclear family system from joint family system which also contributed to the construction of individual houses in their agricultural areas.

Vegetation: The vegetation category in the study area experienced a continuous increasing trend. It was covering an area of 66.77ha (3.77% of the total area) in the year 1990 which increased to 124ha (7% of the total area) in 2022 with a net positive increasing rate of 85.71%. The increased awareness and improved irrigation facilities in the study area can be considered as some major reasons behind the increase in this category. After the major cloud burst events in August 2010 people were more aware towards importance of vegetation. Many plantation drives were conducted in the study area. Another important reason for the increase in the vegetation category can be the improved irrigation facilities like borewells, canal, irrigation and construction of water storage tanks which made it possible for the people to plant trees in the areas which earlier came under barren category with no irrigation facilities, e.g. Skampari, Skalzangling, Ibex colony, etc. Due to these improved irrigation facilities these areas also experienced some vegetation cover in the study

period. The construction of houses in these barren areas have also contributed in the increase in the vegetation category as people tend to plant trees in these areas after they started living in these areas.

Meadows: The meadows in the study area followed a decreasing trend during the study period. In 1990 this category covered a total area of 68.19ha (3.85% of the total area) which decreased to 21.5ha (1.21% of the total area) in 2022. It decreased with a net decreasing rate of (-68.47%) within the study period. These meadows mainly consist small shrubs, grasses and plants, which were mainly used as grazing land for the cattle, during the early 90s. The reason behind the decrease in this category can be the overgrazing of cattle in the area. This category can mainly be found in the areas like Gonpa, Gangles, Skara, which earlier used to have a huge no. of cattle, which used to graze in these areas, leading to the decrease in this category due to overgrazing. Another reason behind this decrease in this area is the over extraction of ground water through borewells and tubewells near to the ecological sensitive meadows. The locals of Skara consider this over extraction of ground water from the nearby army water pump as a major reason for the drying-up of the meadows in their village. Some of the meadows are also converted into residential areas and hotels, as some construction had also been seen in these areas within this study period. The Flash-floods events during the 2010 also destroyed much of these meadows covering them with mud and debris which can also be considered as a reason behind the decrease in this category.

Barren: Ladakh is considered a cold desert, and most of the area of the region comes under barren or un-cultivated category. In Leh Town also most of the area comes under this area. This category also experienced a decreasing trend during the study period, covering 1293ha (72.88% of the total area) in 1990 it decreased to 1151.5ha (65.02% of the total area) in 2022, with net decreasing rate of (-10.98%). The urbanization trend in this study area is one of the major reasons behind this decrease in this category. The number of houses increased from 3186 in 1990 to 8232 in 2022 (*Manual digitization*). Areas like Skampari, Skalzangling, Ibex-colony, Housing Colony etc., were earlier barren but due to this migration from the remote areas of Leh district led to the transformation of these areas into residential areas. The increase in the population of this study area can also be considered as one of the reasons behind the decrease in this category. The increase in the population from 21175 (2001) to 30880 in (2011) led to the construction of many new houses in these barren or un-cultivated lands. The increase in vegetation from 66.77ha to 124ha (1990-2022) has also contributed in the decrease in this category as some of these barren areas were converted into vegetated areas due to the improved irrigation facilities. Many recreational works were also initiated by the government to use these un-productive lands for construction of stadiums, play grounds, parks etc., which also contributed in the decrease of these barren areas.

4. CONCLUSION

The spatiotemporal analysis of Land Use Land Cover (LULC) changes in Leh Town, Ladakh, reveals significant transformations over the past three decades, driven primarily by rapid urbanization and shifts in land management practices. The study, spanning from 1990 to 2022, uncovers a marked increase in urban areas and vegetation cover, juxtaposed with a concerning decline in agricultural land, meadows, and barren land. The net increase in urbanization, measured at 232.41%, underscores the growing demand for infrastructure and housing in response to population growth and developmental activities. However, this urban expansion has come at the expense of traditional agricultural practices, with agricultural land experiencing a net decrease of -33.65%, raising concerns about the sustainability of food resources and traditional livelihoods in this fragile region.

The Ladakh region's unique topography, characterized by high-altitude deserts, rugged mountains, and limited arable land, makes it particularly vulnerable to the impacts of LULC changes. The sharp decline in meadows and barren land, with net decreases of -68.47% and -10.98%, respectively, signals potential disruptions in the region's natural habitats, which could have cascading effects on local biodiversity and ecosystem services. The increase in vegetation cover, although positive, must be interpreted with caution, as it may reflect changes in land management practices that do not necessarily align with the region's ecological balance.

Leh Town's rapid urbanization, driven by both economic aspirations and external influences, poses a significant challenge to the region's delicate ecosystem. The unplanned expansion of urban areas threatens to exacerbate environmental stressors, including soil erosion, water scarcity, and the loss of traditional land use practices. Given

Ladakh's harsh climatic conditions, characterized by extreme temperatures, low precipitation, and fragile soils, the resilience of local ecosystems is at risk. The study highlights the urgent need for comprehensive land use planning and sustainable development strategies that consider the region's ecological constraints and cultural heritage.

In conclusion, the LULC changes observed in Leh Town reflect broader trends of modernization and development in high-altitude regions. However, without careful management and planning, these changes could undermine the very ecological and cultural foundations that sustain life in Ladakh. Future research should focus on integrating geospatial analysis with community-based approaches to develop sustainable land use strategies that balance development needs with environmental preservation in this unique and vulnerable region.

CONFLICT OF INTERESTS

None

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