

International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483

E-ISSN: 2706-7491

NAAS Rating (2025): 4.5

IJGGE 2025; 7(12): 33-39

www.geojournal.net

Received: 07-10-2025

Accepted: 13-11-2025

Amjad Ali

Ph.D. Scholar, PG

Department of Geography,

Government Vidarbha

Institute of Science and

Humanities, (Autonomous)

Amravati, Maharashtra, India

Prashant P Magar

Professor, PG Department of

Geography, Government

Vidarbha Institute of Science

and Humanities,

(Autonomous) Amravati,

Maharashtra, India

Anthropogenic transformation of landscape in the Leh city and its surrounding regions of Leh district, Ladakh, India

Amjad Ali and Prashant P Magar

DOI: <https://www.doi.org/10.22271/27067483.2025.v7.i12a.458>

Abstract

With continuous improvements in human lifestyles, people have been increasing their capacity to reshape and utilise nature. As a result, the original geomorphological landscape has been largely changed, and a variety of manmade geomorphological landscapes have been formed. The present study examines the role of human impact in shaping and altering the natural landscapes around Leh city in the Indus Valley, Ladakh, India. A wide range of human activities in transforming the natural landscape has been observed during the field survey in the study region. The results showed that Water management, traffic, urbanisation, and mining activities are some of the interventions that have influenced the transformation of natural landforms into anthropogenic landforms. The most significant changes are related to the construction of road infrastructure and the removal of large volumes of material resulting from mining activities. The anthropogenic macro- and micro-features significantly impact the study region's environment and surface. Without adequate planning, land alterations lead to landslides, increased sedimentation risks, and increased soil erosion.

Keywords: Mining, land use and land cover, anthropogenic landforms, Leh, soil erosion

Introduction

Nowadays, humans have become an important geomorphic agent or process, able to alter the surface of the earth at a rate many times faster than natural geomorphological processes (Nir, 1983) ^[11]. Anthropogenic landforms result from human activities and can directly or indirectly alter the environment or modify the surface of the Earth. According to estimates from Hookie *et al* (2012) ^[6], more than 50% of the world's ice-free land area has now been directly altered by human intervention. These estimates are based on the land area modified by humans in 2007. Nemours' work has focused on the positive and negative impacts of human influence on landscapes. Nowadays, human activities that alter the earth's landscapes have become a major issue worldwide. To meet the demands of the population, humans have continuously modified natural landscapes. Human activities are profoundly altering the fragile Himalayan landscape, exacerbating its natural vulnerabilities to produce wide-ranging environmental and socio-economic impacts. These transformations are driven by rapid population growth, increased demand for resources, large-scale infrastructure projects, and the indirect effects of global climate change caused by human emissions (Pandit *et al.*, 2014) ^[13]. Leh, the largest district of the Union Territory of Ladakh, is located in the trans-Himalayan region of northern India. The region lies between the Karakoram Range to the north and the Great Himalayas to the south, making it one of the highest regions in the world and often referred to as a cold desert. Ladakh is one of India's popular tourist destinations, known for its stunning natural beauty, mountain vistas, high-altitude lakes, rich Tibetan Buddhist culture, and a wide array of adventure activities. The unique biodiversity of Ladakh faces challenges arising from both the exponential growth of anthropogenic activities and the significant threat of climate change to the region's environmental landscape and physiographical variations (Gaur *et al.*, 2024) ^[5]. Human activity has significantly impacted the fragile landscape and environment of Leh Ladakh, with the most prominent drivers being tourism, urbanization, and infrastructure development.

Corresponding Author:

Amjad Ali

Ph.D. Scholar, PG

Department of Geography,

Government Vidarbha

Institute of Science and

Humanities, (Autonomous)

Amravati, Maharashtra, India

Study area

Leh city is the administrative centre of the Leh district in the Union Territory of Ladakh, which lies in the northernmost Part of India. Leh is situated in the upper Indus River basin at an altitude of approximately 3,500 m above sea level, surrounded by the high-altitude ranges of the Ladakh and Zaskar mountains (Kumar & Srivastava, 2018) [8]. The area is one of the most elevated permanently inhabited regions in the world, characterized by harsh environmental conditions, barren vegetation, and a predominantly cold-arid climate (Rizvi, 1999) [14]. The geographic remoteness and unique physiography of the region have created a distinct cultural,

ecological, and geomorphological environment, rendering Leh an important location for landscape research. Climatically, the Leh region belongs to a cold desert ecosystem, and its annual precipitation is less than 100 mm, which is mainly in the form of snowfall (Ali *et al.*, 2022) [1]. In this upper part of the Indus, the river passes through a broad alluvial valley with steep side-mountain slopes and vast glaciogenic and fluvio-glacial formations (Nusser *et al.*, 2012) [10]. The human settlement is concentrated on the Indus River and its tributary streams, where irrigation with glaciers has long supported small-scale irrigation, which includes barley, wheat, and vegetables.

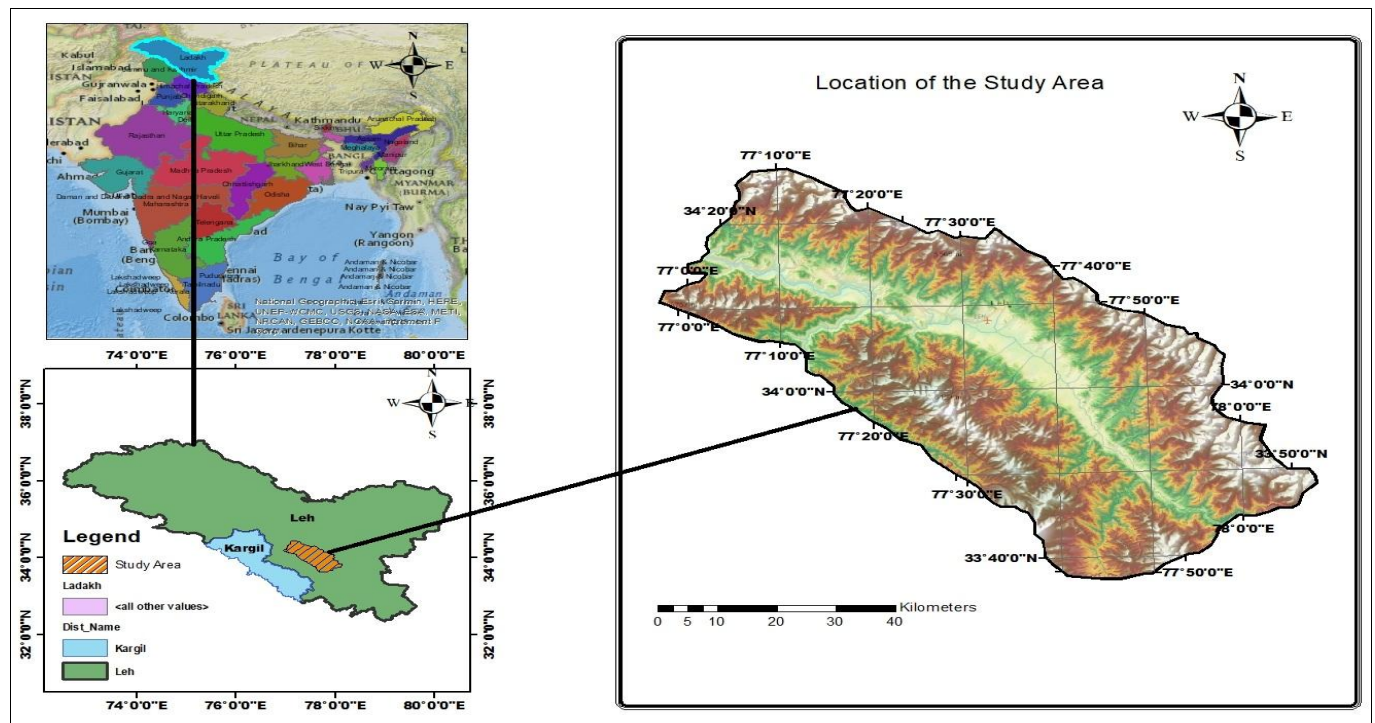


Fig 1: Location of the Study Area

Methodology

The research approach in this study consists of a descriptive and evaluation-based methodology to categorize human activities impact on the landscapes. The technique incorporates field recording, remote sensing, and process-based interpretation to determine and classify the anthropogenic alteration. Anthropogenic landforms at each observation point were recorded by field surveys, GPS geotagging, and visual interpretation of high-resolution satellite images. The features of landforms were documented under: surface modification (cutting, filling, levelling), removal of vegetation, Hydrological alteration, and construction of artificial structures. The anthropogenic landscapes in this study were also classified according to the type of human interference, which was categorized under the Szabo and Dávid anthropogenic landform classification system. The study also uses multi-temporal satellite images and GIS-based analytical approaches to detect, quantify, and assess LULC changes in Leh during a 30-year period (1990-2020). The study aims to identify major land transformation processes, spatial patterns of change, and their consequences

for landscape stability and resource management in this high-altitude cold desert environment using a uniform classification scheme and change detection approach.

Results and Discussion

The landscapes of Leh city and its surrounding areas are undergoing a profound change due to multiple forms of anthropogenic intervention. Urban expansion, intensification of tourism, infrastructural development, road construction, water management, agricultural change, resource extraction, and climate adaptation action measures all contribute to the reshaping of the natural and cultural environment of the region. These interventions have transformed Leh from a traditional high-altitude settlement with an agrarian base into a quickly urbanising, service-oriented and strategically important centre. Using the modified Szabo and David classification, the identified anthropogenic landforms in each observation point were categorized based on the type of intervention and process, as shown in (Table 1).

Table 1: Classification of direct and indirect anthropogenic impacts on landscapes

S. No.	interventions	Direct impact on landscapes	Indirect impact
1	Urbanisation	Replacement of agricultural land for built-up areas, such as hotels, guest houses, and restaurants. Cut and fill for housing on steep slopes	Reduced groundwater recharge. Increased slope failures and landslides.
2	Minning	Create Open pits And Spoil heaps	Reduced soil stability, increased erosion and desertification.
3	Road	Cut and fill slopes	Increased erosion Slope failure
4	Water management	Alter flow velocity and sediment transportation	Altered sediment balance and channel morphology

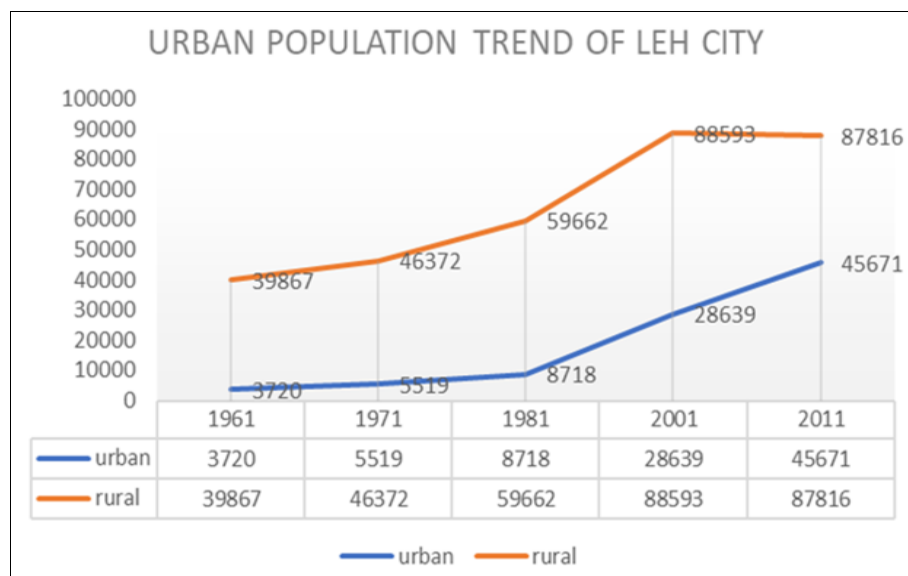
Anthropogenic impact on landforms due to Urbanization

The development of cities and urban areas often involves extensive modification of natural landscapes. Skyscrapers, roads, bridges, and other infrastructure can transform the topography and create new landforms (McGrane, 2016) [9]. Leh City's urban growth is driven by several factors, including the development of administration and infrastructure, migration from rural to urban areas, the

expansion of the tourism industry, and the region's geopolitical significance (Dame *et al.*, 2019) [4]. Rapid changes in infrastructure development, the socioeconomic conditions of society, and the expansion of urbanization and population began after 1975, when the region opened to tourists. This is the turning point for the gradual expansion of urbanization in Leh Town. The urban population of Leh increased gradually from 1961 to 1981, but after 1981 it increased rapidly, as shown in the graph (Figure 2).

Table 2: Urban population Trend of Leh City from 1961 to 2011

Year	Urban population of Leh district	Total population of Leh district	The percentage of the population living in urban areas
1961	3720	43,587	8.53
1971	5519	51,891	10.63
1981	8718	68,380	12.74
2001	28,639	1,17,232	24.42
2011	45671	1,33,487	34.21



(Sources Compiled based on Census of India (1961, 1971, 1981, 2001, and 2011))

Fig 2: Urban population Trend of Leh City from 1961 to 2011

Earlier, the people of Leh town were largely dependent on agricultural activities. However, then, after a few decades, gradual increases in tourists and rural-urban migration led to the transformation of agricultural and barren land into a built-up area for hotels, Guest houses, and restaurants. The classified Land Use and Land Cover (LULC) maps for 1991, 2001, 2010, and 2020 (Table 3) reveal clear differences in the spatial distribution and extent of major land-cover categories in urban Leh. 1991 satellite images show that the urban Leh was quite small and compact. Barren land was the most prevalent land-cover type, comprising about 65.94 percent of the total study area. The

agricultural land and vegetation combined occupied approximately 30 percent of the area, concentrated in pockets of Skara, Sankar, Horzey and Shaynam. The built area was just 4% and covered only the old town, the area surrounding the Leh palace, and some isolated settlements. The noticeable changes took place between 1990 to 2010. The built-up area increased to almost 29.76 percent. This growth was driven by the expansion of the administration, improved connectivity, the development of military infrastructure, and the increase in tourist arrivals. Agricultural land has been reduced to 24.32 percent due to the conversion of agricultural land to residential and

commercial uses. The most dramatic change to the landscape happened in 2020. Constructed land was 50 percent which was much higher than it was in 1991. The settlements were in Airport Road, Skara - Ibex colony, Housing colony, shaynam, skamapari and the slope of the north. The agricultural and vegetation land reduced to 17.68 percent, which was 30 percent in 1990, which is a significant loss of the traditional farming fields. There has been a drastic increase in unplanned residential areas in Skampari, Skalzanling, and the bus stand areas, as people migrating from far-flung areas of Leh district are mostly

settling there. With limited space accompanied by dense settlement in these areas, slopes are excavated for planation for the construction of residential buildings, hotels, guesthouses, etc fig displays the residential buildings of the Skampari area constructed on the foothill of the Ladakh Batholith. Slope cutting for building has increased the frequency and magnitude of debris flows in Leh. During heavy rainfall events such as cloudbursts, slope cut areas become major sources of debris flows, endangering lives and infrastructure (Figure 4b).

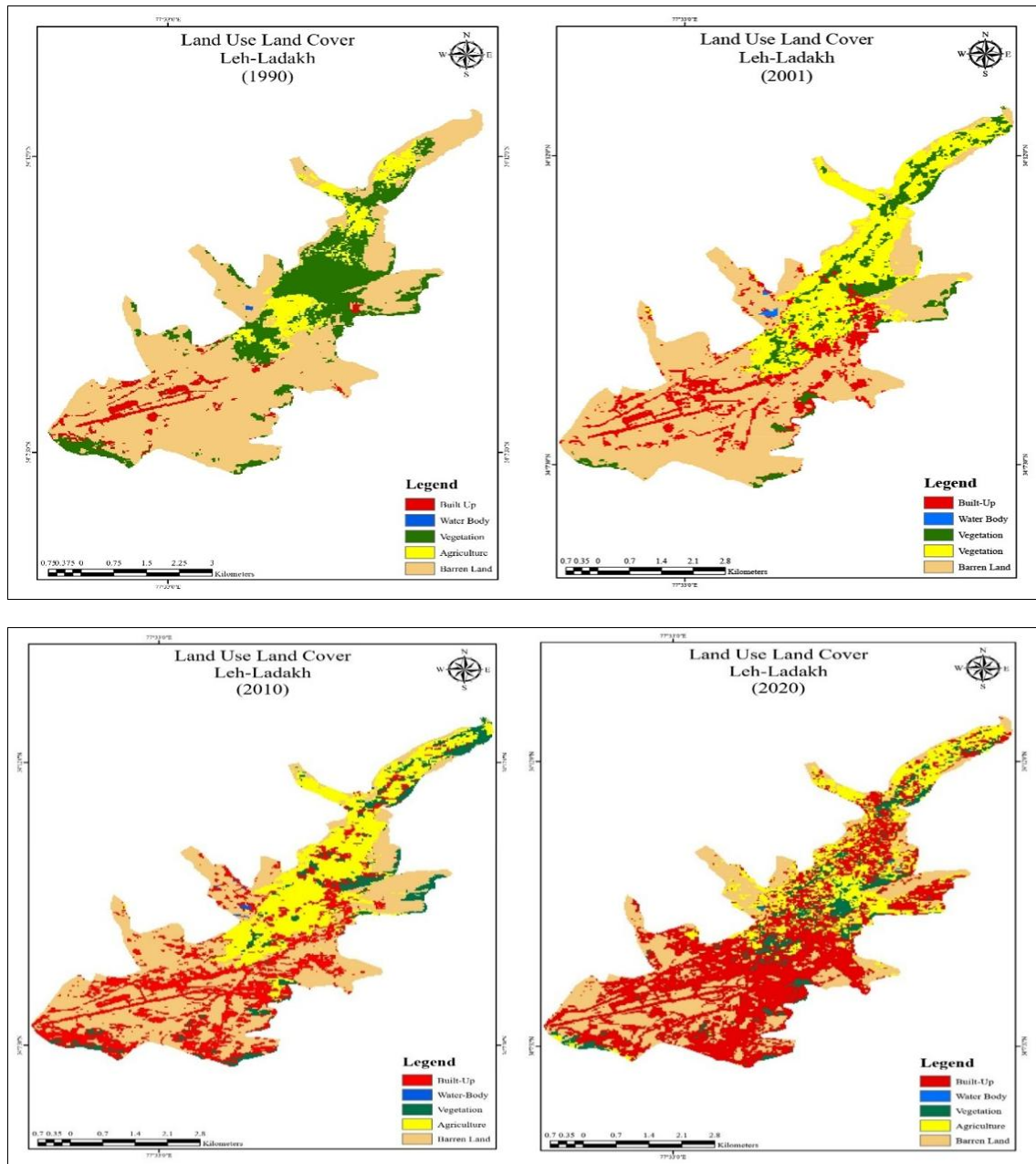


Fig 3: Land use Land cover change detection of Leh urban from 1990 to 2020.

Table 3: Land use land cover change detection of Leh city from 1990 to 2020.

Class	Year 1990		Year 2001		Year 2010		Year 2020	
	Area in Hectare		Area in Hectare		Area in Hectare		Area in Hectare	
Barren Land	1747.51	65.94%	1485.98	55.88%	1216.65	45.75	854.67	32.14%
Agriculture and vegetation	797.77	30%	745.23	28%	646.74	24.32%	469.81	17.68%
Build-up	112.20	4%	422.19	15.91%	790.97	29.76	1331.98	50.09%
Water Bodies	1.60	0.06%	5.68	0.21%	4.72	0.17%	2.62	0.09%
Total	2659.08	100%	2659.08	100%	2659.08	100%	2659.08	100%

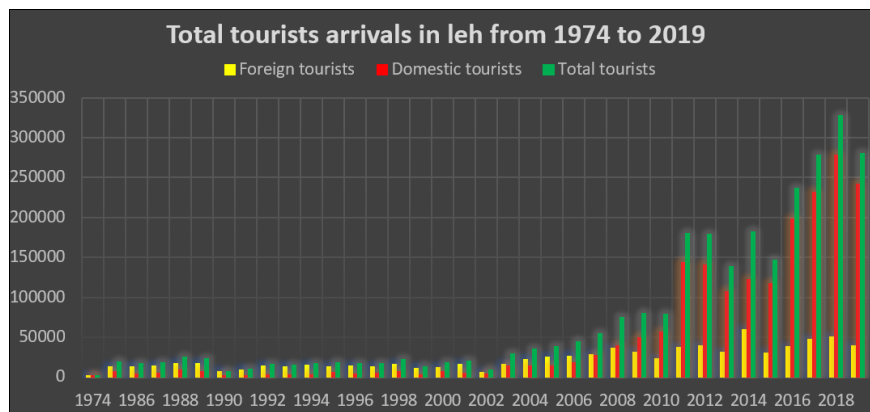


Fig 4: Total tourist's arrival in Leh from 1974 to 2019 (Source Department of Tourism Leh)



Fig 5: Houses constructed on the hill slopes the Skampari area in Leh city (b) Debris flow damage houses in skampari in august 2024 cloudburst.

Anthropogenic impact on landscapes due to irrigation and water management

Humans have intentionally transformed fluvial landscapes by constructing artificial embankments, irrigation channels, dams, and reservoirs (Hudson & Middelkoop, 2015) [7]. Almost the entire agricultural Land in Ladakh is dependent on Irrigation canals. Two types of irrigation systems can be distinguished in the study area 1) the glacier-fed irrigation in the tributary valleys, and the main valley irrigation system fed by the Indus River. Numerous large and small artificial irrigation canals have been constructed by farmers to divert water from the Glacial-fed streams and the Indus River to carry water to their fields. These artificial irrigation canals, on the one hand, play a major role in agricultural land use in the study region, and on the other hand, they alter river flows and sediment transport by diverting large amounts of water. Major land cover changes from barren to cultivable land in areas under irrigation in the Indus Valley and its tributary valleys increased from 88km in the late 1960s to 100km in 2009 (Nusser *et al.*, 2012) [10]. The most massive human intervention in the development of the irrigated area was the government-funded launch of the Igu-Phey canal in 1979. The purpose of these 43 km-long canals is to divert water from the Indus River to arable barren lands along the left bank of the Indus River from Igoo to Phey. Another major human influence on the region's hydrological regime is the river embankment and the hydroelectric project Dam. River embankments are observed in the wide flood plain between Stakna in the west to Spituk in the east. Steel net stone cage river embankments (Figure 6a) are used to protect land on flood plains from river flooding and also to divert water from the Indus to irrigate the field located on the edge of the braided channel. The Nimmo-Basgo hydro-project (Figure 6b) situated on the Indus River at Alchi village acts as a barrier to trap a huge quantity of sediments in the upstream and also changes the flow of stream.



Fig 6: (a) Steel net stone cage river embankment on river Indus (b) Nimo- Basgo Hydro project at Basgo village.

Anthropogenic influence on the Landscape due to Road infrastructure

Road reconstruction in the Leh-Ladakh region has become one of the most important agents of anthropogenic landscape modification within the last few decades. Ladakh, its geopolitical importance, and the road infrastructure development in the region have been maintained and monitored by the Border Road Organization under the Ministry of Defence. Owing to its geopolitical importance, harsh climate, and difficult terrain, the region is undergoing continuous upgradation, widening, and realignment of existing roads to enhance connectivity and facilitate tourism and military mobility. Lying in the trans-Himalaya, road construction in the region often requires cutting into the hillside to create a level for the road. This alteration of natural slopes during road construction destabilizes them and leads to increased soil erosion and landslides (Figure 7a).

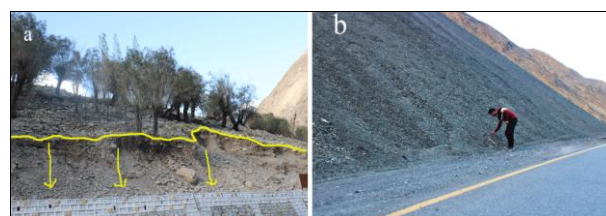


Fig 7: (a) soil erosion due to the road widening at upshi Village (b) Road widening for better connectivity on the Leh Srinagar Highway at nurla increases the volume and frequency of scree (talus) slope.

Anthropogenic impact on landforms due to Mining and Quarrying

Mining and Quarrying extract a wide range of useful materials (such as sand, stone, gravel, coal, and iron) directly from the surface and from the ground. These substances are widely used in the building and manufacturing industries, and they have been directly

altering the landscape by creating new landforms (Bell *et al.*, 2001) [2]. Stone crushing and sand Quarrying are dominant activities in the study area. Due to the increasing demand for building materials and the rapid growth of construction activity in Leh city and the nearby areas, to meet society's needs for housing and infrastructure development, as well as the modern requirements of an expanding population, several stone crushing and quarrying units are opening around the peripheral areas of Leh town. During the field observation, 13 stone crushers and mining units were identified, of which two are not in Operation. The most significant area affected by mining activities in the study area is Phey 2, where mining has transformed 3,10,678 Sqm. These mining and quarrying activities create large open pits, and the waste materials excavated from mines are frequently deposited on the ground surface as

spoil heaps (Figure 8a). Stone crushing and quarrying activities in this area have a significant impact on the environment and the health of people in the surrounding areas.



Fig 8: (a) (Spoil heap) accumulations of waste material generated by mining at Tuchik1(b) Sand quarrying in Shey

Table 4: Area affected by mining and Quarrying activities in the study area

Mining /Quarrying area	Sub-area	Geo coordinates	Elevation	Area of parameters	Area affected by Mining in Sq.m
TUCHIK	Tuchik 1	34°02'20.55" N 77°35'48.54" E	3517m	1407m	76,901 Sq.m
	Tuchik 2	34°02'35.54" N 77°35'26.45" E	3465m	3228m	1,45, 923sq.m
STOK	Stok 1	34°04'42.18" N 77°32'40.26" E	3432m	2872m	101,134 sq.m
	Stok 2	34°04'48.86" N 77°32'21.91" E	3428m	777m	18283 sq.m
	Stok 3	34°05'11.03" N 77°32'14.76" E	3426m	1282 m	68,176 Sq. Mt
	Stok 4	34°05'17.97" N 77°32'37.29" E	3368m	1340Mt	64,996 Sq. Mt
SPITUK	Spituk 1	34°06'09.91" N 77°30'29.39" E	3396m	2438 Mt	176,669 Sqm
	Spituk 2	34°06'39" N 77°29'21" E	3422m	1451 Mt	84,919 Sqm
PHEY	Phey 1	34°07'33.26" N 77°28'13.68" E	3220m	2938 Mt	2,01,619 Sqm
	Phey 2	34°08'27.14" N 77°27'46.78" E	3253m	3089 Mt	3,10,678 Sqm
SHEY	Shey	34°4'31.71" N 77°38'4.24" E	3319m	1250m	61,491 Sqm
STONGSER	Stongser	34°36'32.11"N 77°36'32.33"E	3476m	336m	7285 Sqm
Kharu	Kharu	33°56'10.66" N 77°43'52.51" E	3363m	1196M	50,620 sqm

Conclusion

The natural landforms of Leh city and its surrounding areas are greatly affected by human activities. The most notable human activities that have transformed Leh's natural landforms into highly anthropogenic landscapes are urbanization, mining, road construction, and water management practices. Among them, urbanisation and mining activities have had the most significant and enduring impacts. Land Use and Land Cover (LULC) change analysis of Leh City, Ladakh, between 1990 and 2020 shows significant and spatially disproportionate changes which are mainly caused by the rapid urbanisation, population increase, growth in tourism activities as well as development of infrastructures. Remote sensing and GIS-based change detection evidently indicate that natural and agricultural landscapes have been encroached by anthropogenic land use, which has grossly transformed the delicate cold-desert environment of the area. The most noticeable alteration that has been witnessed in the period of

the study is consistence growth of built-up areas and most especially in valley floors and lower valley slope of hills. Rapid growth in settlements, the construction of buildings and tourism infrastructure, and the growing demand for land and resources have significantly altered the original terrain. Although road building and water-management interventions also lead to landscape change, their effect is relatively minor. To protect the region's fragile high-mountain ecosystem, a careful planning, regulated resource extraction, and sustainable development strategies are essential for managing future landscape change.

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