Decades of Transformation: Land Use and Land Cover Shifts in the Upper Beas River Basin of Western Indian Himalayan Region (2005-2023)

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Abstract

The Beas River, one of the main tributaries of the Indus River System, is renowned for its natural scenery, adventure sports, and hill stations such as Manali and Solang along its course. This study investigates the Land Use and Land Cover (LULC) changes over approximately two decades, from 2005 to 2023, within the originating stretch of the Beas River. The LULC classification includes seven primary categories: Agriculture, Barren/Unculturable/Wastelands, Built-up, Forest, Grass/Grazing, Snow and Glacier, and Wetlands/Water bodies. By analyzing data from 2005 to 2023, significant trends and transformations in land use patterns were identified. Key findings include a substantial decline in agricultural land, significant expansion of scrublands, notable decreases in forest areas, and dynamic changes in snow and glacier cover. This study highlights the complex interplay of natural processes, human activities, and environmental factors influencing land cover dynamics. The results underscore the need for sustainable land management practices to mitigate adverse environmental impacts and ensure ecological balance.

Keywords: Land Use and Land Cover (LULC), Himalayas, Urbanization, Climate Change, GIS, IHR

Introduction

The Indian Himalayan Region (IHR) falls under the Hindu Kush Himalayas, a pre-eminent mountain range due to its significant water resources, which serve both the mountain and downstream populations ("Adaptation Outlook for the Hindu Kush Himalaya in the Making," 2017). Land Use and Land Cover (LULC) mapping is critical for understanding environmental changes and planning sustainable land management. This research aims to analyze the LULC changes over approximately two decades, from 2005 to 2023, focusing on seven primary categories and their subcategories. The study area encompasses diverse landscapes, including agricultural lands, forests, urban areas, and snow-covered regions. Understanding the trends and transformations in these categories provides valuable insights for policymakers and environmentalists. Notably, similar studies in regions like the Sikkim Himalaya have demonstrated the effectiveness of geospatial techniques in monitoring and assessing LULC changes (Mishra et al., 2019). Such methodologies are crucial for comprehensively understanding the dynamics of land cover changes in the IHR and informing sustainable land management strategies.

Study Area

The study area is situated in the transitional zone between the lesser and greater Himalayas, specifically in the northern zone of the Beas Basin, covering the Kullu and Mandi districts. This region falls within the highly vulnerable zones of Himachal Pradesh. Himachal Pradesh, an Indian Himalayan state, spans 55,673 square kilometers, primarily consisting of mountains and hills.(Kaushik et al., 2019) It extends from the Shivalik hills in the south to the Great Himalayan range, including a part of the Trans Himalayas, in the north. Geographically, it lies between latitudes 30°22'44" N and longitudes 79°04'20" E. Himachal Pradesh is the source of four major rivers that flow through northern India, with four principal river basins: Beas, Sutlej, Ravi, and Chenab. The study sites fall under the Beas River Basin.

The Beas River originates from Beas Kund near Rohtang Pass at an elevation of 4,062 meters above sea level, located at the southern tip of the Pir Panjal Range in the Kullu district. The river flows for about 245 kilometers within the state, supporting economic development and sustaining livelihoods in Himachal Pradesh, Punjab, and Rajasthan.(Kumar et al., 2018)

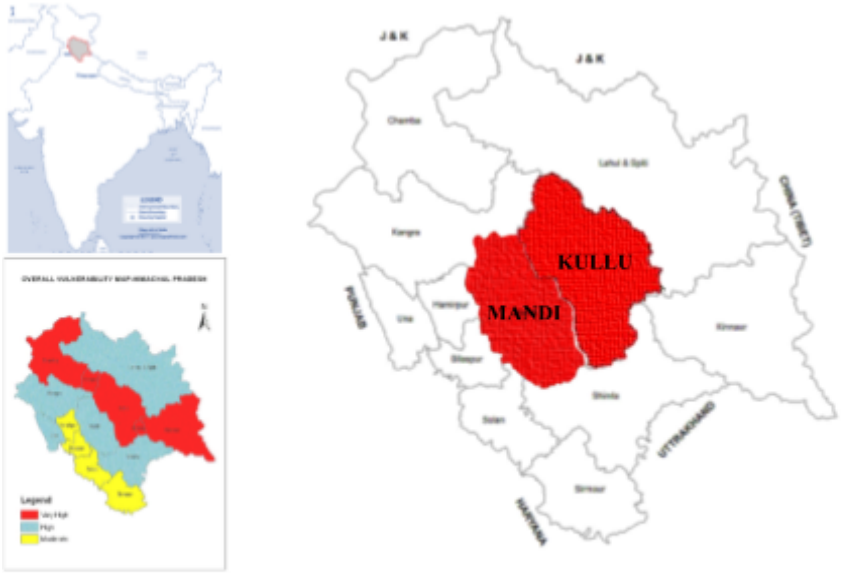


*Figure SEQ Figure * ARABIC 1 Study Sites: Kullu & Mandi in Himachal Pradesh*

(Source: Author)

The Beas River receives snowfall in its higher sub-catchment from December to April due to western disturbances, and about 70% of its annual precipitation occurs during the monsoon season from June to September. The river is divided into three stretches: the Higher Himalayas or High Hill zone, the Lower Himalayas or Mid-Hill zone, and the Outer Shiwalik or Sub-Himalayan Zone.(*The Wonderland Himachal Pradesh By Jag Mohan Balokhra – H.G Publications*, n.d.) This Himalayan region is prone to various natural disasters, making it one of the most vulnerable regions, necessitating specific planning solutions.(Bisht et al., 2018)

Data Sources and Methodology

Changes in land cover were analyzed and compared across multiple years to identify significant trends and transformations. Understanding the impact of land use changes over specific periods, using data from Bhuvan and Esri-Sentinel-2 Land Cover Explorer, is crucial for grasping the complex implications of climate change. By

examining land use changes from 2005-2006, 2011-2012, 2015-2016, 2017-2018, and 2023-2024, valuable insights into the dynamics of landscape alterations can be gained. Bhuvan's robust geospatial data capabilities, combined with Esri-Sentinel-2's high-resolution imagery, provide a comprehensive means to analyze and classify land cover types across various temporal scales. Additionally, converting Sentinel-2 raster data to vector format using ArcGIS allows for a deeper understanding of the extent and spatial distribution of land use changes within the study area. Land use detection has been quantified for the years 2017 and 2023 using ArcGIS. The methodology for the change detection map involved converting raster to vector format and calculating the area of polygons for each of the eight categories, such as Vegetation to Barren Land and Barren Land to Scrubs.

Results and Discussion

Land Use Land Cover (LULC) mapping was conducted over nearly two decades, from 2005 to 2023, to understand changes in land cover within the study area. The LULC classification consists of seven primary categories: Agriculture, Barren/Unculturable/Wastelands, Built-up, Forest, Grass/Grazing, Snow and Glacier, and Wetlands/Water bodies. These categories are further divided into various subcategories, as shown in Table 1, which presents the land cover area (in square kilometers) for the years 2005, 2011, and 2015. Notable changes in land

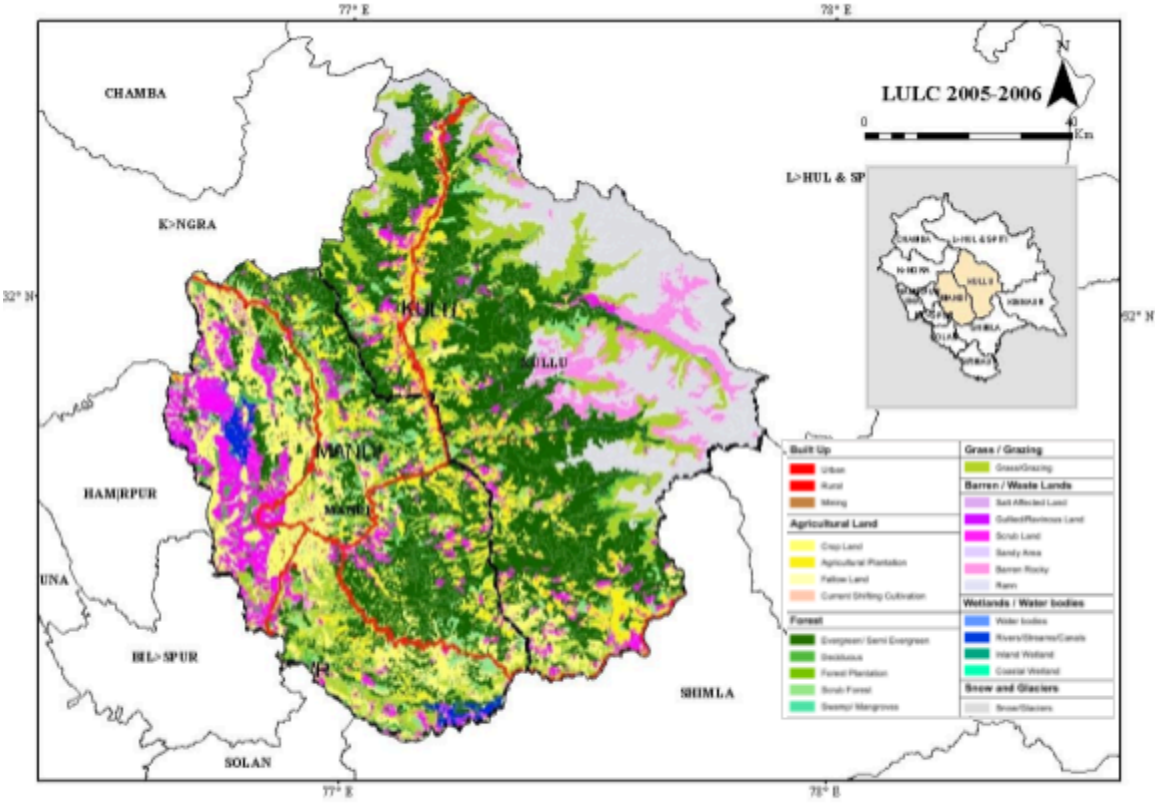
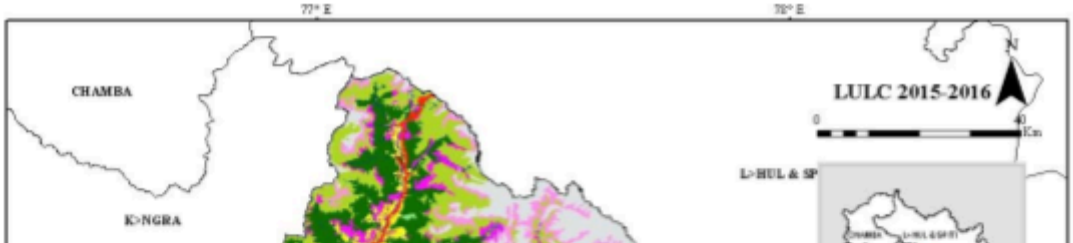


*Figure SEQ Figure * ARABIC 2 LULC of Study Area 2005-2006 year*

cover during the first decade include a decrease in cropland by 10.7 square kilometers. Further quantitative analysis of these changes is discussed in subsequent sections.

Between 2005 and 2015, agricultural land experienced a slight decline in total area. Cropland decreased from 1011.94 km² in 2005 to 1001.24 km² in 2015, plantations decreased from 882.19 km² to 871.82 km², and fallow areas slightly increased from 0 km² to 0.63 km². These minor changes collectively indicate relatively stable



agricultural land use dynamics during this period. The category of barren rocky and scrub land saw a significant increase in total area, with scrub land rising from 786.53 km² in 2005 to 1523.88 km² in 2015, and barren rocky land increasing from 379.28 km² to 463.57 km². This substantial expansion suggests a trend of land degradation and loss of vegetative cover, with a cumulative increase of 737.35 km² in scrub land and 84.29 km² in barren rocky land. Urban areas have seen a slight increase, while mining

areas have experienced a minor decrease. Urban land expanded modestly from 23.23 km² in 2005 to 24.68 km² in 2015, reflecting trends in urbanization and population growth. In contrast, mining land decreased from 2.99 km² to 1.85 km², possibly due to regulatory measures or resource depletion. The forest category saw significant declines in total area during the study period. Deciduous forest shrank from 182.83 km² in 2005 to 120.25 km² in 2015, evergreen/semi-evergreen forest decreased from 3160.49 km² to 3093.62 km², and scrub forest reduced from 310.16 km² to 53.99 km².

Table 1 LULC 2005-2015

Category	Subcategory	2005 (km^2)	2011 (km^2)	2015 (km^2)	Change in 2005 to 2015
Agriculture	**Crop land**	1011.94	1002.32	1001.24	-10.7
	Fallow	0	0.63	0.63	0.63
	Plantation	882.19	872.77	871.82	-10.37
Barren/ unculturable/ Wastelands	**Barren Rocky**	379.28	463.61	463.57	84.29
	Gullied / Ravinous Land	13.82	15.78	15.78	1.96
	Sandy Area	0.21	0.2	0.2	-0.01
	Scrub Land	786.53	1525.49	1523.88	737.35
Built up	**Mining**	2.99	3.93	1.85	-1.14
	Rural	66.08	66.47	66.55	0.47
	Urban	23.23	24.02	24.68	1.45
Forest	**Deciduous**	182.83	120.48	120.25	-62.58
	Evergreen/Semi evergreen	3160.49	3094.3	3093.62	-66.87
	Scrub Forest	310.16	53.54	53.99	-256.17
Grass / Grazing	**Grass / Grazing**	1151.22	1177.41	1176.71	25.49
Snow and Glacier	**Snow and Glacier**	1316.51	922.24	922.24	-394.27
Wetlands / Water bodies	**Inland Wetland**	0.09	0.09	0.09	0
	River/Stream/Canals	163.4	107.25	105.04	-58.36
	Water bodies	2.03	2.47	10.85	8.82

These reductions indicate a concerning trend of deforestation and habitat loss, with notable decreases of 62.58 km² in deciduous forest, 66.87 km² in evergreen/semi-evergreen forest, and 256.17 km² in scrub forest. This significant decrease in forest areas suggests deforestation or degradation of forested lands.

Grass and grazing lands experienced a slight increase in total area, with grass/grazing land expanding from 1151.22 km² in 2005 to 1176.71 km² in 2015. This trend suggests potential shifts in land use patterns or grazing practices, resulting in a cumulative increase of 25.49 km² in grass/grazing land. Snow and glacier areas saw a notable decrease,

likely due to climate change impacts such as glacier retreat. The snow and glacier areas significantly decreased from 1316.51 km² in 2005 to 922.24 km² in 2015, indicating impacts like glacier retreat and snowpack reduction. This represents a substantial reduction of 394.27 km² in snow and glacier areas. River/stream/canal areas decreased in total area, while water bodies exhibited an increase, possibly due to changes in water management or land use practices. River/stream/canal areas declined from 163.4 km² in 2005 to 105.04 km² in 2015, while water bodies increased from 2.03 km² to 10.85 km². These changes highlight the dynamic nature of freshwater ecosystems and riparian habitats, with notable decreases of 58.36 km² in river/stream/canal areas and a significant increase of 8.82 km² in water body areas.

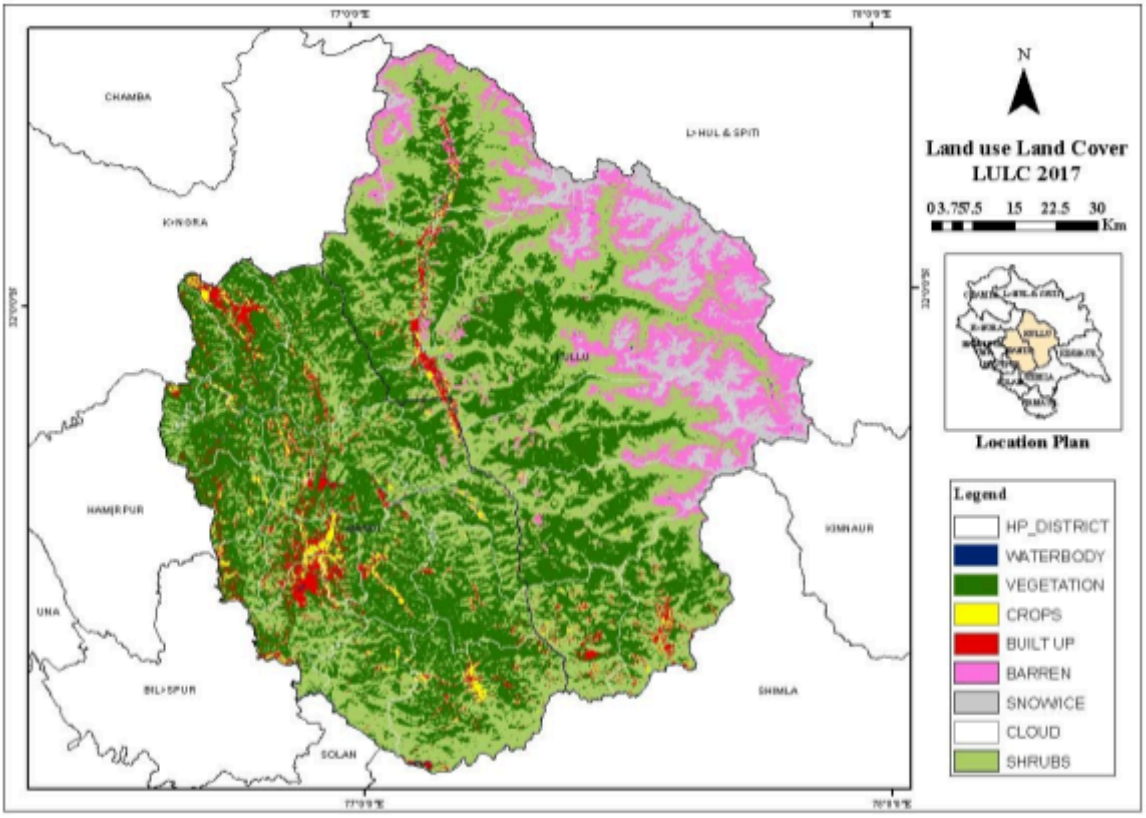


*Figure SEQ Figure * ARABIC 5 LULC of Study Area year 2017-2018*

Overall, the data reflects dynamic changes in land use patterns over the specified time periods, with some areas experiencing significant transformations, such as forest loss and urban expansion, while others remain relatively stable.

The analysis of Land Use Land Cover (LULC) change from 2017 to 2023 reveals dynamic trends influenced by various environmental, socioeconomic, and climatic factors. In the agricultural sector, there was a notable decrease of 39.603 km² in agricultural land, reflecting broader global trends of urbanization and land use diversification. Economic development and population growth pressures likely prompted the conversion of agricultural land for industrial or residential purposes in specific regions. Conversely, the significant reduction of 578.96 km² in barren, unculturable, or wasteland areas suggests efforts towards land reclamation and ecosystem restoration. Government

initiatives, alongside community-driven conservation projects, may have contributed to this positive change. Advancements in land management practices could also have led to the rehabilitation of degraded lands, reflecting a commitment to sustainable resource management.

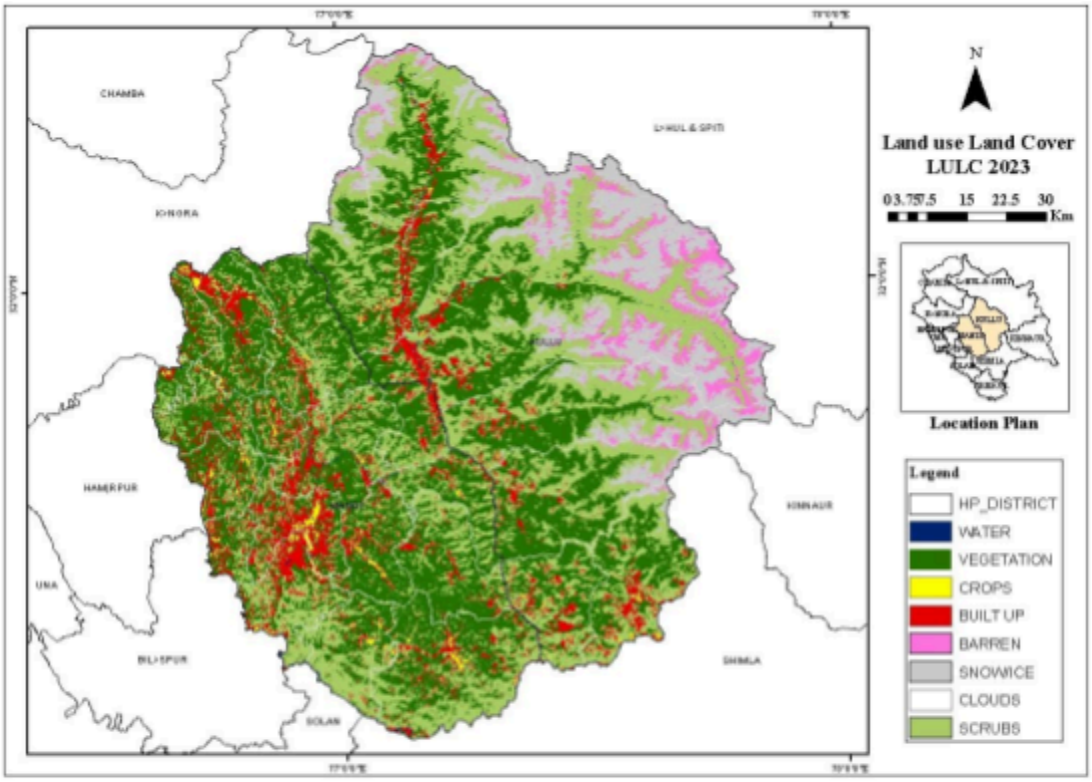


*Figure SEQ Figure * ARABIC 7 LULC of Study Area year 2023-2024*

Yet, the notable rise of 430.875 km² in built-up areas highlights the swift urban expansion and infrastructure development. Increasing urban populations, alongside economic growth, spur the demand for residential, commercial, and industrial spaces. This trend underscores the necessity for sustainable urban planning strategies to manage environmental impacts and safeguard natural habitats amid urbanization.

*Figure SEQ Figure * ARABIC 6 LULC Change 2017-2023*

Despite efforts toward forest conservation, forested areas have decreased by 227.2 km². Illegal logging, agricultural expansion, and wildfires contribute to this deforestation, threatening biodiversity and ecosystem services. Sustainable forest management practices and stricter enforcement of conservation policies are essential to mitigate further forest loss and protect critical ecosystems. Grass or grazing lands have slightly declined by 103.28 km², potentially due to land degradation, overgrazing, and conversion for other uses. Implementing sustainable land management practices, such as rotational grazing and reforesting degraded pastures, is crucial for preserving grassland ecosystems and supporting livestock livelihoods. The significant increase of 515.492 km² in snow and glacier coverage reflects climate change-induced changes in precipitation patterns. Increased snowfall, especially during peak seasons like February, indicates more intense winter weather conditions. This trend underscores the need for proactive measures to address the impacts of climate change on water resources, ecosystems, and human communities.

Table 2 2005-2023 Land Use

Category	2005	2011	2015	2017	2023	Change in 2005-2023
	(km^2)	(km^2)	(km^2)	(km^2)	(km^2)	
Crop Plantation	1894.13	1875.72	1873.69	140.068	100.465	-1793.7
Barren	1179.84	2005.08	2003.43	945.344	366.381	-813.46
Built up	92.3	94.42	93.08	332.978	763.853	671.553
Forest vegetation	3653.48	3268.32	3267.86	3918.17	3690.97	37.489
Scrubs	1151.22	1177.41	1176.71	3540.77	3437.49	2286.27
Snow and Glacier	1316.51	922.24	922.24	529.032	1044.52	-271.99
Water bodies	165.52	109.81	115.98	31.99	36.49	-129.03

Lastly, the marginal increase of 4.50 km² in wetlands and water bodies suggests natural processes such as sediment deposition and hydrological fluctuations. These transitions reflect urbanization, infrastructure development, and changes in land use patterns within the study area. These changes likely reflect the impacts of climate change, glacier retreat, and alterations in high-altitude ecosystems.

*Figure SEQ Figure * ARABIC 8 Land use change 2005-2023*

The Figure 9 shows significant land use variations. Crop plantations and barren lands have notably decreased, likely due to urbanization and land reclamation efforts. Built-up areas have slightly increased, reflecting urban expansion and infrastructure development within the study area over 2 decades. Forest vegetation shows minor change, indicating a balance between conservation efforts and deforestation pressures. Scrub lands have substantially increased, possibly due to land degradation and reduced agricultural activities. Snow and glacier areas have decreased, likely due to climate change and glacial retreat. Water bodies have slightly increased, possibly due to natural hydrological processes and improved water management practices. These changes reflect the dynamic interplay of natural processes, human activities, and environmental factors shaping land cover dynamics. Understanding these trends is crucial for informed land management and conservation efforts to ensure sustainable land use practices in the face of ongoing environmental changes.

Key Figures

1. **Agricultural Land**

Agricultural land experienced a notable decline from 1011.94 km² in 2005 to 1001.24 km² in 2015, with crop land decreasing by 10.7 km² and plantation areas reducing by 10.37 km². By 2023, agricultural land further decreased, reflecting broader global trends of urbanization and land use diversification. The decline of 39.603 km² in agricultural land from 2017 to 2023 underscores the pressures of economic development and population growth on agricultural spaces.

2. **Barren/Unculturable/Wastelands**

The category of barren, unculturable, and wastelands showed significant changes. Barren rocky land increased by 84.29 km² from 2005 to 2015, while scrubland expanded dramatically by 737.35 km². This trend suggests land degradation and loss of vegetative cover. However, from 2017 to 2023, there was a significant reduction of 578.96 km² in barren lands, indicating efforts towards land reclamation and ecosystem restoration.

3. **Built-up Areas**

Urban areas exhibited modest growth, increasing from 23.23 km² in 2005 to 24.68 km² in 2015, and further to 763.8532 km² by 2023. This reflects ongoing urbanization and infrastructure development. Conversely, mining areas decreased slightly, suggesting regulatory measures or resource depletion.

4. **Forest Cover**

Forest areas experienced significant declines. Deciduous forests decreased by 62.58 km², evergreen/semi-evergreen forests by 66.87 km², and scrub forests by 256.17 km² from 2005 to 2015. This deforestation trend continued, with a total loss of 227.2 km² in forest cover from 2017 to 2023. Factors such as illegal logging, agricultural expansion, and wildfires contribute to this trend, highlighting the need for sustainable forest management.

5. **Grass/Grazing Lands**

Grass and grazing lands showed a slight increase from 1151.22 km² in 2005 to 1176.71 km² in 2015, indicating shifts in land use patterns or grazing practices. However, a decline of 103.28 km² was observed from 2017 to 2023, possibly due to land degradation or conversion for alternative uses.

6. **Snow and Glacier**

Snow and glacier areas significantly decreased from 1316.51 km² in 2005 to 922.24 km² in 2015, reflecting climate change impacts such as glacier retreat. Interestingly, there was an increase of 515.492 km² in snow and glacier coverage from 2017 to 2023, possibly due to changes in precipitation patterns and increased snowfall.

7. Wetlands/Water Bodies

Water bodies exhibited dynamic changes, with an increase of 8.82 km² from 2005 to 2015, likely due to changes in water management practices. From 2017 to 2023, water bodies increased by 4.50 km², indicating natural processes such as sediment deposition and hydrological fluctuations.

Conclusion

The analysis of LULC changes from 2005 to 2023 reveals significant transformations in land use patterns. The decline in agricultural and forest areas, expansion of scrublands, and dynamic changes in snow and glacier cover underscore the complex interplay of natural processes, human activities, and environmental factors. These findings highlight the need for sustainable land management practices and proactive measures to address environmental challenges such as deforestation, urbanization, and climate change impacts.

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