

## Assessing Urban Heat Island Effects from Urbanization in Skardu Using Remote Sensing (1994–2024)

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### Abstract

The thermal environment and Land Surface Temperature (LST) are both directly impacted by the drastic changes in natural Land Use and Land Cover (LULC) brought about by rapid urbanization. Over the three-decade period from 1994 to 2024, this study offers a thorough examination of the thermal environment of Pakistan's high-altitude Skardu District. We quantified LULC shifts and changes in land surface temperature (LST) using multi-temporal Landsat datasets (TM, ETM+, and OLI) that had been processed using Google Earth Engine (GEE) and ArcMap 10.8. According to the findings, there has been a significant increase in the built-up area, which has grown from 5.67% (147.42 km<sup>2</sup>) in 1994 to 9.29% (241.54 km<sup>2</sup>) in 2024. At the same time, the majority of the land, which was unproductive, shrank from 57.75% to 52.74%. The mean LST increased significantly as a result of these spatial changes, increasing from 15.89°C in 1994 to 25.53°C in 2024. The analysis demonstrates a strong positive link between the spread of impermeable surfaces and regional warming, suggesting the emergence of a Surface Urban Heat Island (SUHI) effect in mountain ecosystems. In order for climatologists and urban planners to create laws for climate-resilient mountain towns, these results are essential.

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## 1. Introduction

With a dramatic movement of people from rural to urban locations, the world's population is expanding at an astounding pace. With significant contributions from Asian nations, it is predicted that by the middle of the twenty - first century, almost 70% of the world's population will live in cities . The fundamental factors driving changes in land usage patterns are the rising need for amenities, road infrastructure, and building construction that come with this quick urbanization. The Urban Thermal Environment (UTE) has been negatively impacted in recent decades as a result of the dramatic decline in green spaces around the world due to population expansion.

Changing LULC classes , notably increasing urban areas at the expense of vegetation or natural soil, has a significant impact on the environment since urban development raises the proportion of impermeable surfaces such as concrete , asphalt , and high-rise structures . These surfaces absorb a lot of solar radiation and retain heat in buildings because of a restricted view of the sky, which changes the surface energy balance. As a result, urban areas experience the Surface Urban Heat Island (SUHI) effect, in which they get much hotter than the surrounding natural environment.

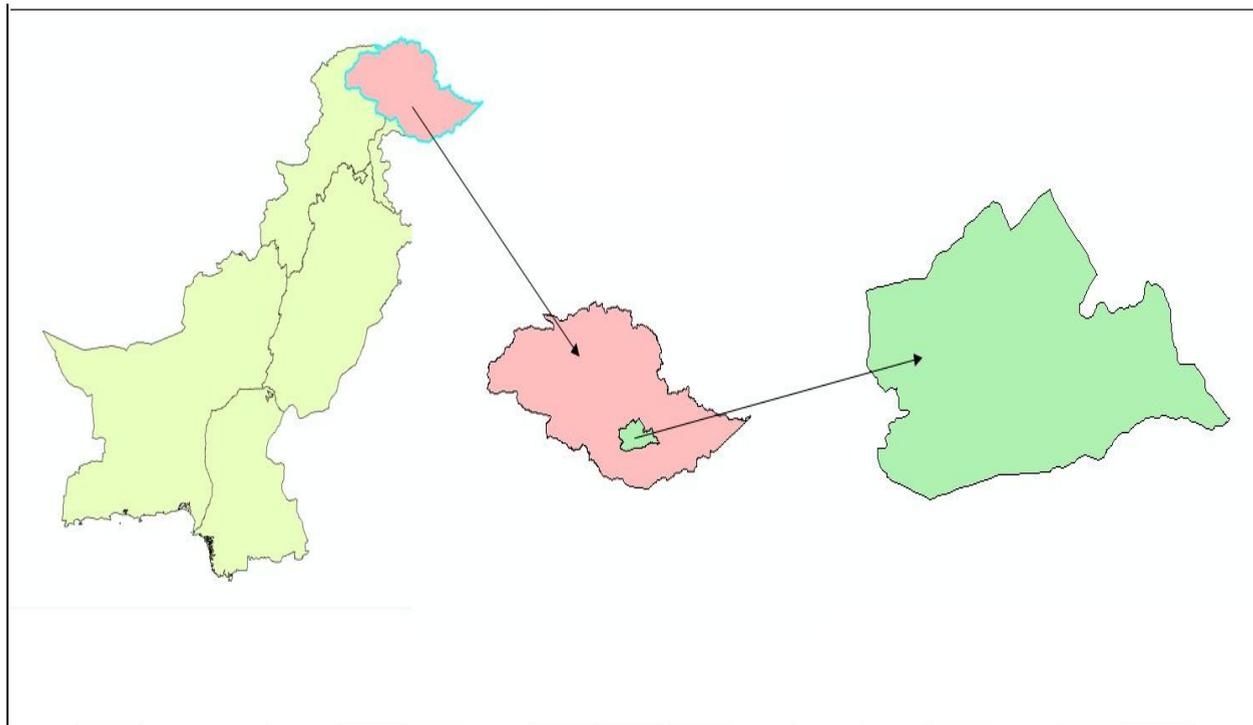
The negative effects of SUHI include increased greenhouse gas emissions, higher energy usage , and serious health hazards like heat strokes and cardiovascular illnesses . Despite the large amount of study done on megacities, Skardu and other high-altitude mountain areas are still understudied . Since high -altitude areas serve as early indicators of climate change , they are especially at risk . Using 30 years of satellite data, this research fills this gap by examining the trend of urban warming in the vulnerable environment of Gilgit-Baltistan.

## 2. Materials and Methods

### 2.1. Study Area

The geographic location of Skardu District is around  $35^{\circ}17' 48''$  N latitude and  $75^{\circ}38' 39''$  E longitude. It is situated in Pakistan's Gilgit-Baltistan area, in the middle of the Karakoram mountain range. The average elevation of the research site is about 2,200 meters (7,200 feet) above sea level. Its defining feature is a Cold Desert climate, with the vast Indus River valley in the middle of its harsh, rugged mountain surroundings . Importance: Skardu is a crucial center for tourism , commerce, and administration . Because it provides access to some of the highest mountains in the world, such as K2, it is a vital location for both mountaineering and international tourism. Its exceptional geographical position makes it an ideal location for researching the interaction between mountain climate change and urbanization.

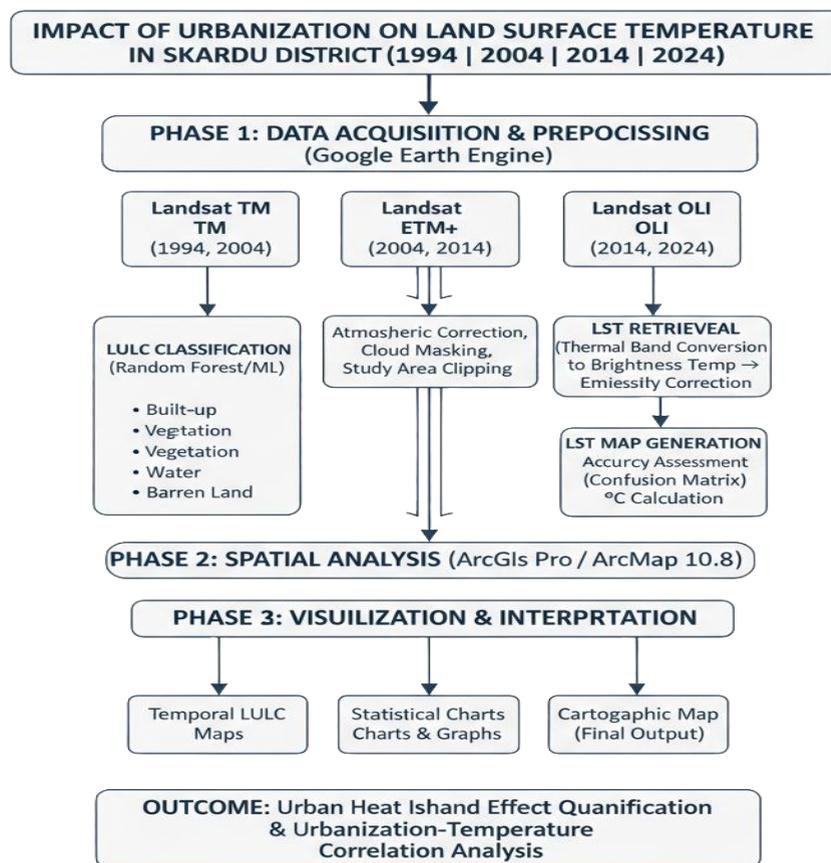
## Study Area



*Figure 1: Study Area*

### 2.2. Data Acquisition and Pre-Processing

Landsat data from several sensors was used for the years 1994 (Landsat 5 TM), 2004/2014 (Landsat 7 ETM+), and 2024 (Landsat 8 OLI). The Google Earth Engine (GEE) platform was used to capture and pre-process all images in order to guarantee a high standard of analysis. Because of GEE's cloud-based processing, it was simple to perform cloud masking, atmospheric correction (ToA and Surface Reflectance), and study area cropping. This stage was essential in maintaining the uniformity and comparability of spectral data across various decades.

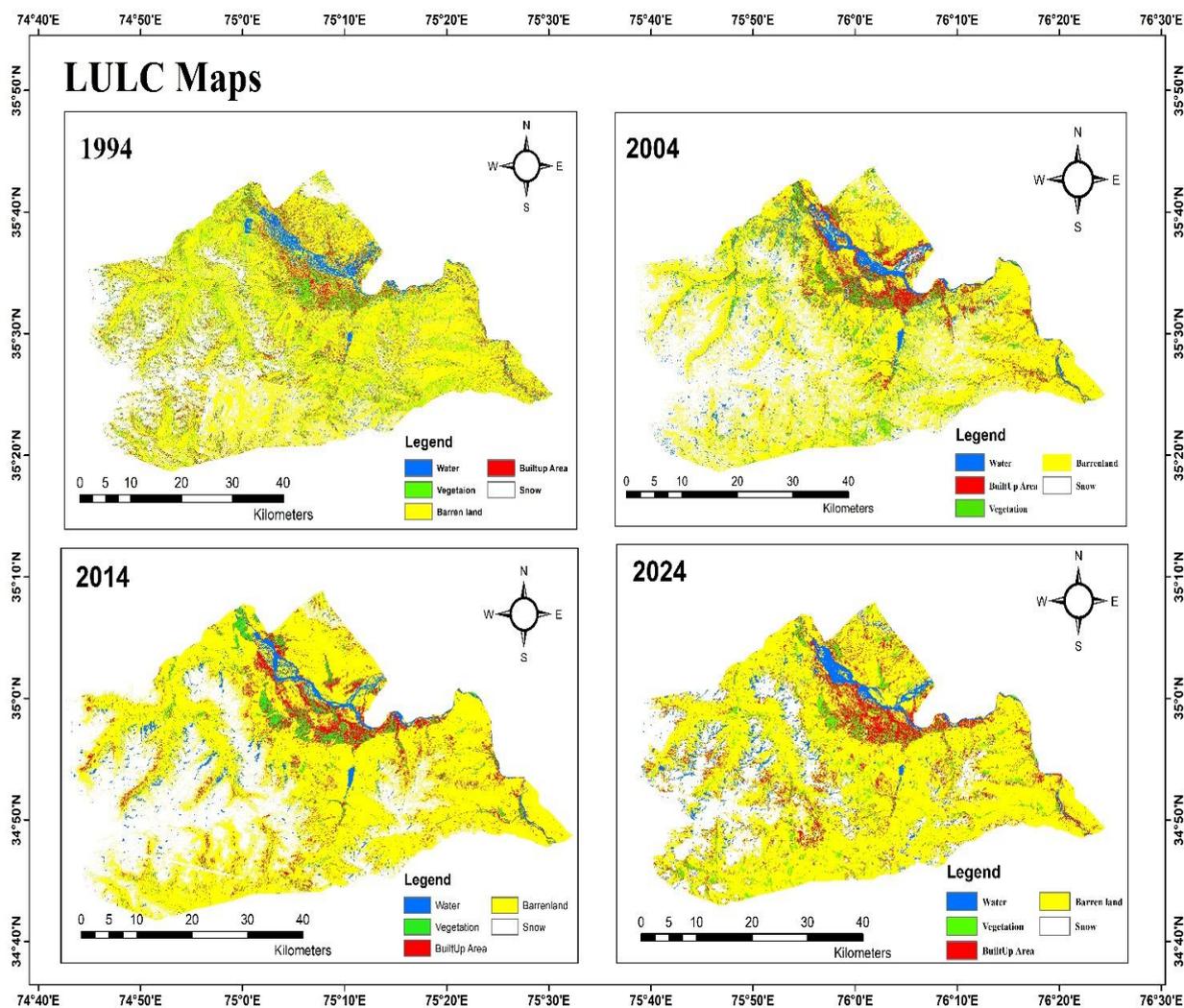


**Figure 2: Research Methodology**

**2.3. LULC Classification Framework**

Land Use and Land Cover (LULC) classification was performed using ArcMap 10.8. The methodology employed Random Forest (RF) and Maximum Likelihood (ML) algorithms, which are widely recognized for their robustness in classifying complex, high-relief terrains like those found in Gilgit-Baltistan. The study area was categorized into five distinct classes:

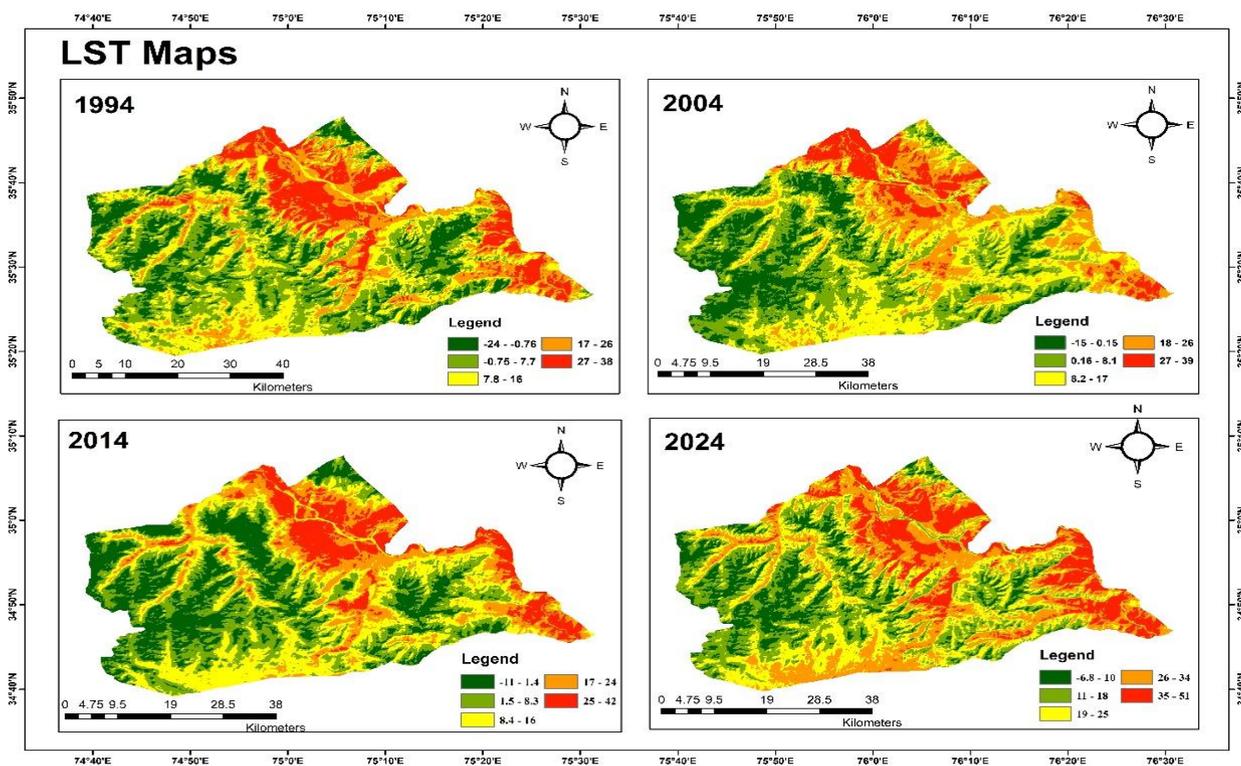
1. **Built-up Area:** Residential buildings, commercial zones, and road networks.
2. **Vegetation:** Agricultural fields, orchards, and natural forests.
3. **Barren Land:** Exposed rocky soil, mountain slopes, and sand dunes.
4. **Water:** The Indus River and associated tributaries.
5. **Snow:** Permanent and seasonal glaciers at high altitudes.



**Figure 2: Land Use of Skardu 1994-2024**

**2.4. LST Retrieval Methodology**

Land Surface Temperature (LST) was derived from the thermal infrared bands (Band 6 for TM/ETM+ and Band 10 for OLI). Following the established protocol of Artis and Carnahan (1982), the Digital Numbers (DN) were first converted to Spectral Radiance and then to Brightness Temperature in Celsius. A Land Surface Emissivity (LSE) correction was applied using the NDVI-based threshold method. This correction is essential because different surfaces (e.g., asphalt vs. grass) emit thermal radiation differently even at the same temperature.



**Figure 4: Spatial Distribution of Last From 1994-2024**

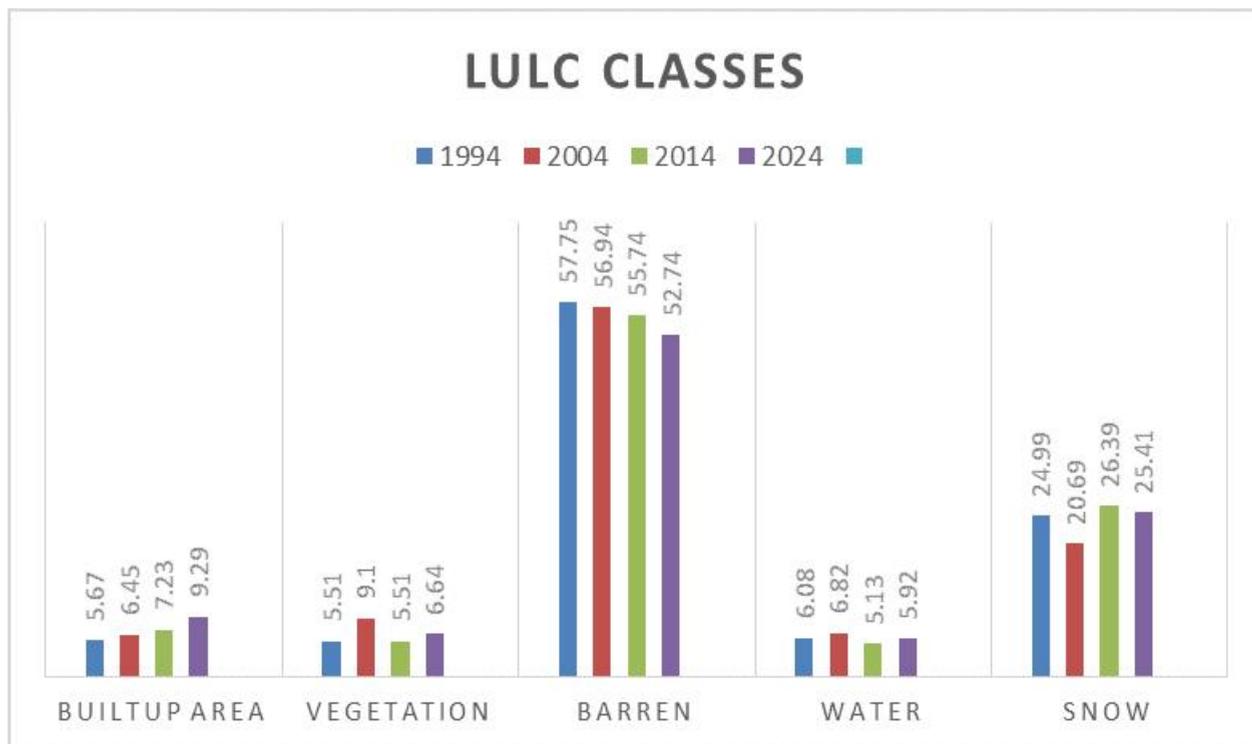
**2.5 Accuracy Assessment**

In Google Earth Engine (GEE), the classification accuracy was assessed using a 70/30 training - validation split approach. For five land use/land cover categories, including water bodies, vegetation, developed regions, bare land, and snow, a total of 1,090 reference samples were gathered. The Random Forest classifier was trained using around 70% of the samples, while the remaining 30% were utilized for separate validation. To evaluate the performance of the classification, a confusion matrix was created. The dependability of the categorization findings was assessed by computing the Kappa coefficient, the overall accuracy, the producer's accuracy, and the user's accuracy.

**3. Results**

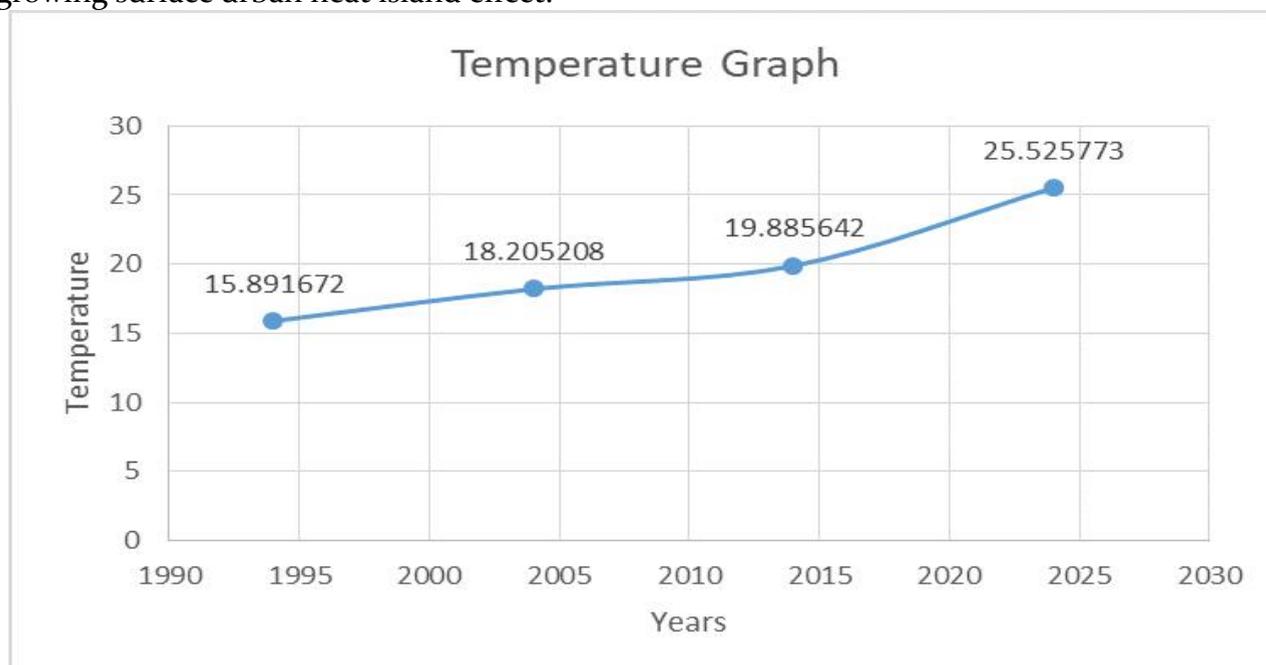
**3.1. Spatio-Temporal Dynamics of LULC (1994–2024)**

The study shows a consistent and noticeable increase in Skardu's urban footprint. Between 1994 and 2024, the built-up area increased from 147.42 km<sup>2</sup> (5.67%) to 241.54 km<sup>2</sup> (9.29%). The decadal breakdown reveals that the urban region increased from 167.7 km<sup>2</sup> (6.45%) in 2004 to 187.98 km<sup>2</sup> (7.23%) in 2014. The main cause of this growth was the reduction of unproductive area from 1501.5 km<sup>2</sup> (57.75%) to 1371.24 km<sup>2</sup> (52.74%). This suggests that the majority of the new construction was done on rocky or sandy ground on the outskirts of the current town. Despite seasonal variations between 5.51% and 9.1%, the vegetation stayed fairly consistent.



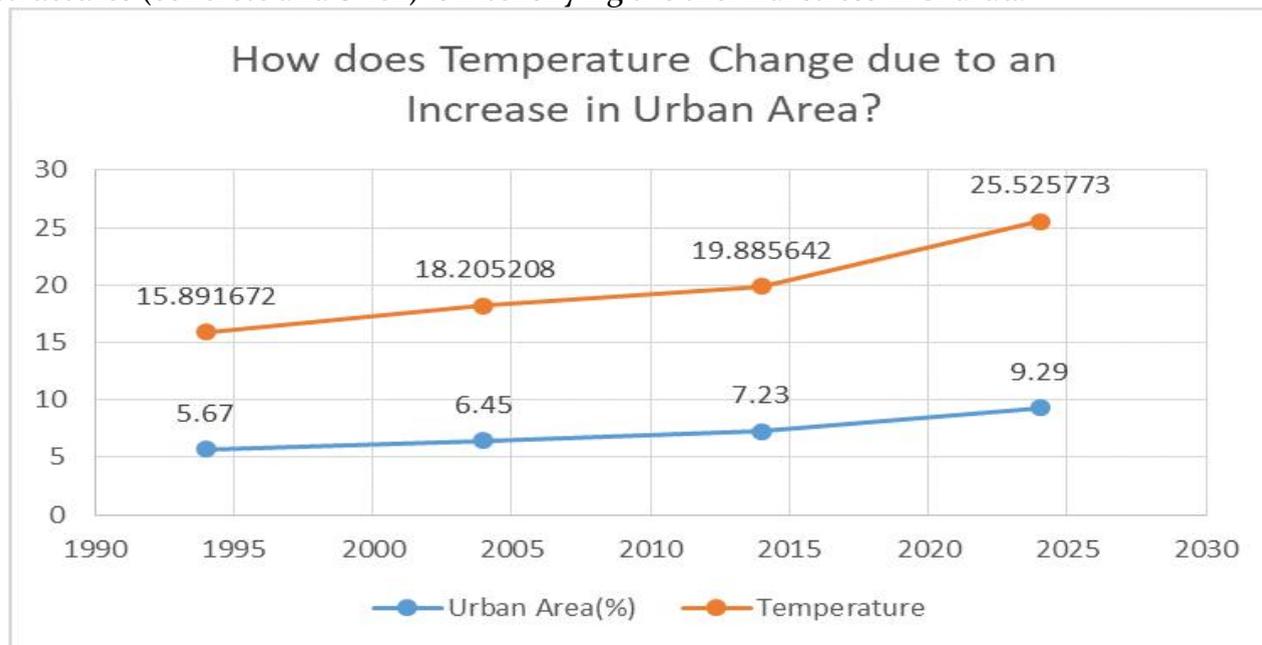
**3.2. Spatio-Temporal Trends in LST**

Over the last 30 years, Skardu's thermal environment has changed significantly for the better. In 1994, the average LST was measured to be 15. 89°C. The highest point of this number was 25. 53°C in 2024, with values of 18. 21°C in 2004 and 19. 89°C in 2014. Spatial distribution maps consistently reveal the highest temperatures in the urban center and on bare mountain slopes, while the coldest areas are still water bodies and snow-covered summits. The combined effects of urban growth and the loss of natural land cover are reflected in this gradual increase in temperature. The reduction in evapotranspiration capacity and improvement in heat absorption are a result of the change from permeable surfaces to impermeable built-up structures. As a result, the local thermal environment has gotten worse over time due to the growing surface urban heat island effect.



**3.3. Impact of Urbanization on Thermal Intensity**

Correlation analysis proves that urbanization is a dominant driver of regional warming. As the built-up percentage increased from 5.67% to 9.29%, the average temperature rose by 9.64°C. This direct relationship confirms that replacing natural, porous surfaces with impervious structures (concrete and brick) is intensifying the thermal stress in Skardu.



**3.4 Classification Accuracy**

The results of the accuracy assessment reveal an overall classification accuracy of 68.03% and a Kappa coefficient of 0.58, which suggests a fair level of consistency between the categorized and reference datasets. The highest producer's accuracy was found for the snow class (92.85%) and water bodies (81.39%), while built-up areas (59.61%) and barren land (58.13%) had lower accuracy due to terrain-induced shadow effects and spectral similarity. The findings indicate a fair level of categorization accuracy in challenging mountainous terrain.

Specified Classes	1994		2004		2014		2024	
	Covered Area in km (sq)	Covered Area in Percentage	Covered Area in km (sq)	Covered Area in Percentage	Covered Area in km (sq)	Covered Area in Percentage	Covered Area in km (sq)	Covered Area in Percentage
<b>Water</b>	<b>158.08</b>	<b>6.08</b>	<b>177.32</b>	<b>6.82</b>	<b>133.38</b>	<b>5.13</b>	<b>153.92</b>	<b>5.92</b>
Vegetation	143.26	5.51	236.6	9.1	143.26	5.51	172.64	6.64
<b>Built up</b>	<b>147.42</b>	<b>5.67</b>	<b>167.7</b>	<b>6.45</b>	<b>187.98</b>	<b>7.23</b>	<b>241.54</b>	<b>9.29</b>
Barren	1501.5	57.75	1480.44	56.94	1449.24	55.74	1371.24	52.74
<b>Snow</b>	<b>649.74</b>	<b>24.99</b>	<b>537.94</b>	<b>20.69</b>	<b>686.14</b>	<b>26.39</b>	<b>660.66</b>	<b>25.41</b>

**4. Discussion**

The outcomes of this research align with observations noted in other areas experiencing urban growth, although Skardu displays a distinct intensity. For example, on Jeju Island, urban development resulted in a SUHI intensity rise of just 0.63°C. In contrast, Skardu experiences a much more significant increase in LST of 9.64°C. This heightened intensity is presumably

linked to the elevated altitude, where solar radiation strikes more directly, along with the considerable thermal absorption of the nearby unoccupied desert soils.

Urban areas characterized by impervious materials, such as asphalt and concrete, have decreased albedo and increased heat retention compared to green spaces. Therefore, these materials collect more heat throughout the day and release it gradually during the night. Our findings indicate that even though barren land naturally remains warm, the shift to urbanized regions amplifies this heat due to human-induced elements, including emissions from vehicles and home heating, alongside diminished air circulation in densely developed zones. Such patterns are similar to those seen in significant cities such as Islamabad and Lahore.

The moderate level of classification accuracy achieved in this research can be linked to the intricate landscape of Skardu District. In areas of high-altitude mountainous terrain, barren ground and constructed surfaces frequently demonstrate comparable spectral reflectance traits, resulting in errors in classification. Furthermore, shadows cast by the terrain and mixed pixels add to the uncertainty in classification. Regardless of these challenges, the level of classification accuracy is still deemed appropriate for analyzing land use and thermal conditions at a regional scale.

## 5. Conclusion and Recommendations

The effects of urbanization on land use and land cover are thoroughly examined in this work. Land surface temperature (LST) and land use and land cover (LULC) dynamics in Skardu District over a 30-year period (1994–2024). Skardu has undergone a notable land cover change, mainly defined by [list of characteristics], as evidenced by the data. through the quick development of built-up regions at the expense of undeveloped land and natural surfaces. During the research period, the built-up area grew by about 64%, indicating rapid urbanization. growth fueled by tourism growth, infrastructure development, population growth, and commercial activity.

Additionally, the data indicate a significant increase in average land surface temperature, which rose from 15. From 89°C in 1994. 2024 will see a rise of 9 degrees to 53°C. 64°C. Spatial analysis shows that the greatest concentrations of temperature are always linked to urbanized regions. and exposed barren land, while comparatively lower temperatures are seen across water bodies, flora, and areas covered in snow. The emergence is confirmed by the strong positive link between the growth of impervious surfaces and the rise in LST. within this high-altitude mountainous area.

Even comparatively little and growing mountain towns are not immune to the thermal effects of uncontrolled urban growth, as shown by these results. Given the ecological vulnerability and climatic sensitivity of Skardu, proactive and climate-responsive urban planning In order to lessen additional thermal stress and promote long-term environmental sustainability, urgent strategies are needed.

The following recommendations are made in response to the observed warming trends:

### 5.1 Creating Green Infrastructure

The incorporation of green infrastructure, such as roadside tree belts, green roofs, vertical gardens, and urban plantations, and public green areas, may greatly lower surface temperatures by means of evapotranspiration and shading. Planting more vegetation in urban centers may help lower the temperature there by about 0. 3°C to 3. varies by plant density and geographic distribution, ranging from 0°C.

## 5.2 Employing Reflective and Cool Materials

The use of high-albedo building materials for roads, pavement, and building facades can lower heat absorption and improve surface reflectivity. Reflective coatings, cool roofs, and porous pavements can all help reduce heat buildup in heavily populated areas.

## 5.3 Urban Planning That Takes Climate Change Into Account

Sustainable land use planning laws should govern metropolitan growth. The thermal trends discovered in this study should be included in Skardu's future Master Plan to avoid heat-trap development and uncontrolled expansion. Priority should be given to zoning rules, managed building density, and the maintenance of open spaces.

## 5.4 Safeguarding Water Resources and Natural Surfaces

To sustain natural cooling processes, it is vital to protect existing plants, river corridors, wetlands, and snow-fed bodies of water. These organic attributes serve as thermal buffers and should be included in urban development plans.

## 5.5 Surveillance and Future Research

To aid evidence-based policy choices, continuous monitoring of LULC and LST using remote sensing and geographic technology is advised. Future studies may integrate climate modeling, seasonal analysis, and higher-resolution satellite data to gain a deeper insight into the thermal dynamics of cities in mountainous areas.

## 6. Study Limitations

This study faced certain limitations, including moderate classification accuracy and spectral confusion between barren and built-up surfaces in mountainous terrain. Future research may incorporate higher-resolution satellite imagery, texture-based classification approaches, and advanced machine learning techniques to improve classification precision and enhance urban thermal assessments in high-altitude regions.

## References

- Akbari, H., et al. (2001).** Cool surfaces and shade trees to reduce energy use and improve air quality. *Solar Energy*, 70(3), 295-304.
- Artis, D. A., & Carnahan, W. H. (1982).** Survey of emissivity variability in thermography of urban areas. *Remote Sensing of Environment*, 12(4), 313-329.
- Aslam, A., et al. (2021).** The spatiotemporal dynamics of urbanisation and local climate: A case study of Islamabad, Pakistan. *Environmental Impact Assessment Review*, 91, 106666.
- Bowler, D. E., et al. (2010).** Urban greening to cool towns and cities: A systematic review. *Landscape and Urban Planning*, 97(3), 147-155.
- Breiman, L. (2001).** Random Forests. *Machine Learning*, 45(1), 5-32.
- Chakraborty, T., & Lee, X. (2019).** A simplified urban-extent algorithm to characterize surface urban heat islands. *International Journal of Applied Earth Observation and Geoinformation*, 74, 269-280.
- Chander, G., et al. (2009).** Summary of current radiometric calibration coefficients for Landsat sensors. *Remote Sensing of Environment*, 113(5), 893-903.
- Estoque, R. C., et al. (2017).** Effects of landscape composition and pattern on land surface temperature. *Science of the Total Environment*, 577, 242-259.
- Farid, N., et al. (2022).** Monitoring the Impact of Rapid Urbanization on Land Surface Temperature in Lahore. *Frontiers in Remote Sensing*, 3, 847720.
- Foley, J. A., et al. (2005).** Global consequences of land use. *Science*, 309(5734), 570-574.
- Gorelick, N., et al. (2017).** Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18-27.

- Gu, Y., et al. (2021).** Spatiotemporal variation of land surface temperature in the Hindu Kush Himalaya region. *Science of the Total Environment*, 775, 145695.
- Jimenez-Munoz, J. C., et al. (2014).** Land surface temperature retrieval from Landsat 8 TIRS-binary thermal bands. *IEEE Geoscience and Remote Sensing Letters*, 11(10), 1840-1844.
- Kennedy, C., et al. (2009).** Greenhouse gas emissions from global cities. *Environmental Science & Technology*, 43(19), 7297-7302.
- Moazzam, M. F. U., et al. (2022).** Impact of Urbanization on Land Surface Temperature: A Case Study of Jeju Island. *Building and Environment*, 213, 108873.
- Mountain Research Initiative (2015).** Elevation-dependent warming in mountain regions. *Nature Climate Change*, 5(5), 424-430.
- Oke, T. R. (1982).** The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, 108(455), 1-24.
- Patz, J. A., et al. (2005).** Impact of regional climate change on human health. *Nature*, 438(7066), 310-317.
- Sobrino, J. A., et al. (2004).** Surface temperature retrieval from LANDSAT TM 5. *Remote Sensing of Environment*, 90(4), 434-440.
- Ullah, S., et al. (2019).** Analysis of land cover changes and their impacts on LST in a lower Himalayan region. *Journal of Environmental Management*, 236, 103-112.
- United Nations (2019).** World Urbanization Prospects: The 2018 Revision. *UN Department of Economic and Social Affairs*.
- Voogt, J. A., & Oke, T. R. (2003).** Thermal remote sensing of urban climates. *Remote Sensing of Environment*, 86(3), 370-384.
- Weng, Q., et al. (2004).** Estimation of LST-vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment*, 89(4), 467-483.
- Wheeler, S. M. (2004).** *Planning for Sustainability: Creating Livable, Equitable, and Ecologically Sound Communities*. Routledge.
- Xiong, Y., et al. (2012).** The impacts of rapid urbanization on the thermal environment: A remote sensing study of Guangzhou, South China. *Remote Sensing*, 4(7), 2033-2056.