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Tourism based landuse change and Recurring Land subsidence events in Joshimath area, Uttarakhand

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Abstract : *Land subsidence in Joshimath is a pressing issue driven by a combination of natural and human-induced factors. The town's seismic activity and fragile geology have been exacerbated by rapid and uncontrolled tourism growth, which has led to unplanned construction, deforestation, and inadequate drainage systems. These land use changes, spurred by tourism, have placed immense pressure on the town's already unstable slopes. Recurring land subsidence incidents, particularly severe in 2022-23, have caused widespread damage, forcing residents to abandon their homes due to large cracks in buildings and infrastructure. This study focuses on the recurring subsidence events in Joshimath, a part of the Alaknanda Basin, and highlights the significant role that tourism-driven development plays in destabilizing the region. Despite its growing population and strategic importance, Joshimath remains highly vulnerable to both gradual and sudden subsidence events. The paper also examines the socio-economic impacts of these events and calls for sustainable tourism practices to mitigate future risks.*

Key words: *Joshimath, Land subsidence, Uncontrolled development, Population pressure, Infrastructure expansion.*

Introduction

Joshimath, a prominent town in the Chamoli district of Uttarakhand, holds immense geographical, religious, and ecological significance. Nestled in the Garhwal Himalayas at an elevation of over 6,000 feet, it serves as a gateway to several revered pilgrimage sites, including Badrinath and Hemkund Sahib, as well as the popular ski destination of Auli. However, in recent years, the town has faced alarming environmental challenges, primarily due to recurring land subsidence events, which have posed significant risks to its infrastructure and inhabitants.

Several studies have examined the issue of land subsidence in Joshimath (Fig.1) and its surrounding areas. Bisht (2010) identified both natural and anthropogenic causes as contributors to the recurring subsidence events. His research emphasized the urgent need to study the impacts of uncontrolled tourism, a factor often overlooked by many scientists, despite its significant role in altering land use patterns. Valdiya (1984) provided a comprehensive review of the tectonic landscape in South-Central Asia, shedding light on the complex geological processes shaping

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the region's seismic activities. His work offers a foundational understanding of the tectonic vulnerabilities of the region, which are crucial for contextualizing land subsidence in Joshimath.The Mishra Commission Report (1964) remains a seminal work that stressed the need for sustainable development in the fragile Himalayan landscape. It highlighted the geological risks associated with land subsidence and called for strict regulations on construction in areas like Joshimath, which rests on ancient landslide debris. Bisht (2010) reinforced the importance of ongoing tectonic research, recognizing the dynamic nature of the region's geology. Awasthi et al. (2024) specifically analyze the sinking of Joshimath, utilizing remote sensing techniques to assess the causes, consequences, and future prospects of land subsidence. Their study synthesizes geological, climatic, and anthropogenic factors, providing a comprehensive view of the issues facing this vulnerable region. By highlighting the intricate interplay of tourism, land use changes, and environmental hazards, this research contributes valuable insights for policymakers aiming to achieve sustainable development in ecologically sensitive areas.

Tourism's impact on the environment has long been debated, with Budowski (1976) discussing the conflict between tourism and environmental conservation. His work advocates for a balanced approach, promoting coexistence where tourism activities can sustain local economies without further degrading natural resources. Similarly, Hunter and Green (1995) explored sustainable tourism, proposing that environmental impacts can be mitigated through responsible tourism practices. Mathieson and Wall (1982) extended this discussion by analyzing tourism's economic, physical, and social impacts, offering insights into how tourism can reshape destination areas like Joshimath.Urbanization in mountain towns also brings unique challenges. Damea et al. (2019) studied Leh in Ladakh, identifying how urbanization strains natural resources and alters landscapes, similar to what has occurred in Joshimath. Their findings suggest the need for sustainable urban planning in fragile environments. Holloway (2009) explored the business aspects of tourism, emphasizing its economic importance while also pointing out the risks of overdevelopment, which parallels the situation in Joshimath, where rapid infrastructure growth has contributed to land instability.In the context of tectonics, Valdiya (2003) investigated seismic activities in the Himalayan region, providing crucial insights into fault reactivation and its potential to exacerbate subsidence. The tectonic setting of Joshimath, located near the Main Central Thrust, makes it particularly susceptible to these risks. Sharma and Mohanty (2018) expanded on this by using morphotectonic analysis and GNSS observations to assess the tectonic activity in the Alaknanda Basin, reinforcing the connection between seismicity and land subsidence.

The intersection of tourism, environmental change, and geological stability has garnered significant attention in recent research. Peeters et al. (2023) address current issues in sustainable tourism, emphasizing the critical need to mitigate climate change impacts within the tourism sector. Their findings highlight how tourism practices can be adapted to contribute positively to environmental sustainability, framing climate change as a pressing concern for tourism stakeholders.In the context of geological hazards, Rawat and Pant (2023) developed a

geoenvironmental Geographic Information System (GIS) to investigate landslides and slope instability in the Central Himalayas. This study underscores the importance of integrating advanced technology (Awasthi, S. et al) with traditional environmental studies to enhance understanding of land instability, which is particularly relevant to regions like Joshimath, where tourism and natural hazards intersect. Nautiyal et al. (2022) further explore the geo-climatic environment's spatio-temporal variations in the Central Himalayas, focusing on the vulnerability of glacial lakes. Their research reveals how climatic changes threaten glacial stability, leading to significant consequences such as glacial lake outburst floods, which align with Sati's (2022) study on debris flows and flash floods in the Rishi and Dhauli Ganga valleys. This work highlights the critical relationship between glacial dynamics and water-related disasters, emphasizing the need for disaster preparedness in vulnerable mountain regions.Siddique et al. (2022) provide an in-depth analysis of the geological and meteorological factors contributing to the Chamoli disaster of 2021, highlighting the complex interactions that precipitated the catastrophic event. Their research underscores the need for a multidisciplinary approach to disaster risk management, integrating geological assessments with meteorological data to improve predictive capabilities. The National Disaster Management Authority (NDMA) provided a detailed report on the February 7, 2021, disaster, offering comprehensive insights into the extent of the disaster's impact and the effectiveness of response measures. This document serves as a vital resource for understanding the lessons learned from past events and improving future disaster preparedness strategies.

The Uttarakhand Tourism Development Master Plan (2007 - 2022) provides a strategic framework for tourism development in the state, emphasizing the importance of sustainable practices to preserve natural and cultural resources. This plan is vital for guiding tourism policies in light of the region's vulnerability to disasters, reinforcing the need for sustainable tourism development that minimizes environmental impact. Bisht and Rautela (2010) discuss the looming threats to Joshimath, focusing on the interplay of rapid urbanization and geological instability. Their work highlights the urgent need for proactive measures to address the risks associated with land subsidence and tourism-related pressures in the area.Koens et al. (2018) investigate the phenomenon of overtourism, analyzing its effects on urban environments. Their research draws attention to the necessity of understanding tourism's impact within a broader urban context, which can provide valuable insights for managing tourist influxes in sensitive areas like Joshimath.

Overall, these studies underscore the urgent need for integrated approaches that consider environmental sustainability in tourism development, particularly in regions prone to geological instability and climate change. The collective findings advocate for proactive measures to mitigate risks, preserve natural resources, and promote sustainable practices that balance economic growth with ecological integrity. The rapid growth of tourism and urbanization, compounded by the region's inherent tectonic vulnerabilities, necessitates ongoing research and policy adaptation to mitigate environmental degradation and land subsidence. Despite existing literature on environmental challenges in Joshimath, a significant gap remains regarding the impact of tourism-

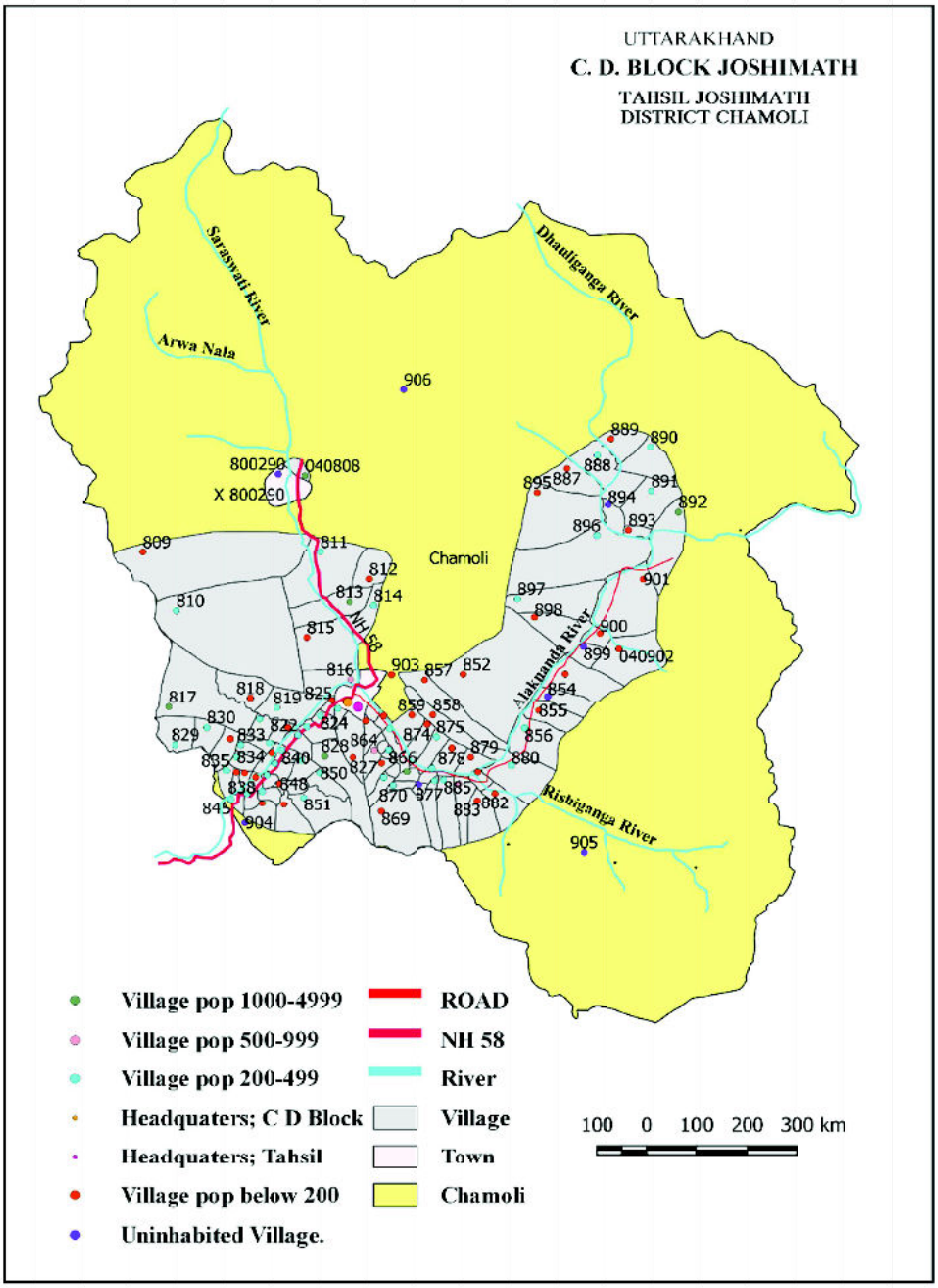

Fig. 1. Location Map of Joshimath: Area of Land Subsidence

(Source: Census of India, 2011, Prepared by author)

driven land use changes on recurring land subsidence events. While studies identify various natural and anthropogenic factors contributing to subsidence, the specific role of uncontrolled tourism in exacerbating land instability has not been adequately explored. Additionally, there is limited empirical data quantifying the relationship between tourism intensity and land subsidence. This research aims to bridge these gaps by examining the interconnections between tourism, land use changes, and geological stability, providing insights for more effective management strategies in the region.

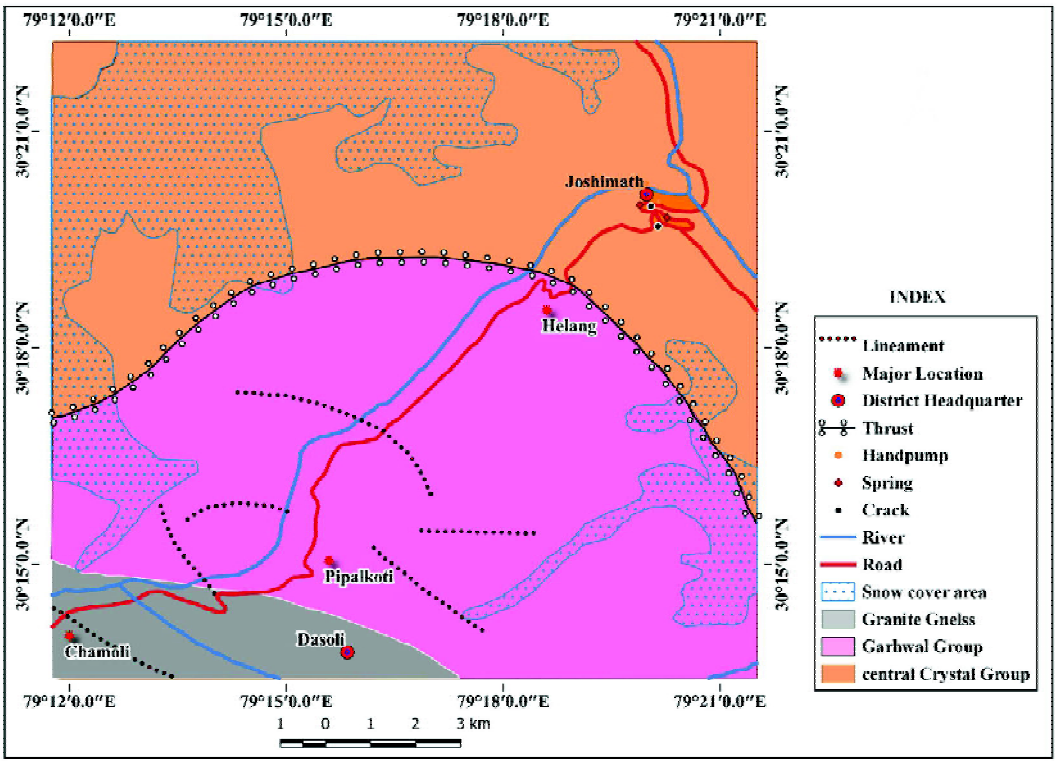

Fig. 2. Geological Structure of the Joshimath Region: Mapping Faults and Rock Formations

(Source: After: K. S. Valdiya, 1999, Prepared by author)

Regional Setting:

Joshimath is located in the Chamoli district of Uttarakhand, India, nestled in the Garhwal Himalayas. Positioned at an elevation of approximately 1,890 meters (6,200 feet) above sea level, it is situated on the northwestern bank of the Alaknanda River. The study area (Fig.1) encompassing Joshimath town (79.56° N; 30.55° E) is located in the Higher Himalayas within the

Chamoli District of Uttarakhand, India.Joshimath is situated in the highly vulnerable seismic Zone V of the Himalayas, built on approximately 0.5 meters of debris from ancient landslides.

The underlying bedrock consists of sheared, folded, fractured, and faulted gneisses typical of the Higher Himalayas. The town is located near two major intracontinental thrusts: the Munsiari Thrust and the Main Central Thrust (Vaikrita Thrust). The Munsiari Thrust places various Lesser Himalayan gneisses and schists over metasedimentary rocks of the Lesser Himalayas. The landscape is marked by a series of ridges with progressively decreasing heights, featuring limited flat land.The soils in this region are natural, dynamic, and heterogeneous, supporting diverse plant life and agricultural ecosystems. These soils have developed from various rock types, including granite, schist, gneiss, phyllite, shale, and slate, under cool and moist climatic conditions. Previous studies have highlighted the combination of eco-tectonic and geomorphic factors, along with meteorological influences, that render Joshimath particularly susceptible to land subsidence.Located in Chamoli District, Joshimath has experienced several minor earthquakes (below 5 on the Richter scale). It is positioned near significant geological fault lines, including the Vaikrita Thrust, Main Central Thrust (MCT), and Pandukeshwar Thrust (PT). The MCT runs (Fig.2) beneath Helang, just south of Joshimath, and interacts with the Garhwal Group's rocks, making the area susceptible to tectonic activity. Despite these vulnerabilities, the Border Roads Organisation (BRO) is constructing the Helang bypass, aimed at reducing travel distance to Badrinath by approximately 30 km. However, the use of heavy machinery in this construction poses an increased risk of landslides. The Mishra Commission Report of 1976, led by then-Commissioner MC Mishra, had already recommended a ban on heavy construction in the Joshimath area due to its geological vulnerabilities.

Materials and methods

Materials

This study investigates tourism-based land use changes and recurring land subsidence events in the Joshimath area of Uttarakhand, utilizing a range of advanced remote sensing and GIS techniques. The methodology is structured to provide comprehensive insights into land use and land cover (LULC) dynamics, particularly in relation to the impacts of tourism planning.High-resolution satellite imagery from Google Earth was used to obtain baseline data for visual interpretation and preliminary analysis of land use changes in the Joshimath area.This dataset provided detailed imagery that supports the identification of specific land cover types and changes over time, particularly in relation to urban development and natural landscape alterations.The Sentinel-2 dataset was utilized for its high spatial resolution and spectral bands, which are essential for accurately identifying various land cover types.ArcGIS software was employed for spatial analysis and mapping of LULC changes. It facilitated the integration of various data layers, including tourism infrastructure and natural features.This software was used for processing satellite images, enabling tasks such as radiometric correction, geometric correction, and dark object

subtraction, which are crucial for enhancing the quality and accuracy of the images.Cloud-free median images from the non-monsoon period were downloaded from GEE, ensuring the use of optimal images for analysis.The SVM algorithm was applied for image classification within ArcGIS, allowing for the effective categorization of land cover types based on spectral characteristics.

This study focuses on understanding tourism-driven land use changes and recurring land subsidence events in the Joshimath area, Uttarakhand. To achieve the desired results, the research was designed around advanced remote sensing and Geographic Information Systems (GIS) technologies, combined with field observations. The approach ensures that the analysis of land use and land cover (LULC) dynamics in the context of tourism planning is both comprehensive and accurate. The research employed two key datasets: Google Earth Imagery, which provided high-resolution visual data (up to 30 cm) for historical analysis of land use changes, and the Harmonized Sentinel-2 MSI: MultiSpectral Instrument, Level-2A, January 2024 dataset from the European Space Agency (ESA), featuring a spatial resolution of 10 meters for visible and near-infrared bands. Together, these datasets enabled a comprehensive analysis of land use dynamics and subsidence patterns, offering valuable insights for effective tourism planning in the region.

Methodological Approach

This study employs a comprehensive methodology to analyze tourism-based land use changes and their correlation with recurring land subsidence events in the Joshimath area, Uttarakhand. Through the integration of satellite imagery, remote sensing techniques, and GIS-based analysis, this study provides a comprehensive framework for understanding the relationship between tourism development and recurring land subsidence in Joshimath. The chosen parameters—LULC changes, tourism infrastructure expansion, and geological vulnerability—are key to deriving actionable insights for sustainable land management in the region. The results will inform better decision-making, aimed at mitigating the environmental and human risks associated with unregulated tourism. The study mapped Land Use and Land Cover (LULC) changes to assess how tourism-related developments, such as infrastructure expansion and deforestation, have affected Joshimath's fragile landscape, highlighting areas increasingly vulnerable to subsidence. A detailed analysis of tourism infrastructure, including hotels and roads, identified how construction activities compromise land stability, pinpointing subsidence-prone areas where preventive action is needed. Additionally, geological maps and GIS data were used to examine fault lines and subsurface conditions, linking tourism-induced changes to the region's geological vulnerability and identifying areas most at risk for future subsidence events.

The research utilizes various satellite datasets, including Google Earth images, Planet-Scope imagery, and Sentinel-2 MSI Level-2A data, to capture and assess LULC dynamics over time. The process begins with downloading cloud-free median images from the non-monsoon periods via Google Earth Engine (GEE) to ensure clarity and accuracy in the analysis.Following the acquisition of images, radiometric correction, geometric correction, and dark object subtraction are performed

using ENVI 5.3 to enhance image quality and reduce distortions caused by atmospheric conditions. The corrected images are then classified using the Support Vector Machine (SVM) algorithm in ArcGIS. SVM is selected for its effectiveness in handling complex data and its ability to accurately classify various land cover types based on training data.To detect land use changes, classified images from different time periods are compared, allowing for the identification of trends related to tourism development and its impacts on the landscape. Additionally, the study integrates tourism data, including infrastructure expansion and visitor statistics, to analyze how these changes influence land subsidence in the region.Finally, statistical analyses and spatial correlation techniques are employed to examine the relationship between identified LULC changes and occurrences of land subsidence. By combining remote sensing and GIS technologies, this methodology aims to provide valuable insights into the interconnections between tourism, land use changes, and geological stability in Joshimath, ultimately informing sustainable development practices in the area.In summary, the methodologies employed in this study, combining advanced remote sensing techniques with rigorous spatial analysis, provide a comprehensive framework for understanding the intricate relationship between tourism-driven land use changes and the recurring subsidence events in Joshimath, ultimately contributing to the development of informed and sustainable management strategies for this vulnerable region.

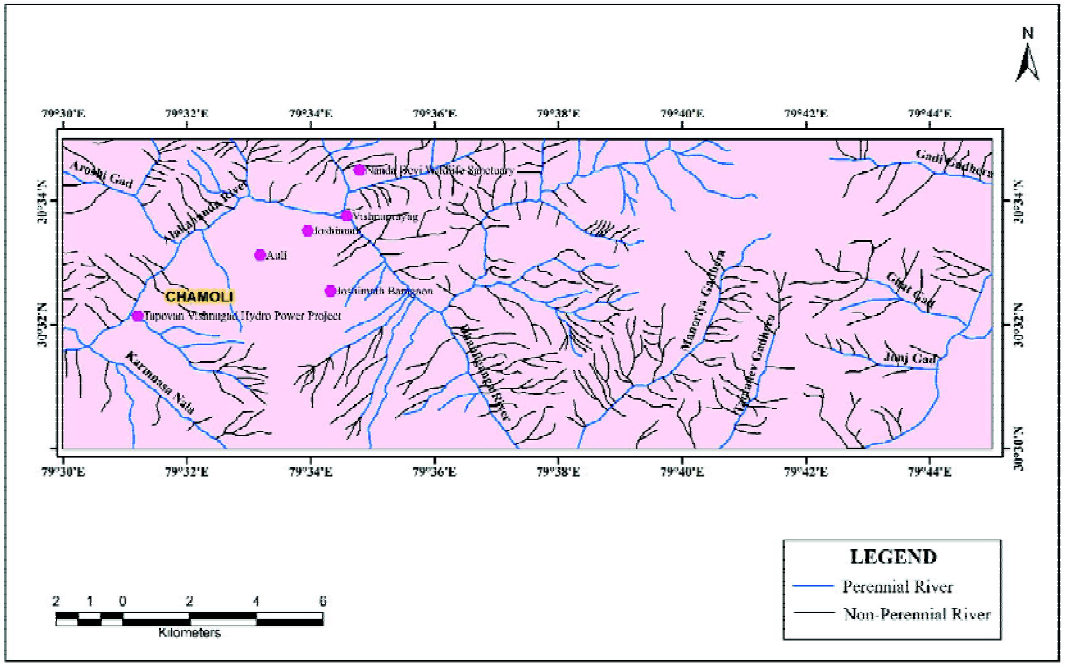

Fig. 2a. Hydrological network within the Joshimath region.

(Source: Toposheet 53N/10, 2011, Prepared by author)

Results and Discussion on Land Subsidence in Joshimath: Impacts and Implications

Results:

The field survey was carried out to document the physical signs of land subsidence and gather data on affected structures and infrastructure. The survey encompassed various neighborhoods within Joshimath, including residential areas, commercial zones, and key infrastructure sites such as roads, bridges, and public buildings.Many of these cracks were found to be deepening, with widths ranging from 2 m to over 4 m in some areassuch as Singhdhaar, Hotel Mountain View, Malhari Hotel, and Manoharbagh. The most severely affected structures included older buildings and those constructed without adhering to modern engineering standards.Notably, the majority of cracks were concentrated in areas experiencing high tourist footfall and rapid construction activity, indicating a potential correlation between subsidence and anthropogenic pressures.Roadways and pathways showed signs of subsidence, with uneven surfaces and fissures causing accessibility issues.

The region has experienced several significant landslides, particularly during the monsoon season, with notable events occurring in the 1970s and 1980s, as well as more recent incidents in 2021-2022 that led to infrastructure damage and displacement of residents. Human activities, including construction and urbanization, have exacerbated the landslide risk by destabilizing slopes and disrupting natural drainage patterns. As per the Joshimath Bulletin 2023, the data highlights a critical issue of land subsidence impacting various parts of the city. A total of 868 buildings have been reported with cracks, with 181 of these structures located in unsafe zones. The most severely affected area is Singhdar, where 98 buildings are classified as unsafe, followed by Gandhinagar and Sunil, each with 28 unsafe structures. In contrast, wards like Paika-Marwari, Lower Bazar, Uppar Bazar, Parsari, and Ravigram have buildings with cracks but are not considered immediately unsafe. The Joshimath Bulletin 2023 emphasizes the urgency of addressing these vulnerabilities, particularly in high-risk zones, where evacuation and structural reinforcement may be necessary to ensure the safety of residents and prevent further damage. This data underscores the need for a coordinated response to mitigate the ongoing subsidence crisis and safeguard the infrastructure of Joshimath.

Older Structures in Joshimath:

The analysis revealed that older structures in Joshimath were more significantly affected by land subsidence compared to newer constructions. The field survey documented that many of the older buildings, some dating back several decades, exhibited extensive damage, including deep cracks and structural instability. In contrast, newer constructions, which generally adhered to more modern engineering standards and regulations, showed relatively minor signs of subsidence.The older structures were often built without adequate consideration for the geological conditions of the area, lacking essential provisions for drainage and stability. As a result, they have been more vulnerable to the ongoing subsidence issues, particularly in a region where the underlying

geological conditions are characterized by ancient landslide debris and a loose matrix of unconsolidated materials.In many cases, the foundations of these older buildings did not account for the subsurface instability, leading to greater susceptibility to ground movement. This was particularly evident in neighborhoods where heavy rainfall or seismic activity had exacerbated the effects of subsidence. For instance, during the recent subsidence events, older homes were found to tilt or suffer from significant structural damage, while newer buildings, designed with more robust construction techniques, exhibited only minor cracking.This disparity in the extent of damage between old and new structures highlights the critical need for assessing the structural integrity of existing buildings and enforcing strict construction guidelines for future developments. Addressing the vulnerabilities of older buildings is essential to ensuring the safety of residents and mitigating the impacts of ongoing subsidence in Joshimath.

History of Land subsidence:

Subsidence in Joshimath is not a new phenomenon; rather, it has a long history of land subsidence issues. Since 1962, extensive construction activities have been ongoing in the town, primarily driven by the influx of tourists attracted to skiing and other winter sports. This construction boom has resulted in the significant deforestation of the area, as large numbers of trees were cut down to facilitate development and improve facilities for visitors. Historical records indicate that unregulated construction practices, lacking adequate provisions for water drainage, have led to subsidence in various parts of Joshimath (Bhatt, 1994).In 1976, the Uttar Pradesh government established an 18-member committee led by M.C. Mishra, then the Commissioner of Garhwal, to investigate the issue of land subsidence in the area. The committee's report emphasized that "Joshimath is not situated on in situ rocks but rather rests on weathered landslide debris composed of large unsettled boulders embedded in a loose matrix of fine micaceous sandy and clayey materials." It also noted that the town is built on an ancient landslide site of substantial size, highlighting the inherent geological vulnerabilities of the region.

Sinking town:

Beginning in early January 2023, Joshimath gained notoriety as a "sinking town," with both residential and commercial structures, as well as road infrastructure, showing significant cracks. Many areas became unlivable or unusable, prompting the state government to declare Joshimath a "disaster-prone area." In response, authorities banned further construction in and around the town and ordered the evacuation of over 600 families from danger zones, while also demolishing several unsafe structures.Recent observations from the Indian Space Research Organisation (ISRO) have confirmed ongoing subsidence in Joshimath. Between April and November 2022, the rate of subsidence was recorded at approximately 9 cm. However, from December 27, 2022, to January 8, 2023, the situation escalated as slow subsidence transformed into rapid subsidence. The crown of the subsidence event was identified near the Joshimath-Auli road at an elevation of 2,180 meters, correlating with new satellite data acquired from Cartosat-2S.In the early hours of January 2, 2023,

residents in several buildings were startled awake by the sounds of cracking walls and floors. While the development of cracks had been observed in the past, the speed and severity of this recent event were unprecedented. Reports indicated that approximately 670 houses exhibited multiple cracks of varying widths, and water began to seep out of agricultural fields, indicating the ground's instability. Several buildings started to tilt, providing clear evidence that parts of the town were subsiding.

In response to the ongoing land subsidence crisis in Joshimath, local authorities implemented a systematic assessment of affected buildings, marking those with significant structural damage with a "red cross." This designation serves as a warning to residents and indicates that the buildings are deemed unsafe for occupancy due to the severity of the cracks and other signs of instability.The field survey revealed that many structures marked with a red cross were older buildings that had not been constructed with modern engineering practices. These buildings exhibited deep and widening cracks, tilted foundations, and signs of subsidence that posed serious risks to the safety of their occupants. In contrast, newer constructions generally fared better, with fewer instances of significant damage, although some newer structures also showed minor cracking due to the overarching geological instability.The decision to mark these buildings was made after thorough inspections by engineers and local officials, who assessed the extent of the damage and the potential risks posed by ongoing subsidence. The red cross designation effectively communicated the urgency of the situation to the community, prompting evacuations in some cases and raising awareness about the need for immediate action.

Residents living in buildings marked with a red cross were advised to vacate the premises to ensure their safety, and local authorities began coordinating temporary housing solutions for displaced families. This proactive measure reflects the seriousness of the subsidence issues in Joshimath and underscores the need for ongoing monitoring and assessment of building conditions in the context of the region's geological vulnerabilities.

Discussion

The results of the field survey underscore the multifaceted nature of land subsidence in Joshimath, revealing a complex interplay between geological, environmental, and human factors.

Geological Context:

The geological composition of Joshimath, characterized by its location on ancient landslide debris and proximity to active fault lines, contributes significantly to its vulnerability to subsidence. The ongoing tectonic movements associated with the Himalayan uplift result in stress accumulation within the earth's crust, leading to gradual land sinking.The loose and unconsolidated materials in the subsurface amplify the effects of heavy rainfall and groundwater infiltration, particularly during the monsoon season. Saturated soils lose cohesion, leading to increased risks of landslides and further subsidence.

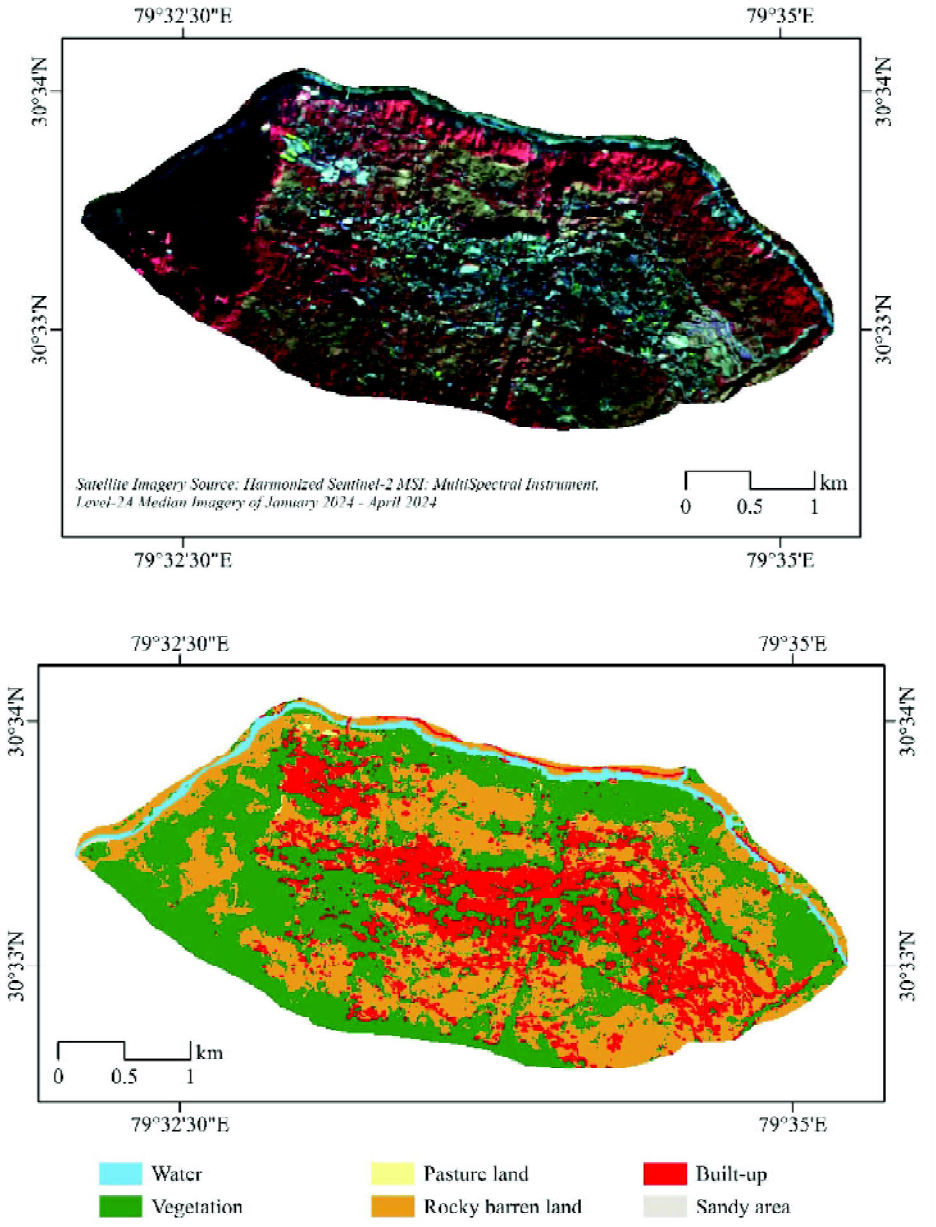

Fig. 3 Land Use Map of the Joshimath Area Using Sentinel Data

(***Source:*** *Harmonized Sentinel-2 MSI: Multi Spectral Instrument, Level-2A, January, 2024, Prepared by author)*

Landuse Changes:

The analysis of land use in the Joshimath Block, based on the 2011 Census data, reveals significant insights into the region's agricultural and non-agricultural land distribution, population density, and land management practices. The block encompasses a total forest area of 23,993 hectares, constituting approximately 10.6% of the total area, while 178,952 hectares (around 79.2%) are allocated for non-agricultural uses, reflecting urbanization trends. Additionally, 2,670 hectares (about 1.2%) are classified as barren and uncultivable land, presenting challenges for productivity. The presence of 1,506 hectares (approximately 0.7%) for permanent pastures suggests a continued reliance on traditional livestock farming. Notably, the net area sown is 3,505.5 hectares (about 1.5%), while 10,061 hectares (approximately 4.4%) of land remain fallow, indicating underutilization of agricultural potential. The low irrigated area of 180.4 hectares (around 0.1%) compared to 3,325.1 hectares (about 1.5%) of un-irrigated land highlights a dependence on rain-fed agriculture, increasing vulnerability to drought. With a population of 29,053 across 7,608 households and a density of 13.04 persons per square kilometer, the block appears sparsely populated, suggesting a need for improved infrastructure and services to support rural development and economic sustainability.

The land use (Fig.3) changes in Chamoli District over the last 20 years reveal significant transformations. Built-up areas have dramatically increased from 552.58 km² (7.27%) in 2000 to 1,094.15 km² (14.39%) in 2020, indicating urbanization and development pressures. Water bodies

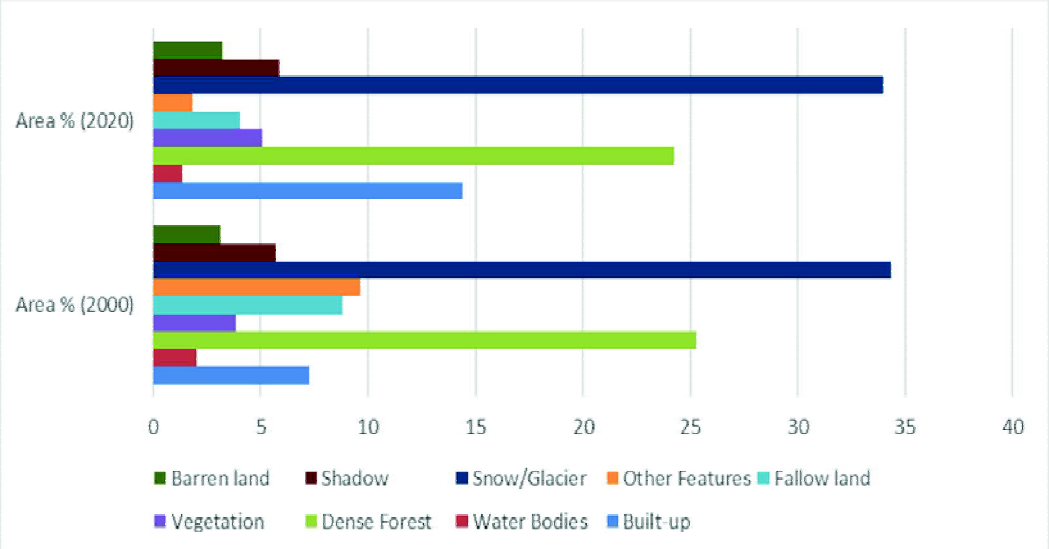

Fig. 4. Two Decades of Land Use Transformation in Chamoli District (2000-2020)

(Source: Image Analysis, LISS III, NRSC, 2020 & 2000 & Chamoli District Land Use Analysis Data, Prepared by author)

have decreased from 155.41 km² (2.04%) to 103.78 km² (1.36%), reflecting potential environmental challenges. Dense forest cover slightly decreased from 1,920.51 km² (25.26%) to 1,843.55 km² (24.24%), while vegetation increased (Fig.4&5) from 290.81 km² (3.82%) to 385.88 km² (5.07%). Notably, snow and glacier areas expanded from 2,610.07 km² (34.32%) to 3,039.52 km² (39.97%), highlighting the effects of climate change in the region.

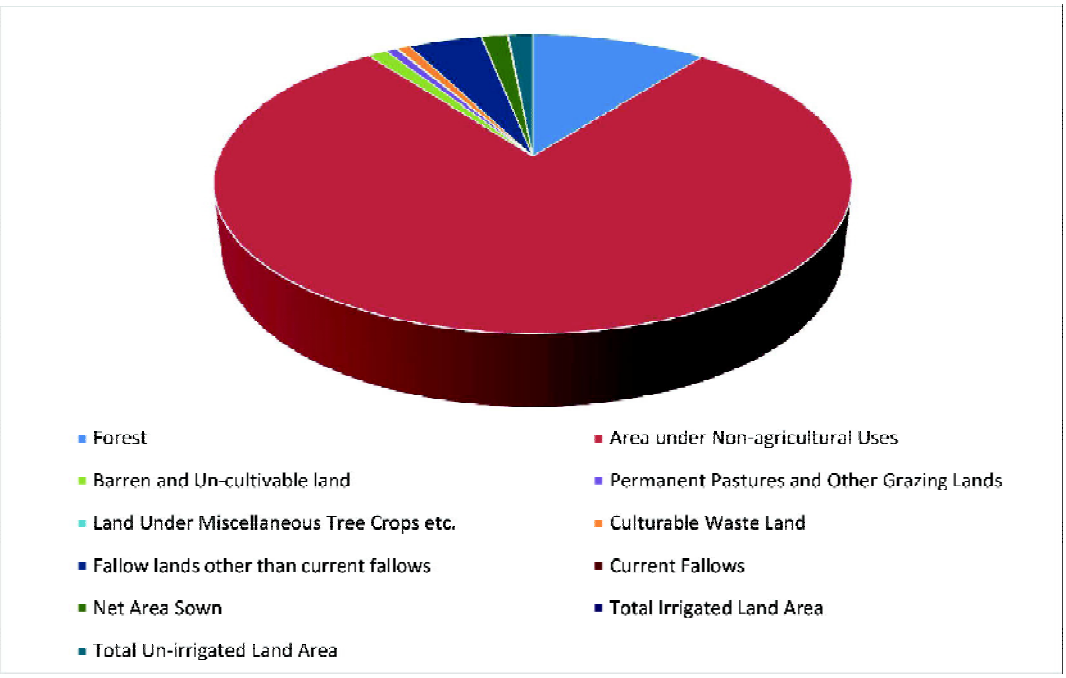

Fig. 5. Distribution of Various Land Use Categories in the Joshimath Block as Recorded in the 2011 Census *(Source: Census of India, 2011, Prepared by author)*

Impact of Tourism and Urbanization on Land Subsidence:

The rapid urbanization driven by the burgeoning tourism industry has intensified land use changes in Joshimath, leading to unregulated construction practices and deforestation. This growth has placed immense pressure on the region's delicate geological framework, exacerbating the potential for subsidence.Construction activities often overlook essential engineering principles necessary for building in a seismically active area, leading to structures that are ill-equipped to withstand the challenges posed by both subsidence and seismic events.The surge in tourism has led to extensive construction activities aimed at developing infrastructure, including hotels, restaurants, and recreational facilities. This unregulated construction often overlooks the region's geological vulnerabilities, resulting in buildings erected on unstable soil and without adequate

provisions for drainage and stability. The weight of new structures can exacerbate ground instability, particularly in areas built on ancient landslide debris.The construction of roads, paths, and other infrastructure for tourism can contribute to soil compaction and erosion. The heavy machinery used during construction alters the natural landscape and can disturb soil layers, making them more prone to failure during periods of heavy rain or seismic activity. This disturbance can lead to increased rates of subsidence, particularly in regions where natural drainage patterns have been altered.

Table 1: Landuse Data of Joshimath Block, 2011

Area under different types of land use	Forest	Area under Non-agricultural Uses	Barren and Un-cultivable land	Permanent Pastures and Other Grazing Lands	Land Under Miscellaneous Tree Crops etc.	Culturable Waste Land	Fallow lands other than current fallows	Current Fallows	Net Area Sown	Total Irrigated Land Area	Total Unirrigated Land Area
(in hectares	23993	178952	2670	1506	177.5	1768	10061	76.5	3505.5	180.4	3325.1

Source: Statistical Report of Chamoli District, 2011

Socio-Economic Implications:

The rapid urbanization associated with tourism can lead to changes in the social fabric of Joshimath. As the population grows and the town transforms to accommodate tourists, local residents may face challenges such as displacement, loss of cultural heritage, and changes in their traditional lifestyles. These social dynamics can further complicate the management of land subsidence and the implementation of sustainable development practices. The implications of land subsidence extend beyond structural damage; they pose a significant threat to the local economy, particularly tourism, which is a primary source of income for many residents. Disruption of access to pilgrimage sites due to damaged roads and infrastructure could deter visitors, negatively impacting local businesses.The increasing population in Joshimath, driven by the growth of tourism, has intensified the demand for infrastructure and services, further straining the region's already fragile environment.Furthermore, the psychological impact on residents cannot be understated. The fear and uncertainty surrounding land stability affect community well-being and may lead to migration pressures as people seek safer living conditions.

Impact of Tourism:

Tourism is one of the biggest and fastest-growing economic sectors in the global economy and has significant environmental, cultural, social, and economic effects, both positive and negative(Singh,2018). The author thinks that there is a clash between uncontrolled tourism and

environmental condition of the area.Generally, conflicts emerge when tourism has detrimental effects on the environment and when there is little contact between tourism and conservation. Day by day environmental condition of Joshimathis being deteriorated by intensive anthropogenic activities increasing ecological vulnerability. So, the present research on uncontrolled tourism and recurring Land subsidence events has a great significance in terms of sustainability of the town and conservation of its natural resources. The present discussion must play important role towards sustainable development of tourism in Joshimath.

Recommendations for Mitigation:

To address the challenges of land subsidence, a multi-faceted approach is essential. This includes implementing strict building regulations that consider the unique geological conditions of Joshimath, enhancing monitoring systems for subsidence and seismic activity, and investing in infrastructure upgrades.

The relief fund distributed to affected families in Joshimath totaled ₹ 3,935 lakh, providing essential support for immediate needs and long-term rehabilitation efforts in response to the structural damage caused by land subsidence.A total amount of ₹ 3935.00 lakh was disbursed to 173 families as part of the compensation outlined in the rehabilitation policy. Additionally, further breakdowns reveal specific funds allocated for various needs. For instance, an advance special rehabilitation package of ₹ 324.00 lakh was provided to 324 families before their permanent residences were prepared. Funds for transportation and immediate relief amounted to ₹ 180.50 lakh for 361 families, while ₹ 150.00 lakh was distributed as a one-time special grant to 300 families for carrying goods. Other disbursements include ₹ 3.60 lakh for household items, ₹ 13.00 lakh for severely damaged buildings, ₹ 2.42 lakh for house rent, and ₹ 4.93 lakh in ex-gratia relief through MNREGA. In total, ₹ 678.45 lakh was distributed through these specific relief measures, reflecting the efforts to address both immediate and long-term rehabilitation needs for the affected families.

Conclusions

The discussion surrounding tourism-based land use changes and recurring land subsidence events in the Joshimath area highlights the complex interplay of physical factors, including geotectonics, topography, and climatic characteristics within a periglacial environment. These factors have shaped the polygenetic landscapes of the Alakananda Valley through various geomorphic processes such as glacial, periglacial, fluvial, and tectonic activities. The region's susceptibility to extreme climatic events, coupled with its inherent tectonic vulnerabilities, significantly impacts the changing land use patterns in Joshimath and its surroundings.The rapid expansion of manmade constructions and settlement areas, particularly in unstable slope regions, has raised critical concerns regarding safety and sustainability. The ongoing large-scale interventions in fragile mountain ecosystems threaten not only precious lives and livelihoods but also the integrity of the landscapes themselves.In light of these findings, it is imperative for stakeholders to adopt a proactive approach to urban planning that prioritizes sustainable

development and disaster risk reduction. This includes implementing rigorous land use regulations, promoting responsible tourism practices, and enhancing community engagement in decision-making processes. Failure to address these challenges may result in irreversible damage to the unique and vulnerable ecosystems of Joshimath, compromising the future well-being of its residents and the preservation of its natural heritage.

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