



# Disaster-development interface and its impact on emerging vulnerability scenario in Ladakh region of northwestern Himalayas

M. Shafi Bhat<sup>1</sup> · Amir Ali Khan<sup>2</sup> · Mohmad Akbar<sup>1</sup> · Sumira Mir<sup>1</sup>

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## Abstract

The Union Territory of Ladakh, located in the northwestern Himalayan region, is highly vulnerable to natural and anthropogenic hazards like earthquakes, landslides, snow avalanches, flash floods, cloud bursts, and border conflicts. Occurrences of these disasters have significantly influenced the development and vulnerability scenario of Trans-Himalayan Ladakh. Findings reveal that despite suffering losses from natural and human-induced disasters, the region has benefited by grabbing the attention of policymakers at the national level. Consequently, long-term developments were positively impacted, reflecting infrastructural upgradation, improved transportation and communication, profoundly improving the socio-economic well-being of the people. Furthermore, post-disaster developments have managed to showcase the unique physiography and adventurous terrains of Ladakh, promoting tourism as the main economic driver in the region. The exponential growth of tourism and associated sectors have influenced the vulnerability scenario, which was quantified using the multi-criterion-based analytical hierarchical processes (AHP) method, indicating an increase in climate change-related vulnerability, followed by socio-cultural, environmental, and physical vulnerabilities. Specifically, the vulnerabilities with respect to flash floods, landslides, erratic rainfall, haphazard constructions, cultural dilution, water crisis, and changes in land use patterns have been exacerbated across the study area. The study highlights the need for effective management of these emerging vulnerabilities through proper planning to ensure long-term sustainable development goals in this environmentally fragile region.

**Keywords** Disaster · Kargil-Ladakh · Trans-Himalayas · Tourism · AHP method · Vulnerability

## Introduction

Disasters and development have been part of the human experience since people started living in stable communities (Van Bavel et al. 2020). Disaster and development, in general, are categorized as two complementary domains, wherein disasters are associated with adverse changes and developmental activities signify positive prospects. The available literature provides enough evidence confirming this close linkage between disaster, development, and vulnerability (UNDP 2011; Mochizuki et al. 2014). Disaster and development events can result in positive opportunities or negative setbacks, affecting physical, social, and economic vulnerabilities of a region (Manyena

2012). The relationship between disaster events and counter-developmental efforts has followed a nonlinear trend of ups and downs that influenced civilizations from early times (Collins 2018; Kelman et al. 2016).

The mutual existence of disasters and development has been a part of human progression (Campbell-Miller 2018). The development and growth of ancient civilizations along the major rivers, the invention of fire, the industrial revolution, and urbanization have suffered setbacks from disasters like floods, famines, earthquakes, cyclones, tsunamis, wars, and plagues, which ultimately resulted in the destabilization of many great civilizations such as the Mayans, the Norse, and the Old Egyptian Empire (Norio et al. 2011; Coppola 2015). Humans, individually or communally, have responded to these disasters to reduce loss of life and property damage through innovation and adaptations (Van Bavel et al. 2020). The existence of caves and rock shelters in different locations of the world is a manifestation of earlier communities' adaption to various risks like dumping and habitation to avoid extreme weather and wild animal threats (Chaddha et al. 2021).

✉ Mohmad Akbar  
mmeer1634@gmail.com

<sup>1</sup> Department of Geography and Disaster Management, University of Kashmir, Srinagar 190006, India

<sup>2</sup> National Institute of Disaster Management (NIDM), New Delhi 110001, India

The gradual systematic response to disasters at national and international levels have been witnessed after catastrophic events like the 2004 Indian Ocean tsunami, the 2005 Kashmir Earthquake, the 2008 Cyclone Nargis, the 2010 Haiti Earthquake, the 2011 Japan earthquake, and the 2015 Nepal Earthquake (Coppola 2015). These mega-disasters have resulted in the formulation of well-known global frameworks like the Hyogo Framework for Action (HFA), Sustainable Development Goals (SDG), Sendai Framework for Disaster Risk Reduction (SFDRR), and formulation of disaster management plans at national or regional level (Akbar et al. 2023). These frameworks have a primary objective to achieve the risk reduction targets for which assessing vulnerability and risk are considered important components for reducing the degree of harm or exposure to hazards for effective disaster risk reduction (Prasetyo et al. 2020).

The development and vulnerability scenario of a region gets influenced by emerging risks from various hazards such as geophysical, meteorological, climatological, biological, and technological (Gill 2014). The occurrence of multiple disasters characterized by high rates of poverty, illiteracy, social exclusion, and environmental degradation is widespread in developing countries (Barrantes 2018). The impacts of these hazards on the development and vulnerability scale depend on a region's socio-economic profile and geophysical attributes (Kim et al. 2015; Armas et al. 2017; Eckerstorfer et al. 2015). The vulnerability gets enhanced when the hazard profile of a region is ignored in developmental prospects (Gallina et al. 2015). Vulnerability is also influenced by the physical location and economic status of an area which keeps changing in spatial and temporal contexts (Birkmann 2006).

Moreover, the movement of less developed countries towards greater economic development has led to an unplanned use of natural resources, application of new technologies in agriculture, and modernization of construction and transport sectors which have resulted in significant impact on physical, socio-economic, and climate change vulnerabilities (UNDP 2020). Similarly, the focus on recreational sectors, like tourism, trekking, and sports, has increased the footprints, affecting the vulnerability scenario of most mountainous regions (Tahira et al. 2020).

Various studies have been carried out in disaster and development fields with a narrow focus on understanding the relationship between the two fields (Fordham 2007; Kapuca and Liou 2014). Some of the existing studies have covered the linkage of natural, anthropogenic, and technological aspects and the influence of the geophysical environment on hazards (Liu et al. 2016; Gill and Malamud 2014; Gill 2016; Akbar et al. 2022a, b, 2023). In other studies, disaster-induced damages and losses have been highlighted. Most of these hazards, when they result in disasters, have the potential to cause primary and secondary impacts (Han and Wang 2007).

Therefore, multi-approach studies for disasters and development have to be a key focus to address emerging vulnerability concerns (Kapucu and Liou 2014). The vulnerability profile of a region is a crucial parameter in the sustainable development of an area. As core concepts, disaster and development have helped to address emerging challenges and to reduce disaster risks (Fordham 2007; UNDP 2011; SFDRR 2015). In most of the studies, various management strategies, including vulnerability, are addressed through integrated mechanisms (Birkmann 2006; Kappes et al. 2012).

The Hyogo Framework of Action (HFA) and Sendai Framework for Disaster Risk Reduction (SFDRR) are two well-known initiatives undertaken for systematic risk reduction at global and regional levels (Girgin et al. 2019), with set priorities for action to be completed within a fixed time frame (SFDRR 2015).

Mountainous regions, especially in developing countries, are going through a phase of rapid transformation, which has increased the flow of tourists and settlements in previously unexplored areas (Singh and Mishra 2004). Like many other mountain regions (Jeelani et al. 2022), Ladakh region has been attracting tourists for the last seven decades (Hassnain 2012). The tourism industry is considered an economically important sector worldwide, yet deemed to be most vulnerable to risks and disasters (Ritchie and Campiranon 2014). The overall tourism growth is a complex and nonlinear phenomenon depending on several factors like conflicts, economic slowdowns, global capital flows, tourist habits, new trend destinations, local weather, climate change, and recent disasters (Peliciardi 2016). The Ladakh region has undergone a strong transformation because of disaster-induced developmental initiatives, resulting in considerable improvement in socio-economic sectors. The tourism sector has been one of the main positive parameters that have gone through different phases because of numerous deciding factors like high altitude, extreme weather, and the remote border location. The construction of new roads, the shift from traditional to modern structures, new business establishments, and job opportunities have witnessed a positive change along with increasing vulnerability concerns in the region (Dar et al. 2021).

The existing studies have a limited focus on understanding the relationship between disasters, development, and their impacts on a region's vulnerability. The interface analysis is vital because of rapid developmental transformations in different regions of the world. Therefore, a close coordination among disaster, development, and vulnerability sectors is highly favored for effective development and disaster management (Higgins 2018). The present study aims to understand the linkage between disasters and development events and their impacts on the vulnerability scenario for long-term sustainable development strategies in the region. The present study, on account of the diverse availability and applicability of vulnerability indicators, preferred an indicator-based approach to assess the different types of vulnerabilities. The indicators used have been selected from the available literature.

The study covered numerous issues from diverse fields like disasters, environment, development, and tourism. The diverse concerns covered in the study highlight the need for multidisciplinary studies because of their increasing relevance in long-term planning prospects. The complex nature of the environment has a specific threshold of available opportunities and resources that need special attention when it comes to developmental prospects. Tourism, as one of the region's major development sectors, was chosen as the principal criterion for interface analysis between disaster and vulnerability. Multidisciplinary studies promote understanding of a common problem using knowledge from diverse fields, that helps to analyze the same problem from different perspectives, alienate the chances of biasness, and increases the capacity to handle the intermingling nature of problems effectively. The developmental strategies through integrated approaches would help to maintain proper management over a substantial period without compromising a region's emerging vulnerabilities.

## Materials and methods

### Study area

The present study has been carried out in the Union Territory of Ladakh (UT), India, located in the northwestern Himalayan region. Ladakh region is one of the remotest and largest UT in terms of area in India. It is also known as the “cold desert” or “moon land” due to its extreme climatic conditions and barren topography (Dar et al. 2021; Gompertz 2000). The region shares international borders with countries like China in the north and east and Pakistan and Afghanistan in the west and northwest, respectively. The region lies amidst the world's highest mountain ranges, at an elevation ranging from 2500 to 7400 m (Fig. 1).

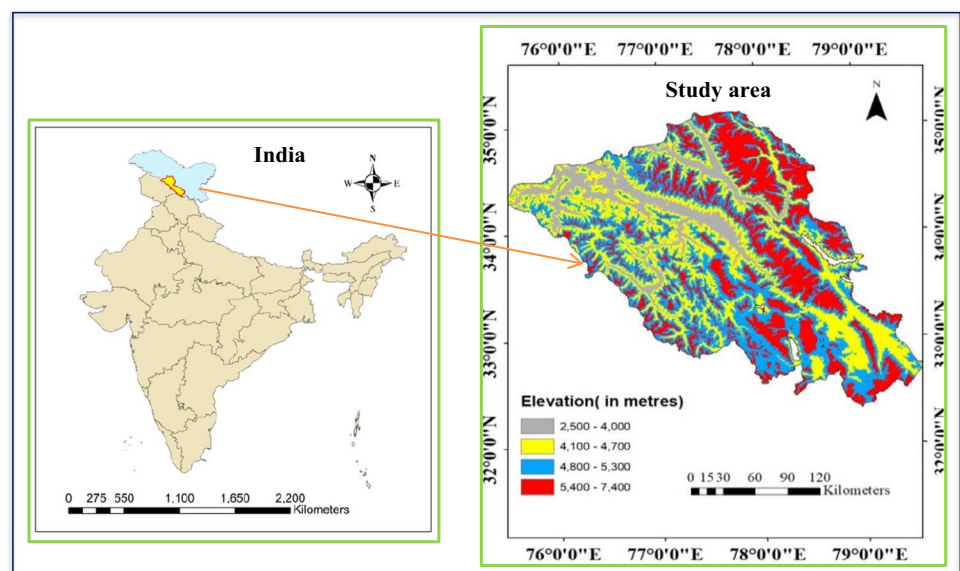
The Karakoram and Hindu-Kush mountains lie to the north, the Himalayas to the south, and the vast Tibetan Plateau to the east (Shafiq et al. 2016; Akbar et al. 2022b). The study area is divided into three significant sub-regions: Upper Ladakh, Central Ladakh, and Lower Ladakh. The Upper and Central Ladakh have most of the Buddhist population, whereas the Lower Ladakh has a majority of Muslims (Dar 2017). Because of its high-altitude location, the region experiences extreme winters and is known for heavy snowfall. The entire region remains cut off from the rest of the country due to the closure of two main highways, Zojila and Manali pass (connecting roads of Ladakh with other states), from November to May every year (Akbar et al. 2022b). The Ladakh Region comprises Leh and Kargil districts with a population of around three lakhs (Plan, 2017–18). The area is prone to multiple hazards, such as earthquakes, floods, landslides, wind/snow storms, snow avalanches, lightning, hailstorms, and wars, because of its mountainous nature and complex topography (Disaster Management Plan Leh District 2011–12).

The region has faced the recent deadliest experience of cloud burst-induced flash floods of 2010 (Preeti Gupta 2015). In addition, many local-level hazards like flash floods, landslides, and snow avalanches are witnessing changes because of ensuing global warming and prevailing climate change (Hewitt 2010). As the region lies close to the international border with Pakistan and China, it has witnessed several minor-to-major conflicts in the past, and the presence of a significant military makes it vulnerable to potential future conflicts (Muller et al. 2018).

### Methodology

The present study utilizes both primary and secondary data to understand disasters, development, and vulnerability

**Fig. 1** Location map of the study area: (a) India and (b) study area



scenario of the region (Fig. 2). The secondary data was collected from various sources such as journal articles, reports, and books to identify major disaster and development events in the region (Table 3). Tourism has been selected as the main development sector to understand the disaster-development interface and the emerging vulnerability scenario. In addition, remote sensing data sets were used to examine the geo-environmental conditions of the region. The remote sensing based data layers have been derived from the digital elevation model (DEM) obtained from the earth explorer website (<https://earthexplorer.usgs.gov/>) and the web portal of Geological Survey of India (GSI). Some important layers, such as slope, aspect, elevation, and geomorphology, have been derived from DEM with the help of ArcGIS software. The elevation, slope, aspect, and geomorphology map generated for the area provides a better understanding of the geophysical attributes of the region. The secondary data was enriched with the help of primary data collected through field surveys and interviews with local respondents. In the present study, two sample areas from each district were chosen for primary

surveys. Leh town (34.15N, 77.57E) and Nubra valley (34.68N, 77.56E) were selected from the Leh district. Kargil town (34.55N, 76.13E) and Drass valley (34.42N, 75.74E) were chosen from the Kargil district (Fig. 9). The sample areas were selected from urban and rural centers of the region witnessing a close association with disasters, tourism, and development. The target participants of the survey were important stakeholders, district officials, guest house owners, and local residents. The discussion questionnaire was developed based on selective indicators applicable to the study area. The vulnerability indicators have been divided, keeping in view their applicability, into two groups covering the main and sub-indicators. The indicators used were quantified with the help of the well-known AHP method to interpret the findings comprehensively. The major indicators were selected for estimation of the physical, socio-cultural, economic, environmental, and climate change vulnerabilities (Ge et al. 2021; Azar 2007; Cutter et al. 2003; Zhao et al. 2018; Beccari 2016; Birkmann 2006; Agliata et al. 2021; Gupta et al. 2020; Terzi 2019; Feldmeyer et al. 2020; Rafiq and Blaschke 2012; Holub

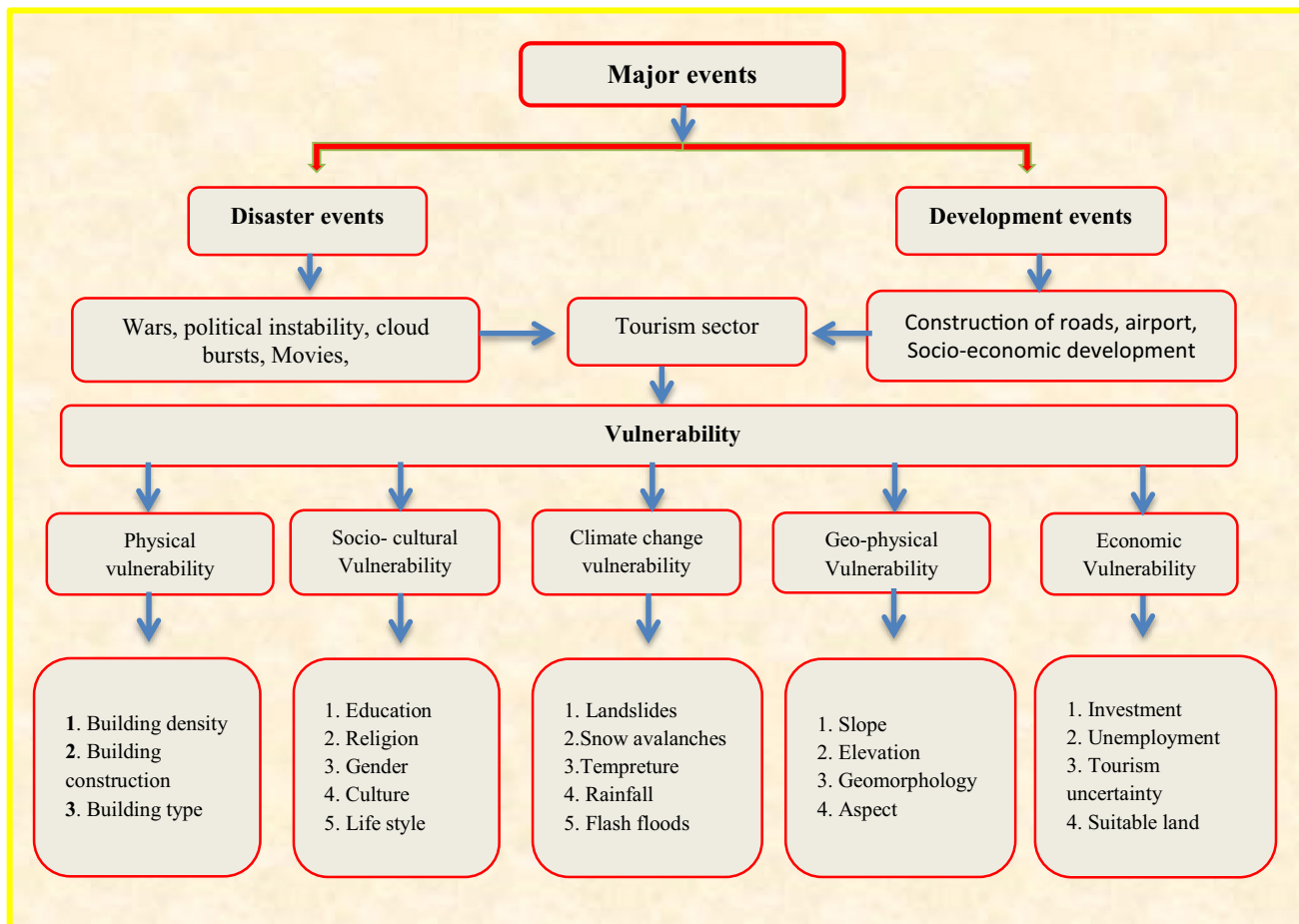


Fig. 2 Flowchart for the study

et al. 2012; Djalante et al. 2017). The main indicators were further divided into sub-indicators based on criteria associated with the main vulnerability factor: physical vulnerability with the sub-indicators – building density, construction pattern, and construction type (Prasetyo et al. 2020); socio-cultural vulnerability with sub-indicators – education, culture, lifestyle, religion, and gender (Fatemi et al. 2017; Kulatunga 2010; Rufat et al. 2015; Ashraf et al. 2017); economic vulnerability with sub-indicators (Chen et al. 2013); climate change with sub-indicators – flash floods, snow avalanches, landslides, temperature, and rainfall (Shah et al. 2020; Agliata et al. 2021; Edmonds et al. 2020); and geophysical environment vulnerability with sub-indicators – slope, geomorphology, elevation, and spect (Zhao et al. 2018). The field survey and interviews focused on understanding emerging vulnerabilities in the region which were analyzed and calculated with the help of the AHP method. AHP is a multi-criterion decision-making technique introduced by Saaty (1977) which allows subjective and objective factors to be considered in decision-making (Kumar 2016). AHP breaks complex problems into several factors and alternatives by following a stepwise procedure (Akbar et al. 2022b; Costache and Tien 2020). The essential steps, as explained in detail, are as follows:

1. dividing the unstructured problem into main components,
2. establishing alternatives with detailed criteria,
3. constructing pairwise comparison based on expert opinion with the help of a scale of preference, as shown in Table 1,
4. calculating the eigenvalue for the relative weight of each criterion, and
5. the consistency ratio (CR).

CR is one of the essential steps for the quality of pairwise comparisons of the weights assigned and the scale of

preference (Table 1). CR for the weights assigned is calculated using the equation  $CI = \lambda - n/n - 1$ , where  $\lambda$  is the largest eigenvalue of the pairwise comparison matrix and CI is the consistency index. The CR is calculated with the help of the equation  $CR = \frac{CI}{RI}$ , where R.I. is the random consistency index identified and assigned values by Saaty (1977; Saaty and Vargas 2012), as shown in Table 2. The consistent comparison is accepted if the CR has a value less than 0.1. If it exceeds, the matrix table is reconsidered until it gets less than 0.1

### Major disaster and development events

Ladakh region is known for its peculiar charm, complex topography, and cultural harmony among the ethnic tribes. On the one hand, the Ladakh region is known for its glorious history of having its kingdom and charm, and on the other hand, it has been continuously affected by wars, natural disasters, and extreme climate events (Dewan 2004; Masson 2013). Before India’s independence from Great Britain in 1947, the Ladakh region acted as a major center for trade in the Great Silk Route. Local kings mainly ruled it until its capture by Dogra ruler Zorawar Singh in 1834 (Gagne 2017). The region has historically been known for involvement in conflicts due to its close strategic location on international borders, surrounded by nuclear countries like Pakistan and China (Mueller et al. 2018). The region has also witnessed many regional-level conflicts in the pre-independence phase under the leadership of local rulers, which have been discussed in detail in the literature (Davis et al. 2020). In post-Independence India, Ladakh’s geo-political scenario changed from a vital trade corridor to a strategic region along the hostile international borders of China and Pakistan, resulting in major wars like 1962, 1965, 1971, and 1999. Moreover, political turmoil in the neighboring Kashmir region has resulted in secondary economic loss to the Ladakh region because of the only feasible national highway

**Table 1** Scale of preference of factors (Saaty 1977; Saaty and Vargas 2012)

Intensity	Degree of preference	Explanations
1	Equally	Factors contribute equally to the objective
3	Moderately	One factor moderately favors over another
5	Strongly	Experience and judgment strongly favor one factor over another
7	Very strongly	One factor strongly favored over another
9	Extremely	The evidence one factor favoring over another is of the highest degree possible
2, 4, 6, 8	Intermediate	Represent compromises between the preferences in weights 1, 3, 5, 7, and 9
Reciprocals	Opposites	Specifies inverse comparison

**Table 2** Random inconsistency indices (RI) for  $n = 1, 2, \dots, 12$  (Saaty 1977)

<i>N</i>	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54

route connecting Ladakh through Jammu and Kashmir with the rest of the country.

Ladakh region is also known for frequent natural disasters, which may significantly increase because of population growth, climate change, and haphazard development around previously unoccupied unstable slopes (Suri 2018). The region, because of its barren topography and mountainous location, is vulnerable to multi-hazards such as earthquakes, landslides, snow avalanches, wind/snow storms, lightning, hailstorms, flash floods, cloud bursts, and wars (DMP-2011; Akbar et al. 2023; Hewitt 1982, 2010).

The strategic location and growth of tourism have attracted investments in communication, transport, and construction sectors after major wars like 1962, 1971, and 1999, which have helped to improve the region's socio-economic conditions. The construction of the National Highway, Srinagar-Leh, the construction of Leh airport, the opening of tourism officially in 1974, media attention at the national and international level, and the shooting of movies are some of the major initiatives that have improved the developmental prospects in the region. The impacts of disasters and development of the area have been evaluated on the tourism sector, which is considered one of the major economic lifelines of the region. The major disaster and development events are shown in Table 3.

## Results

The results are covered under two components. The first component analyzes the impacts of major disasters and development events through the region's tourism sector. In the second component, the emerging vulnerability (UNDP (United Nations Development Programme) 2021) scenarios from the developmental sectors have been quantified using the AHP method. In order to understand the linkage properly, tourism is considered one of the region's major developmental sectors. Various factors like improvements in better accessibility, communication, transport, and widespread publicity at the national and international levels have resulted in the enormous growth of the tourism sector in this secluded and remote region of trans-Himalayas. The tourism sector has opened new avenues and has played a vital role in the socio-economic transformation of the area (Pellicciardi 2013). The growth in the tourism sector witnessed a non-linear pattern revealing a sudden dip or increase in tourist flow after the major events (Fig. 3). However, long-term impacts from these disaster events have now proven beneficial in attracting a large number of tourists to the region (Pellicciardi 2021). The tourism sector has gone through subsequent phases of ups and downs (Fig. 3) which have been discussed in subsequent sections.

Although there is evidence of tourists' arrival in Ladakh from earlier times in literature, no actual figures existed until tourism was officially opened in 1974 (Aabedi 2015). Since then, tourism has contributed exceptionally to the region's socio-economic development (Dewan 2004; Gompertz 2000). The construction of national highways (NH-ID) after the 1962 war and the construction of Leh airport in the 1980s have improved transport connectivity in this remote region. Over time, Ladakh's economy became more dependent on the tourism industry and consequently went through unexpected fluctuations induced by various events like the wars of 1962, 1965, 1971, and 1999 (Dar et al. 2016). From Fig. 3, it is evident from the tourism data that Ladakh has witnessed modest and steady growth in tourist arrivals after it was formally thrown open in 1974 until the outbreak of insurgency in Jammu and Kashmir state in 1989. The overall tourist flow in Ladakh registered a compound annual growth rate (CAGR) of 5.37% from 1980 to 1989.

The insurgency and political turmoil in Jammu and Kashmir from 1990 onwards had severe implications on the tourism of the whole region, including Ladakh. Tourist arrivals declined significantly as most foreign countries have issued advisories for tourists to avoid the region. Although the Ladakh region was free of insurgency, the only summer feasible highway connecting the region with the rest of India (Srinagar-Leh) passes through the Valley of Kashmir, a highly disturbed area during that phase. Ladakh has registered a decline in tourist flow during this phase (Fig. 3).

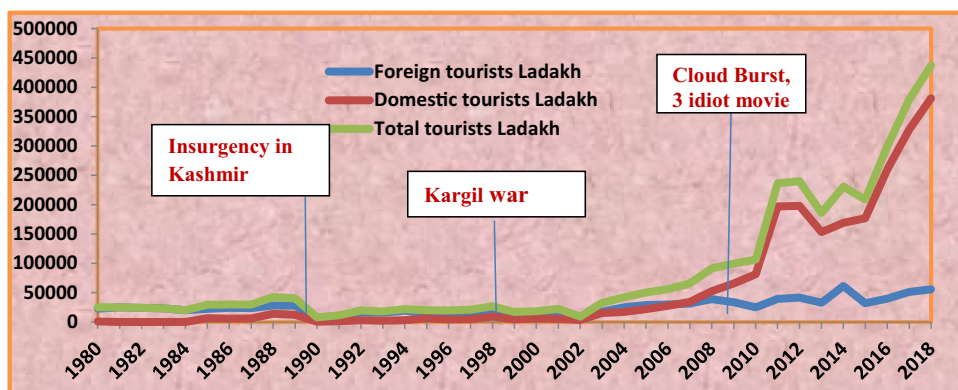
Similarly, the 1999 war, also known as the Kargil war, resulted in the considerable loss of life and property in the region. The war ended after 74 days, but ceasefire violations continued until 2002. Thousands of people were temporarily displaced, and the war incurred a substantial financial burden on both the countries involved (Dewan 2004). It was one of the region's worst events but was followed by many positive regional developments. The war has attracted widespread media coverage and publicity, highlighting the unique topography, pristine nature, and potential site for adventure tourism. Many new areas of the region came into the limelight after the war. Tiger hill, Tolling, Drass valley, Manman top, Mushkoo valley, Batalik sector, and war memorial Bhimbat, Drass, became household names in India. Besides, the Kargil war also grabbed the attention of Indian cinema, which resulted in the making of movies like LOC Kargil and the later 3 Idiots, which caused a spurt in tourist arrivals in the first decade of the twenty-first century (Dar et al. 2016). The shooting of the 3 Idiots in Ladakh (2009) put the region in the limelight at national and international forums. The tourism trend, which emerged due to publicity post-Kargil war, has shown a phenomenal increase in domestic tourism in the Ladakh region for the first time. The compound annual growth rate of tourist arrival from 2000 to 2010 was 19.21%.

**Table 3** Major disaster and development events in the Ladakh region

Major events	Year	Description	Reference
Pre-partition scenario	Before 1947–1948	The greater Ladakh had a separate kingdom of its own. The silk route was a bustling entry point connecting India's plains to central and west Asia. The silk route played an important role in the development of the Ladakh region	Hassnain (2012); Gagne 2017
India-China war	1962	India–China war resulted in a large number of casualties. However, the Srinagar-Leh national highway construction and other associated developments followed the 1962 war	Dewan (2004); Gompertz (2000)
Formation of Ladakh scouts	After 1962	Ladakh scouts came into existence, mostly consisting of the local Ladakhi army, highly capable of operating in hilly terrains. This has generated employment opportunities at the regional level	Gagne (2017)
India-Pakistan war	1971	The 1971 war, also known as the battle of Turtuk, in which India captured Turtuk and adjoining areas. Loss of life and separation of families/relatives were reported on both sides of the border	Gompertz (2000)
Tourism focus	1974	Ladakh was formally thrown open for tourists except for restrictions to a few places until 1993. An increase in tourist flow and prosperity in other sectors have been reported	Barrett (2014); Dewan (2004); Aabedi (2015),
Highway and airport construction	After 1962 war	Post-1962 and 1971 war, the construction of roads and airports has been a priority development agenda	Dewan (2004)
Political turmoil and militancy in Kashmir	1989 onwards	Political turmoil and militancy in Kashmir resulted in secondary impacts on the tourism industry of the Ladakh region. Tourism got considerably affected because of feasible and preferred Srinagar-Leh national highway	Dewan (2004)
India-Pakistan war (Kargil war)	1999	The war was fought for 74 days (May–July). Besides the loss of life and property damage, the war resulted in wide-scale publicity and media attention, boosting tourism and subsequent developments	Dewan (2004)
LOC Kargil movie, 3 Idiots movie	2004, 2009	The shooting of popular movies helped to showcase the region to outsiders, which helped in the subsequent growth of domestic tourists post-1999 war	From tourism data and field surveys
Leh cloud burst/flash floods	2010	The cloud burst-induced flash floods of 2010 caused one of the deadliest disasters in the Ladakh region, resulting in huge loss of life and damage to property	Gupta (2012); Sati and Litt (2011); Zainab Jalis (2016)

**Table 3** (continued)

Major events	Year	Description	Reference
Formation of UT Ladakh	2019	The region's tourism faced a massive loss in the year 2019. The people believe that the formation of the UT will enhance developments in many sectors in the coming years	Field survey and interviews
Covid-19 pandemic	2020–2021	The Covid -19 pandemic resulted in a major loss to tourism and the region's economy, like in many other parts of the world	Emanuel (2020); Ardebili et al. (2020); Akbar (2022a)
Snow avalanches	1967–2019	A total of 33 major avalanches are witnessed in the Kargil district resulting in more than 300 deaths	Akbar et al. (2022b)
Landslides	--	More than 300 landslide events are witnessed in UT Ladakh over the period of time	Akbar et al. (2023); GSI

**Fig. 3** Tourist flow trends in Ladakh from 1980 to 2018

The 2010–2018 period is one of the most crucial phases of the tourism industry in the region. The cloud burst incident of 2010 drew the attention of researchers and policy-makers to this highly vulnerable and remote region of the country. Cloud bursts are common and unpredictable events in mountainous areas, which result in excessive rainfall in a short time. Cloud bursts provide a limited chance to warn the people and are responsible for triggering flash floods and mudslides. The 2010 cloud burst in Ladakh resulted in 234 casualties and 500 missings (Dimri et al. 2017). Besides incurring substantial economic losses, the cloud burst event has received high media coverage on the national and international levels, which has drawn the attention of policy-makers and researchers toward the region's susceptibility to natural hazard occurrences. This has also shifted the perception of people toward the pros and cons of tourism-induced developments in the area. The surge in tourist arrivals has continued in the subsequent years, breaking all records for tourist arrivals. Around 22, 57,283 tourists (foreign 3, 75,018 and domestic 18, 82,265) visited Ladakh during 2010–2018 (Fig. 3). The Compound Annual Growth Rate

(CAGR) of tourist flow post-2010 cloud burst until 2018 is impressive at 19.29%.

Recent events like the removal of article 370 and formulation of a separate UT on August 5, 2019, resulted in a significant decline in tourist flow in the year 2019 compared to previous years (Pellicciardi 2021). Furthermore, a more drastic decline in tourist numbers was witnessed in 2020 and 2021 because of the COVID-19 pandemic (Tahira et al. 2020). However, it could be inferred from past events that developments in the region would benefit from the formation of UT and the recent border skirmish with China. The area could see more developments covering border roads, infrastructure, communication, and tourism sector growth due to the construction of the Zojila tunnel as an all-weather connectivity route to Ladakh.

The findings indicated that disasters helped in long-term development with occasional setbacks in the region, which paved the way for new developments. Like in other parts, the region's tourism growth is influenced by many factors, including language, transportation, communication, culture, religion, comfort, weather, and disaster events (Pellicciardi



2010). Tourism growth in this fragile region has been large because of disaster-induced development opportunities. Tourism growth proved to be a great developmental driver for the area but has been noticed lately as a reason for new emerging vulnerabilities. The bloom in the tourism sector of Ladakh post-1999 Kargil conflict has increased at the cost of a spurt in domestic tourist arrivals, which has promoted unplanned growth in the tourism industry and related infrastructural developments. The construction of new guesthouses and hotels has multiplied in recent years. The number of hotels and guesthouses around Leh alone has increased from 30 in 1974 to around 191 in 2005 and 650 in 2015 (Dame et al. 2019).

Furthermore, regional developments have found a close link with the region's physical, socio-cultural, climate change, and environmental vulnerabilities, which have been quantified using the AHP method using main and sub-indicators (Table 4 and Table 5). The importance of disaster and development has been ignored in developmental planning resulting in long-term negative impacts on vulnerability scenarios. Vulnerability as a dynamic phenomenon is highly influenced by physical, social, economic, and geophysical factors. These factors can increase or decrease vulnerability because of human actions (Coppola 2015). The vulnerability is quantified using main indicators and sub-indicators (Table 4 and Table 5). In addition, remote sensing-based geophysical analysis has been used to link the developments with future land use planning in this highly fragile region. The haphazard constructions aim to generate profit from the tourism sector, which has increased at the cost of growing vulnerabilities.

The AHP-based results have been calculated and quantified for major factors/indicators (Table 4), followed by the quantification of the sub-indicators (Table 5). The results for the major indicators witness a higher vulnerability for climate change, witnessing a weighted score of (0.36). The socio-cultural vulnerability witnessed a weighted score of (0.29), followed by environmental vulnerability (0.16), economic vulnerability (0.12), and physical vulnerability (0.7). The vulnerability weights were separately

calculated for the sub-indicator. In the socio-cultural vulnerability factor, the highest weights were obtained for lifestyle change and cultural dilution (0.31), followed by gender bias (0.15), religious concerns (0.15), and educational concerns (0.08). The water resource crisis (0.34) witnessed the highest weight in environmental factors, followed by a shift in cropping pattern (0.24), land use changes (0.18), solid waste issue (0.15), and air pollution (0.09). Furthermore, in the economic factor, the highest vulnerability weights have been recorded for uncertainty in tourism (0.37), followed by lack of suitable land (0.28), unemployment issue (0.20), and fear of investments (0.15). Among the sub-indicators selected in the climate change factor, the highest weights have been recorded for flash floods (0.38), followed by erratic rainfall (0.22), temperature (0.20), snow avalanches (0.12), and landslides (0.08). Slope witnessed the highest vulnerability weight in geophysical factors, followed by elevation (0.28), geomorphology (0.20), and aspect (0.15).

### Socio-cultural vulnerability

The study reveals that massive influx of tourists in the region has increased socio-cultural vulnerability, profoundly impacting the lifestyle of people like in other regions (Van Bavel et al. 2020). Based on residents' perception, the present generation is getting more involved in smoking and alcohol because of exposure through tourism-induced interaction with people from different parts of the world. Transformations have also been observed in the traditional food, clothing, marriage ceremonies, and overall lifestyle (Aengst 2013). People perceive that changing lifestyles have impacted the religious practices among youth, making them more vulnerable to religious conversions and inter-religious marriages (Aengst 2013; Williams-Oerberg et al. 2021). Gender bias is still found with evidence of males getting more opportunities than females in the emerging development sectors, including tourism (Fig. 4). Females have a limited role in decision-making processes. Lifestyle changes, cultural dilution, and

**Table 4** Pairwise comparison of main indicators, normalized weights, and consistency ratio

Main indicators	Physical vulnerability	Economic vulnerability	Environmental vulnerability	Socio-cultural vulnerability	Climate change vulnerability	Normalized Weights
Physical vulnerability	1					0.07
Economic vulnerability	2	1				0.12
Environmental vulnerability	3	2	1			0.16
Socio-cultural vulnerability	4	3	3	1		0.29
Climate change vulnerability	4	2	3	2	1	0.36
CI	0.07	( $\lambda$ max)		5.28	CR	0.06

**Table 5** Pairwise comparison of Sub- indicators, normalized weights, and consistency ratio

Physical vulnerability	Building density	Construction pattern	Construction type			Normalized weights
Building Density	1					0.16
Construction pattern	2	1				0.30
Construction type	3	2	1			0.54
<b>CI: 0.01</b>	<b>(λ max): 3.02</b>	<b>CR: 0.02</b>				
Socio-cultural vulnerability	Educational concerns	Religious concerns	Gender biases	Culture influence	Lifestyle changes	Normalized weights
Educational concerns	1					0.08
Religious concerns	2	1				0.15
Gender biases	2	2	1			0.15
Cultural dilution	3	2	2	1		0.31
Lifestyle changes	4	2	2	1	1	0.31
<b>CI: 0.02</b>	<b>(λ max): 5.10</b>	<b>CR: 0.02</b>				
Environmental vulnerability	Air pollution	Solid waste issues	Land use issues	Shift in cropping	Water resources	Normalized weights
Air Pollution	1					0.09
solid waste issues	2	1				0.15
Land use changes	2	1	1			0.18
Shift in cropping	2	2	1	1		0.24
Water resources	4	3	2	1	1	0.34
<b>CI</b>	<b>0.02</b>	<b>(λ max)</b>	<b>5.10</b>	<b>CR</b>	<b>0.02</b>	
Economic vulnerability	Investment issues	Unemployment	Lack of suitable land	Uncertainty of tourism		Normalized weights
Investment	1					0.15
Unemployment	1	1				0.20
Suitable land	2	2	1			0.28
Tourism uncertainty	3	1	2	1		0.37
<b>CI: 0.07</b>	<b>(λ max): 4.21</b>	<b>CR: 0.07</b>				
Climate change vulnerability	Landslides	Snow avalanches	Temperature change	Rainfall patterns	Flash floods	Normalized weights
Landslides	1					0.08
Snow avalanches	2	1				0.12
Temperature change	2	2	1			0.20
Rainfall patterns	3	2	1	1		0.22
Flash floods	4	3	2	2	1	0.38
<b>CI: 0.05</b>	<b>(λ max): 5.05</b>	<b>CR: 0.04</b>				
Geophysical factors	Aspect	Elevation	Geomorphology	Slope		Normalized weights
Aspect	1					0.15
Geomorphology	1	1				0.20
Elevation	2	2	1			0.28
Slope	3	1	2	1		0.37
<b>CI: 0.07</b>	<b>(λ max) 4.21</b>	<b>CR 0.07</b>				

gender bias are the three main factors enhancing socio-cultural vulnerability in the region, which is evident from results as witnessed in Table 5 and Fig. 5

### Climate change vulnerability

Climate-related vulnerabilities are identified as a major

**Fig. 4** Field photograph showing a recent flash flood event in the region



**Fig. 5** Field photograph showing transformation in constructions (Leh town)

concern in the study area by local respondents which are in line with the various studies carried out in the region. The studies have discussed the region's changing climate and associated vulnerabilities after the 2010 cloud burst event (Dimri et al. 2017). The survey results reveal that the region is experiencing a change in rainfall and temperature patterns and a consequent increase in hydrometeorological

incidents like flash floods, cloud bursts, landslides, and snow avalanches (Kumar et al. 2018; Barrett 2014; Hart and Hearn 2018). The precipitation studies also witness a change in overall precipitation for the region (Bhat and Rather 2018).

### Environmental vulnerability

The increasing environmental vulnerability of the area can be attributed to socio-economic transformation with a greater influx of tourists and changing climate. From various studies, a decrease in underground water level is evident from the extinction of many natural springs and the faster retreating of glaciers in the region (Masson 2013; Mir et al. 2018) (Fig. 6). The socio-economic transformation has resulted in higher daily consumption of water (Pelliciardi 2021). A continuous water supply is essential during summers in almost every new construction. The use of washing machines, replacing traditional pit toilets with flush toilets, and high water-dependent cement building constructions have increased the water demand. One of the respondents stated that around 3000 plastic bottles are collected daily from Nubra valley during the tourist season. The solid waste generated during the tourist season gets less attention along national highways and desolate far-off locations like Hunder, Pangong Tso, Turtuk, and Panamik, increasing the water, soil, and air pollution-related concerns.

**Fig. 6** Field photograph showing the retreat of Parkachik glacier, Kargil



The physical vulnerability of the region is strongly influenced by the geomorphology and topography of an area (Gill and Malamud 2014). The geophysical conditions of the region have been analyzed through remote sensing (Fig. 8). The geophysical factors help to understand its role in future development scenarios of the region. The slope factor strongly influences the hazard occurrence and vulnerability scenario of developmental activities in the area (Akbar et al. 2023). The constructions and developments across the unfavorable steep slopes make the conditions highly susceptible to flash floods, earthquakes, and landslides.

The region's high elevation makes the winter conditions unfavorable during peak winters. The elevation classes were divided into four classes ranging from 2500 to 7000 m. The high altitude and unfavorable climatic conditions are a reason for the barren land and low vegetation in the area (Akbar et al. 2022b). Similarly, the area's geomorphology confirms the presence of highly dissected mountains, bare land, snow/glaciers, and small herbs/shrubs. The aspect layer highlights the complex topography of the region.

### Economic vulnerability

The economic vulnerability of the region has been unpredictable. Despite tremendous growth in the tourist inflow and enhanced economic growth, the tourism sector is uncertain. People have seen disaster phases like wars and

the COVID-19 pandemic negatively impacting tourism and associated sectors (Akbar et al. 2022b). The proximity to borders always poses an uncertain threat of possible conflicts emerging in the region, which could considerably impact the region's economic well-being. People perceive that most of their investments are susceptible to losses from earthquakes, landslides, flash floods, and border conflicts. Therefore, considering the results, a well-balanced approach must be adopted to achieve a sustainable link between developments and emerging vulnerabilities.

### Discussion

Ladakh region presents a perfect example or model area that has witnessed a cycle of disaster and development phases in the trans-Himalayas. Ladakh has borne the brunt of disaster and development changes. The region is characterized by an extreme climate, rugged topography, and a sparse population composed of ethnic communities with unique indigenous cultures (Gompertz 2000). The present study focused on the importance of understanding the linkage between disasters and developments for long-term sustainable growth of the area by stressing on region-specific mitigation through vulnerability parameters for disaster proactive preparation and response. Identifying and quantifying vulnerabilities can help in better preparedness and response in case of a sudden disaster (Akbar et al. 2022a).

In this regard, the applied methodological approach and findings could prove vital in determining the underlying factors to establish a link between disasters, development, and increasing vulnerability scenarios. In addition to the physical distinction, the area has a religious, ethnic, and political peculiarity (Cunningham 1854), which could pose challenges in planning. Despite being located in a remote and high-altitude region, the importance of the place as a center for trade between South-Asian and Central-Asian countries (Bhasin 2006) provided it with particular importance in the past that helped the region to sustain itself economically and socio-culturally during the pre-independence phase. However, political instability, wars, and decay of the Central Asian trade route over time have adversely affected the economic prospects (Dewan 2004) and have resulted in the transformation of the region into a strategic area. After the independence of India in 1947, entry was restricted mainly by a strict permit regime because of its highly strategic position along the border of China and Pakistan, which has hampered trade and tourist flow abruptly to this region (Aabedi 2015).

The results reveal that there has been growth in many sectors in the post-independence era following the major events (Table 1). The construction of new roads for effective transportation, communication, and associated developments has increased hope for stable developments. The region's rugged terrain and complex topography have been a reason for many natural and anthropogenic hazard occurrences, such as landslides, earthquakes, flash floods, snow avalanches, and cloud bursts (Akbar et al. 2023; Ziegler et al. 2016). The region has well-recorded disaster events such as earthquakes, landslides, wars (Fig. 9), and, most recently, the COVID-19 pandemic (Akbar et al. 2022a).

The pace of developmental transformation has been noticed since the tourism sector officially opened in the region. The opening of the tourism sector officially in 1974 witnessed a continuous increase with occasional dramatic fall in tourist flow and related activities in the area (Pellicciardi 2010, 2013). The increase in new settlements due to population growth and tourism progression have resulted in haphazard constructions along unstable slopes (Fig. 7). The constructions still overlook the building codes and proper engineering techniques in the region. The study reveals an apparent shift in the region's construction patterns and construction type (Table 5). Traditional construction pattern is gradually giving way to modern constructions, which lack compatibility with the delicate geo-environmental conditions of the region (Pandey et al. 2018; Johnson 2014). The newly constructed Reinforced Concrete Cement (RCC) buildings with large windows and tin roofs are materially dependent on other states, increasing the construction costs. During winters, the spontaneous snowmelt and snowfall from tin roof constructions need comparatively more surface area than



**Fig. 7** Field photograph highlighting haphazard constructions coming along the base of a highly unstable slope (Kargil town)

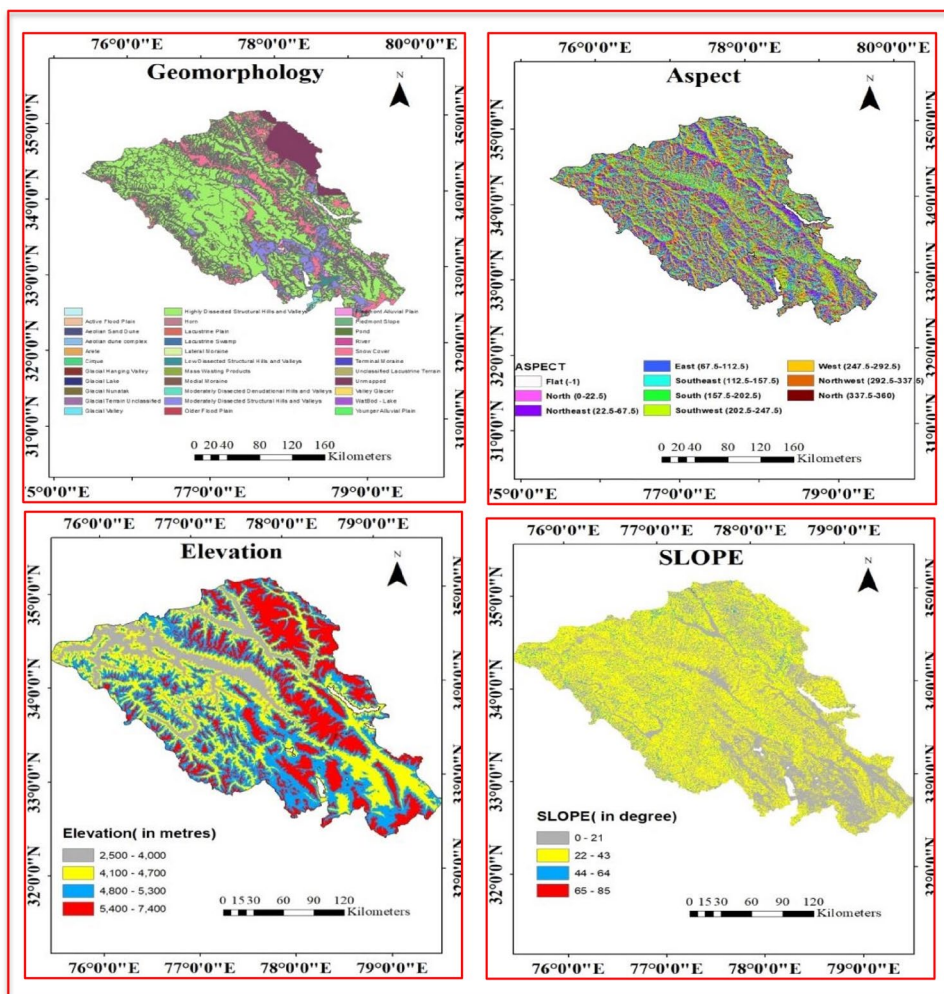
traditional constructions, resulting in disputes between neighbors, thus creating disharmony among otherwise peaceful residents (Fig. 8).

The region has witnessed multiple disasters associated with loss of life and damage to properties and the environment (Fig. 9). The historical and spatial distribution of the landslides and earthquakes across the region is shown in Fig. 9. The distribution pattern of landslides overlaps with the spatial extent of road networks across the terrain. The cumulative effects of seismic activities and the construction of new roads result in landslides and snow avalanches in the area.

The study region has faced multiple challenges from natural and anthropogenic disasters, resulting in environmental, social, and climate-related vulnerabilities (Richardson and Reynolds 2000). Therefore, there is a need to identify the susceptible areas to mitigate these disasters. These multiple challenges increase vulnerability apprehensions if appropriate strategies are not adopted (Birkmann 2006). Depleting water resources, changing cropping patterns, and unsustainable land use changes in the area are important concerns enhancing the region's environmental vulnerability (Table 5). These uncertain events increase the economic vulnerability of the people who had already invested heavily in anticipation of good returns from tourism. In addition, the shrinkage of suitable land resulted in unplanned and haphazard constructions, which have increased economic vulnerabilities (Dame et al. 2019). As per the resident's perception, new construction patterns need extra heating arrangements and are highly energy-dependent and less cost-effective to combat extreme weather as compared to traditional constructions.

The disaster development interface and vulnerability scenarios discussed here also covered geophysical and

Fig. 8 Geophysical factors



anthropogenic parameters that could help in a comprehensive understanding of long-term positive development for cost-effective measures in the region. Vulnerability varies spatially and temporally because of people’s movement through different stages with varying mixes of resources and liabilities (Anderson 1995; Azzimonti et al. 2019). In order to understand and analyze the emerging vulnerability and related concerns in detail, a multi-criteria approach has been adopted in the present study to analyze the multi-dimensional aspects of vulnerability. The study indicates an uncertain increase in the developments amid increasing susceptibility to various natural and anthropogenic hazards.

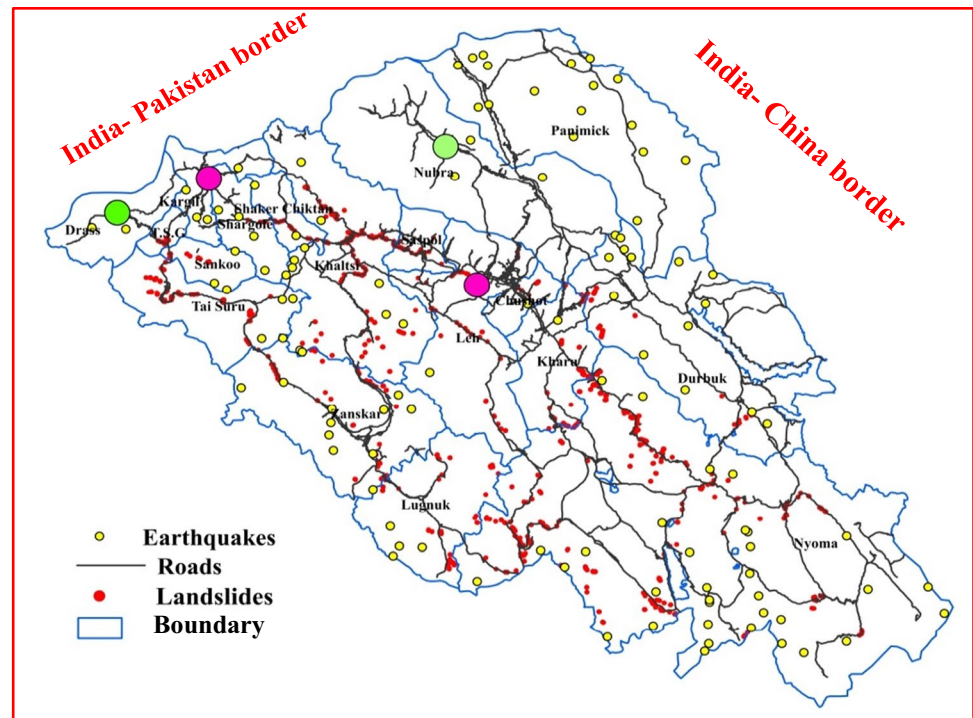
Although the disasters faced by Ladakh have many adverse implications, a deeper analysis reveals that they have benefitted the region by boosting the basic infrastructure, transportation, communication, media coverage, and publicity, which helped showcase the immense tourism potential in Ladakh. The improvement in infrastructures such as roads and construction has been a positive development. The study also highlighted the positives of the disasters and developmental events. The positive and negative effects of

disasters and development events on vulnerability scenarios are discussed, considering tourism as a major sector. The tourism sector is considered one of the crucial economic sectors in this remote trans-Himalayan region. Furthermore, these developments have bought along a chain of vulnerability concerns discussed in detail that needs an immediate focus to overcome these emerging challenges in the region. Therefore, through this study, an emphasis has been made to highlight the importance of close coordination between disasters and development activities to minimize vulnerability and disaster risk for sustainable growth.

### Conclusion

The present study attempted to explore linkages between disaster and development events to understand the increasing vulnerability scenario in the Ladakh region of trans-Himalayan, India. A central focus has been given to the region’s tourism sector – a strong positive indicator of development – to understand the linkage between disasters, development,

**Fig. 9** Map showing the distribution of hazards events and road network



and vulnerability. The results revealed that the region had undergone both disaster and development phases. The disaster events have helped in tourism growth and developments in other sectors like transportation, communication, trade, employment, and housing, which have gradually improved the socio-economic well-being of the people. The study found that the region is facing imminent physical, socio-cultural, economic, environmental, and climate-related vulnerability threats from the developments that have happened on account of various events such as the 1999 Kargil war, the 2010 cloud burst, abrogation of Article 370, and formation of UT Ladakh. Moreover, climate change and existing hazard scenarios pose hydrometeorological hazards challenges like glacier retreat, flash floods, and water crises, which need in-depth studies to combat the adverse impacts through proper management. The study concludes that disasters resulted in long-term development, whereas developments are again increasing vulnerabilities.

The rising vulnerabilities in the region emphasize the need for appropriate mitigation measures for the integration of disasters and development management strategies in the long-term growth of every sector. The inferences drawn are significantly important for establishing sustainable development in the region. The interface between disaster, development, and vulnerability can be understood locally to adopt appropriate management practices. The tourism scenario needs to be made a sustainable tool for long-term benefits without compromising the increasing vulnerability risks. The mitigation strategies

should include proper land use laws/practices involving local communities and stakeholders to overcome emerging vulnerability threats. Local participation needs to be strengthened by raising awareness among the people about rising vulnerability concerns. The results could be helpful for in-depth studies involving more detailed vulnerability analysis to frame region-specific disaster and development policies. The aim should be to achieve a positive relationship between disaster, development, and vulnerability, which could help to reduce disaster risks for sustainable growth and development.

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**Data Availability** All the data sources are cited and referenced which have been used in this study.

**Code availability** Not applicable.

## Declarations

**Ethical approval** All ethical standards were taken care of during this study.

**Consent for publication** This publication is nowhere else under consideration for publication.

**Conflict of interest** The authors declare no competing interests.

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