Developing Landslide Hazard Scenario of Kashmir Himalaya from the Historical Events

Bilquis shah (bilquisshah121@gmail.com)
University of Kashmir https://orcid.org/0000-0001-9919-2716
M. Sultan Bhat
University of Kashmir
Akhtar Alam
University of Kashmir
Hilal Sheikh
University of Kashmir
Noureen Ali
University of Kashmir

Research Article

Keywords: Kashmir Himalaya, NH-44, Landslides database, Early warning, Hotspots

Posted Date: December 28th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1145281/v1

Abstract

Kashmir Himalaya being a rugged and tectonically active zone has complex, unstable geology along with steep slopes, creating a favorable environment for landslide hazards, especially along the National Highway (NH-44) that connects the Vale of Kashmir with the rest of India. The historical landslide database for the whole country has not yet been developed and the data provided by various government organizations are often very limited because most of the time local and small-scale landslide events do not get recorded, thus, leading to misinterpretations. The present study focuses on retrieving the information on landslide events and their impacts to develop a comprehensive database for the period from 1990 to 2020 in Jammu and Kashmir, emphasizing Jammu-Srinagar National Highway (NH-44). A hotspot analysis tool (Getis-ord-Gi* algorithm) was used to understand the spatial distribution and concentration of the events throughout the region. The annual and seasonal analysis of the 739 landslide events reported in the valley for the selected period suggests an increasing trend causing 1000 fatalities and 267 injuries. The findings show that out of 20 districts, 16 are relatively more exposed to landslides and the socio-impact induced by landslides was found more along the NH-44 with 303 landslide occurrences reported in 260 days in the past three decades having a high intensity of damage and loss. The results of this study are expected to be of potential use for developing a Landslide Early Warning System (LEWS) and for mitigating the impacts of landslides in the Kashmir Himalaya.

1. Introduction

UNDRR has defined landslide as the downhill movement of a mass of rock, debris, or earth down a slope under the direct influence of gravity, ranging from rapidly moving catastrophic rock avalanches and debris flows in mountainous regions that can destroy property and take lives suddenly and unexpectedly, to more slowly moving earth slides like creeps that may cause damage gradually. The elements that make an area prone to landslides generally include bedrock geology, geomorphology, land use and land cover, type of soil, and precipitation (Chingkhei et al. 2013). Landslides cause loss of human lives, damage to property, road infrastructure, and may block the streams and rivers as well as impacting the water quality (Righini et al. 2012; Metternicht et al. 2005; Qiu 2014; Alexander 2005). Landslides also play the main character in landscape and slope ecosystem evolution (Cendrero and Dramis 1996; Parker et al. 2011; Geertsema et al. 2009).The total number of fatalities caused by all types of landslides, rock falls, debris flows, or volcanic debris flows globally per year is in the thousands (USGS). According to WHO, from1998-2017, landslides affected an estimated 4.8 million people and caused more than 18,000 deaths. The International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED), EM-DAT, reports1, 30,000 persons have lost their lives since the 1900s to landslides and flash floods, and the economic losses to be over US$ 50 billion. In the period from 2000 to 2014, landslides caused about 26,000 deaths, and the estimated economic loss was US$ 40 billion (UN-SPIDER). For examining and evaluating the damage caused, the landslide inventory maps (LIM) are prepared to estimate the risk associated with landslides for a particular area and generally record the location, frequency, date of occurrence, triggering factor, magnitude or size, type, and damage (Guzzetti et al. 2012;

McCalpin 1984). Landslide inventory maps also help in generating the hazard scenario of any region (Antonini et al. 1993; Remondo et al. 2008). Based on the accessible resources, landslide inventories are prepared in several ways using different techniques which incorporate field survey, visual interpretation of aerial photographs, and collected data from historical archives and by using remote sensing techniques (Mohammadi et al. 2018; Fiorucci et al. 2019; Mondini et al. 2014; Lazzari and Anzidei 2018).

Globally, several studies have been carried out on landslides and their impacts with the help of historical databases (Guzzetti et al. 2012; Martha et al. 2013). Nadim et al. 2006 portrayed global landslide and avalanche hotspots and identified the country's most exposed to landslide hazard based on the number of people killed per year per 100 km^2 which was found greatest in countries like Colombia, Tajikistan, India, and Nepal. Kirschbaum et al. 2015 studied the trend of global landslides by analyzing the global landslide catalogue of 5741 events from 2007–2013 where the highest number of events occurred in Asia, North America and Nadim et al. 2006 Southeast Asia. Jessee et al. 2020 compiled 127 global, earthquake-induced landslide events in 207 years from 1811 to 2016; Petley 2012 assessed the global patterns of loss of life caused by 2620 fatal landslide events with 32,322 recorded fatalities. Froude and Petley 2018 catalogued 4862 landslide events globally in which a total of 55,997people died from 2004 to 2016.

On a national scale, many researchers have made efforts in generating inventories for different countries. Sultana 2020, gathered a catalogue of 204 reported landslides in Bangladesh that caused 727 deaths and 1017 injuries during the period 2000–2018. Petley et al. 2007 documented a database of landslide fatalities in Nepal from 1978–2005 depicting the trend of increased landslide fatalities during monsoon season. Among the Asian countries, India is highly exposed to landslides (Dikshit et al. 2020; Bhandari, 2006) and the area most vulnerable to fatal landslides is found to be the west and the north-west Himalayas, followed by east and north-east India and South-India indicated by a study (Prakash 2011). According to National institute of Disaster Management in the year 2011, an estimate suggested that India suffers a monetary loss of Rs 150-200 crore every year from landslide and by the Geological Survey of India, 420,000 sq km, or 12.6% of the total land area, is landslide-prone, which spreads over more than 65,000 villages in hilly/mountainous regions of the country (NDMA). Out of the total landslide-prone area of India (12.6%), North-western Himalayas constitute 33%, which grasps the attention of researchers to study this part of the Himalayas. In a data-scarce environment like India, there is still a lack of comprehensive documentation of historical landslide events. The available data has huge time gaps and are at different scales, which create a barrier in the reconstruction of past scenario of the hazard prone areas (Van et al. 2013). Several authors have attempted to depict a picture of landslide-prone areas of India by generating landslide databases through various methods at regional scale like Hao et al. 2020, compiled a landslide inventory which contains 4728 events mapped by object-based image analysis and field survey; Ghosh et al. 2020 prepared an inventory of 151 landslides for Mandakini valley of Uttarakhand Himalayas and Martha et al. 2021 constructed a dataset for risk assessment by employing semi-automatic methods from post-event satellite images. Zhang et al. 2019 generated a map of 5858 rainfall-triggered landslides from 1992 to 2015 using satellite images and field surveys for the Koshi River basin, Central Himalayas. However, few researchers have contributed towards generating a database of fatal landslides like Lukose et al. 2010 who prepared an inventory of 63 landslide incidents from 1961 to 2009 causing 257 deaths in the Western Ghats, Kerala. Parkash 2011 gathered a total of 371 socio-economically significant events in which 3971 deaths were reported in 248 fatal events for about 300 years.

Kashmir Himalaya prone to multi-Hazards has witnessed several catastrophic disasters in the past and has suffered heavily in terms of life and property. According to the Jammu and Kashmir State Disaster Management Policy 2011, 11% of the total area of the state comes under Seismic zone V and the rest of the area comes under Seismic Zone IV, and out of 100 districts in India 13 from the state have been identified as Multi-Hazard Districts. The region is largely impacted by Landslide Hazard and there is no official database available to analyze the trend and impacts of landslide occurrence and to facilitate the landslide risk reduction measures. Notwithstanding such constraints, we generated a historical event landslide database for the entire Kashmir Himalayas with specific reference to Jammu and Srinagar National Highway (NH-44) for the time period 1990-2020. The study focuses on the spatial and temporal distribution of landslide episodes and analysis the trend of events, fatalities, and injuries caused by the landslides. The socio-economic impacts of the landslides in the Himalayas particularly along the national highway (NH-44) are also discussed in the paper. The results of the study determine the need for Landslide Early Warning System (LEWS) in the Kashmir Himalayas and measures for landslide risk mitigation and prevention in the region.

2. Study Area

The Himalayas are the youngest mountain range in the world formed due to the subduction of the Indian plate under the Eurasian plate that started during the Eocene epoch (Gansser 1964; Bhat 1987). The Himalayas extend over 2500 kilometers, from north-east to north-west of India containing syntaxial bends on both ends. The width of this mountain range varies from 230 to 330 kilometers.

The Himalayas consist of four parallel mountain ranges; Shiwaliks or the outer Himalayas, lesser Himalayas or lower Himalayas, Higher Himalayas or Greater Himalayas, and Trans Himalayas or Tibetan Himalayas from south to the north (Wadia 1931; Steck 2003; DiPietro and Pouge 2004). The study area lies in the Kashmir Himalayas situated between the Pir Panjal range in the west-southwest and the Zanskar range in the east-northeast constituting a large part of the western Himalayas encompassing the upper Indus Basin (Shah 2021). The elevation of the area ranges from 242 to 6277 meters above mean sea level (fig 1). The region is drained by three major tributaries of Indus: Chenab, Jhelum and Indus (Albinia 2010). The valley basin is drained by the river Jhelum, and its main tributaries such as Sindh, Lidder, Pohru, Rambiara, etc. The region is a multi-hazard prone area with distinct topography, climate, and strategic location. The geomorphology of the basin is very diverse including deep lakes, flood plains, tablelands (Karewas), and steep hill slopes. The average annual rainfall in the Valley is 670 mm and in the Jammu region, it is 1251 mm. The climate of the region varies from subtropical to temperate (Ahmad et al. 2016) and the demography of the region is mainly concentrated in the valley floor and the foothills.

Srinagar and Jammu are the major cities in the area. The economy of the area is mainly dependent on horticulture and tourism. Major cash crops are apple, pear, walnut, almond, grapes, and cheery. Major tourist destinations are Gulmarg, Sonamarg, Mughal gardens, dal lake, Pahalgam, tulip garden, Amarnath holy cave, Vaishno Devi, etc. The valley is connected to the other parts of India mainly through two links, the Jammu-Srinagar National Highway (NH1A) and the Mughal Road that pass through fragile Himalayan terrain (Singh 2010).

3. Material And Methods

Landslide Database Inventory of Kashmir Himalayas has been compiled for the time period of 1990-2020 with special reference to Jammu–Srinagar national highway (NH-1A). The data for generating the landslide Database has been collected from multiple sources mainly: National newspapers (Hindustan Times, Times of India, Economic Times, and The Tribune), Regional newspapers (Greater Kashmir, Daily excelsior) shown in table 1, Research articles (Prakash 2011; Singh 2018), online media reports (Ndtv, India Today, Kashmir mirror), Government Organisations (Border Road Organization (B.R.O) Rangreeth, Srinagar., Geological Survey of India and National Institute of Disaster Management) and the Disaster Reports (Data Inventory report-Nov 2018 by RMSI private limited India and EM-DAT International Disasters Database).

The methodology adopted in this paper set off with the collection of historical events for which the newspaper archive of the Central Library of the University of Kashmir was utilized (Taylor et al. 2015). The newspapers available from the 1990s were selected for the study and the rest of the data used was obtained from the B.R.O department Srinagar and the online sources. The landslide events reported in different sources were documented systematically and any repetition of the events was removed by proofreading (Kirschbaum et al. 2010; Devoli et al. 2007; Pennington et al. 2015). The variables used for the preparation of the historical landslide Database of Kashmir Himalayas (DKH) include date, season, district, reported events, fatalities, injuries, damage, etc. given in table 2 (Lin and Wang 2018; Pereira et al. 2014).The fields for the database were selected based on the consistency of the information available and the variables like victims' information, type of slide, etc. were excluded because of the unavailability of the data (Sultana 2020). Along with the Landslide episodes, some major fatal avalanche episodes that may have triggered landslides were also documented in the database. Landslide inventory maps were generated using Arc-GIS software. Annual, decadal, and seasonal trends and frequency of the landslide events were analysed. District-wise landslide maps were prepared with the help of GIS techniques to find the districts most susceptible to fatalities and injuries caused by landslides and landslides associated with avalanches. Also, a catalogue of major fatal events of landslide/avalanches was prepared to help in the management of landslide disaster risk reduction. A Hotspot analysis tool (Getis-ord-Gi* algorithm) was used to map the spatial distribution and concentration of events, fatalities, and injuries by the Fishnet polygon and aggregation polygon method (Haque et al. 2019; Sultana 2020).

Jammu-Srinagar National Highway NH-44 being highly prone to landslides was studied individually. Along the national highway NH-44, dozens of places get hit by multiple landslides on a single date which is not reported individually. Due to the lack of reported data, the estimation of the no. of landslides has been calculated by multiplying the days on which land sliding was reported (LD) with the number of places hit (PH) at a particular date. The socio-economic impact of landslides along the highway has been shown by the intensity of the damage caused throughout the time period 1990-2020 based on the obtained data.

Table 1 Newspaper sources of data used in the study

Newspapers	*Type*	*Distribution*	*Publication Head office*	*source*
Hindustan Times	Daily	National	18–20 Kasturba Gandhi Marg, New Delhi	http://hindustantimes.com/
Times of India	Daily	National	Bombay, Maharashtra, India	https://timesofindia.indiatimes.com/
Economic Times	Daily	National	Times House, DN Road, Mumbai, India	https://economictimes.indiatimes.com/
The Tribune	Daily	National	Sector 29-C, Chandigarh (UT), India.	https://www.tribuneindia.com/
Greater Kashmir	Daily	Regional	Srinagar, Jammu and Kashmir	http://greaterkashmir.com/
Daily Excelsior	Daily	Regional	Jammu, Jammu and Kashmir	http://www.dailyexcelsior.com/

3.1 Measurement of damage intensity

The socio-economic impact in terms of monetary losses caused by landslides was not available and to calculate the intensity of damage over the time period 1990-2020, a general scale of four classes was devised for measuring the impact in the area of interest prepared in accordance with the damage and loss database given as below (Table 3).

Table 3 Scale for measuring the damage intensity

Range	*Class*	*Description*
0-0.25	Low	Damage of property
0.25-0.50	medium	Damage of property, and Highway closure
0.50-0.75	High	Stranded passengers and vehicles, Damage of property and Highway closure
0.75-1	Very High	Fatality and injury, Stranded passengers and vehicles stranded, Damage of property and Highway closure

Table 2 Details of the variables used in the landslide database development		
Category	*No. of Variables*	*Description of the variables*
Id	1	Each reported landslide event has a Unique Id
Date	3	Date(day-month-year),Year, Month has been given separately for each event
Season	4	Season include Pre-monsoon (March toMay), Monsoon (June to September), Post-Monsoon (October to November) and Winter (December to February)
Number of reported days	1	Total number of days per year which reported the landslide occurrences
Number of Landslide events	1	Total number of events on a particular date
District	1	District in which landslide occurred at a particular date
Affected area	1	Areas in which landslide occurred at a particular date
Number of Landslide Fatality events	1	Total number of reported landslide fatality events on a particular date
Number of landslide/Avalanche Fatality events	1	Total number of reported landslide/ Avalanche fatality events on a particular date
Fatalities	2	Total no. of reported deaths per fatal event (landslide) and Total no. of reported deaths per fatal event(landslide/avalanche)
Injuries	2	Total no. of reported injuries per fatal event (Landslide and landslide associated with avalanche)
Associated Damage	1	The associated damage of landslide occurred on particular date in terms of socio-economic

4. Results

There is an asymmetrical distribution of landslide events along the Kashmir Himalayas. From the landslide database prepared for the Kashmir Himalayas during 1990-2020, it was found that the entire region is prone to landslides that are largely distributed along the major transport routes passing through Greater Himalayas and PirPanjal ranges including; NH-44 (Jammu Srinagar national highway), Mughal Road, NH-1D (Srinagar-Sonmarg-Gumri Road, NH-1B (Sinthan Top-Kishtwar-Batote Road), Bandipora-Gurez Road, Baramulla-Uri Road (NH-1A) and Kupwara-Machhil Road (Fig. 2a). The study area lies within administrative boundaries of the Union Territory Jammu and Kashmir comprising 20 districts. The geographical distribution of total landslide events and of major catastrophic fatal events is shown in

Figs. 2(a) and (b). The Landslide Database of Kashmir Himalayas (LDKH) identifies about 739 landslide events reported in 506 days at the regional scale (Table 4). The most affected local areas were the Banihal-Ramban stretch, Baltal route (Ganderbal), Sonmarg-Gumri route (Ganderbal), Uri (Baramulla), Dawar-Gurez (Bandipora), and Kishtwar route outlined in Table 4. Out of the 739 landslide events, 180 fatal events were identified from 1990-2020 that were discussed in detail in the fatal landslide Catalogue.

Preparing the inventory for fatal landslides was a challenge because most of the fatal landslides were associated with avalanches and documented in landslide disaster reports, therefore making it difficult to isolate major avalanche events from landslides (Prakash 2011). Hence, the inventory of fatal landslide events included major avalanche events. Results show that many disastrous events have stroked the Himalayas in the past 30 years which include the events like; 18Jan 1995, a catastrophic event that occurred near the Jawahar -Tunnel caused 200 casualties; 18-Feb-2005, a massive avalanche near Waltangu Nad Kulgam caused 175 casualties; 28-Jan-2006, 6 men were buried under a heavy landslide in Uri, Baramulla; 1-may-2008, 20 people were killed by a large landslide in Poonch; 6-September-2014, entire Saddle village came under a massive landslide in Udhampur buried 40 people alive and 4-July-2018, Amaranth Yatra suspended by a massive landslide buried 10 pilgrims, etc. LDKH recognises about 127 fatal landslides and 54 fatal landslide/avalanche episodes having a large impact on the region in terms of the damage caused from 1990-2020.

The total deaths caused by landslides and landslides associated with avalanches counted 1000 (including Catastrophic events) and the total number of reported injuries were 267(Table 4). Fig. 3 represents the hotspot analysis of historical landslide events, fatal landslides and fatal landslide/avalanche events (L/A) for the study period 1990-2020 in the Kashmir Himalayas. The results identified three historical landslide hotspots on the main transport routes as Srinagar-Jammu highway (Banihal to Udhampur), Srinagar-Sonamarg-Gumri road and Bandipora-Gurez road (Fig. 3). The concentration of the event occurrences was found low in the valley floor and dense along the transport routes. Considering the LDKH, the Landslide fatality hotspot lies on the Jammu-Srinagar Highway from Banihal to Udhampur and the landslide/ Avalanche fatality hotspot lies in the Gurez Valley (Bandipora).

The district-wise spatial distribution of fatal landslide events and the frequency of deaths and injuries caused by them has been shown in Fig. 4. Fig. 4(a) shows that the districts with the most frequently occurring fatal landslide events from 1990-2020 were Ramban with 24 fatal events and Baramulla with 15 fatal events, followed by district Kishtwar (14), Doda (13), Reasi (12), Ganderbal (9) and the districts with an average of 5 to 9 events were Poonch, Kupwara and Anantnag. The districts with zero occurrences of fatal Landslide events were Jammu, Kathua and Shopian. From the Analyses of the database the highest frequency of deaths caused by landslides from 1990-2020 were reported in District Ramban (44), Kishtwar (38) followed by District Doda (32), Reasi (27), Poonch (29), Baramulla (24), Ganderbal (19), Rajouri (18) and districts with Minimum fatalities were Udhampur, Samba, Pulwama and Srinagar (Fig. 4c).The districts with the highest number of injuries were identified as Ramban with 57 reported injuries and Reasi with 33 reported injuries followed by Kishtwar (21), Ganderbal (17), Baramulla (16) and Doda (14) (Fig. 4d).

The major catastrophic events were separated that could have triggered the landslides, where the death toll crossed 30 to 200 deaths /per event, were stroked in the districts Kulgam and Bandipora. Figs. 4(b), (e) and (f) show the frequency of landslide/avalanche (L/A) events (landslide associated with snow avalanches), fatalities and injuries caused by them from 1990-2020. The results show that the highest frequency of fatal L/A events was seen in districts Kupwara with 14 fatal L/A events, Bandipora (11) and Kulgam (6) followed by Aanatnaq (5), Ganderbal (4) and the district with the minimum occurrence of fatal events has been found in Ramban, Reasi and Doda (Fig. 4b). It has been noticed that the districts with the highest fatalities caused by L/A events were Bandipora with 67 deaths, Kupwara (53) and Budgam (40), followed by Kulgam (31), Baramulla (25) and Reasi (17) shown in Figs. 4(e) and (f). The South –West of the Kashmir Himalayas was found to be less prone to avalanches and the landslides associated with them. Fig. 4(f) represents the spatial distribution of the injuries caused by L/A which was found to be highest in districts Anantnag, Budgam, Bandipora and Baramulla.

Table 4 Spatio-temporal attributes of the landslides in Kashmir Himalayas (LDKH), 1990-2020

Year	*Total No. of reported Days*	*Total No. of reported landslide events*	*Total No. of deaths*	*Total No. of Injuries*	*Area affected*
1991	1	1	–	–	Nashri (Ramban)
1992	5	13	–	–	Sutrun, Gainwan, Sumbal, Rishigund, Dehi Nallah, Peerah
1993	3	9	–	–	Badwaan, Gulgulosa, Hayan, Mamar, Pharoo, Rawatpur, Z-khushi, Badwan
1994	2	2	–	–	Trahagam, Bali Nala and Narsoo slide
1995	17	29	218	–	Jawahar tunel, Chandigam, Gund , Haknar, Karalpora, Lalpur, Phoroo, Siphon,Tuarkapur, Chaandigi nallah, Baltal, Pani nallah, Kishtwar, Gangangir, Hawas, Ganiwan, Z-khushi, Banihal-Ramban stretch
1996	12	24	1	–	Ramwari, Shadgund, Matrigam, Ganiwan, Ganangir, Sarebal, Chandigi nallah, Gutlipur, Wangat, Kankanaz, Haripora, Hawas, Baltal, Badwan, Vehama, Tragbal, Banihal-Ramban stretch
1997	10	15	–	–	Gangangir, Chandigi nallah, Kovpora, Hawas, Batgund, Kralapur, Ninao, Tagbal, Banihal-Ramban stretch
1998	20	28	–	–	Charpathar, Dand Behan, Shekhpur, Wanjan, Waripur, Chandigi Nallah, Baltal, Haripora, Gumri, Banihal-Ramban stretch
1999	4	6	–	–	Baltal, Ramban
2000	6	9	1	–	Srinagar-Sonmarg-Gumri road, Baltal, Banihal-Ramban stretch
2001	2	5	–	–	Baltal, Ramban
2002	9	18	4	3	Boniyar, Gagangir, Gumri road, Baltal, Uri, Banihal-Ramban stretch
2003	28	34	5	–	Uri-Santra -Mike, Red-Bridge -Dedrain road, Mouhurra-Bazzroad, Batote Kishtwar road, Banihal-Ramban stretch
2004	3	5	–	–	Srinagar-Sonmarg-Gumriroad, Baltal, Chandigi Nallah
2005	30	50	175	–	Waltengu Nad, Gangagir, Srinagar-Gumriroad, Kishtwar-Sinthan road, Banihal-Ramban stretch
2006	18	25	7	–	Uri, Panthal, Sheshnag-Panjtarnitrack, Srinagar-Sonmarg-Gumri road, MahaGunas and Posh

					Pathri areas ,Dawar, Koragbal, Wampur Banihal-Ramban stretch
2007	17	21	22	26	Doda, Ramban, Panthihal, Khabbak Village, Ganderbal, Charpathar, Koragbal, Nayalgoan,Kishtwar, Banihal-Ramban stretch
2008	7	8	81	16	Uri, Qazigund, Srinagar, Chakoti, Banihal-Ramban stretch
2009	9	13	15	5	Chokoti-Uri, Atholi, Vaishno Devi, Srinagar, Gurez, Baltal, Kupwara, Amarnath tack, Kishtwar, Railpahri, Keran, Banihal-Ramban stretch
2010	33	51	91	53	Chadiyan Baramulla, Lahama Uri, Pahalgam Route, Uri, Gharkote, Gulmarg, Ganderbal, Kangan, Reasi, Veshno Dev, Baltal and Pahalgam, wanjan, Hafkalan, Rangdur, Doda, Kanmaoh Pampore, Lassi Banna, Banihal-Ramban stretch
2011	19	32	21	27	Doda, Banzur, Bunakut, Hajinar, Kuljan Gali, Nalchain, Panar, Riddi, Tangtori, Kishtwar, Uri, Bramullah-khudpora, Sarna, Salamabad, Phimram Shangus, Doda, Kishtwar, Baltal, Amarnath Nath route, Gurez, Banihal-Ramban stretch
2012	14	21	67	16	Kulgam, Doda, Kupwara, Kishtwar, Khoni Nallah, AnokhiFall, Bandipora, Ganderbal, Gurez, Aitmal, Drangyari, GundManchar, Guzarbal, Khori, Vewan, Mughal Road, Banihal-Ramban stretch
2013	6	6	4	_	Mughal Road, Banihal-Ramban stretch
2014	13	16	76	3	Anantnag, Digdole, LadiAngan, Banali Boniyar, Bandi and Jal Sheeri areas of Uri, Kulgam, Batote- Kishtwar road, Kupwara-Machhil, Mughal road, Banihal-Ramban stretch
2015	32	36	17	6	Awantipora, Pulwama,Baltal and Pahalgam route, Batote-Kishtwar road, Budgam, Uri, Baramulla, Keran sector, Mughal road, Peer ki gali, Banihal-Ramban stretch
2016	12	19	24	10	Wangat, Handwara, Mughal Road, Waniarm Kangan, Fatehchak, Lamchak, Daadchakh-Halmatpora kupwara, Kandi belt Baramullah, Dara Harwan, Banihal-Ramban stretch
2017	31	34	43	15	Kupwara, Veshno Devi, Batote-Doda-Kishtwar, Mughal road, Kishtwar, Machhil sector, Anantnag, Baltal and Phalgam route, Banihal-Ramban stretch, Bandipora
2018	34	45	68	52	Tragbal, Baltal-Pahalgam route, Anantnag, Ganderbal, Railpathri and Brarimarg, Kupwara - Tanghdar road, Sadhna Pass-Kupwara,

					Happatkol-appharwat, Machhal-Kupwar, Mughal road, Banihal-Ramban stretch
2019	41	56	45	11	Kokernaq, Jawahar tunel, Anokhifall, Peer ki gali, Tanghdar road, Dawar, Tragbal, Sonawari, Bhaleesa-doda, Mughal road, Baltal and pahalgam route, Machhil sector-Kupwara, Tanghdar road, Banihal-Ramban stretch
2020	68	108	15	24	Panthal, Ramsu, Karna, Sallar-Pahamlgam route, Srinagar-Sonmargroad, Mughal road, Dawar, Tanghdar road, Uri, Kulgam , Z-khushi road, Dawar, Tanghdar road, Uri , Kulgam, Z-khushi road, Banihal-Ramban stretch

4.1 Landslide and their impacts from 1990-2020

The Decadal frequency of the landslide events with the reported days and related fatalities and injuries from 1990-2020 is presented in Fig. 5. It was found in the decadal analysis that the decade 1990-2000 has total of 136 landslide events reported in 80 Days causing 20 deaths with no reported injuries. In the decade 2001-2010, almost 230 landslide events were reported in 156 days causing 206 deaths and 103 injuries. During 2010-2020 the frequency of landslide events was 373 reported events in 270 days inducing 380 deaths and 164 injuries in the region. Fig. 5, indicates that decade, 2011-2020 was very impactful with a higher number of fatalities and injuries.The annual distribution and trend of landslides and reported days of land sliding are presented in Fig. 6 (a). From the analysis of collected data, it was seen that landslides were reported every year from 1990-2020. The trend of landslide events and their reported days was found to be increasing from 1990-2020. The results show that the frequency of landslides has increased along with their reported days during the period. In the initial years of the study period, the year 1995 shows the highest no. of landslide events whereas in the mid-years of the study period, 2010, 2005 and 2003 show the highest number of events and the years 2001, 2004,2008 have minimum no. of reported landslide events. In the final years of the study period 2020, 2019 and 2015 have the highest no. of landslide incidents and the years 2013 and 2014 reported a minimum no. of landslides in the region. Fig. 6 (b) shows the temporal variation in the frequency of fatal landslides and the related fatalities and injuries from 1990-2020. From the Fatal landslide database, it was found that the years 1995, 2005, 2008, 2010, 2012, 2014 and 2018 reported the highest no. of fatalities caused by Landslides and L/A events and the years 2007, 2010 and 2020 have the highest no. of injuries in the study area.

The highest number of fatal events recorded in the years 2010(26), 2018(20) and 2019 (20) and the years from 1995-2006 reported lesser number of fatal events. Fig. 7 shows the seasonal variation in the frequency of landslide events during the period 1990-2020 and from the database, it was perceived that an increasing trend of landslides was seen in all seasons where the winter season has the highest reported landslide incidents in the Himalayas followed by Monsoon and Pre-monsoon. The post-monsoon season has comparatively a lower number of reported landslide incidents from 1990-2020. From the LDKH the total landslide events reported in the winter season were 245, monsoon season (242), pre-monsoon (218) and post-monsoon (34).

4.2 Historical Landslides along Jammu-Srinagar National Highway (NH-44) from Udhampur-Banihal

Jammu-Srinagar National Highway (NH-44), old numbering NH-1A is one of the principal highways of India for its Geo-strategic location connecting the Valley with the rest of the country. The landslide database prepared for the Jammu-Srinagar NH has been incorporated in LDKH. Out of the total739 landslides documented in the database, 303 were outlined for NH-44 (Udhampur-Banihal) in 260 reported days from 1990-2020. The database collected reveals that on average, dozens of places were hit on a single reported day, and the landslide incidents were not numbered quantitatively concerning the places hit that may result in a biased database.

An approximate figure of historical landslides from the past 30 years was obtained by multiplying the reported days of land sliding with the number of places hit on a particular date. The results show that the total estimated landslides were 1482 causing considerable damage to the National Highway over the period of time. Fig. 8 (a) represents the geographical location of NH-44 from Udhampur-Banihal and Fig. 8(b) represents the spatial distribution of landslides. The landslide-prone areas of NH-44 were identified as Jawahar tunnel, Shaitani Nallah, Banihal, Moum-Passi, Makarkote, Panthal, Anokhi Fall, Khoni Nallah, Digdol, Maroog, Serri, Deswal, Karol, Chanderkote, Nashri, Patnitop, and Khari Belt. For assessing the variations in the frequency of landslides in different areas of NH-44 over the study period, the Jammu–Srinagar National Highway (NH-44) from Udhampur to Banihal was divided into eight sections based on the occurrence of Landslides. It was found that Section Maroog-Ramsu has the highest frequency of landslides followed by Ramban-Maroog, Nowgam-Jawahar Tunnel, Ramsu-Banihal and the sections with the lowest occurrence of landslides were Udhampur-Chenani, Banihal-Nowgam, and Chenani-Nashri. The hotspot analysis of the National Highway NH-44 from Udhampur to Banihal using the Fishnet and Polygon methods has been shown in Figs. 8 (c) and (d). From the hotspot analyses three hotspots were found, one with 99% confidence and the other two with 95% and 90% confidence level for the historical landslides lying between Nashri-Ramsu.

The annual variation in the frequency of the landslides from the database of NH-44 from 1990-2020 shows that in the initial years of the study period, the year 1998 has reported the highest no. of landslides whereas the mid-years, 2002, 2005, and 2007 have recorded the highest number of landslide incidents and in the final years of study, 2015, 2018, 2019, and 2020 have the maximum number of landslides incidents for 30 years (Fig. 10 a). From the decadal analysis of 303 reported landslides, the decade 2011-2020 (146) has the highest frequency of landslides followed by the decade 2001-2010 (71) and 1990-2000 (43). From the analysis of the seasonal variation in the frequency of the landslides from 1990-2020, the maximum number of landslides were reported in the winter season (139) and monsoon (83) followed by pre-monsoon (69) and the lowest was found in post-monsoon (12).

Socio-economic impact

To examine the socio-economic impact of landslides along NH-44 in the Kashmir Himalayas, the intensity of the damage has been measured from 1990-2020 through a scale prepared using the data gathered from different sources given in Table 3.The socio-economic impact caused by landslides in the region is discussed in detail in Table 5 and from which it is evident that the Jammu-Srinagar highway has proven disastrous to the people of the region. It has been noticed that from 2007 onwards the intensity of damage has been very high from 1990-2006 the damage intensity ranges from low to high (Fig. 9 b) and also, the number of causalities has increased from 2007 onwards.

From the database (Table 5) it is manifested that the highway remains closed for most of the winter due to landslides which hike the prices of the necessary commodities in the basin leading to short-term inflation. The passengers, supply trucks, oil tankers, and tourists get stranded on the highway for dozens of days in the winter season with no availability of food and water. The stranded passengers sometimes travel kilometers on foot to reach their homes. During monsoon season lacs of pilgrims who visit the Amarnath temple in the Kashmir valley frequently get stuck on the highway. The majority of the time Yatra is suspended for many days due to landslide incidents. The landslide fatality database shows that many pilgrims have lost their lives in these past years. Besides government of India started the road widening project of NH-44 in the year 2011 which has exposed new landslide-prone areas making the situation more depressing (Pandey et al. 2014). Due to the increased frequency of landslides, the cost for the maintenance of the highway has also increased.

Table 5 Socio-Economic impact due to landslide hazard along Jammu-Srinagar National Highway (1990-2020)

Year	Associated Damage of landslide episodes (Socio-economic)
1991	Section of Jammu Srinagar highway badly damaged
1992	Section of Jammu Srinagar highway badly damaged
1994	Section of Jammu Srinagar highway badly damaged
1995	Closure of highway, scarcity of essential commodities, prices of several daily consumer goods including eggs, butter, chicken and vegetables gone up,1000's of passengers stranded and road was damaged
1996	Highway was closed and section of highway was badly damaged
1997	Highway was closed and damage of road surface
1998	4000 Passengers stranded on highway from both sides and also there was the damage of road surface
1999	Highway was closed and road surface was damaged
2000	Highway was blocked and 298 vehicles were stranded
2001	Highway closed and damage of road surface
2002	Highway closed for several days and 5000 passengers were stranded on highway along with the 850 vehicles between Batote to Banihal
2003	Highway closed for several days, road surface was damaged and vehicles stranded
2004	NA
2005	Highway was closed and the road surface was damaged
2006	One causality, highway was closed for several days ,300meter highway stretch washed by heavy landslides and 1000's of trucks leaded essential commodities and 400 passenger vehicles were stranded
2007	Eight causalities, highway was closed and the road surface was damaged
2008	Three killed and sixteen injured, highway was closed, damage of road surface and 400-500 trucks stranded
2009	Highway was closed and one injured
2010	Four killed and one injured, passengers along with 2000 small and heavy vehicles stranded on the highway and 44 structures damaged in Dharam-Tharad area
2011	One causality, 1,200 vehicles stranded, highway was closed for traffic, 400 passengers evacuated from Jawahar tunnel and road was damaged
2012	Nine causalities, highway closed for several days leads to scarcity of essentials in Kashmir, 2000 vehicles stranded and road was damaged
	Highway was closed and 500 vehicles stranded

2013	
2014	Two killed, highway closed and traffic suspended
2015	Four causality and two injured, highway closed for several days, Amarnath yatra suspended, massive landslide buried some vehicles and highway closure leads to scarcity of essentials in Kashmir
2016	Two houses and a school damage in Mundjhal area by massive landslide, highway was closed for several days and the road was damaged
2017	A massive landslide blocked the arterial road and also damaged a bridge in Udhampur district, highway closed for 6th day, 1000 passengers carried journey on foot, highway closure leads to scarcity of essentials in Kashmir and shortage of supplies hikes prices
2018	Seven causalities and four injured, vehicles damaged, 20,000 amaranth pilgrims staying back and highway closed
2019	Fourteen causalities, highway closure 21times in two months, over 6,500 vehicles were stranded at various places between Jammu to Banihal and other side of the Jawahar tunnel towards Kashmir, fuel crises in Kashmir,300 tankers lined up, highway closure leads to scarcity of essentials in Kashmir, shortage of supplies hikes prices and highway badly damaged
2020	Eight causalities and eleven injured, damaged 28 houses in Dhalwas village near Chanderkot, 500-meter stretch damaged at Ramban, over 1500 trucks remain stranded by a massive landslide, 7000 Vehicles Stranded in winter slide, highway closure leads to scarcity of essentials in Kashmir, shortage of supplies hikes prices and highway badly damaged

5. Discussion

Landslide inventory with all the attributes is quite strenuous to prepare for the unavailability of data as most of the landslides are reported only for their induced impact. The localized Landslides are mainly ignored and not documented, which is a vital constraint in analyzing the spatial distribution pattern of landslides in an area (Sultana 2020; Brabb and Harrod 1989; Lin and Wang 2018).To find the expanse of the vulnerability of the living beings concerning different hazards drafting of the past disaster incidents is very vital and can provide details of past circumstances in which the hazard occurred (Ahmad et al. 2021). Studying the historical background of disasters that are not restricted to political borders is a challenge in the conflicted zone like Jammu and Kashmir where the selection of methodologies such as random sampling, field surveys, and collection of primary data has never been easy for the researchers (Silkin and Hendrie 1997). Jammu and Kashmir a conflicted zone has widespread violence, a large military movement in the region and the atmosphere is often very tense and the people of the region are suffering from stress, trauma, and depression (Housen et al. 2019; Wani et al. 2020). The ongoing unrest in the region with the high Disaster vulnerabilities potentially accelerates the adverse psychological impacts on the people (Patel et al. 2020). The region is less developed compared to the other states of

India where a localized hazard like Landslide creates havoc due to late response from the authorities. Landslides mostly affect the inhabitants residing in hilly areas and remain unnoticed leaving the people with no option of shifting to any safer place but to live in these prone areas.

According to the historical account of landslides, the Valley of Kashmir has been prone to landslides for ages. The epic Rajatarangini written in 1150 by Kalhanan (Stein 1898) and the Tarikh-i-Hassan written in 1896 has mentioned briefly the landslide triggered by an earthquake in 843 CE that blocked the Jhelum River at Khandanyar Baramulla. The damming of the Jhelum River has flooded the Kashmir Valley from Baramulla in the north to Bij Behera in the south and impacted the whole valley (Bilham and Bali 2014). The entire Valley was shaken by a disastrous earthquake that happened in the year 1885 near Baramulla with magnitude 6.8 and intensity VII-IX (40) activated a huge landslide at Loridora 11km south of Baramulla (42). The whole village of Loridora got buried under this giant slide (Jones 1885). The recent earthquake of October 8, 2005, shook lesser Himalayas in India and Pakistan and triggered thousands of landslides in the region (Ray et al. 2009; Kamp et al. 2010; Dunning et al. 2007). Owen in 2008 had examined around 1293 landslides at 174 locations in Pakistan administered Kashmir (Owen et al. 2008; Kamp et al. 2010). Landslides in the Indian administered Kashmir were observed mainly due to failure of the faces of the river terraces and steep slopes in the road section at 8–10 km before Uri (Ray et al. 2009). The October 2005 earthquake also reactivated a large landslide known as the Hattian slide in the Jhelum Valley. The Hattian slide blocked the two tributaries Karli and Tung of Jhelum River as well as buried the entire Dandbeh hamlet (Schneider 2009; Dunning et al. 2007; Mahmood et al. 2015).

The Kashmir Himalaya has witnessed major landslides activated by catastrophic rains and cloud bursts. The September 2014 floods of the valley caused large-scale mass movements in the region. In September 2014 a major landslide happened in Sadal village of Udhampur buried 75 houses, 45 people, and livestock alive (Kumar et al. 2017). In Dharam Village of Sangaldan area of Ramban district, a huge landslide occurred on 25th September 2010 damaging 50 houses and government buildings in the region (Singh et al. 2014). In between the reservoir area of Baglihar, hydropower project a slope failure along National Highway -1B(NH-1B) in 2009 at Dharamsala area of Assar village 21 km from Batote left 20 families homeless and following the landslides the Border road organization has declared the 30km stretch unsafe(Singh et al. 2012). The Cloudburst of 2010 in the Ladakh region has triggered the most destructive landslides in the region resulting in the deaths of 234 people (Gupta et al. 2012)

The probable reason for the high susceptibility of landslides in the Himalayas is because the region lies in seismic zone 5 where we can experience earthquakes often resultin in huge mass movements (Rashid et al. 2017).The south-facing slopes of Himalaya that are largely exposed to Freeze-thaw conditions and have a lack of vegetation cover are more prone to landslides (Ambraseys and Bilham 2012). The heavy rains and snow during winter and monsoon months along the unstable slopes have resulted in deep weathering profiles. Water seeps into the porous rocks cause intense pressure which leads to slope failure mainly parallel to transport routes (Rashid et al. 2017). High precipitation has been the main triggering factor for landslides in the region similar to the other prior studies (Sultana 2020; Lin and Wang 2018; Niculita et al. 2017). Apart from the natural factors, the vulnerability to hazards has increased over years by anthropogenic activities such as the construction of roads, hydropower project dams, removal of vegetation, simplification of slopes, heavy vehicular vibrations, road widening, etc., (Sharma et al. 2012, Barnard et al. 2001). It has been noticed that the number of landslide events, fatalities, and injuries have increased over the period of time, and the results of the study match with other works of identical nature, Haque et al., 2016 and Lin and Wang, 2018, etc. that also indicate an increasing trend of the landslides.

The Jammu-Srinagar highway (NH-44) also known as the "death highway" or the "no man's highway" because of its high susceptibility to landslides has caused great damage over the years in terms of fatalities, injuries, suffering, heavy maintenance charges, etc. Because of the unstable terrain, complex geology, seismic activity, high precipitation, high traffic flow, and other anthropogenic activities along NH-44 has gained the attention of many authors (Singh et al. 2010; Chingkhei et al. 2014). Steep and unstable slopes are developed from hill cutting which gradually disunites the slope forming materials like stones and soil followed by heavy rainfall accumulated in those fractures resulting in sudden landslides (Bhat 2019). These sudden landslides along the NH-44 have caused great havoc in the region for decades and left the people with sufferings and scares, who have lost their loved ones on this route. Analyzing the impact of the landslides along the Jammu-Srinagar National Highway, it was found that the Kashmir basin has been affected the most at the hands of this highway, for being the only one out of the two routes (the other being the Mughal Road) that connect it to the rest of India, depicting its socio-economic importance in the region. Out of the prone areas, district Ramban shows the highest frequency of landslides and the related consequences also, recognized in similar works done by Tyagi and Kumar 2021; Fayaz and Abdul 2020.

6. Conclusion

For the Kashmir Himalaya currently, there is no complete historical landslide database available, at the Provincial scale, the impacts of landslides are not recognized clearly which is why the planning and mitigation measures for reducing the impact of landslides are vague. For bridging this wide gap in the datasets available the present study prepared a Historical landslide Inventory from 1990-2020 which could be used as a base data for developing a landslide early warning system in the Himalayas (LEWS), measure susceptibility, hazard, and risk analysis and could help planners, researchers, and decision-makers in analyzing the spatio-temporal trends of landslide and their consequences in the region. The study documents 739 landslides reported in 506 days in the past 30 years from 1990-2020 resulting in 1000 deaths and 267 injuries. The findings emanate that each year has reported landslides from 1991-2020 in the Kashmir Himalayas and it has been found that on average 25 landslide events reported in17 days cause 34 deaths and 9 injuries annually. The decadal distribution pattern of the landslides shows that out of the three decades, 2011-2020 has the highest frequency of landslides which represents 50% of total landslide events causing 62.7 % of total fatalities and 61.42% of total injuries. Decade 2001-2010 has 31.2% of total landslide events causing 34% of total deaths and 38.5% of total injuries and the decade 1991-2000 has reported 18.4% of total landslides with 3.3% of total deaths identified in the period 1990-2020. The seasonal distribution of landslides reveals that the winter season has recorded the maximum number of landslides which is about 33.2% of the total events followed by the monsoon

(32.7%) and pre-monsoon (29.5%). The post-monsoon season depicted the least no. of landslide incidents in the region, only 5% of the total landslides. The district-wise spatio-temporal pattern of the landslides was studied, out of 20 districts, 16 districts were found to be more vulnerable to landslides.

The study specifically identified 303 landslides reported in 260 days in the Jammu-Srinagar Highway from Udhampur to Banihal and the total estimated landslides for the highway were 1482. The spatial distribution of the landslide incidents analyses that section Marroog-Ramsu has the highest concentration of events from 1990-2020. An increasing trend of landslides was found with the highest frequency in the winter season accounting for 45.8% of total landslides, and monsoon season (29.3%) followed by pre-monsoon(22.7%) and the lowest frequency of landslides was found in the post-monsoon season (3.9%). The socio-economic damage caused by landslides annually is shown in table (5) and the maintenance costs of the highway are found to be very high, usually intensive labor and heavy machinery are employed to clear the debris of landslides along the roads.

The Landslide Database intimates that the northwestern Kashmir Himalayas is largely impacted by the landslide and avalanche episodes. The concentration of landslides is highest at three places identified by hotspot analysis, among which one lies in the Pir Panjal range and the other two lie in the Greater Himalaya, whereas, the fatal Landslide/Avalanche hotspots lie in the Pir Panjal range and in the Greater Himalaya. With real-time reporting and advancement of technology, data is readily available which is why maximum landslides are found in later years of the study. It was detected that in the Kashmir Himalaya maximum deaths were reported from Landslide/Avalanche incidents that occurred in highly elevated areas. The fatal landslides have caused maximum casualties of Army officials and soldiers with huge damage to Army check posts and camps situated in the susceptible areas. The findings manifest that the winter and the monsoon seasons have the highest occurrence of landslide events establishing the fact that landslides are mostly induced by rainfall in this region. The results of the study largely emphasize the need for a landslide early warning system in the Kashmir Himalayas to mitigate the impacts of landslide Hazard.

7. Declarations

Acknowledgment

Thanks to the support of all the authors who have contributed in the collection and compilation of the historical Landslide database of the Kashmir Himalaya.

Conflict of Interest/Competing Interests

The authors have no conflict of interest to declare.

References

1. Ahmad, B., Alam, A., Bhat, M. S., Bhat, K. A., Ahmad, H. F., & Qadir, J. (2021). Retracing Realistic Disaster Scenarios from Archival Sources: A Key Tool for Disaster Risk Reduction. *International Journal of Disaster Risk Science*, 1-14.
2. Ahmad, L., Parvaze, S., Majid, M., &Kanth, R. H. (2016). Analysis of historical rainfall data for drought investigation using standard precipitation index (SPI) under temperate conditions of Srinagar Kashmir. Pakistan Journal of Meteorology Vol, 13(25).
3. Albinia, A. (2010). Empires of the Indus: The story of a river. WW Norton & Company.
4. Alexander, D. (2005). Vulnerability to landslides. In Landslide hazard and risk (pp. 175–198). Wiley
5. Ambraseys, N., & Bilham, R. (2012). The Sarez-Pamir earthquake and landslide of 18 February 1911. *Seismological Research Letters*, *83*(2), 294-314.
6. Antonini, G., Cardinali, M., Guzzetti, F., Reichenbach, P., & Sorrentino, A. (1993). Carta InventariodeiFenomeniFranosidellaRegione Marche ed areelimitrofe, CNR Gruppo Nazionale per la DifesadalleCatastrofiIdrogeologiche Publication no. 580, 2 sheets, scale 1: 100 000. GNDCI internal report
7. Barnard PL, Owen LA, Sharma MC and Finkel RC. (2001). Natural and Human-induced Landsliding in the Garhwal Himalaya of Northern India. Geomorphology, 40(1-2):21-35. https://doi.org/10.1016/s0169-555x(01)00035-6.
8. Bhandari, R. K. (2006, November). The Indian landslide scenario, strategic issues and action points. In *India disaster management congress, New Delhi* (pp. 29-30).
9. Bhat, Bilal. (2019). Developmental Activities and Rampant hill cutting are the main reasons for a landslide in Srinagar Jammu Highway.
10. Bhat, M. I. (1987). Spasmodic rift reactivation and its role in the pre-orogenic evolution of the Himalayan region. Tectonophysics, 134(1-3), 103-127.
11. Bilham, R., & Bali, B. S. (2014). A ninth century earthquake-induced landslide and flood in the Kashmir Valley, and earthquake damage to Kashmir's Medieval temples. *Bulletin of Earthquake Engineering*, *12*(1), 79-109.
12. Brabb, E. E., & Harrod, B. (Eds.). (1989). Landslides: extent and economic significance (p. 385). Rotterdam: AA Balkema.
13. Cendrero, A., &Dramis, F. (1996). The contribution of landslides to landscape evolution in Europe. Geomorphology, 15(3-4), 191-211.
14. Chingkhei, R. K., Shiroyleima, A., Singh, L. R., & Kumar, A. (2013). Landslide hazard zonation in NH-1A in Kashmir Himalaya, India. International Journal of Geosciences, 2013.
15. Devoli, G., Morales, A., &Høeg, K. (2007). Historical landslides in Nicaragua—collection and analysis of data. Landslides, 4(1), 5-18.
16. DiPietro, J. A., & Pogue, K. R. (2004). Tectonostratigraphic subdivisions of the Himalaya: A view from the west. Tectonics, 23(5).

17. Dikshit, A., Sarkar, R., Pradhan, B., Segoni, S., &Alamri, A. M. (2020). Rainfall induced landslide studies in Indian Himalayan region: A critical review. Applied Sciences, 10(7), 2466.
18. Dunning, S. A., Mitchell, W. A., Rosser, N. J., & Petley, D. N. (2007). The Hattian Bala rock avalanche and associated landslides triggered by the Kashmir Earthquake of 8 October 2005. *Engineering Geology*, *93*(3-4), 130-144.
19. Fayaz, Mohsin & Abdul Khader, Sheik. (2020). Identifying the parameters responsible for Landslides on NH-44 Jammu Srinagar National Highway for Early Warning System. Disaster Advances. Vol. 13 (2). 32-42.
20. Fiorucci, F., Ardizzone, F., Mondini, A. C., Viero, A., & Guzzetti, F. (2019). Visual interpretation of stereoscopic NDVI satellite images to map rainfall-induced landslides. Landslides, 16(1), 165-174.
21. Froude, M. J., &Petley, D. N. (2018). Global fatal landslide occurrence from 2004 to 2016. Natural Hazards and Earth System Sciences, 18(8), 2161-2181
22. Gansser, A. (1964). Geology of the Himalayas.
23. Geertsema, M., Highland, L., &Vaugeouis, L. (2009). Environmental impact of landslides. In Landslides–disaster risk reduction (pp. 589-607). Springer, Berlin, Heidelberg.
24. Ghosh, T., Bhowmik, S., Jaiswal, P., Ghosh, S., & Kumar, D. (2020). Generating Substantially Complete Landslide Inventory using Multiple Data Sources: A Case Study in Northwest Himalayas, India. Journal of the Geological Society of India, 95(1), 45-58.
25. Gupta, P., Khanna, A., & Majumdar, S. (2012). Disaster management in flash floods in Leh (Ladakh): A case study. *Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine*, *37*(3), 185.
26. Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M., & Chang, K. T. (2012). Landslide inventory maps: New tools for an old problem. Earth-Science Reviews, 112(1-2), 42-66.
27. Hao, L., Rajaneesh, A., Van Westen, C., Sajinkumar, K. S., Martha, T. R., Jaiswal, P., & McAdoo, B. G. (2020). Constructing a complete landslide inventory dataset for the 2018 monsoon disaster in Kerala, India, for land use change analysis. Earth system science data, 12(4), 2899-2918.
28. Haque, U., Da Silva, P. F., Devoli, G., Pilz, J., Zhao, B., Khaloua, A., ...& Glass, G. E. (2019). The human cost of global warming: Deadly landslides and their triggers (1995–2014). Science of the Total Environment, 682, 673-684.
29. Housen T, Lenglet A, Shah S, Sha H, Ara S, Pintaldi G and Richardson A. (2019). Trauma in the Kashmir Valley and the Mediating Effect of Stressors of Daily Life on Symptoms of Posttraumatic Stress Disorder, Depression and Anxiety. Conflict and Health, 13:58. https://doi.org/10.1186/s13031-019-0245-6.
30. Jones, E.J., (1885) Report on the Kashmir earthquake of 30 May 1885. Rec Geol Surv India 18(4):221–227
31. Kamp, U., Owen, L. A., Growley, B. J., & Khattak, G. A. (2010). Back analysis of landslide susceptibility zonation mapping for the 2005 Kashmir earthquake: an assessment of the reliability of susceptibility zoning maps. *Natural hazards*, *54*(1), 1-25

32. Kirschbaum, D., Stanley, T., & Zhou, Y. (2015). Spatial and temporal analysis of a global landslide catalog. Geomorphology, 249, 4-15.
33. Kirschbaum, D. B., Adler, R., Hong, Y., Hill, S., &LernerLam, A. (2010). A global landslide catalog for hazard applications: Method, results, and limitations. Natural Hazards, 52(3), 561–575. https://doi.org/10.1007/ s11069-009-9401-4
34. Kumar, A., Asthana, A. K. L., Priyanka, R. S., Jayangondaperumal, R., Gupta, A. K., & Bhakuni, S. S. (2017). Assessment of landslide hazards induced by extreme rainfall event in Jammu and Kashmir Himalaya, northwest India. *Geomorphology*, *284*, 72-87.
35. Lazzari, M., Gioia, D., &Anzidei, B. (2018). Landslide inventory of the Basilicata region (Southern Italy). Journal of Maps, 14(2), 348-356
36. Lin, Q., & Wang, Y. (2018). Spatial and temporal analysis of a fatal landslide inventory in China from 1950 to 2016. Landslides, 15(12), 2357-2372.
37. Lukose Kuriakose, S., Sankar, G., &Muraleedharan, C. (2010, May). Landslide fatalities in the Western Ghats of Kerala, India. In EGU general assembly conference abstracts (p. 8645).
38. Mahmood, I., Qureshi, S. N., Tariq, S., Atique, L., & Iqbal, M. F. (2015). Analysis of landslides triggered by October 2005, Kashmir Earthquake. *PLoS currents*, *7*.
39. Martha, T. R., Roy, P., Jain, N., Khanna, K., Mrinalni, K., Kumar, K. V., & Rao, P. V. N. (2021). Geospatial landslide inventory of India—an insight into occurrence and exposure on a national scale. Landslides, 1-17
40. Martha, T. R., van Westen, C. J., Kerle, N., Jetten, V., & Kumar, K. V. (2013). Landslide hazard and risk assessment using semi-automatically created landslide inventories. Geomorphology, 184, 139-150.
41. Metternicht, G., Hurni, L., &Gogu, R. (2005). Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments. Remote sensing of Environment, 98(2-3), 284-303.
42. McCalpin, J. (1984, April). Preliminary age classification of landslides for inventory mapping. In Proceedings 21st annual Enginnering Geology and Soils Engineering Symposium (pp. 5-6).
43. Mondini, A. C., Viero, A., Cavalli, M., Marchi, L., Herrera, G., & Guzzetti, F. (2014). Comparison of event landslide inventories: the Pogliaschina catchment test case, Italy. Natural Hazards and Earth System Sciences, 14(7), 1749-1759
44. Nadim, F., Kjekstad, O., Peduzzi, P. et al. Global landslide and avalanche hotspots. Landslides 3, 159–173 (2006). https://doi.org/10.1007/s10346-006-0036-1
45. NDMA (2019) National Landslide Risk Management Strategy A publication of the National Disaster Management Authority, Government of India. September 2019, New Delhi
46. Niculiţă, M., Andrei, A., Lupu, C., Niculiță, M., &Mărgărint, M. C. (2017). The landslide database of North-Eastern Romania. In Proceedings of romanian geomorphology symposium (Vol. 1, pp. 11-14).
47. Nowicki Jessee, M. A., Hamburger, M. W., Ferrara, M. R., McLean, A., & FitzGerald, C. (2020). A global dataset and model of earthquake-induced landslide fatalities. *Landslides*, *17*(6).

48. Owen, L. A., Kamp, U., Khattak, G. A., Harp, E. L., Keefer, D. K., & Bauer, M. A. (2008). Landslides triggered by the 8 October 2005 Kashmir earthquake. *Geomorphology*, *94*(1-2), 1-9.
49. Pandey, V. K., Srinivasan, K. L., & Kulkarni, U. V.(2014) Landslide Challenges Due to Widening of Road Section Between Udhampur and Chenani Along National Highway-44, Jammu and Kashmir, India. *Disaster& Development*, 84.
50. Parkash, S. (2011). Historical records of socio-economically significant landslides in India. J. South Asia Disaster Stud, 4(2), 177-204.
51. Patel, S. K., Nanda, A., Singh, G., & Patel, S. (2020). A review of disasters in Jammu and Kashmir, and Ladakh region in India. *International Journal of Population Studies*, *6*(1), 69-81.
52. Pereira, S., Zêzere, J. L., Quaresma, I. D., & Bateira, C. (2014). Landslide incidence in the North of Portugal: Analysis of a historical landslide database based on press releases and technical reports. *Geomorphology*, *214*, 514-525.
53. Pennington, C., Freeborough, K., Dashwood, C., Dijkstra, T., & Lawrie, K. (2015). The National Landslide Database of Great Britain: Acquisition, communication and the role of social media. Geomorphology, 249, 44-51.
54. Petley, D. (2012). Global patterns of loss of life from landslides. Geology, 40(10), 927-930.
55. Petley, D. N., Hearn, G. J., Hart, A., Rosser, N. J., Dunning, S. A., Oven, K., & Mitchell, W. A. (2007). Trends in landslide occurrence in Nepal. Natural hazards, 43(1), 23-44
56. Qiu, J. (2014). Landslide risks rise up agenda. Nature News, 511(7509), 272.
57. Romshoo, S. A., Rashid, I., Altaf, S., & Dar, G. H. (2020). Jammu and Kashmir state: an overview. Biodiversity of the Himalaya: Jammu and Kashmir State. Topics in biodiversity and conservation, 18, 129-166.
58. Rashid, M., Bhat, S. H., & Bahsir, I. A. (2017). Road construction, maintenance challenges and their solutions in Kashmir. *Irrigation & Drainage Systems Engineering*, *6*(1), 1-5.
59. Ray, P. C., Parvaiz, I., Jayangondaperumal, R., Thakur, V. C., Dadhwal, V. K., & Bhat, F. A. (2009). Analysis of seismicity-induced landslides due to the 8 October 2005 earthquake in Kashmir Himalaya. *Current science*, 1742-1751
60. Remondo, J., Bonachea, J., &Cendrero, A. (2008). Quantitative landslide risk assessment and mapping on the basis of recent occurrences. Geomorphology, 94(3-4), 496-507
61. Righini, G., Pancioli, V., &Casagli, N. (2012). Updating landslide inventory maps using Persistent Scatterer Interferometry (PSI). International Journal of Remote Sensing, 33(7), 2068-2096.
62. Schneider, J. F. (2009). Seismically reactivated Hattian slide in Kashmir, Northern Pakistan. *Journal of Seismology*, *13*(3), 387-398. Parvaiz, I., Champatiray, P. K., Bhat, F. A., & Dadhwal, V. K. (2012). Earthquake-induced landslide dam in the Kashmir Himalayas. *International journal of remote sensing*, *33*(2), 655-660.
63. Shah, B. (2021). Traditional Kashmiri Herbal Shera (soup) Boosts Immunity –Owing To COVID-19 pandemic. International Journal of Recent Advances in Engineering and Technology, Vol. 9(8), 1-7.

64. Sharma, R., Sharma, V. K., & Waris, V. I. S. (2012). Impact of peace and disturbances on tourism and horticulture in Jammu and Kashmir. *International Journal of Scientific and Research Publications*, *2*(6), 1-7.

65. Silkin, T., & Hendrie, B. (1997). Research in the war zones of Eritrea and Northern Ethiopia. *Disasters*, *21*(2), 166-176.

66. Singh, Y., Bhat, G. M., Sharma, V.,)Pandita, S. K., & Thakur, K. K. (2012). Reservoir induced landslide at Assar, Jammu and Kashmir: A case study. *Journal of the Geological Society of India*, *80*(3), 435-439.

67. Singh, Y., Sharma, V., Pandita, S. K., Bhat, G. M., Thakur, K. K., & Kotwal, S. S. (2014). Investigation of landslide at Sangaldan near tunnel-47, on Katra-Qazigund railway track, Jammu and Kashmir. *Journal of the Geological Society of India*, *84*(6), 686-692.

68. Singh, Tarun. (2018). Landslide Inventory of India 1948 - 2017.

69. Singh, Y. U. D. H. I. B. I. R., & Bhat, G. M. (2010). Role of basin morphometric parameters in landslides along the national highway-1A between Udhampur and Batote, Jammu and Kashmir, India: a case Study. HimalGeol, 31(1), 43-50.

70. Steck, A. (2003). Geology of the NW Indian Himalaya. EclogaeGeolHelv, 96, 147-196.

71. Stein , A. (1898) Kalhana's Rajatarangini: a chronicle of the kings of Kashmir, vol 2. Constable and Co, Calcutta

72. Sultana, N. (2020). Analysis of landslide-induced fatalities and injuries in Bangladesh: 2000-2018. Cogent Social Sciences, 6(1), 1737402.

73. Taylor, F. E., Malamud, B. D., Freeborough, K., & Demeritt, D. (2015). Enriching Great Britain's national landslide database by searching newspaper archives. *Geomorphology*, *249*, 52-68.

74. Tyagi, Priyanka & Kumar, Naveen. (2021). Landslides in Jammu & Kashmir Union Territory: A Data Inventory from the Year 2018 To 2021.

75. UN-SPIDER; https://www.unisdr.org/files/52828_03landslidehazardandriskassessment.pdf

76. USGS; https://www.usgs.gov/faqs/how-many-deaths-result-landslides-each-year

77. Wadia, D. N. (1931). The syntaxis of the northwest Himalaya: its rocks, tectonics and orogeny. Rec. Geol. Surv. India, 65(2), 189-220.

78. Wani, S. M., Suhaff, A.A., Khan, A.W., and Teli BA. (2020). Prevalence of Depression and Anxiety Symptoms in People Affected by Flood in Kashmir. International Journal of Health Science Research, 10(6):24-9.

79. W.H.O landslide report; (https://www.who.int/health-topics/landslides)

80. Van Westen, C. J., Ghosh, S., Jaiswal, P., Martha, T. R., & Kuriakose, S. L. (2013). From landslide inventories to landslide risk assessment; an attempt to support methodological development in India. In Landslide science and practice (pp. 3-20). Springer, Berlin, Heidelberg.

81. Zhang, J., Westen, C. J. V., Tanyas, H., Mavrouli, O., Ge, Y., Bajrachary, S., ... &Khanal, N. R. (2019). How size and trigger matter: analyzing rainfall-and earthquake-triggered landslide inventories and

their causal relation in the Koshi River basin, central Himalaya. Natural hazards and earth system sciences, 19(8), 1789-1805.

Figures

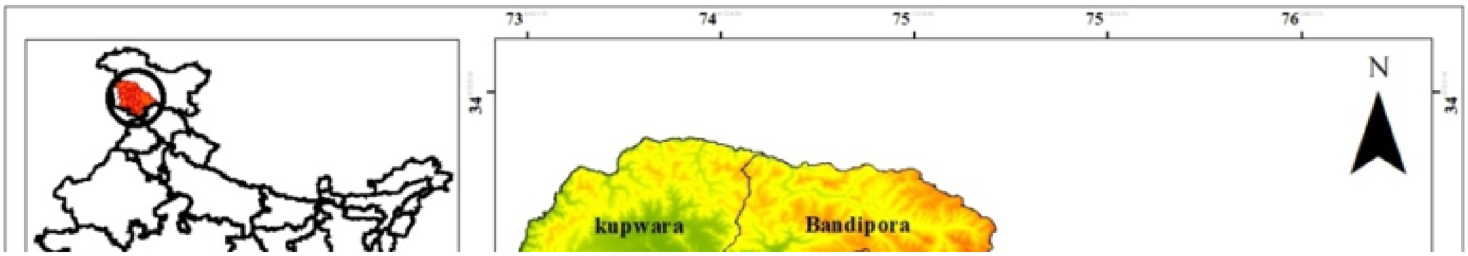

Figure 1

location map of the study area

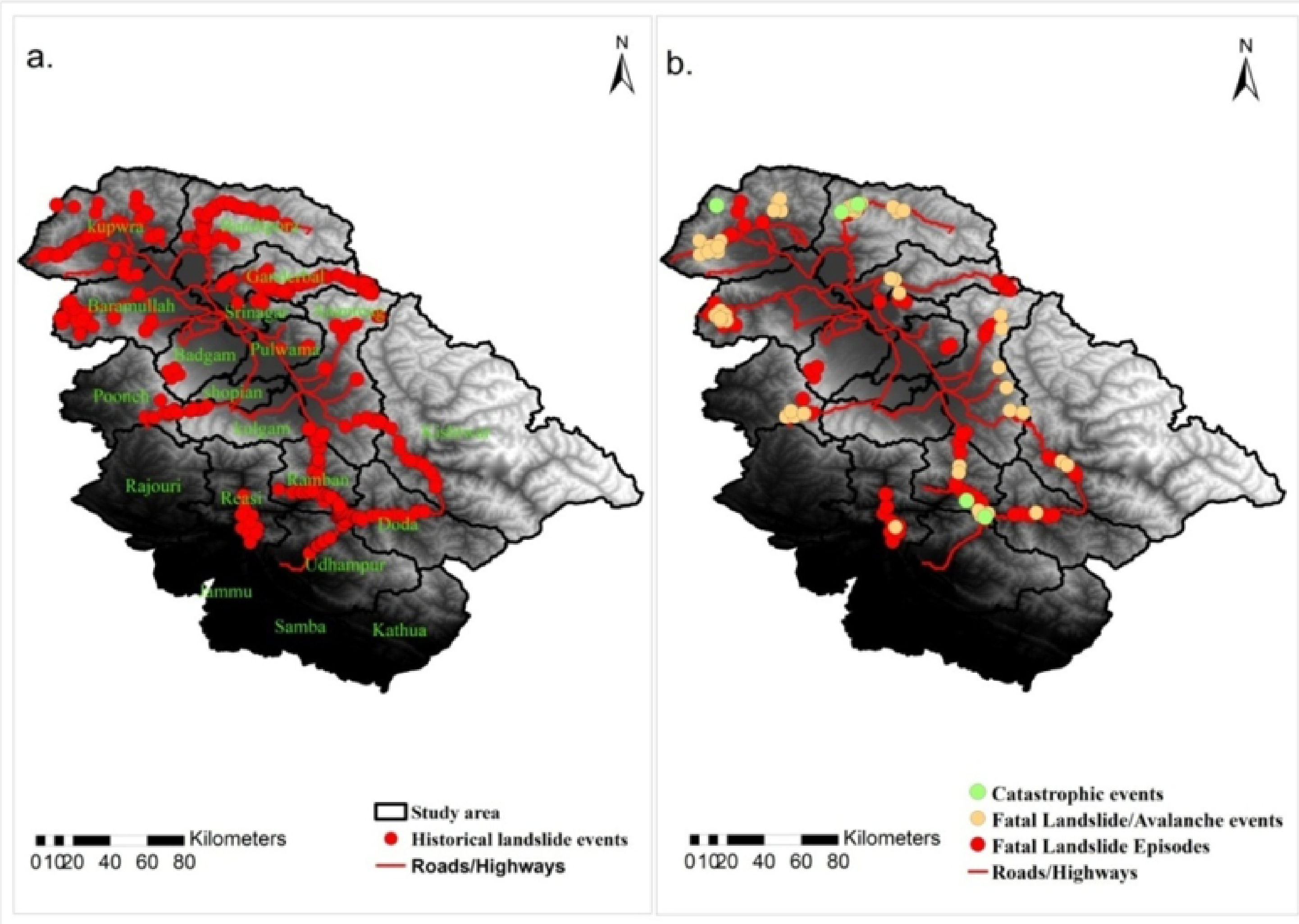

Figure 2

Spatial distribution of **(a)** 736 landslide events and **(b)** 180 fatal events (landslide/avalanches) in Kashmir Himalayas (1990-2020)

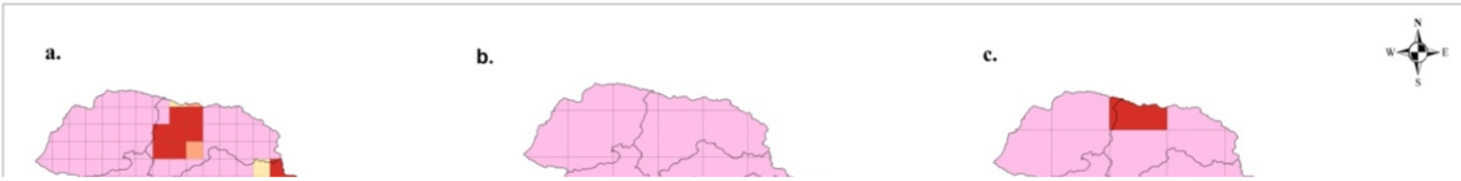

Figure 3

Geographical Location of **(a)** historical landslides hotspots, **(b)** fatal landslide hotspots and **(c)** fatal landslide/avalanche hotspot

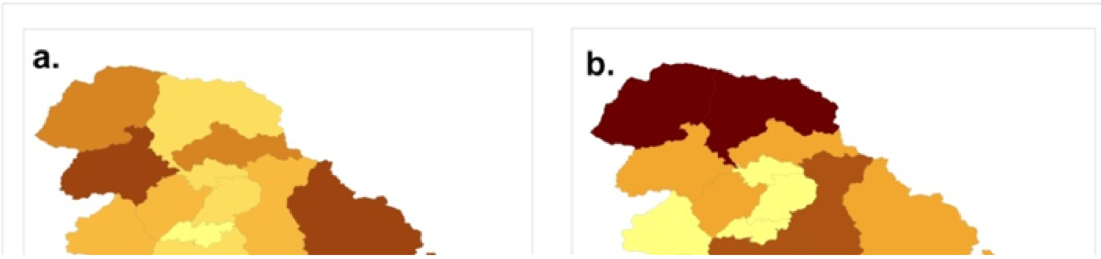

Figure 4

District-wise Spatial Distribution of **(a)** No. Of reported fatal landslides, **(b)** No. of reported fatal L/A (landslide/avalanche) events, **(c)** reported landslide fatalities, **(d)** reported landslide injuries, **(e)** reported L/A fatalities and **(f)** reported L/A injuries

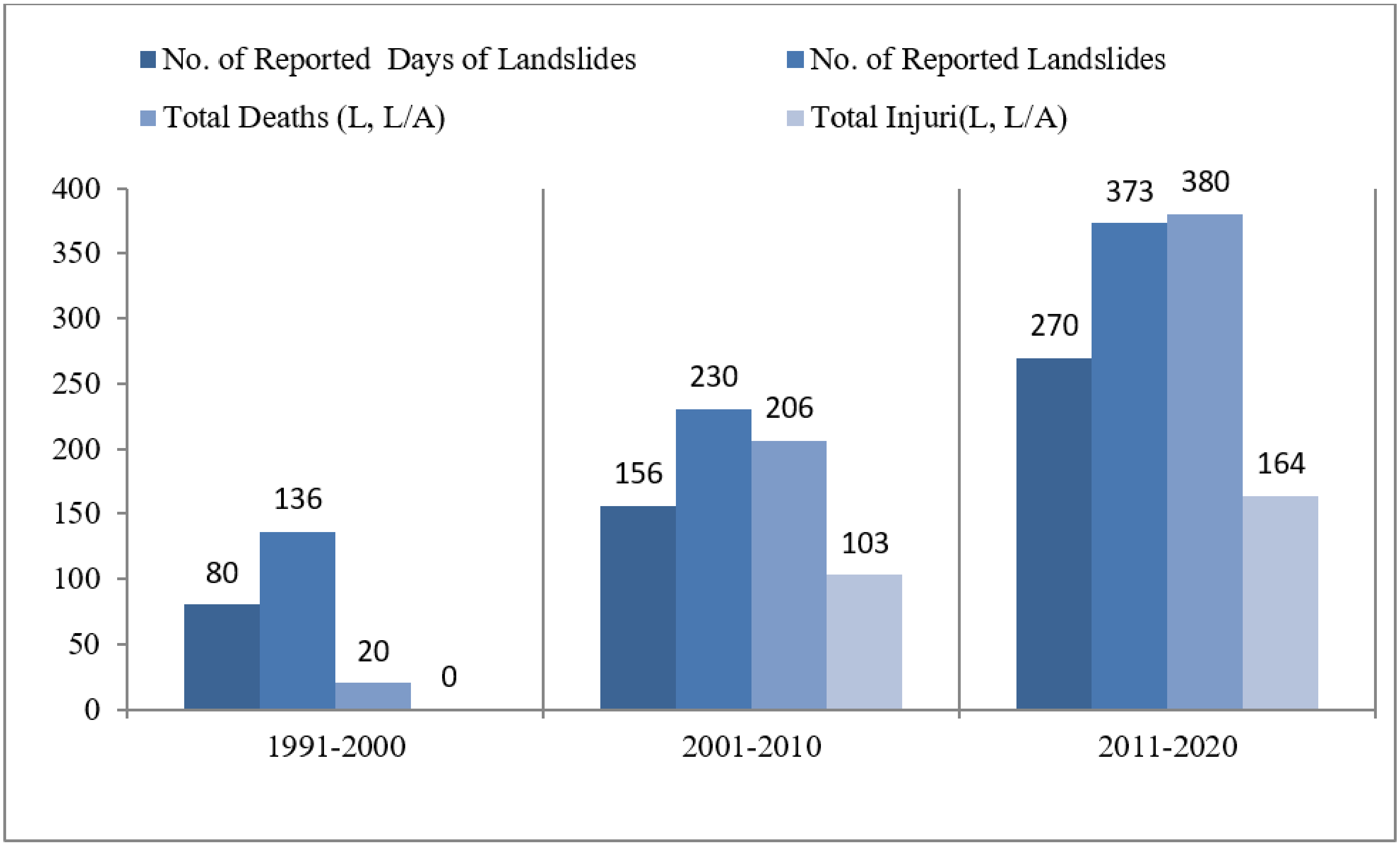

Figure 5

Decadal variation in the frequency of landslide events and the resulting fatalities and injuries in the Kashmir Himalayas (1990-2020)

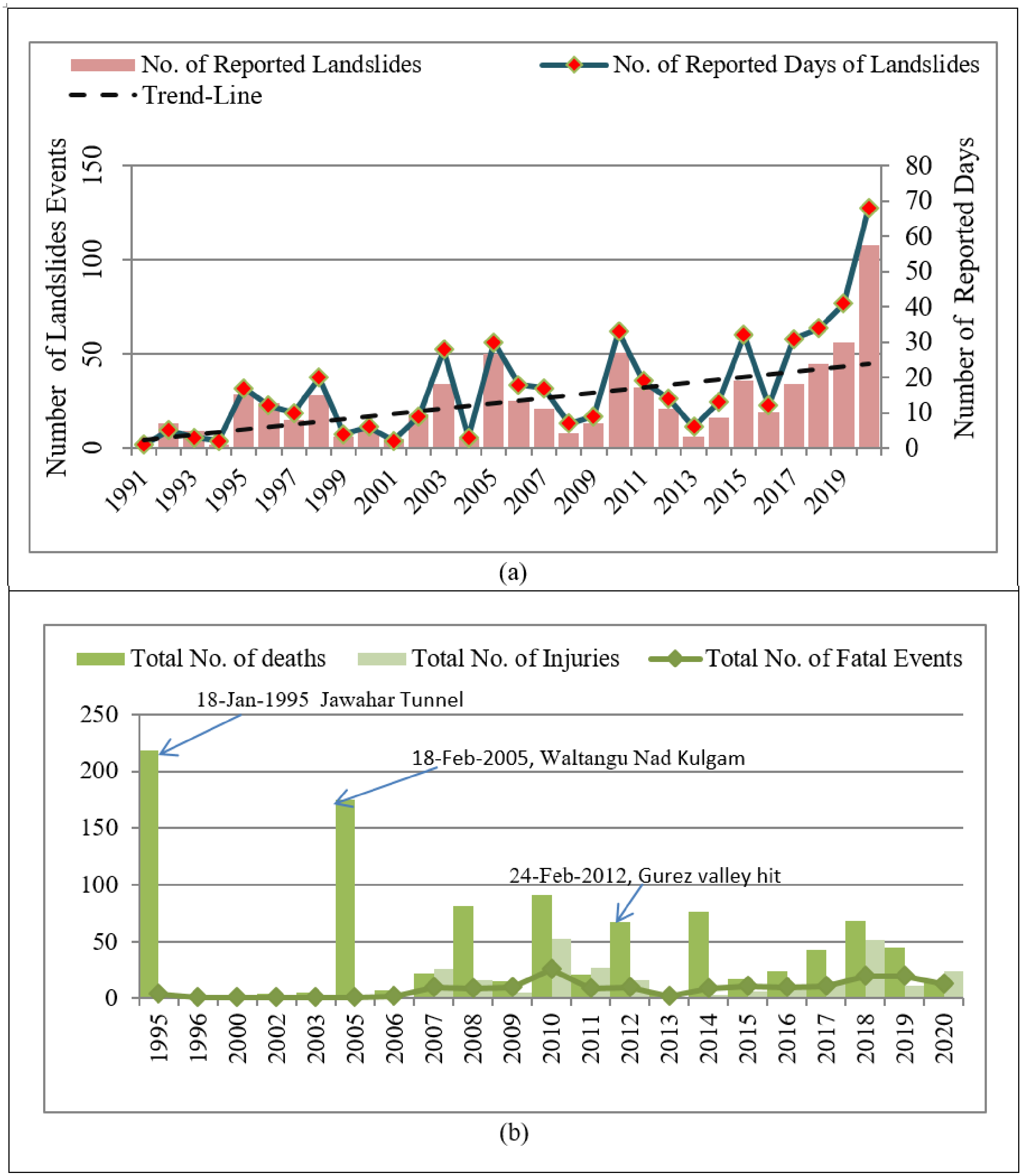

Figure 6

(a) Yearly distribution of landslide events and their reported days (1990-2020) and **(b)** Temporal variation in the frequency of fatal landslides and related fatalities and injuries (1990-2020)

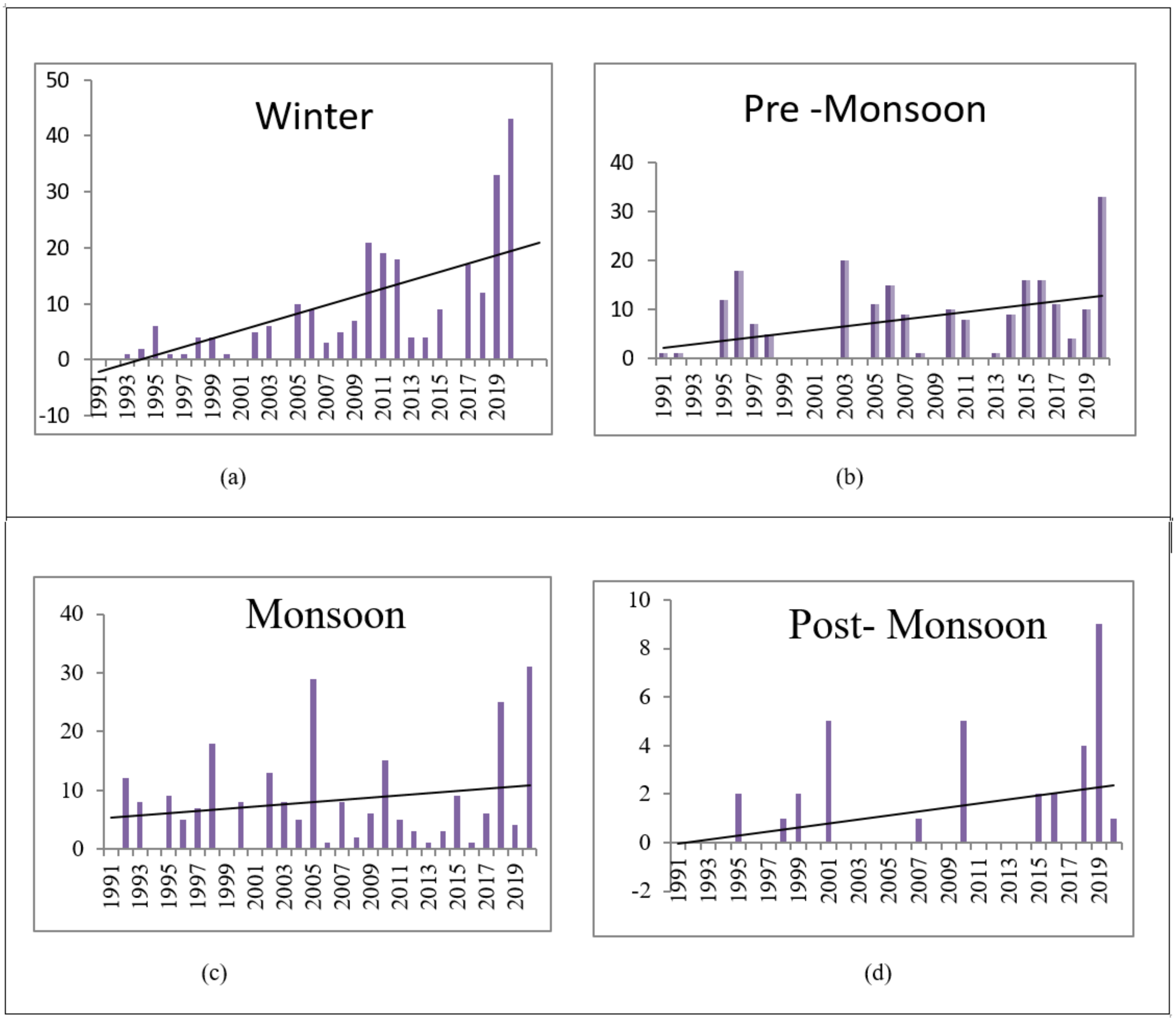

Figure 7

Seasonal Trends of landslide Events (1990-2020)

Figure 8

(a) The geographical location of Jammu-Srinagar National Highway (NH-44) , **(b)** Spatial Distribution of landslides in different sections of the National Highway (NH-44) , Hotpot Analysis of Historical Landslides along the National Highway using **(c)** Fishnet method **(d)** Polygon Method

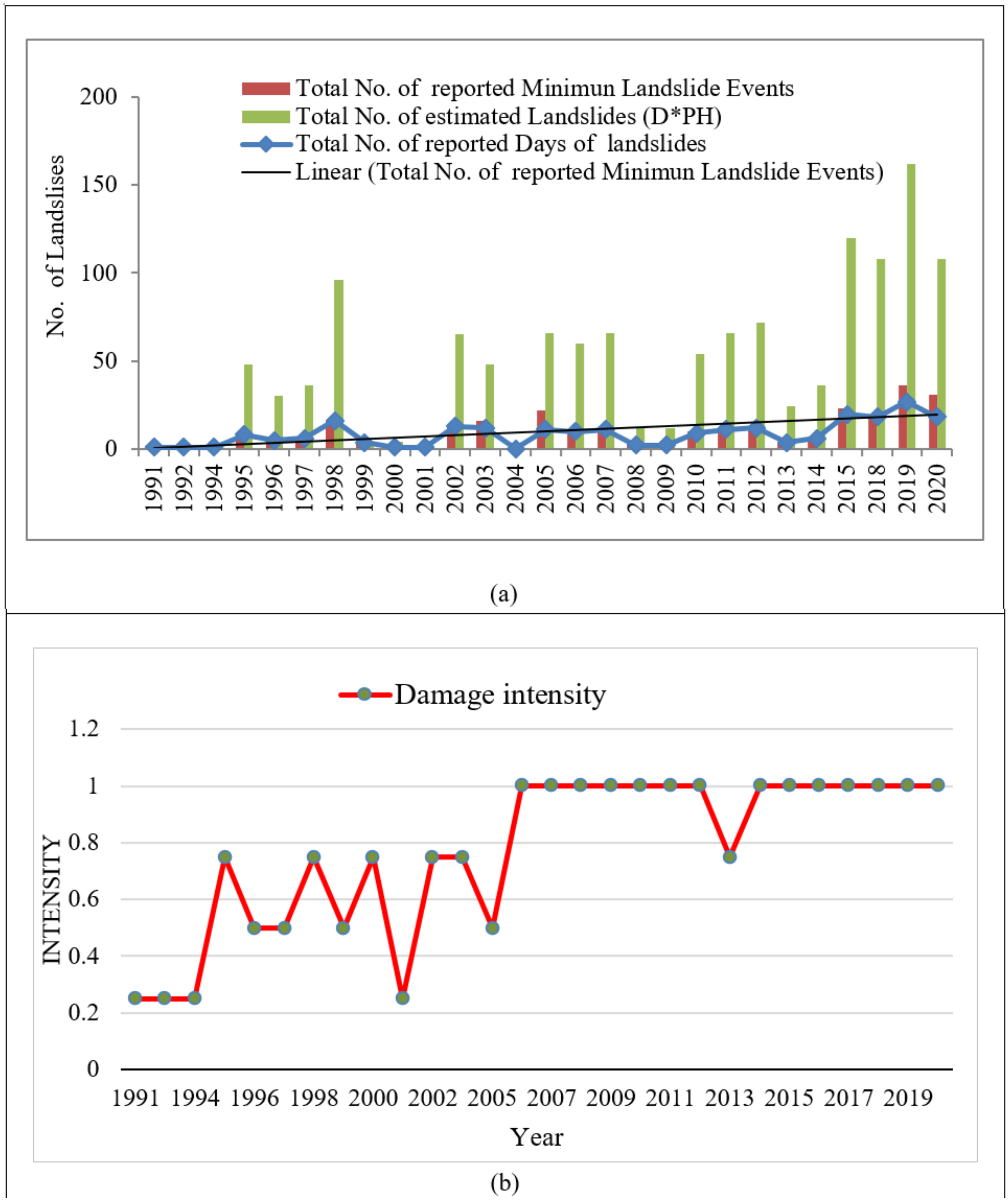

Figure 9

(a) Annual variation in the frequency of the landslides along NH-44 from 1990-2020 and **(b)** Graph showing Damage intensity annually caused by landslides along NH-44 from 1990-2020