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Landslide Hazard Assessment of Kashmir

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Abstract
The Kashmir Valley is a scenic region located in north western India, known for its natural beauty and cultural significance. Despite its attractive features, the valley is situated in a multi hazard prone region and is vulnerable to multiple disasters like landslides, floods, earthquakes, cloud burst snow avalanches, resulting in widespread infrastructural damage and loss of life. In this paper, we present landslide hazard assessment of the Kashmir Valley to understand the potential risk posed to the region. Landslide hazard assessment is an important step towards landslide hazard and risk management. There are several methods of Landslide Hazard Zonation (LHZ) viz. heuristic, semi quantitative, quantitative, probabilistic and multi-criteria-decision-making process. However, no one method is accepted universally for effective assessment of landslide hazards. In recent years, several attempts have been made to apply different methods of LHZ and to compare results in order to find the best suited model. The advanced multivariate techniques are proved to be effective in spatial prediction of landslides with high degree of accuracy. Physical process based models also perform well in LHZ mapping even in the areas with poor database. Multi-criteria decision making approach also play significant role in determining relative importance of landslide causative factors in slope instability process. Remote Sensing and Geographical Information System (GIS) are powerful tools to assess landslide hazards and are being used extensively in landslide researches since last decade. Aerial photographs and high resolution satellite data are useful in detection, mapping and monitoring landslide processes. GIS based LHZ models helps not only to map and monitor landslides but also to predict future slope failures. The advancements in Geo-spatial technologies have opened the doors for detailed and accurate assessment of landslide hazards. The study provides a comprehensive analysis of the geophysical setting of the valley, historical landslide activity, and the current landslide hazard assessment. The paper also highlights the measures being taken to reduce the impact of landslides in the valley of Kashmir, with a focus on the role of the government, local communities, and NGOs in disaster risk reduction.

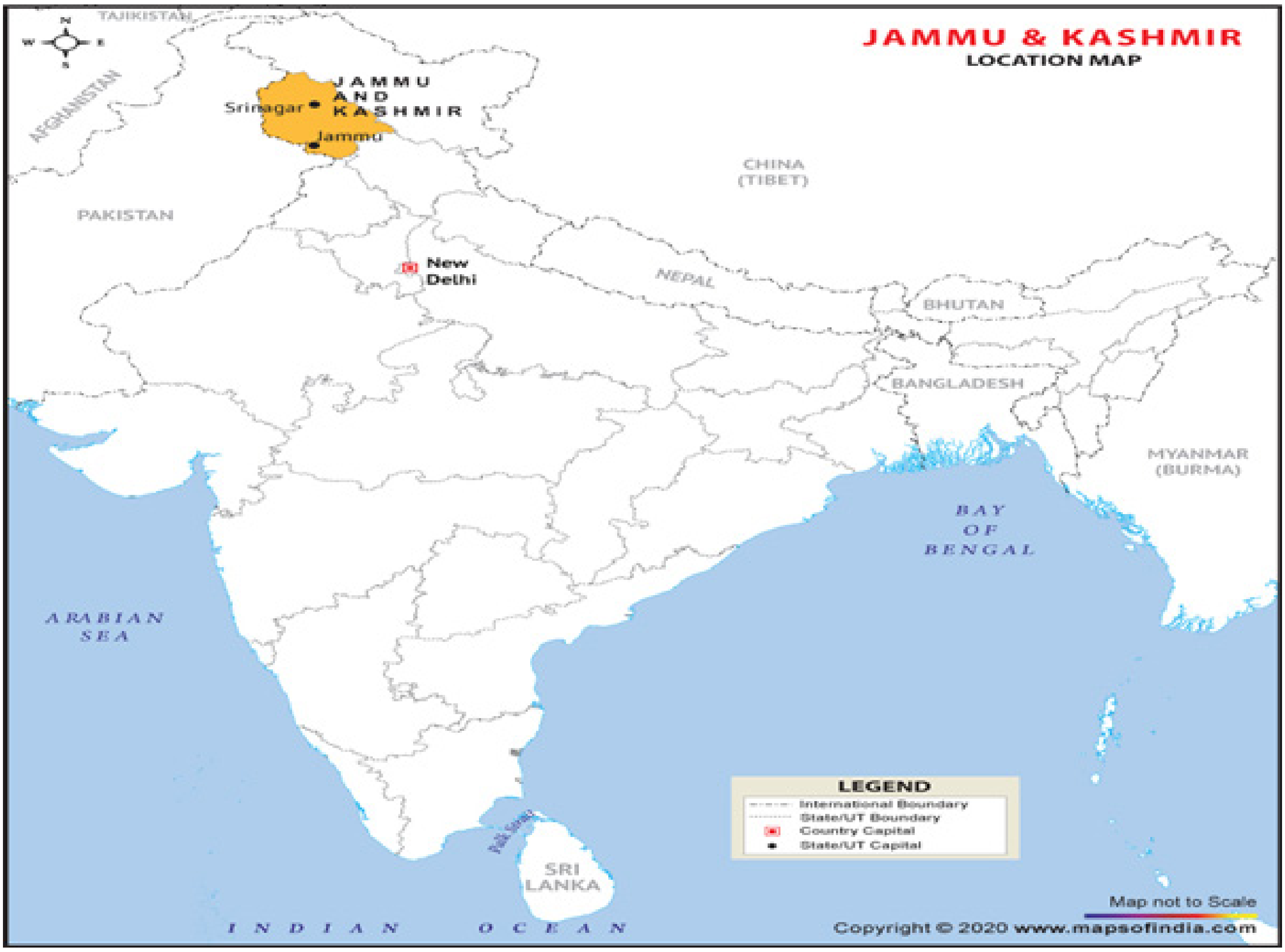
Keywords: Landslides, assessment, hazard, disaster, Kashmir, Early Warning

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. Landslide is an important geological hazard that causes damage to natural and social environment. The concept of landslide is dealt by many authors differently. Varnes and IAEG (1984) defined landslides as 'almost all varieties of mass movements on slope including some such as rock falls, topples and debris flow that involve little or no true sliding'. Brusden (1984) considered landslides as a unique form of mass transport and a process which do not require a transportation medium such as water, air or ice. Crozier (1986) defined landslides as 'the outward and downward gravitational movement of the earth material without the aid of running water as a transporting agent'. According to Hutchinson (1988), 'A landslide in its strict sense is a relatively rapid mass wasting process that causes the down slope movement of mass of rock, debris or earth triggered by variety of external stimulus'. A recent definition by Courture R (2011) simply states that 'landslide is a movement of mass of soil (earth or debris) or rock down a slope'. This concept of landslide is more broaden with respect to the type of material that moves down slope. Landslide causes loss of around 1000 lives and property worth $4 billion annually (EM-DAT 2007). According to the database created by the Centre for Research on Epidemiology of Disasters, landslides and related processes have killed over 61,000 people world over in the period between A.D. 1900 and A.D. 2009 (EMDAT 2010). According to Brabb (1993), at least 90% of landslide losses can be avoided if the problem is recognized before the landslide event. Hence, there is a dire need for landslide hazard assessment at various spatial scales.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 & 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). Kashmir Himalaya being a rugged and tectonically active zone has complex, unstable geology along with steep slopes, creating a favourable environment for landslide hazards, especially along the National Highway (NH-44) that connects the Valley 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 landslide events and their impacts on humans emphasizing Jammu-Srinagar National Highway (NH-44) .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. As per study 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 (Shah.B et al., 2021).The results of this study are expected to be of potential use for developing a Landslide mitigating strategies to minimize the impacts of landslides in the Kashmir. 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. 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 valley and measures for landslide risk mitigation and prevention in the region.

Study Area

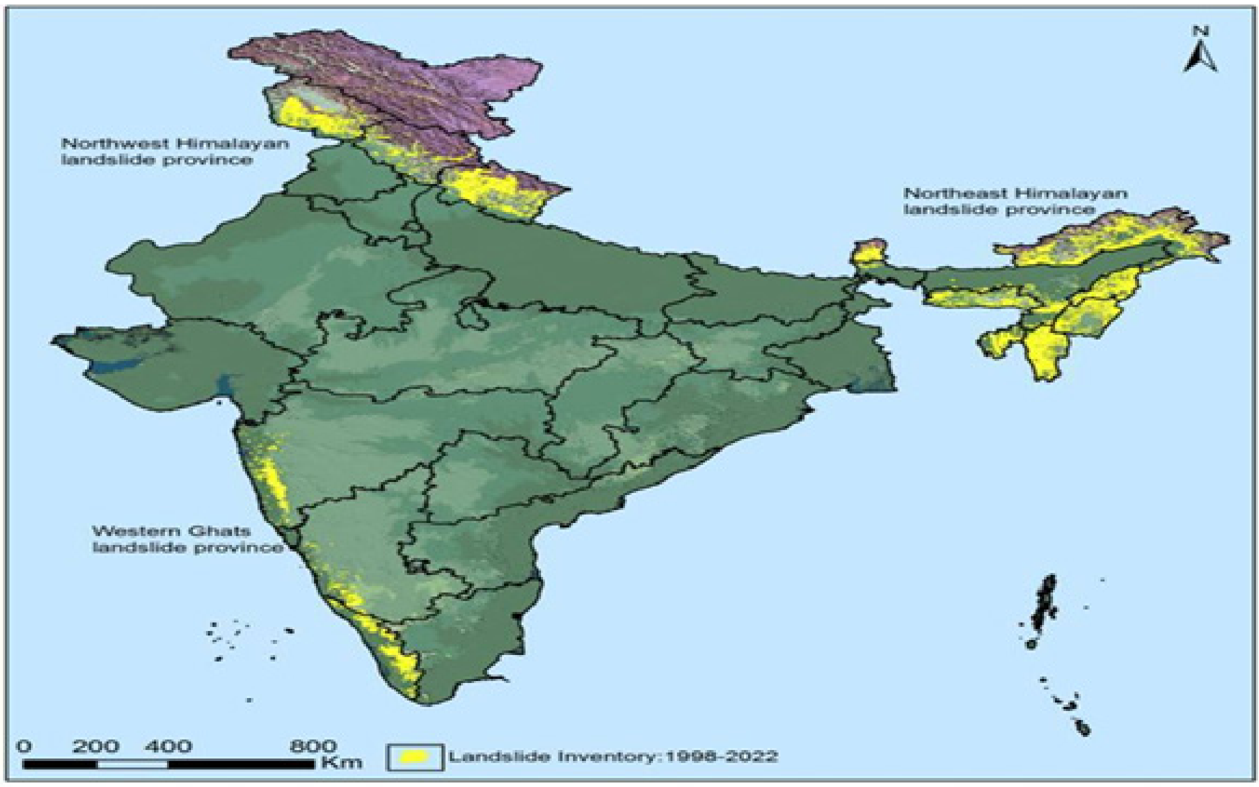
The Kashmir valley, nestled in the north-western folds of the Himalayas, is surrounded on almost all sides by mountain ranges (Hussain. M, 2002). The Kashmir region lies between latitudes 32° and 36° N, and longitudes 74° and 80° E. It has an area of 68,000 sq. mi (180,000 km2). The Himalayas are the 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 & 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. 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).



(Source: https://www.mapsofindia.com/maps/jammuandkashmir)

Historical Scenario of landslides

Historical records reveal that in 883 AD, an earthquake triggered a landslide that impounded the River Jhelum and flooded the Kashmir Valley. 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). High precipitation has been the main triggering factor for landslides in the region similar to the other prior studies (Sultana 2020; Lin & 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; Lin & Wang, 2018,) that also indicate an increasing trend of the landslides.



landslide-atlas-of-India

(Source: https://pwonlyias.com/current-affairs/landslide-atlas-of-india)

How prone is India to landslides?

India is prone to landslides due to its diverse topography, geological formations, and climatic conditions and is one of the top five landslide-prone countries globally, with high vulnerability in the Himalayas and Western Ghats. Rainfall variability is the biggest cause of landslides in India. 12.6% of India's geographical land area (0.42 million sq. km) is prone to landslides excluding snow-covered areas. 66.5% of landslides occur in the North-western Himalayas, 18.8% in the North-eastern Himalayas, and 14.7% in the Western Ghats.

Some of the landslide-prone regions in India include:

- **Himalayan Region:** The Himalayas, especially in states like Uttarakhand, Himachal Pradesh, and Jammu and Kashmir, are highly susceptible to landslides due to steep slopes, fragile geological formations, particularly during the monsoon season and after seismic events.
- **Eastern and Western Ghats:** Certain areas in the Eastern Ghats, including parts of Odisha, Andhra Pradesh, and Tamil Nadu, are susceptible to landslides, particularly in hilly and forested regions. The Western Ghats, particularly in states like Kerala, Karnataka, and Maharashtra, are prone to landslides, especially during the monsoon season, due to heavy rainfall and deforestation.
- **Central India:** Certain hilly areas in central India, including parts of Madhya Pradesh, Chhattisgarh, and Maharashtra, are also susceptible to landslides, especially in areas with deforestation and improper land use.

Landslide Hazard Assessment

Landslide hazard assessment is an important tool for evaluating the potential for landslides to occur in a particular area. Several approaches are used to assess landslide hazards, incorporating various techniques and methodologies to identify and mitigate potential risks.

- **Geomorphic Mapping:** by utilizing digital elevation models (DEMs) for terrain analysis to identify slope steepness, aspect, curvature, and topographic features associated with landslides. In addition identifying and mapping different landforms, such as scarps, and debris fans, which are indicative of past or potential landslide activity. Assessing historical rainfall patterns, intensity-duration-frequency (IDF) curves, and runoff characteristics to understand the role of water in slope instability. Studying the influence of groundwater fluctuations on slope stability and potential groundwater-induced landslides. With help of conducting in-situ and laboratory investigations to characterize soil and rock properties, including shear strength, permeability, and compressibility, to assess slope stability. Using geotechnical models and software to analyze slope stability and potential failure mechanisms.
- **Remote Sensing and GIS:** Satellite Imagery Analysis: Utilizing satellite or aerial imagery to identify land cover changes, slope movements, and other indicators of potential landslide activity. More over GIS-based Mapping including Integrating various spatial datasets to create landslide susceptibility and hazard maps, incorporating factors such as geology, land use, and slope characteristics.
- **Historical Data and Field Surveys:** Compiling historical landslide data to identify high-risk areas and understand past landslide distribution. In addition, Conducting field investigations to validate remote sensing data, map geomorphic features, and collect detailed information

on local geological and hydrological conditions. Using statistical and probabilistic approaches to assess landslide susceptibility and hazard based on historical data and spatial analysis.

Mitigation measures to minimize the impacts of landslides

Land-Use Planning and zoning including Identifying and avoiding high-risk areas for development and regulate construction in landslide-prone areas through zoning laws and building codes and promote safer construction practices. Conducting detailed risk assessments and mapping of landslide-prone areas to identify high-risk zones and inform land-use decisions and infrastructure development. Risk identification, assessment and monitoring are very important for timely and effective response. Conducting public awareness campaigns and educational programs to inform communities about the potential risks of landslides, emergency procedures, provide training to local authorities, emergency responders, and communities on about landslide preparedness. More over Establishing early warning systems that utilize technology such as monitoring sensors, weather forecasts, to alert people and communities to provide advance notice of potential landslide hazards for timely evaluation and disaster risk reduction. In addition, Install and maintain landslide monitoring systems, including inclinometers, ground-penetrating radar, and remote sensing technologies, to detect slope movement. Implementing measures to preserve and restore natural vegetation, manage drainage, and control erosion to stabilize slopes and absorb water and reduce landslide risk. Conduct reforestation and afforestation programs in landslide-prone areas to enhance slope stability. In addition develop and enforce regulations and policies to ensure responsible land use and development practices in landslide-prone areas. Integrate landslide risk assessment into land-use planning and environmental impact assessments. In addition creating hazard maps help in identification of hazard zones and vulnerable areas of landslides. So by having such maps in hand will help people to restrict construction and developmental activities in these areas. This will also help in land use planning.

Conclusion and Discussion

Landslide hazard assessment involves a multidisciplinary approach, integrating geological, hydrological, geotechnical, and remote sensing techniques to comprehensively evaluate the factors contributing to landslide susceptibility and potential hazards in a given area. It is an effort to quantify landslide hazard and its associated uncertainty in time and space and to provide estimates for risk assessment. Although landslide hazard assessment is more a scientific issue, it deserves special attention because of its direct impacts upon the society. Landslide inventory maps also help in generating the hazard assessment 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). Landslide hazard assessment is a critical task in landslide management process. Landslides are influenced by several preparatory and triggering factors which vary significantly from region to region. Quantitative methods on the other hand, provide objective methods for determining weights for a given parameter based on their relationships with landslide occurrence. Application of Remote Sensing and Geographical Information System is of immense importance for effective landslide hazard assessment. High resolution satellite data combined with powerful GIS techniques improves the level of accuracy of LHZ maps in recent times. 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 resulting 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). Winter and the monsoon seasons have the highest occurrence of landslide events establishing the fact that landslides are mostly induced by rainfall in Kashmir region which largely emphasize the need for a landslide early warning system in the Kashmir Himalayas to mitigate the impacts of landslide Hazard. Additionally, mapping and surveying the valley's landslide hazard zones might help with landslide hazard assessment. This can be a tool useful in the pre as well as a post landslide disaster occurrences.

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