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Landslide Hazard Zonation Mapping Techniques on Himalayan Region in India: A Survey

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Abstract- This review article is focused on the modern mapping techniques for creating a near-accurate landslide hazard zonation (LSZ) map focused on the different parts of the Himalayan Mountain region in India. The necessity of an LSZ map has been discussed by some given examples showing the vulnerability that comes with every landslide. As one of the youngest folded mountain ranges, The Himalayas are very much prone to landslides, with the development of modern technologies, the way of research has also transformed. In this article, the focus is identifying some recent techniques based on GIS and Remote sensing technologies which proves the accuracy and necessity of more research work. There are many areas that are vulnerable to landslides but completely untouched. The focus is to merge different techniques to create an understanding of how the technology can be a useful tool to create more accurate LHZ maps for different locations.

Key Words: Landslide Hazard Zonation (LHZ), Technologies, GIS, Remote Sensing

Introduction- Landslide is a very frequent phenomenon in the Himalayan Mountain region. As it is one of the youngest folded mountains, the formation is still in the process which brings unpredictable natural hazards. For the past several years, landslide events have been increased throughout the whole Himalayan region (Verma & Khanduri, 2019). Landslide is the result of a variety of geo-environmental processes (Anbalagan, Kumar, Lakshmanan, Parida, & Neethu, 2015), some of the major factors behind landslides are, crisscrossed ridges and river valleys, complex geological structures, geomorphology, hydro-meteorology, tectonic activity (Bera, Mukhopadhyay, & Das, 2019) and in recent days one of the major causes is human interferences due to unplanned development. With the development of technology, the methodologies have also been modified to create and interpret Landslide Hazard Zonation (LHZ) maps. Modern GIS and remote sensing technologies are one of the most used in this field. LHZ mapping works as an assessment, management, and mitigation planning for landslides by locating the probable earthquake-prone areas with detailed descriptions with the prediction of hazards and how it can be used effectively to achieve hazard reduction with the help of disaster management (Bera, Mukhopadhyay, & Das, 2019). Remote sensing and GIS have a huge impact on LHZ mapping. For the process of factor characterization and landslide inventory map, the contribution of remote sensing is undeniable. Remote sensing techniques have the capability of temporal analysis which gives past and present data for effective manipulation and statistical measures (Anbalagan, Kumar, Lakshmanan, Parida, & Neethu, 2015). The hazard caused by landslides can never be controlled but the severity and potential damage can be minimized with the help of proper planning before any kind of infrastructural development by cutting down trees and destroying natural ecosystems. Therefore, the need for the identification of steep unstable slopes which are prone to landslides is necessary for landslide hazard zonation mapping. It helps to identify landslide potential zones with a proper order of degree and intensity of probable landslides (Sarkar & Kanungo, 2005). Various techniques have carried out LHZ mapping throughout the Himalayan region, here I have discussed a brief outline of some of the modern and unique techniques.

Landslide Problems in The Himalayas:

According to Global Landslide Disaster Database, 5318 non-seismic landslides have been recorded from 2004 to 2017 out of which rainfall was the major cause behind 3285 landslides. In the context of the Indian Himalayas, during the same period, 580 landslides occurred out of which 477 was due to rainfall which contributes 14.52%of the global landslide data (Dikshit, Sarkar, Pradhan, Segoni, & Alamri, 2020). According to the data published by NASA GLC, the number of landslides in the Indian Himalayan region is much higher from 2007 to 2015 is 691 with 6306 deaths (NASA, 2015).

Landslide Incidents Throughout The Himalayan Region (2009-2020):

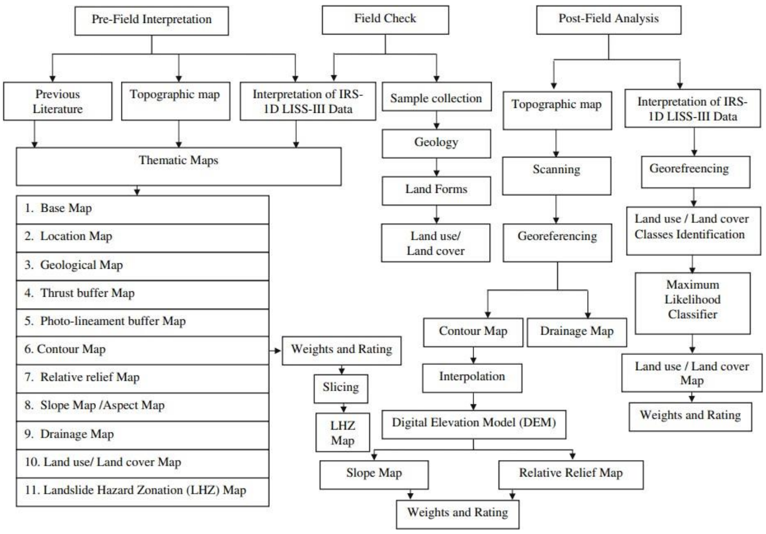
Region	Date of occurrence	Deaths & Damages
Gopeshwar, Chamoli district, Uttarakhand	26th July 2009	Landslide nearby an under-construction bridge killed two people
Jawharlal Nehru Marg, Kyongsala, Sikkim	August, 2009	Blocked the Nathula – Gangtok-road hampering connectivity. Caused one death.
Landslide incidence in Jammu & Kashmir	18th April 2011	Five members of a family were killed and one injured in a landslide triggered by heavy rains
Landslide incidence in West Bengal, Shevok	26th and 27th March 2011	2 people died and many were injured.
Uttrakhand Floods	16-17th June 2013	Over 5700 were reported dead and over 4,200 villages had been affected by the floods and post- floods landslide.
Solan, Himachal Pradesh	15th October 2014	2 people were killed in a mine during a landslide
Jammu- Srinagar National Highway	26th February 2015	2 people were killed and several were injured.
Mirik, Darjeelng	1st July 2015	More than 40 people died, many houses were destroyed.
Sikh shrine Gurdwara Manikaran Sahib in Himachal Pradesh	18th August 2015	At least10 people have died.
New Salem, New Kanan, and Neigailong villages of Tamenglong district, Manipur	11th July 2018	Took nine lives and was destroyed under-construction buildings.
Lunglawn landslide, Mizoram	4th June 2018	10 people lost their lives and buildings were buried.
Siam, East Sikkim	June 2019	Rock slide occurred approximately at a distance of 20kms from Gangtok on the Gangtok-Rangpo-Siliguri National Highway-31
Tigdo Village, Arunachal Pradesh	10th July 2020	A house was totally destroyed. Four people living in it died.
Cachar, Hailakandi and Karimganj district, Assam.	June 2020	Total eight landslides throughout three districts in Assam due to heavy rainfall.

Source: (GSI, 2020)

Review Section:

Landslide hazard zonation mapping has been done throughout the Himalayas by various techniques. Due to the known previous incidents of landslides, extensive research has been done in both qualitative and quantitative manner to find out a proper solution. Landslide hazard analysis focuses mainly on the spatial zoning of the hazard (Beek & Asch, 2004).

On a research work is carried out by on Dikrong river basin of Arunachal Pradesh by (Pande, Dabral, & Chowdari, 2008) it has been observed that the research work had been done by creating various thematic layers such as slope, photo-lineament buffer, thrust buffer, a relative relief map, geology and land use/land cover map with the help of GIS and Remote Sensing techniques. To create a drainage map and for elevation, 20 m interval for contours had been taken and it was digitized with the help of ARC/INFO GIS software from Survey of India toposheets on a scale representing RF 1:50,000.



After that, from the elevation

Fig. 1 Research Framework by (Pande, Dabral, & Chowdari, 2008)

map with the help of digitized contours, a DEM map was created having 200 m · 200 m resolution. The DEM has been further used to generate slope and relative relief maps to get a clearer picture of possible landslide-prone zones. To create land use/ land cover information, four spectral bands of IRS- 1D LISS III geocoded imagery were used. The collected imagery was classified by using ERDAS IMAGINE Software. As a result, the data accuracy was 88.84%, and was observed that the area is highly landslide prone because of its complex geological characteristics and geo-environmental conditions.

According to another study focused on Landslide susceptibility zonation using geospatial technique and analytical hierarchy process in Sikkim Himalaya by (Sonker, Tripathi, & Singh, 2021). They have used three techniques by creating an integrated approach of remote sensing, geographical information system (GIS), and Analytical Hierarchy Process (AHP) to create an LSZ map. Apart from that, to understand landslide triggering factors, DEM data, conventional maps, Rainfall data, and Landsat 8 OLI were used to prepare eight different thematic layers to show various characteristics such as, geomorphology, geology, drainage

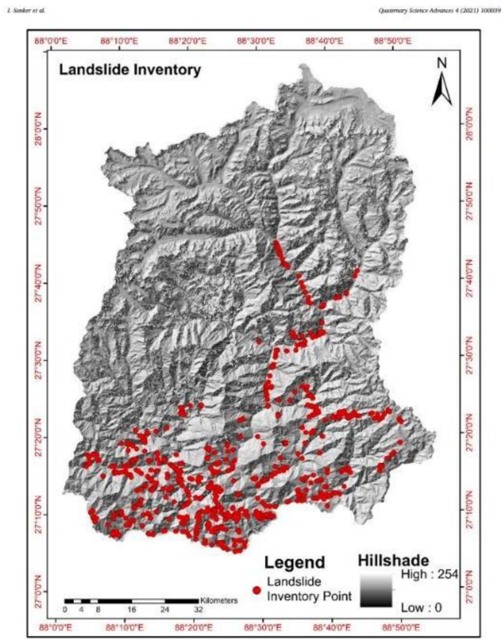


Fig.2 Sikkim Landslide Inventory

by (Sonker, Tripathi, & Singh, 2021)

density, lineament-density, soil, slope, annual rainfall, and land use. With the help of Satty's scale, the produced thematic layers were added and the features were balanced properly by AHP techniques. After the whole process, all of the thematic outputs were merged in a GIS environment by linear combination method with

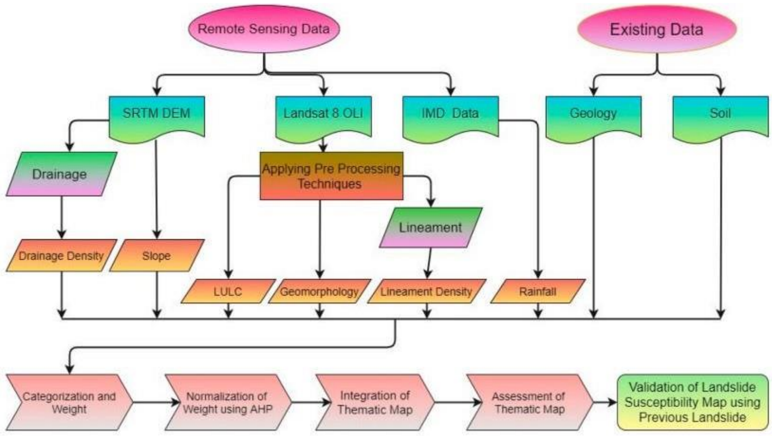


Fig.3 Methodological Framework by (Sonker, Tripathi, & Singh, 2021)

ARC GIS 10.4 software. As a result, the area was divided into five landslide zones from very low, low, moderate, high to very high having 73% of landslide inventory.

The state of Uttarakhand falls under one of the most landslide-prone zones. During the previous decade, some massive disasters due to landslides have had occurred in this region, destroying infrastructures and taking a lot of lives. The research work entitled, "Study of landslide hazard zonation in Mandakini Valley, Rudraprayag district, Uttarakhand using remote sensing and GIS" by (Rawat, et al., 2015) gave us a detailed landslide inventory research work which was influenced after the 2013 Uttarakhand glacier break and flash flood. For the inventory work, Pre and post-flood high-resolution imagery and satellite data from LISS IV and Cratosat-2 SOI toposheets pre- and post- flood satellite data have been used to create a landslide hazard zonation map. Weightage rating systems have been used. With a 1 to 9 ordinal rating, thematic layers were

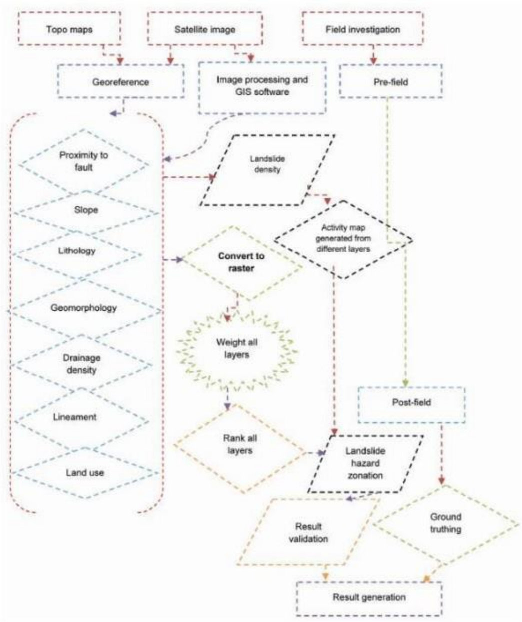


Fig.4 Methodology Flow Chart by (Rawat, et al., 2015)

prepared. As a result, 5 different hazard zones from low to very high have been pointed out. The value of chi-square test is statistically appropriate and also validates the hazard zonation classes of the map. Hence, it can be concluded that the map correlates well with existing field conditions.

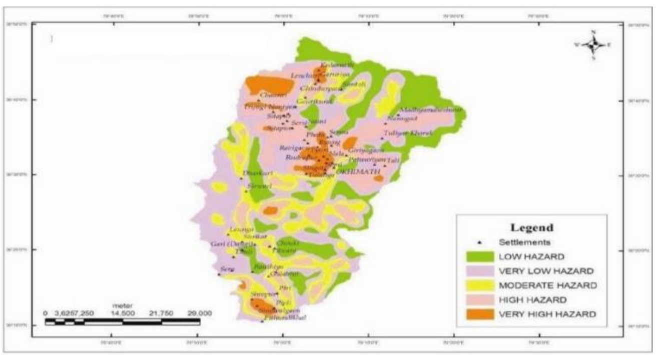


Fig.5 LSZ map of the study area by (Rawat, et al., 2015)

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On 8th October an earthquake of 7.8 magnitude jostled the lesser Himalayan region of Kashmir and its adjacent areas which causes major destruction and massive landslides. In the study entitled "Back analysis of landslide susceptibility zonation mapping for the 2005 Kashmir earthquake: An assessment of the reliability of susceptibility zoning maps" by (Camp, Owen, & Growly, 2010) they have discussed thoroughly an LSZ mapping technique of this region. DEM of 15mm horizontal resolution from ASTER Satellite images was used for the analysis of

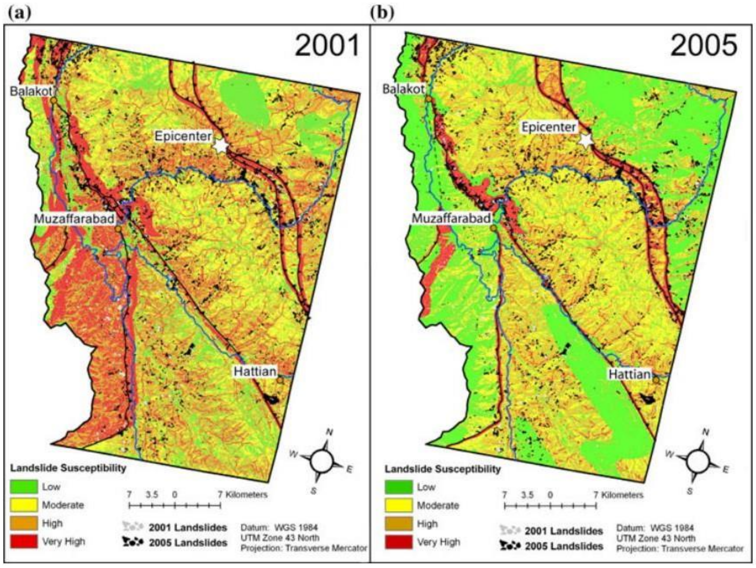

Fig. 3 Landslide susceptibility maps for the 2005 Kashmir earthquake study area: **a** for 2001 (this study); **b** for 2005 (after Kamp et al. 2008: Fig. 3). In 2001, more than half (55%) of the study area was highly or very highly susceptible to future landsliding, while a quarter showed moderate and a fifth only low susceptibility. In their susceptibility map 2005, Kamp et al. (2008) concluded that a third of the study area were high to very high susceptible to future landsliding, while 2/3 showed moderate to low susceptibility. This general decrease from 2001 to 2005 in landslide susceptibility reflects the earthquake-triggered landsliding as predicted in the 2001 map

Fig.6 Source: Camp, Owen, & Growly, 2010)

terrain which includes information regarding slopes, elevation, and other aspects. For landslide inventory, IDRISI Andes for ASTER imagery has been used which further helps classification of land cover. For multicriteria evaluation of event controlling parameters (ECP) with the help of ArcGIS 9.2. for calculating a comparative result between 2001 and 2005. Most of the LSZ maps were made based on multi-criteria evaluation of event controlling parameters. In this study, there are a total

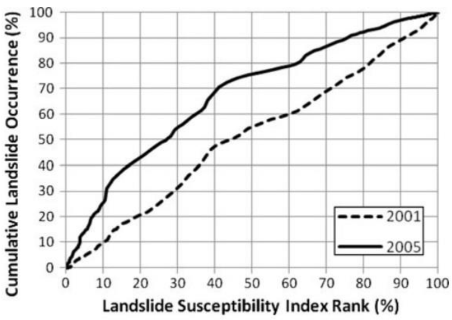

Fig. 4 Success rates for the landslide susceptibility maps in the 2005 Kashmir earthquake study area for 2001 (this study) and 2005 (after Kamp et al. 2008: Fig. 4). While the accuracy of the 2005 map is ~67%, it is only ~50% for the 2001 map. A possible explanation for this relatively low accuracy of the 2001 map might be a too small number and/or size of landslide training sites for the satellite imagery analysis

Fig.7 Source: Camp, Owen, & Growly, 2010)

of eight ECP – Lithology, Faults, Topography, Elevation, Slope Gradient, Slope Aspect, Landcover, River, and roads. The accuracy of the LSZ map is usually described with the success rate, which is based on a comparison of the prediction with already existing landslides. In most cases, the susceptibility map was never evaluated against actually occurred landslides. This is the case, of course, because the susceptibility map is a prediction tool looking into the future.

Conclusion: This review article discussed various research works based on different modern techniques for landslide susceptibility zonation. Landslide Susceptibility Zonation techniques showed that there are two measurement techniques. It can be seen that the quantitative approach has become more and more popular due to the development and advancement of GIS and Remote sensing techniques. All the research work in this review has been focused on GIS technologies. It is prominent that, using these modern technologies for creating LSZ Maps is effective and it gives accuracy as well. Compressing different types of GIS-based approaches along with field surveys and secondary data sources helps to create comparative as well as temporal analysis of natural and man-made earth surface features. It provides the opportunity for planning and sustainability. Using GIS-based software such as Q- GIS, Arc GIS is highly effective for identifying different characteristics such as slope, elevation, etc.

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