Original Article
ISSN (Online): 2350-0530
ISSN (Print): 2394-3629

International Journal of Research - GRANTHAALAYAH
April 2025 13(4), 163–174

A CONCEPTUAL STUDY ON METHODOLOGIES FOR LANDSLIDE HAZARD: INVENTORIES, SUSCEPTIBILITY, VULNERABILITY, AND RISK ANALYSIS

Amar Jyoti Taye [1], Rubi Tamang [2]

[1] PhD. Research Scholar, Department of Geography, North-Eastern Hill University, Shillong, India
[2] PhD. Research Scholar, Department of Education, North-Eastern Hill University, Shillong, India

ABSTRACT

Landslides pose a significant geohazard globally, particularly in Asia, which accounts for nearly 75% of worldwide landslide-related fatalities. The regions under the Himalayan Arc in India are especially vulnerable due to complex geomorphological, climatic, and anthropogenic factors. This conceptual review synthesizes existing methodologies for landslide hazard mapping by exploring four key dimensions: inventories, susceptibility, vulnerability, and risk assessment. The study highlights the importance of landslide inventories which serve as the foundation for accurate susceptibility modelling. Various susceptibility mapping approaches—qualitative, semi-quantitative, and quantitative have been reviewed. Further, vulnerability assessments through multidimensional frameworks, including heuristic and index-based methods, fragility curves, and numerical modelling, which evaluate the impact on both human and structural assets, are discussed. Finally, risk analysis is also deliberated through qualitative and quantitative lenses, integrating hazard intensity, vulnerability, and value of elements at risk. This review highlights the need for a multidisciplinary and mixed-method approach to enhance the accuracy, reliability, and practical applicability of landslide hazard assessments, particularly in data-scarce and high-risk regions.

Keywords: Landslide Parameters, Susceptibility, Vulnerability Assessment, Risk Analysis, Methodology

Received 21 March 2025
Accepted 15 April 2025
Published 12 May 2025

Corresponding Author
Amar Jyoti Taye, tayeamar76@gmail.com

DOI
10.29121/granthaalayah.v13.i4.2025.6139

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

1. INTRODUCTION

Landslides are among the most devastating natural hazards, resulting in significant human casualties, economic losses, and environmental degradation globally. The problem is particularly acute in Asia, which accounts for approximately 75% of landslide-related fatalities, with countries like India, Nepal, Bangladesh, and Myanmar facing recurrent disasters, especially during the monsoon season Froude and Petley (2018), UNISDR. (2017). India ranks third globally in landslide risk, with the states under the Himalayan terrain being highly vulnerable due to the combination of steep slopes, intense rainfall, tectonic instability, and unregulated anthropogenic interventions such as deforestation and mining Ray (2018).

Given this complex hazard landscape, landslide hazard mapping has emerged as a critical tool for identifying at-risk zones and informing mitigation strategies. Central to this process are landslide inventories, susceptibility models, vulnerability assessments, and comprehensive risk analyses. Despite decades of research, there remains no universally accepted framework for landslide hazard assessment, with methodologies varying widely in terms of data inputs, analytical approaches, and spatial scales Guzzetti et al. (1999), Westen et al. (2003). This review critically synthesizes the wide-ranging methods applied in landslide hazard mapping—spanning qualitative, quantitative, and semi-quantitative frameworks, to assess their applicability, strengths, and limitations. It also addresses the need for integrating multi-criteria approaches and validating susceptibility models using predictive techniques such as the Area Under the Curve (AUC).

2. LANDSLIDE INVENTORIES AND SUSCEPTIBILITY MAPPING PARAMETERS

According to Cruden (1991) “Landslide is the movement of a mass of rock, earth or de¬bris down a slope.”

Landslide inventories, often developed using high-resolution satellite imagery, field surveys, and historical data, are essential tools for assessing landslide risk. These inventories help in mapping past landslide events, which in turn aid in creating susceptibility models Guzzetti et al. (1999). The use of landslide inventory during landslide hazard assessment is ubiquitous, however, the component used to develop a landslide inventory may differ according to the specific needs of the study. Researchers worldwide had developed a landslide inventory using mostly field surveys Asmare (2023), Guzzetti et al. (1999), Guzzetti et al. (2006), Guzzetti et al. (2012), Intarawichian and Dasananda (2010), Jamaludin et al. (2008), Panchal and Shrivastava (2022), Silalahi et al. (2019), Sun et al. (2018), Westen et al. (2003), past landslide data Flentje et al. (2007), Froude and Petley (2018), Guzzetti et al. (1999), Guzzetti et al. (2006), Guzzetti et al. (2012), Jamaludin et al. (2008), Martha, Kerle, et al. (2012), Martha et al. (2012), Nguyen and Liu (2019), Panchal and Shrivastava, (2022), Silalahi et al. (2019), Westen et al. (2003) or by the combination of both.

Different data sources most commonly used were the Digital Elevation Model (DEM) Asmare (2023), Flentje et al. (2007), Guzzetti et al. (2012), Intarawichian and Dasananda (2010), Martha et al. (2012), Nguyen and Liu (2019), Panchal and Shrivastava (2022), Shah et al. (2023), Silalahi et al. (2019), Sun et al.(2018) followed by High-resolution satellite data Asmare (2023), Intarawichian and Dasananda (2010), Martha et al. (2012), Martha, van Westen et al., (2012), Sun et al. (2018), GIS-based map Flentje et al. (2007), Intarawichian and Dasananda (2010), Shah et al. (2023), and Google Earth Asmare (2023), Panchal and Shrivastava (2022), Shah et al. (2023). The use of Digital Elevation Models (DEM) and GIS-based tools has been crucial in identifying landslide-prone areas, with studies showing that higher resolution imagery provides more accurate results than lower-resolution alternatives Meena and Piralilou (2019).

Some of the parameters studied by previous researchers are as follows:

Table 1

Table 1 Parameters Studied by Previous Researchers on Landslide Hazard Susceptibility

Parameters	Authors
Geology	Flentje et al., (2007), Martha et al. (2012), Panchal and Shrivastava (2022), Silalahi et al. (2019), Syam et al. (2019)
Distance to fault	Sun et al. (2018)
Fault Density	Panchal and Shrivastava (2022)
Structure	Guzzetti et al. (2006), Westen et al. (2003)
Surfacial Meterials	Westen et al. (2003)
Bedrock	Westen et al. (2003)
Lithology	Asmare (2023), Guzzetti et al. (2006), Intarawichian and Dasananda (2010), Martha et al. (2012), Nguyen and Liu (2019), Panchal and Shrivastava (2022), Sun et al. (2018)
Vegetation	Flentje et al., (2007), Sun et al. (2018)
Slope Inclination/Slope Angle	Asmare (2023) , Flentje et al. (2007), Intarawichian and Dasananda (2010), Jamaludin et al. (2008), Martha et al. (2012), Panchal and Shrivastava (2022), Shah et al. (2023), Sun et al. (2018), Syam et al. (2019)
Slope Aspect	Asmare (2023), Flentje et al. (2007), Intarawichian and Dasananda (2010), Martha et al. (2012), Nguyen & Liu (2019), Panchal and Shrivastava (2022), Shah et al. (2023), Silalahi et al. (2019), Sun et al. (2018), Syam et al. (2019), Westen et al. (2003)
Slope Shape	Jamaludin et al. (2008)
Slope distance from road	Asmare (2023), Panchal and Shrivastava (2022), Westen et al. (2011)
Slope distance from streams	Westen et al. (2011)
Distance from lineament	Intarawichian and Dasananda (2010)
Distance to ridge	Jamaludin et al. (2008)
Relative relief	Martha et al. (2012), Panchal and Shrivastava (2022)
Terrain Units	Flentje et al. (2007)
Terrain Elevation	Asmare (2023), Intarawichian and Dasananda (2010), Shah et al. (2023)
Topographic relief	Sun et al. (2018), Syam et al. (2019)
Topographic Wetness Index	Flentje et al. (2007), Panchal and Shrivastava (2022), Sun et al. (2018), Syam et al. (2019)
Curvature	Asmare (2023), Flentje et al. (2007), Panchal and Shrivastava (2022), Shah et al. (2023), Sun et al. (2018)
Flow Accumulation	Flentje et al. (2007)
Feature Area	Jamaludin et al. (2008)
Percentage of feature uncover	Jamaludin et al. (2008)
Presence of rock exposure	Jamaludin et al. (2008)
Presence of bench drain	Jamaludin et al. (2008)
Presence of horizontal drain	Jamaludin et al. (2008)
Presence of erosion	Jamaludin et al. (2008)
Soil depth	Martha et al. (2012), Nguyen and Liu (2019), Sun et al. (2018)
Soil Type	Intarawichian and Dasananda (2010), Silalahi et al. (2019)

Soil Texture	Intarawichian and Dasananda (2010)
Drainage density	Nguyen and Liu (2019), Panchal and Shrivastava (2022)
Distance to River/Drainage	Asmare (2023), Intarawichian and Dasananda (2010), Sun et al. (2018)
Stream Network	Shah et al. (2023)
Steam Power Index	Sun et al. (2018)
Sediment Transport Index	Sun et al. (2018)
Rainfall Intensity	Intarawichian and Dasananda (2010), Silalahi et al. (2019), Sun et al. (2018)
Land use/Land cover	Guzzetti et al. (2006), Intarawichian and Dasananda (2010), Martha et al. (2012), Nguyen and Liu (2019), Silalahi et al. (2019), Westen et al. (2003)
Normalized Difference Vegetation Index (NDVI)	Asmare (2023), Intarawichian and Dasananda (2010), Sun et al. (2018), Syam et al. (2019)
Morphology	Guzzetti et al. (2006)

3. LANDSLIDE SUSCEPTIBILITY MAPPING METHODS

Since there is no one-size-fits-all approach in research, so there is no universal consensus on the methods, approaches, and scope of landslide hazard assessment Guzzetti et al. (2006). A similar idea was also expressed that there doesn't exist a universally recognized geomorphological classification system Westen et al. (2003).

Landslide susceptibility refers to the likelihood of a terrain to fail under certain conditions, often triggered by rainfall, earthquakes, or human activity World Bank. (2020). Landslide susceptibility mapping can be performed using a combination of qualitative, semi-quantitative, and quantitative methods. Among these, the Analytical Hierarchy Process (AHP) has been widely adopted for its ability to integrate expert judgment with spatial data, while statistical methods like Frequency Ratio and Weights of Evidence provide more objective, data-driven analyses Saaty (1977), Lee and Talib (2005). These methodologies help in identifying the most influential factors contributing to landslides, such as slope angle, rainfall, and geology, which can then be incorporated into predictive models.

3.1. QUALITATIVE APPROACHES

The qualitative approach category includes expert-based techniques for assessing landslide hazards Aleotti and Chowdhury (1999). When assigning the relative weights of the various landslide parameters, expert opinion is taken into consideration. The elements that cause landslides are identified, and the proficiency of the expert is used to assess each factor's influence on the likelihood of landslides. In such an expert-based method, the outcome is determined by the expert's subjective judgement, which may not always be accurate Panchal and Shrivastava (2022).

3.2. QUANTITATIVE APPROACHES

As the outcomes of quantitative approaches are grounded on scientific procedures and do not involve subjectivity, they are considered to be more objective and accurate than those of qualitative and semi-quantitative approaches. Among the quantitative approaches, statistical analysis is found to be the most frequently used. Again, within the statistical analysis approach, many studies have incorporated the Frequency Ratio (FR) method Shah et al. (2023), Silalahi et al. (2019); some have used the Weights of Evidence method Martha et al. (2012), Westen et al. (2003), while the use of discriminant analysis Guzzetti et al. (2006) and linear regression method Jamaludin et al. (2008) are less common. Frequency ratio is a frequently used bivariate statistical method Ehret et al. (2010), Lee and Talib (2005), Mondal and Maiti (2013), Sheng et al. (2022), Silalahi et al. (2019) which is very commonly employed in research.

3.3. SEMI-QUANTITATIVE APPROACHES

Numerous studies worldwide have adopted the Semi-quantitative approach since it is less complicated and combines both qualitative and quantitative approaches. Among these approaches, the Analytical Hierarchy Process (AHP) Method is frequently used Asmare (2023), Nguyen and Liu (2019), Panchal and Shrivastava (2022), Sun et al. (2018), Syam et al. (2019). Additionally, studies using both AHP and Weighted Linear Combination were also demonstrated Intarawichian and Dasananda (2010), Panchal and Shrivastava (2022).

In the Analytical Hierarchy Process (AHP) Method, decisions are made based on weight. It was developed by Saaty (1977), who used pair-wise comparison without inconsistencies to evaluate the decision model by constructing the evaluation matrix with the absolute number scale 1–9. This AHP model delivers a pairwise matrix, eigenvalue, and weighting coefficient and allows a priority ranking check by calculating the consistency ratio (CR).

3.4. MIXED-METHOD APPROACHES

Since employing a single research strategy has its limitations, researchers can benefit more by employing multiple approaches, as the findings of these approaches can be compared and triangulated to increase the accuracy and reliability of such findings.

Landslide susceptibility models have been developed through a combination of numerous methods, such as the AHP and Frequency Ratio method Asmare (2023); and in another study, researchers used quantitative methods, such as bivariate and correlation statistics, for weighing instead of expert judgement when using the AHP method Nguyen and Liu (2019). Additionally, three methods—the FR technique, the AHP method, and the logistic regression approach—were used in an investigation where the principal component analysis (PCA) was employed by the researchers to minimize the dimension of the influencing factors and to get rid of the collinearities between them Sun et al. (2018). Further, when using a dichotomous dependent variable in research, the statistical analysis frequently performed is through the logistic regression method (the dependent variable only takes two values). A binary dependent variable and a series of independent variables can be related to each other using this method. The independent variable does not need to fit into a normal distribution; it might be discrete or continuous. In addition to predicting the likelihood of an event occurring, logistic regression may be used to explain the complicated nonlinear relationship between natural phenomena using simple linear regression. Testing the degree of correlation between the independent and dependent variables that are estimated by the Odds ratio within the logistic regression method is another advantage. Thus, studies carried out on landslide analysis have made extensive use of this technology Sun et al. (2018).

4. PREDICTION RATE OF THE LANDSLIDE SUSCEPTIBILITY MODEL

After developing the landslide susceptibility model, the researcher must determine the model's predictive rate, for which the most widely used technique seems to be the Area Under the Curve (AUC) technique Asmare (2023), Intarawichian and Dasananda (2010), Panchal and Shrivastava (2022), Shah et al. (2023), Silalahi et al. (2019), Sun et al. (2018). However, only a small number of studies have shown that the accuracy of the prediction rate is greater than 80% (82.50% by Panchal and Shrivastava (2022), 90.10% by Silalahi et al. (2019). Furthermore, a finding indicated that the AHP approach was more accurate than the FR method, with success rates under AUC of 85.80% and 82%, respectively, and prediction rates of 88.2% and 84.8% Asmare (2023). Nonetheless, researchers who had mapped landslides assessed the accuracy of their susceptibility model by dividing the landslide data into two categories, viz. 70% for susceptibility modelling and the remaining 30% of the landslide data for validation Asmare (2023), Shah et al. (2023), Silalahi et al. (2019).

5. LANDSLIDE HAZARD VULNERABILITY AND RISK ASSESSMENT

5.1. LANDSLIDE HAZARD VULNERABILITY

The following are the definitions provided by The United Nations International Strategy for Disaster Reduction UNISDR (2009): (UNISDR)

Hazard: “The combination of the probability of an event and its negative consequences.”

Vulnerability: “The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.”

Landslide vulnerability has multiple facets and is caused by a range of environmental, social, economic, and physical variables. Such as poor building design and construction; insufficient asset protection; lack of public knowledge and awareness; lack of government identification of hazards and precautionary measures, and a disdain for prudent environmental management. The degree of vulnerability fluctuates throughout time and within a community. Vulnerability is defined in this definition as an attribute of the interest element (system, community or asset) that exists regardless of its exposure. Nonetheless, the term is frequently used more widely in everyday speech to refer to the element's exposure UNISDR (2009).

In most cases, vulnerability is measured using a set of values (0 representing no damage and 1 representing total damage) or values determined by experts Westen et al. (2011). Evaluation of vulnerability can be done through quantitative, qualitative or mixed methods Corominas et al. (2014). A possible approach is to create an index of multiple indicators, including an index of social, economic, human and environmental vulnerabilities Glade (2003). A study that introduced a vulnerability matrix method made use of historical recorded data that was found to be relatively more adaptable to various settings, as it helped limit subjectivity to some extent when compared to other stated methods Leone et al. (1996).

In the past, research on landslide vulnerability assessment was carried out using a vulnerability map created by combining landslide-triggering factors with their corresponding classification using two methods, viz. AHP and Simple

Numerical Rating methods for assigning the weights and classes to develop the Landslide Potential Index (LPI). Here, LPI was used to determine the landslide vulnerability zones Banuzaki and Ayu (2021). The use of the heuristic method for vulnerability assessment was carried out, where the process and its magnitude were taken into consideration to determine the vulnerability values to People (Vpe) buildings (Vp), and people in buildings (Vpep). Here, distinct values were directly assigned to events with varying return periods Bell and Glade (2004).

Furthermore, attempts were made to use an analytical fragility curve to evaluate the structural vulnerability of buildings in landslide risk assessment Mavrouli et al. (2014), Negulescu and Foerster (2010). It was also found that with the use of a numerical modelling approach for differential situations, factors like displacement angles, foundation, displacement magnitudes, cross-section form, and level of section reinforcement were influencing the structural behaviours of the buildings Negulescu and Foerster (2010).

5.2. RISK ASSESSMENT

Risk Assessment has been defined as “A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.” UNISDR. (2009).

Risk assessments (and related risk mapping) include viz. reviewing the technical aspects of hazards, such as their location, intensity, frequency, and probability; analysing exposure and vulnerability, including the physical, social, health, economic, and environmental dimensions; and assessing the efficacy of existing and alternative coping mechanisms in light of likely risk scenarios UNISDR. (2009). Risk is the non-normalized likelihood that an adverse occurrence will have a bad outcome (i.e., cause harm of a particular kind and severity) within a specified time frame Marzocchi et al. (2009).

$$\text{Risk} = (\text{hazard index}) \times (\text{vulnerability}) \times (\text{value at risk}) \quad (1)$$

The methods for risk assessment include both quantitative and qualitative approaches. Studies on qualitative approaches to landslide risk map can be developed using GIS by superimposing the exposed items' consequences and hazard maps Wang et al. (2013). Further, qualitative approaches to risk assessment were attempted in the past Ko Ko et al. (2004), Remondo et al. (2008) where the factors were scored and weighted in the field sheets. Further, the rating and scoring of hazards and their consequences were employed for the risk assessment Ko Ko et al. (2004). Additionally, a geomorphological approach to assess the risk of landslides was carried out based on examining historical and site-specific data, where the hazards assessment was carried out, followed by mapping the risk elements and vulnerability assessment Cardinali et al. (2002).

Besides the above method, quantitative approaches were also carried out for risk assessment that made use of hazard, vulnerability and value of the elements at risk. Here, the value evaluation of the element at risk was expressed as a specific monetary loss, and the vulnerability assessment, expressed in the range of 0 to 1, was computed. The landslide hazard's spatial and temporal probabilities were examined, and the hazard frequency, elemental vulnerability, and elemental monetary value were computed to determine the risk associated with each element Remondo et al. (2008). Again, a risk estimation was done by overlapping the intensity map of the hazard and the elements at risk map in space and time, considering vulnerabilities where frequency vs. consequences plots for different countries where the number of fatalities were shown against the frequency or probability of the hazard Sim et al. (2022). Additionally, a modified method was utilized to perform a quantitative analysis to assess landslide hazards, where elements at risk were identified and values were attributed to vulnerability of people and buildings. Here, the assessment was carried out to assess the likelihood of spatial and temporal impact of landslide and that of seasonal occurrences Bell and Glade (2004).

Bell and Glade (2004) has given the following expression to calculate the risk:

Risk = Natural hazard × Consequence × Elements at Risk (R = H×C×E)

C =Ps×Pt×Vp×Vpe×Pso,

Where, Ps = probability of spatial impact given an,

Pt =probability of temporal impact given an event,

Vp =vulnerability of the building,

Vpe= vulnerability of the people and

Pso= probability of seasonal occurrence (2)

6. CONCLUSION

Landslide hazard mapping is an essential component of disaster risk management, especially in high-risk regions like the Himalayan terrain in India. This review highlights the methodological diversity that characterizes current practices in landslide hazard assessment. While landslide inventories remain foundational, the integration of high-resolution data, GIS tools, and various modelling techniques—from expert-based qualitative assessments to statistically grounded quantitative models—has substantially advanced hazard zonation accuracy. Among these, semi-quantitative methods like the Analytical Hierarchy Process (AHP) offer a pragmatic balance between data availability and methodological rigor.

However, the absence of a standardized methodological framework continues to limit cross-regional comparability and the transferability of findings. Many studies also fail to rigorously validate model outputs, with only a few demonstrating high prediction accuracy (>80%). Furthermore, while susceptibility mapping is widely practiced, fewer studies extend the analysis to include vulnerability and risk components, which are crucial for informed policy and planning. Additionally, structural vulnerability assessment methods, such as fragility curves and numerical modelling, offer significant potential but remain underutilized.

Ultimately, the multifactorial nature of landslide risk necessitates an interdisciplinary and integrated approach—one that combines physical, social, and economic dimensions, and is grounded in both empirical data and contextual knowledge.

7. SUGGESTIONS

Based on the conceptual review of the methodologies for landslide hazard, viz., Inventories, Susceptibility, Vulnerability, and Risk Analysis, the following suggestions can be made:

1) **Standardize Methodological Frameworks:** Establishing a unified, flexible framework for landslide hazard assessment that accommodates regional differences while enabling methodological comparability is essential. This would enhance consistency and reproducibility across studies.

2) **Promote Multi-Method Approaches:** Researchers should be encouraged to adopt mixed method approaches such as AHP, frequency ratio, logistic regression, machine learning and PCA to enhance model robustness and reduce reliance on any single methodology's limitations.
3) **Incorporate Vulnerability and Risk Components:** Future studies must go beyond susceptibility mapping to include vulnerability and risk assessments, using both qualitative (e.g., vulnerability matrices) and quantitative (e.g., fragility curves, monetary loss estimates) tools.
4) **Capacity Building and Policy Integration:** Training programs and policy guidelines must be developed to translate scientific findings into actionable strategies for planners, engineers, and disaster managers, especially at the local governance level.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

REFERENCES

Aleotti, P., & Chowdhury, R. (1999). Landslide Hazard Assessment: Summary Review and new Perspectives. Bulletin of Engineering Geology and the Environment, 58, 21-44. https://doi.org/10.1007/s100640050066

Asmare, D. (2023). Application and Validation of AHP and FR Methods for Landslide Susceptibility Mapping Around Choke Mountain, Northwestern Ethiopia. Scientific African, 19. https://doi.org/10.1016/j.sciaf.2022.e01470

Banuzaki, A. S., & Ayu, A. K. (2021). Landslide Vulnerability Assessment Using GIS and Remote Sensing Techniques: A Case Study from Garut - Tasikmalaya Road. IOP Conference Series: Earth and Environmental Science, 622(1). https://doi.org/10.1088/1755-1315/622/1/012005

Bell, R., & Glade, T. (2004). Quantitative Risk Analysis for Landslides—Examples from Bíldudalur, NW-Iceland. Natural Hazards and Earth System Sciences, 4, 117-131. https://doi.org/10.5194/nhess-4-117-2004

Cardinali, M., Reichenbach, P., Guzzetti, F., Ardizzone, F., Antonini, G., Galli, M., Cacciano, M., Castellani, M., & Salvati, P. (2002). A Geomorphological Approach To the Estimation of Landslide Hazards and Risks in Umbria, Central Italy. Natural Hazards and Earth System Sciences, 2, 57-72. https://doi.org/10.5194/nhess-2-57-2002

Corominas, J., van Westen, C., Frattini, P., Cascini, L., Malet, J. P., Fotopoulou, S., Catani, F., Van Den Eeckhaut, M., Mavrouli, O., Agliardi, F., Pitilakis, K., Winter, M. G., Pastor, M., Ferlisi, S., Tofani, V., Hervás, J., & Smith, J. T. (2014). Recommendations for the Quantitative Analysis of Landslide Risk. Bulletin of Engineering Geology and the Environment, 73(2), 209-263. https://doi.org/10.1007/s10064-013-0538-8

Cruden, D. M. (1991). A Simple Definition of A Landslide. Bulletin of the International Association of Engineering Geology, 43(1), 27-29. https://doi.org/10.1007/BF02590167

Ehret, D., Rohn, J., Dumperth, C., Eckstein, S., Ernstberger, S., Otte, K., Rudolph, R., Wiedenmann, J., Xiang, W., & Bi, R. (2010). Frequency Ratio Analysis of Mass

Movements in the Xiangxi Catchment, Three Gorges Reservoir Area, China. Journal of Earth Science, 21(6), 824-834. https://doi.org/10.1007/s12583-010-0134-9

Froude, M. J., & Petley, D. N. (2018). Global Fatal Landslide Occurrence from 2004 to 2016. Natural Hazards and Earth System Sciences, 18, 2161-2181. https://doi.org/10.5194/nhess-18-2161-2018

Glade, T. (2003). Vulnerability Assessment in Landslide Risk Analysis. DIE ERDE, 134, 123-146. Retrieved from https://www.researchgate.net/publication/279555131

Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1999). Landslide Hazard Evaluation: A Review of Current Techniques and Their Application in A Multi-Scale Study, Central Italy. Geomorphology, 31, 181-216. https://doi.org/10.1016/S0169-555X(99)00078-1

Guzzetti, F., Galli, M., Reichenbach, P., Ardizzone, F., & Cardinali, M. (2006). Landslide Hazard Assessment in the Collazzone Area, Umbria, Central Italy. Natural Hazards and Earth System Sciences, 6, 115-131. https://doi.org/10.5194/nhess-6-115-2006

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, 42-66. https://doi.org/10.1016/j.earscirev.2012.02.001

Intarawichian, N., & Dasananda, S. (2010). Analytical Hierarchy Process for Landslide Susceptibility Mapping in Lower Mae Chaem Watershed, Northern Thailand. Suranaree Journal of Science and Technology, 7(3), 1-16.

Jamaludin, S., Huat, B., & Omar, H. (2008). Assessment of Landslide Hazard of A Cut-Slope Using Linear Regression Analysis. Landslides and Engineered Slopes, 1919-1924. https://doi.org/10.1201/9780203885284-c266

Ko Ko, C., Flentje, P., & Chowdbury, R. (2004). Landslides Qualitative Hazard and Risk Assessment Method and Its Reliability. Bulletin of Engineering Geology and the Environment, 63, 149-165. https://doi.org/10.1007/s10064-004-0231-z

Lee, S., & Talib, J. A. (2005). Probabilistic Landslide Susceptibility and Factor Effect Analysis. Environmental Geology, 47, 982-990. https://doi.org/10.1007/s00254-005-1228-z

Leone, F., Aste, J. P., & Leroi, E. (1996). Vulnerability Assessment of Elements Exposed To Mass Movements: Working Towards A Better Risk Perception (K. Senneset, Ed.; Vol. 1).

Martha, T. R., Kerle, N., van Westen, C. J., Jetten, V., & Vinod Kumar, K. (2012). Object-Oriented Analysis of Multi-Temporal Panchromatic Images for Creation of Historical Landslide Inventories. ISPRS Journal of Photogrammetry and Remote Sensing, 67, 105-119. https://doi.org/10.1016/j.isprsjprs.2011.11.004

Martha, T. R., van Westen, C. J., Kerle, N., Jetten, V., & Vinod Kumar, K. (2012). Landslide Hazard and Risk Assessment Using Semi-Automatically Created Landslide Inventories. Geomorphology. https://doi.org/10.1016/j.geomorph.2012.12.001

Marzocchi, W., Mastellone, L. M., Ruocco, A. Di, Novelli, P., Romeo, E., & Gasparini, P. (2009). Principles of Multi-Risk Assessment. https://doi.org/10.2777/30886

Mavrouli, O., Fotopoulou, S., Pitilakis, K., Zuccaro, G., Corominas, J., Santo, A., Cacace, F., De Gregorio, D., Di Crescenzo, G., Foerster, E., & Ulrich, T. (2014). Vulnerability Assessment for Reinforced Concrete Buildings Exposed To

Landslides. Bulletin of Engineering Geology and the Environment. https://doi.org/10.1007/s10064-014-0573-0

Meena, S. R., & Piralilou, S. T. (2019). Comparison of Earthquake-Triggered Landslide Inventories: A Case Study of the 2015 Gorkha Earthquake, Nepal. Geosciences (Switzerland, 9). https://doi.org/10.3390/geosciences9100437

Mondal, S., & Maiti, R. (2013). Integrating the Analytical Hierarchy Process (AHP) and the Frequency Ratio (FR) Model in Landslide Susceptibility Mapping of Shiv-Khola Watershed, Darjeeling Himalaya. International Journal of Disaster Risk Science, 4(4), 200-212. https://doi.org/10.1007/s13753-013-0021-y

Negulescu, C., & Foerster, E. (2010). Parametric Studies and Quantitative Assessment of the Vulnerability of A Rc Frame Building Exposed To Differential Settlements. Natural Hazards and Earth System Science, 10, 1781-1792. https://doi.org/10.5194/nhess-10-1781-2010

Nguyen, T. T. N., & Liu, C. C. (2019). A New Approach Using AHP To Generate Landslide Susceptibility Maps in the Chen-Yu-Lan Watershed, Taiwan. Sensors (Switzerland, 19), 505. https://doi.org/10.3390/s19030505

Panchal, S., & Shrivastava, A. K. (2022). Landslide Hazard Assessment Using Analytic Hierarchy Process (AHP): A Case Study of National Highway 5 in India. Ain Shams Engineering Journal, 13. https://doi.org/10.1016/j.asej.2021.10.021

Ray, K. (2018). India Tops the world in Landslide Deaths. Deccan Herald.

Remondo, J., Bonachea, J., & Cendrero, A. (2008). Quantitative Landslide Risk Assessment and Mapping on the Basis of Recent Occurrences. Geomorphology, 94, 496-507. https://doi.org/10.1016/j.geomorph.2006.10.041

Saaty, T. L. (1977). A Scaling Method for Priorities in Hierarchical Structures. Journal of Mathematical Psychology, 15, 234-281. https://doi.org/10.1016/0022-2496(77)90033-5

Shah, N. A., Shafique, M., Ishfaq, M., Faisal, K., & Van der Meijde, M. (2023). Integrated Approach for Landslide Risk Assessment Using Geoinformation Tools and Field Data in Hindukush Mountain Ranges, Northern Pakistan. Sustainability, 15, 3102. https://doi.org/10.3390/su15043102

Sheng, M., Zhou, J., Chen, X., Teng, Y., Hong, A., & Liu, G. (2022). Landslide Susceptibility Prediction Based on Frequency Ratio Method and C5.0 Decision Tree Model. Frontiers in Earth Science, 10. https://doi.org/10.3389/feart.2022.918386

Silalahi, F. E. S., Pamela, Arifianti, Y., & Hidayat, F. (2019). Landslide Susceptibility Assessment Using Frequency Ratio Model in Bogor, West Java, Indonesia. Geoscience Letters, 6(10). https://doi.org/10.1186/s40562-019-0140-4

Sim, K. B., Lee, M. L., & Wong, S. Y. (2022). A Review of Landslide Acceptable Risk and Tolerable Risk. Geoenvironmental Disasters, 9(3). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s40677-022-00205-6

Sun, X., Chen, J., Bao, Y., Han, X., Zhan, J., & Peng, W. (2018). Landslide Susceptibility Mapping Using Logistic Regression Analysis Along the Jinsha River and Its Tributaries Close to Derong and Deqin County, Southwestern China. ISPRS International Journal of Geo-Information, 7, 438. https://doi.org/10.3390/ijgi7110438

Syam, M. A., Heryanto, & Balfas, M. D. (2019). Mapping of Landslide Susceptibility Using Analytical Hierarchy Process in Sukamaju Area, Tenggarong Seberang, Regency of Kutai Kartanegara. IOP Conference Series: Earth and

Environmental Science, 279(1). https://doi.org/10.1088/1755-1315/279/1/012002

UNISDR. (2017). Words into Action Guidelines: National Disaster Risk Assessment Hazard-Specific Risk Assessment. Retrieved from https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

UNISDR. (2009). UNISDR Terminology on Disaster Risk Reduction.

Wang, H. B., Wu, S. R., Shi, J. S., & Li, B. (2013). Qualitative Hazard and Risk Assessment of Landslides: A Practical Framework for A Case Study in China. Natural Hazards, 69, 1281-1294. https://doi.org/10.1007/s11069-011-0008-1

Westen, C. J. van, Alkema, D., Damen, M. C. J., Kerle, N., & Kingma, N. C. (2011). Multi-Hazard Risk Assessment.

Westen, C. J. van, Rengers, N., & Soeters, R. (2003). Use of Geomorphological Information in Indirect Landslide Susceptibility Assessment. Natural Hazards, 30, 399-419. https://doi.org/10.1023/B:NHAZ.0000007097.42735.9e

World Bank. (2020). The Global Landslide Hazard Map Final Project Report.