Land Risk Susceptibility, Hazard and Risk Factors in Western Ghats, India – A review

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Abstract: Landslides are a severe geological phenomenon prevalent in mountainous areas. Landslides usually happen without explicit notification. Landslip/ Landslide creates a broad range of terrain inclinations, such as rockfalls, the great collapse of slopes, and slight residue flows. It causes extensive destruction across highways, connecting bridges, it affects the entire transportation, civilized residences, cultivating fields, meadows, forests areas, etc. This geological change might commence to immense loss of people's livelihood and property, natural resources which is the key to the economy of the country, being an urbanized area there could be loss in economic activities. But, this Economic degradation of highland is one of the foremost reasons for the frequent phenomenon of avalanches. This write up is an effort to know the detail about landslides and various factors influencing Landslide which suits Indian landscape and climatic conditions. Several aspects of avalanches like landslides inventory, susceptivity, detection, and risk assessment and mitigation are discussed.

1. Introduction

The topography is a critical factor for landslide susceptibility. Slips can occur in the coastal plain, highland, midland, and inland environments. Gravitation force is weak in flat terrain, which is a prime source for disaster occurrence. Soil materials withstand up to 270 degrees in slope area, if slope goes steeper than rocks and loose soil loses its hold and it creates tremendous landslides spreading over the area. Other predominant resources contribute to test the stability of the slope region. Moisture due to heavy rainfall induces landslides are often occurring in tropic and subtropic areas where the slope holds the residual soil. Kerala is a humid, wet tropical state located in the extreme southwest region of India. It spreads 38,863km^2. The massively influenced region is having annual heavy cloudbursts served up by the monsoon. On average, it receives 3107mm per annum. The variation of annual rainfall is minimum when compared to neighbor states. However, there are historian wet years noted with a total of 3368mm in 1924. In 48 hours, there was a rain of 310mm received in 2018. The main objective of this work is to analyze the landslide possibilities and risk regions in Kerala, Idukki district, in particular. The above Fig 1 highlights the geographical area of Kerala and the flood-affected area as an aerial view. The study area Idukki district received 36% excess thundershower than average, leads to massive floods and experienced widespread landslides, thereby nearly 445 people lead to death. During the August 2018 Massive flood disaster witnesses more than 90% raise in water-covered areas[1]. Rainfall is one of the predominant parameters to trigger landslides and is one of the most disastrous naturally happening disasters across the atmosphere[2]. To obtain a patterned and stable forecast event of landslides, we must examine the geological and climate conditions. Various factors like inclination, features, height, elevation, curvature, soil nature, distance from sewerage, land use, and land cover, maps are taken under consideration. Hence, it is necessary to distinguish vulnerable landslide areas to overcome the probability of further loss. Initially, we can analyze the vulnerability region by calculating the spatial (place) and temporal (times series) value of landslide for further assessment. Contemporary disaster aid activities are depending on satellite data for the rapid marking of risk area, providing emergency relief to the affected region, assessment for post-disaster management, and identify accurately.

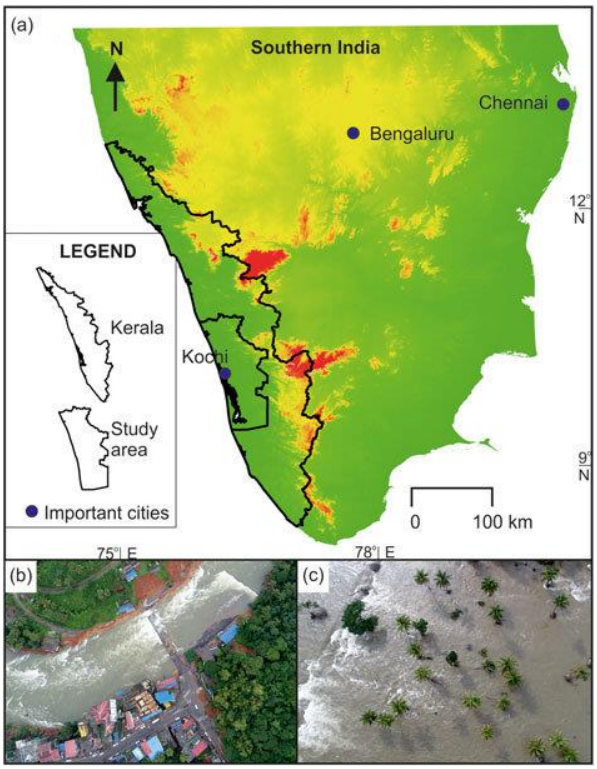

Fig 1: Map of TamilNadu highlighting Kerala flood-affected region. (b) and (c) Birds view of the Periyar river.

Authorities are hence involved in co-operating with researchers to identify landslides and moderate their impacts. Considerably, researchers concentrated on observing research areas like landslide susceptibility area, vulnerability areas, early warning systems, predictive models, inclined area detection, geohazard, and risk assessments. The mapping of landslide areas uses various algorithms, machine learning techniques, and using several open-source tools. This landslide leaves a distinct impression on Earth's surface; it is well captured accurately with regular intervals by earth observation satellites or remote sensing techniques. We can take freely available Multi-temporal high-resolution satellite data like resource sat-2, sentinel Asia, ICSMD, kompsat- 3, GF - 2, Worldwide -2, European copernicus, etc.

1.1 Scope of the Research

The significant work of this research is to inventing the landslide affected area as landslide mapping and identification of the specific landslide risk area. Based on this landslide monitoring, the risk of the disaster is evaluated and An early warning system can be developed. The data sets (satellite images) that we are going to take from google Earth engine for identifying the landslide vulnerability area and thereby we will probably create an Early warning prediction zones, whereas we cannot predict the occurrence of the landslide. The goal is to use satellite images and correlated data to enrich the public repository of data and guide disaster relief efforts for locating precise areas where landslides have occurred. The possibility of producing reliable zonings of landslide susceptibility for large areas based on verifiable methods., Further, Machine learning techniques such as logistic regression and Support Vector Machines (SVM) were used for accurate results for landslide forecast as confirmed by a survey with the related research reports. Thus, the landslide hazard mapping is the preliminary process that will provide us the supporting data for making decisions concerning the affected area and for distinguishing the preferences for relevant mitigation strategies.

2. Datasets

Various remote sensing data have been well used, including digital elevation models (DEMs), Multi-temporal LiDAR images, Optical remote sensing images, spaceborne synthetic aperture radar (SAR), including in site surveying measures and considerations of environmental circumstances. The collection of the dataset from the new launch Sentinel-2 satellite. The conquering peculiarity of the Sentinel-2 satellite is its revisit at the Equator with the regular interval of once in 5 days, under cloud-free circumstances spatial resolution of a satellite ranges up to 10m for different frequency bands or channels like Band 2 - blue, Band 3 - green, Band 4 - red, and Band 8 - infra-red. Each band has specific characteristics where we can combine two or more bands for our application. The method produced with the multiple bands provides relative results, revealing relative patterns. These results are prepared using the Digital Elevation Model (DEM) to extend the image into geometry cartographic visualization [3]. The Indian Remote Sensing Satellite (IRS) generates Digital elevation models. The Utilization of DEMs is to prepare region properties such as the altitude at any point, incline, and appearance. DEM is a 3D image of a terrain surface. DEM generates by the transformation of printed contour lines(Active contour techniques in DIP) [4]. Specific digital outlines use to generate polygons, and every polygon traces with the elevation data from the bounding contour, then it used as a raster or vector data format. GIS applicability mainly depends on DEMs. The DEM can be changed to quantify the erosion, bluff collapse, and to estimate the landslide quantity [5].

Landslide primary trigger/occurance resources

1. RainFall
2. Earthquake
3. Vegetation &Anthropogenic activities

Secondary resources

1. Accelerated snowmelt
2. Speedy drawdown or filling(floods/tides in the coastal region)
3. Volcanic explosion
4. Thawing
5. Deforestation in highland
6. Imposed land-use planning

2.1 Landslide due to Rainfall

In August 2018, Heavy rainfall triggered diverse landslips including the states of Kerala, part of Tamil Nadu, and Karnataka in the western ghats region. Fig 2: shows the average rainfall as time series in Idukki District. These states witnessed landslides, resulting in loss to farms and estates of profit crops like rubber, pepper, coffee, and other spices.

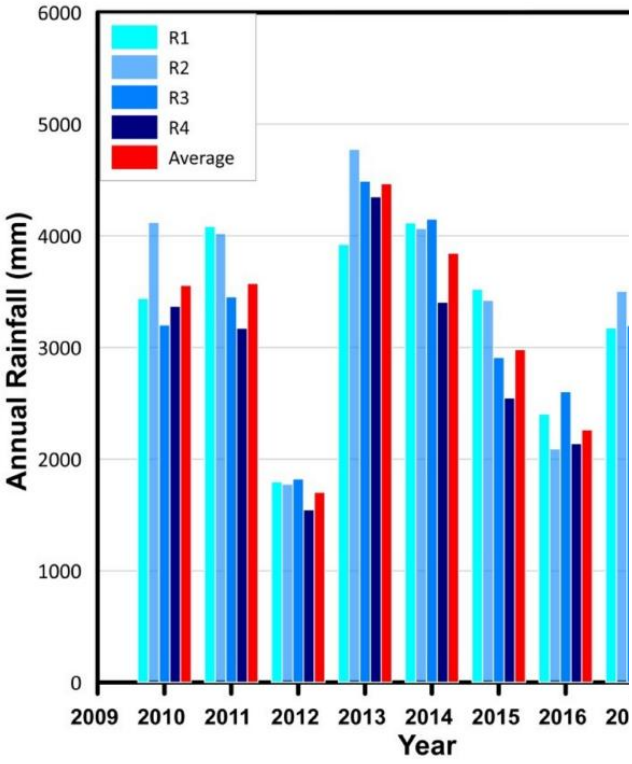

Fig 2: Graphical representation of Annual Rainfall in Idukki district (2009 -19)

- According to Tapas R. Martha et al. [6], Landslides Inventory is necessary to determine the scope of the damage. It is the key to risk assessment and prioritization of rescue and mitigation. The excess rainfall is a trigger for landslides. The affected region area can be mapped and evaluated by utilizing high-resolution satellite images. Inaccessibility of the risk zones is usually a huge amount of the study area that can be obtained using remote sensing data for landslide mapping. Active landslides inventory and associated loss using satellite data is a conventional process of determining the landslide risk assessment [6] [7] [8] . In the southern part of India, Western Ghats is the common likely area to landslide occurrences region of prime concern [9]. Rainfall and the district reservoir scheduling period is also an important triggering factor for the landslide. Zizheng Guo says rainfall is a periodic influencing factor, where the threshold curve looks like a step-like shape. The other influencing factors like earthquake, Anthropogenic activities threshold curve appears like undulation shape. [10].
- Veena VS et. al [11] narrates about landslide detection. this detection is necessary and stepping forward towards rapid risk assessment and mitigation. Using landslide Mapping, the landslide vulnerability area is extracted using various open-source tools. The landslide areas are classified based on their spectral characteristics. The technique applied comprises image segmentation accompanied by the removal of non-susceptible areas using an object-based approach to identify the change detection and finally, the output is extracted and categorized using the unsupervised algorithm is used to cluster the image objects. The pre and post landslide satellite images are distinguished by the brightness of the output of the post landslide image. The threshold value of the post landslide determines the landslide affected area from the landslide mapping. Besides, landslide distinguishing constraints such as the variation in, Digital Elevation Model - DEM, slope, Principal Component Analysis (PCA), Green Normalized Difference Vegetation Index (GNDVI)assessments were applied to reduce stimulating fake prediction. The objects retained after reducing fake

resources, then it is categorized as a couple of groups using the k-means clustering algorithm. The geographical characteristics incorporated with a model can be estimated by determining the essential features.

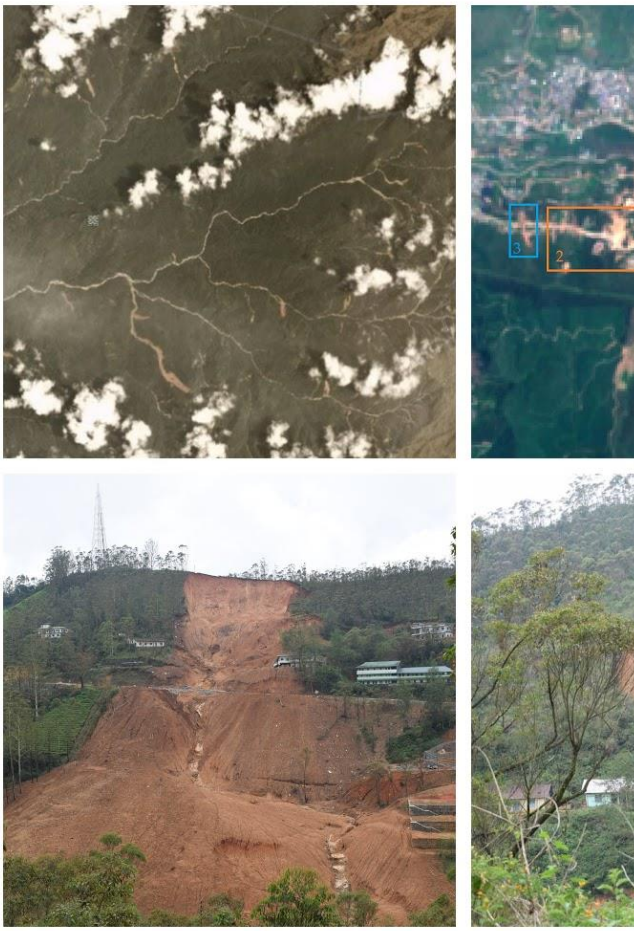

Fig 3: (a)Cloudy satellite images (b) Sentinel 2 Satellite image of the landslide
(c) Road affected between Munnar to Madurai (d) Long view of the Slope.
Source:
https://twitter.com/rajbhagatt/status/1046287561595875329

Fig 3: shows the various ways to investigate the landslide details. The first image is a satellite image observed by sentinel 2 in the year 2018. (b) The image exhibits the identification of the accurate place of the landslide. Rajbhagat - An Earth Observer describes the landslide that happened in Idukki district - 2018. He went in-person to gather all the data associated with the landslide. He states due to this disaster, the road between Munnar to Madurai is affected and the road becomes widen. The landslide inventory is prepared using pre and post landslide using high-resolution satellite data. Various freely available satellite images are taken for landslide mapping. In the case of landslide occurs due to rainfall, multiple satellite data are taken under consideration to obtain cloud-free data. Besides, yearly rainfall statistical data are considered for accuracy.

Hasali Hemasinghe et.al [12] explain Landslide susceptivity is interpreted as a trend towards landslide that is induced in a particular area in the future. This is an estimation of the relationship among deciding agents coincidentally with the spatial pattern of the inclinations [13]. Landslide susceptivity mapping points to recognize areas of landslide happening over a country based on a collection of physical precipitative circumstances. In particular, it is recognized as Landslide susceptivity Zonation, or otherwise the range of land cover into expected comparable zones and then ranking these regions as potential danger zone due to landslides.

Baeza [14] uses the GIS-Based Slope Unit Approach. Interpreting landslides inventory, k means cluster separates landslides and non-landslides area. the separated data with the equivalent sample dimension are casually chosen as training data for generating the landslide forecast modeling. The rest were chosen as forecasting samples or the testing set to verify the landslide forecast design. The spatial forecast of landslides depends on discriminative interpretation. This is a general technique applied in precipitation based landslide susceptivity mapping [15].

The discriminant interpretation was utilized to define the weighting of the discriminant function equation, it performs the detachment among the landslide susceptible and non-susceptible area. The data want to be separated into a susceptible and non-susceptible area for training the landslide forecast model. The hazard susceptivity ranges from low susceptibility to high susceptibility and extremely high susceptibility. Predominant of the district is seismic activation and head to intense downpours, so the condition becomes most dangerous with the rise in man-made actions and the appearance of weather variation. It is an authenticated evidence that most maximum landslides in this area are fundamentally influenced by precipitation[13] [16]

Abhirup Dikshit et.al. [17] gives a brief description of various stages in landslides and the factors influencing for landslide occurrence. The identification, anticipation, and patterned classification is a significant move for pre and post landslide investigation[18]. Refinement of earth science and the easy access to high spatial and multi-temporal satellite images, scholars have strived to describe landslides and its related consequences using stereo image processing. Pre and post landslide image Change detection, image matching, and automation of DEM generation are the base technique for landslide identification.

Generally, there are many techniques for image classification. pixel-based identification method has some restrictions when it is used for high-resolution images description is conveyed by utilizing an object than a pixel, it delivers added understanding for habitual calamities like avalanches as the losses are of unusual measurement and appearance. Object-based methods use shape, contextual, spatial, and spectral properties. Digital Elevation Model can derive quantitative analysis effectively.

2.2 Landslide due to Earthquake

An earthquake produces ground vibration that initiates vulnerable inclines to fail. Inclination substance that becomes wet with rainwater may generate a wreck flow or mudflow. Aftershocks of measure 4.0 and more noted should be associated to trigger avalanches. The outcome sediment of rock and clay may pluck up trees, residences, and vehicles, thus the floating objects may block the bridges and rivers inducing flood on its pathway. Landslide risk maps allow administrators and planners a clear view of wherever this risk must be accurately estimated before development can reliably happen in high-risk zones.

In India, An Earthquake influenced landslides are recorded as the Macro level in the Himalayan region and Micro-level in the Western Ghats region. Like any other country, India doesn't affect much because of the moderate climatic condition. About 15% of the cumulative land use is estimated to be influenced by landslide possibilities says the National Disaster Management Authority (NDMA). It is obvious that the mountainous area in Karnataka is likely to landslide risk [19], the consolidated result of seismic earth-shaking and precipitation will occur in broad range defoliation. An Earthquake influenced landslides frequently interpreted as the earthward and visible vibration of slope materials like rock or soil in the hill region under the influence of gravity reported by NDMA.

Naveen James et. al. [18] used GIS techniques for Earthquake-induced landslides assessment. He says Acknowledging the linear source pattern, deterministic seismic risk investigation was taken to determine peak level acceleration at rock bed, where the terrain angle should be greater than 10° at each of the grid points. The Tectonic landslide risk to all grids of the surface was calculated concerning the latent representative of protection expected to maintain the landslide.

A slope map is formulated to evaluate the slope angle of all the grid points using GIS. The latent representative of the protection needed to sustain slip can be estimated for all the grid points. The resistance of an inclination on tremor remarkably depends on the latent factor of protection correlated with that inclination. The inclination value should be large static factors for protection, to prove that the area is more stable than earthquake vibration. The progressive filling due to earthquake develops the trim pressure implemented to the sliding area, then the trim forces can defeat the trim unsusceptibility [20].

S. Martino et.al.[21] introduces the Probabilistic Approach to pRovide Scenarios of earthquake- Induced slope FAiLures (PARSIFAL) to analyze the earthquake based landslide scenarios. The PARSIFAL model analyses both the recurrence of preliminary landslides and Micro level earthquakes[22]. Micro-level collapse occurs on inclines earlier not impressed by fluctuations, while recurrence of this micro-level may change into a macro level that can be influenced by additional rearrangements of Earth's tectonic plates. Both movements of surface are activated through unless outside or interior forces, like seismic activity and hole pressures, progress reported to extreme precipitation. The susceptivity to recurrence is estimated by identifying and reviewing the previously existing landslides using GIS.

2.3 Landslide due to Vegetation & Anthropogenic activities

Anthropogenic factors such as the reconstruction of the river flow, adjustment of the topography, land-use conversions, legal and illegal mining, road and railway constructions, aging of infrastructure, deforestation, etc. are considered as

growing landslide hazards. Highway and railway development often involve intersecting slopes and extracting soil from hills. Removing trees for widening the highway, yet when there is no soil to excavate. Highways at midland and the foot of the slope create the most distinguished landslide hazard due to rainwaterInterference. Approximately, the death rate touches 50,000 per year by landslides throughout the world within 2004 and 2016, according to the latest investigation by researchers at the University of Sheffield in the UK. In India, estimates about 20% of those situations.K. G. Avinash et. al says in upper parts of the western ghats region usually have high susceptible landslides, because of the anthropogenic activities[23][24]. It is additionally the nation wherever human-induced disastrous landslides are expanding at a tremendous rate, accompanied by Srilanka, Nepal, Pakistan, Myanmar, and other neighboring countries.

Froude [25] said: "Avalanches triggered by cutting trees in slope are frequently an obstacle in rural zones, where several tribes and villagers unlawfully pick wooden sticks and other raw materials from the slope of the hill to construct their homes". Martin Haigh et Jiwan Singh Rawat [26] did a case study at the Almora District - Uttarakhand. He says that the contemporary evolution of urban areas impacts a lot. In 2010, there existed barely 9 landslides on the Kilbury Road however 108 landslides in the district of Almora Lower Mall.

P. Canuti et.al.[27] say landslide occurrence must be observed at various geographical and terrestrial frequencies. The application of remote sensing techniques for estimating landslide limitation and for landslide surveillance is considerably undeveloped, considering that certain methods provide accelerated procurement of data across extensive regions and serve a vital device for thoughtful management of landslides.

The Landslide frequency is estimated by an essential key factor termed Landslide mapping. Inventory data describes the social and economic importance of landslide erosion. Satellites are now competent in implementing a quantitative evaluation of terrain rearrangements at a geographical range in sparsely vegetation regions. SAR satellite will feasibly enhance the conventional mechanism for observing slope progression at a geographical range. The use of Terrestrial or ground-based SAR interferometry system procedures is an important tool for landslide monitoring or unpredictable inclinations. The consolidated performance of the sensors and terrain operations, acknowledging the planned developments, can seriously assist in overwhelming several limitations of data and monitoring affiliated with the landslide indicator.

3. Landslide risk Assessment & Mitigation

The research and review of the slope are necessary for assuming their performance and, more about their resistance, safety, stability, and deformations. A. R. Amashi et.al. [28] say the resistance of the inclination is investigated depends on statistical reflection using various GIS software. Investigation of slope resistance has evermore significant study fulfilled in the discipline of geospatial engineering.

OldrichHungr [29] says he focuses on landslide susceptivity interpretation and the forecast of landslide behavior. Landslide Risk assessment commences with the classification of components at chances to risk like persons, constructions, buildings, and infrastructure of the region, vegetation property, or environmental conditions. Existing things and also the area under hazard susceptibility zone in the future. The risk is assessed using the intersection between the hazard intensity map and map of an element at risk, where spatial and temporal values are taken into account of vulnerability. Tapas R. Martha[30] explains the landslide inventories developed by semi-automated techniques from satellite images were taken after the occurrence of landslide incidents. It is applied in the estimation of landslide susceptivity, risk, and hazard hillslope region in India.

4. Conclusion

This review article attempts to understand the Landslide influencing factors for Indian climatic conditions. Landslide is an important natural disaster especially in the Himalayan region as well as in the Western ghats region. This study reports that the Rainfall and the stressed water after rainfall from the neighboring state has a major role in Indian Landslide accidents. We discussed the flow of the landslide events as the Mapping of landslides is the initial task. Then it is taken forward as different phases like Measurement, monitoring, modeling, and finally risk assessment, mitigation as Management. This work can be progress by machine learning techniques and remote sensing data to give a valid input as a

dynamic event or disaster alert. Further, we can generate an early warning model to overcome the destruction. We can download various data of time-series images for understanding the characteristics of the landslide in a particular region. In the future, we will experience extreme climatic variations, so that we can develop a knowledge-based creation using deep learning from the historic data. The appropriate advancement in the satellite images gives a better opportunity to rapidly recognize the immersed zones for organizing rescue operations and the government can allocate funds for effective relief operations. Additionally, The research work will be beneficial for an administrator, engineers to plan, guidelines to technical experts in planning and developing socio-economy activities in such a region.

References

[1] C. L. Vishnu *et al.*, "Satellite-based assessment of the August 2018 flood in parts of Kerala, India," *Geomatics, Nat. Hazards Risk*, vol. 10, no. 1, pp. 758–767, 2019, doi: 10.1080/19475705.2018.1543212.

[2] D. Petley, "Global patterns of loss of life from landslides," *Geology*, 2012, doi: 10.1130/G33217.1.

[3] M. Drusch *et al.*, "Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services," *Remote Sens. Environ.*, 2012, doi: 10.1016/j.rse.2011.11.026.

[4] Y. Hou *et al.*, "NLH: A Blind Pixel-Level Non-Local Method for Real-World Image Denoising," *IEEE Trans. Image Process.*, 2020, doi: 10.1109/TIP.2020.2980116.

[5] L. Luo *et al.*, "Freeze/thaw-induced deformation monitoring and assessment of the slope in permafrost based on terrestrial laser scanner and GNSS," *Remote Sens.*, 2017, doi: 10.3390/rs9030198.

[6] T. R. Martha, P. Roy, K. Khanna, K. Mrinalni, and K. Vinod Kumar, "Landslides mapped using satellite data in the Western Ghats of India after excess rainfall during August 2018," *Curr. Sci.*, vol. 117, no. 5, pp. 804–812, 2019, doi: 10.18520/cs/v117/i5/804-812.

[7] T. R. Martha, P. Roy, R. Mazumdar, K. B. Govindharaj, and K. V. Kumar, "Spatial characteristics of landslides triggered by the 2015 Mw 7.8 (Gorkha) and Mw 7.3 (Dolakha) earthquakes in Nepal," *Landslides*, 2017, doi: 10.1007/s10346-016-0763-x.

[8] T. R. Martha, P. Roy, and K. Vinod Kumar, "Assessment of the valley-blocking 'So Bhir' landslide near Mantam village, North Sikkim, India, using satellite images," *Current Science*. 2017.

[9] S. L. Kuriakose, G. Sankar, and C. Muraleedharan, "History of landslide susceptibility and a chorology of landslide-prone areas in the Western Ghats of Kerala,

India," *Environ. Geol.*, 2009, doi: 10.1007/s00254-008-1431-9.

[10] Z. Guo, K. Yin, L. Gui, Q. Liu, F. Huang, and T. Wang, "Regional Rainfall Warning System for Landslides with Creep Deformation in Three Gorges using a Statistical Black Box Model," *Sci. Rep.*, 2019, doi: 10.1038/s41598-019-45403-9.

[11] V. S. Veena, S. G. Sai, R. M. Tapas, M. Deepak, and R. N. Rama, "Automatic detection of landslides in object-based environment using open source tools," no. September, 2016, doi: 10.3990/2.366.

[12] H. Hemasinghe, R. S. S. Rangali, N. L. Deshapriya, and L. Samarakoon, "Landslide susceptibility mapping using logistic regression model (a case study in Badulla District, Sri Lanka)," in *Procedia Engineering*, 2018, doi: 10.1016/j.proeng.2018.01.135.

[13] S. R. Yang, "Assessment of Rainfall-Induced Landslide Susceptibility Using GIS-Based Slope Unit Approach," *J. Perform. Constr. Facil.*, 2017, doi: 10.1061/(ASCE)CF.1943-5509.0000997.

[14] C. Baeza and J. Corominas, "Assessment of shallow landslide susceptibility by means of multivariate statistical techniques," *Earth Surf. Process. Landforms*, 2001, doi: 10.1002/esp.263.

[15] E. Arnone, A. Francipane, and L. V Noto, "Landslide Susceptibility Mapping : a Comparison of Logistic Regression and Neural Networks Methods in a Small Sicilian Catchment," *I0th Int. Conf. Hydroinformatics*, 2012.

[16] C. S. Dubey, M. Chaudhry, B. K. Sharma, A. C. Pandey, and B. Singh, "Visualization of 3-D digital elevation model for landslide assessment and prediction in mountainous terrain: A case study of Chandmari landslide, Sikkim, eastern Himalayas," *Geosci. J.*, 2005, doi: 10.1007/BF02910325.

[17] A. Dikshit, R. Sarkar, B. Pradhan, S. Segoni, and A. M. Alamri, "Rainfall induced landslide studies in indian himalayan region: A critical review," *Appl. Sci.*, 2020, doi: 10.3390/app10072466.

[18] N. James and T. G. Sitharam, "Assessment of Seismically Induced Landslide Hazard for the State of Karnataka Using GIS Technique," *J. Indian Soc. Remote Sens.*, 2014, doi: 10.1007/s12524-013-0306-z.

[19] T. G. Sitharam, N. James, K. S. Vipin, and K. Ganesha Raj, "A study on seismicity and seismic hazard for Karnataka State," *J. Earth Syst. Sci.*, 2012, doi: 10.1007/s12040-012-0171-0.

[20] N. Bontemps, P. Lacroix, E. Larose, J. Jara, and E. Taipe, "Rain and small earthquakes maintain a slow-moving landslide in a persistent critical state," *Nat. Commun.*, 2020, doi: 10.1038/s41467-020-14445-3.

[21] S. Martino *et al.*, "Earthquake-induced landslide scenarios for seismic microzonation: application to the Accumoli area (Rieti, Italy)," *Bull. Earthq. Eng.*, 2019, doi: 10.1007/s10518-019-00589-1.

[22] S. Martino, S. Battaglia, J. Delgado, C. Esposito, G. Martini, and C. Missori, "Probabilistic approach to provide scenarios of earthquake-induced slope failures (PARSIFAL) applied to the alcoy basin (South Spain)," *Geosci.*, 2018, doi: 10.3390/geosciences8020057.

[23] T. Carlà, F. Raspini, E. Intrieri, and N. Casagli, "A simple method to help determine landslide susceptibility from spaceborne InSAR data: the Montescaglioso case study," *Environ. Earth Sci.*, vol. 75, no. 24, 2016, doi: 10.1007/s12665-016-6308-8.

[24] K. G. Avinash and K. G. Ashamanjari, "A GIS and frequency ratio based landslide susceptibility mapping: Aghnashini river catchment, Uttara Kannada, India.," *Int. J. Geomatics Geosci.*, 2010.

[25] M. J. Froude and D. N. Petley, "Global fatal landslide occurrence from 2004 to 2016," *Nat. Hazards Earth Syst. Sci.*, 2018, doi: 10.5194/nhess-18-2161-2018.

[26] M. Haigh and J. S. Rawat, "Landslide causes: Human impacts on a Himalayan landslide swarm," in *BELGEO*, 2011, doi: 10.4000/belgeo.6311.

[27] P. Canuti, N. Casagli, L. Ermini, R. Fanti, and P. Farina, "Landslide activity as a geoindicator in Italy: Significance and new perspectives from remote sensing," *Environmental Geology*. 2004, doi: 10.1007/s00254-003-0952-5.

[28] A. R. Amashi, A. M. Hulagabali, C. H. Solanki, and G. R. Dodagoudar, *Landslide risk assessment and mitigation—A case study*, vol. 15. Springer Singapore, 2019.

[29] O. Hungr, "A review of landslide

hazard and risk assessment methodology," in *Landslides and Engineered Slopes. Experience, Theory and Practice*, 2016, doi: 10.1201/b21520-3.

[30] T. R. Martha, C. J. van Westen, N. Kerle, V. Jetten, and K. Vinod Kumar, "Landslide hazard and risk assessment using semi-automatically created landslide inventories," *Geomorphology*, vol. 184, pp. 139–150, 2013, doi: 10.1016/j.geomorph.2012.12.001.