Risk Assessment and Early Warning System for Landslides in Himalayan Terrain

R. K. Panigrahi and Gaurav Dhiman

1 Introduction

Landslides hazards are the most occurring among the hydro geological hazards because the aftermath of landslides disaster is both in loss of life and property. The term landslides hazard is described by many authors among which the definitions given by Burton et al. [1], Varnes [2], Rezig et al. [3], and Guzzetti [4] are important. It also cause severe disruptions to the environment and large part of mountains area and in India most of the landslides occurrence has been seen in the hilly ranges of the country because these regions are both affected by landmass movement and anthropological activities. Some of the most devasting landslides has been seen in Himachal Pradesh, Maharashtra, Nagaland, West Bengal, Uttrakhand and Kerala (NDMA [5]). The development of new trends for landslides mitigation and remediation both depends upon the pros and cons of the existing methods of implementation. The following are the recent developments in the mitigation of landslides disasters.

2 Early Warning System for Landslides (LEWS)

Landslides are one of the most difficult disaster to predict because of the factors involved that affect slope stability vary in both space and time, but the advancement in the satellite imaging, mapping, and rainfall estimations have made it possible to develop a system to monitor the real time assessment of landslides hazards threat across the country. The Landslide Early Warning System (LEWS) is based on the type of landslides, the targeted geological area and the population under risk. The

R. K. Panigrahi (✉) · G. Dhiman
CSIR-Central Road Research Institute, New Delhi 110025, India

C. N. V. Satyanarayana Reddy et al. (eds.), *Stability of Slopes and Underground Excavations*, Lecture Notes in Civil Engineering 185,
https://doi.org/10.1007/978-981-16-5601-9_3

LEWS can be for a single landslides based on the movement sensor or for a large area using rainfall threshold and for a very large area based on the weather prediction. The LEWS subdivision consists of design, monitoring, forecasting, and education. The design of EWS is based on the geological knowledge of the area to be included in EWS. The recent developments in remote sensing and Geographical Information System (GIS) are being used in accessing landslide hazards (Pardeshi et al. [6]). The key factors that are to be considered while designing a EWS for landslides is (a) to know the vulnerabilities of the population at risk and (b) determining the geologic and meteorological settings and conditions that lead to landslides initiation. Monitoring in EWS refers to the installation of instrument and the analysis of data communication throughout the life of the EWS. The component forecasting is the core element in EWS system, as this component is very crucial to know the threshold of any type such as rainfall intensity, movement velocity, and mass movement (Nadim et al. [7]). Finally, education is very necessary to cover all the social and logistic issues that every EWS must consider to be people centric (Twigg [8]). The main objective of this component is to aware public with risk perception and to correct behaviors during landslides occurrence events to prevent damage or losses. The subdivision diagram for typical Landslide Early Warning System is shown in Fig. 1.

The block diagram of typically Landslide Early Warning System is shown in Fig. 2.

Besides the advancement in LEWS in India there are many shortcomings which are needed to overcome to provide a more productive and societal beneficial EWS which is both economic as well people centric. A well-illustrated and functional rainfall threshold model is not yet available in India due the missing corresponding daily/hourly rainfall data. Information on the time of landslides based on real time monitoring is still lacking in India. The existing network and technology are not sufficient to tackle landslide predictions, and there is a need of extensive research in the literature of EWS; the single EWS should be modified and used as multi-hazard EWS.

If the implementation of EWS is done without the consideration of the social aspects, in particular without considering the public response, this results in an incomplete EWS. There is also problem for installing the sensors because of the inaccessible locations and later maintenance problems. Another important issue is inclement weather such as high winds, low temperatures, snowfall, and rainfall, which may affect the sensors and/or the communication lines. Snow may block radar reflectors; heavy rainfall may cause leakages, rotting, or corrosion; high winds may destroy antennas, signs, or aerial cables (NDMA Report [5]).

3 Landslides Zonation Mapping

Landslide zoning is division of the hills or mountains with respect to their degree of slope susceptible to landslide hazard or risk. 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

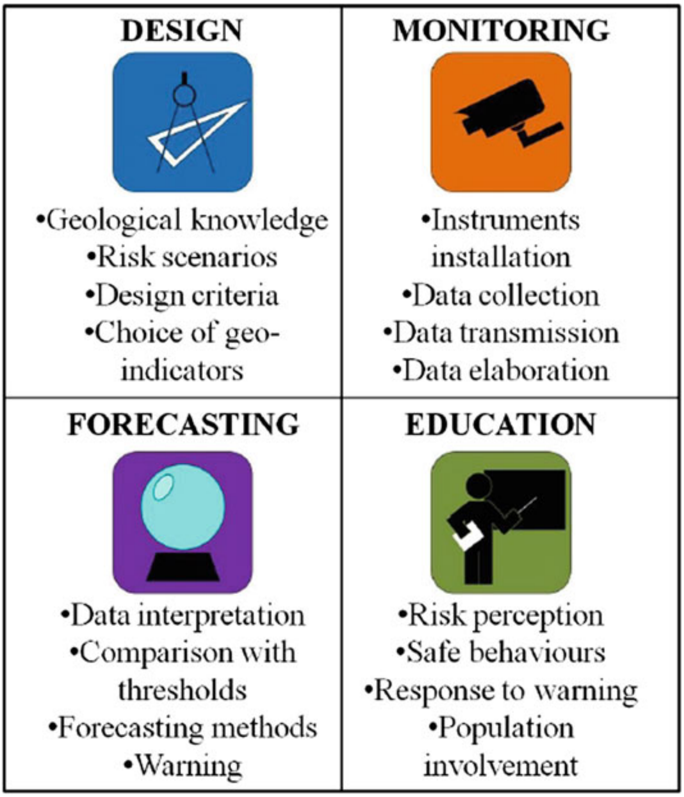

Fig.1 Subdivision of a generic EWS in four fundamental components

accepted universally for effective assessment of landslide hazards. The aim of zonation mapping is to provide a broad trend of landslides potential zones, and also if it is done at macro level, it can lead to concrete insight into the landslide hazards. A brief outline of different methods for LHZ is shown in Fig. 3 and are explained further.

Direct method

The direct method consists of geomorphological mapping where the earth scientist evaluates the direct relationship between the hazard and the environmental setting during the survey at the site of the hazard event.

Indirect method

The indirect methods include two different approaches, namely, the heuristic (knowledge driven) and statistical (data driven) techniques. To overcome the problem of the “hidden rules” in geomorphological mapping, heuristic approach has been developed based on factors influencing landslides, such as rock type, slope, landform, and land use.

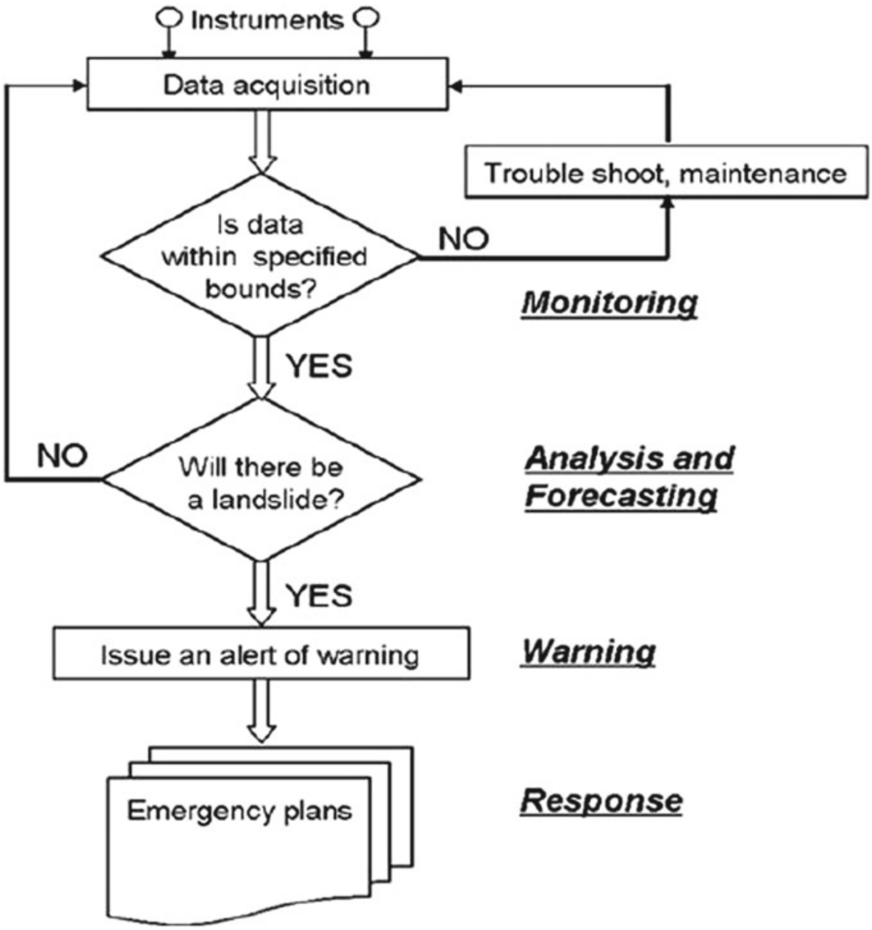

Fig. 2 Block diagram of a typical landslide early warning system DiBiagio and Kjekstad [9]

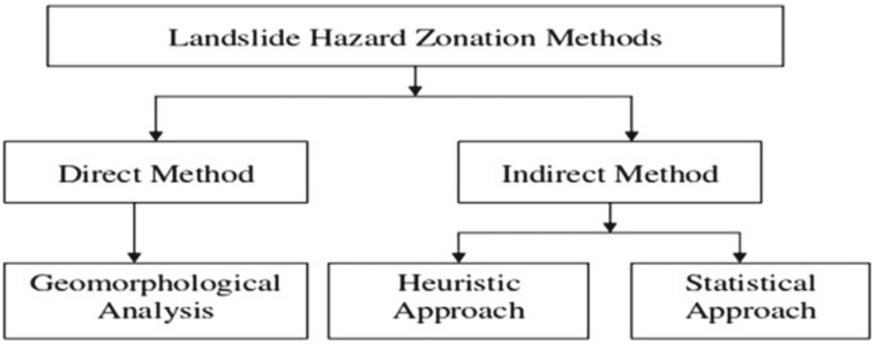

Fig. 3 Various approaches for LHZ

Table 1 Categories of slopes

Slope type Slope angle		
1	Cliff	> 80°
2	Precipitous	50–80°
3	Very steep or steep	20–50°
4	Moderate	6–20°
5	Gentle slope	1–6°
6	Flat terrain	< 1°

Table 2 Various scales used in LZM (Landslide Zonation Mapping)

1	National scale	< 1:1000,000
2	Regional and synoptic scale	1:100,000–1:1000,000
3	Medium scale	1:25,000–1,50,000
4	Large scale	1:5,000–1:15,000

The categories of slope and the common scale used in LHZ maps is given below in Tables 1 and 2.

The assessment of hazard, vulnerability, and risk is a crucial element in landslide hazard. The following definition given by Varnes [2] is generally accepted.

Natural Hazard (H): The probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area.

Vulnerability (V): The degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0 (no damage) to 1 (total loss).

Specific Risk (Rs): The expected degree of loss due to a particular natural phenomenon. It may be expressed by the product of H and V.

Element at Risk (E): The population, properties, economic activities, including public service, etc., at risk in a given area.

Total Risk (Rt): The expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon. It is therefore the product of specific risk (Rs) and elements at risk (E) which gives the total risk as given in the Eq. (1.1).

$$\text{Rt} = \text{E}\,(*)(\text{Rs}) = \text{E}\,(*)(\text{H} * \text{V}) \tag{1}$$

The landslide zoning is further divided into following subtypes.

3.1 Landslide Susceptibility Zoning (LSZ)

This type of zoning is done after studying the past landslides that occurred in that area following to future prediction of susceptible areas and likelihood of landslides in future. The LSZ maps are formed after critically studying the topography, geology, geotechnical properties, and climate of the vulnerable area. It also focus to study vegetation and anthropogenic factors such as development and clearing of vegetation.

3.2 Landslide Risk Zoning (LRZ)

The LRZ maps are created for planning and allocation of resources before occurrence of landslides. In the recent developments the landslide hazard zonation mapping for a small area using a hazard evaluation factor rating scheme was done by S. Sarkar et al. [10] which divides the zone into two classes, viz. high hazard zones and high frequency of landslides. The macro hazards maps prepared using LHEF techniques have predicted landslide hazards little better than SRZ subjective regional zonation and ORZ objective regional zonation maps. The MHZ maps are shown below in Fig. 3, and the hazard classes for MHZ maps are shown in Table 3 and (Fig 4).

LHZ maps are very useful in identifying delineate unstable hazard prone areas and to choose favorable locations for sitting development schemes. But besides several applications landslide zonation mapping in India is still lacking in giving complete use of them because of the various reasons such as only LSZ maps are mostly available in India; the maps are not available for states wise/district wise, northeastern states, and eastern and western Ghats. Most of the LSZ maps are prepared with 1:50,000 scale only. Most of the LSZ maps are lacking in incorporating the details of past landslides details, and active landslide zones of smaller dimensions having sizes of 50×50 m appear as a dot (1×1 mm) on 1:50,000 scale map. Existing LHM maps do not address the crucial aspects of overloading and or under cutting of hill slope due to anthropogenic activities and, therefore, provide no clear guidelines for removal of those manmade constructions in particular which are overloading or undercutting the hill slope or blocking, diverting or narrowing the natural drainage courses.

Table 3 Landslide density of hazard classes for MHZ Map

Hazard class	Area (km^2)	Number of landslides	Landslide density
Very low	4.54	0	0.00
Low	15.64	2	0.13
Moderate	27.62	20	0.72
High	19.78	23	1.16
Very high	10.42	14	1.34

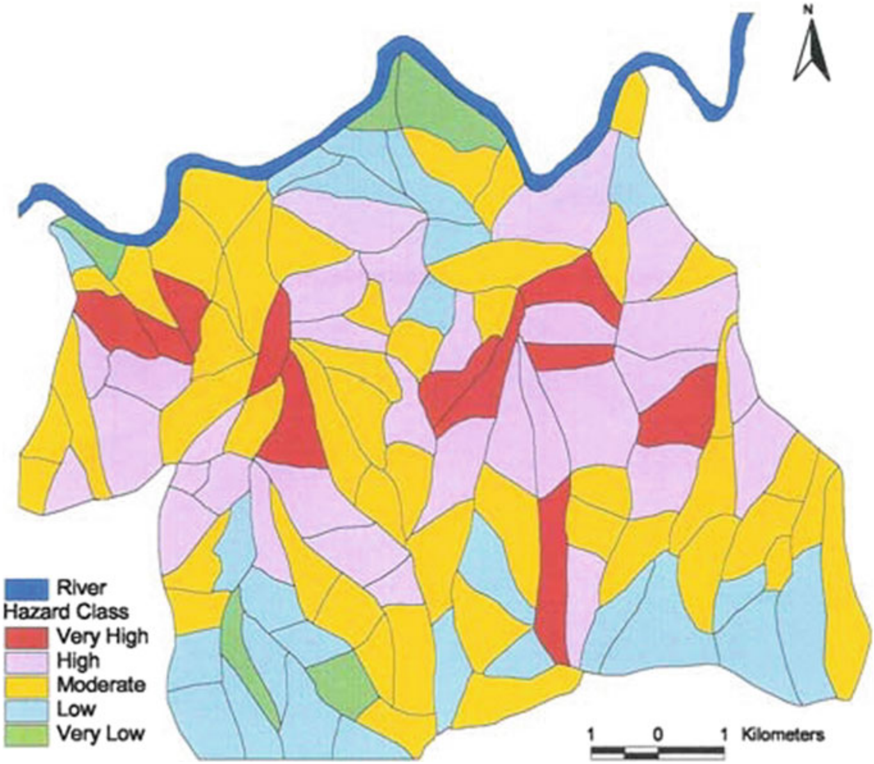

Fig. 4 MHZ Map using LHEF factor technique

The improvements needed in landslides zonation should focus on Preliminary to intermediate level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways Detailed (Site specific zoning) > 5,000 1–10 km^2 • Intermediate and advanced level hazard and risk zoning for local and site-specific areas and for the design phase of large engineering structures, roads and railways. The landslide hazard mapping techniques are so many, but the selection of method should be based on the scale of mapping, data availability, and nature of hazards.

4 Mountains Zones Regulations

In India the hilly regions are vulnerable to landslides and this results in loss of property, lives, and economy. The wide study of these natural disasters shows that the construction plans are ill implemented and do not follow standard norms. The cities of the Himalayas are growing and beginning to turn into the mountains of garbage and plastic, untreated sewage, chronic water shortages, unplanned urban growth, and even local air pollution because of vehicles (NDMA report [5]). There is need to formulate new policies or improvement of existing methods of construction and strict adherence to the construction norms. There should be use of bio engineering methods in the landslides affected areas. There is a need of making strategies for utilization of land use in these areas. The existing building bye laws and construction methods used in these areas are needed to improvement considering the present scenario.

5 Existing Methods of Landslide Remediation and Mitigation

The designing of landslide remedial measure is done after studying field investigation data and cause of landslide. The remedial measures are broadly classified into three main categories.

(a) Reinforcement measures

This type of remedial measure consists of Earth Reinforcing structures which involve insertion of tensile resisting materials such as steels rods, metal strips, geosynthetics of cloths and steel angles into the soil to improve stability. Soil nailing is also a reinforcement technique in which closely spaced parallel steels bars are installed into the face of a slope or vertical cut to improve stability. This technique consists of improving the soil resistance to failure and to deformation by the inclusion of elements which are resistant to tensile, compressive shear, and/or bending forces. Reinforcement remedial measures are widely used because of flexibility, ease of construction and are inexpensive as compared to large retaining walls but these methods have limitations such as soil nailing technique has to occur above groundwater level and away from seepage location. Also, the surface runoff water should also be intercepted before reaching a soil nailed wall, and any collected water should be disposed of rapidly.

(b) Retaining structures

The restraining structures such as gravity walls, cantilever walls, tied back walls, sausage walls, and mass gravity Gabion walls are designed to retain rock/soil and are generally economically cheaper as compared to other categories of remedial measures but have numerous drawbacks such as water drainage problem in sausage walls, base sliding failure in concrete gravity walls, need of bearing surface in case of anchored walls, etc. (Panigrahi and Dhiman [11]).

(c) Surface—sub surface drainage measures

Drainage measures which are most effective in the geological condition which allow interference with natural water regime.

(d) Bio-Engineering remedial measures

Bioengineering techniques are useful approaches to prevent landslides as they improve slope stability and maintain ecological balance. They are mostly suitable to be deployed in developing countries because of their cost effectiveness and environmentally friendly nature. The effectiveness of Bio-Engineering technique further depends upon the survival and growth rate of plants.

6 Conclusions

The risk assessment of landslides in predicting the occurrence of hazard is very critical task in landslide mitigation and remediation. Landslides are influenced by several preparatory and triggering factors which vary significantly from region to region. The paper provides a substantial contribution in knowing the latest trends in EWS and improvement of existing methods which will lead to developments of new standards. The EWS are becoming one the main pillars of hazard prevention in areas where mitigation strategies are not up to the mark. The modern sensor networks, like ad hoc wireless sensor networks, have the advantage over currently existing landslide monitoring systems that they can be used as very variable and the installation is quite simple. The advancements in geo-spatial technologies have opened the doors for detailed and accurate assessment of landslide. The accuracy of the LHZ maps is improved with the use of high resolution satellite data combined with GIS. The LHZ maps if are prepared with accuracy can result in designing cost effective methods such as bio-engineering (grass plantation, shrubs plantation, and tree plantation) in conjunction with small civil engineering structures. It is also concluded that the mitigation approach in landslide hazards is much more cost effective than construction cost. The use of improved methods of EWS, LHZ, and improved mountainous areas policies will help in delineating the hazards caused by landslides in a concrete manner.

Acknowledgements Author is grateful to Director, Central Road Research Institute, New Delhi, for his kind permission to publish this paper.

References

1. Burton, I., Kates, R., White, G.: The environment as hazard. Oxford University Press, New York (1978)
2. Varnes, D.: Landslide hazard zonation: a review of principles and practice, pp. 1–6. United Nations Scientific and Cultural Organization, Paris (1984)
3. Rezig, S., Favre, J., Leroi, E.: The probabilistic evaluation of landslide risk. In: Sennset (ed) Landslides. Rotterdam, Balkema, pp. 351–355. (1996)

4. Guzzetti, F.: Landslide Hazard Assessment and Risk Evaluation: Limits and Perspectives. In: Proceedings of the 4th EGS Plinius Conference held at Mallorca, Spain, pp. 1–4. University de les Illes Balears, Spain. (2003)
5. NDMA Report.: National Landslides Risk Management Strategy Report (2019)
6. Pardeshi, S.D., Autade, S.E., Pardeshi, S.S.: Landslide hazard assessment: recent trends and techniques. SpringerPlus (2013)
7. Intrieri, E., Gigli, G., Casagli, N., Nadim, F.: Landslide Early Warning System: toolbox and general concepts. Nat. Hazards Earth Syst. Sci. **13**, 85–90 (2013)
8. Twigg, J.: Disaster early warning systems: people, politics and economics, benfield hazard research centre disaster studies. Working Paper, No. 16 pp. 1–4 (2006)
9. DiBiagio, E., Kjekstad, O.: Early warning, instrumentation and monitoring landslides. In: Proceedings of the 2nd Regional Training Course, RECLAIM II, 29th January– 3rd February 2007 2007.
10. Sarkar, S., Anbalagan, R.: Landslides hazards zonation mapping and comparative analysis of hazard zonation maps. J. Mount. Sci. (2008)
11. Panigrahi, R.K., Dhiman, G.: Critical review of different types of remedial measures for landslides. Indian Highways J Indian Road Cong New Delhi **10**(3), 38–45 (2020)