REMOTE SENSING AND GIS APPLICATION IN LANDSLIDE RISK ASSESSMENT AND MANAGEMENT

Dinesh Pathak

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Abstract: *Small as well as large scale landslides are common in the Himalayas, especially in the monsoon period. This natural disaster occurs in all the physiographic divisions of the Himalayas. Landslide is the result of a wide variety of processes which include causative and triggering factors. A complete landslide hazard assessment requires an analysis of these factors leading to instability in the region. Therefore, there is a need of multidisplinary studies of landslide hazards, which combines geology, hydrogeology and, geomorphology.*

The landslide risk is directly associated with the development activities, which will increase with increased urbanization and development, continued deforestation in landslide-prone areas, increased precipitation and seismic activity. In order to reduce the landslide risk, it is necessary to understand the underlying the processes, study the impact of landslides on the socio-economic development of the affected areas, prepare landslide hazard zonation maps to minimize the risk involved in developmental schemes, evolve a methodology for mitigation and control measures, monitor change in land use pattern and landslide occurrence, establishing early warning system and development landslide 'databank' on national level and identify potential landslides zones and prepare population maps of the critical areas.

Landslide disaster management includes a series of actions and instruments aimed at reducing the landslide risk in endangered regions and mitigating the extent of disasters. The application of Remote Sensing using aerial photographs and satellite images for landslide study, identification and inventory as well as GIS digital formats of data layers including the social data all form an integral part of landslide risk assessment and management. This paper provides synopsis about the various methods for landslide risk assessment with the use of remote sensing and GIS, which will be supportive to landslide disaster management.

1 INTRODUCTION

The mountainous region of Nepal belongs to active Himalayan Range with complex geological set up represented by many geological structures, fractured rocks, steep hill slope, diverse climate and intense precipitation. Nepal faces many natural hazards like earthquakes, floods, GLOFs, landslides and debris flows. Every year floods and landslides kill hundreds of people and causes loss of hundreds of millions rupee due to the natural disasters. About 28 percent of Nepal's total land area is degraded, when all the poorly managed forests, sloping terraces and pastures and areas damaged by floods and landslides are considered (MoEST, 2008).

Landslide is a common geological phenomenon that is dominantly affecting the human activity and development process in the mountainous region. The loss of lives and property is taking place due to landslide and flood each year in the Himalayan region. However, huge damage on human life has been occurring during the monsoon period (Pathak et al., 2010). In 2014 alone, 113 people died, 129 were missing and 96 were injured and 491 families were affected with the estimated loss of around 24 million rupees due to landslide event alone (DWIDP, 2015). Number of livestock loss is found many times than the human loss and the damage to infrastructure costs unbearably high in comparison to the economic condition of the country.

Landslide risk mapping and risk management should be aimed to reduce the disaster risk. The relevancy of Hyogo Framework for Action is equally valid till date that has identified five priorities of actions focused to risk mapping and risk management (UNISDR, 2007). These areas mainly concerned to policy issues, early warning mechanism, disaster education, risk reduction and strengthening disaster preparedness at all levels. In this context, the system of hazard mapping, vulnerability and risk assessment have to be properly developed in a systematic manner for better management of the landslide disaster.

2 LANDSLIDE HAZARD, VULNERABILITY AND RISK ASSESSMENT IN GENERAL

Hazard is defined as a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009). Thus, landslide hazard indicates the probability of landslide event with a certain magnitude, which is the function of a number of factors that includes causative and triggering. It represents the existing condition of the slope that has potential to develop a disastrous consequence. The magnitude of landslide hazard can be classified as high, moderate and low (number of classes varies as per the objective and site condition) based upon the volume, duration, possible effect in terms of distance, area and speed at which the slope fails.

Landslide vulnerability assessment is a process to identify what elements are at risk and to analyze the root causes of why these elements are at risk. This information is useful in decision making process leading to landslide disaster mitigation measures; guide to land use zoning; helps as planning tool in landslide management plan; information dissemination to general public; enhancing institutional capacity; public awareness raising and to establish emergency management and response mechanism like establishment of early warning system. It provides technical basis for policy formulation. Landslide vulnerability can be categorized as physical (potential loss of buildings, assets, infrastructure, lifeline facilities etc.); social (age, gender, poverty, culture, attitudes of population etc) and economic (potential loss of investment, crops, etc). The latter two factors is directly associated with the coping capacity. In other words, landslide vulnerability is the expected degree of loss of the elements at risk with the scale ranging from 0 (no vulnerability) to 1 (highly vulnerable). It is concerned about the degree of damage that the event can impose which is a function of magnitude of landslide event and type of element at risk.

Landslide risk is the expected number of lives lost, people injured, or economic losses due to a potentially damaging landslide event within a period of time. Thus, landslide risk can be expressed as the product of landslide hazard, vulnerability and elements at risk. The elements at risk could be population, infrastructures, economic activities and environment exposed to landslide hazard, which are likely to be adversely affected by the impact of the hazard. The first step towards landslide risk assessment is the identification of landslide hazards followed by deciding who/what might be harmed and how. Once the landslide risk is evaluated, appropriate mitigation measures can be proposed for landslide risk reduction: The risk assessment must be updated with time as there might be changes in hazard condition and elements at risk.

3 REMOTE SENSING DATA: SOURCE OF INFORMATION

3.1 The remote sensing (RS) data

The use of remote sensing data (satellite imageries and aerial photographs) in geohazard studies is common nowadays (Pathak, 2014; Subramani and Nanda Kumar, 2012; Farina et al., 2005). Extraction of relevant spatial information related to landslide occurrence is an integral part of hazard assessment. Remotely Sensed (RS) data combined with Geographical Information System (GIS) are proved to be effective tools for generating and processing spatial information. The advancement in earth Observation (EO) techniques facilitate effective landslide detection, mapping, monitoring and hazard analysis (Tofani et al. 2013). Remote sensing data are the major source of information required for landslide risk information. High spatial resolution satellite imageries are useful for terrain feature extraction, which are the major sources of data for the preparation of different thematic layers and spatial data analysis in GIS. Some of the thematic layers are lithology, slope, land use, lineament density, precipitation distribution, altitude, slope aspect, drainages and roads etc.

3.2 Extraction of geological information

Remote sensing technology is an effective and widely established analytical method in geological investigations, especially at the inaccessible sites (Kruse and Dietz, 1991; Al Rawashdeh et al., 2016; Schetselar, 2001). Aerial imagery acquired from hyperspectral and multispectral imaging sensors such as Landsat, ASTER, AVIRIS, ALOS, IRS, Quickbird etc. are applied to geological surveys, and geomorphology applications. Nowadays, wide varieties of satellite imageries from various sensors are available at affordable cost. Moreover, limited financial resources is not the constraints like before because the satellite images can be downloaded free of cost from various sources and Google earth covers significant area of the country with high resolution imageries and it is being constantly updated with the new images. Satellite imagery correlated with ground truth data is also used for assessments of change due to natural events such as floods, landslides and earthquakes. Lineaments are the expressions of geological and structural features and form an important parameter in landslide hazard assessment (Fig. 1). These can be identified well on the aerial photograph and satellite image, which otherwise would be very time consuming and difficult to map the entire study area in the field (Rowan and Bowers, 1995). Thus extracted lineament is used to prepare lineament density map, which is an integral part of landslide hazard mapping.

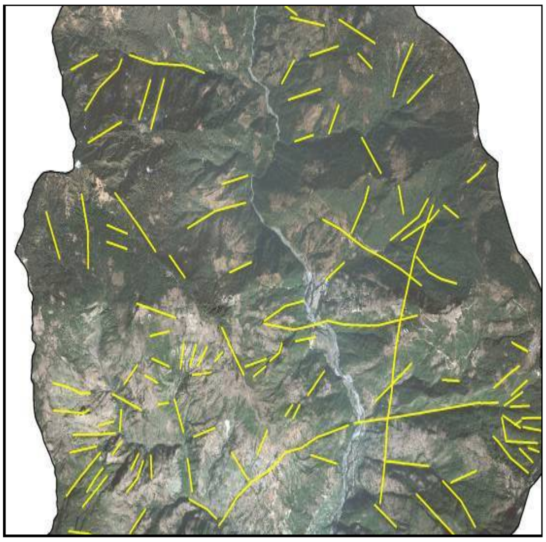

Fig. 1: Lineament extraction from the satellite image

In addition, the satellite imageries can be a valuable resource through which the small scale geological maps can be updated to large scale followed by field verification (Crippen and Bloom, 2001). Likewise, the landslide (or mass wasting) risk to settlement and infrastructure that are at the proximity of major geological structure (like thrust) can be effectively evaluated on the images and photographs (Fig. 2).

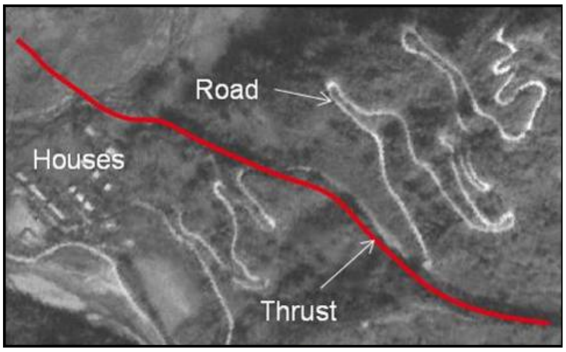

Fig. 2. Settlement and infrastructure at the proximity of major geological structure.

Such information is very useful for the image based assessment of various elements at risk due to landslide disaster.

3.3 Landslide inventory and monitoring

Preparing landslide inventory is always a difficult task if it is to be carried out through the field observation. However, use of aerial photograph and satellite image always makes it possible to complete the task at less time and effort with considerable accuracy.

The landslide activity can be well monitored through the satellite image, assessing the disastrous consequence. The temporal images of Mankha VDC, Sindhupalchowk district clearly shows the landslide disaster that occurred on August 2, 2014 (Fig. 3). The comparison of imageries before and after the event would be helpful to plan the disaster management through identification of the affected area and its severity.

Fig. 3. Monitoring the landslide activity through satellite image (Jure landslide, Sindhupalchowk). Images of 13 Feb. 2013 (left) and 10 Aug. 2014 (right).

The satellite images are equally important to assess the earthquake induced landslides through visual inspection of the images before and after the occurrence of earthquake event (Fig. 4). The earthquake may either generate new landslide or reactivate the existing landslide. The figure shows the reactivation with increase in areal extent of existing landslide.

Fig. 4. Assessment of landslide reactivation due to earthquake. Images before (left image) and after (right image) Gorkha Earthquake of April 25, 2015.

The information on spatial location of landslide, its size and activity, relationship with geology and major geological event helps to prioritize the landslides for further intervention through the application of mitigation measures. The mitigation measures at the upper catchment area and at the lower catchment area could be different.

4 LANDSLIDE ASSESSMENT IN GIS AND APPLICATION IN DISASTER MANAGEMENT

The data required for landslide hazard assessment are slope, aspect, geology and structures, land use/land cover, road network, slope curvature, drainage density, lineament density and many more. These data are obtained from existing maps, digital data, remote sensing as well as from field observation, which are stored in GIS database for analysis.

The data required for vulnerability mapping are principally the socio-economic data like population, economic condition, educational condition, awareness level in terms of disaster etc. that overall represents their coping capacity. However, the risk map incorporates both social as well as technical aspect and hence helpful to prioritize the areas for intervention leading towards landslide risk reduction initiatives (Fig. 5). Furthermore, the individual landslides should be considered as unique in nature and hence each larger landslide that could potentially harm infrastructure, settlement and agriculture fields should be studied in detail.

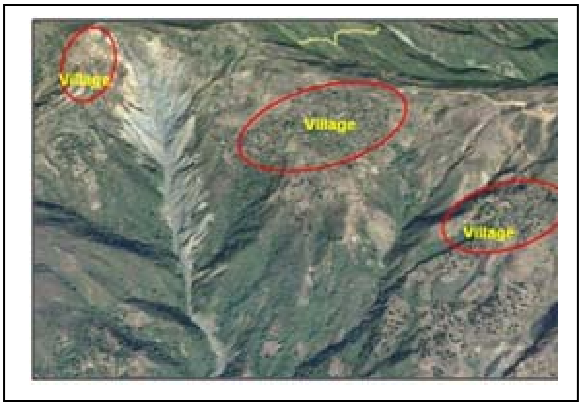

Fig. 5: The risk of landslide to settlements is clearly visible in satellite image.

Once the elements at risk are identified through the landslide assessment, the required risk reduction measures can be applied at various locations in connection to the landslide disaster management activities (Fig. 6).

Fig. 6: Landslide mitigation measure at the source area.

The type of mitigation measures to be adopted at the source area (upper catchment) and at the affected areas (lower catchment) can be assessed well. The first step towards landslide hazard assessment is to make the inventory of existing landslides in the study area and spatially locate them (Fig. 7).

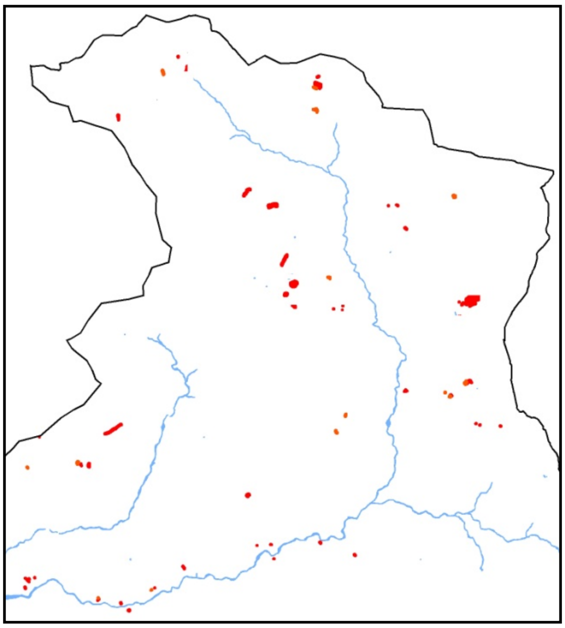

Fig. 7: Landslide inventory made through remote sensing and field survey.

So far as the complete database is prepared, landslide hazard map can be prepared through the established methodology like bivariate, logistic, knowledge based etc. (e.g. Pardeshi et al., 2013; Dahal et al., 2012; Pradhan et al., 2010; Lee, 2004; van Westen, 1997). The classified landslide hazard map is an important output to be used for the landslide disaster management activities (Fig. 8).

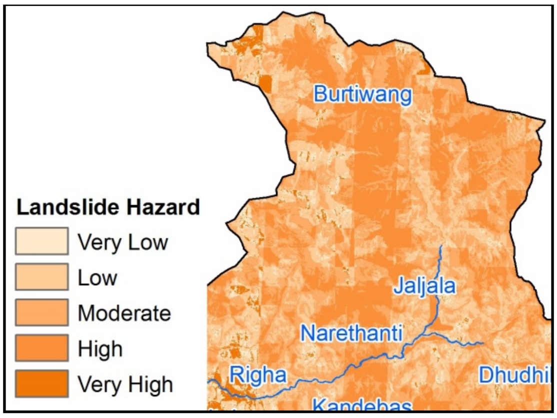

Fig. 8: Classified landslide hazard map.

Landslide hazard map prepared in this way can be used to assess the possible impact of hazard to different elements like building, infrastructures etc. Delineating the building locations with respect to landslide hazard classes provides important information regarding the consequences to be faced by the residents in case of occurrence of landslide disasters (Fig. 9). The disaster management experts should be specially focused to the buildings falling within high to very high hazard classes so as to ensure that required mitigation measures are adopted to reduce the loss of lives and properties.

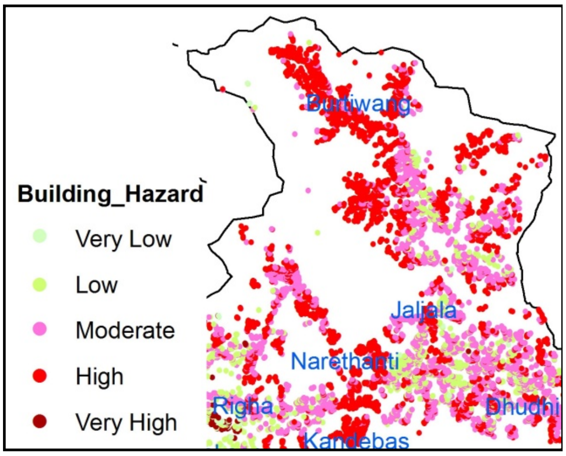

Fig. 9: Location of buildings at different hazard classes.

More importantly, the disaster risk reduction practitioners always seek for the possible evacuation center in case the disaster occurs. The possible evacuation sites should have open space, can accommodate many people and itself should be safe from the landslide disaster. Public schools are the appropriate sites to be used as evacuation centers. The schools located at the low landslide hazard can be considered to be the suitable schools to be used as evacuation center (Fig. 10).

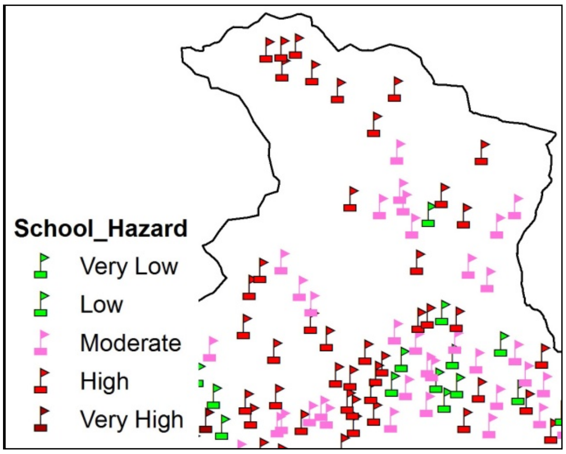

Fig. 10: Location of schools with respect to landslide hazard classes.

The schools situated at very low and low hazard classes need to be further upgraded to be suitable to accommodate large number of people and required relief materials can be stored. The facility and materials can be made available to the people taking shelter during the landslide disaster at nearby locations. The people living in the area falling within moderate to very high hazard zones need to be made aware to use the specific safe route to reach the evacuation centre. Thus, an effective landslide disaster management system can be established in the mountainous area.

5 CONCLUSIONS

The use of remote sensing and GIS for landslide risk assessment and management presented in this article are only indicative from a wide realm of potential use of remote sensing data and GIS tools. This shows that RS data can significantly contribute in various programs related to the natural resources management including landslide disaster management. The spectrum of satellite sensors with large swath and moderate-low spatial resolution to those with narrow swath and very high spatial resolution are valuable remote sensing resources for geological applications. The following conclusions can be drawn based on the various aspects of remote sensing and GIS application in landslide risk assessment and disaster management:

- Landslide hazard map is pre-requisite for assessing the landslide risk in a watershed/sub-watershed scale. However, individual landslide should be studied particularly to assess site condition and adopt appropriate mitigation measures.
- Interpretation of remote sensing data (satellite image and aerial photograph) is useful to locate/monitor the landslide whether it is rainfall-induced or earthquake-induced.
- RS is also useful to update the existing geological map and extract lineaments.
- Remote Sensing is a good tool for mapping elements at risk, especially through high-resolution satellite imagery.
- An updated GIS database forms basis for further analysis of hazard, vulnerability and risk leading towards the activities of disaster management.

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Author's Information

Name:	Dinesh Pathak
Academic Qualification:	Ph. D. in Geosciences
Organization:	Central Department of Geology, Tribhuvan University.
Current Designation:	Associate Professor
Work Experience:	25 years
Published Papers/Articles:	25 +
e-mail:	dpathaktu@gmail.com