Implementation of landslide susceptibility mapping programme, vulnerability and risk assessment - a gateway to research and development of early warning systems in India

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Abstract

Landslides being a geomorphic mass-wasting phenomenon largely depend on various pre-disposing geofactors such as slope morphometry, lithology, structure, land use/ cover, geohydrology etc., and a variety of triggering factors such as rainfall, earthquake etc. About 15% of India's landmass (~0.49 million km2) including the Himalaya, the Arakan Yoma Mountains (covering a part of northeastern states), the Western Ghats and the Nilgiris are prone to the landslide hazard. Generally, these areas experience frequent landslides during monsoon. Besides, numerous landslides are generated/ triggered by earthquakes having their epicenter in the landside prone region.

Geological Survey of India being a nodal agency is associated with all types of landslide studies in India. In order to build up a modern scientific data base on GIS platform it was decided to launch a nation-wide program of Land Slide Susceptibility Mapping [NLSM] incorporating all available geoscientific data and generating remote sensing aided geoparametric data sets together with detailed field surveys on 50K scale geocoded maps. Landslide Susceptibility Zonation [on 1: 50,000 scale) leads to classify the landslide prone terrains of the country into different zones according to their degree of susceptibility to landslides for perspective project planning and mitigation. It is a multi-thematic exercise taking into account the relevant causal geofactors such as i) *slope morphometry* (Slope gradient, aspect, slope shape), ii) *lithology, iii) structure, iv) geomorphology, v) land use/cover, vi) geohydrology, etc.* as separate causative themes and by establishing an expert-driven or data-driven interrelationships with different types of landslides, following a number of standard and well-established guidelines.

It imperative that collation and syntheses of such dynamic data sets will enable formulations on Early Warning Systems (EWS) including: Landslide Hazard Warning - plans, routines and participation, monitoring using in-situ real-time monitoring devices (e.g., geophones, inclinometers, piezometers, extensometers etc.), monitoring using geodetic scanners (Terrestrial Laser Scanner), Geodetic monitoring using differential GPS systems and detailed-scale field mapping of permanent surface features using Total Station, remote monitoring systems for field measurements with automated data collection by web-enabled devices, for comprehensive determination of both empirical and deterministic threshold modeling of triggering factors (e.g., rainfall, earthquakes) for devising an empirical system of early warning based on triggers.

It is intended to present here various features of such country-wide programs on Landslides related geohazards characterization and its implications on evolving EWS and societal preparedness and resilience for mitigating impending disasters.

1. Introduction:

Landslide is a geomorphic physical mass-wasting phenomenon when a part of rock and/or debris/ soil fall due to the action of gravity. It is caused by a set of terrain-specific geofactors (e.g., slope, geomorphology, bed-rock lithology, nature of weathered material, rock structure, land use/ cover, etc.) and in general is triggered by heavy rainfall or earthquake tremors. In Indian terrain, landslide events are mostly triggered by monsoonal rainfall but examples of earthquake-triggered landslide is also not uncommon in India (e.g., Uttarkashi Earthquake, Chamoli Earthquake, Kashmir Earthquake, Sikkim Earthquake, etc., in recent years that induced landslides, Champati Ray et al. 2009; Ghosh et al., 2012a). The entire Himalayan tract, hills/ mountains in sub-Himalayan terrains of North-east India, Western Ghats, the Nilgiris in Tamil Nadu Konkan areas are landslide-prone (~ 0.42 Million Sq. Km.; including the permafrost regions makes it about 0.49 Million Sq. Km). Besides the rainfall and earthquake, the toe erosion by stream and adverse or unscientific anthropogenic interferences such as excessive cutting of slope for construction of roads and buildings can also trigger landslides.

It is estimated that landslides will cause more damage to properties than any other geological hazard (Varnes, 1984; Schuster and Fleming, 1986; Petley et al., 2005). The reasons attributed to this include: overexploitation of natural resources, rapid deforestation, change in climate, increase in hill population and uncontrolled excavations resulting in a higher susceptibility of surface soil to instability and higher vulnerability of the exposed population (Nadim et al., 2006; Hoyois et al., 2007, Sarvothaman and Kumar 2013).

According to the National Disaster Management Act (2005), Landslide Disaster Management Plan should give maximum stress on preparedness and mitigation rather than incurring more expenditure and making ad-hoc arrangements for relief and rehabilitation measures. Thus, the onus of effectively managing landslide related hazards becomes a challenging task because preventing or minimizing losses owing to an inevitable and consequential geomorphic phenomenon like landslides needs proper geoscientific appraisal and studies which should be the integral part of any detailed disaster management plan and development of EWS (Wadhawan et al. 2013a, b).

At the instance of National Disaster Management Authority [NDMA] and Ministry of Mines, the Policy Support System (Planning & Monitoring) arm of GSI had created an exclusive Geohazards Research & Management (GHRM) Cell under the direct supervision of Director General, GSI at Kolkata in September 2013. This Specialised R&D Cell in GSI has been engaged in promoting landslide research for the benefit of society and environment, formulating relevant programmes of GSI and augmenting the expertise in the field of landslide research and managing all sorts of landslide related research and survey activities, capacity building, act as partner in various international and national joint ventures and coordinating with all stakeholders on matters related to landslide hazards monitoring and mitigation strategies, etc. (e.g., Indo–Netherlands and Indo-Canadian joint ventures; GSI-DTRL collaboration, etc.). GSI GHRM Cell has also embarked on taking-up pilot projects on landslide monitoring and developing early warning systems in selected sectors in the Himalayas.

In order to formulate strategies to minimize societal impacts of landslides, a systematic approach would entail preparation of Landslide Susceptibility Maps linked to landslide incidence inventory and making them available to the concerned stake holders for necessary preparatory and mitigation measures. Landslide Susceptibility Mapping is an exercise in making quantitative or qualitative estimate of spatial distribution of landslides which either exists or has the potential to occur in a given area. Although such exercise is intended to provide potentially most vulnerable areas where landslide is expected to occur, yet it has not been feasible to predict time frame or magnitude of the event.

As per the National Disaster Management Act 2005, the Union Government (National Disaster Management Authority, NDMA, 2009) is engaged in strengthening nation's preparedness to prevent any hazard rather that stressing more on relief and rehabilitation. Accordingly the task of multi-scale landslide hazard zonation is an important geo-information tool to the planners and administrators to minimize such losses due to any landslide hazard. To accomplish this target, the nodal Ministry of Mines and its attached Department - the GSI had taken up NLSM Programme to complete macro-scale (1:50,000) landslide susceptibility mapping of the entire landslide prone areas of India in a planned manner which are likely to be completed by 2020. GSI had started working on NLSM programme with effect from FS 2014-15 after it was formally launched in New Delhi on February 05, 2014 by the Hon'ble Minister of Mines, Govt. of India. Presently 17 NLSM Items in 37 Survey of India Toposheets is operational in different parts of the country. Out of this, 12 items in 26 Toposheets are operational in Uttarakhand as a priority work. Presently fieldwork in all the items of NLSM programme is in progress (Ghosh et al. 2014). Similar studies on Meso (1:10,000) and Micro (1:2000/1000) scale at specific problematic sites are also being taken up by GSI as per the requests received from the State Governments and Road Building & Maintaining Authorities.

Another major concern is the maintenance of the transportation corridors or the so called "Life Line" in hill areas. Frequent landslides along transportation lines not only result in the direct loss to properties but also indirect loss by blocking the road and rail and communication links (Jaiswal et al., 2011, Jaiswal et al. 2013). A timely forecasting of landslides along the transportation corridors and issuance of early warning to alert the traffic is extremely important for the benefit of the society.

Early warning of landslide is also important in the context of the 'residual risk'. Humans deliberately thrive in such areas and tolerate the risks because of certain inherent benefits such as running businesses, proximity to workplace, etc. Studies have shown that people residing in such areas for many generations do not want to leave their native and ancestral places in spite of having witnessed landslide disasters (Jaiswal and Westen, 2012). Under such circumstances, the only opportunity to minimize the landslide loss is to issue timely alert to the community about the impending hazard through the use of an early warning system. In India, Geological Survey of India (GSI), the Nodal Agency for landslide investigation in India' realized the importance of landslide forecasting in the aftermath of 2003 Varuna Parvat Landslide in Uttarakashi, Uttarakhand. Landslide forecasting and risk analysis is especially relevant in developing countries where spatial planning is mostly given much less attention, leading to civic and infrastructural developments in hazardous areas where landslide disasters take place. The recent research in risk quantification and threshold modeling for landslide initiation (Jaiswal and Westen 2009 and 2012) formed reasonable basis for GSI to step into a multi-disciplinary science of landslide risk reduction through early warning system (Wadhawan et al. 2013b).

2. Implementation Landslide Susceptibility Mapping Programme:

Geo-parametric data sheet for collecting information on landslide inventory and details on consequent damages is compiled and documented at national level by GSI. As a first step, it is imperative also to develop a Landslide Inventory which documents the specific spatial and temporal and other attributes of a land slide incidence in a GIS platform (Ghosh et al. 2013, 2014). Thus a georeferenced spatial database is created. GSI's endeavour in preparing such a national landslide database for the entire country in a GIS-based dynamic platform would be extremely beneficial in future and will also enable the Indian landslide scientists to work on predicting the temporal and magnitude component of such hazard. As a necessary logical follow-up implementation of NLSM is facilitated which would lead finally to research and developement of EWS at the most vulnerable selected sites in India.

Web-Based Landslide Incidence Inventory Map Service

Geological Survey of India (GSI) has developed a Web-Based Landslide Incidence Inventory Map Service where details of 281 (two hundred eighty-one) nos. of landslide incidences are currently available (as on 20/11/2014). Landslide incidence compilation and uploading in such web-based interactive platform is a dynamic exercise and needs updation on a regular basis as and when new landslides occur. In this endeavour, GSI has already taken up a Field Season Programme, the first phase of which is scheduled to be completed by September 2016. GSI primarily gathers the relevant information for this purpose from two types of sources: **i)** GSI's old landslide investigation reports through compilation, and **ii)** from the on-going landslide investigation programmes of GSI such as National Landslide Susceptibility Mapping (NLSM) Projects which is targeted to be completed by 2020 and post-monsoon field-based landslide inventory mapping programmes taken up in all the landslide-prone areas each year. To access this data, one can visit GSI Portal (**www.portal.gsi.gov.in**) and navigate to "Recent Landslide Occurrences in India" under "Interactive Maps" within "Interactive GIS Maps". Or, the following link can be used to access the Beta-version of the map service directly.

<**http://www.portal.gsi.gov.in/gismap/landslide/index.html**>

The spatial database of landslide incidences can be seen on an Indian base map with important roads, State boundaries and important places (towns, villages) marked on it. Landslide incidences are shown as point objects. Details about various attributes (maximum 41 attributes) per landslide incidence are also listed (Wadhawan et al. 2013a), which can be observed using "identify" button in an interactive GIS Map Service environment. The metadata showing such textural attributes can also be exported as "pdf".

Benefits likely to accrue as a result of this project include the following:

- Can give pan-Indian geospatial scenarios about past/ historic landslide occurrences or hazard
- Can evaluate the vulnerability and risk to roads, buildings and other physical features etc.
- Such type of GIS-based landslide inventory is easier to update, retrieve and also to spatially evaluate its relations with other geofactors such as slope, geology, land use, geomorphology etc.
- Acts as the most crucial and fundamental input to any landslide susceptibility, hazard and risk analyses

Landslide susceptibility zonation on macro scale (1:50,000) is followed to classify the landslide prone terrains of the country into different zones according to their degree of susceptibility to land sliding for perspective project planning. It is a multi-thematic exercise taking into account the relevant causal geofactors such as i) *slope morphometry* (Slope gradient, aspect, slope shape), ii) *lithology, iii) structure, iv) geomorphology, v) land use/cover, vi) geohydrology etc.* as separate causative themes and by establishing either through an expert-driven or data-driven interrelationships with different types of landslides, following a number of standard and well-established techniques (BIS, 1998; 1999; Fell et al., 2008; Ghosh et al. 2013; Sarkar et al. 2013; Sharma and Rawat, 2013) . The main objective of this susceptibility zonation is to facilitate the planners and inhabitants to understand the slope stability potential of the land parcels in an area in fragile hilly or mountainous terrains for use, development and deciding on protection measures to ameliorate the stability conditions.

However, based on the experiences of major event like that of the recent Uttarakhand disaster of June 2013, several lessons were learnt which compelled re-evaluation of the existing methodology to of conducting preparation of macro scale landslide susceptibility maps. Additional geofactors that also need to be considered in light of the initiation of numerous landslides and colossal damages in Uttarakhand event include: i) effect of toe erosion by higher order streams, ii) effects on settlements that are built on lower-level geomorphological terraces and flat lands and proximal to trunk or higher order river/ drainage systems, iii) effect of long run-outs of the debris flows, iv) nature and size of clastic components, etc.

The existing landslide susceptibility maps exhibit zones having varying degree of susceptibility (e.g., high, low, moderate, etc.) should also depict the basic information such as location of stable flat ground nearby which are to be delineated away from the river and the steep potentially failure-prone back slopes, roads/ foot tracks leading to stable higher grounds that could act as safe escape routes in the event of a landslide / debris flow/flash flood, etc. It is thus relevant that after evaluating the scientific results of the landslide susceptibility maps, a user-friendly map depicting stable and unstable slopes along with all the available road/ foot-tracks, rivers, higher order streams/ drainages etc. need also be prepared. These NLSM products are made available to the stakeholders and end-users thereby to facilitate them in planning disaster escape routes and relief and rehabilitation measures.

Earlier GSI had carried out Landslide Susceptibility Zonation of about 60,000 km2 of selected and scattered segments of the country by adopting BIS guidelines in about a decade so far out of the total requirement of about 0.49 million sq km. In the wake of Uttarakhand disaster in June 2013 and in order to expedite, GSI proposed to take up rapid assessment of the terrain to delineate vulnerable areas which can be studied in detail subsequently by following standard detailed procedures. In order to meet the immediate requirement, GSI has initiated national project "**National Landslide Susceptibility Mapping (NLSM) Programme**" on 1:50,000 scale, which was formally launched by Hon'ble Minister of Mines during inaugural function of the 53rd Central Geological Programming Board [CGPB] Meeting at New Delhi on 5th February 2014. The NLSM project aims to prepare seamless Landslide Inventory and Landslide Susceptibility maps in the mountainous areas of India on 1:50,000 scale which would act the fundamental inputs to prepare the macro scale landslide hazard and risk maps of India. It will give pan India macro scale baseline information for the first time to accurately and quantitatively assess the spatial locations of landslide prone areas in the country. It will also help in disaster preparedness of the country and to indicate areas critical for landslide monitoring and early warning. Besides it will facilitate prioritization of areas for further detailed studies (Meso- and Micro- scales) and to help in Regional Land Use Planning and to provide the scientific basis for framing the Land Use Zoning Regulations.

The NLSM project has been envisaged to be completed in six years with engagement of 70 geoscientists in GSI. A collaboration framework has already been finalized between NRSC and GSI regarding event-based landslide inventory mapping and landslide susceptibility/hazard zonation in the prioritized landslide vulnerable areas of India and integrated application of modern GIS based remote sensing data products and field surveys and processing. Standard operating procedures for NLSM have been discussed and debated amongst the stake-holders during three major regional workshops on Landslide Disaster management held in 2013-14 respectively at Shimla, Shilling and Wellington [Nilgiris] and the Brain Storming Sessions held at GSI Kolkata and presented during the 2nd Meeting of the Technical Advisory Committee [TAC] on Landslide Mitigation and Management in India held on 23rd April 2014 at Ministry of Mines, New Delhi (GSI 2013a,b & 2014). It is formulated to prepare various geofactors layers on GIS platform such as satellite based inventory data on slope aspects, curvature, elevation, landuse-landcover, geomorphology, tectonic features: Faults/ Lineaments buffer and thrust buffer, drainage buffer, upslope contributing area and field survey based data on slope forming material and its thickness, morpho-tectonic interpretation and geoscientific integration of all thematic layers for assigning appropriate weightage and risk assessment for modelling. However, any method of predicting landslide susceptibility needs validation which sometimes may be difficult in areas having no land sliding history. But in general for all NLSM programmes, quantitative validation through preparation of success and prediction rate curves, following the internationally-accepted methods proposed by Chung and Fabbri (1999) and adopted by Ghosh et al. (2011) are strongly recommended, which would also facilitate classification of raw landslide susceptibility score maps into qualitative ("High", "Moderate", "Low") landslide susceptibility maps, easily understandable by all stakeholders.

3. Vulnerability and risk assessment:

Landslide susceptibility analysis is performed utilizing modern techniques to predict spatial locations of future landslide occurrences. That mean it answers where a future landslide can occur. This requires prior knowledge about the landslides that occurred in any area. **Landslide hazard analysis uses** techniques to predict both spatially and temporally the locations of future landslide occurrences of certain magnitudes (Guzzetti et al. 2005). This means that this predictive analysis would answer where, when and how large the future landslide could take place. For landslide hazard analysis, availability of historical information on past landslides is essential.

Landslide risk analysis involves techniques to predict or estimate monetary losses caused to an element-at-risk (roads, buildings) or estimation of losses to human lives due to any landslide hazard (Sterlacchini et al. 2007). This is the ultimate aim of any landslide hazard studies and mostly be useful to planners and insurance agencies.

- However, the above analysis is extremely difficult due to non-availability of both spatial and temporal information of landslide occurrences.
- Like many landslide-prone countries, India is also having the similar problems. That is why landslide hazard and risk analysis in truest sense are rare in India.
- To remedy the above and to prepare a dynamic, and spatially-distributed national landslide repository, the Web based National Landslide Incidence Inventory project of GSI has been taken up which will ultimately prepare a comprehensive nation-wide landslide database.

Landslide Risk Management is the whole gamut of exercises in landslide studies starting from identification of a landslide-related problem, knowing its susceptibility (predictions of spatial locations), hazard (combination of spatial, temporal and magnitude predictions) and estimation of risk (loss estimation), followed by risk evaluation and process to define and implement ground-level actions towards mitigation and reduction of the risk. Therefore, GSI's endeavour in preparing such a national landslide database for the entire country on a GIS-based dynamic platform would be extremely beneficial in future and will also enable the Indian landslide scientists to work on predicting the temporal and magnitude component of such hazard.

4. Development of Early Systems in India:

GSI is already having the database structure prepared with a provision of storing as many as 41 different attributes per landslide incidences, which is currently operational and any stake-holder can access about 281 such data in GSI Portal. The web-based landslide incidence inventory will also have spatial locations of all the landslides that are being mapped in the on-going National Landslide Susceptibility Mapping (NLSM) programme of GSI which is expected to collate and map several landslides in different landslide-prone areas in the country. Collation and syntheses of such dynamic data sets will enable formulations on Early Warning Systems (EWS) including: Landslide Hazard Warning Plans, routines participation and operating procedures, monitoring using in-situ real-time monitoring devices (e.g., geophones, inclinometers, piezometers, extensometers etc.), monitoring using geodetic scanners (Terrestrial Laser Scanner). Geodetic monitoring using differential GPS systems and detailed-scale field mapping of permanent surface features using Total Station, remote monitoring systems for field measurements with automated data collection by web-enabled devices are needed for comprehensive determination of both empirical and deterministic threshold modeling of triggering factors (e.g., rainfall, earthquakes, etc.) for devising an empirical system of early warning based on triggers. Development of Early Warning System is considered to be the next higher-level step towards forecast or pre-warn the essential elements-at-risks. Therefore, the general step for developing Early Warning System is essentially to be preceded by detailed site-specific stability and hydrologic modeling, followed by sufficiently long-term monitoring of any particular landslide. Developing such site-specific landslide early warning system is mainly instrument-based, time-consuming, and costly and requires specialized knowledge on this particular subject.

The most popular method of monitoring followed so far by GSI is the time-dependent geodetic monitoring using Total Station or Differential GPS. The geodetic monitoring aided by Total Station/ GPS, facilitates understanding the kinematic behavior of the 2-D surface of any potentially failing landslide, but the same is rarely used for continuous monitoring for generating time series maps of deformation. However, monitoring of landslides in a 3-D medium requires installation of very high-end and costly instruments such as piezometers, geophones, inclinometers, etc. after geo-scientifically delineating the 3-D disposition of failure surfaces through detailed geological mapping and sub-surface exploration. Because of the complexity and high cost, the application of such multidimensional instrument-aided approach is rare barring a few (e.g. Varunabhat Landslide in Uttarakhand) to monitor three dimensionally the most conspicuous landslide in the country. However, these attempts are only warranted if locations of related elements-at-risk (e.g., large human settlement, strategic installations such as dam, power house, etc.) that cannot be relocated anywhere away from such potential landslide-prone slope.

Besides, early warning system on regional to local scale can also be developed using rainfall threshold modeling considering rainfall as the trigger for landslides in a particular area (Gabet et al., 2004; Dahal and Hasegawa, 2008; Jaiswal and van Westen, 2009; Ghosh et al., 2012). Empirical modeling using past event-based landslide data and rainfall has already been tried by GSI as pilot project in Nilgiri, which will be replicated elsewhere. However, for successful prediction and modeling following this method, past rainfall data (daily or hourly) for longer periods and complete landslide information are essential (Harp et al. 2009; Ramesh and Vasudevan, 2012), which remains to be a big constraint in many landslide-prone terrains of the country. We need to install weather monitoring equipments close to the landslide prone areas for a more realistic site specific data generation activities. Similar attempt as a R&D initiative has also been endeavoured by GSI in collaboration with Indian Meteorological Department (IMD) for Mandakini valley.

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One of the important components of landslide forecasting is the establishment of rainfall threshold value for rain-induced landslides. In 2009, GSI made an attempt to model rainfall threshold for shallow landslides in Nilgiri hills using landslide events up to 2006 (Jaiswal and Westen, 2009). The model was found accurate in forecasting 2009 landslide events in Nilgiri hills (Jaiswal et al., 2010, 2013). Taking one step ahead of the threshold model, GSI published a conceptual model and operating procedure of an early warning system after evaluating the risk perception of the community in Nilgiri hills (Jaiswal and Westen, 2012). However, the efficacy of the model is yet to be tested further in the field and in real situation. The model includes the establishment of rainfall-landslide thresholds, rainfall forecasting methods, real-time rainfall monitoring and an automated computing system for evaluation of warning. The system is essentially based on a quantitative precipitation forecast using remote sensing data and a large network of automated rain gauges to issue warning message on exceeding the threshold limits.

Recently, GSI has initiated a joint venture with Defense Terrain Research Laboratory (DTRL) and Amrita University, Kollam for automated instrumentation based monitoring of landslides in Himalayan region. The objective is to develop an early warning system for a single landslide. DTRL and Amrita University is already in advance stage of data collection for the pilot study sites in Uttarakhand and Sikkim respectively. GSI is also in advance stage of communication with Indian Meteorological Department (IMD) for rainfall threshold modeling on a catchment scale, with an aim to develop an early warning system for multiple landslides covering a large area. GSI has also launched a nationwide programme NLSP on the generation of seamless landslide susceptibility maps for the entire country on scale 1:50,000. The integrated processing of thematic data sets, modeling and final outputs will form important inputs in targeting potential hazardous areas for landslide monitoring and development of an early warning system.

5. Conclusions:

As per the National Disaster Management Act 2005, the Union Government (National Disaster Management Authority, NDMA, 2009) is engaged in strengthening nation's preparedness to prevent any hazard rather that stressing more on relief and rehabilitation. Accordingly the task of multi-scale landslide hazard zonation is an important geo-information tool to the planners and administrators to minimize such losses due to any landslide hazard. To accomplish this target, the nodal Ministry of Mines and its attached Department - the GSI embarked upon the NLSM Programme to complete macro-scale (1:50,000) landslide susceptibility mapping of the entire landslide prone areas of India in a planned manner which are likely to be completed by 2020. Standard operating procedures for NLSM have been discussed and debated amongst the stake-holders during three major regional workshops on Landslide Disaster Management held in 2013-14 respectively at Shimla, Shilling and Wellington [Nilgiris] and the Brain Storming Sessions held at GSI Kolkata (GSI 2013a,b & 2014).

GSI started working on NLSM programme with effect from the Field Season 2014-15 after it was formally launched on February 05, 2014 by the Hon'ble Minister of Mines, Govt. of India. The NLSM project aims to prepare and integrate seamless Landslide

Incidence Inventory and Landslide Susceptibility Maps in the mountainous areas of India on 1:50,000 scale on GIS platform which would act the fundamental inputs to prepare the macro scale landslide hazard and risk maps of India. It will give pan India macro scale baseline information for the first time to accurately and quantitatively assess the spatial locations of landslide prone areas in the country. It will also help in disaster preparedness of the country and to indicate areas critical for landslide monitoring and developing early warning system.

Importance of landslide forecasting was realized in India in the aftermath of Varuna Parvat Landslide in Uttarakashi, Uttarakhand in 2003. Landslide forecasting and risk analysis is especially relevant in developing countries where spatial planning is given inadequate attention, leading to unscientific civic and infrastructural developments in hazardous areas. The recent multi-disciplinary and collaborative research in risk quantification and threshold modeling for landslide initiation will pave way for landslide risk reduction through development of Early Warning System (Wadhawan et al. 2013b). However, any method of predicting landslide susceptibility needs validation which sometimes may be difficult in areas having no land sliding history. Himalayan landscape is relatively young and slopes are steeper, hence causative factors triggering landslide will be more complex. Besides, slopes in the Himalayas are covered under a very different type of material which is mostly transported fluvio-glacial and slope-wash from younger geological formations. Therefore, geo-scientific considerations will play greater role in the Himalayas in Uttarkhand, Himachal and Kashmir as well as in Sikkim, Arunanchal Pradesh, Nagaland and Mizoram in addition to rainfall and meteorological parameters and will have to be factored in for evolving appropriate models for EWS. These are the areas of continuing research for developing excellent geo-information tools to enable the planners/ administrators for framing land-use zoning regulations which in turn facilitates preparation of better and safe disaster-resilient infrastructures and add to the sense of true preparedness in tackling such impending geohazards. It is reasonable to assert that EWS research and development will take off from the robust products and outcomes of the NLSM programme. EWS need also to highlight mitigation efforts / remedial measures through geotechnical and engineering solutions as suited to Indian conditions on case to case basis for optimum utilization of available resources.

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