ArcGIS BASED LANDSLIDE HAZARD MANAGEMENT ON HIGHWAYS

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Abstract

The safety of highways as well as the public commuting on these life lines is always under threat from variety of landslides, especially in mountainous regions and hence the need for an advanced and interactive Landslide Hazard Management system (LHMS). The Geographical Information System (GIS) with its advanced application/tools is being used comprehensively for identification of potential landslide areas and to frame out proper LHMS. In this paper we have discussed the role of GIS in landslide hazard management and some of the work carried out at CRRI this on LHM on highways using ArcGIS.

About the Author

Recent Photograph

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Geology from India in the year 1982 and PhD from Moscow Institute of Geology and Prospecting, Moscow, Russia in the year 1991. He was involved in R&D studies on various aspects of landslide hazard and risk assessment in Hilly terrain of India from 1982 – 1986 at Central Building Research Institute Roorkee and from 1991- till date at Central Road research Institute, New Delhi. Currently he is Chief Scientist in Geotechnical Engineering Area of Central Road Research Institute and looking after Landslide Hazard and Risk Management. He is also one of the Faculty coordinators of Post Graduate Research Programme in Engineering under Academy of Scientific and Innovative Research. He has in his credit more than 60 reports on R&D and consultancy projects. Around 100 research papers in International/National journal/conferences. A few of his articles have also been awarded as best articles. He is the member of many professional international/national bodies and technical committees.

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Introduction

The recent disaster in Uttarakhand in the month of June 2013 was a nightmare for the people of the region. Though many such disasters have been experienced before, it was the first of its kind in respect of coverage and magnitude of destruction and loss of life. Over 5000 people have been killed & property over worth 488 million dollars has been reportedly destroyed. It would take many years to fill the wide gap left after the disaster in the socio-economical, environmental & cultural harmony of the region. It has put a bright penetrating light on the wide crevasses on the disaster management platform of the area specific & country as a whole.

The heavy downpour followed by flash flood which has been the primary cause of destruction in many river valleys was not experienced first time, it has also occurred before, many times, in neighboring areas. One thing, that has stuck our attention, was the sorry state of the highways during the disaster and was the most worrisome situation. Most of the highways have been blocked, damaged or washed off due to landslides, debris flow, Rockfall & like phenomenon (Fig 1). It was one of the biggest setbacks to the state & district administration because the communication disruption has badly affected the rescue & rehabilitation works at the time of want.

The post disaster management which includes the rescue, rehabilitation & restoration are directly linked with the communication lines. If transport communication is disrupted rest of the things get disrupted automatically therefore the roads & highways are one of the primary things required not only to be properly constructed but always maintained in good health so that they don't or get least affected during any disastrous situation of a widespread nature.

A large number of landslides which have occurred in the past on various highways of the region have been recurring every time the rain falls. Starting from a small patch of slip or erosional scarp or vertical road cut, these have grown to a gigantic size. Most of these landslides repeatedly create problems during every monsoon rain. Additionally, numbers of more landslides also occur every year. During unprecedented rain as happened during 15-20 June 2013, these landslides have recurred with a considerable magnitude & damaged the road at a much needed time; a few of the examples are shown in Fig.1.

Although authorities are well aware of such troublesome landslides on highway, they often fail to prevent road from damage. Though, they do commendable job to post disaster situation and try to restore the traffic. Even the most carefully constructed roads suffer from such disasters. In this article, we try to look into the use of Geographic Information System in the management of landslide disasters on the highways to minimize the suffering & loss of the life of people & property. A few examples of CRRI shall also be worth sharing with the people & mentioned in this article.

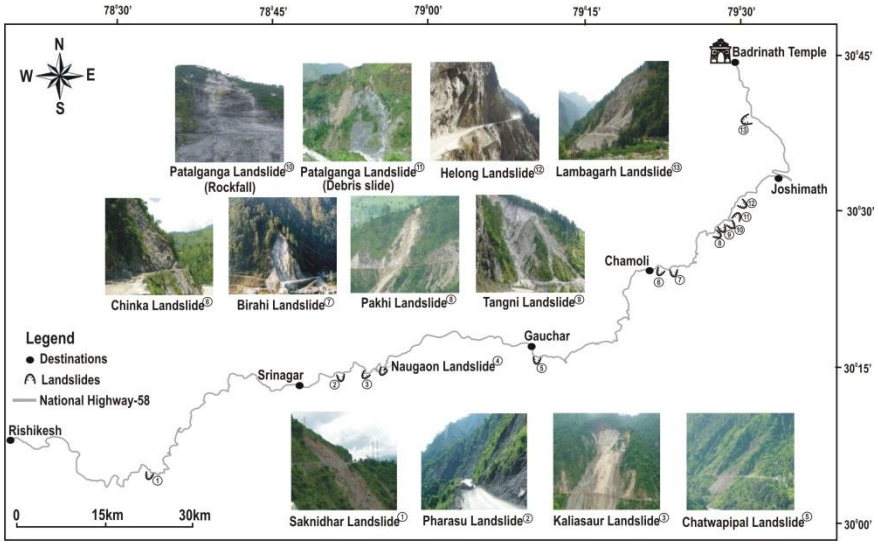

Fig 1 Locations of Landslide on National Highway 58

The proposed hazard management system

The use of GIS has become an integrated, advanced and successful tool in landslide disaster management. It is a very useful and handy tool to complement conventional methods of Landslide Disaster Management and Mitigation. It is a part of Geospatial technology involving components like remote sensing, Global Positioning System (GPS), information technologies and field based sensors that helps in capturing/storing/processing/retrieving/displaying/ disseminating information pertaining to various aspects of disaster prevention. To manage landslide hazards it is required to assess the causative factors of landslides, their intensities, areas of occurrence and their impact. With the data collection, storage and retrieval becoming highly technological and scientific, specialized techniques like GIS are extensively used in disaster management. This technology allows visualization of an emergency situation arising out of disaster, by placing the accurate physical geography of an event on a computer monitor, and then aligning other relevant features, events, conditions, or threats with that geography (http://www.cyber-swift.com/old/disaster-gis.html). GIS brings many information sources into one focus, prioritize the elements based on the need of attention. Some may require immediate attention while other can wait some can be delegated and therefore allows decision making.

A brief of the proposed landslide management system on highways (Fig 2) is described below, in very brief, highlighting few component of the system.

Inventory and Database of Highway Network & landslides (INDA)

Deployment of geographical information system for digital inventory of highways along with existing landslides is one of the primary requirements of management plan. The ArcGIS based digital database allows an easier management of large amount of multi-scale data collected from multi-temporal studies. The database and inventory of landslides prior to any mitigation and management planning and construction of any highway infrastructure is

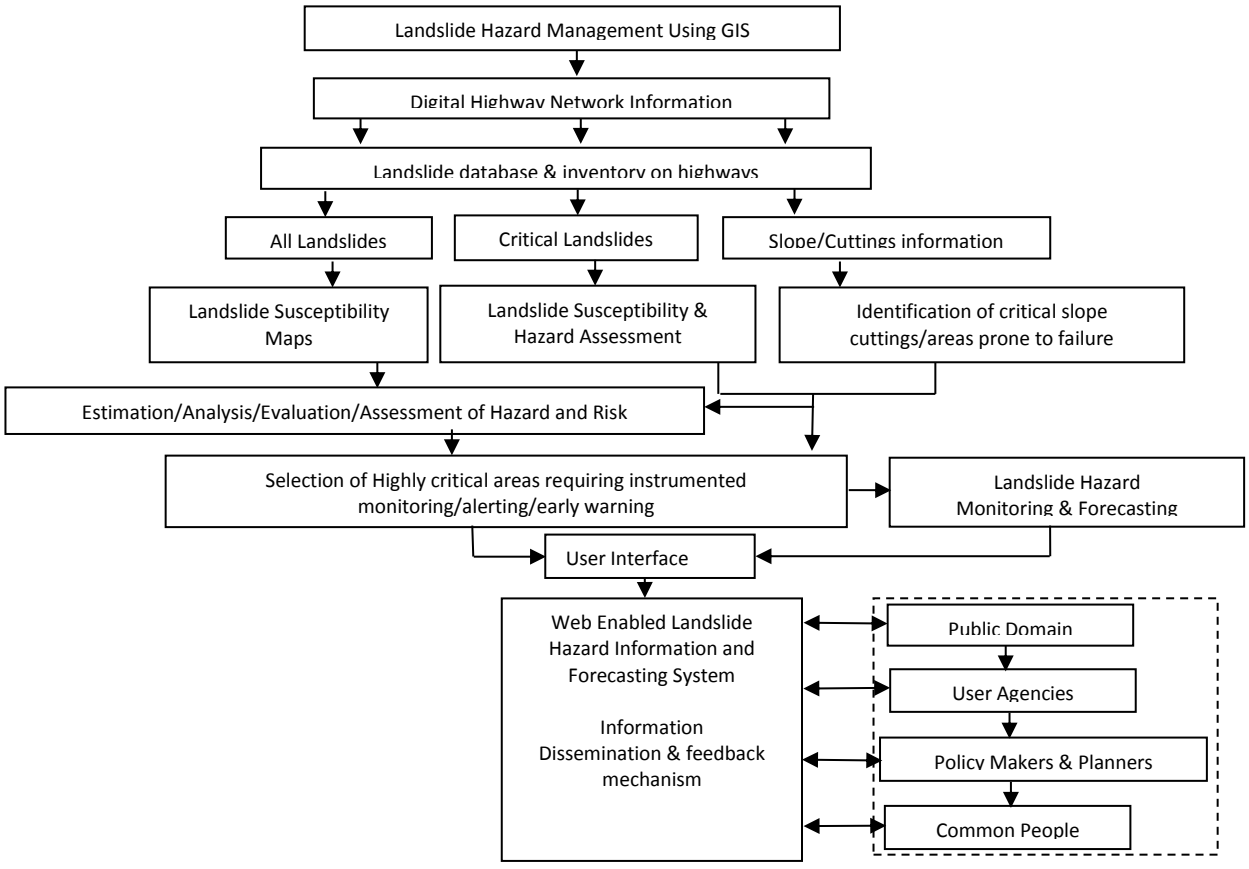

Fig 2 Landslide Hazard Management Plan Using GIS Application

prerequisite because the area under consideration can be said susceptible to landslides, when the terrain conditions are comparable to those where a slide has occurred (S. Gangopadhyay et. al. 2012). Moreover, the database could be of immense help to get useful indicators for landslide hazard assessment such as frequency of landslides, runout distance, velocity etc. Therefore the first step of the management plan is to prepare an inventory of the landslides along with the network of the highways. The digital database and inventory of landslides in GIS could also be of immense use in areas of multiple hazard situations like cloudbursts, creation and beaching of artificial landslide or glacial lakes/dams and earthquakes, all leading to creation of landslides in hilly areas such as Uttarakhand. Following points indicate the level of importance of the database.

1. Modelling of the factors creating the circumstances for initiation/occurrence of cloudburst and the areas vulnerable to be affected if such hazard strikes will be valuable to minimize the consequences of the cloudburst and associated hazards like landslides and flashflood.
2. A GIS based inventory and database of such incidences where breaching of landslide dam creates number of landslides will be supportive to mark those valley zones which are having similar condition and thus favourable to develop a landslide dam on heavy precipitation.
3. GIS based seismic hazard zonation of earthquake along with database and inventory of landslide will be helpful to delineate probable risky zones for earthquake inducing landslides.

At Central Road Research Institute we have initiated a task of database creation during 2008-2009. A Relational Database Management System (RDBMS) though initially developed in Visual-Basic 6.0 as front end and MS Access as back end has been linked to the GIS for displaying and dissemination purpose. Data was collected from different agencies through their project reports. Structure of the database was designed in MS Access and data was divided into General Information, Historical, Geological, Geomorphological, Geotechnical, Hydrological, Remedial measures suggested and Remedial measures implemented. Landslide number was defined as a primary key. Data tables in the module is related in such a way that on quarrying one can view the overall information about all fields separately either project name wise or project number wise whatever way the database structure is defined. Since, the data collection is a continuous process, the module is provided with updating facility. To make the database more secure, the module is made with options of entering its login and password. In this case anybody who wishes to contribute to add data can do so after getting proper login and password from the host.

Highway Slope Information System

A GIS sustained information system for highway slope, includes details about the road cuttings and associated details (Fig 2). The planning of hill roads, unlike that of the plain area roads, should be considered in the back ground of a number of unforeseen factors and problems, which may generally arise during actual construction and even during maintenance periods. Road cuts made during construction, left untreated even requiring of preventive measures may generate slides during rains, destabilize hill or strata. There are plenty of such examples where a small erosional patch of slope left untreated got, over the time, transformed into a major landslide needing huge sum of public money to be spent only for restoration of traffic by minor preventive work during every monsoon. All these chronic landslide areas not only damage the road and other property but also threat the life of the people. The frequent and long time damage of highways also creates social unrest in the region. Road cuts may be located in thick forests, steep hill face with heavy undulations requiring excessive cross drainages etc, may be with frequent alternation of different lithologies. Besides other considerations such as to maintain the aesthetics of the hill road, the need to classify the cuts based on their vulnerability is of paramount requirement so that to avoid further development of slides for the benefit of smooth functioning of the road (S. Gangopadhyay and Kishor Kumar 2012) and the task can not be accomplished as effectively as in GIS platform as described under the section Proposed Hazard Management System. The safety of the roads therefore cannot be insured until the information about the cuts and associated feature of the slope, particularly in critical areas are known.

GIS-based System for Landslide Early Warning Index Measurement

The use of GIS, specifically ArcGIS technology in the prediction and monitoring of landslide hazard has been investigated in the last few years by geologist and geotechnical experts. The basic idea of landslide early warning system methodology is the use of Earth Observation (EO) techniques to systematically detect changes of geophysical parameters on the earth surface potentially

correlated with the landslide activation. These EO measurements are integrated in an ArcGIS environment with both the static geophysical parameters (geology, lithology, landslide inventory) and the changes measured on instrumented test sites: the collected data are then processed in automated mode by incorporating expert knowledge into a GIS-based inference engine which allows to express in a spatio-temporal way the likelihood that the detected changes are leading towards a slope instability condition (Fabio Bovenga et al 2007). The final product is a warning map capable of providing periodic warning of areas where significant surface changes on slopes susceptible to instability are taking place, i.e. a periodic cartographic representation of areas where the detected trend of surface changes may be contributing to a landslide hazard. Thus the system measures the warning index and provides a cartographic representation of the spatial distribution of this measurement.

An example of landslide monitoring and warning of Sirobagad landslide on National Highway – 58 at Km 147, which was first initiated in 1920 and since then reoccurring every monsoon season, is given here to illustrate the efforts being done in this direction. 75 numbers of special designed steel pedestals were installed in and around the landslide body and their initial spatial locations were marked with the help of Differential Global Positioning System (DGPS) on the GIS based topographic map of the slide area. The pedestals were monitored at fixed interval of time using DGPS between the years 2008 to pre monsoon 2010 by CRRI. The spatial locations of pedestals obtained at different periods were marked on the digital topographic/contour map (1:500 scale) of the area. The scrutiny of acquired data on digital map shows significant movement in the pedestals which were located near and around the crown part. Monitoring results when matched with field condition indicated surficial movement from the crown part. These results coincide with the activity of slide observed mostly from above the crown part. At that stage sufficient warning was passed to take immediate measures before the coming monsoon season.

Application of ArcGIS towards Landslide Risk Management

Landslides risk management deals with situations that occur preceding, during, and after the landslide in order to reduce or avoid the human, physical and economic losses suffered by individuals, by the society, and by the country at large. The information on prediction and warning, risk assessment or vulnerability analysis of landslide occurrence, and rehabilitation plans for each event forms Landslides management framework (Shattri Mansor et al 2004). From natural hazards point of view landslide risk; the chance of landslide to happen that, will have an impact on human objectives or properties. It is measured in terms of consequence and probability.

ArcGIS applications in landslide risk management and development planning are limited only by the amount of information available and by the imagination of the analyst. Readily available information on landslide events (e.g., previous landslide records), scientific research (papers, articles, newsletters, etc.), and hazard mapping are usually enough to conduct a GIS preliminary evaluation of the landslide hazard situation and guide development planning activities (http://www.oas.org/dsd/publications/Unit/oea66e/ch05.htm).

Use of ArcGIS to combine information on landslide, natural resources, population, and infrastructure can help planners identify less hazard-prone areas most apt for development activities, areas where further hazard evaluations are required, and areas where mitigation strategies should be prioritized. A susceptibility map for example, can give planners the location and extent of areas where heavy capital investments should be avoided and/or areas where activities less susceptible to landslide should be considered. Similarly, in landslide hazard-prone areas, use of ArcGIS to overlay hazard information with socio-economic or infrastructure data can reveal the number of people or type of infrastructure at risk.

CRRI has carried out Landslide Hazard Zonation and Landslide Susceptibility Mapping for two notorious landslides, Sirobagad and Patalganga on National Highway 58. The landslide hazard zonation of Sirobagad map was generated using Landslide Hazard Evaluation Factor (LHEF) rating scheme in ArcGIS platform. Prior to detailed field investigation a large scale digital topographic map on 1:500 scale was prepared, Thereafter the map was divided into grids measuring 45 x 45 m to individually study each grid for a realistic and accurate evaluation of stability of the slope and inferring the type of possible failure for each of the grids. The parameters such as lithology, structures, slope gradients, landuse and landcover and groundwater condition have been quantified and statistically analyzed for evaluating the landslide hazard potential of each of the grid. The landslide hazard zonation map developed indicates three levels of hazard, low, moderate and high (II, III, & IV) in the study area. Low hazard zones represent currently stable slopes whereas the maximum area is covered under the moderate degree of hazard representing the slopes that are not stable and may fail as soon as any of the triggering factors come into play. The Landslide

Hazard Zonation Map has clearly indicated the presently affected areas under high hazard. The results have been justified in the field and found worth recommendation.

Conclusion

To minimize the socio economic and environmental losses during frequent disasters, uninterrupted traffic on highways is desirable for effective and timely management. Landslides and like processes are one of the main hazards responsible for damage and disruption of the highways during disastrous situation arising out of unprecedented rains, flash floods, earthquakes etc. The use of GIS, especially ArcGIS has already become an integrated, advanced and successful tool in landslide disaster management, hence, should be made part planning, construction and maintenance of highways in hilly areas of our country.

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