A Conceptual Framework for GIS Based Web Landslide Susceptibility Information System (WebLSIS)

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Key words: Landslide, Hazard map, WebGIS, Nepal

SUMMARY

In Nepal, a combination of active seismic zone, rugged topography, fragile rocks, steep slopes, and torrential rainfalls in monsoon cause many slope failures and related problems. With the recent massive earthquake events, many landslides were triggered and many locations were left at high risk of landslides in hilly regions. A proper landslide susceptibility assessment of these areas and dissemination of these information to public is crucial step for minimizing loss of life and property in future. For the purpose, this study proposes a conceptual framework for the development of GIS based Web Landslide Susceptibility Information System (WebLSIS) for hilly regions of Nepal. The system composed of server and client part. Server part is responsible for calculation of susceptibility based on landslide inventory and various controlling factors, whereas client part will be a webpage to input landslide points and disseminate information about landslide susceptibility. It will be help in early warning of risk and will also help concerned authorities in mitigation and control strategies against future damage.

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1. INTRODUCTION

Nepal is a landlocked country located between India and Nepal in Hindu Kush Himalayan (HKH) region that resulted from Indian and Eurasian continental plate's collision (Dewey and Bird, 1970; Powell and Conaghan, 1973; Dewey *et al.*, 1989). India tectonic plate converges northward at a relative rate of 40-50 mm/yr. pushing under the Eurasian plate beneath the Himalayas (Turner *et al.*, 2013). Hence, Nepal is situated in a seismically active region. Geographically, the country shows extreme variation form northern highest mountain to southern flat lands in short distance. Moreover, combination of rugged topography, fragile rocks, steep slopes, and torrential rainfalls make the country prone to many natural disasters.

On April 25, 2015 around 11.56 am a massive 7.8MW earthquake hit just 77 kilometres northwest of the capital Kathmandu. Its epicentre was east of the district of Lamjung. Besides the hardest hit central Nepal, the adjoining areas of India, Tibet, and Bangladesh were affected and avalanches triggered on Mount Everest. Unfortunately again 18 days later, on 12 May 2015 at 12:51pm the second major earthquake happened with 7.3MW, about 40 kilometres west of Kathmandu, killing several hundred & injured. The epicentre was near the Chinese border, near the town of Namche Bazaar, in Solukhumbu District in the Sagarmatha Zone of north-eastern Nepal. Ramechhap and Dolakha are the worst hit districts. Casualties and damages also reported from Sindhupalchok. Continued aftershocks occurred in Kathmandu, Gorkha and other places throughout Nepal with short intervals for next few weeks. These earthquakes were resulted from unzipping of the lower edge of the locked portion of the Main Himalayan Thrust (MHT) thrust fault, along which the Himalayan wedge is thrust over India (Avouac *et al.*, 2015). With reported 8856 fatalities, around 23000 injured and 900000 building damaged, it is the largest and most recent destructive disaster in the region since 1934. Apart from the dense cities, the hilly areas were mostly effected where many landslides occurred, roads blocked, hills ruptured and were left fragile. As a long term effect, these unknown fragile slopes increase the risk of multi-hazard thought the hilly region of the country.

Landslide is one of the disaster that Nepal faces which takes lives and damages properties annually. It is movement of soil, mud and/or rocks downhill due to the influence of gravity. It could be big chunk or slip down and composed of mud or rocks and other debris. It usually is triggered by heavy/prolonged rainfall and tremors/shakes naturally as well as human induced activities such as deforestation, improper exaction of slopes for mining, construction or agricultural works etc. Nepal has witnessed many massive landslide loss, but economically it has lost even more in small-scale and unaccounted slope failures.

As the monsoon approaches, the chances of additional landslides will increase, as intense rain and runoff, combined with slopes that have been destabilized by the earthquake and subsequent aftershocks, will increase the chances of that steep and fragile valley slopes could fail. Moreover the increase demand of construction materials for damaged households could also exploit the natural resources like deforestation and extraction of clay soil for fire bricks which could also trigger landslides. Hills above the road had suffered cracks in the earthquake and there is likelihood of severe landslide. Roads are in also in danger of being blocked by landslide. Landslide in roads obstructs and stop the road traffic. The roadside slides are not only risky but costly in nature also, blocking the commercial works.

Hence, a proper landslide susceptibility assessment of the hilly area is a must. The accurate assessment and dissemination of the information to public could minimize loss of life and property in future. A number of researcher has analysed few scattered part of the country which are very small units. Similarly, the findings are not independent and are not included in any national or local databases. For the purpose, this paper recommends a conceptual framework for the development of GIS Based Web Landslide Susceptibility Information System (WebLSIS) for hilly regions of Nepal. The intent is to present general information regarding development and maintenance of the system which include hardware and software, data, susceptibility assessment and accuracy and update, information dissemination and application.

2. CONCEPTUAL FRAMEWORK

The basic concept of system can be understood in two parts. Being a web-based GIS system, a website is an actual visible and interactive client part which could provide input of landslide points and visualization of level of hazard in the certain area. The hidden part is server which is integrated with database and GIS system responsible for processing data from and publishing map to database. Fig. 1 shows the simple conceptual framework for the system.

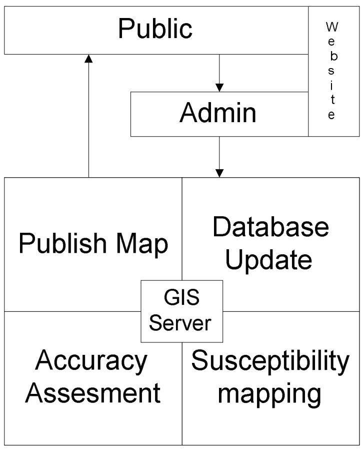

Fig. 1 Conceptual Framework for GIS Based Web Landslide Susceptibility Information System (WebLSIS).

Hardware and Software: In past decade, the computing technology has been benefited by the advancement of both hardware and software. Hardware are faster than ever and cheap. Similarly, availability of many open source computing tools due by internet community, thus large datasets are also computed easily. For the system the server requires fast processor with sufficient RAM and hard disk with interrupting power and network supply. The software components could easily be selected from various open source communities like Ubuntu server as OS, Python, WEKA, R etc. as modelling components.

Database: Database component consists of input landslide points and controlling factor layers, and output susceptibility maps. It will be maintained in the server and can be accessed and modified through website. In susceptibility mapping, past landslide events are very important input based on which susceptibility is predicted. The initial landslide inventory will be based on field observation or high resolution satellite images. The update of the landslide inventory can only be done by the admin authorities, but general public can easily suggest the point of interest. The submitted points will be added only after the admin verifies its reality. The input inventory will act as the counter to recalculate the susceptibility of the whole region if changed i.e. the model will run completely to publish new maps. The inventory will be randomly divided into 70-30 ratio for model training and validation purpose. Similarly, the possible controlling factors layers in the system will be as follows:

- Geological factors: lithology (texture, weathering), fault density, distance from faults / lineaments
- Geomorphological factors: Digital elevation Model (DEM), relative relief, slope, aspect, general curvature (plan, profile), tangential curvature, longitudinal curvature, cross-section curvature, roughness index, topographic wetness index (TWI), stream power index (SPI), stream transport index (STI) , surface area, diagonal length
- Hydrological factors: River density, distance from river
- Land use/cover factors: Land cover, NDVI, forest (type, age, diameter, and density of timber), road density, distance from road
- Soil factors: depth, inner texture, surface texture, erosion, slope, stoniness, drainage and hydraulic conductivity, permeability, porosity, effective thickness
- Triggering factors: Rainfall, Earthquake

The use of the controlling factors for the susceptibility mapping will depend on its availability and importance in the model applied. The importance of the factors could be checked using statistical tools like relief, information gain, and information gain ratio.

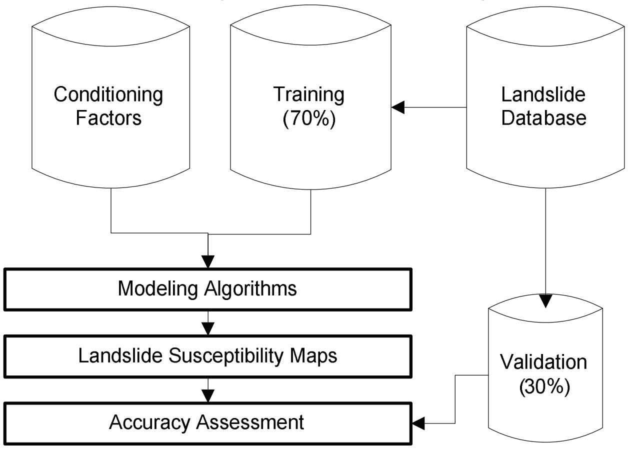

Fig. 2 Workflow of landslide susceptibility mapping and accuracy assessment.

Susceptibility Mapping: With the help of landslide inventory and various controlling factors, landslide susceptibility can be produced with good accuracy. In literature various methods has been used, but models such as logistic regression (LR), support vector machine (SVM), artificial neural network (ANN) and decision tree (DT) outperform conventional methods (Jebur *et al.*, 2014; Tien Bui *et al.*, 2015; Tien Bui *et al.*, 2012). Hence, we propose to use at least 4 models which will be trained using 70% landslide inventory and controlling factors. Each map will be go through accuracy assessment process to select final most accurate one to publish. Fig 2 shows the workflow of GIS based susceptibility mapping including accuracy assessment process.

Accuracy Assessment: The overall performance of the susceptibility models can be measured though Operating Characteristic (ROC) curve whereas the reliability of the susceptibility models was measured using the Cohen's Kappa index. Both methods are widely used in the literatures. The overview of the confusion matrix is given in table 1 based on which further statistical evaluation could be derived table 2. Upon comparison of these index, most accurate and reliable model will be published for the public.

Table 1. Overview of confusion matrix

		Observed	
		Landslide	Non-landslide
Predicted	Landslide	True Positive (TP)	False positive (FP)
	Non-landslide	False negative (FN)	True negative (TN)

Table 2. Accuracy of statistics derived from confusion matrix

Index	Equation	Description
Efficiency	(TP+TN) / N	Proportion of correctly classified observations
Positive predictive power	TP / (TP+FP)	Proportion of true positive in the total of positive predictions
Sensitivity	TP / (TP + FN)	Proportion of positive cases correctly predicted

Publish Map: Nowadays, web has been fast means of information dissemination to public due to advancement in telecommunication technology and cheap electronic devices. Thus, web based GIS has been selected for the publishing. The map could be either simply published through website or mobile app. Information provided to the public is map depicting the susceptibility index along which is further divided into various level of landslide susceptibility zones. In case of offline service, short message service based on query at specific locations indicating the susceptibility index.

Application: The main application of this web-map system is to inform public and local government regarding the potential disaster and problems. Upon regular update and maintenance, identification of trigging factors could also be identified for specific regions, which could further be helpful in relating with weather conditions. In case of disaster situation, these maps could also be used as emergency maps to find safe place and avoid further risk. These maps could be used for land use and planning tools.

3. CONCLUSION

Nepal, being one of the most vulnerable country in world, more importance should be given to make proper strategic plans to manage disaster. Landslide has always been a cause of much damage annually. And now with the massive earthquake, the landscape dynamic: especially glaciology, hydrology and ecosystems has changed, the occurrence of landslide events will be even more. Hence, analyzing data, evaluating the hazard zones and proper dissemination of information is necessary step to be taken with priority. With recent hardware, open source software, telecommunication and internet technology, susceptibility information could be easily disseminated to the general public. These results could be further used for further understanding landslide, emergency management, and land use planning. Moreover, integration of other disasters and interrelated effects could be applied to achieve a multi-hazard monitoring and early warning system.

REFERENCES

Avouac, J., Meng, L., Wei, S., Wang, T. and Ampuero, J. (2015). "Lower edge of locked Main Himalayan Thrust unzipped by the 2015 Gorkha earthquake." *Nature Geosci*, Vol. advance online publication.

Dewey, J.F., Cande, S. and Pitman, W.C. (1989). "Tectonic evolution of the India/Eurasia collision zone." *Eclogae Geologicae Helvetiae*, Vol. 82, No. 3, pp. 717-734.

Dewey, J.F. and Bird, J.M. (1970). "Mountain belts and the new global tectonics." *Journal of Geophysical Research*, Vol. 75, No. 14, pp. 2625-2647.

Jebur, M.N., Pradhan, B. and Tehrany, M.S. (2014). "Optimization of landslide conditioning factors using very high-resolution airborne laser scanning (LiDAR) data at catchment scale." *Remote Sens. Environ.*, Vol. 152, No. 0, pp. 150-165.

Powell, C.M. and Conaghan, P.J. (1973). "Plate tectonics and the Himalayas." *Earth Planet. Sci. Lett.*, Vol. 20, No. 1, pp. 1-12.

Tien Bui, D., Tuan, T., Klempe, H., Pradhan, B. and Revhaug, I. (2015). "Spatial prediction models for shallow landslide hazards: a comparative assessment of the efficacy of support vector machines, artificial neural networks, kernel logistic regression, and logistic model tree." *Landslides*, pp. 1-18.

Tien Bui, D., Pradhan, B., Lofman, O. and Revhaug, I. (2012). "Landslide Susceptibility Assessment in Vietnam Using Support Vector Machines, Decision Tree, and Naïve Bayes Models." *Mathematical Problems in Engineering*, Vol. 2012, pp. 26.

Turner, B., Jenkins, J., Turner, R., Parker, A.L., Sinclair, A., Davies, S., Hayes, G.P., Villaseñor, A., Dart, R.L. and Tarr, A.C. (2013). *Seismicity of the Earth 1900–2010 Himalaya and Vicinity*, US Geological Survey.

BIOGRAPHICAL NOTES

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