Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Natural Hazards and Earth System Sciences
Open Access
Discussions

An Offline-Online WebGIS Android Application for Fast Data Acquisition of Landslide Hazard and Risk

Roya Olyazadeh [1], Karen Sudmeier-Rieux [1], Michel Jaboyedoff [1], Marc-Henri Derron [1], and Sanjaya Devkota [2]

[1] University of Lausanne, ISTE - Institut des Sciences de la Terre, Faculté des géosciences et de l'environnement, Lausanne, Switzerland,
[2] Department of Civil Engineering, Institute of Engineering, Tribhuvan University, Kathmandu, Nepal

Correspondence to: Roya Olyazadeh (Roya.Olyazadeh@unil.ch)

Abstract. Regional landslide assessments and mapping have been effectively pursued by research institutions, national and local governments, NGOs and different stakeholders for some time; and a wide range of methodologies and technologies are proposed consequently. Land-use mapping and hazard event inventories are mostly created by remote sensing data, resulting in complications subject to accessibility and terrain. However, landslide data acquisition for the field navigation can magnify the accuracy of database and analysis. Analysing hazard patterns and triggering factors can take advantage of Open Source web and mobile GIS tools for an improved ground-truthing of critical areas. This paper reviews implementation of a secure mobile-map application called ROOMA (Rapid Offline-Online Mapping Application) for the fast data collection of landslide hazard and risk. This prototype assists for quick creation of landslide inventory maps by collecting information on the type, feature, volume, date and pattern of the landslide using Open Source web-GIS technologies for instance Leaflet maps, Cordova, GeoServer, Postgis and Postgres database. This application comprises of Leaflet map coupled with satellite images as base layer, drawing tools, geolocation (using GPS and Internet), photo mapping and events clustering. All the features and information are recorded into a Geojson file in an offline version (Android) and consequently uploaded to the online mode (using all browsers) with the availability of internet. Finally, the events can be accessed and edited after approval by an administrator and then be visualized by general public. ROOMA was tested for the collection of landslides in post-earthquake Nepal and can be applied as well for all other events and hazards such as floods, avalanches, etc.

Keywords: Landslide Hazard and Risk, Landslide inventory, Post Disaster, Open Source Geospatial Software, Offline-Online Android

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Natural Hazards and Earth System Sciences
Discussions

1. Introduction

Landslides incorporate all types of mass movements on slopes (Varnes , 1984) and can be triggered by various external events such as intense rainfall, earthquakes, water-level changes, storm waves or human activities. The location, the time of event and the types of displacement can be recorded in a landslide inventory map. In this paper, we do not distinguish between “landslide map”, “landslide inventory map”, and “landslide inventory”. Landslide maps are important factors for landslide hazard and risk assessments, particularly if there is a significant number of landslides with different types, dates, volumes and trigging factors (Coe , et al., 2004). They can be produced using diverse methods however the selection of techniques relies on the size of the area, the resolution , the scale of the map, land use, land cover, soil and geomorphology (Coe , et al., 2004; Guzzetti , et al., 2006; Hungr , et al., 2014). Formulating and documenting landslide maps is essential to define landslide susceptibility, hazard and risk and to survey types, patterns, distributions, and statistics of slope failures. However developing complete landslide inventories are difficult, due to accessibility, the dynamic nature of landslides and also the time required (van Westen, et al., 2006). Conventional techniques lead to the development of landslide inventories mainly based on the visual interpretation of satellite images, assisted by field surveys. Typical issues for creating these maps include (Guzzetti, et al., 2012; van Westen, et al., 2006; Safaei, et al., 2010):

1. All methods for developing landslide inventories have long process and intensive resource.
2. Landslides are often small with high frequency of occurrence which located in remote areas and difficult to access
3. Landslides often have different characteristics which require them to be mapped and documented individually.
4. The lack of landslide documentation and databases are the main disadvantages in the evaluation of landslide hazard risk.
5. Limited damage data are available for landslides, which is why developing landslide vulnerability assessments is challenging.
6. The source of landslide inventories such as aerial photography, satellite imagery, InSAR (Interferometric Synthetic Aperture Radar) and LiDAR (Light Detection and Ranging) are expensive.

GIS for landslide susceptibility and hazards with respect to the type of data available, landslide type and potential extension have been described by several authors (van Westen, 1993; Guzzetti, 2000; Van Den Eeckhaut, et al., 2009; Carrara, et al., 1991; Dhakal, et al., 2000) . While the above authors have noted the importance of enhanced mapping, mobile-GIS offers technology for more effective ground-truthing and a rapid tool which can systematically fill a database, especially for unexperienced mappers. Currently, there is a high possibility to apply mobile-GIS including GPS and mapping tools to significantly increase data collection efficiencies.

In this paper, an offline-online application based on Geospatial Open-Source technologies (Called ROOMA : Rapid Offline-Online Mapping Application) is described to collect data on landslide events, hazard impacts and damaged infrastructure, which can be made readily accessible to authorities, stakeholders and the general public. This prototype provides a solution

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

for preparing landslide hazard maps in relation with vulnerability. Besides, the advantage of an offline technology helps to map the events, especially in rural areas where internet is not available. This prototype has following objectives:

1. An android mobile application with possibility of both Offline-Online access
2. Fast and easy acquiring and storing of data and information
3. Advanced visualization and drawing tool
4. Central database with availability by different services (mobile, PCs (Personal Computers) and standard web browser)
5. Data management improvement in hazard event mapping and storage

The paper is structured as follows. In section 2, we first present the background, principles of the different approaches for landslide inventory, and the importance of landslide inventories maps in hazard and risk assessment. We also review some GIS tools that simplify field navigation. Then, Section 3 discusses the description of mapping method, with field survey for preparation of landslide maps in relation with elements at risks. Section 4 illustrates the architecture and platform using open source geospatial technologies to map landslides by using an android application. Section 5 and 6 focus on study area and results. Finally, section 7 concludes by discussing the advantages of mobile-GIS, with the future outlook of producing landslide hazard and risk.

2. Background

Landslide risk management estimates risk options with different levels of acceptance criteria by a number of stakeholders. It includes estimations for various levels of risk, decisions on the acceptable level, recommendations and implementation of suitable control measures to reduce risk. It requires that a number of key elements to be addressed (Figure 1): Landslide inventory, susceptibility assessment, hazard assessment, risk assessment, management strategies and decision-making (Dai, et al., 2002; Fell, et al., 2005). Landslides present visible signs for reorganization, classification, and mapping in the field, completed by the interpretation of satellite imagery, aerial photography, or the topographic surface (Guzzetti, et al., 2012). There are many methodologies for landslide hazard assessment using geospatial technologies. Likewise, overviews of these methods can be seen in (van Westen, et al., 2006; van Westen, 1993; Guzzetti, 2000; Dai, et al., 2002). The classification comprises three different methodologies: 1. Qualitative 2. Semi-quantitative and 3. Quantitative. These three methods can be categorized by: 1. Landslide inventory methods 2. Heuristic methods (Ruff & Czurda, 2008; Safaei, et al., 2010; van Westen, et al., 2006) 3. Statistical methods (Huabin, et al., 2005) and 4. Deterministic methods (Hammond, et al., 1992; Zhou, et al., 2003). A disadvantage of statistical models is difficulty to prepare landslide hazard (Huabin, et al., 2005). Landslide inventories are the simplest and the most straightforward initial approach form of landslide mapping and they are the origin of most susceptibility mapping techniques (Dai, et al., 2002; Wieczorek, 1983). Landslide inventory maps can be ready by gathering historic information on different landslide events or Remote Sensing (RS) data like satellite imagery and aerial photographs together with field verification using GPS. They can be used as a source for hazard mapping as well because they show the locations of recorded landslides.

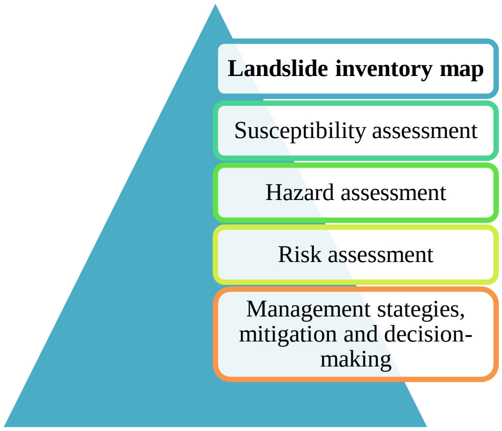

Figure 1: Landslide inventory maps are the origin for landslide hazard and risk (Dai, et al., 2002; Fell, et al., 2005)

2.1 Database

Landslide inventory data, hazard factors, and elements at risk (Figure 2) are the main three essential layers for landslide hazard and risk (van Westen, 2004). The landslide inventory is the most significant among them because it acquires the location information of landslide phenomena, types, volume, and damage (van Westen , et al., 2008). In the past years, some places have a complete historical landslide record. Some countries such as Italy (Guzzetti, 2000) , Switzerland, France, Hong Kong (Ho, 2004),Canada and Colombia have developed landslide databases and some can be accessed by internet however difficulties related to completeness in space and time is one of the drawbacks (van Westen, et al., 2006).

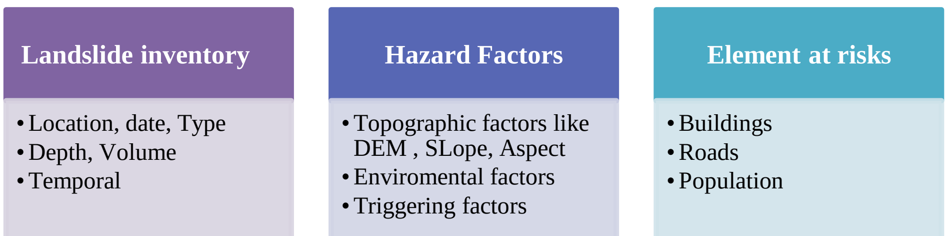

Figure 2: Database for Landslide risk assessment and management (van Westen, 2004)

2.2 Techniques of landslide data collection

Landslide inventories can be characterized by scale and the type of mapping (Guzzetti , et al., 2006). The different techniques for data collection are divided to: 1. Image interpretation 2. Semi-automated classification 3. Automated classification and 4. Field navigation including total stations, GPS and recently GIS mobile. Field works mostly are carried out to classify group of

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Natural Hazards and Earth System Sciences
Open Access
Discussions

landslides triggered by an event, acquire data about characteristics of landslides, check inventory maps prepared by other methods, and improve visual interpretation of satellite images (van Westen, et al., 2006; Safaei, et al., 2010; van Westen , et al., 2008). Figure 3 illustrates all the available techniques for the landslide data collection.

Data:	•Techniques:
Satelite imagery	•Optical , Radar,Frequency
Airbone data	•Aerial photography , LiDAR, InSAR
Exicting data	•Geodesy , land use
Field data	•GPS,Total station, Mobile mapping
Labratory testing	•Soil, rock
Real time data	•Rainfall, earthquake

Figure 3 : Overview of techniques for landslide data acquisition (van Westen, et al., 2006; Safaei, et al., 2010; van Westen , et al., 2008)

2.3 Using GIS for landslide inventory

Data obtained from field survey, laboratory, and image analysis can successfully been manipulated in the Open Source GIS and allow for graphics production, visualization, image processing, data management and spatial modelling. Many improvements in digital mapping and mobile GIS using Open-Source Geospatial technologies have been revealed in the field of data acquisition for landslide hazard and risk,. The BGS digital field mapping system (BGS-SIGMA mobile 2012) includes customises ArcMap 10 and Ms Access 2007. It is designed to capture the data in the field on rugged tablet PCs with integrated GPS units and requires Arc Editor Licence to run (BGS, 2013). Geodata implemented a mobile application that can add hazards as point markers with an attached image (GeoData, 2015). Another prototype for landslide geomorphological mapping using Geospatial Open Source software such as MapServer and Postgis was implemented in the Olvera area, Spain (Mantovani, et al., 2010). WbLSIS (Acharya, et al., 2015) is Conceptual Framework for Web-GIS Based Landslide Susceptibility. Another web-GIS tool was (Latini & Köbben, 2005) developed for landslide inventory with paper field works for landslide data collection. Temblor is a mobile application for visualizing hazard maps online anywhere (Temblor, 2016). And finally, Global disk platform by UNEP is a web-GIS platform by using open source can visualize hazard maps and some other data from so many countries (UNEP, 2014). Data available in that platform is limited. However there are few works with an option of using mobile technology for landslide field survey, there are some other works related using satellite images and mobile GIS. For example, there is a GIS mobile application for data collection of cadastre mapping using Esri and Google SDK (Bronder & Persson, 2013). Besides, Geoville has a highly-automated land cover and land use mapping solution that transforms satellite images into intelligent geo-information (Geoville, 2016). Besides, USHAHIDI can build tools to solve

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

countless data acquisition, data management, mapping, and visualization challenges using multiple sources such as mobile application, email, and twitter (USHAHIDI, 2015).

3. Methodology

Natural hazards present some of the greatest impediments to development in mountain areas. Landslides are impacted by huge number of components, for example geology, land cover, land use practices and earthquakes. Discovering number of landslides and spatial distribution is one method of creating hazard maps. Table 1 illustrates different types of information which can be collected during a field trip of mapping landslides. Landslide inventory is a primary and significant factor of the hazard assessment for qualitative and statistical analysis (van Westen, et al., 2006).

The application was developed to complement conventional remote sensing for landslide inventory creation. It is based on a prototype web and mobile GIS application including an online database to overcome some of the aforementioned problems related to landslide database development. This methodology compensates the lack of landslide inventory and precise topographic process diminishing the resources and time for storage and update. In addition, the combination of the ROOMA data collection method in the field with GPS and satellite image as source maps can significantly improve the accuracy of input field data.

Table 1. Landslide data and their characteristics in database: Landslide ID is given automatic and Landslide Name and Shape are the obligatory fields

Seq.	Field Name	Description
1	Landslide ID	Numbers of landslides
2	Landslide Name	Name of landslide
3	Shape	Point, Line, Polygon
4	Date of event	01-01-2015
5	Date of record	01-01-2015
6	Type of material	Debris, Earth, Rock
7	Type of movement	Slide, Flow , Fall , Rotational slump, Flow slide, Initiation
8	Landuse Features	Forest, Road, River, Agriculture field, House
9	Damage	Road, House, School, Forest , Communication line
10	Triggering factor	Rainfall, Earthquake, Human activity, others

11	**Reactivated?**	**Yes, NO**
12	**Presently active?**	**Yes, NO**
13	**Possible reactivation?**	**Yes, NO**
14	**Hazard Degree**	**No hazard, Low, Medium, High**
15	**Possible Evolution**	**Up, Down, Widening**

3.1 Recording not only landslide characteristics but also elements at risk

Elements at risk are the obligatory data for landslide risk assessment. Elements at risk state buildings (houses, schools and etc.), inhabitants, road networks, utilities, infrastructure and many other factors which can be at risk in an affected area. Importance is placed on data related to houses and people. Generally, data for elements at risk are collected by satellite images and result in the production of versatile databases. However for this prototype, elements at risk (Figure 4) can be recorded directly in the field along with gathering other attributes of landslide event data (Table 1). Elements at risk have different characteristics including spatial (the feature in relation to the landslide) and non-spatial like temporal (e.g. inhabitants) and thematic characteristics (e.g. material type of the buildings). Figure 4 describes different types of spatial and non-spatial data that are recorded in our database. However, the only mandatory data to be recorded is the feature and name of event, the rest of data can remain null and be filled later if necessary.

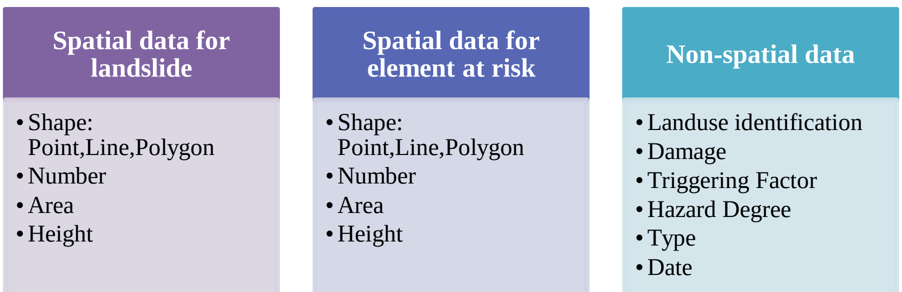

Figure 4: Database for Landslide collection information

4. Technology and Platform: Mobile GIS

Free and Open Source Geospatial Software (FOSS4G) have significantly improved the efficient mapping and management of post disaster and impacted areas around the world (UNEP, 2014; Geoville, 2016; USHAHIDI, 2015). GIS can integrate different layers of spatial data on landslide occurrence to define the effects of various parameters.

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

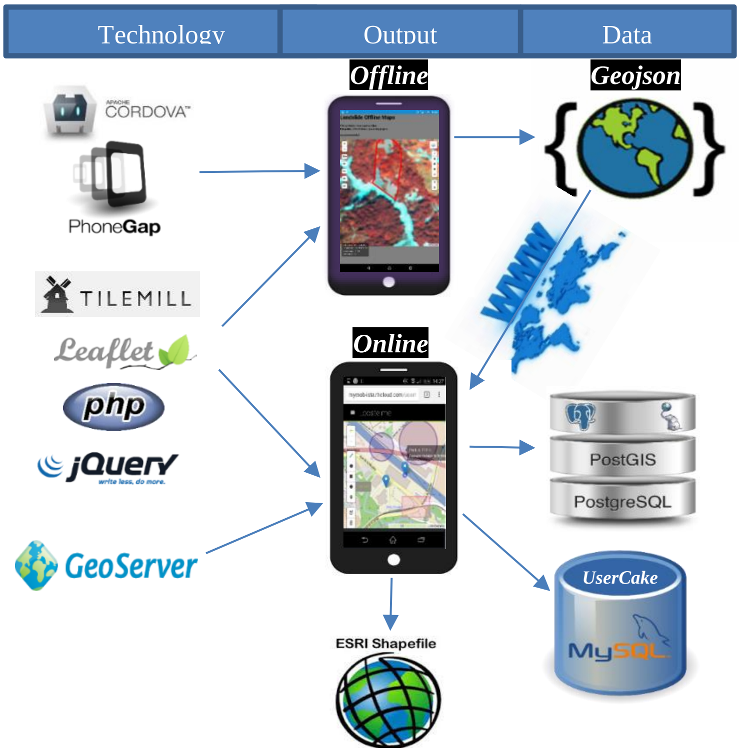

Figure 5 : Technology of ROOMA

There are new developments in Open-source geospatial technology for visualization and analysis landslide maps, including (Leaflet, 2015; BoundlessSpatial, 2016; Cordova, 2015): 1.Digital acquisition and editing tools, 2. Advanced geo-visualization, 3. Enhanced integration with satellite imagery using TileMill (Mapbox, 2016), 4. Well-organized combination with database management systems and 5. Amplification of the accuracy by using mobile GPS (Cordova, 2015).

In an inventory map, the different geometrical features (points, lines, and polygons) by different descriptive attributes e.g. type, date, activity, triggering factor and hazard degree are given in GIS format. The landslide data can be displayed using a combination of points (markers), lines and polygons. The best practice is to gather them as polygon features to have the option to calculate the area. With the help of Cordova (Cordova, 2015) and PhoneGap (PhoneGap, 2015) for android, the offline component of ROOMA was developed to simplify data collection in the field in remote areas where internet access is poor. The data can be exported to GeoJSON-TXT (GeoJSON is a format for encoding a variety of geographic data structures (GeoJSON, 2015)) files and transferred through the internet to the online component where the main database is located. This enables the collection of data from multiple data collectors to be entered into the same database. The geodatabase was designed to incorporate geospatial data acquired in the field, delivered as an input to the system (e.g., type, shape, volume, date, triggering factor, hazard degree) with elements at risk data connected to a specific event (e.g., building information, road network, damage information). The FOSS4G technologies selected to provide this module were PostgreSQL 9.4 (PostgreSQL, 2015) and Postgis 2.1 (PostGIS, 2015) for spatial database management. The GeoServer 2.6 (Geoserver, 2015) module, in

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Natural Hazards and Earth System Sciences
Open Access
Discussions

connection with Geodatabase (Postgis), is delivered for spatial analysis and visualization. This component brings a complete and up-to-date description of the different layers including a landslide event layer, elements at risk layer and detailed information of landslides in the study area including event descriptions and photo clusters. Finally, the outcomes are captured and shown through GeoServer and OGC services such as Web Map Service (WMS) and Web Feature Service (WFS) as well as being exported as shapefile format and visualized in other GIS software like ArcGIS or QGIS. MySQL database (MySQL, 2015) and UserCake library (UserCake, 2015) improve the user management and authentication. Two type of users are available in the system: Public and Administrator. Based on their privilege, they can access to different components of the online version. For example, only the administrator can define a new study area and assign it to different users. Figure 5 displays the technologies and the frameworks of this prototype.

The offline component of ROOMA (Figure 6) contains the following modules: 1. Geolocation, 2. Map with combination of multi-source base layer 3. Map drawer (Line, Polygon, Rectangle and Marker) 4. Satellite image as the base layer and 5. Saving options as Geojson-txt file in the offline mode. The mapping process is quick and easy; different features such as polygons, points or lines can be drawn on a map drawer after geolocation. Following, different satellite images as base layers assist for finding different objects on the map. However, the online component presents more modules besides map and geolocation modules: 1. Map with combination of multi-source base layer, 2. Saving online events directly to database, 3. Photo mapping, 4.Photo and event clustering, 5. User privileges 6. Data storage and analysis, 7. Import from/Export to Shape files.

The user can save or upload these features as one event and define additional characteristics such as land use, damage, trigger, possibility of hazard etc. Figure 7 and 8 illustrates how an admin can view different landslide events in the online version with the possibility of editing events.

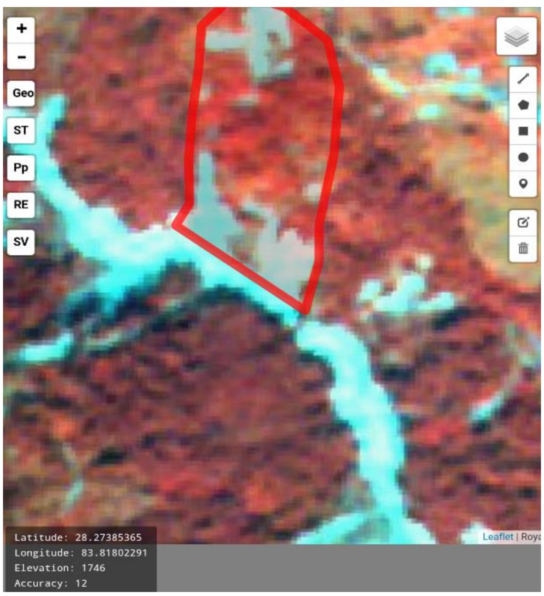

Figure 6 : Offline Component with a satellite image as a background: Geolocation (Geo), Stop Geolocation (ST), Show all the attributes in a pop up window (Pp), Reset the map (RE) Save as Geojson-TXT (SV)

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Natural Hazards and Earth System Sciences
Discussions
Open Access

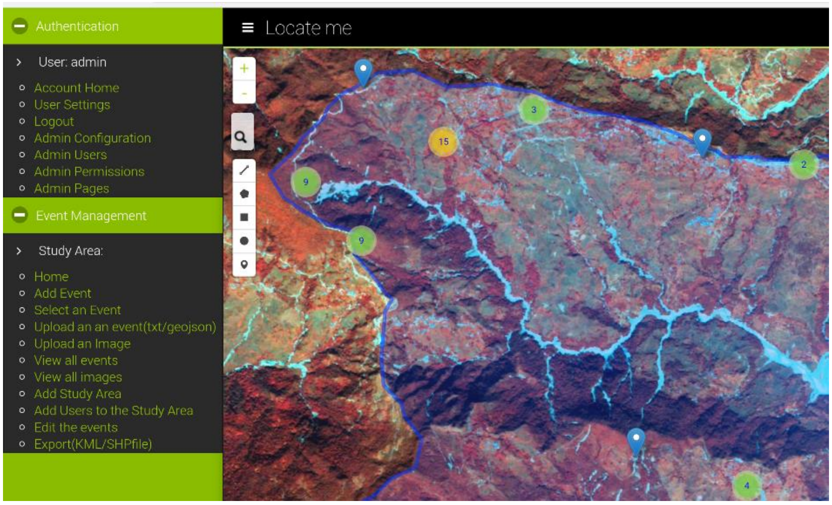

Figure 7 : Online component: User authentication and event management as an admin user: all the recorded events shown as cluster points

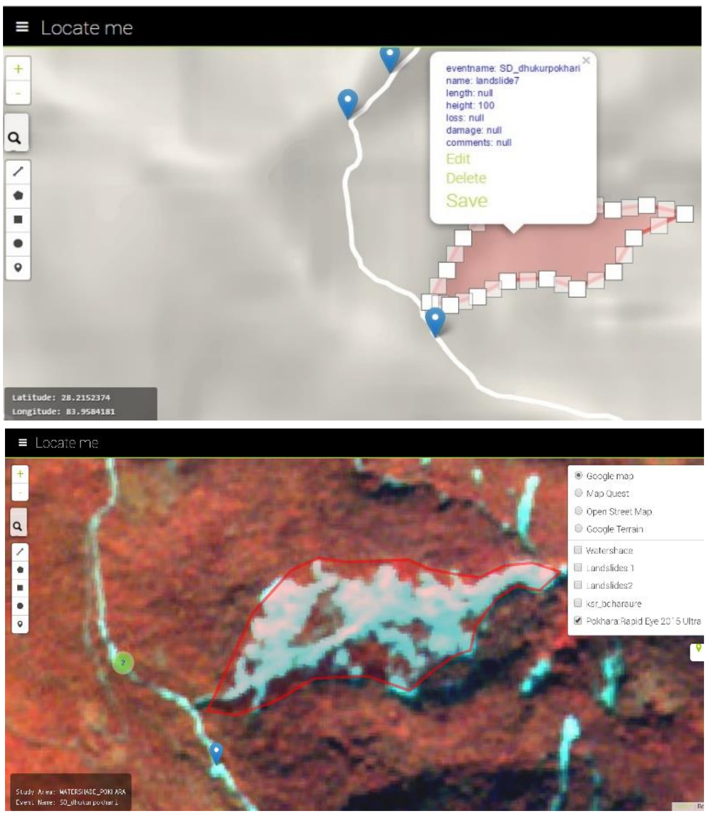

Figure 8 : Online component: A landslide event with the options of editing the feature and adding different layers as a base layer such as google map, a shape file or satellite image

5. Study area

Many landslide studies have been conducted in the Everest regions (Gupta & Saha, 2009; Bajracharya & Bajracharya, 2010; ICIMOD, 2016; Sato & Une, 2016). The 7.6 magnitude earthquake in Nepal on 25th April 2015 and a series of aftershocks significantly increased the risks of landslides (Collins & Jibson , 2015). Nepal has a high natural geological fragility which was further increased by the 2015 earthquake, which triggered several thousand landslides (ICIMOD, 2016; Collins & Jibson , 2015). The ROOMA application was tested in the Phewa Lake Watershed (123km2) in Western Nepal, Kaski District (Figure 9) where our team has been monitoring landslides since 2013. An intense rainfall event (315 mm in 4 hours) killed 9 people on 29 July 2015 in Bhadaure-5 near Pokhara and another 25 people were killed nearby Lumle in Parbat District (BBC, 2015). It was very hard to differentiate those landslides and their properties through image interpretation so the urge for field mapping was very high and the landslides have to be identified on the field whether close to the event or far. The ROOMA application was run for a rapid assessment of landslides triggered by this event or reactivated along with their land-use characteristics and damages such as houses, schools, roads, rivers, agriculture fields and forest area. (Figure 10).

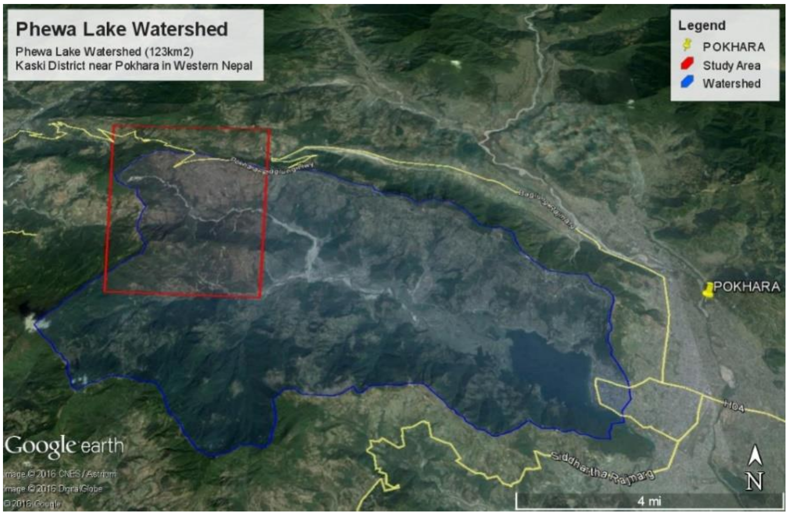

Figure 9 : Google earth image for Phewa Lake watershed, Pokhara, Nepal

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Figure 10 : Photo of the area with so many landslides near Pokhara watershed in Nepal

6. Results

To test the prototype, two days of field work were conducted in the Phewa Lake watershed, and based on medium resolution satellite image (GeoEye 2015, 5 meter resolution) added to ROOMA application, 59 landslides were mapped. The mapping of landslides (using polygons) was accompanied by data collection on land use features for each event (e.g. adjacent roads, rivers, forest, and critical infrastructure) to give better indications of surrounding features. The extreme advantage of mobile-GIS is gained in relation to the existence of landslides and determination of the frequency distribution of landslide areas. The satellite image added to the application significantly eased the exploration of this area and assisted the visual interpretation process. The data were collected on-site either close to road or from a distance which enabled easy interpretation for landslides which would have been difficult to access otherwise (Figure 11 and 12). Figure 11 represents a new landslide documented near the road that was not visible in satellite image and figure 12 shows a larger landslide which was located within a distance and it is clearly visible in image interpretation. Most of large landslides were mapped by distance. Figure 13 shows the distribution of landslides in that area where most landslides occurred in the centre.

All data were uploaded to the online version and then exported to a shape file. It was possible to perform the rest of the analysis in QGIS however it is planned to add extra modules in online version for querying, summarizing results and finally having landslide susceptibility map. Data obtained from the field survey were successfully analysed in the Open Source GIS with more detailed analysis possible such as distribution of landslide type, material, elevation, damages, surface areas and volume, graphics production, spatial modelling, and visualization of many types of data. For example, all the information about land use characteristics and their damages for different landslide were gathered separately in our database and can be useful for more detailed analysis.

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Natural Hazards and Earth System Sciences
Open Access
Discussions

Figure 11: DATA collection close to the event

Figure 12 : DATA collection by distance

Graph in figure 14 represents that a majority of the landslides occurred near forest areas and most damaged areas were related to forest, roads and agriculture.

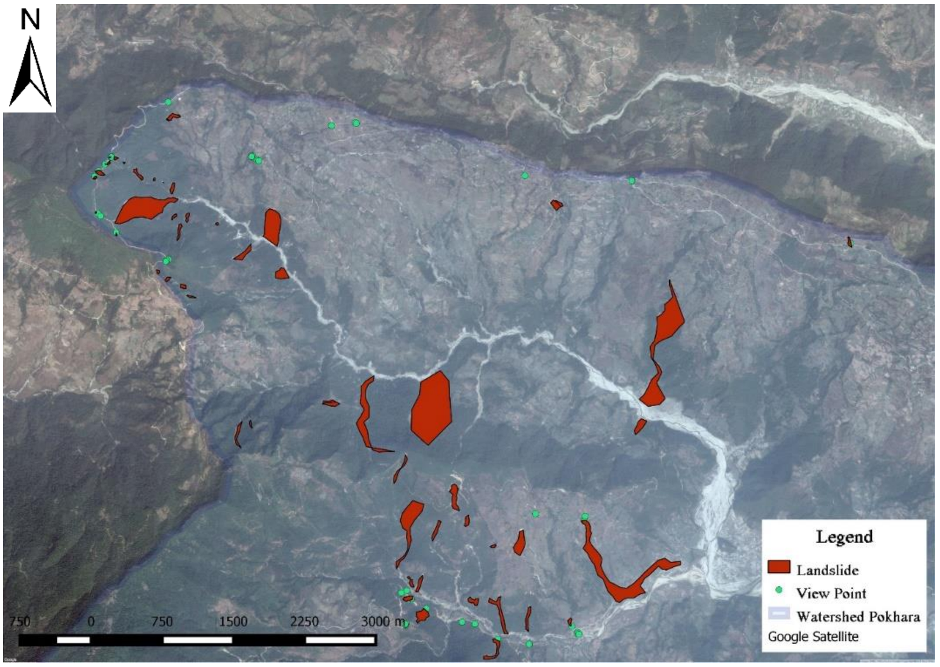

Figure 13: Distribution of landslides in Phewa Lake watershed based on the two-day data collection

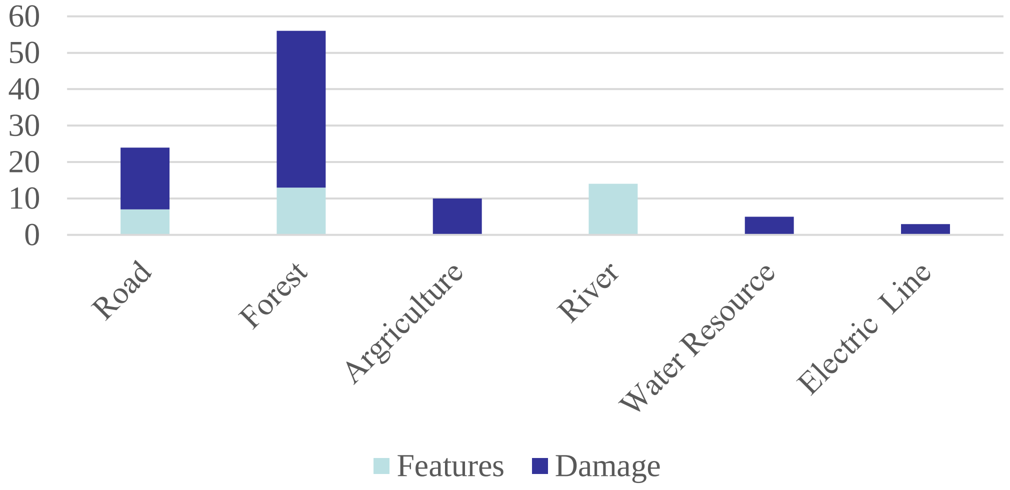

Figure 14: Relationship between features and landslides damage

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

Moreover, further analysis of land use/cover changes has been carried out based on visual interpolation on a multispectral satellite image (SPOT 2016, 2 meter resolution) acquired in 2016 after this field checking. Basically our ground truthing brought the confidence for further mapping (177 Landslides mapped afterward) of the additional smaller landslides that were not mapped during the field survey. Figure 15 shows these landslides on the map.

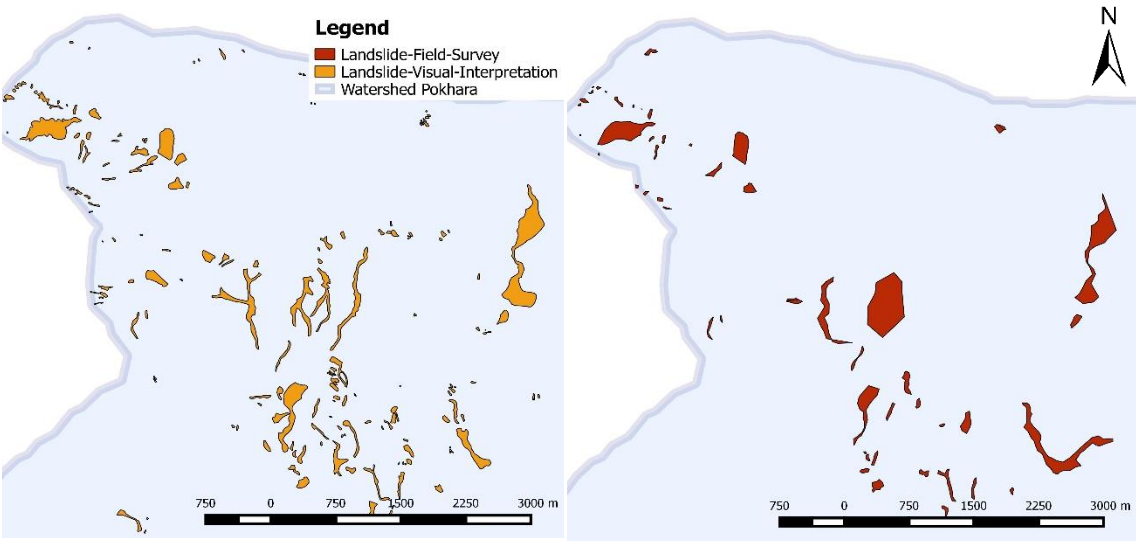

Figure 15: Maps of landslides by using field survey (red polygons) and visual interpretation (orange polygons)

The advantage of a mobile version in field over mapping using only GIS and high resolution satellite images (in office), is that some features characteristics of landslides are not visible only on images. Coupling satellite image interpretation with field observation allow to identify better the type of landslide, even using a medium resolution satellite image (~5 m). The figure 16 shows such example: the detail mapping on standard GIS permits to identify active landslides in the gullies, i.e. debris-flow and shallow landslides, while the lower resolution image coupled with field survey permits to identify a larger landslide. The landslides linked with the gullies is simply the limits of the larger one, where the activity is obvious.

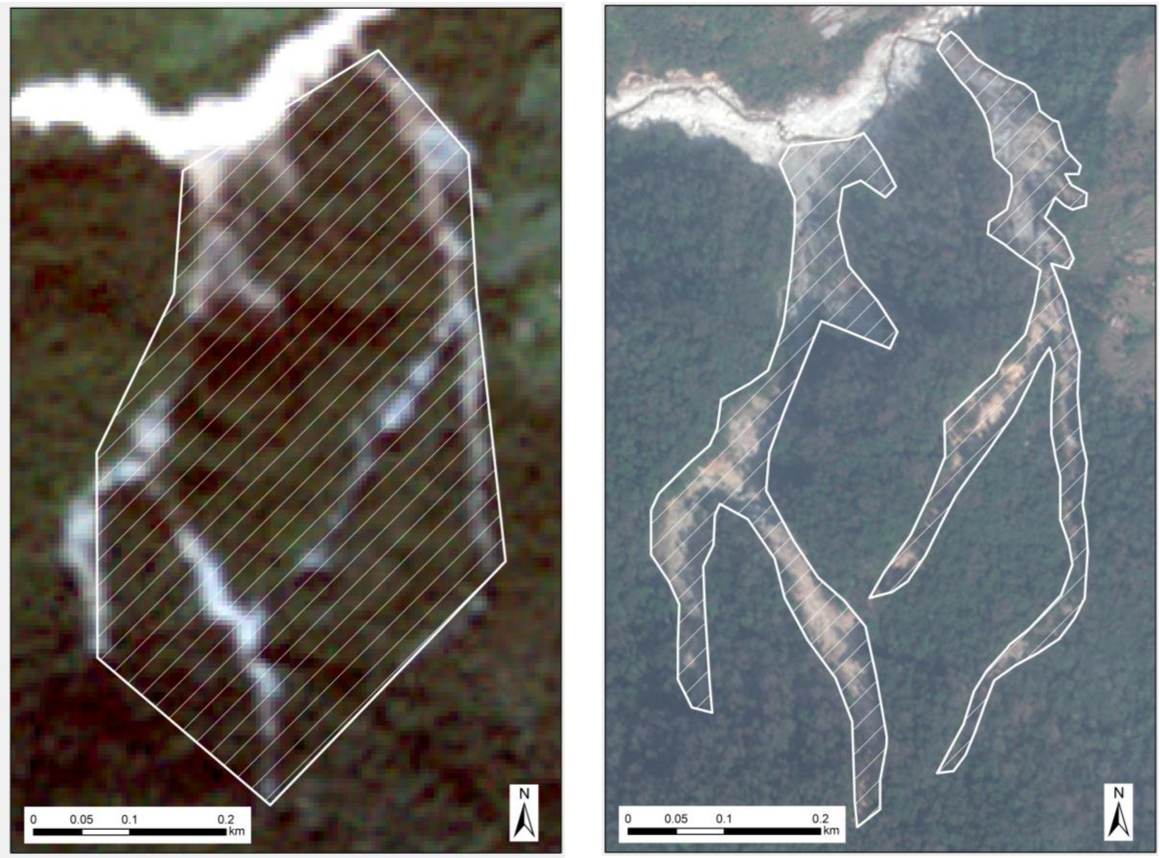

Figure 16: The map on the left shows the lower resolution image coupled with field survey and the map on right shows the same area with the detail mapping on standard GIS

7. Discussion and Conclusion

Landslide inventories define vulnerability, hazard, landslide susceptibility and risk by investigating the information on type, pattern, distribution and slope failures (Guzzetti, et al., 2012).Earlier works on landslide hazard evaluation shows that considerable developments have been accomplished in the last decade, GIS tools are now crucial for landslide hazard and risk assessments, however, the generation of landslide maps including elements at risk and an online database in a larger scale appears a stage too far especially in data poor countries having such an offline application can provide a significant technological leap and save valuable resources. The value of landslide inventories relies on the accuracy and certainty of the information which is problematic to define (discussed in introduction) however, different mapping approaches on Open Source Geospatial technologies, can significantly simplify the production of these maps. Moreover, the ability to use the Open Source software indicates that analyses can be carried out without incurring the high costs associated with software acquisition, a particular advantage for developing country, researchers and government officials.

This application incorporates rapid, economic and participatory methods for mapping landslides. It uses satellite images as multi-source map and enables multiple data collection to finally be collated in a centralized database. Data can be acquired in offline version using android device or an online mode using all browsers in Pcs, tablets and mobiles. The study was applied for mapping landslides in post-earthquake Nepal, but, it can be practical for other hazard events such as floods, avalanches, etc. Nevertheless, this offline version can be improved by adding more components for distance calculation, continuous lines sketch, recording foot paths and merging the GPS located camera with the azimuth of data to help generating 3D models of the area.

Considering all the difficulties stated in this work, a landslide mapping are typically carried out based on the experience of the expert however, by getting support of mobile GIS, this application is easy to be run by non-expert and general public as well. A combination of satellite data and web-GIS technologies brings the ideal solution for landslide hazard and risk data acquisition especially more high resolution satellite images can be available recently and sometimes freely. The paper concludes that the ROOMA tool will increase the quality of landslide maps as well as susceptibility, hazard, risk assessments, and landscape modelling and will also assist the speed for preparation of above products.

The paper accomplishes several of new improvements and future works, for example adding the topographic data DEM, spatial-temporal modelling by using landslide inventory maps. More works are needed to incorporate vulnerability components, where more attentions are needed in defining vulnerability values in order to generate risk maps. Finally, it is essential to integrate a spatial decision support systems to use such data for landslide hazard and risk assessments for both stakeholders and local authorities

Acknowledgement

We would like to thank Faculty of Geoscience at University of Lausanne and EPIC team (Ecosystems Protecting Infrastructure and Communities) for the funding of this project. We appreciate Institute of Engineering, Department of Civil Engineering at Tribhuvan University in Kathmandu, Nepal for their supports, friendship and leadership, and likewise their efforts for finishing this project. Finally, we would like to thank Professor Brian G McAdoo at Yale-NUS College in Singapore for testing the application and their helpful feedbacks and comments, which some mentioned above.

References:

Acharya, T. D., Shin, M. S. and Yoo, K. W.: A Conceptual Framework for Web-GIS Based Landslide Susceptibility (WbLSIS). Kathmandu, Nepal, 2015.

Bajracharya, B. and Bajracharya, S. R.: Landslide mapping of the Everest region using high resolution satellite images and 3d visualization, Kathmandu, Nepal: ICIMOD, 2010.

BBC: Available at: http://www.bbc.com/news/world-asia-33714147, Accessed 10 April 2016.

BGS, BGS SIGMA mobile 2013: Available at: http://www.bgs.ac.uk/research/sigma/download.html , Accessed June 2016.

Boundless Spatial: Available at: http://boundlessgeo.com/ , Accessed July 2016.

Bronder, A. and Persson, E.: Master of Science Thesis in Geoinformatics: Design, Implementation and Evaluation of a Mobile GIS Solution for a Land Registration Project in Lesotho, Stockholm, Sweden: Royal Institute of Technology (KTH), 2013.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V. and Reichenbach, P.: GIS techniques and statistical models in evaluating landslide hazard. Earth surface processes and landforms, 16, 427-445, 1991.

Coe, J.A., Godt J.W., Baum, R.L., Bucknam, R.C. and Michael, J.A: Landslide susceptibility from topography in Guatemala. In: Landslides: Evaluation and Stabilization/Glissement de Terrain: Evaluation et Stabilisation. Rio de Janeiro: Proceedings of the 9th international symposium on landslides, 69-78, 2004.

Collins, B. and Jibson, R.: Assessment of Existing and Potential Landslide Hazards Resulting from the April 25, 2015 Gorkha, Nepal Earthquake Sequence, Virginia: U.S. Geological Survey Open-File Report, 2015.

Cordova, Cordova Apache: Available at: https://cordova.apache.org/ , Accessed 15 July 2015.

Dai, F., Lee, C. and Ngai, Y.: Landslide risk assessment and management: an overview. Engineering Geology, 64, 65-87, 2002.

Dhakal, A. S., Amada, T. and Aniya, M.: Landslide hazard mapping and its evaluation using GIs: An investigation of sampling schemes for a grid-cell based quantitative method. Photogrammetric engineering and remote sensing, 66(8), 981-989, 2000.

Fell, R., Ho, K., Lacasse, S. and Leroi, E.: A framework for landslide risk assessment and management. In: Landslide Risk Management. London: Taylor and Francis Group, 3-25, 2005

GeoData, MGB-LGSD Mobile GIS Application Development Project: User's Manual – Public Application Version 1: Available at: http://gdis.denr.gov.ph/mgbpublic/help.pdf , Accessed 15 May 2016.

GeoJSON: Available at: http://geojson.org/ , Accessed 15 July 2015.

Geoserver: Available at: http://geoserver.org/ , Accessed July 2015.

Geoville: Available at: http://www.geoville.com/index.php/land_cover_mapping.html , Accessed 13 May 2016.

Gupta, R. and Saha, A. K.: Mapping debris flows in the Himalayas. Geospatial World by Geospatial Media, 2009.

Guzzetti, F.: Landslide fatalities and the evaluation of landslide risk in Italy. Engineering Geology, 58(2), 89-107, 2000.

Guzzetti, F., Reichenbach, P., Ardizzone, F., Cardinali, M. and Galli, M..: Estimating the quality of landslide susceptibility models. Geomorphology, 81, 166-184, 2006.

Guzzetti, F., Mondinia, A. C., Cardinalia, M., Fioruccia, F., Santangelo, M. and Chang, K.-T.: Landslide inventory maps: New tools for an old problem. Earth-Science Reviews, 112(1-2), p. 42–66, 2012.

Hammond, C., Prellwitz, R. and Miller, S.: Landslide hazard assessment using Monte Carlo Simulation. Christchurch, New Zealand, 1992.

Ho, K.: Keynote paper: Recent advances in geotechnology for slope stabilization and landslide mitigation—perspective from Hong Kong In: Lacerda WA et al. (ed). Rio de Janeiro, vol 2, pp 1507–1560, 2004.

Huabin, W., Gangjun, L., Weiya, X. and Gonghui, W.: GIS-based landslide hazard assessment: an overview. Progress in Physical Geography, 29(4), 548-567, 2005.

Hungr, O., Leroueil, S. and Picarelli, L.: The Varnes classification of landslide types, an update. Landslides, 11, 167-194, 2014.

ICIMOD: Available at: http://www.icimod.org/?q=22085 , Accessed 21 May 2016.

Latini, M. and Köbben, B.: A Web application for landslide inventory using data-driven SVG. In: Geo-information for disaster Management.:Springer, 1041-1054, 2005.

Leaflet: Available at: http://leafletjs.com/ , Accessed July 2015.

Mapbox TileMill. Available at: https://www.mapbox.com/tilemill/ , Accessed 10 July 2016.

Mantovani, F., Gracia, F. J., Domenico de Cosmo, P. and Suma, A.: A new approach to landslide geomorphological mapping using the Open Source software in the Olvera area (Cadiz, Spain). Landslides, 7, 69-74, 2010.

MySQL, 2015: Available at: https://www.mysql.com/ , Accessed July 2015.

PhoneGap, Adobe PhoneGap: Available at: http://phonegap.com/ , Accessed July 2015.

PostGIS, Available at: http://postgis.net/ , Accessed July 2015.

PostgreSQL: Available at: https://www.postgresql.org/, Accessed July 2015.

Ruff, M. and Czurda, K.: Landslide susceptibility analysis with a heuristic approach in the eastern Alps. Geomorphology, 98, 314-324, 2008.

Safaei, M., Omar, H., Yousof, Z. B. M. and Ghiasi, V.: Applying geospatial technology to landslide susceptibility assessment. EJGE, 15, 677-696, 2010.

Sato, H. P. and Une, H.: Detection of the 2015 Gorkha earthquake-induced landslide surface deformation in Kathmandu using InSAR images from PALSAR-2 data. Earth, Planets and Space, 68:48, 1-13, 2016.

Temblor, Earthquake damage, faults, liquefaction, landslide and seismic hazard rank for home: Available at: https://temblor.net/, Accessed 25 May 2016.

UNEP, Global Risk Data Platform 2014: Available at: https://preview.grid.unep.ch /, Accessed 15 May 2016.

UserCake Available at: http://usercake.com/ , Accessed July 2015.

USHAHIDI: Available at: https://www.ushahidi.com/ , Accessed 9 June 2016.

Van Den Eeckhaut, M. Reichenbach, P. Guzzetti, F. Rossi, M and Poesen, J.: Combined landslide inventory and susceptibility assessment based on different mapping units: an example from the Flemish Ardennes, Belgium. Nat. Hazards Earth Syst. Sci., 9, 507-521, 2009.

van Westen, C.: Application of Geographic Information Systems to Landslide Hazard Zonation., ITC, Enschede, The Netherlands: PhD Dissertation Technical University Delft. ITC Publication Number 15, 1993.

van Westen, C.: Geo-Information tools for landslide risk assessment: an overview of recent developments. Proceedings of the Ninth International Symposium on Landslides, Rio de Janeiro, Brazil, 2004.

Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-267, 2016
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Published: 29 August 2016

van Westen, C., van Asch, T. and Soeters, R.: Landslide hazard and risk zonation—why is it still so difficult?. Bulletin of Engineering Geology and the Environment, 65(2), 167-184, 2006.

van Westen, C. J., Castellanos, E. and Kuriakose, S. L.: Spatial data for landslide susceptibility, hazard, and vulnerability assessment:An overview. Engineering Geology, 102, 112-131, 2008.

Varnes, D.:Landslide hazard zonation: a review of principles and practice., Paris: United Nations International, 1984.

Wieczorek, G.: Preparing a detailed landslide-inventory map for hazard evaluation and reduction. Bulletin of the Association of Engineering Geologists, 21(3), 337-342, 1983.

Zhou, G., Esaki, T., Mitani, Y., Xie, M. and Mori, J.: Spatial probabilistic modelling of slope failure using an integrated GIS Monte Carlo simulation approach. Engineering Geology, 68(3-4), 373-386, 2003.