

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

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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 and selected results 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 (LIMs) 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-txt 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.

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Keywords: Landslide Hazard and Risk, Landslide inventory, Post Disaster, Free and Open Source Software for Geoinformatics (FOSS4G), Offline-Online Android

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 (LIM). ~~In this paper, “landslide map”, “landslide inventory map”, and “landslide inventory” are used as synonyms. Landslide maps~~ LIMs are important factors for hazard and risk assessments, particularly if there is a significant number of landslides with different types, dates, volumes and triggering 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 landslides 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 are resource intensive and time consuming”~~ (van Westen, et al., 2006).
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 efficiencies in data collection ~~such as location accuracy, detailed information of features.~~

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 freely accessible to authorities, stakeholders and the general public. Besides, ~~the preliminary result of this~~

application is also compared to the results of satellite image interpolation. 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
- 5 3. Advanced visualization using satellite images 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 using new technologies such Postgis and Geoserver.

The paper is structured as follows. In section 2, we first present the background, the importance of landslide inventories maps in hazard and risk assessment and principles of the different approaches for landslide inventory. 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 LIMs 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 data on landslide.

2. Background

Landslide risk management estimates risk options with different levels of acceptance criteria. 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; Soeters & van Westen, 1996). The classification comprises three different methodologies: 1. Qualitative 2. Semi quantitative and 3. Quantitative. The classification methods can be categorized by: 1. Landslide inventory methods (Soeters & van Westen, 1996; Sumaryono, et al., 2014; Galli, et al., 2008). 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 mapping and they are the origin and the significant factor of most susceptibility mapping techniques and hazard assessment for qualitative and statistical analysis because they show the locations of recorded landslides.

(Dai, et al., 2002; Wiczorek, 1983; van Westen, et al., 2006). LIMs 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 are different purpose to prepare LIMs, such as location and the type of landslides, showing the effect of landslide triggering events like earthquake or intense rainfall and information for landslide susceptibility (Galli , et al., 2008) and they are different techniques to prepare them including Landslide distribution analysis, landslide activity analysis and landslide density analysis (Soeters & van Westen, 1996). Besides they can be used as a source for hazard mapping because they show the locations of recorded landslides.

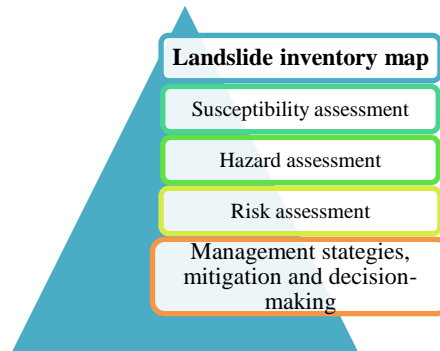


Figure 1: Landslide inventory maps are the origin for landslide hazard and risk (Dai, et al., 2002; Fell, et al., 2005)

2.1 ~~Techniques of~~ Landslide data collection

Data collection includes office and field studies and involve different activities ranging from low cost to expensive (Soeters & van Westen, 1996). 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 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). Landslide inventories can be characterized by scale and the type of mapping (Guzzetti , et al., 2006) and they 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 (Soeters & van Westen, 1996). Some examples of different methods using RS, LIDAR and comparisons on inventory maps can be found in: (Pirasteh & Li , 2016; Galli , et al., 2008). Figure 2 illustrates all the available techniques for the landslide data. 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).

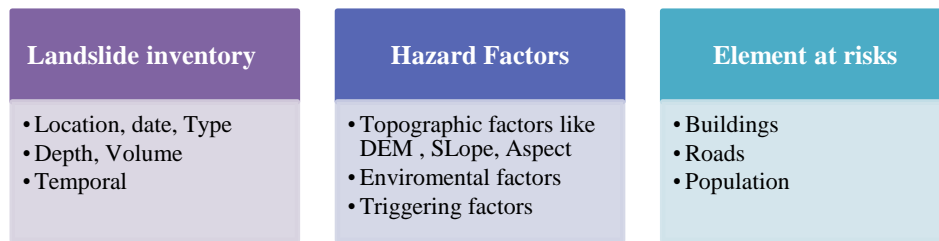


Figure 2: Database for Landslide risk assessment and management (van Westen, 2004)

2.2 Mobile and web GIS for landslide inventory

5 ~~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 customised of two toolbars for mobile and desktop. The mobile toolbar is

10 to capture the data in the field on rugged tablet PCs with integrated GPS units and desktop toolbar focuses on data interrogation, data interpretation and the generation of finalised data. This is a free software however it 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). This application runs on desktop

15 and focus more on data management system and visualisation of data. WbLSIS (Acharya, et al., 2015) is a desktop conceptual framework for Web-GIS Based Landslide Susceptibility for Nepal with emphasis on data management system. 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 the purpose of 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

20 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. There is a GIS mobile application for data collection of cadastre (cadaster) 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). And USHAHIDI can build tools to solve countless data acquisition,

25 data management, mapping, and visualization challenges using multiple sources such as mobile application, email, and twitter (USHAHIDI, 2015). All the above mentioned works have some disadvantages for our study such as: licence code which means it is not free (BGS, 2013), limited drawing tools (GeoData, 2015) just using point markers, desktop GIS (Mantovani, et al., 2010; Acharya, et al., 2015), paper-field works (Temblor, 2016), and limited to visualization and data (UNEP, 2014). They are different works in mobile GIS and data collection; however, the possibility for having an open-source- mobile

application, with an added satellite image in offline mode, precise mobile GPS, easy and fast drawing tools, advance visualization, and database management system, for landslide data collection is quite necessary.

3. Methodology

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 inventories and precise topographic process, and decreases the resources and time needed 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 and quality of input field data. The satellite image added to the application significantly eased the exploration of this area and assisted the visual interpretation process.

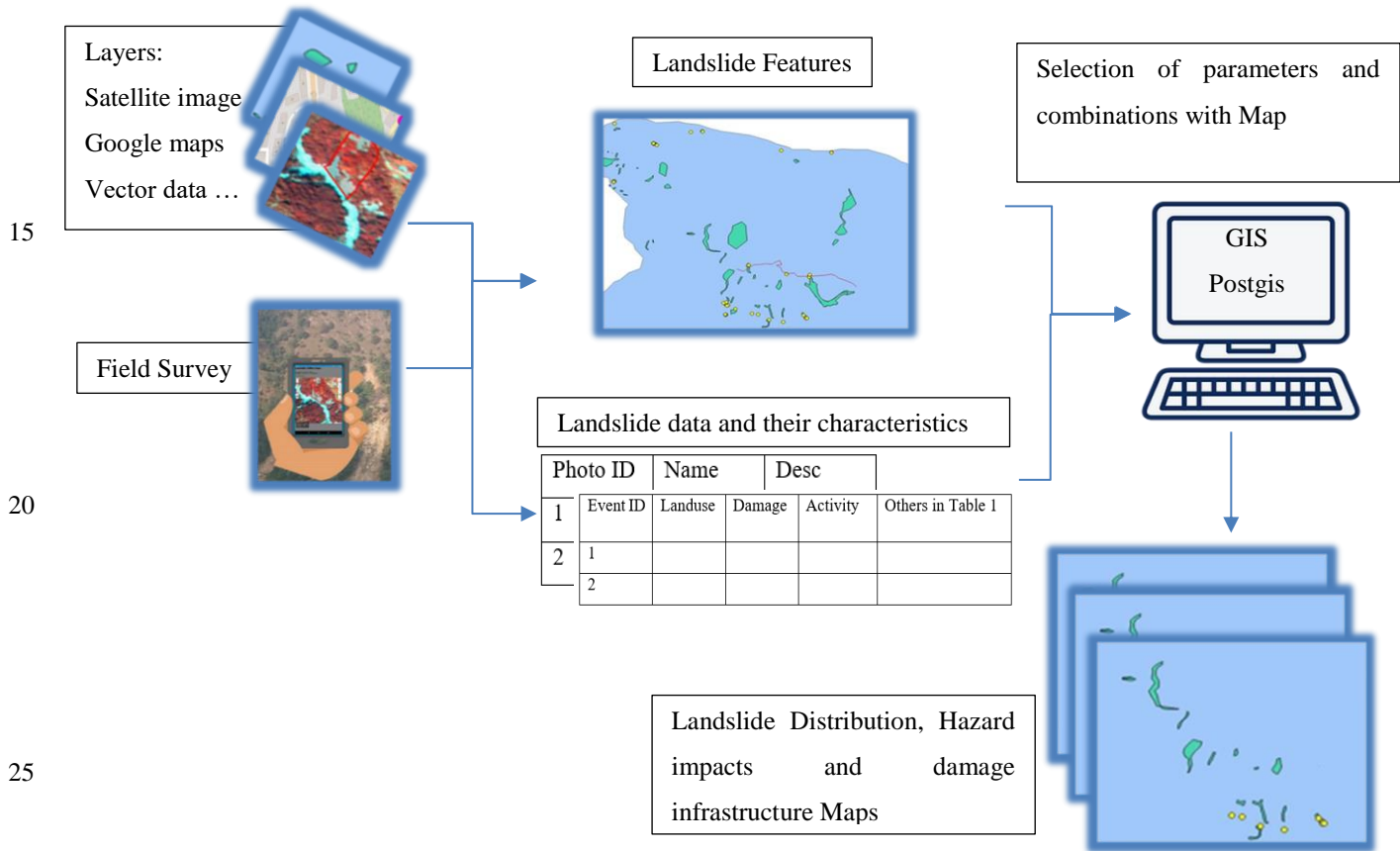


Figure 3: Workflow of ROOMA

Natural hazards present some of the greatest impediments for development in mountain areas. Landslides are impacted by huge number of components, for example geology, land cover, land use practices and earthquakes. Table 1 illustrates different types of information which can be collected during a field trip of mapping landslides in this prototype. Discovering number of landslides and spatial distribution is one method of creating landslide inventory. Figure 3 demonstrates the workflow of this method. Coupled image interpolation with field survey leads to a complete database of landslide data and their characteristics. Then different maps of landslide distribution, hazard, and damage infrastructure can be produced by manipulation in GIS,.

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	Land use 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

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 commonly placed on data related to houses and people; though in this work, emphasis is given to buildings, road networks and infrastructure. 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 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). Saving land-use features among with event data in the field (Element at risk which are damaged or not) is another advantage of this application compared to those mentioned in the background.

Figure 4 demonstrates different types of spatial and non-spatial data that are recorded in the data model of ROOMA. 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. Upon the creation of a new study area in the online platform, a new database and schema are created dynamically to store all the events related to that study area. Each study area has many “event” tables which can record information on landslides and the view-points (as Geometry POINT) where this event is mapped. Each event is associated with different feature tables (feature_polygon, feature_line or feature_point table) and “photo” tables that can represent landslides, damage (Element at Risk), and photos. The data in these tables are automatically created from Geojson-txt files which have been uploaded into online version of ROOMA. This data model made it easy to query on and analyse data based on each study area. The study area for this project is explained in chapter 5.

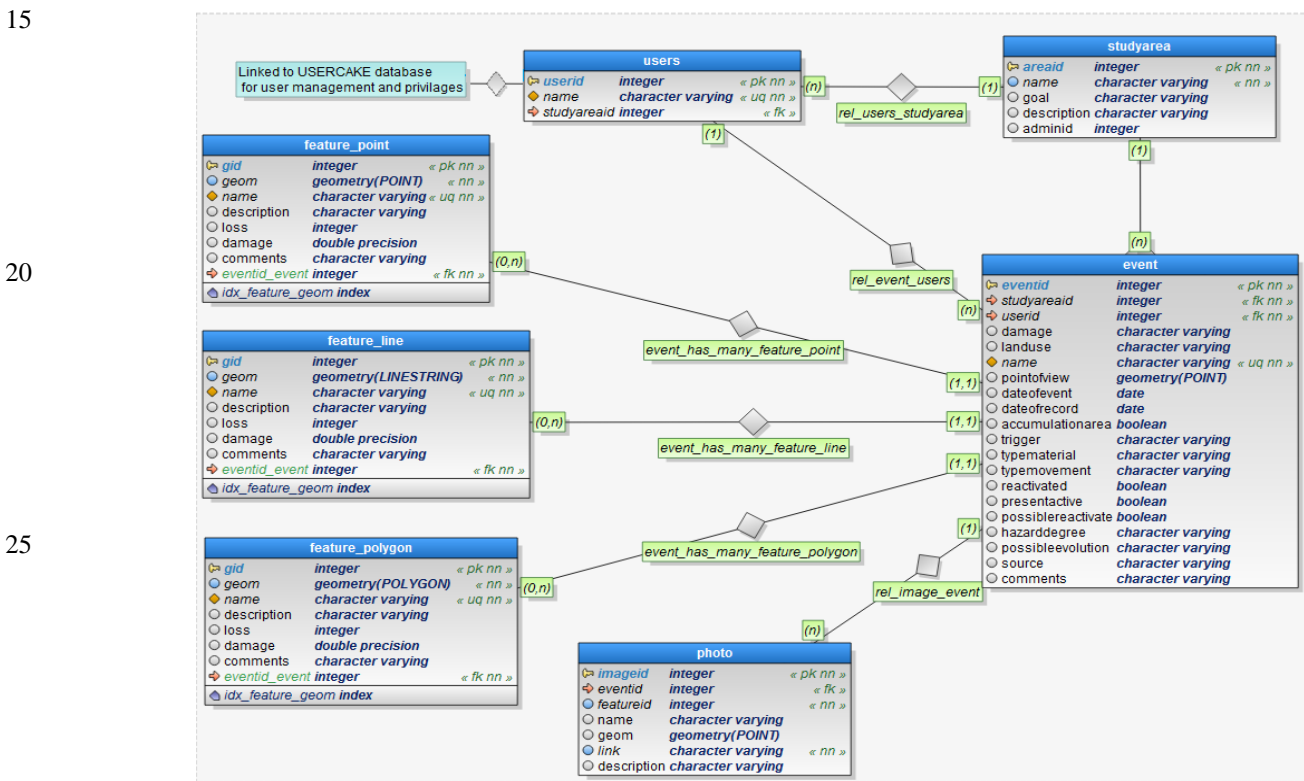


Figure 4 Data model of ROOMA: The database automatically created from Geojson-txt files which have been uploaded into online version of ROOMA.

4. Technology and Platform: Mobile GIS

Free and Open Source Software for Geoinformatics (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.

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

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Figure 5 : Technology of ROOMA

The satellite images are transferred to Tiles using TILEMILL (Mapbox, 2016) and added to Leaflet map library. The client-side is using jQuery and leaflet library together with offline and online versions. The different geometrical features (points, lines, and polygons) for landslide data by different descriptive attributes e.g. type, date, activity, triggering factor and hazard degree are given in GIS format called GeoJSON (GeoJSON, 2015) using Leaflet map (GeoJSON is a format for encoding a variety of geographic data structures which is similar to Keyhole Markup Language (KML) format). Server-side is taking

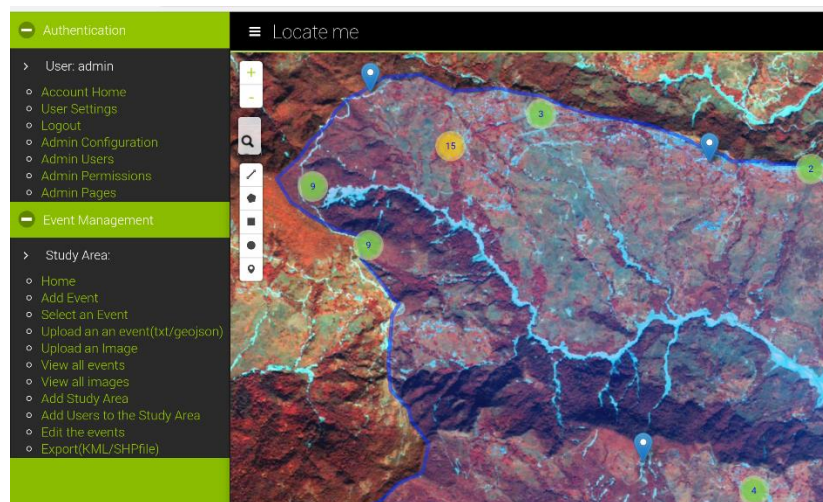
advantages of PHP which transfers the data to database and helps to save the output of Leaflet map in GeoJSON. ~~The best practice is to gather features as polygon features to have the option to calculate the area.~~ With the help of Cordova (Cordova, 2015) and PhoneGap (PhoneGap, 2015) for android (~~Android environment based on JavaScript~~) the offline android component of ROOMA is implemented to simplify data collection in the field in remote areas where internet access is poor. The data can be exported to GeoJSON-TXT files and ~~uploaded~~ 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) ~~in relation~~ with elements at risk data (~~Land-use features : e.g., building information, road network, damage information~~) connected to a specific event . The FOSS4G technologies ~~were~~ 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 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 mapping ~~if any georeferenced photos uploaded to the online version.~~ 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 privileges, 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 (~~OpenStreetMap, Satellite image, vector data can be seen in figure 8~~) 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 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 (Figure 7 and 8): 1.Saving online events directly to database, 2. Photo mapping, 3.Photo and event clustering, 4. User privileges 5. Data storage and analysis, 6. Import from/Export to Shape files.

The user can save or upload these features as one event and define additional characteristics ~~as mentioned in table 1 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 ~~different base layers and editing events directly into the online database.~~



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)



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

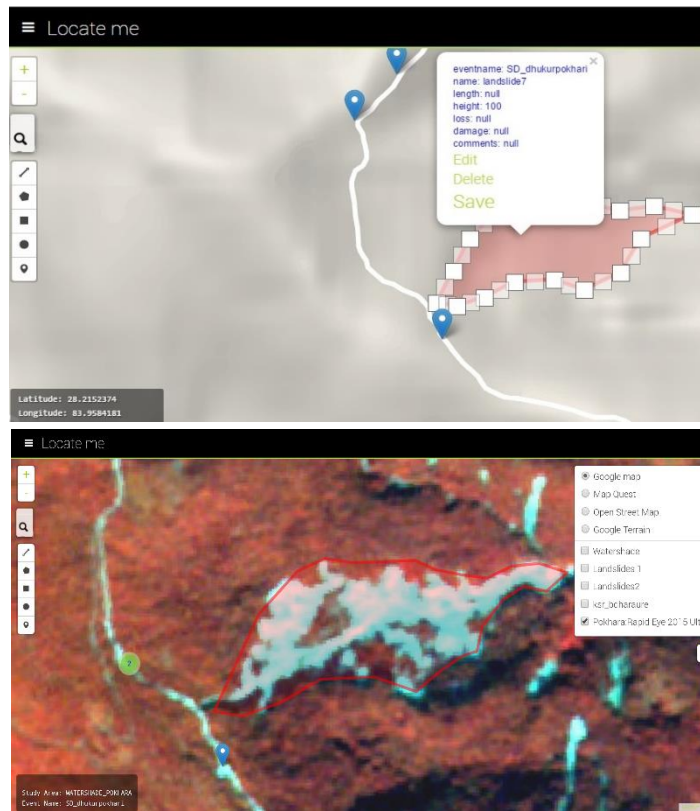


Figure 8 : Online component: A landslide event with the options of editing the feature **directly into the online database and adding different layers as base layer such as google map, a shape file or satellite images**

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).

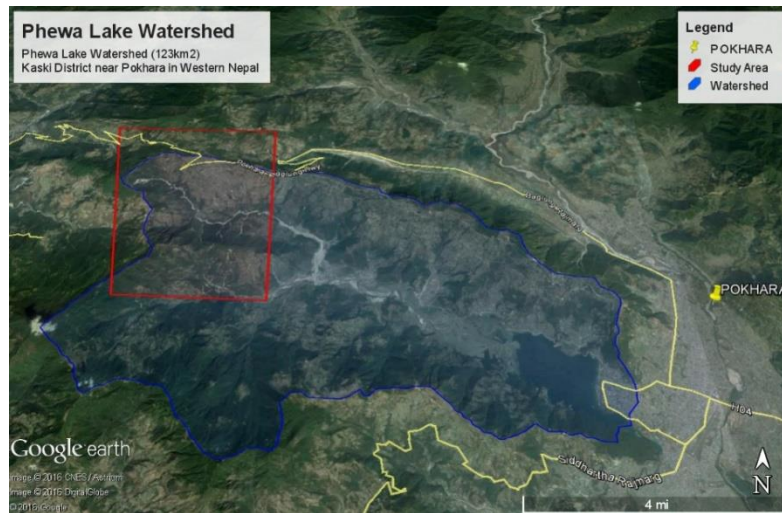


Figure 9 : Google earth image for Phewa Lake watershed, Pokhara, Nepal



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. roads, rivers and forests)** 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 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.

- 5 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 was performed 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. **In this work, we**
- 10 **present some selected results.** 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. 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.

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Figure 11: DATA collection close to the event

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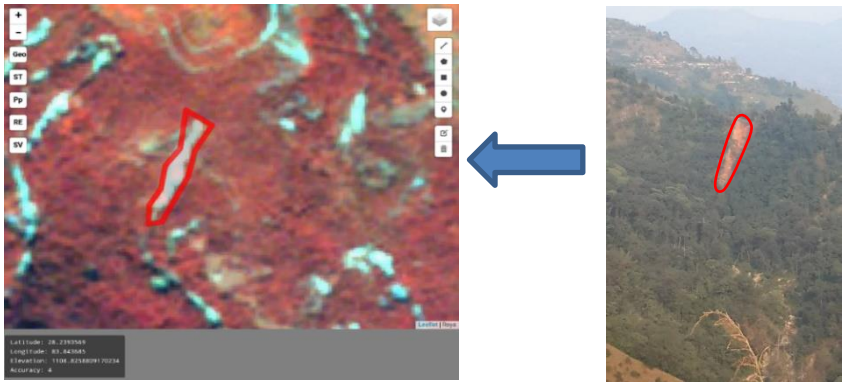


Figure 12 : DATA collection by distance

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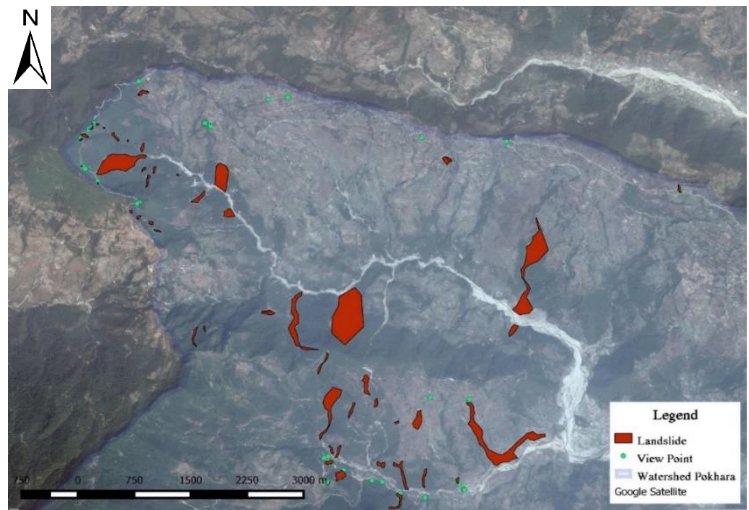


Figure 13: Distribution of landslides in Phewa Lake watershed based on the two-day data collection

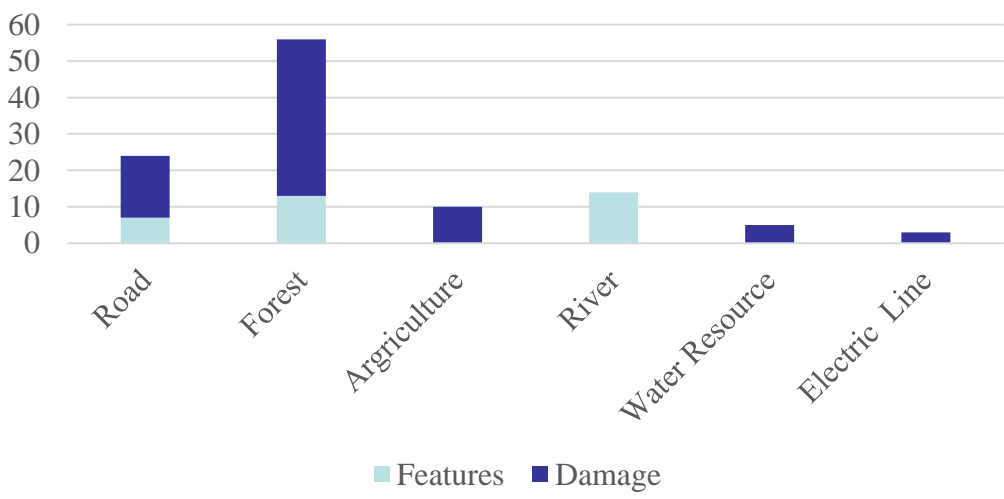


Figure 14: Relationship between features and landslides damage

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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.

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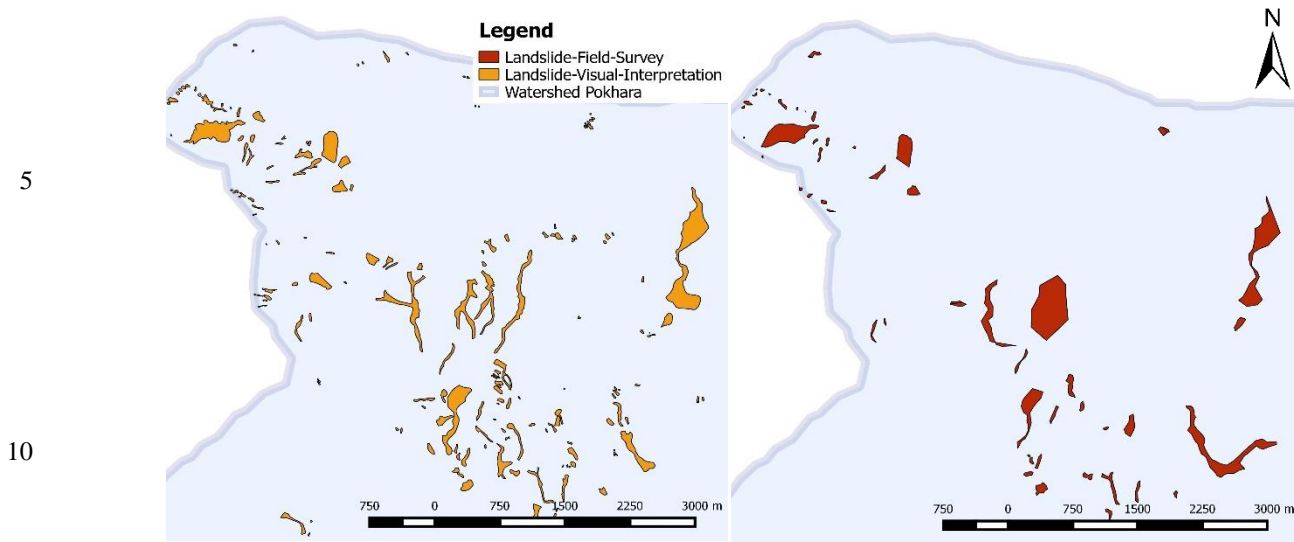


Figure 15: Maps of landslides by using field survey (red polygons) and visual interpretation (orange polygons)

15 The advantage of a mobile version with field survey compared to a mapping using only GIS and high resolution satellite images (in office) is that some feature characteristics of landslides are not visible on satellite images; therefore, coupling satellite image interpretation with field observation allows one to identify better the type of landslide even using a medium resolution satellite image (~5 m). Figure 16 shows such an example that 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

20 survey permits to identify a larger landslide. The landslides linked with the gullies are simply the limit of the larger one, where the activity is obvious. **This result can definitely show that using this platform will raise the quality of LIMs including susceptibility and hazard maps.**

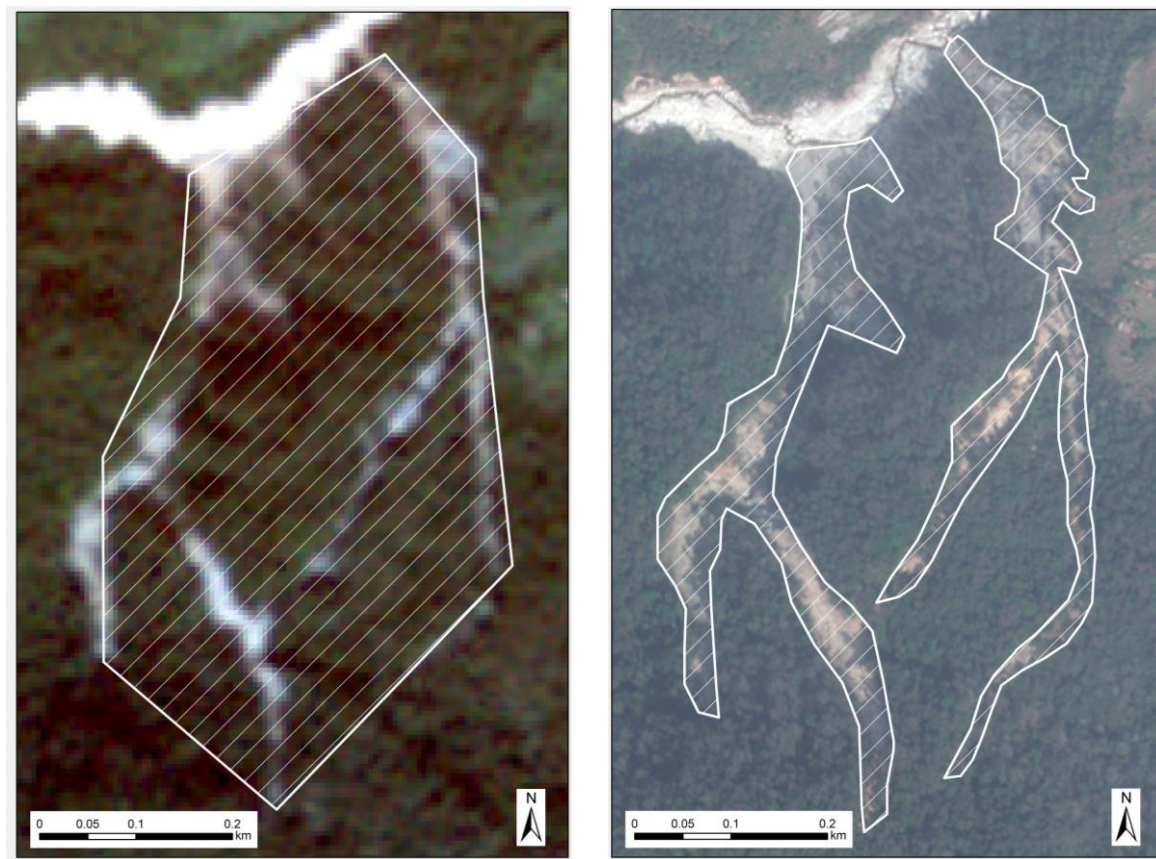


Figure 16: The map on the left shows the lower resolution image coupled with field survey and the map on right shows the same area with the detail mapping on standard GIS

7. Concluding remarks and discussions

- 5 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 assessments, however, the generation of **landslide inventory maps (LIMs)** 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
- 10 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. Furthermore, 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.

5 The result has been compared to the same study done in the office using image interpolation, and it shows that coupled field mapping with satellite image can improve the quality of landslide hazard and risk. Other institutes and universities were provided with the latest version for their work and tests and some feedbacks and comments were made by them for the future version; thus, 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
10 the area.

Considering all the difficulties stated in this work, mapping a landslide is 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
15 ROOMA tool will increase the quality of LIMs 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 (LIMs). 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
20 essential to integrate a spatial decision support systems to use such data for landslide hazard and risk assessments for both stakeholders and local authorities.

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