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A Conceptual framework for web-based Nepalese landslide information system

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Abstract. Comprehensive and sustainable landslide management, including identification of landslide susceptible areas, requires a lot of organisations and people to collaborate efficiently. Often, landslide management efforts are made after major triggering events only, such as hazard mitigations that applied after the 2015 Gorkha earthquake in Nepal. Next, to a lack of efficiency and continuity, there is also a lack of sharing of information and cooperation among stakeholders to cope with significant disaster events. There should be a system to allow easy update of landslide information after an event. For a variety of users of landslide information in Nepal, the availability and extraction of landslide data from the database are a vital requirement. In this study, we propose a concept for a web-based Nepalese landslide information system (NELIS) that provides users with a platform to share the location of landslide events for the further collaborations. The system will be defined as a web-based geographic information system (GIS) that supports responsible organisations to address and manage different user requirements of people working with landslides, thereby improving the current state of landslide management in Nepal. The overall aim of this research is to propose a conceptual design of NELIS and to show the current status of the cooperation between involved stakeholders. A system like NELIS could benefit stakeholders involved in data collection and landslide management in their efforts to report and provide landslide information. Moreover, such a system would allow for detailed and structured landslide documentation and consequently provide valuable information for susceptibility, hazard, and risk mapping. For the reporting of landslides directly to the system, a web portal is proposed. Stakeholders who can contribute to the reporting of landslides are mostly local communities and schools. Based on field investigations, literature reviews and user interviews, the practical structure of the landslide database and a conceptual design for the NELIS platform is proposed.

Keywords: Landslide database, hazard management, Landslide reporting, web-GIS.

1 Introduction

Landslides are one of the significant hazards that contributes to damages in the Himalayas. About 70 % of the total area of Nepal is mountainous terrain and prone to landslides (Kargel et al., 2016). Currently, several fatalities are caused by natural disasters in Nepal, and the death toll and destruction caused by landslides is rising (Meena et al., 2019a). Many landslides are triggered every year, mainly by heavy rainfall during the monsoon period. A lot of landslides gets reactivated and extended during the monsoon rains and lead to the destruction of infrastructure and human losses in the country (Pourghasemi and Rahmati, 2018). Due to a high rate of population growth and unplanned dense building activities in susceptible areas, there is an increase in damage. Limited investments in slope protection and absence of spatial planning reveal the lack of intervention

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measures for reducing the landslides risk in Nepal. As a result, there is an increment of socio-economic problems in the hilly regions due to landslides, like loss of agricultural fields, deforestation, homeless population due to house damage. One of the most severe landslide events in recent years happened as a result of the Gorkha earthquake in April 2015(Meena et al., 2019b). The earthquake had a magnitude of (M) 7.8 and caused landslides in an area of 10,000 km² located in Nepal and China, which led to damage of property and about 9000 human fatalities (Kargel et al., 2016; Tsou et al., 2018). As Nepal is located in the indo-Eurasian tectonic zone, it is prone to earthquakes (Meena et al., 2019c). Authorities in Nepal have to realise that their management of the landslide hazard and risk mitigation programs seem to be insufficient at both regional and national scale (Corominas et al., 2014; Rosser et al., 2017). There are some reasons for these insufficiencies. On the one hand, there is little collaboration happens between the authorities in charge of landslide management in Nepal so far. On the other hand, the information basis for landslides in Nepal is heterogeneous and dispersed over several organisations.

Moreover, each organisation follows its own rules to collect landslide information, i.e. no standard approach for data collection. Although efforts to tackle these problems exist among organisations in Nepal, they do not yet exploit opportunities provided by state-of-the-art technologies that are already in use in other countries or that are currently researched. Currently, there are some organisations like Tribhuvan University, International Centre for Integrated Mountain Development (ICIMOD) who have prepared pre-earthquake (Pokharel and Bhuju, 2015) and post-earthquake (Gurung and Maharjan, 2015) landslide inventories. However, access to these inventories is limited.

A comprehensive web-based landslide inventory can include some data illustration options such as aerial photographs, satellite data, monitoring data, and attribute information (Chen et al., 2016). Several landslide inventory preparation techniques can be considered: visual image interpretation (Cheng et al., 2018; Roback et al., 2018), semi-automated image analysis techniques (Hölbling et al., 2012), convolution neural networks and deep learning approaches (Ghorbanzadeh et al., 2019), UAV based mapping (Rossi et al., 2018; Suwal and Panday, 2015), use of tablet-based GIS (De Donatis and Bruciatelli, 2006; Knoop and van der Pluijm, 2006), and involvement of local communities as an alternative approach (Carr, 2014; Devkota et al., 2014; Jaiswal and van Westen, 2013). For every landslide, the accessible data should be transferred to one central database so that clients can retrieve, include, update or expel information in an automated way (Klose et al., 2014).

In the natural hazards domain, endeavours are made to generate landslide inventory databases following triggering events such as earthquakes (Meena et al., 2019a; Regmi et al., 2016), tsunamis (Aniel-Quiroga et al., 2015), heavy rainfalls (Kumar et al., 2008) and floods (Chendes et al., 2015). The international Emergency Events Database (EM-DAT) lists events in which at least ten persons died or at least 100 people were affected (CRED, 2018). A study carried out by (Van Den Eeckhaut and Hervás, 2012) in Europe shows the status of landslide databases and the value for attaining landslide susceptibility hazard and risk analysis (Westen et al., 2014). It indicates that a total of 25 European Union members maintain national landslide databases. In another effort, (Herrera et al., 2018) analysed the landslide databases from the European countries' geological surveys by concentrating on their interoperability and completeness. In general, geological surveys are most often responsible for creating landslide databases in their country; for example, the digital landslide database of France was developed by the French Geological Society already in 1994 (BRGM, 2018). Some countries like Italy have two landslides databases: The Inventory of the Landslide Phenomena in Italy (IFFI) (Lazzari et al.,

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2018) and the AVI Project (Vulnerable Italian areas) (Guzzetti et al., 1994). In Great Britain, there is a national landslide database (Pennington et al., 2015) that is developed by the British Geological Survey. It has the point and polygon-based landslide information with attributes attached for each landslide and covers approximately 17,000 records of landslides in Great Britain. Recent national landslide databases have been developed by, for example, China (Xu et al., 2015) and New Zealand (Rosser et al., 2017). In the USA, landslide inventory data is managed by the United States Geological Survey (USGS).

Web-based landslide inventory databases provide vital baseline information about landslide areas, location, types, triggers, geometry, distribution and a broad scope of extra attributes (Guzzetti et al., 2012). Landslide databases considered important for various purposes, such as susceptibility analysis, hazard evaluation and risk assessment (Feizizadeh et al., 2014). Landslide inventory databases provide the base data for carrying out susceptibility analysis using multiple knowledge-based and data-driven models at various spatial levels from regional to national levels (Hölbling, 2017; Meena et al., 2019a).

In our case study of Nepal, the situation is different as there are multiple agencies responsible for landslide management. Therefore, there is a need of a platform for collaboration between all involved organisations in landslide management. Such a platform will provide researchers and policymakers with an updatable database for preparing landslide zonation of the country and identifying most susceptible regions for quick response during landslide hazards. At the local level, people are the best source of landslide information for updating of the database. However, currently, there are not enough efforts to involve local people in landslide management in Nepal. Considering this issue, there is an essential need for a comprehensive nodal agency for hosting such a platform at a national scale, while at the same time, different agencies and local people can be incorporated.

A landslide information system is required that can incorporate information about different landslide characteristics and types (Meena et al., 2018). Availability and extraction of landslide data from the system for the public and all government agencies are essential aspects. For the reporting of landslides directly in the system, a web portal is needed that is connected to the internet and the central database (Meena et al., 2018). The development of the Nepalese landslide information system (NELIS) to report and arrange landslide data will facilitate better data sharing among stakeholders. Consequently, it can lead to improved reconstruction planning for minimising the impacts and consequences of landslides in Nepal, also there is a need for incorporating landslide hazard and risk in the planning process at the regional level.

2 Workflow

In this section, the workflow of the present study adopted for the development of NELIS is detailed. Our workflow consists of three main components of a) user requirements analysis of stakeholders, b) landslide reporting, and c) landslide database generation. There are two types of landslide reporting in the system, voluntary mapping and mandatory mapping from organisations working on landslide research. Also, users and providers of landslide data are identified based on a questionnaire survey and field visits. To determine the potential users and providers of landslide information, interviews and questionnaire survey were conducted during a field visit in July 2018. The objective was to identify aspects related to the development of a landslide database structure, for users and information providers. For example, we locally investigated whether preliminary users like schoolteachers and students can report a landslide event by pointing it in the reporting

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system. In this frame, the ability of schools for organising monthly meetings with the teachers and students regarding collecting information of any landslide event occurred in nearby areas was assessed.

For the identification of stakeholders for the NELIS, a questionnaire survey was carried out, and organisations dealing with landslide management were visited. The questionnaire was conducted with 40 officers from different governmental organisations in Nepal. Information related to their position in the organisation and how they could contribute to the national landslide information system was gathered. Considering the questionnaire survey, we collected information about user needs and requirements towards a landslide information system and functionalities that should be prioritised when setting up the system.

It is crucial to understand the administrative, organisational structure of Nepal before carrying out stakeholder's analysis. In Nepal, the lowest administrative unit is VDC, which is administered by the district office at the district level. All district level officers are governed by national departments which are headed by various ministries. All ministries are governed under the central government (see Figure.1).

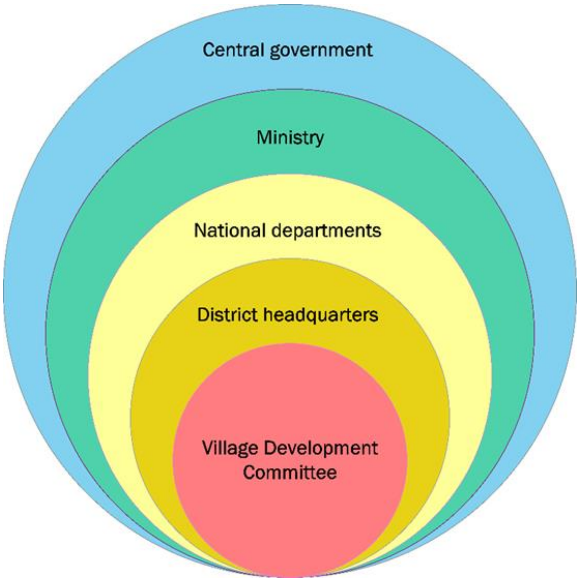

Figure. 1 Administrative, the organisational structure in Nepal.

There are three main components of NELIS, stakeholder overview, landslide reporting, and data sources for inventory generation. In the stakeholder overview, the potential users and data providers of the system are discussed. Then the potential landslide reporting stakeholders and methods are discussed with possible data sources for landslide inventory generation. After gathering user information and data sources, the final conceptual structure of NELIS is proposed (see Figure.2).

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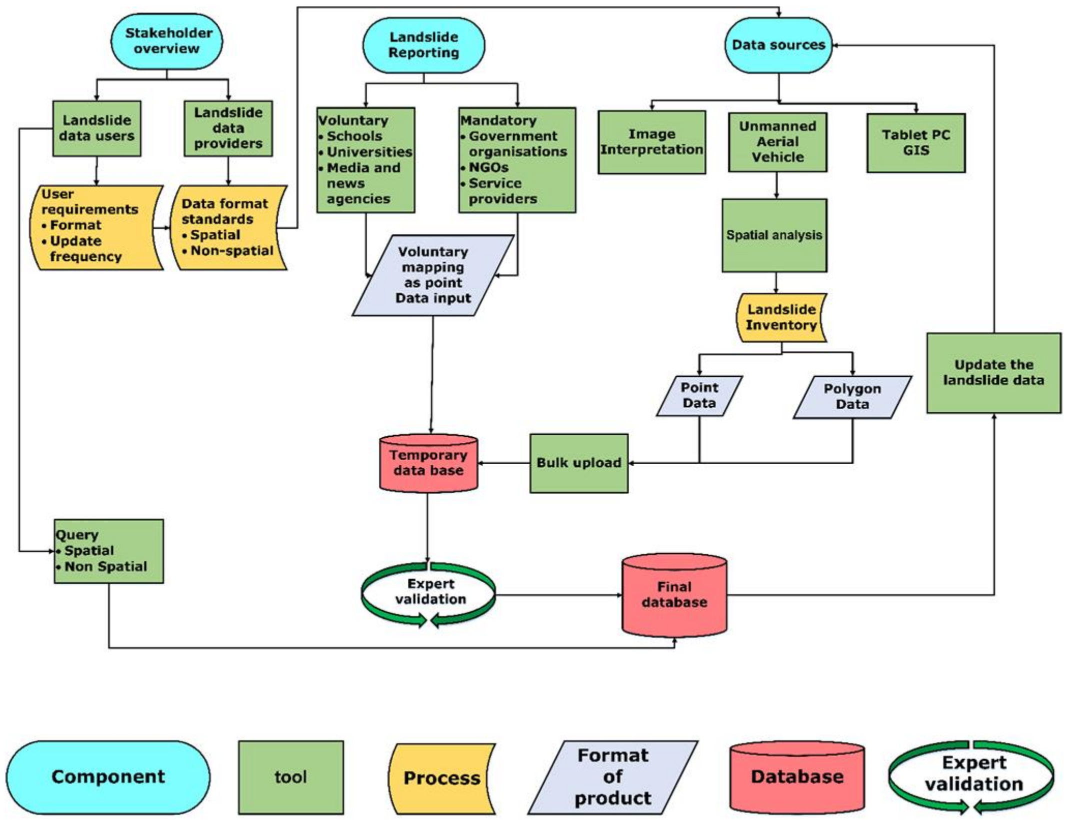

Figure. 2 The flowchart of the conceptual framework.

3 Results

3.1 Stakeholder overview and status of landslide management in Nepal

The first step for setting up the NELIS is to investigate the administrative and organisational structure in Nepal, along with the information that could be collected and disseminated. The smallest administrative unit in Nepal is the Village Development Committee (VDC) which is headed by the VDC head. At the district level, there is a district headquarter which manages various administrative departments. Knowledge of the structure of the administrative organisations leads to a better understanding of the stakeholder distribution at the different organisational levels.

During the interviews and open questionnaire survey, several suggestions and requirements of the various stakeholders were identified, as well as additional organisations that are working in landslide research and mitigation. The evaluation of the stakeholder's roles and requirements for the NELIS showed that many suggestions resulted from the questionnaire survey for the development of the NELIS. The results of the survey were analysed; Figure. 3 shows the components of the NELIS that needs to be prioritised during development. Four components are of most importance, a reporting system (18 %), the collection of new data from various sources after an event (23.08 %), updating of already existing datasets (32.98 %), and development of new

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guidelines for a mapping workflow (26.37 %). Results show that most of mapping or data collection work has been carried out after the Gorkha event, but that hardly any updates of the datasets were made afterwards. It also became evident that landslide inventory data are not available to the public, and it is difficult to get permissions from authors to share the data to external scientists or organisations.

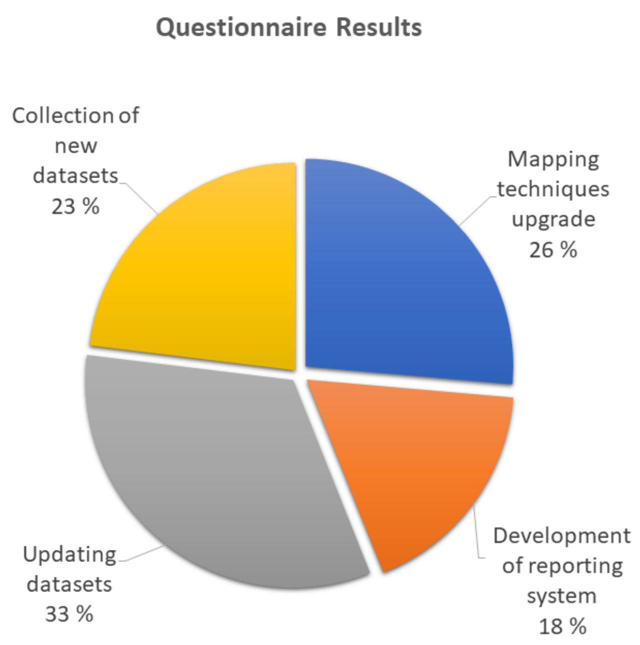

Figure. 3 Results of the questionnaire showing the components that should be prioritised in the development of the NELIS.

In Nepal, a wide range of stakeholders are active in landslide management. Stakeholders involved in landslide related work such as the rural road development department, land management authorities, forest department, disaster management department and the Nepalese army. Some agencies are dealing with land degradation, soil erosion, a different type of landslides, such as the DSCWM, DMG and the DWIDM, they can be considered as the potential nodal agencies for the development of the NELIS. Other organisations like the Department of Hydrology and Meteorology and ICIMOD have the technical expertise and workforce that is necessary for the development of the proposed system. Some of the mentioned organisations already have landslide inventories and socio-economic data for most of the districts, but the information is often only in the form of reports. The collaboration between these organisations and transferring the data into geocoded landslide information at the national scale can lead to improved spatial planning in landslide-prone areas. There are maintenance reports by rural road department offices available, which were created after road blockages. DSCWM has prepared a

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landslide inventory, but landslide data is compiled into reports, and there is no geocoded information about the landslides.

After visiting a range of organisations (governmental organisations, NGOs, INGOs) during the field visit, a list of main stakeholders as users of the system was compiled (Table 1). Moreover, potential data providers and their contribution to a landslide information system in Nepal and were identified. The organisations can be grouped into several categories, such as national organisations, international research groups, academia, and news and media. Table 1 lists the main actors and describes their tasks for landslide management. NELIS supports in landslide data collection and landslide management in their efforts to report and provide landslide information.

Table 1 Presentation of the stakeholder overview and their contribution to the NELIS.

	Organisation	Contribution
1.	Academic and research institutes	• They can provide landslide inventory data prepared by them. • Analogue reports and also digital landslide inventories prepared for research purposes (Gnyawali et al., 2016).
2.	News and Media	• The news and media agencies can provide the geocoded location of the event to the system. • Getting information about landslides by searching newspaper archives (Taylor et al., 2015).
3.	Department of Soil Conservation and Watershed Management (DSCWM)	• DSCWM has landslide information at the regional and local level. • They maintain a landslide database in their department. • DSCWM has prepared guidelines to map landslides.
4.	Department of Mines and Geology (DMG)	• Development of landslide inventory at the local level. • Can provide regional landslide inventories.
5.	Rural Roads and Construction Authority (RRCA)	• Maintain analogue database in the form of registers and know about landslides in the countryside; they get information from local people during road clearance. • Maintenance reports after a landslide blocked a road. • They can provide road clearance reports that will help to identify landslides.
6.	Department of water-induced disaster management (DWIDM)	• Mitigation works for landslide hazard prevention. • Landslide prevention by constructing gabion walls and similar preventive measures.
7.	Department of Hydrology and Meteorology	• Provide landslide induced dams data.

8.	Village Development Committee (VDC)	• Help in providing local ground data about recent hazards.
9.	UNDP (Foreign organisations working in Nepal)	• Financial and workforce support.
10.	UNEP (Foreign organisation working in Nepal)	• Financial and human resources support.

3.2 Available landslide inventories

After the Gorkha earthquake in 2015, several attempts were made to carry out landslide inventory mapping for the affected area of about 10,000 km² located in Nepal and China (Gnyawali et al., 2016; Goda et al., 2015; Kargel et al., 2016; Martha et al., 2017; Roback et al., 2018; Robinson et al., 2017; Shrestha et al., 2016; Valagussa et al., 2016). Table 2 lists the landslide inventories created for Nepal. There is a variation in the number of landslides for the same event. Some of the inventories were accessed through the online portal of earthquake response (HDX, 2015), and for the pre-earthquake inventories, authors were contacted for the data. Most inventories are polygon-based, hence enable the statistical analysis of area distribution for hazard analysis (Malamud et al., 2004). Other inventories are the point-based, compiled just after the earthquake by ICIMOD (Gurung and Maharjan, 2015) and the British Geological Survey (BGS).

There were several attempts made to map landslides by teams from the University of Arizona, Tucson, AZ, USA (Kargel et al., 2016); NASA-USGS earthquake response team (Roback et al., 2018); Chinese Academy of Sciences (Zhang et al., 2016). A total of 19,332 landslides were mapped by (Gnyawali et al., 2016) using Google Earth imagery. Researchers from the Indian Space Research Organisation (ISRO) (Martha et al., 2017) mapped a total of 15,551 landslides using object-oriented image classification. (Valagussa et al., 2016) mapped a total of 4,300 co-seismic landslides using Google Earth satellite images; it is lesser than other studies as they did not consider whole affected districts while mapping. Recently, a landslide inventory related to the Gorkha earthquake was created by (Roback et al., 2018), mapping 24,915 landslides, which covered most of the area affected by the earthquake. The large quantity of identified landslides is the result of using very high-resolution WorldView/GeoEye satellite imagery for the mapping. They also differentiated source area and body of the landslides, which makes it distinct from other inventories. There are three rainfall-induced landslide inventories collected during fieldwork. Pre-earthquake landslides were mapped by (Zhang et al., 2016) and by (Pokharel and Bhuju, 2015).

Table 2 Current status of landslide inventories in Nepal.

Landslide inventory	No. of landslides	Geometry type	Area coverage	Produced by
Tribhuvan University	5003	Point	Nepal	(Pokharel and Bhuju, 2015)
ICIMOD Koshi River Basin 1992	3559	Polygon	Koshi River Basin	(Zhang et al., 2016)

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ICIMOD Koshi River Basin 2010	3398	Polygon	Koshi River Basin	(Zhang et al., 2016)
Valagussa et al. 2016	4300	Polygon	Central Nepal	(Valagussa et al., 2016)
ICIMOD	5159	Polygon	Central Nepal	(Gurung and Maharjan, 2015)
USGS	24915	Polygon	Central Nepal	(Roback et al., 2018)
Indian Space Research Organisation (ISRO)	15551	Polygon	Central Nepal	(Martha et al., 2017)
Chinese Academy of sciences	2645	Polygon	Central Nepal	(Zhang et al. 2016)
ITC, University of Twente	2513	Polygon	Central Nepal	(Meena et al., 2018)
The University of Arizona, Tucson, USA	4312	Polygon	Central Nepal	(Kargel et al. 2016)
Gnyawali and Adhikari 2016	19332	Point	Central Nepal	(Gnyawali et al., 2016)

3.3 User needs and requirements

For better addressing, the user needs the conceptual design of the NELIS includes four pillars: concept definition, user requirements assessment, EO database and database structure for the NELIS(see Figure.4) (Hölbling, 2017). The needs and requirements of stakeholders working on landslide management are identified, and the type of landslide and the format are already available for them. For example, news and media can provide information related to significant size landslide events, which caused fatalities or infrastructural damage. Government departments can supply different kinds of landslide datasets based on their work, like the DSCWM who has field-based landslide inventories for small watersheds in Nepal. They could transfer all their data to digital format as in DSCWM they use a GIS platform to map landslides. Also, DMG has several geological hazard assessment reports that were produced after the earthquake based on field investigations, which should be included in the NELIS.

Based on the questionnaire survey, following user needs and requirements for the development of the NELIS are compiled:

i. Some of the organisations have already done data collection and reporting at a large scale, but there is a lack of transferring this knowledge into preparing hazard maps for mitigation works.
ii. There is a need for harmonised guidelines for mapping landslides. Mapping guidelines are already existing at DSCWM but based on a questionnaire survey; these guidelines need to be improved.
iii. Landslides are dynamic processes, and thus landslide databases require updating of datasets after each monsoon season at least once a year.
iv. The use of remote sensing data is not enough; field verification should be carried out in addition.
v. Universities and academia can contribute to reporting and information sharing of research work in landslide hazards that will help in methodological advancement.
vi. There is a need for transparency and exchange of information to mitigate the effects of landslides.

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vii. Users can switch between different GIS layers such as land use, settlements, geology, and should be able to retrieve the requested information quickly.

viii. Coordination between organisations is necessary to avoid duplicate efforts.

Requirements and suggestions can be included in the development of the system; the technical, as well as management limitations at the national level, should be considered. Thus, after analysing the user requirements and the contribution of landslide data, a conceptual structure of the NELIS is proposed.

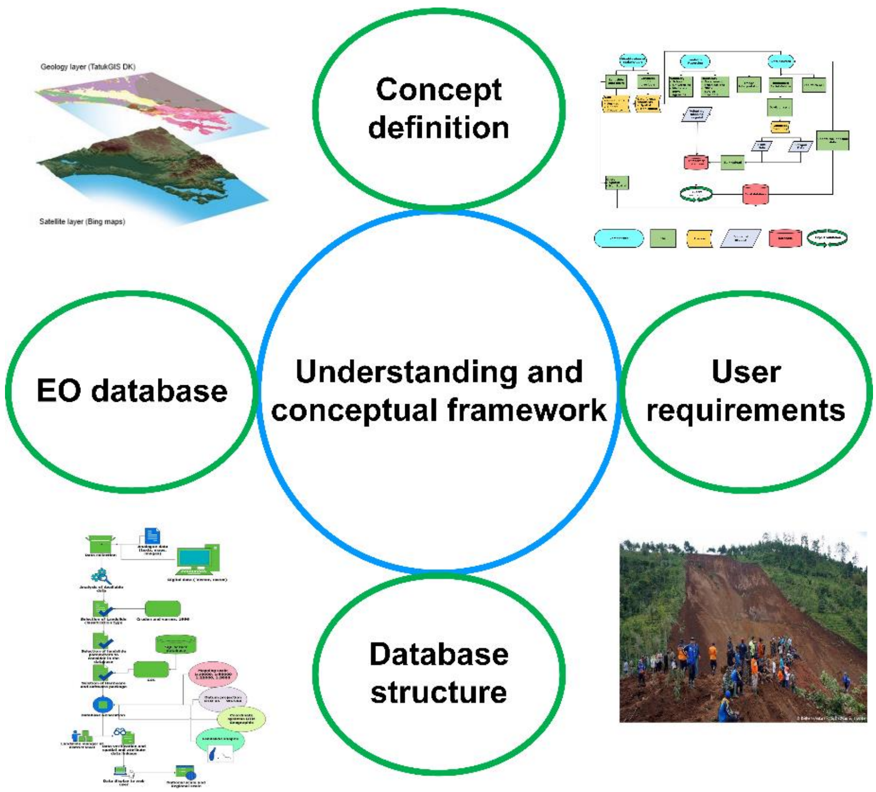

Figure.4: Understanding and conceptual framework for the development of NELIS. Adopted from (Hölbling, 2017).

3.4 The targeted landslide data sources for NELIS

For the development of comprehensive landslide database identification of sources of the landslide, the input is important. Based on the literature review and available landslide information in Nepal, we found some of the possible sources of landslide data input. There are several sources of landslide data in Nepal such as historical documents, news and media archives, past development projects and technical data. In this section, we also discussed the data attributes and corresponding metadata format of entering landslide data in the NELIS.

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3.4.1 Historical documents, news and media archives

Newspaper and media report archives are one of the crucial sources of landslide information all over the world. An example is the global landslide database by The National Aeronautics and Space Administration (NASA), which is based on news reports (Kirschbaum et al., 2010). News articles may be the first way by which people hear about a hazard. In Nepal, landslides that occur near the road network or near the built-up area are sometimes covered by the newspaper and media agencies. Newspaper archives can give information about the damage caused by a landslide and the most probable landslide location near to a locality or village. Sometimes, photos of the event shown in newspapers can provide information on the spatial extent of the landslide. In today's digital era, some newspapers in Nepal are also available online, which enables readers to find news from the past. Newspapers like The Himalayan Times, the most popular newspaper in Nepal, sometimes cover stories about landslides that affect the populated area or block rivers.

3.4.2 Landslide inventory maps as part of development projects

The primary purpose of this section is to provide indications for the use of techniques for collecting data for NELIS. Landslide mapping is performed for reporting and showing the distribution and spatial extent of the landslide occurrence from local level VDC to large watersheds, and from regional to national level. Despite the significance of landslide inventories and the way that landslide maps have been prepared for a long time, there are no clear guidelines for the creation of landslide maps and the assessment of their quality in Nepal. Sources of landslide information vary in Nepal as various organisations are working in the field of landslides, and most of the information is in analogue format in the form of reports. The selection of a specific mapping technique depends upon the purpose and the extent of the study area. There are other criteria for selection of mapping techniques discussed by (Guzzetti et al., 2012) like mapping scale, the spatial resolution of the available satellite imagery and most importantly the skills and resources available for completing the task (Guzzetti, 2000; Guzzetti et al., 2012; Van Westen et al., 2006).

3.4.3 Technical reports

Different technical reports are available which were collected during fieldwork by several organisations. After the Gorkha earthquake, initial assessment of earthquake affected settlements was carried out by DMG and DSCWM, DWIDM and Tribhuvan University. An example of a technical report collected by DSCWM is shown in Table 3. The information related to the occurrence of a landslide, its dimensions, damage caused, impacted area and also sketch map are compiled in a table within the report.

Table 3. Landslide Mapping Information sheet (DSCWM, 2016)

District: Rasuwa	VDC: Yarsa	Ward: 09 Ghormu	Village/Tole:
1. Dimension of Landslide:	Length: 200m	Width: 20m	
2. Position on Hill:	Middle		

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3. Land Crakes	Length	Width	
4. Impacted area:	2000m2		
5. Possible impact area:	500m2		
6. Property in possible impact area:	a. Farmland: Ropani b. Settlement: c. Road: 10m Goreto bato d. Irrigation canal e. Other property: Water supply, water mill		
7. GPS points:	Longitude: 0623293	Latitude: 3100224	Elevation: 1748m
8. Sketch map of Landslide			

9. Information collected by:	Name of the person

3.4.4 An instance of landslide attributes and their corresponding metadata

Landslide features can be stored as a single feature with a point representing the landslide location. A landslide ID can be assigned to an individual landslide with associated attributes like the date of the event, the resulting damage, the people affected, and the landslide type, if such information is available. Illustration of landslide ID linkage to the associated feature is shown in Figure. 5, where landslide polygons were obtained from the existing landslide inventory by (Roback et al., 2018). There can be variation among different datasets regarding their attributes. Based on expert opinion and literature, a set of the essential attributes needs to be defined and to be used as a specification for a new landslide database. Hence, not all the data from the primary databases will be transferred to the new database.

Landslide attributes and the type of information can be taken from Varnes classification (Varnes, 1978). There is a list of attributes proposed by (Huang et al., 2013), primary attributes are landslide location, date and time of the event, type of landslide, and secondary attributes like triggering factors, damage. However, information for some of the identified attributes probably lacks because of data scarcity in Nepal. Based on local Nepalese situation and data availability, we presented a simple illustration of the linkage of spatial and metadata attributes to a single landslide polygon (see Figure. 5).

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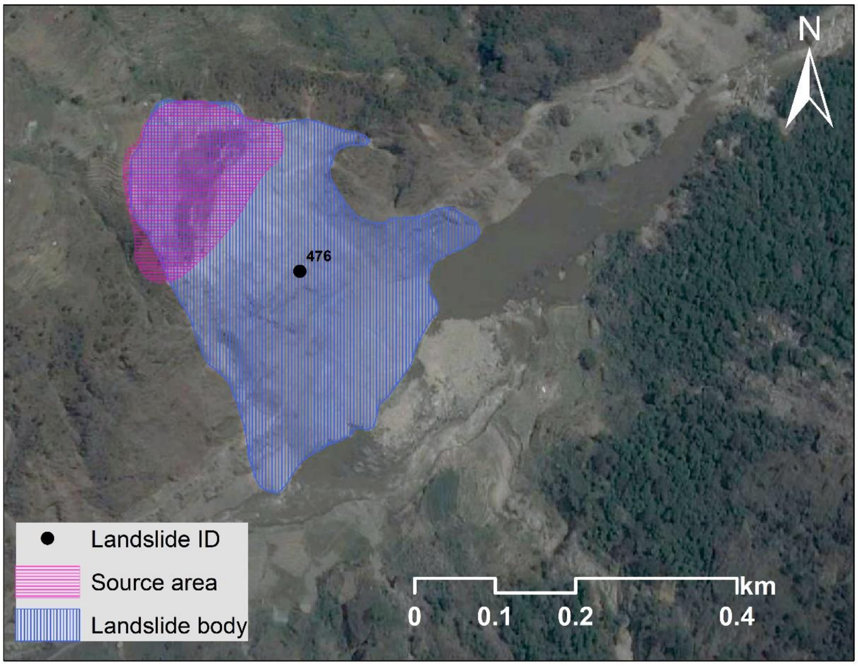

Figure. 5: Example of landslide polygon from an existing landslide inventory (Roback et al., 2018). A common landslide ID links the two polygon features.

3.5 Landslide reporting to NELIS

The communities can directly report landslides into the system. NELIS will provide the users with an opportunity to participate in the mapping process by pointing out a landslide on the web-based platform. After reporting, the information will be stored in a temporary database. There could be false information entered by non-experts so that landslide expert should check the data at the district level. At every district headquarter there is a landslide expert from DSCWM, and this expert can be the responsible person for validating the public reported landslides.

Governmental organisations like DSCWM, DMG and DWIDM, are the key organisations who work in the landslide management. After the development of the NELIS officers from organisations should be given training regarding the use of the system and also the management of the information from different sources. Experts can also transfer bulk data directly to the system, both point and polygon data (see Figure. 6).

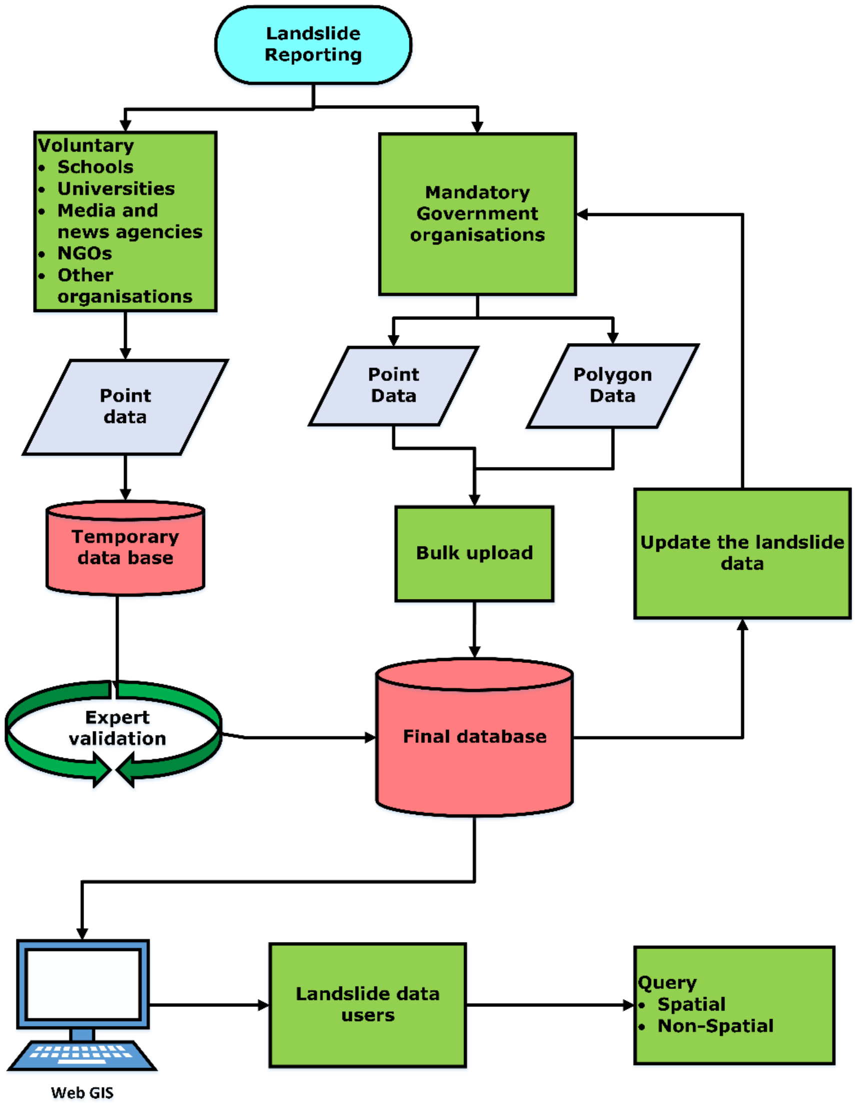

Figure. 6 The workflow of landslide reporting is presented.

3.6 The database structure of the web-based Nepalese landslide information system (NELIS)

The main aim of this section is to conceptualise a web-based information system that allows stored landslide data to be easily accessible, displayed and queried and to add new information. The existing landslide datasets from different sources have various structures and types, making it challenging to transfer and compare the data. Therefore, a unified data model for landslide storage is needed. However, datasets can be from different sources and at variable scales and accuracy levels. It is very challenging to transfer data from different sources, so there is a need for harmonising existing datasets such as the development of guidelines for data provision following a defined structure. The NELIS is proposed to have a series of views and tables in a relational spatial database. Location and shape of landslides represent the spatial information. The database should be designed to store landslide information as polygon and point features and also information related to the projection system. There is a need to transfer landslide information from technical reports to topographic maps by experts with geocoded information and then upload to the NELIS. So, experts who are working in landslide data management can take the initiative to transfer the analogue data from reports to geocoded information.

The web service platform can be implemented as a spatial relational database and can be hosted, developed and maintained by a nodal agency in Nepal. The web interface comprises of tools for displaying and searching landslide information in the form of maps and tables. The web service can allow and display the information to the user to interact with the map layers (Rosser et al., 2017). An advantage of the proposed concept for NELIS is that it is exclusively based on Opensource software. The object-relational database management system (DBMS) will be based on PostgreSQL Query Language, providing all functions of SQL as a database language for a generation and manipulation of stored data and data queries. To process and store spatial data, PostGIS can be integrated as an extension for PostgreSQL. PostGIS not only improves the storage of GIS information in the DBMS but also offers spatial operations, spatial functions, spatial data types, as well as a spatial indexing enhancement (Obe and Hsu, 2011).

The first and foremost step is data collection from analogue reports and already available digital data. Then transfer the data to vector or raster layers for further analysis by experts (see Figure. 7). After that, the available landslide data can be classified into different landslide types (Cruden, 1996). In the next step, data is stored in a database with keeping the shapes of landslides, projection of maps. Furthermore, a landslide manager can verify the landslides in their respective areas, and after the final check, data can be uploaded to the web-based system to be available online.

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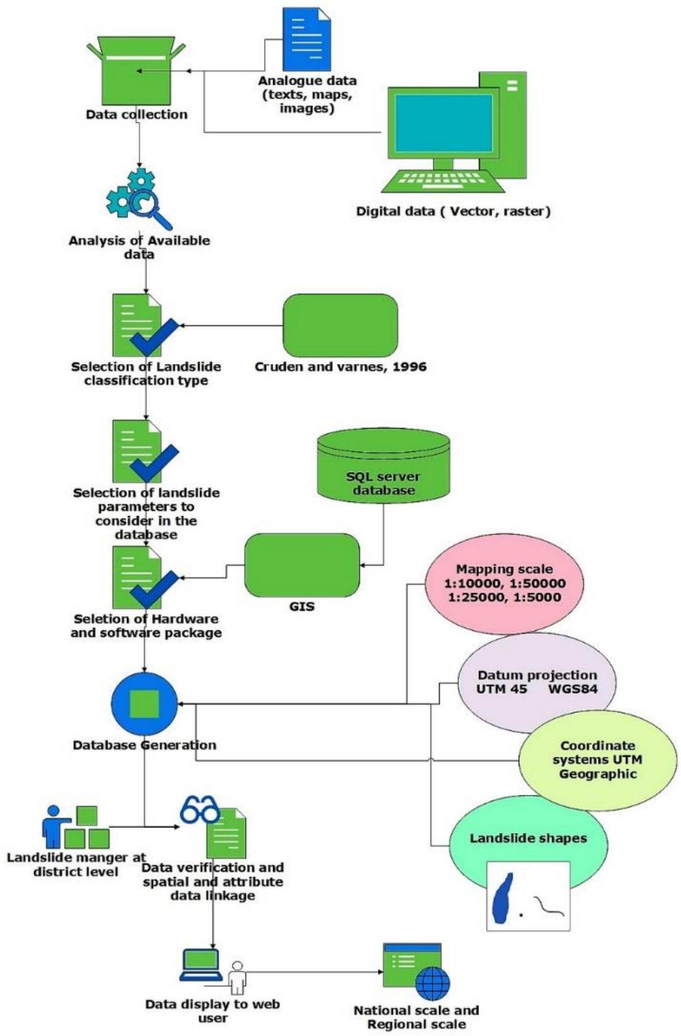

Figure. 7 The architecture of the proposed structure for the NELIS; adapted from (Devoli et al., 2007)

4 Discussion and Conclusion

The development of the Nepalese landslide information system (NELIS) to report and arrange landslide data will facilitate better data sharing among stakeholders and will provide a platform for future risk mitigation efforts. Any produced landslide inventory cannot be fully complete or entirely accurate; also, just because a landslide is not recorded, this does not mean a landslide has not occurred. The quality of the data in the NELIS will be dependent on the completeness of data recorded in the source database. Many landslide records only store location data, with no information about the boundary, area, the date of movement, type of landslide, or

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triggering event. In contrast, there are some landslides like the Jure landslide in Nepal, that have been the subject of intense research with detailed information (Acharya et al., 2016).

One of the limitations of the data to be joined into the landslide database is the inconsistency of the spatial correctness of landslide features, which is depended on the method of mapping. Generally, landslide polygons that are delineated from high-resolution satellite imageries are accurate at the scale at which they are delineated. Landslide point location accuracy is highly variable and ranges from sub-meter precision measured by GPS devices.

There can also be landslides in the database that have been mapped using different techniques such as field study based detailed inventories or semi-automatically generated inventories, which leads to some limitations. Landslide datasets often contain point data, generally located in the center of the landslide, whereas large datasets of polygons such as inventory produced by (Roback et al., 2018) which consists of around 24000 landslides after the Gorkha earthquake, including two different types of information of the source and deposition areas of the landslides. There are some solutions but not cover all the limitations such as sub-areas of a single landslide can be linked in the database by the landslide ID. Storing all mapped landslides in a single database has the advantage of allowing better characterisation of landslides such as for identifying landslides related to a particular rainfall or earthquake event in a particular area (Rosser et al., 2017). Comprehensive information about the spatial and temporal distribution of landslides allows also establishing links to the triggering mechanisms and to estimate the damage and impact caused by a landslide. This information is useful for land-use planners and policymakers for managing of landslide hazard and its associated environmental impacts.

The conceptual framework presented in this paper shows for the first time the available information in Nepal related to landslide hazard and allows us to characterise the landslide stakeholders involved. The framework also allows for detailed investigation of the design, and structure and helps us to identify the organisations working on landslides in Nepal. In the future study, the conceptual framework presented in this paper can be extended to the development of the National scale landslide management system for Nepal. The system can be beneficial for specifying the potential risky regions and consequently, the development of risk mitigation strategies at the local level.

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