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# Development of community-based landslide early warning system in the earthquake-affected areas of Nepal Himalaya

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**Abstract:** In the central Nepal Himalaya, landslides form the major natural hazards annually resulting in many casualties and damage. Structural as well as non-structural measures are in place to minimize the risk of landslide hazard. To reduce the landslide risk, a Landslide Early Warning System (LEWS) as a non-structural measure has been piloted at Sundrawati village (Kalinchowk rural municipality, Dolakha district) to identify its effectiveness. Intensive discussions with stakeholders, aided by landslide susceptibility map, resulted in a better understanding of surface dynamics and the relationship between rainfall and surface movement. This led to the development of a LEWS comprised of extensometers, soil moisture sensors, rain gauge stations, and solar panels as an energy source that blows siren receiving signals via a micro-controller and interfacing circuit. The data generated through the system is transmitted via a Global System for Mobile Communications (GSM) network to responsible organizations in real-time to circulate the warning to local residents. This LEWS is user-friendly and can be easily operated by a community. The successful pilot early warning system has saved 495 people from 117 households in August 2018. However, landslide monitoring and dissemination of warning information remains a complex process where technical and communications skill should work closely together.

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## Introduction

Landslide occurrence in central Nepal Himalaya is a common phenomenon causing many casualties and loss of properties every year. Inadequate provisions for early warning systems (EWS) and disaster prevention with mitigation measures further exacerbate this situation. The stability of this steep and dynamic mountainous terrain is affected by torrential rainfall, seismic activity, environmental degradation and construction that together constitute major natural and anthropogenic factors that accelerate the occurrence of landslides (Upreti 2001). In 2017, some 276 people died and approximately USD 7 million was lost as a direct consequence of landslide in Nepal (MoHA 2017). Most of the landslides are triggered by precipitation, seismic activity, and anthropogenic interventions (Gariano and Guzzetti 2016). Monsoon rains with low intensity and long duration are responsible for triggering a large proportion of the landslides and related disasters in the central Himalayan range of Nepal (Dahal 2012). Moreover, earthquakes are able to change the mountain landscape (Arora et al. 2017; Bilham 2019) and the recent 2015 Gorkha Earthquake in Nepal triggered more than 19,332 co-seismic landslides covering some 61.5 km$^2$ (Gnyawali and Adhikari 2016). These co-seismic landslides involved mainly shallow slope failures that were primarily controlled by faults and major discontinuities, and the direction of the fault rupture (Roback et al. 2018). Anthropogenic factors such as the construction of roads, slope modifications, deforestation and improper land use form increasingly important factors contributing to the triggering of landslides (McAdoo et al. 2018) and, in turn, this has led to the destruction of houses, irrigation canals, and farmland, and it has affected the supply chain, local livelihoods and access to markets (Van der Geest and Schindler 2016).

Landslide mitigation is very important to save lives and livelihoods and appropriate interventions need to consider the range of possible triggering factors such as earthquakes, rainfall, flood and anthropogenic influences in the landscape (Campbell 1974; Choi and Cheung 2013; Crosta and Frattini 2003; Ramesh 2014; Senneset 2001; Wieczorek and Glade 2005). Different initiatives such as structural and non-structural measures have been developed in an attempt to mitigate the impact of landslides (Cornforth 2005; Marui 2017; Fowze et al. 2012). Structural measures include examples such as bio-engineering, retaining walls, drainage management, and river toe protection are in practice in the Nepal Himalaya (Dahal et al. 2006; Florineth et al. 2002; Gabet et al. 2004; Howell 1999; Khanal and Watanabe 2005; Paudel et al. 2003). In Nepal, structural landslide mitigation is being practiced by controlling soil erosion and mass movement using dams and walls in landslide prone areas (DSCWM 2016). Successful non-structural mitigation accounts for a major proportions of the disaster risk reduction and includes the establishment and use of landslide susceptibility/hazard maps, early warning systems, better landuse practices, and awareness education about landslide disasters (Amatya 2016). Non-structural measures can benefit the populations at risk by increasing their awareness and enhancing their preparedness through the implementation of early warning systems (Bednarczyk 2014; Fathani et al. 2016; Michoud et al. 2013; Piciullo et al. 2018. In this context, early warning systems form "*the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately in sufficient time to reduce the possibility of harm or loss*" (UNISDR 2009). It is an integral part of community based disaster risk reduction which consists of 4 key elements; risk knowledge, monitoring, forecasting and education (Intrieri et al. 2013).

Previous research (e.g. Di Biagio and Kjeksdad 2007; Piciullo et al 2017) introduced a framework based on landslide models, warning systems and dissemination to support landslide early warning systems (LEWS). LEWS has become increasingly popular because it is considered to be both an economically and environmentally attractive approach. It forms a good option in mountainous areas where implementation of engineered interventions is not feasible or prohibitively expensive. However, LEWS cannot guarantee to save lives and livelihoods in hazardous areas in all circumstances. The successful prediction of landslides is influenced by limitations in technology and by our understanding of the hazardous process involved, in particular with respect to its timing, size, extent, severity, and duration.

Many LEWS are based on past rainfall events that triggered landslides in regional scale and have used this information to establish empirical rainfall thresholds that can be used to issue warnings (Brunetti et al. 2018; Dahal and Hasegawa 2008; Guzzetti et al. 2007; Peruccacci et al. 2012). However, good LEWS require detailed hazard and risk assessment and appropriate monitoring techniques to result in more reliable slope failure forecasts that are coupled with a thorough understanding of the associated social implications of these warning systems (Basher 2006; Biansoongnern et al. 2016; Dash and Gladwin 2007; Michoud et al. 2012).

Different monitoring methods have been proposed that include the measurement of crack widths, displacement measurement using simple extensometer, rainfall measurement, piezometer installation and measurement of change in weathering for different landslides in the Nepal Himalaya (Mercy Corps 2014). A single rainfall threshold parameter was mostly used as a predictive tool for LEWS in this region (JICA 2009; Dahal and Hasegawa 2008). However, these rainfall thresholds are not always adequate in these diverse landscapes where the differences in geomorphology, geology, land use and climate are substantial (Brunetti et al. 2018, Guzzetti et al. 2007; Peruccacci et al. 2012). Pecoraro et al. (2019) summarized warning systems operating in different parts of the world and tabulated the available information for concerned stakeholders, but there is still a paucity of research regarding the practical considerations and relevance to the local scale for the successful implementation of a reliable EWS (Michoud et al. 2013). Multiple threshold criteria that combine precipitation, displacement and soil moisture to support a LEWS is not well practiced yet in the Nepal Himalaya. Therefore, this research intends to address a low cost and community-based LEWS comprising a soil moisture sensor, rain gauge and auto-extensometers for the detection of slope movement that is coupled with an improved understanding of slope processes and an awareness of the social implications of issuing landslide hazard warnings.

## 1 Study Area

The study area involves the Mehele landslide which is located in the Sundrawati village, Kalinchowk rural municipality in the Dolakha district of central Nepal near Charikot-Singati road (Figure 1). The area is bounded by 86°2'00''-80°5'00''E and 27°41'50''N-27°44'40''N covering a total area of 12.2 km² with a population of some 2766 people (CBS 2011). Sundrawati lies in the Mahabharat Lekh physiographic region and is close to the epicenter of a M7.3 aftershock that occurred on 12th May 2015 in Dolakha district, shortly after the 2015 Gorkha earthquake (Thapa et al. 2018; Martha et al. 2016). Most of the slopes in Sundrawati are covered by forest and agricultural land and the altitude varies from 1019m to 3420 m (Niraula and Maharjan 2011). The study area is frequently hit by landslides following heavy rains during the annual monsoon. Geologically, this area is mostly dominated by mica-schist, augen gneiss, greenish-grey phyllites and quartzites (DMG 2011; Figure 2A). Debris flows, translational slides, rotational failures and rock falls are common (Figures 2B and 2C). The Mehele landslide is particularly important because it lies just above the village of Sundrawati, the hillslope shows multiple signs of instability in the form of small cracks and local displacements (Figure 2D). The potential landslide is some 160m in length and 40m in width and is covered by grassland and forest. In this undulating landscape it is difficult to discern this landslide from satellite images and from even a moderate distance its features rapidly disappear, masked by vegetation.

## 2 Methods

Preparation of a landslide susceptibility map, a landslide monitoring strategy, field verification, interaction with the local community and the establishment of monitoring systems comprise major steps in the establishment of a community-based landslide early warning system.

Landslide inventories are prepared based on a Google Earth ® image of 2017 and verified and

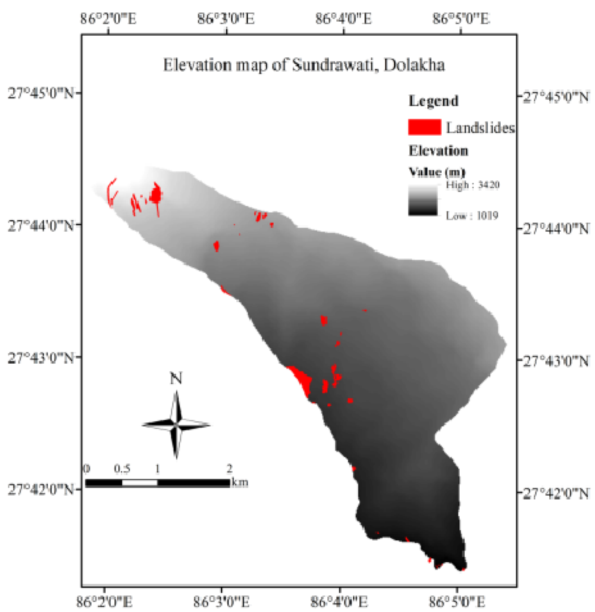


**Figure 1** Location map of the study area showing major Landslides in Sundrawati, Kalinchwok rural municipality, Dolakha, Nepal.

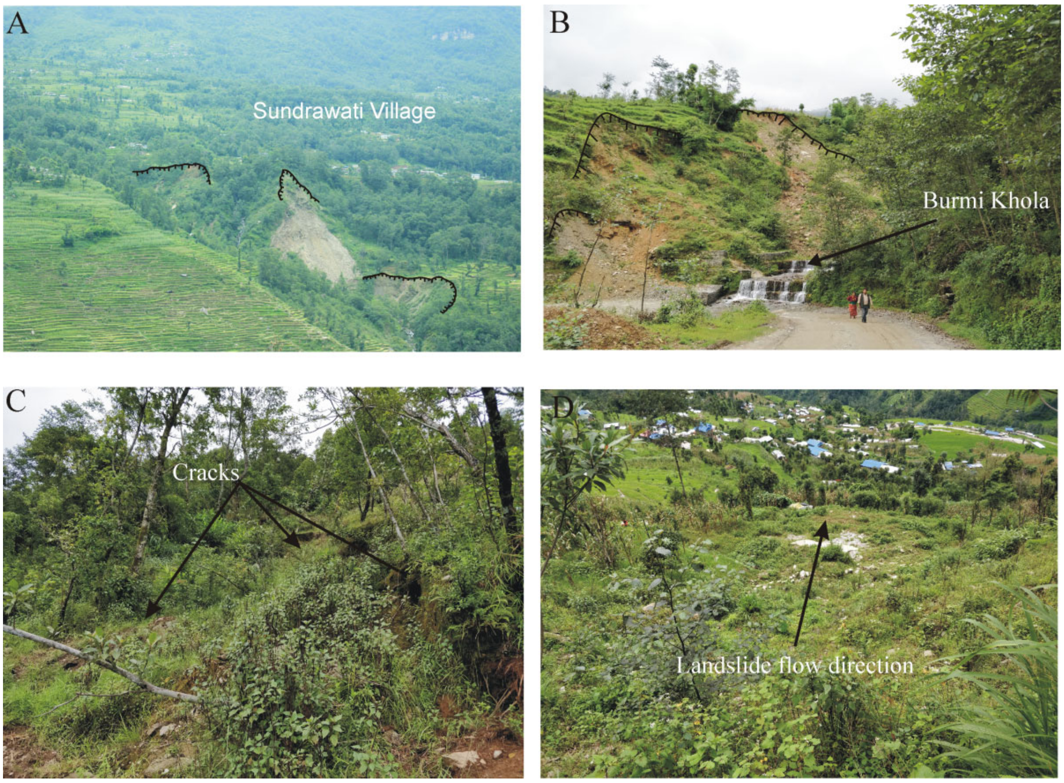


**Figure 2** Landslide spots, crack formation and vulnerable settlement in Sundrawati village. A. Old and active slides; B. BurmiKhola landslide; C. Cracks in the Mehele region above monitored landslide; D. Vulnerable community just below the potential Mehele landslide region.

updated by a series of field visits in 2017 using Global Positing System (GPS) (Garmin e Trex 30x). Lithological information was collected from the geological map of Department of Mines and Geology (DMG 2011) and verified in the field. Land use and land cover (LULC) data has strong influence on landslide susceptibility and these data were extracted from the 30m spatial resolution of the land cover of Nepal (ICIMOD 2013). Eight factors: elevation, aspect, slope, geology, landcover, curvature, distance to drainage and road are considered as important predisposing factors determining landslide susceptibility (Table 1). Geomorphological parameters such as elevation, aspect, slope, curvature, proximity of road and drainage are extracted from a 12.5 m×12.5 m Digital Elevation Model (DEM) from the Advanced Land Observation Satellite (ALOS) image (PALSAR 2016).

A range of methods can be used to determine landslide susceptibility (Devkota et al. 2013; Kayastha et al. 2012; Pradhan and Kim 2014; Pradhan 2010; Regmi et al. 2014; Regmi and Poudel 2016; Youssef 2015). For this research the frequency ratio method (Lee and Talib 2007) is used. The Frequency Ratio (FR) model is a quantitative approach to determine locations of potential landslides in a GIS environment that takes into account the local terrain conditions (Khan et al. 2019; Kose and Turk 2018; Lee and Dan 2005; Li et al. 2017; Yilmaz 2007). The frequency ratio (FR) values were obtained by calculating landslide occurrences and non-occurrences in each of the factor classes based on the landslide relative frequency ratio (*FR*) (Eq. 1)

$$FR = \frac{LF}{CA} / \sum \frac{LF}{CA} \quad (1)$$

where *LF* is the landslide number frequency present in the individual class and *CA* is the proportional class area.

The obtained FR value was normalized by the sum to assign a weight value to the classes of each factor to produce weighted factor thematic map. An analytical hierarchy process (AHP) was used to quantify the relative weight of the eight landslide determinants (Komac 2006) resulting in eight thematic maps (one for each factor). Subsequently, all thematic maps were overlaid and numerically

**Table 1** Relative frequency and weight value of factors to landslide occurrences

| Factor | Class | Percentage of Landslide Pixels | Percentage of Class Area | Ratio | $X_{ij}$ | $W_j$ |
|---|---|---|---|---|---|---|
| Elevation (m) | 1019-<1400 | 3.3 | 9.8 | 0.3 | 0.4 | 16 |
| | 1400-<1800 | 48.5 | 30.3 | 1.6 | 1.9 | |
| | 1800-<2200 | 5.8 | 32.6 | 0.2 | 0.2 | |
| | 2200-<2600 | 9.7 | 17.2 | 0.6 | 0.7 | |
| | 2600-<3000 | 29.0 | 6.0 | 4.8 | 5.7 | |
| | 3000-<3420 | 3.7 | 4.2 | 0.9 | 1.1 | |
| Aspect | F | 0.0 | 0.0 | 0.0 | 0.0 | 10 |
| | N | 0.0 | 0.0 | 0.0 | 0.0 | |
| | NE | 0.0 | 0.1 | 0.0 | 0.0 | |
| | E | 0.2 | 3.4 | 0.1 | 0.1 | |
| | SE | 19.5 | 14.3 | 1.4 | 3.5 | |
| | S | 46.5 | 37.6 | 1.2 | 3.2 | |
| | SW | 30.7 | 35.2 | 0.9 | 2.3 | |
| | W | 3.0 | 8.5 | 0.4 | 0.9 | |
| | NW | 0.0 | 0.9 | 0.0 | 0.0 | |
| Slope (°) | 0-<15 | 8.5 | 15.1 | 0.6 | 0.7 | 17 |
| | 15-<30 | 51.2 | 58.3 | 0.9 | 1.1 | |
| | 30-<50 | 28.5 | 24.4 | 1.2 | 1.5 | |
| | 50-<70 | 11.8 | 2.2 | 5.3 | 6.7 | |
| Geology | Seti Fm | 61.3 | 82.4 | 0.7 | 2.5 | 14 |
| | Ulleri Fm | 38.7 | 17.6 | 2.2 | 7.5 | |
| Landuse | Forest | 31.2 | 54.8 | 0.6 | 1.1 | 19 |
| | Shrubland | 0.0 | 0.0 | 0.0 | 0.0 | |
| | Grassland | 15.0 | 4.3 | 3.5 | 6.5 | |
| | Agricultural area | 53.8 | 40.9 | 1.3 | 2.4 | |
| Curvature | Positive | 46.6 | 40.4 | 1.2 | 3.7 | 4 |
| | Flat | 40.2 | 48.1 | 0.8 | 2.7 | |
| | Negative | 13.2 | 11.6 | 1.1 | 3.6 | |
| Distance to drainage (m) | 0-<50 | 27.1 | 10.1 | 2.7 | 4.5 | 11 |
| | 50-<150 | 21.6 | 17.9 | 1.2 | 2.0 | |
| | 150-<300 | 19.6 | 20.8 | 0.9 | 1.6 | |
| | 300-<500 | 9.5 | 20.4 | 0.5 | 0.8 | |
| | >500 | 22.2 | 30.8 | 0.7 | 1.2 | |
| Distance to road (m) | 0-<100 | 1.1 | 15.2 | 0.1 | 0.1 | 9 |
| | 100-<200 | 2.9 | 12.2 | 0.2 | 0.3 | |
| | 200-<300 | 13.0 | 10.3 | 1.3 | 1.8 | |
| | 300-<400 | 19.6 | 9.2 | 2.1 | 3.1 | |
| | 400-<500 | 17.8 | 7.8 | 2.3 | 3.3 | |
| | >500 | 45.5 | 45.3 | 1.0 | 1.4 | |

**Notes:** $X_{ij}$, Relative frequency; $W_j$, Weight value.

added using the raster calculator in GIS to produce a Landslide Susceptibility Index (LSI) based on the weighted linear sum method (Deoja et al. 1991) (Eq. 2).

$$LSI=\sum_{j=1}^{n}(W_j \times X_{ij}) \quad (2)$$

where $W_j$ is weight value of parameter $j$, $X_{ij}$ is the rating value of class i of parameter $j$ and $n$ is number of parameters. The natural break method was used to reclassify the landslide susceptibility into three classes: low, medium and high.

## 3 Results and Discussion

### 3.1 Landslide susceptibility mapping

Preparation of landslide susceptibility map (LSM) (Figure 3I) depends on different landslide predisposing factors and very close relationship between landslides and earth's surface data. Most of the landslides are concentrated and abundant on south-east, south and south-west because the south facing slopes in the Nepal Himalaya are generally steep, rain-bearing wind, exposure with sunshine and on the windward side of the summer monsoon rain with sunlight (Ghimire 2011). Slope is another important factor for determining the landslide distribution because shear stress increases in the soil or in other unconsolidated materials as slope increases and downhill component of force is high on the steeper slopes (Chapin et al. 2002; Dai et al. 2001; Lee and Choi 2010) and therefore the landslide distribution is high in higher slope (Table 1). Similarly, the landslide distribution is frequent in higher elevation because higher elevation has generally higher rainfall in the mid-hill of Nepal and higher rate of weathering which leads to instabilities. The curvature represents the geomorphology of the topography and controls the distribution of landslides (Lee and Dan 2005). The frequency ratio is more or less equal in positive and negative curvature. Positive curvature in this area exposes to changing of mechanical properties of loose debris (Figure 2A & C) which induced creeping or slide during rainy season and slope failure also common in concave area due to long-term accumulation of sediment transported from adjacent slopes resulting in thicker soils and the convergence of subsurface flow leading to higher pore pressure (Gabet and Dunne 2002).

Drainage (streams and rivers) and roads are predisposing factors for landslide occurrences and distances from those attributes are important because saturation degrees of the materials directly affect the slope stability and also the slope change during road construction. The relation between drainage and landslide clearly shows that the distributions are high near the drainage. However, there appears to be an inverse relation with proximity with road because the frequency is

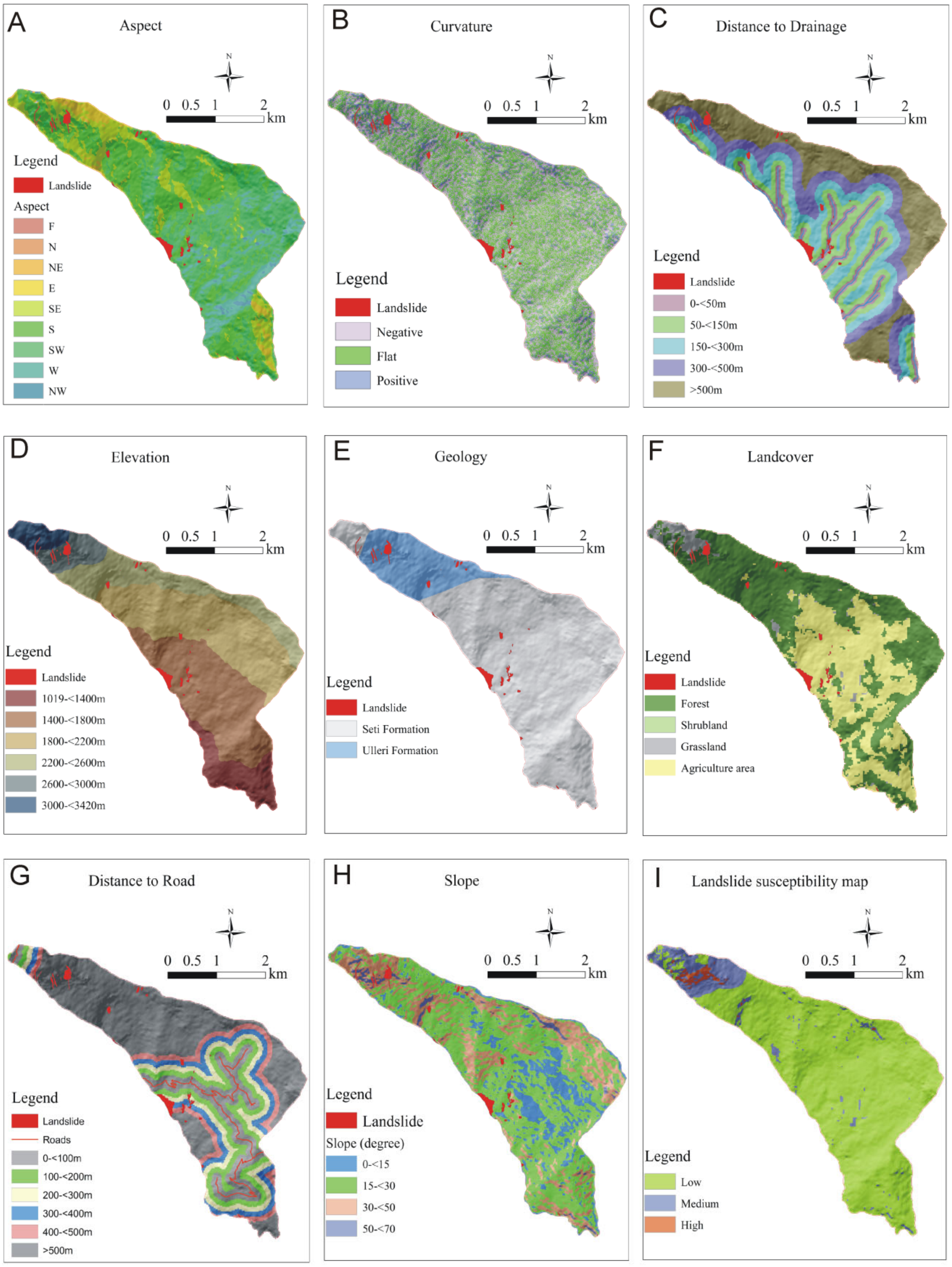


**Figure 3** Different predisposing factor maps (A, B, C, D, E, F, G, H) and Landslide susceptibility map (I) of Sundrawati Village.

higher as distance increases. This shows that geomorphological parameters in this area exert a greater influence on landslide signatures than road construction in this particular area. The relation between landslide and land cover/land use is very important because roots can contribute to the shear strength of soils and thus decrease the probability of landslide occurrences (Sivakami and Sundaram 2014). Landslide frequency is high in grassland compared to agricultural land, shrub land and forest. The observed landslide frequency is high in Ulleri Formation than Seti Formation, because the former contains highly weathered augen gneiss and schist, and grey to greenish-grey phyllites that have relatively low shear strength and are therefore more likely to generate unstable slopes (Figure 4).

**Figure 4** Moderately weathered thinly foliated schist with quartz band of Seti Formation. The thickness of schist band is ranges from 2 cm to 20 cm with lots of discontinuities.

The landslide susceptibility index was calculated by summation of all scores based on Deoja et al. (1991) and most of the area (89%) (10.9 km$^2$) lies in low susceptible zone followed by Medium (9%) (1.2 km$^2$) and High (1%) (0.2 km$^2$) (Figure 3I). Landslide susceptibility is mostly controlled by land cover, slope and elevation in this study area which is also mentioned by Gautam (2011) in Siwalik region of Nepal that landslide susceptibility is dominantly controlled by slope gradient and relative relief. The landslide susceptibility map (LSM) (Figure 3I) reflects a series of landslide predisposing factors. The highest landslide susceptibilities are concentrated south-east, south and south-west facing slopes in the Nepal Himalaya as these are generally steep and subject to significant soil moisture variations as these slopes capture the monsoon rains, are exposed to solar radiation and the prevailing wind direction (Ghimire 2011). Slope angle is another important factor for determining landslide distribution; there is an important balance between the frictional resistance of soils and slope angle and generally the stability of slopes diminishes with increasing slope angle (Chapin et al. 2002; Dai et al. 2001; Lee and Choi 2010; Table 1). Landslide frequency is generally higher at greater elevations as these often capture more rainfall than the mid-hills of Nepal and have a higher rate of weathering. Slope curvature can also be a useful parameter as this can be used to identify potentially unstable topographic features (Lee and Dan 2005). In the study area it appears that the frequency ratio is more or less equal for both positive (convex) and negative (concave) curvatures. Positive curvature in the study area represents changes in the mechanical properties of loose debris (Figure 2A & 2C) and this can lead to creep or sliding during the rainy season. Slope failure is also common in concave areas, often due to long-term accumulation of sediments transported from adjacent slopes resulting in thicker soils and the convergence of subsurface flows leading to higher pore pressure (Gabet and Dunne 2002).

### 3.2 Early warning systems

The Mehele landslide in Sundrawati Village was selected for the LEWS establishment based on the landslide susceptibility map (Figure 3) and rigorous discussions with community, community leaders, local government and experts. Based on landslide susceptibility map and further field verification coupled with community interaction an early warning system was installed within the landslide area. Relatively stable land was identified to establish the LEWS just above the crown of creeping Mehele landslide. The system consists of a microcontroller and interfacing circuit, extensometer, solar panel, siren and soil moisture sensor (Figure 5A and 5B). The microcontroller and interfacing circuit consists of an Arduino Mega controller, flash memory of 256 KB, SRAM 8Kb, EEPROM 4 KB, Click Speed 16 MHz, Click Speed 19MHz, and an LCD 16×2 display. The extensometer is a combination of a probe/wire and a displacement resolution of approximately 2mm.

The power supply is supported by a 50W solar panel, a 12-38Ah dry battery and a charge controller. The LEWS is located at N 27°43'22.54''; E 86°03'49.11'' at an altitude of 1952 m (Figure 5C). The area is fenced with gabion wire and a caretaker monitors the system. If the system detects deformation/soil moisture changes that exceed certain threshold the system will send the information to an assigned person from the community and security personnel of the government.

The total length of the landslide is 160 m and 4 extensometers are installed by connecting one standing rod for every 40m. The monitoring system was put in place in May 2018 with the technical support of the Food and Agricultural Organizations of the United Nations (FAO) and Department of Forests and Soil Conservation (DoFSC), Government of Nepal.

Community interaction provided significant assistance to better understand the local knowledge about landslide risk, to develop appropriate strategies to present a scenario of the settlement in relation to landslide, to gain an insight into which portions of the landslide are most susceptible to movement, to assess the locals' acceptance of new technology, to raise the awareness level and address gaps in knowledge among the community, local leaders, local administration and district administration. The community allocated private land for the installation of the LEWS and committed to protect the system.

Previous studies showed that the accumulated rainfall amounts and intensities are important for the LEWS. For example, a modified JICA (2009) threshold of 60 mm rainfall in 12 hours was adopted in the Kabilsh village (Chitwan). In normal conditions, when daily rainfall exceeds 144 mm there is always an elevated probability of landslide occurrence in Himalayan slopes (Dahal and Hasegawa 2008). It was decided to lower this threshold for the Mehele landslide as it already has extensive surface cracking and was activated by the 2015 Gorkha earthquake and its aftershocks. The threshold value considered relevant for this landslide was 60 mm or more in 24 hours. The establishment of a soil moisture threshold value for landslide triggering is quite limited in the context of Nepal. Elsewhere, a number of false warning system were observed when a soil moisture threshold set at below 54%, but a 75% threshold appears to generate satisfactory results as part of a warning system in Italy (Segoni et al. 2018). The Mehele landslide area is characterized by wet and

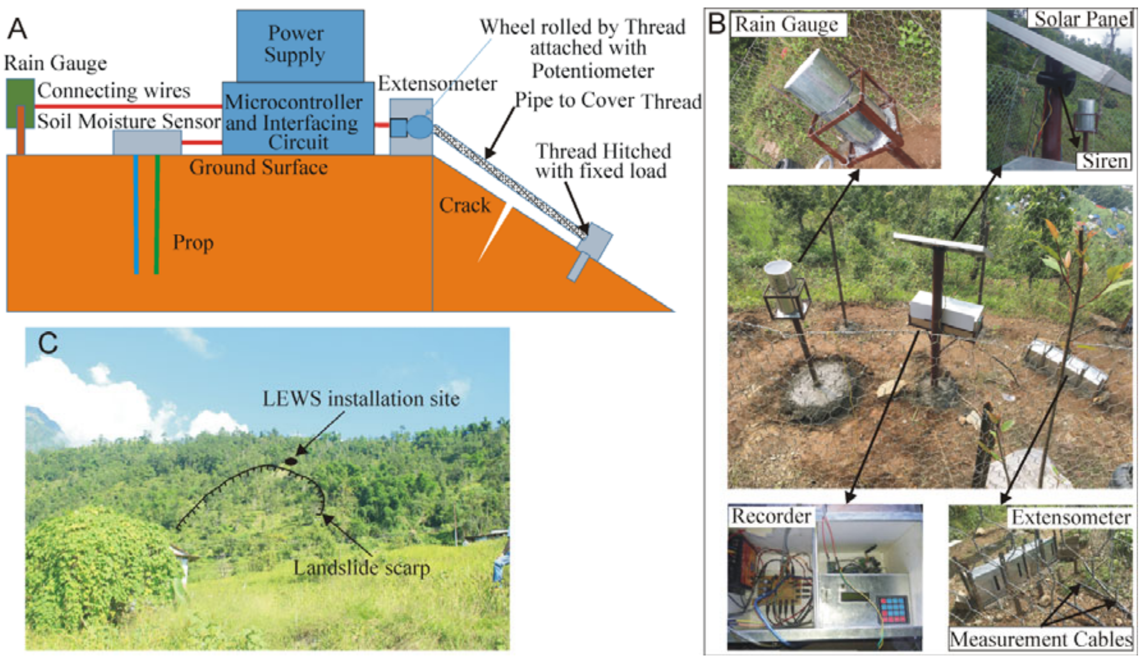


**Figure 5** Different parts of monitoring systems. A. Schematic diagram of automatic extensometer; B. Installedextensometer showing different parts; C. The landslide scarp. The 50W solar panel is oriented towards SW direction and the Tipping box rain gauge is installed with concrete. The recorded is connected with Soil moisture, 4 automatic extensometer and rain gauge.

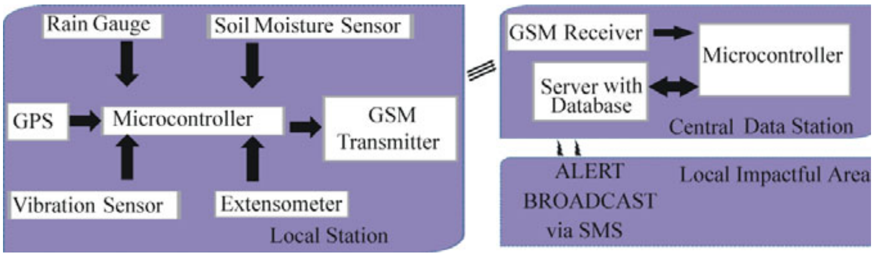


**Figure 6** The Short Message Service (SMS) alert sending mechanism through Global System for Mobile Communications (GSM) network from station to affected area.

soft ground conditions and therefore a soil moisture content equal to or more than 60% was considered as an upper threshold. Crack widening equal to or greater than 30 cm was considered as a minimum threshold for LEWS (see Yin et al. 2010). A combination of four extensometers was assigned to collect real time data of surface movement of the landslide.

The system applies an algorithm based on movement, soil moisture and rain-gauge to provide the alert message. If rainfall crosses the threshold of 60 mm within 24 hours or cracking increases equal or greater than 30 cm and moisture content in the soil exceeds more than 60% then the system alarm the siren as well as send alarm SMS to key focal persons, including the caretaker. The warning message is transmitted in two ways: short message service (SMS) and siren. The system is connected through a GSM network and data is transmitted to the authorities in the form of SMS (Figure 6). Based on the SMS alert and siren the local people have been advised to evacuate the settlement and move to the safe house prepared for emergency shelter during any kind of disaster in the area (Figure 7).

The EWS was set up on 28th May 2018 to monitor the Mehele Landslide in Dolakha District. Altogether 495 people from 117 households benefited from this system and most of them are from marginalized populations living under the threat of landslide disaster. Local governmental organizations such as the Rural Municipality/Ward office and the Local Disaster Management Committee (LDMC) are responsible for circulating the warning to the local resident, whereas the local police is actively involved in security management, and search and rescue operations. The district coordination committee is responsible for coordination among different stakeholders working in the district and sharing information with the national level organizations based on priority. This landslide early warning system is user friendly and easily operable, but this system can generate data only about rainfall, soil moisture information and displacement and therefore some little training is required to interpret this data and provide appropriate information dissemination.

*"False alerts were noticed on 13th August 2018. Local people heard the alarm and Caretaker informed the concerned authority i.e. District Soil Conservation Office and local community about the situation. The caretaker has examined the LEWS physically and confirmed that LEWS was working perfectly with no large displacement. The rainfall was not heavy on that day. According to locals they perceived it as onsetting of landslide however nobody left home with that siren".*

The LEWS has been functioning properly after installation (Figure 8) until the landslide has destroyed extensometer at 11 pm on 23rd August, 2018. High rainfall (88.7 and 49.5mm/24hours) on 22nd and 23rd August, 2018 had increased the moisture content (63%) and finally landslide had occurred destroying the extensometer wires and

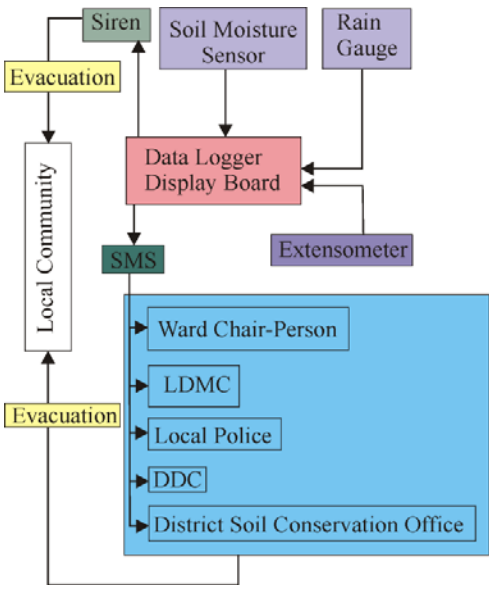


**Figure 7** Two way early warning in the form of SMS and siren for evacuation (LDMC, Local Disaster Management Committee; DCC, District Coordination Committee; SMS, Short Message Service).

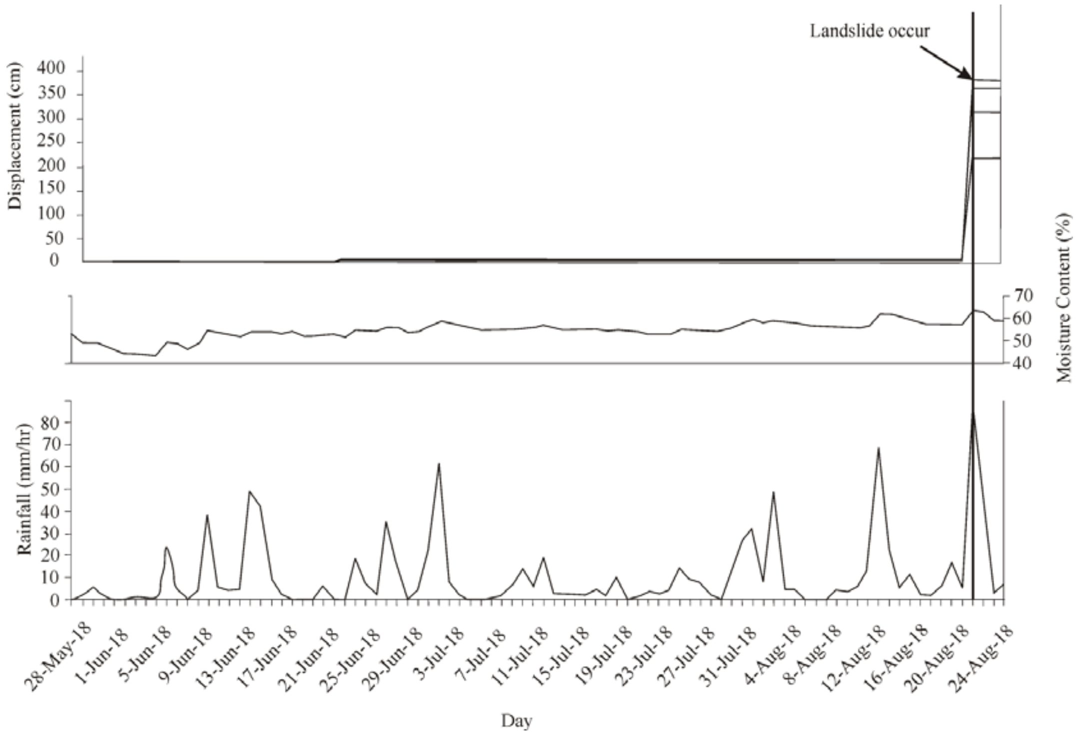


**Figure 8** The result of measurement by 4 extensometers, rain gauge, and moisture content.


**Figure 9** Mehele landslide, A. Trees and drainage canal destroyed by a landslide; B. Landslide has destroyed wire extensometer and pegs.

pegs (Figure 9).

*According to Locals (i.e Mr. Ganesh Thami), the night was terrible with heavy rainfall with windstorm and people were afraid from this kinds of unusual phenomena. Families having with concrete roofing material were able to hear the sound of siren but the families having roofs of corrugate Zinc sheets were unable to hear the sirens.*

The local community was alert after hearing the siren and prepared for evacuation. However, the landslide did not destroy any houses because of short run-out distance. After the event, there is some good learning and this includes the need for the siren tower to be placed higher than the trees and with a double siren attached to make sounds audible for all. Also, its location should be at a place nearest to the settlement. The community perceived that if there is adequate readiness time then they would be able to save their livestock, food materials and other valuable goods. The local community has already taken ownership for this LEWS, therefore, sustainability of the system is already secured there. This system has already set a landmark in the history of landslide early warning system in Nepal. The Government of Nepal is also trying to replicate the community-based landslide early warning system to reduce disaster risk in earthquake affected districts in the Nepal Himalaya. DoFSC, Government of Nepal is ready to continue technical support for one more year for the sustainability of this system. This system is user friendly, easily operable and can generate data about rainfall, soil moisture and displacement. The major limitations of this system are associated with the lifespan of the battery, the need for continuous power supply and continuous monitoring.

## 4 Conclusion

Community-based landslide early warning systems form very important tools for landslide risk reduction in the Nepal Himalaya. Landslide susceptibility mapping helps to identify the probable locations of potentially unstable slopes and therefore helps to indicate the most vulnerable places. Local knowledge and field verification of observations provide additional insights in determining appropriate threshold conditions. Additionally, factors such as easy operation, user friendly interaction and the use of economically viable low-cost technology are very important to ensure successful implementation. The landslide early warning system in Sundrawati can be considered as a landmark for the communities vulnerable to landslide risk in Nepal as it has given a clear indication of the potential of such a system to save lives. Continuous monitoring of displacement is clearly a very useful technique to understand the landslide mechanism. This can also inform strategies for the stabilization of the slope and the preparation and communication of an evacuation plan to save lives and property of the communities living under the threat of landslide disaster.

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