Adoption of Four Pillars of Landslide Early Warning System in Neelkantha Municipality

1. Introduction

According to the United Nations International Strategy for Disaster Risk Reduction (UNISDR)[1], Early Warning System (EWS) is defined as the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by hazards to take necessary preparedness measures and act appropriately in sufficient time to reduce the possibility of harms and losses. The UNISDR defines hazard as a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage. Examples of hazards are floods, landslides, earthquakes, etc. EWS essentially comprises of the four key elements of (a) risk knowledge, (b) monitoring and warning services of hazard (c) communication and dissemination of alerts and warnings and (d) response capacity development.

Data compiled by the Ministry of Home Affairs (MoHA)[2] for the year 2017 and 2018 show that the 483 landslide events triggered across the hilly and mountainous regions of the country caused an annual average loss of life of 82 people and uncountable loss of property amounting to an estimated value of NPR 191.662 million in the 2 year. The events are in increasing trend due to the impacts of climate change. The Sixth Assessment Report (AR6) of the Inter-Governmental Panel on Climate Change (IPCC) estimates that more intense rainstorms are likely in future leading to increased landslides in the fragile mountain landscape of Nepal. It is therefore very important to design and implement various activities and options that help to save the lives and properties of the country's vulnerable people. The design and implementation of the Landslide Early Warning System (LEWS) has been identified as one of the best options in reducing the loss of lives and properties.

LEWS is limitedly known in Nepal and probably in the world too because of the complexity and uncertainty of the two main components (a) landslide hazard assessment and (b) monitoring and warning services for landslides. The first component is primarily related to a number of landslide causative factors such as slope, soil, land use and land cover, geology, rainfall amount and intensity and historical landslide database. Characteristics of a landscape related to these factors vary in space and time and limitedly available historical landslide database which makes landslide hazard assessment difficult[3]. The second component illustrates on the monitoring and warning services which are related to the soil-water interaction during rain and are very complex to estimate and predict[4].

With these backgrounds, design, implementation and operationalization of LEWS is now gaining interest in the scientific and technical communities among decision makers. With the rapid development of tools and techniques along with mathematical models, significant progress has been made on landslide understanding and prediction which has been recognized as the first step in the LEWS development. Cost effective LEWSs are in practice in different parts of the world like the United

States of America, Taiwan, Canada, Hong Kong, New Zealand, Italy[5] etc., although many of them are still in the research stage. However, it is very new and less effort on its research and development is made in Nepal although large portion of the country is prone to slope failures. In such context, FEED P. Ltd. as a research grantee of the USAID's Tayar Nepal has designed and implemented cost effective LEWS in a research catchment of Arun Khola located in Neelkantha Municipality, Dhading District.

2. The Research Catchment

Located at about 90 km west from Kathmandu, the research catchment lies in Neelkantha Municipality of Dhading District (**Figure 1**). The municipality is divided into 14 wards and the ward is the smallest administrative unit in Nepal. Having a total area of 11.5 km^2, the research catchment of Arun Khola falls partly in the ward 1, 2 and 4.

The landslide inventory prepared for the research catchment by using field observation, community consultation and time series remote sensing data show that there are 56 landslides in the catchment. Majority of them are shallow type and few are deep-seated, debris and road construction induced slope failures.

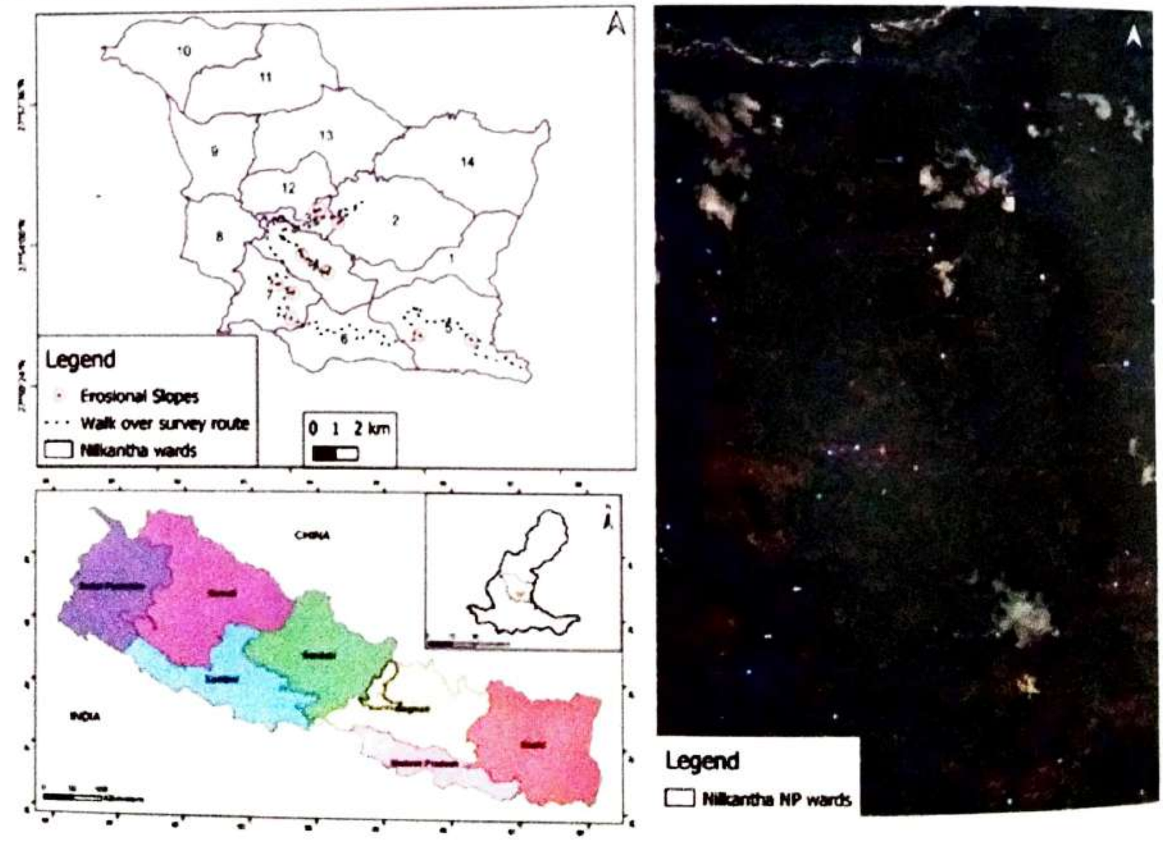


Figure 1: Location Map of the Research Catchment

The Unmanned Aerial Vehicle (UAV) (also known as Drone) was used to map the catchment and derived high-resolution Digital Terrain Model (DTM) and Orthophoto of 40 cm showing that the elevation of the research catchment varies from about 770 m to 1654 m above the mean sea level (masl). The Orthophoto was used to map additional landslides and also to validate the already mapped slope failures.

Geologically, the area is characterized by low angle reverse fault (i.e. thrust) along the contact of Sangram and Naudanda formation. The research catchment comprises Ranimatta, Naudanda, Sangram, Syangja and Lakharpata formations[6], which means that the area is dominated by variant degrees and differential weathering of Phyletic and Meta-Sandstone bedrock. These rocks are prone to slope failures. According to the field measurement, there exist mainly three soil types which are Silty Loam, Loam and Clay-Loam and the soil depth varies from a few cm to more than 2.5 m. Like in other parts of the country, fine-resolution rainfall data is not available in the municipality. The rain gauge established by the Department of Hydrology and Meteorology (DHM) is not functioning for long and hence the data are not available.

The research catchment is now equipped with two sets of automated (a) rain gauges, (2) soil moisture sensors and (3) extensometers. Tipping bucket type two rain gauges have been installed, one each at Pauwaghar and Hilekharka respectively in ward no. 4 and 1 of Neelakantha Municipality. Two sets of soil moisture sensors are also installed, one each at Pauwaghar and Hilekharka. Each set comprises of the three soil moisture sensors installed at 0.30 m, 0.80 m and 1.30 m depth from the earth's surface to see the soil moisture behavior at varying depths during rain. The data from the sensors will help to define soil water interaction during rain and landslides. Finally, two sets of extensometers are installed, one each at Rijalthok, near Pauwaghar and Hilekharka . The total length of the extensometers is 52 m and 55 m respectively at Rijalthok and Hilekharka. The extensometers capture data related to soil movement during slope failures.

Figure 2: Installed Automated Rain Gauges at Pauwaghar 4 and Hilekharka 1

Ministry of Home Affairs (MoHA) data portal (i. e. Bipad Portal)[7] show that there were 9 landslide events between 2002 and 2022 affecting 227 households in the municipality, which is heavily underreported. The most recent one triggered on 25th July 2022 caused the death of a female at Ranagaun in ward number 4. Similarly, a number of landslides were triggered in Hilekharka, Bhulbhule and Rijalthok, and respectively ward No. 1, 2 and 4 of Neelakantha Municipality on 25th July 2022.

3. LEWS Components

3.1 Landslide Risk Knowledge

Landslide Susceptibility Model

Landslide Susceptibility mapping is the first step in the landslide risk knowledge. The Landslide Susceptibility Map (LSM) for the research catchment has been prepared in Geographic Information System (GIS) environment. The UAV derived high-resolution DTM data (40 cm spatial resolution) were used to derive various topographical attributes such as slope, aspect, and curvature which were later applied in GIS to develop the LSM. The digital datasets of DTM, land cover, soil and geology were used to derive various factors maps of (a) distance to drainage, (b) curvature, (c) land use, (d) Normalized Difference Vegetation Index (NDVI), (e) slope, (f) soil type, (g) terrain wetness index and (h) aspect.

The frequency Ratio (FR) technique was applied in preparing LSM which is a bivariate statistical method and is widely used for evaluating the landslide susceptibility. The FR method correlates the past landslide data with different factors leading to the probability and landslide occurrences and provides the extent to which each factor affects the occurrence of landslides. The prepared LSM is presented in **Figure 3** which shows that about 26% of the research catchment is highly susceptible to slope failure followed by 44% and 30% respectively moderate to low susceptibility. The evaluation of the model depicted that the model was able to predict about 84% of the observed landslides and has 87% success rate.

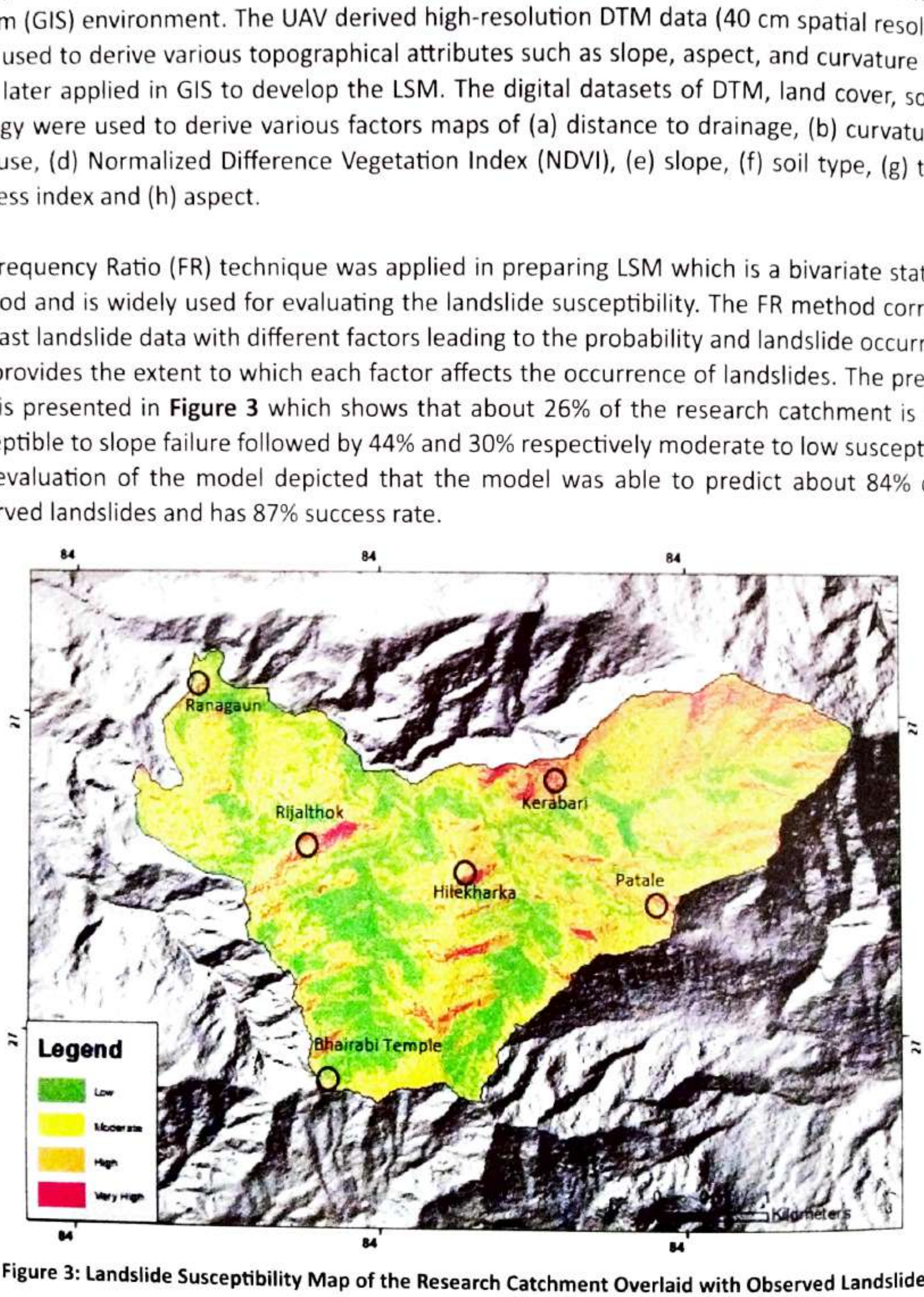


Figure 3: Landslide Susceptibility Map of the Research Catchment Overlaid with Observed Landslides

Physically-based Landslide Hazard Modelling using Factor of Safety

The catchment scale Factor of Safety (FoS) map was developed using the physically based Infinite Slope Stability Model (ISSM) which computes the factor of safety of the slope. The FoS is the ratio of soil's shear strength and developed stress. The use of the FoS helps to evaluate the stability conditions of a slope under varying wetting fronts during real time rainfall or DHM forecast rainfall. Knowing the geotechnical properties (such as soil cohesion, angle of internal friction, soil texture, soil depth etc.), land cover data (root cohesion), DTM data (slope, upslope contributing area etc.) and rainfall characteristics, the FoS of a landscape can be estimated. The landscape having FoS less than a prescribed value (1.50 in this case) are generally regarded as a potentially unstable slope which may lead to failure (**Figure 4**).

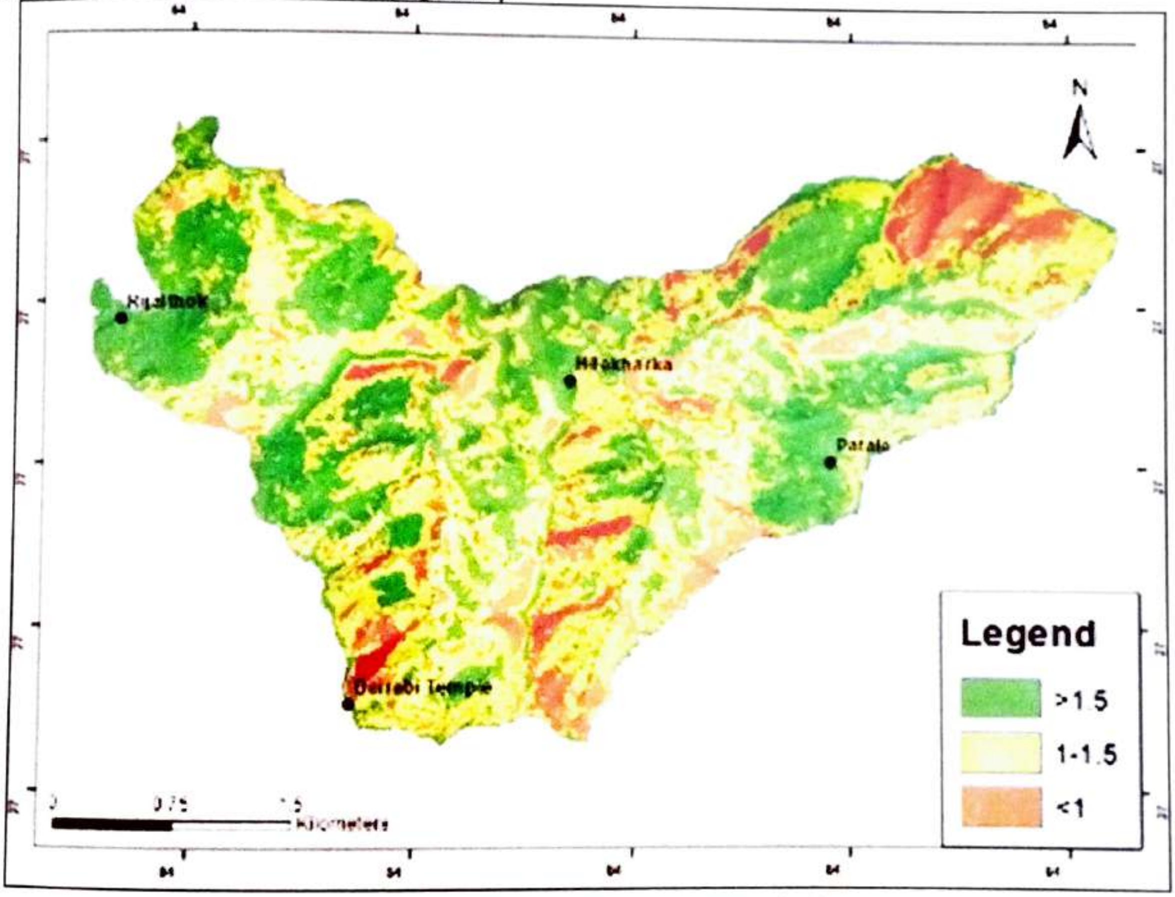


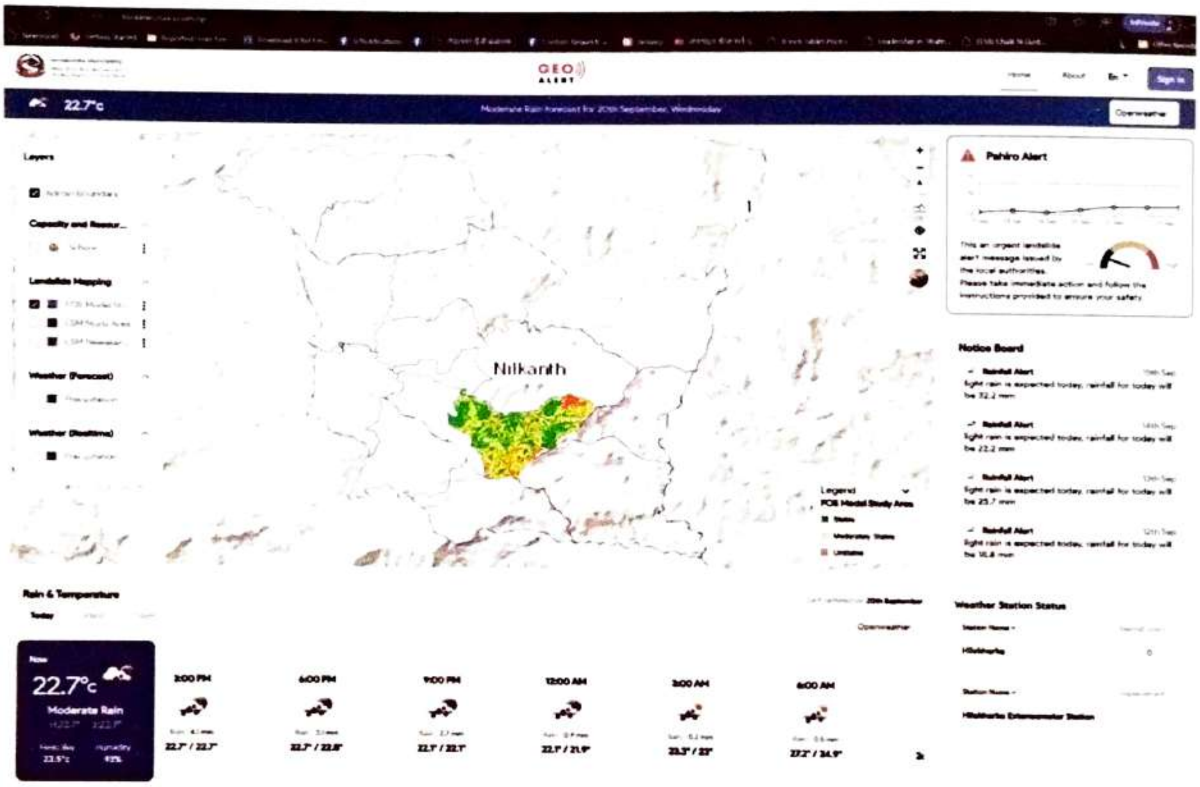
Figure 4: Landslide Hazard Modelling by using Factor of Safety Assessment

The FoS model depicted reasonably representative results and has been able to capture most of the observed landslides. The FoS model depicted that about 26% of the catchment area has FoS less than 1 followed by 48% and 26% has FoS of 1-1.5 and greater than 1.5 respectively. It is important to note here that FoS greater than 1.5 indicates that the slope is stable, FoS of 1-1.5 means moderately stable and FoS less than 1.00 means that the slope is prone to failure during rain.

These two maps are expected to enhance the knowledge of the communities and the municipality's authority on landslide risk assessment. The maps provide information about households, land cover and other infrastructure falling on landslide prone area. Various training programs and capacity development activities have been delivered at the municipality and community levels to enhance their landslide risk knowledge and understanding.

3.2 Monitoring and Warning Services of Landslide Hazard

Monitoring of a real time or potential rainfall event is an important parameter in the LEWS. The real time monitoring is undertaken from the rain gauges, soil moisture and extensometers installed at the research catchment. The data from these stations and sensors are directly displayed at the web-based Dashboard handled by the municipality. Similarly, forecast rainfall from the DHM is also incorporated in the Dashboard so that the upcoming threshold rain can be visualized in advance.



This an urgent landslide alert message issued by the local authorities.
Please take immediate action and follow the instructions provided to ensure your safety.

Figure 5: Geo Alert Dashboard Interface (Top) and Real Time and Forecast Rainfall Visualization in the Dashboard (Bottom)

According to the Standard Operating Procedures (SOP) developed for the LEWS in Neelkantha, the municipality officials (typically LEWS taskforce) regularly monitor both (i. e. real time and forecast) rainfalls. In the dashboard, a 5-day forecast rainfall is displayed which is regularly updated in accordance with the DHM's updates. The officials also monitor the landslide hazard map and LSM to identify the landslide prone zone during extreme events. They are also to assess the rainfall threshold to trigger landslide. Once the real time or forecast cumulative rainfall exceeds the threshold, the municipality will issue the warnings in accordance with the communication channel developed in the SOP. The SOP has identified different stakeholders at federal, provincial, district, municipality and community levels which will also be engaged during landslides.

The rainfall threshold model for the municipality has been developed from the historical landslide events using regression rainfall analysis, considering five days of cumulative antecedent rainfall. According to the regression equation, the threshold rainfall is given by the following equation and **Figure 6**.

"Threshold Rain ≥ 155 - 0.6 x 5days antecedent rainfall"

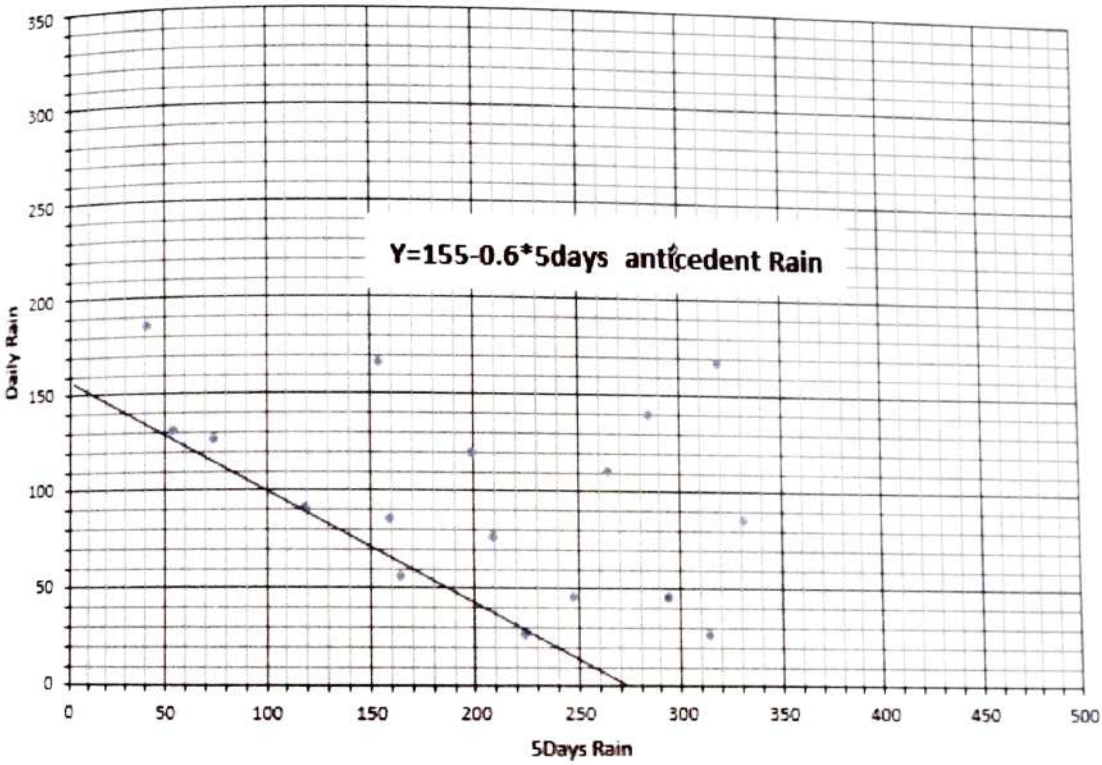


Figure 6: Daily vs. 5-Day Rainfall to Trigger Landslides in Upstream Catchment of Arun Khola

The relationship of threshold rainfall indicated that the daily cumulative rainfall equal to or greater than 155 mm could trigger landslides in the research catchment. Deducting the daily rain (or real time rain or the forecast rainfall) to the threshold rain, shown above often turns negative values if it turns positive and greater than (or approached) to "0", the rain would potentially trigger landslides in the hilly terrain of the municipality. The Dashboard allows the user to graphically visualize on how the threshold rain approaches to the pre-defined threshold line in the dashboard (**Figure 7**).

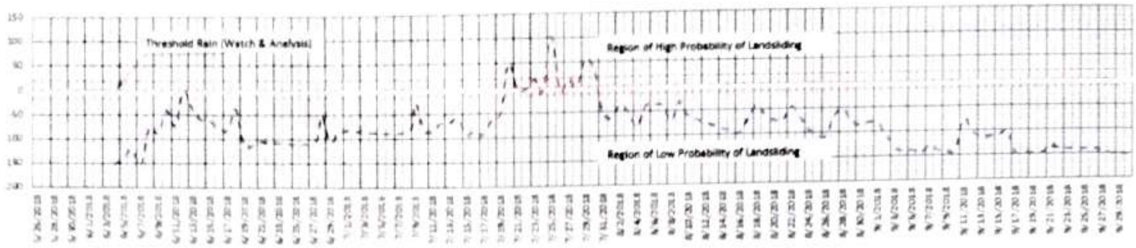


Figure 7: Graphical Visualization of Rainfall in the Dashboard

3.3 Communication and Dissemination of Alerts and Warnings

A LEWS taskforce led by the coordinator of the Local Disaster Management Committee (LDMC) has been provisioned in the SOP which is responsible for the communication and dissemination of alerts and warnings. The SOP's communication channel is presented in the **Figure 8**.

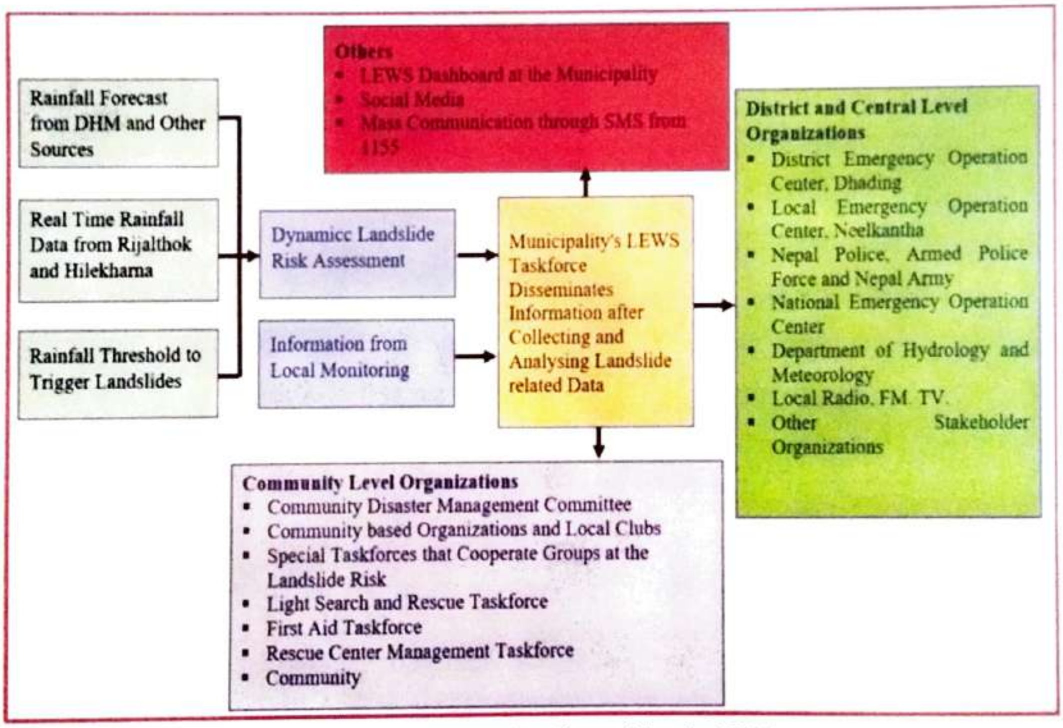


Figure 8: Communication Channel for the LEWS

The Dashboard will be the focal point of the communication because all the data and information related to the landslide hazard are collected, processed and displayed on the board. Sometimes, local level monitoring are also important and therefore information from the local communities are also gathered through the Community Disaster Management Committee (CDMC). Information from the CDMC typically includes cracks formation along hillslope, their expansion rate and other anomalies like tilting of electric pole, wall of buildings etc. Cracks across the hillslopes increase the infiltration of the water below ground leading to the slope failures. The CDMC and local communities regularly undertake such monitoring and subsequently inform the municipality.

Various training and capacity development activities have been organized for the proper and authenticated communication (**Figure 9**). These trainings were targeted to the municipality's officials and LEWS Users' Committee formed at the local level representing entire communities and including elderly people, people with disability, women, Dalit and marginalized group. These trainings have been very beneficial to the target group in terms of data collection and dissemination.

Figure 9: Capacity Building for Communication and Dissemination

3.4 Response Capacity Development

The "Response Capacity Development" is another important component of the LEWS which has been employed at the two levels: Community and Municipality Levels. Municipality level response capacity is required to collect and disseminate landslide and rainfall related data and to mobilize district and central level organizations during extreme events. According to the SOP, the municipality will issue the advisory notice to the communities and other stakeholders in advance based on different scenarios of rainfall forecast (**Table 1**). The advisory notice should provide adequate time to the communities for preparedness and response. The notice of longer duration such as 2 to 5 days generally provides enough time to the communities and other stakeholders to act and for the required preparedness. In such durations, they are engaged in identifying safe evacuation centers and routes, stocktaking of their goods to be saved, preparing "Go Bags", in saving their lives along with livestock. It is also important to mention here that the municipality is to regularly be updated with the rainfall forecast provided by the DHM and other reliable sources prescribed by the DHM. In many cases, DHM's forecast is generally updated frequently which is to be closely monitored and updated by the municipality.

Table 1: Forecast Type and Corresponding Advisory Notice Time

SN	Forecast Type	Advisory Notice Time
1	15-Day Forecast	5 Day
2	7-Day Forecast	3 Day
3	5-Day Forecast	2 Day
4	3-Day Forecast	24 hours
5	2-Day Forecast	24 hours
6	24-hours Forecast	6 hours
7	Less than 24-hours Forecast	Less than 6 hours

To enhance the response capacity of the community, we accomplished a Mock Drill Simulation on 4th September engaging the community members of Kharka Gau, Rijalthok 4 of the municipality. Kharka Gaun is one of the most landslide prone settlements which is also a home of marginalized, Dalit and economically disadvantaged families. Altogether, there were 45 participants which included 30 community members and the rest were municipal official officials, representatives of the security forces, Municipal police, etc.

Figure 10: Mock Drill Simulation for Response Capacity Development

The simulation provided an opportunity for the participants to understand the LEWS and its components. They had a chance to learn various actions that are required prior to receiving early warnings, after receiving early warnings of landslides including travel to the safe evacuation centers and assembling at the center. The participants also learned about the Light Search and Rescue along with First Aid treatment procedures. They also gained knowledge on how to prepare a "Go Bag", and select suitable geographical locations for a helipad and its layout in case of emergency rescue.

4. Future Work

Following future works are suggested for the better and more efficient LEWS.

Landslide Threshold Model: The current landslide threshold model is typically based on the historical data of landslide events which typically include landslide dates and corresponding rainfall amount. The model has been developed using the limited historical landslide data and the data obtained during 2023 monsoon after the installation of instruments for LEWS. The model therefore needs a significant improvement and update upon receiving and using the data from the stations located at Rijalthok, Pauwaghar and Hilekharka. The upcoming data will definitely improve the model and a robust model will be developed.

Rainfall Data Resolution: Landslides are generally triggered during intense but short duration and low intensity long duration rains. The current model is derived using the daily and 5-day cumulative rainfall data which does not consider lower-day (1, 2, 3, and 4 day) cumulative rainfall which is also important in LEWS. Similar threshold models of the lower day cumulative rainfalls need to be developed. More importantly, intense rains of short duration are also to be used to develop the rainfall threshold model. The use of high resolution sub-hourly rainfall data from Pauwaghar and Hilekharka will provide an opportunity to develop another appropriate threshold model which will further help in saving lives and properties in Neelkantha Municipality.

Landslide Risk Assessment and Knowledge: Landslide risk is a dynamic process and various parameter associated with it are changed over time due to number of reasons related to natural process and anthropogenic activities. Therefore, landslide risk assessment should be improved and updated on a regular basis. Accordingly, the knowledge of the community, municipality and other stakeholders on the landslide risk should be assessed regularly and they are to be re-capacitated.

(Endnotes)

1 2009 UNISDR Terminology on Disaster Risk Reduction

2 MoHA, 2019, Nepal Disaster Report

3 Chu, M., Patton, A., Roering, J., Siebert, C., Selker, J., Walter, C. and Udell, C. (2021). SitkaNet: A low-cost, distributed sensor network for landslide monitoring and study. Hardware X.

4 Sehler, R., Li, J., Reager, JT and Ye, Hengchun (2019). Investigating Relationship Between Soil Moisture and Precipitation Globally Using Remote Sensing Observations. Universities Council on Water Resources.

5 Guzzetti, F., Gariano S. L., Peruccacci, S., Brunetti, M. T., Merchesini, I., Rossi, M. and Melillo, M. (2020). Geographical landslide early warning systems. Earth-Science Reviews.

6 Geological Map of Nepal prepared by the Department of Mines and Geology

7 Bipad-Portal (https://bipadportal.gov.np/)

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