TU-CDES & UNDP Cooperation
Strengthening Disaster Risk Management in Academia

Report on
Hazard and Vulnerability Assessment of Darbung VDC, Gorkha

Prepared by
Strengthening Disaster Risk Management in Academia Project
Tribhuvan University
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Executive Summary

In recent years, an increasing number of global and local initiatives have been launched to measure risk and vulnerability with a set of indicators and indices (Birkmann, 2006). Identifying and measuring risks and vulnerability before a disaster occurs—and also after disasters have happened— are essential tasks for effective and long-term disaster risk reduction. In this regard, measuring vulnerability encompasses both quantitative and qualitative methods to describe and operationise vulnerability (Birkmann and Wisner, 2006). In this regard, this study aims to integrate both science and community base knowledge to assess vulnerability of the Darbung VDC, Gorkha District, Nepal. Darbung VDC comprises 9 wards covering the area of 22.14 Km^2. Using GIS application, hazard and landslide susceptibility map were prepared. Accordingly, community based participatory tools were also applied to perform vulnerability assessment.

Weightage method for hazard ranking, found, drought as the most hazardous event having weightage of 15.75 followed by landslide (14), flood (13), forest fire (11.75), wildlife encroachment (5.5), epidemic (5.25), windstorm (2.25), crop disease (1.5) and thunderbolt (0.75) respectively. On the basis of six components viz. human loss, affected families, household damage, economic loss, forest and agricultural land loss, and social impact; vulnerability ranking was calculated and found, ward no. 7 as the most vulnerable ward. Hazard mapping identified ward no 7 covering highest area of landslide. Landslide susceptibility map showed ward no. 2 and 8 located in high susceptible zones. As the drought was seen to be one of the important issues in the place, study about the possible impact and mitigation measures would be very important.

In a nutshell, both science and community base knowledge revealed ward no. 7 as a most vulnerable ward. Community they themselves now can reduce the vulnerability in more extent due to their direct involvement in vulnerability assessment. Hence, if we link science and community base knowledge, disaster reduction efforts in more extents gain the sustainability.

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Abbreviation and Acronyms

CBS	Central Bureau of Statistic
CDES	Central Department of Environmental Science
CFUG	Community Forest Users Group
DAO	District Administration Office
DEM	Digital Elevation Model
DoS	Department of Survey
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
FGD	Focus Group Discussion
GIS	Geographical Information Centre
GPS	Global Positioning System
HECRAS	Hydrological Engineering Centers- River Analysis System
HoD	Head of Department
IOST	Institute of Science and Technology
LDRMP	Local Disaster Risk Management Plan
MHRA	Multi Hazard Risk Assessment
SDRMA	Strengthening Disaster Risk Management in Academia
TU	Tribhuvan University
UNDP	United Nations Development Programme
UNISDR	United Nations International Strategy for Disaster Reduction
VCA	Vulnerability and Capacity Assessment
VDC	Village Development Committee

1. Introduction

1.1 Project Background

TU-CDES is the premier academic institution dedicated to environmental study and research in Nepal since its inception in 2001. With the entry of SDRMA Project funded by UNDP, the Department has extended its activities in the research studies on DRM of national priorities. One important such activity of SDRMA project is to carry out the Multi-Hazard Risk Assessment (MHRA). On the basis of vulnerability severity, TU-CDES has selected Budi Gandaki River Basin as suitable site in its preliminary phase.

Out of five components of SDRMA Project, strengthening institutional capacity of TU-CDES on Disaster Risk Reduction (DRR) is one. To achieve this objective, the Project envisioned professional training on Disaster Risk Management to graduates and faculties of the Environmental Science of the TU under component 3.1 of SDRMA project. Thereby, the aforesaid training was scheduled and performed accordingly with a full cooperation of the UNDP, resource persons and CDES staff **(Annex-1).**

1.2 Training Background

Fifteen days professional Training on DRM was scheduled as in house and field exercise. In the preliminary phase, trainee learnt about the theoretical knowledge on DRM as an in house training from renowned resource person. On the basis, there was five days intensive field exercise to enhance the practical knowledge on hazard and vulnerability assessment. This report is the output of 15 days professional training prepared during the training period.

To attain the training objectives in a most effective way, the following workout was done:

Identification and confirmation of resource persons: Resource persons of various professions and disciplines who have a rich experience on disasters risk assessment and management were explored and indentified and finally their participation was confirmed.

First consultation meeting: First consultation meeting was done on 4th April, 2013 at CDES, Kirtipur to discuss on general course content and schedule of the training. Dr Narendra Raj Khanal, Professor of Geography and DRR expert, proposed draft of 15 days generalized training course content, which was divided into in-house training course (10 days) and field work course (5 days).

Second consultation workshop: Second consultation workshop was held on 16th May, 2013 Dr Pralad Yonzon Memorialat Conservation Chautari, Nayabato Sanepa, Lalitpurto discuss and finalize the contents of training materials and activities.

Announcement of the training and participation selection: Professional Training for the graduates of Environment Science was announced through advertisement in a popular national daily the Kantipur Daily. Seventeen participants, both fresh and earlier graduates who have applied, were registered for the training. These participants comprised mainly of young graduates of environmental science interested to work in DRR. TU-CDES also kept aside some seats for faculties of TU involved in teaching and research of environmental science.

The Professional Training

- Opening ceremony: Having done all preparations, the awaited training had begun from the 16th June and ended on 30th June 2013. On the onset of the training Er. Ganesh Shah, former Minister for Ministry of Science Technology and Environment, expressed his happiness over the inception of such an important training course in Kathmandu. Dr Dinesh Raj Bhuju, the Technical advisor of SDRMA project facilitated the ceremony, and Prof. Dr Madan Koirala and TU-CDES Head Prof. Dr Kedar Rijal highlighted on the project activities and training objectives.

The course of training went smoothly as envisaged and planned. The training adapted the prevalent interactive and participatory methodology using group discussion and brainstorming and reporting while introducing concepts and methods as well as doing activities such as exercises. The use of meta card, flip card, drawing paper were used as training materials.

Highlights of training:

- Introduction to disaster, hazard, risk and vulnerability (Day 1).
- Community based hazard, vulnerability and risk mapping and practical exercises (Day 2).
- Disaster risk management planning and practical exercise (Day 3).
- Landslide hazard mapping: concepts and methods and GIS exercise on deterministic and statistical landslide hazard mapping (Day 4).
- Floods: Causes and Impact, and methods of flood hazard mapping including a use Geo-HECRAS model as practical exercise (Day 5).
- Drought, fire and earthquake hazard and site visit to observe retrofitting of the Hotel Yak and Yeti (Day 6)
- Disaster management Act, policies and Institutional arrangement with a review exercise (Day 7).
- Exposure and Vulnerability assessment using quantification and monetary value and group exercise. Field methods, orientation and preparation instructions for field visit (Day 8).
- Field work training on hazard and vulnerability assessment in Darbung VDC (Day 9-13)
- Use GIS and RS techniques for Hazard assessment of Khani Khola watershed using field and remote sensing data (Day 14)
- Sharing the training output and Closing ceremony (Day 15)

Highlights of field work training (Darbung, Gorkha District)

- Field visit and community interaction followed by data collection through group discussion and short transect walk of damage and risk areas of downstream section of Khani Khola (Day 9).
- Field survey for landslides and debris flow inventory, hazard and risk assessment adapting geomorphic approach (Day 10)
- Community approach of hazard and vulnerability assessment using VCA tool (Day 11).
- Reporting field transect survey and community based hazard assessment (Day 12)
- Return journey (Day 13)

Closing ceremony

The 15th day was observed as a closing ceremony of the professional training on DRM. The occasion was also to share the outcomes of the training course with the invited guests which included various organizations engaged in DRM. The training participants were engaged since morning in preparing individual group report on: Overall training activity, evacuation of the training, management and entertainment activities of the training according to the assignments. The ceremony was organized at the TU Smriti Bhawan, Kirtipurin the presence of former Vice Chancellor Prof. Dr. Madhav Prashad Sharma as Chief Guest, TU-IoST Dean Ms Chirik Shova Tamrakar, as Chair Person. Other invited guests included members of SDRMA Project Steering Committee, HoD of various departments at TU. The resource persons of the training, CDES faculty members and administrative staff also attended the ceremony.

1.3 Hazard and Vulnerability Assessment

Disaster in a general term is a calamity either natural or man-made which shows negative effect on human life and properties along with natural resources. Disasters are the consequence of inappropriately managed risk. Risks are the product of a combination of both hazard/s and vulnerability. Disaster has been defined in different way by different organizations.

The Natural Calamity Act, 1982 of Nepal defined disaster as 'Natural Calamity ' means earthquake, fire, storm, flood, landslide, heavy rain, drought, famine, epidemic and other similar natural disasters- it includes the industrial accident or accidents caused by explosion or poisoning and any other kinds of disaster.

Some key terminologies on Disaster as given by UNISDR are;

Hazard: 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.

Disaster: A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources.

Exposure: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Risk: The combination of the probability of an event and its negative consequences.

Nepal's rugged and fragile geophysical structure, very high peaks, the high angle of slopes, complex geology, variable climatic conditions and active tectonic processes make the country very vulnerable to wide range of natural hazards (UNDP, 2004). United Nations/ International Strategy for Disaster Reduction (UN/ISDR) defines vulnerability as the "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of a community to the impact of hazards: (UN/ISDR, 2004). The characteristics and the situations of a community or asset that make it susceptible to damaging effects of a hazard is vulnerability. Vulnerability of a person or a community remains changing along with the time as well as the influencing factors (Cosic, D. et al., 2011). In recent years, an increasing number of global and local initiatives have been launched to measure risk and vulnerability with a set of indicators and indices (Birkmann, 2006). Identifying and measuring risks and vulnerability before a disaster occurs—and also after disasters have happened— are essential tasks for effective and long-term disaster risk reduction. In this regard, measuring vulnerability encompasses both quantitative and qualitative methods to describe and operationise vulnerability (Birkmann and Wisner, 2006)The vulnerability assessment is considered as the analysis of the potential impact of loss from a successful attack as well as the vulnerability of the facility/location to an attack. Assessing vulnerability of a community beforehand can be considered as the safety measure from probable damage due to disaster. After the vulnerability analysis, it becomes easy to perform various awareness generation activities in order to reduce the vulnerability of the community (Cosic, D. et al., 2011).

Hence, in line with UNISDR terminology, the underlying understanding is that in order to manage risk, decision makers and local communities need to understand the threat posed by a hazard, the magnitude of lives and values exposed to the threat, the specific susceptibility towards hazards through present vulnerabilities, and the range of capacities & measures to protect against risk.

This research was performed incorporating both science and community base principle for the Hazard and Vulnerability Assessment.

1.4 Objective

The overall objective of the study was to assess the hazard and vulnerability of the Darbung VDC, Gorkha District. The specific objectives are:

1. To perform Community Based Vulnerability and Capacity Assessment of Darbung VDC
2. To assess the landslide/debris flow of Darbung VDC
3. To analyze geomorphic characters of debris deposits

2. Study Area and Methodology

2.1 Study Area

Darbung VDC of Gorkha District was selected for the five days field exercise to perform hazard and vulnerability assessment (Map 1). Altogether, deskwork has already been performed for literature review and GIS application. Darbung VDC lies in Election Area 1 with Ilaaka No. 3 of Gorkha District

Latitude: 27°52'14"
Longitude: 84°44'54"
Elevation: 388m

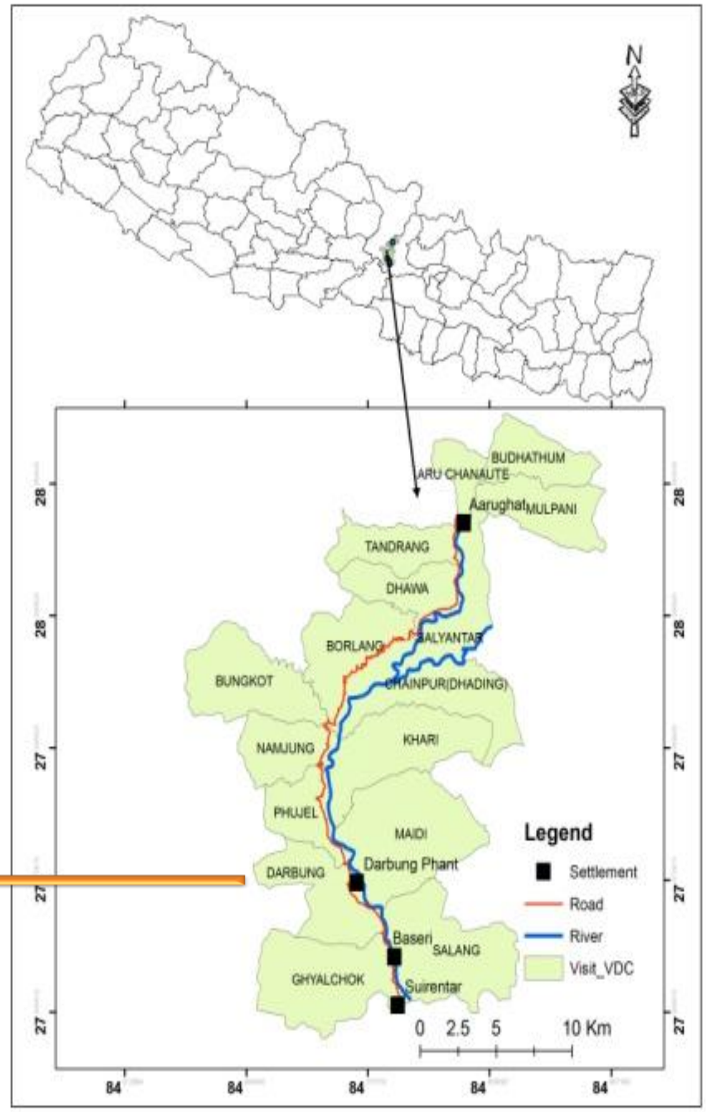
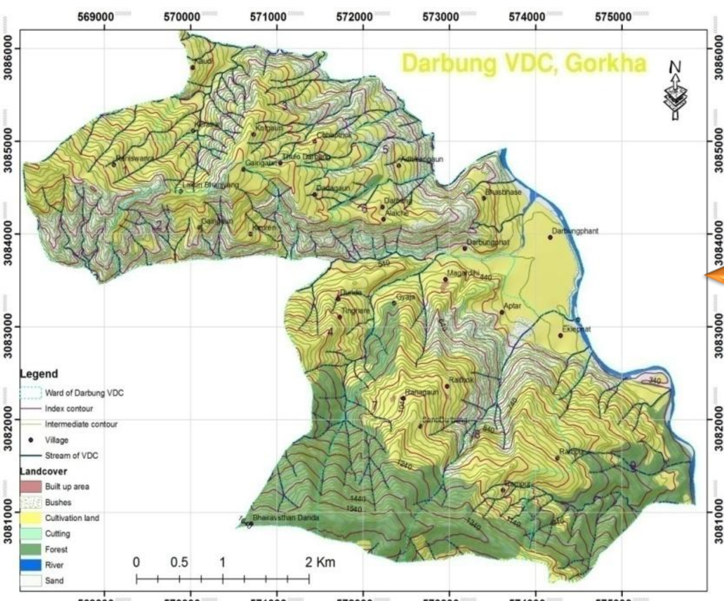


Table 1: Comparative figure of Darbung VDC and Gokrha District (CBS, 2011).

Characters		Darbung VDC	Gorkha District
Area (Km²)		22.14	3610
Household (No)		763	66,506
Population (No)	3386	2,71,061	



Map 1: Study Site, Darbung VDC, Gorkha District

During the assessment, all 9 ward of Darbung VDC was selected and comparative study of vulnerability assessment was done for each ward.

2.2. Methodology

2.2.1 Methodological frame

Different methods were followed to meet each objective. Following table shows the brief information about the methodologies used as per the objectives.

Table 2: Methodological frame

SN	Objective	Methodology
1	**Community based vulnerability assessment**	Community based participatory methods were applied in line with Local Disaster Risk management Plan (LDRMP) Guideline, 2011 published by Ministry of Federal Affairs and Local Development, Government of Nepal.
	• Hazard listing and ranking	
	• Hazard calendar	
	• Historical Timeline	
	• Hazard analysis	
	• Resource Mapping	
	• Problem Tree Analysis	
	• Stakeholder analysis	
2	**Land use pattern & Landslide Susceptibility assessment**	
	• Landslide inventory	Questionnaire survey, Transect survey, GPS boundary, Topographic map interpretations, GPS points, Local Consultations, Resource map verification
	• Spatial distribution of landslide and agricultural land loss	GIS Environment: Cross tabulations
	• Digital Elevation Model (DEM) generation	Combined interpolation of contour and spot height
	• DEM derivation of causative factors	Arc GIS Environment: Surface analysis
	- Aspect	
	- Flow Accumulation	
	- Elevation	
	- Slope angle	
	• Feature Maps - Land use - Road distance - Distance from drainage network	Arc GIS Environment: Feature map of DoS, and Google earth map
	• Landslide index calculation	Landslide index method
	• Landslide susceptible map	Bivariate analysis
	• Landslide susceptibility and Physical Vulnerability	Arc GIS Environment: Cross tabulation of susceptible map with cultivation land and house units of wards.
3	**Analyze geomorphic characters of debris deposited and map the damage area**	Field measurement, GPS boundary survey & mapping

2.2.2. Community based Vulnerability Assessment

Methods suggested in Local Disaster Risk Management Planning (LDRMP) Guideline, 2011 were used to collect and analyse data for community based vulnerability assessment. The study team tried to maintain inclusive participation in term of gender, race, age, ethnicity, and religion, which is crucial for investigating the root causes of social vulnerability (Birkmann and Wisner 2006). Community mobilization was initiated from the beginning of the field visit (Ashad:10-15, 2070 B.S.) through interaction programme held at Magardi, Darbung-7. The program was attended by 31 individuals from Ward citizen forum of Darbung VDC, social mobilizer, CFUG, women group, natural disaster relief and recovery committee, teachers, disaster victims, farmers, students and politicians. Overall disaster scenarios of Darbung VDC were discussed during the interaction programme.

In order to generate data for community based vulnerability analysis, community based participatory methods were conducted. The data so obtained were given weightage for further analysis and interpretation of the findings.

Community based participatory methods are an interactive way of collecting in-depth information on concepts, perceptions, and ideas from a group.

Community Based Participatory methods were conducted in Darbung VDC consisting of approximately 12 to 15 participants from each ward. Participants of wards: 6, 7, 8 & 9 were gathered at Ratneshori Higher Secondary School (Lat/Long: 27.872650°/ 84.749593°) and that of wards 1, 2, 3, 4 & 5 were gathered at Shree Bageshwori Secondary School (Lat/Long: 27.878132° & 84.720256°). Through this methods, hazard were listed and ranked, hazard calendar as well as resource maps were prepared and analyzed with evaluating the data of previous loss of disaster (last 30 year's) through adopting historical timeline tools.

Analysis and interpretation

a) VDC level hazard analysis

The hazards so listed after Community Base Participatory methods were ranked and top four hazards of each ward were taken for further analysis. Matrix was formed on the basis of rank and frequency of thus listed hazard types of Darbung VDC. Additionally, weighted were classified on the basic of equal interval classification and then each weighted were assigned as shown below Table.

Rank (R_i)	Weightage (W_i)
1	3
2	2.5
3	1.5
4	0.75

Each hazard was analysed by using the formula:

$H_T = \sum F_i \times W_i$

Where,

H_T=Hazard type

F_i = Frequency of i^{th} hazard

W_i = weightage given to i^{th} ranked hazard

b) Ward wise hazard and vulnerability ranking

According to LDRMP Guideline 2011, six components viz. human loss; affected families; household damage; financial loss; damage of arable land and forest; and social impact, were used for calculation of vulnerability index. For the analysis, 25% weightage was provided to Human loss while all other got each 15% weightage.

2.2.3. Landslide Susceptibility assessment

Under landslide susceptibility assessment, various activities were carried out. Landslide inventory was performed followed by spatial distribution of landslide and agricultural land loss. The DEM was generated from which causative factor (aspect, flow accumulation, elevation and slope angle) were prepared. Additionally, feature maps (land use, road distance and drainage distance) were prepared in Arc GIS Environment. Similarly, landslide index was calculated then landslide susceptible map was prepared and finally landslide physical vulnerability was done.

Landslide inventory was performed by questionnaires survey followed by transect survey, interpretation of topographic map and AlOS imaginaries (2007). During transect walk, encountered landslide were marked by GPS. The type (shallow, deep seated), material composition, time period of occurrence and potential threat level of each landslide was recorded. Likewise scratch of each landslide was drawn in topomap as well as in high resolution Google Earth Image, 2013. Landslide located on resource map prepared by the community themselves during FGD was also used for identification and digitalization of landslide of Darbung VDCs.

After digitalization of inventoried landslide, the secondary data sets of landslide causative factors (Aspect, Flow accumulation, Elevation, Slope, Landuse, Road distance, Drainage distance) were prepared in Arc GIS environment. These factors map were cross tabulated with inventoried landslide then weightage of classes of each parameter were calculated by using landslide index method which is based upon the following formula introduced by Van Westen, (1979) as:

$$\ln W_i = \ln \left(\frac{Density\ \ class}{Density\ \ map}\right) = \ln \left(\frac{A\ (Si)/A\ (Ni)}{\sum A(Si)/\sum A(Ni)}\right)$$

Where,

W_i = Weight assigned to certain parameters class.

Density Class = the landslide density within the parameter class.

Density Map = the landslide density within the entire map.

A (Si) = Area, which contain landslide, in a certain parameter class.

A (Ni) = Total area, in a certain parameter class.

Thus bivariate analysis was performed in Arc GIS Environment and landslide susceptible map was prepared by summation of each factor's ratings using following equation (*Lee and Pradhan, 2006*):

LSI =$\sum_{i}^{n} Wi$

Where,

W_i = Weight assigned to each i parameters

N= Total number of parameters

LSI map into four different landslide hazard zones as low, moderate, high and very high was prepared with probability rate evaluation. Meanwhile, the effort was prearranged to attain the higher prediction rate that is enough to justify the hazard map. Probability rate is the study of occurrence probability of landslides in different susceptible classes. For this, cumulative of landslide occurrence percentage is plotted against ranked area based on landslide susceptible zone (in cumulative percentage) which gives a curve called probability rate curve.

2.2.4 Debris flow damaged assessment

GPS boundary of cultivation land (Khet/Bari) and other land use were taken with the help of locals and thus prepared map was cross validated in sharing programme. Meanwhile partially recovered cultivation land and displaced houses units were also marked, and then the map was prepared in Arc GIS Environment.

3. Results and Discussions

3.1 Community based vulnerability and capacity assessment

3.1.1 Hazard Ranking

After the listing of hazard, it was ranked as per their impact on lives and livelihoods of locals of each ward. This was done through a simple ranking matrix chart. Major four hazards within each ward of Darbung VDC were tabulated here down in table 3.

Table 3: Hazard ranking of wards of Darbung VDC

Ward no.	Hazard Ranking (major four)			
	1	2	3	4
1	Flood	Landslide	Fire	Drought
2	Wild animal encroachment	Fire	Crop disease	Drought
3	Epidemic	Drought	Fire	Wild animal encroachment
4	Drought	Fire	Landslide	Windstorm
5	Drought	Epidemic	Fire	Thunderbolts
6	Flood	Drought	Landslide	Fire
7	Flood	Landslide	Windstorms	Drought
8	Landslide	Flood	Fire	Wild Animal Encroachment
9	Landslide	Drought	Flood	Wild Animal Encroachment

Altogether nine different hazards were recognized by the locals where we have exluded Earthquake. Considering the frequency of the hazard, drought is recognized to be the major hazard which is followed by landslide, flood and forest fire respectively. Few other hazard as wildlife encroachment, thunderbolt, windstorm are also found in the study area.

When each of these hazard were given separate weightage based on its ranking as well as frequency, drought was calculated to be the most hazardous with weightage of 15.75 where as thunderbolt was found to be the least hazardous with weightage of 0.75. Drought was followed by landslide, flood and fire respectively. Both the wild animal encounter as well as epidemics had same weightage as 5.5 followed by windstorm 2.25 and crop disease 1.5. Even though both thunderbolt as well as crop disease had same frequency (as 1), because of difference in their ranking crop disease was found more hazardous than thunderbolt in Darbung VDC.

3.1.2 Hazard Calendar

A seasonal calendar is a participatory tool for documenting regular cyclical periods and significant events that occur during a year and influence the life of a community. Major hazards of wards were marked in calendar which has allowed participants to represent their understanding of the seasons with relation to hazard. Then, VDC wise hazard calendar was prepared (table-4).

Table 4: Seasonal calendar of respective hazards

	Month											
	Baisakha	Jyestha	Asar	Shrawan	Bhadra	Asoj	Kartik	Mansir	Push	Magh	Falgun	Chaitra
Landslide	■	■	■	■	■	■						■
Flood			■	■	■							
Drought	■	■	■									
Fire	■	■										■
Windstorm	■	■									■	■
Hailstorm											■	
Thunderbolt	■	■	■	■							■	
Earthquake	■	■	■	■	■	■	■	■	■	■	■	■
Wild Animal Encroachment			■	■	■			■	■	■		
Epidemic			■	■	■	■	■					■
Crop Disease			■	■	■			■	■	■		

Note: In case of landslide, Chaitra, Baisakha and Jyestha are for dry landslide (phusphuse Pahiro). Wild animal encroachment was from Leopard, Porcupine, Rabit, Monkey, Jackal are majors.

3.1.3 Hazard Analysis

The hazard analysis in the study area through FGDs pointed the following issues. The table (5) has been prepared summing up the FGDs from all nine wards.

Table 5: Hazard analysis of Darbung VDC

SN	Hazard	Cause	Causal Factor	Impact	Possible solution
1	Landslide and Flood	Natural	Heavy rainfall, Deforestation, steep slope, weak geology	Loss of households, livestock and other properties	-Forestation (there is dire need of forestation around Khani Khola landslide that includes ward no. 7 & 9. -Bio-engineering techniques- Khani khola landslide should be controlled with bioengineering practices (Jatropha sps. could be one option for landslide control). Jatropha is mostly seen in upstream community. -To raise awareness and strengthen capacity of locals in disaster management.
2	Drought	Natural	Erratic rainfall, Deforestation	Deficiency in crop production	- Forest conservation -Preservation of water springs -Promotion of irrigation canal -Rainwater harvesting
3	Fire	Natural and human induced	Dryness	Property loss	-Raising awareness
4	Windstorm	Natural		Crop and Property damage	-Raising awareness -Creating forest as a wind barrier

5	Hailstorm	Natural		Crop and property damage	-Crop pattern change
6	Thunderbolt	Natural			-Earthing and local knowledge
7	Earthquake	Natural			-find the safe place beforehand -raising awareness
8	Wild Animal Encroachment	Natural/ Humane induced	Forest fire, lack of necessary food inside forest	Property loss	-Forest conservation -Afforestation -Making a boundary around the forest area -Encouraging raring of natural enemy
9	Epidemic	Humane induced	Unhygienic activities, carelessness in food selection	Loss in life	-Increasing awareness about sanitation -Encourage habit of visiting health post and doctor instead of witch doctors
10	Crop Disease			Loss of crop	-Practicing crop rotation annually or as per needed -Raising awareness

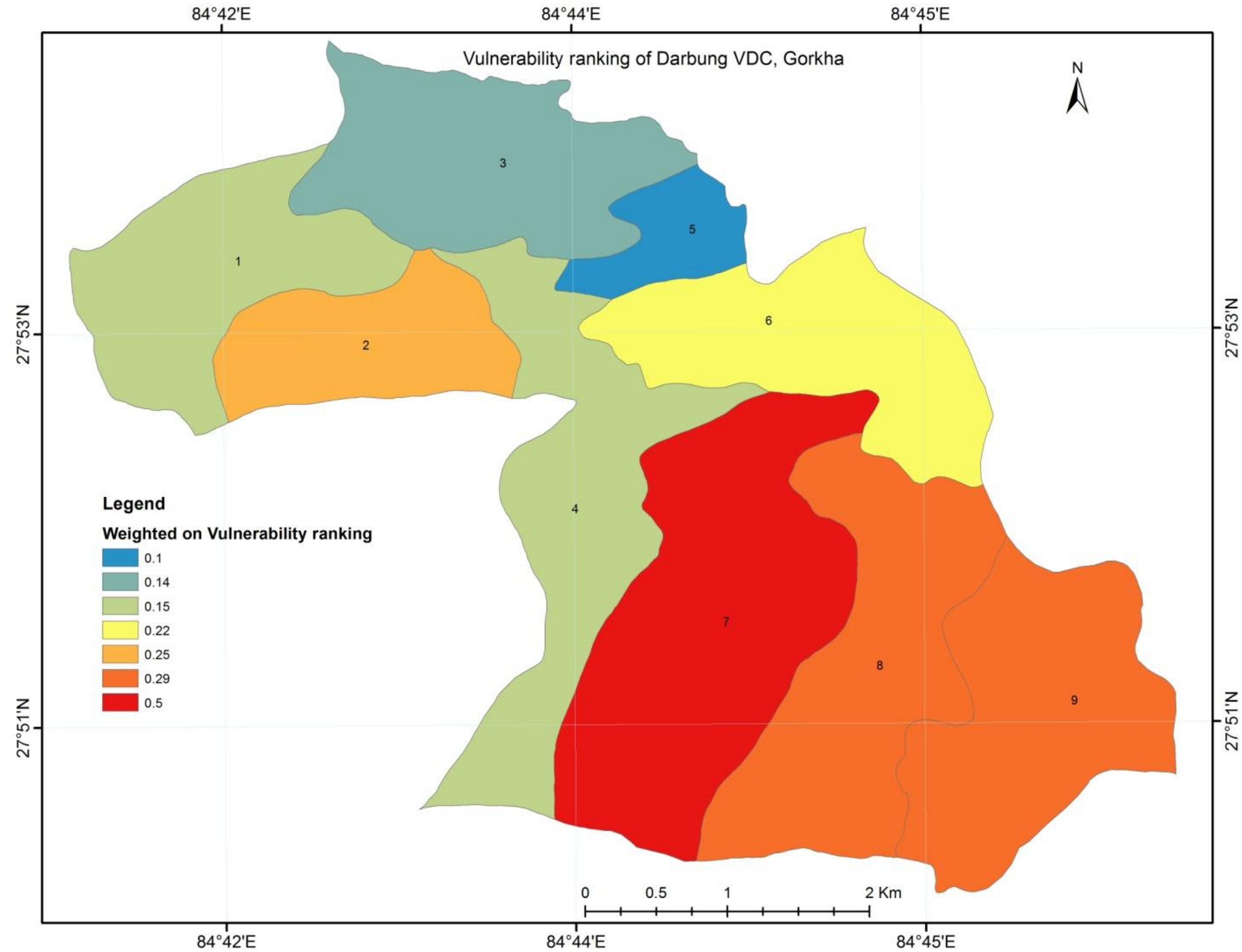
The FGDs in nine wards have highlighted ten disasters in the study area. Each disaster were listed along with their probable causes and solutions. Hence community themselves have ways to solve their problems but they lack proper facilitations.

3.1.4 Vulnerability Ranking

On the basis of six components viz. human loss; affected families; household damage; financial loss; damage of arable land and forest; and social impact, vulnerability ranking was calculated. As per the calculation ward no 7 was the most vulnerable whereas ward no 5 was the least vulnerable (Table 6 and Map 2).

Table 6: Wards wise Vulnerability scoring

Ward no.	Weightage	Rank
1	0.15	Fifth
2	0.25	Third
3	0.14	Sixth
4	0.15	Fifth
5	0.10	Seventh
6	0.22	Fourth
7	0.50	First
8	0.29	Second
9	0.29	Second



Map 2: Vulnerability mapping of Darbung VDC, Gorkha District

3.2 Landslide susceptibility assessment

3.2.1 Landslide Inventory

Altogether 21 active landslide of an area of 0.006506 square kilometer (0.028% of Darbung VDC) was used for landslide susceptibility mapping (table 7).

Table 7: Location and area of Landslide found within Darbung VDC

S.N	Latitude	Longitude	Area (Sq. m)
1	573941.63	3080641.37	6505.94
2	574187.97	3080946.13	702.71
3	573475.21	3080955.53	4536.22
4	572645.53	3080971.34	5304.26
5	573519.84	3081063.11	924.87
6	572419.58	3081067.11	2633.11
7	573545.41	3081126.04	1067.29

8	572626.53	3081128.67	8639.84
9	572414.60	3081355.83	1293.34
10	571803.68	3081531.22	1194.02
11	575688.14	3081532.06	1833.77
12	573005.18	3081867.78	19819.30
13	573477.29	3082212.31	1479.72
14	573237.46	3082192.59	17887.39
15	571768.11	3082522.66	614.48
16	568551.02	3083743.19	1784.07
17	572904.98	3083861.43	653.71
18	570753.48	3084272.82	2501.51
19	570842.89	3084307.09	3731.93
20	571033.77	3084509.11	6738.05
21	568632.17	3084537.16	997.26
		Total	**90842.79**

3.2.2 Spatial distribution of Landslide and agricultural land loss

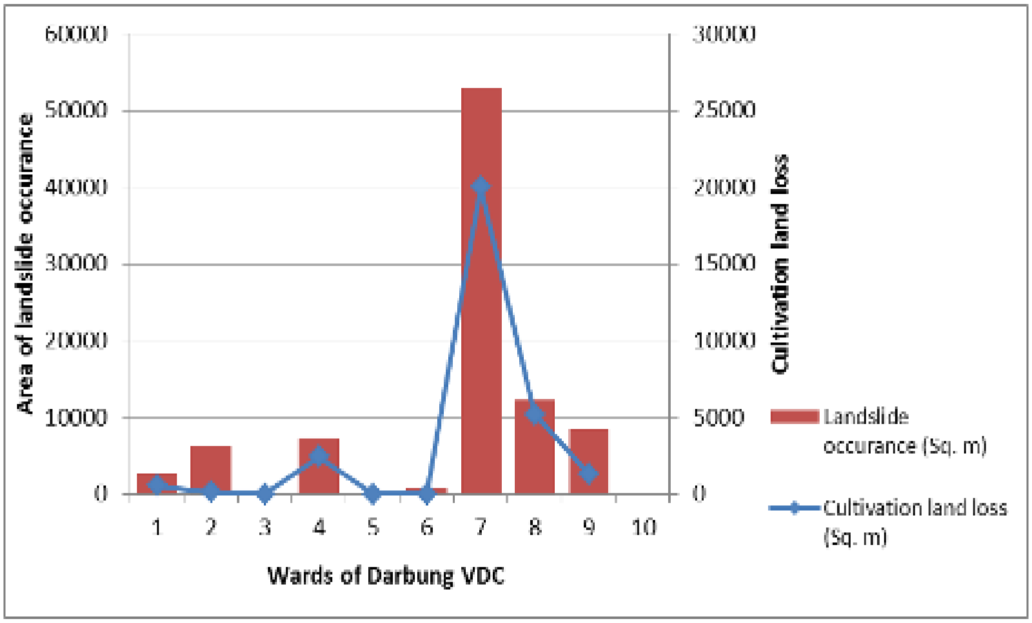
Considering the ward boundary of digital map prepared by the DoS, the landslide that has been identified, spatial distribution of landslide with respect to wards was prepared which is tabulated below in table 8.

Table 8: Wards wise Landslide distribution

Darbung ward	Area (Sq. m)	Area of Landslide (Sq. m)	Area of Landslide %
1	2311789	2700	0.12
2	1617250.09	6275	0.39
3	2619047.17	0	0.00
4	2991289.45	7325	0.24
5	683901.23	0	0.00
6	2502945.60	650	0.03
7	4169355.14	52925	1.27
8	3150168.14	12300	0.39
9	2911474.05	8450	0.29

Accordingly, ward no 7 comprised of highest area of landslide covering 1.27% of total area. In contrast to this, no landslide were observed in ward no. 3 and 5 during the field visit. The South East facing landslide with 300-350m length and average 220m in breadth is located at ward no 7. This land slide was the biggest landslide in the Darbung VDC, which occurred due to continuous rainfall in 2059/04/06. Similarly, following graph (Fig 1) showed the overall view of Cultivation land loss from the landslide.

Figure 1: Cultivation land loss with respect to landslide occurrence in each ward



Ward no 7 consists of largest area of landslide with highest cultivation land loss. Loss of cultivation land was found to be directly related to area of landslides in case of ward number 7, 8, 4 and 1. But the condition is not same in case of ward number 2 and 9. In these two wards even thought area of landslide is high, their corresponding loss of cultivated land was calculated to be low.

3.2.3 Digital Elevation Model (DEM) generation

A digital representation of relief over space is known as a digital elevation model (DEM).

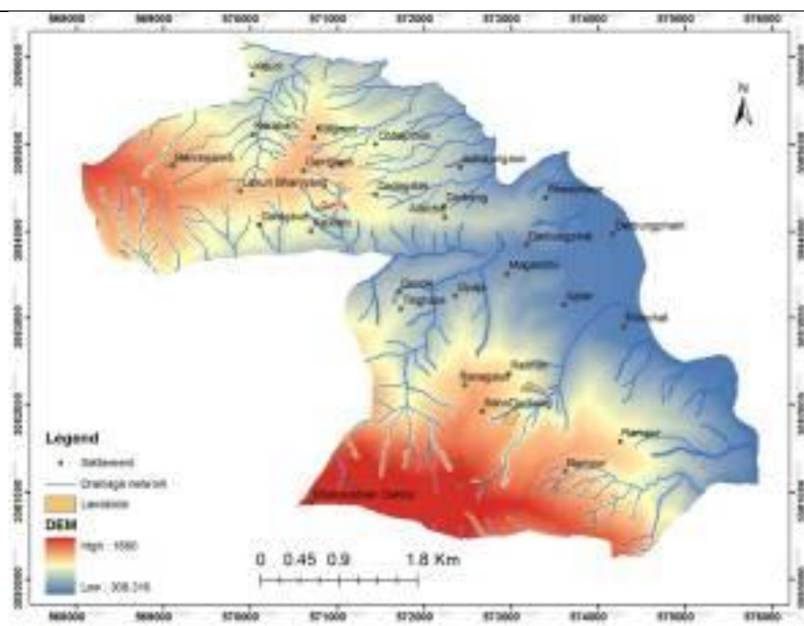


Figure 2: DEM map of Darbung VDC

By relating any map with the corresponding terrain surface in a 3D model, it can be discovered and understood relations between spatial data sets. DEM was derived from the combined interpolation of contour and spot heights.

3.2.4 DEM derivatives of causative factors

Aspect

Aspect indirectly affects the occurrences of landslide because the several parameters such as land cover, lithology, hydro-metrology were dependent upon it.

Aspect	Area (Sq km)
F	0.0023
NE	5.7051
E	4.1255
SE	2.7786
SE	1.9499
SW	1.1557
W	1.0494
NW	2.2183
N	3.9711
Total	22.9559

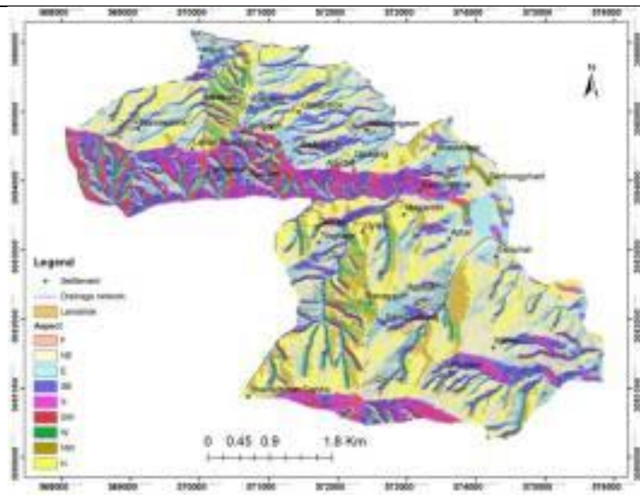


Figure 3: Aspect representation of Darbung VDC

So the nine class of the aspect obtained from the DEM were considered for further processing. Previous studies have shown that landslides were usually abundant on N, NE and SW orientations a fact that was attributed mainly to climatic factors (Koukis et al., 1994). So the nine class of the aspect obtained from the DEM were considered for further processing which is shown in below fig:

Flow accumulation

Flow accumulation raster was prepared in Arc GIS Environment. In GIS flow accumulation at a given location was determined by following two rules:

Accumulation (Cell)	Area (Sq km)
1	8.2184
3	4.0358
5	2.2132
10	2.6797
20	2.0398
50	1.7326
1000	1.5783
>1000	0.4581
Total	22.9559

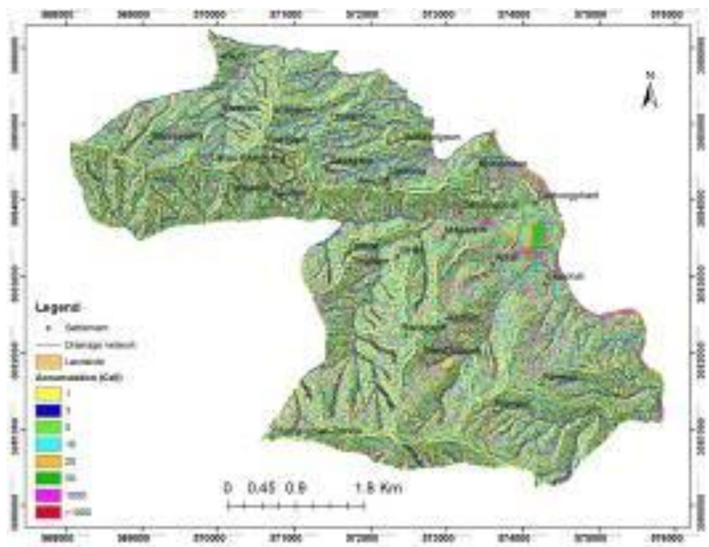


Figure 4: Flow accumulation categorical representation of Darbung VDC

i. If the pixel has no neighboring pixels draining to it, a value of "1" was assigned.

ii. If the pixel drainage from neighboring pixels, it was assigned the value of "1" plus the sum of the flow accumulation draining from each of the neighboring pixels.

Relief factor (Elevation)

Five class of elevation via: <500, 500-750, 750-1000, 1000-1250 and >1250 m were considered for hazard analysis. Though elevation does not influence occurrence of landslide directly, various factors that are affected by elevation may trigger landslide indirectly such as the weathering factor that plays an important role in land sliding is closely related to elevation. Local climate varies with relief and hence local climate influences various factors such as soil

Elevation (m)	Area (Sq km)
<500	3.9073
500-750	6.3561
750-1000	7.0884
1000-1250	3.525
>1250	2.0791
Total	22.9559

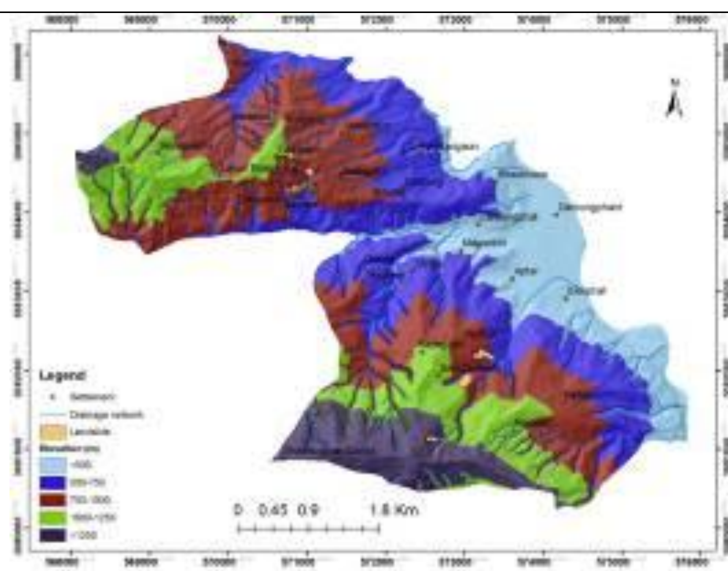


Figure 5: Elevation map of Darbung VDC

moisture, rainfall intensity and frequency, vegetation compositions and density, which as a result plays an important role in occurrence of landslide. Another important aspect relating relief and landslide hazard was construction of roads are preferentially built along the same relief. It is therefore why landslide hazards in an area are observed more or less on the same relief.

The surface relief is the variation in height of a land surface.

Slope angle

It is the inclination of the land surface, in degrees or percent, with respect to horizontal plane. It is a reflection of series of micro-morphological processes and controls imposed on that facet.

Slope (in degree)	Area (Sq km)
<7	1.63
7-15	2.098
15-25	4.7415
25-35	5.5123
35-45	4.0274
45-55	1.9181
55-65	0.8355
>65	2.1931
Total	22.9559

Figure 6: Slope representation of Darbung

The slope gradient map was prepared from the DEM. The ArcGIS Environment was used for the generation of the slope gradient map. Six slopes categories were made for landslide hazard rating. Nearly 63% of the total area of the Darbung VDC was found to be situated in an area having more than 25^0 slopes.

3.2.5 Feature Maps

Landuse

Type of land use/land cover on the slope is an indirect indicator of the slope stability/instability. Land use/land cover of a watershed effects surface runoff and landslide. Well managed forest and grassland/pasture and appropriate land utilization practice will help to stabilize slopes.

Land use	Area (Sq km)
Built up Area	0.0139
Cutting	0.0037
Cultivation land	11.991
Forest	4.7395
Bush	5.869
River	0.3386
Total	22.955

Figure 7: Landuse map of Darbung VDC

Injudicious water management, due to removal of protective vegetation cover, overgrazing, cultivation on the steep land without appropriate terraces, unsuited cropping pattern, and water management are likely to exacerbate the naturally occurring soil erosion and induce slope instability.

Altogether seven different types of land types were identified in the VDC, of which cultivation lands covers highest area followed by bushes land and forest respectively. Only 0.01% of the total area was covered by cutting. The cutting area may represent landslide or slope failure during the period of 1990s survey conducted by department of survey.

Road distance

The problem of landslide becomes more aggravated especially during monsoon season. The main causative factors for the instability of land-surface are geomorphologic and geological in nature including the haphazard road development in Darbung VDC.

Road distance (m)	Area (Sq km)
<50	3.52
50-100	2.47
100-200	3.88
200-500	7.21
>500	5.85
Total	22.95

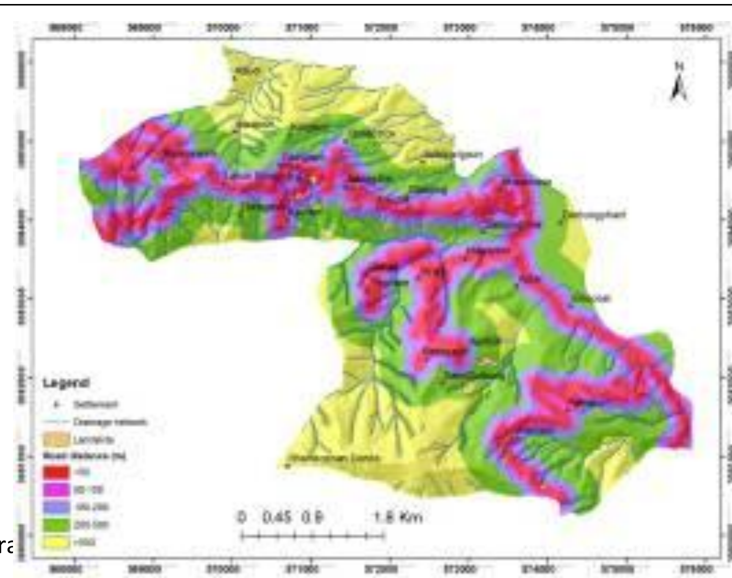


Figure 8: Road coverage and distance map of Darbung VDC

So proximity of road network is also used for this hazard assessment. More than 50% of the total area of the Darbung VDC was at the distance less than 500m from the road network. From the above evaluation of road distance map, it can be concluded that those areas which were at less than 50m, 50-100m and 200-500m away from the road section had more landslides.

Distance from drainage network

Runoff is an important factor to trigger landslide mechanism. Studies have shown that proximity to drainage lines of intensive gully erosion is an important factor controlling the occurrence of landslide (Pachauri et al., 1998). Hence in order to model the influence of runoff on landslide, the distance from river was taken into account.

Drainage Distance (m)	Area (Sq km)
<50	8.0846
50-100	6.2637
100-200	5.6253
200-500	2.7009
>500	0.2814
Total	22.9559

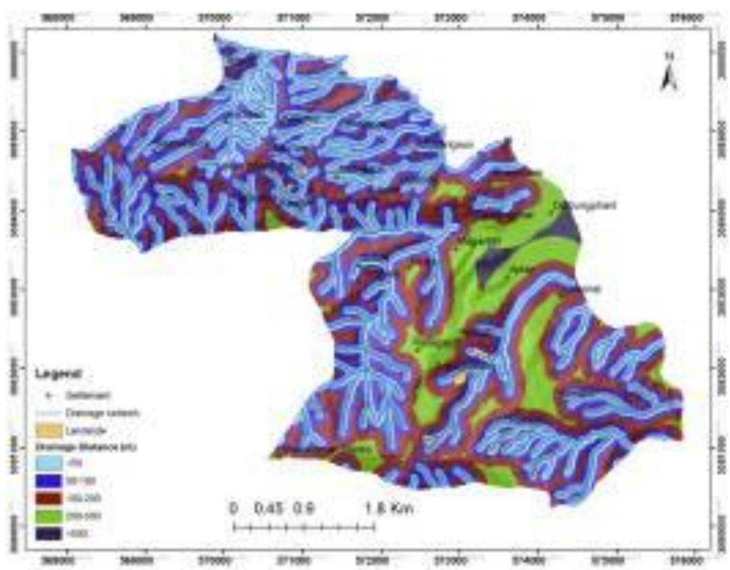


Figure 9: Drainage Distance map of Darbung VDC

On the basis of river and stream on the topographic map, a map of distance from river was calculated by buffering in ArcGIS Environment. Accordingly, area within 50m from the stream covers the larger portion of Darbung VDC. Interestingly, the area of the land has simultaneously decreased with increase in the distance from the stream.

3.2.6 Landslide index calculation

The modelling was performed in a GIS, to derive a landslide susceptible map of the study area. Thematic maps representing various factors (e.g., slope, aspect, flow accumulation, elevation, land use, distance to road network and distance to drainage) related to landslide activity were generated by using field data and GIS techniques. Then statistical index were calculated for weighting value of each classes of each parameter listed in figure 10 linked with annex 1.

The resulting total weights directly indicate the importance of each factor. If the total weight is positive, the factor is favourable for landslide, whereas if negative, it is unfavourable. For instance, cutting feature in land cover acquired the highest positive weight among all which indicates that previous slope failure areas have maximum chances of potential failure.

Weightage of some factors oscillated around both positive and negative values which indicate classes within factors also play an important role in causing landslide. The weightage assure by the class of flow accumulation indicates that middle level accumulation were favourable for landslide and debris flow. Similarly, debris flow in general, strongly controlled by surface topography through shallow subsurface flow convergences, increased soil saturation, increased pores pressures and shear strength reduction (Montgomery & Dietrich, 1994).

Considering the Aspect viz SE, SW, N and NW acquired positive weighted. Likewise the elevation (>750m) of Darbung VDC were landslides prone as elevation more than 750m acquired positive weight. While in landslide index calculation the drainage distance of two classes i.e less than 50m and 50-100m have assured the positive weight which may be due to toe erosion or by saturating the toe material or both are prominent in this region (Gokeceoglu & Aksoy, 1996; Nandi & Shakoor, 2010). Also there is maximum infiltration along slopes adjacent to streams where the materials have maximum permeability. The inclusion of drainage channels as a factor controlling landslide susceptibility is useful for delineating probable travel paths down the slope from susceptible initiation areas. The positive weighted assured by the nearest to road i.e with in 50m reflects that proximity to rural road network also have detrimental role for landslide occurrence. It is noted that landslides occurrence have gradually increased with increase on slope gradient above 35^0 which is coherent with other studies (Dai & Lee 2002; Santacana et al., 2003; Fernandez et al., 2004; Magliulo et al., 2008).

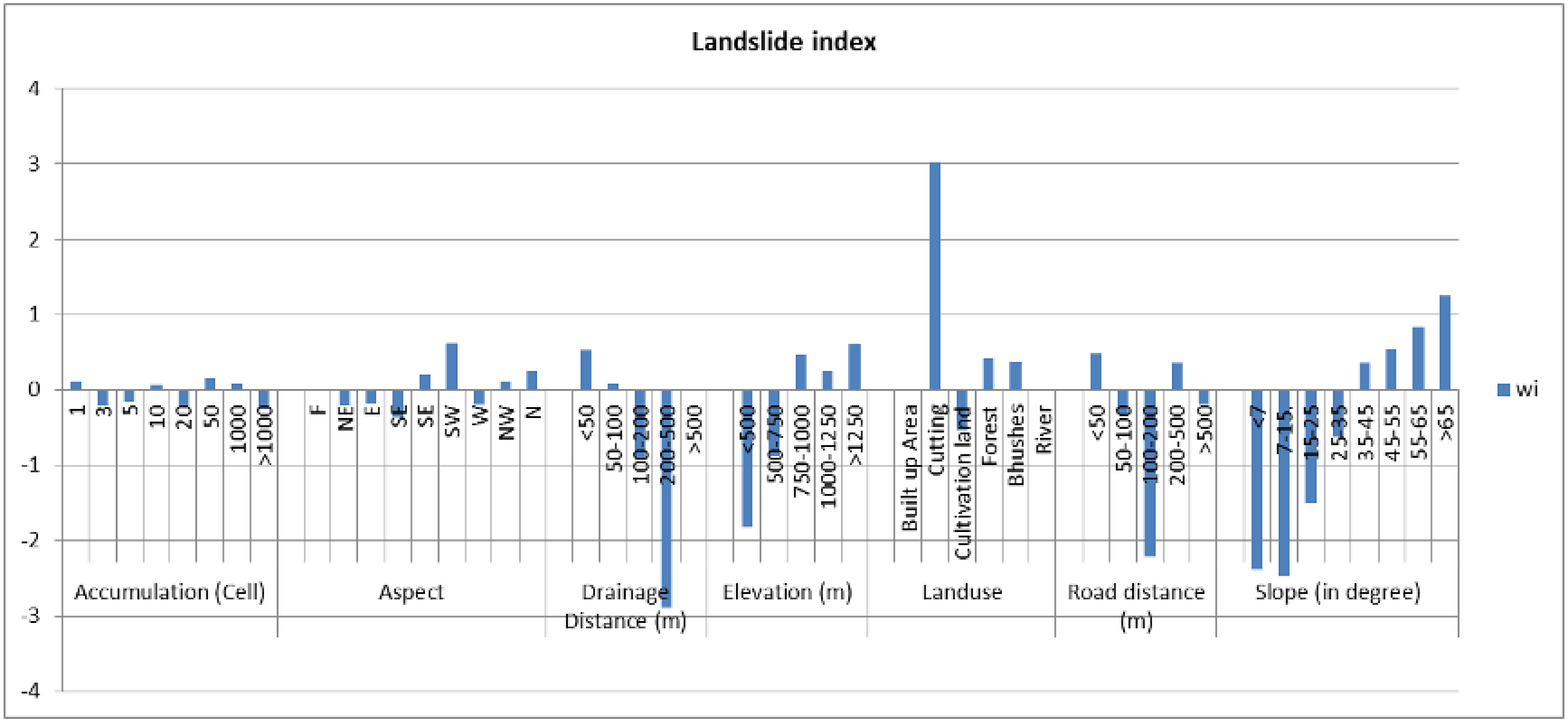


Figure 10: Landslide index of each parameter

3.2.7 Landslide susceptible map

As landslide susceptible zonation is a product of multiple factors summed up to their weightage values, this map suggests combined effect of all factors. This map can be rationalized by comparing each factor to the categories of susceptible zonation. Here, susceptibility map is produced with numerous trail practices to archive the predictive more than 80%.

Landslide susceptible class	Area (Sq km)	Per centage (%)
Low	8.338	36.32
Moderate	8.081	35.20
High	5.095	22.20
Very high	1.441	6.28
Total	22.956	

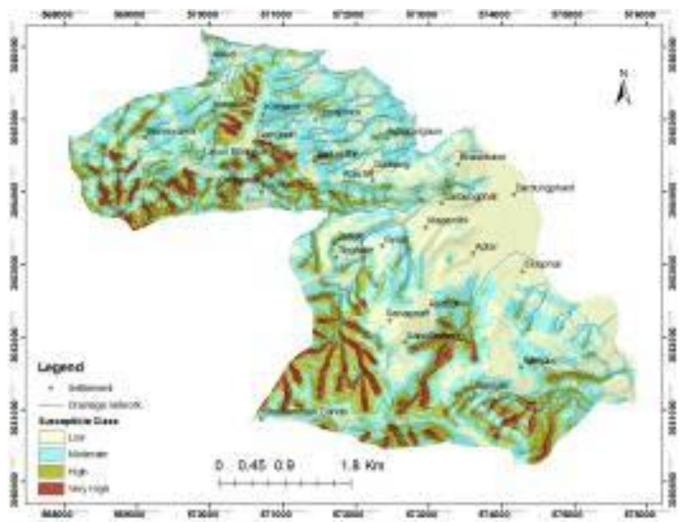


Figure 11: Landslide susceptibility Map

To test the goodness of fit of the replicated models, the cumulative percentage of landslide occurrence with respect to hazard class were plotted in a graph called probability rate curve. The rating curves were analyzed based on two assumptions: a) a hypothetical validation curve coinciding with a diagonal of 0 to 1 would be equivalent to total random prediction. More the upward deviation of validation curve from the diagonal better is the predictability of the model and susceptibility map (Remondo et al., 2005; Lee, 2007). And b) the higher the proportion of landslides in most susceptible zones gives the better predictability of the model (Remondo et al., 2005).

Landslide Occurren ce (%)	Susceptible Classes (%)
0	0.00
0.44	36.32
18.11	71.53
65.86	93.72
100.00	100.00

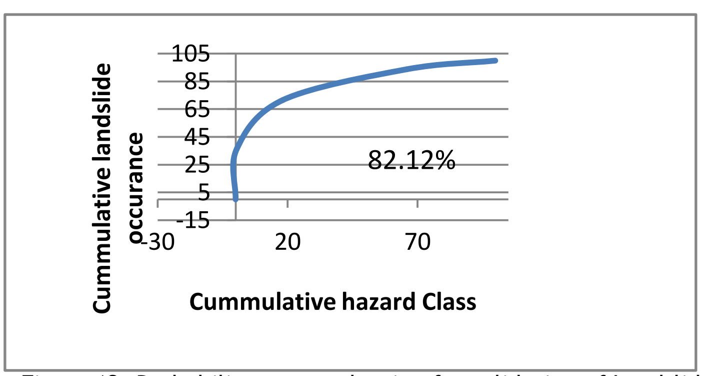


Figure 12: Probability rate evaluation for validation of Landslide susceptibility map

Cumulative percentages of the susceptibility class corresponding to cumulative percentage of landslides were plotted in graphs and the predictive rate was evaluated. Accordingly, the probability rate was calculated by trapezoid rule, resulted with 82.12%.

3.2.8 Landslide susceptibility and Physical vulnerability

Total 913 houses units, obtained by combining digital layers of DoS with addition houses unit from recent Google Earth image were considered for potential threat assessment. The house units considered here for assessment was higher than total household of Darbung VDC coated by CBS (2011). Thus houses unit were considered instead of household.

Houses located within very high, high, moderate and low susceptibility zone from each ward were identified with the help of Arc GIS Environment and result was presented in Figure-13.

A house from each ward 2 & 8 was located at very high susceptible zone and nine house units of ward 2 were located in high susceptible zone (Annex 3).

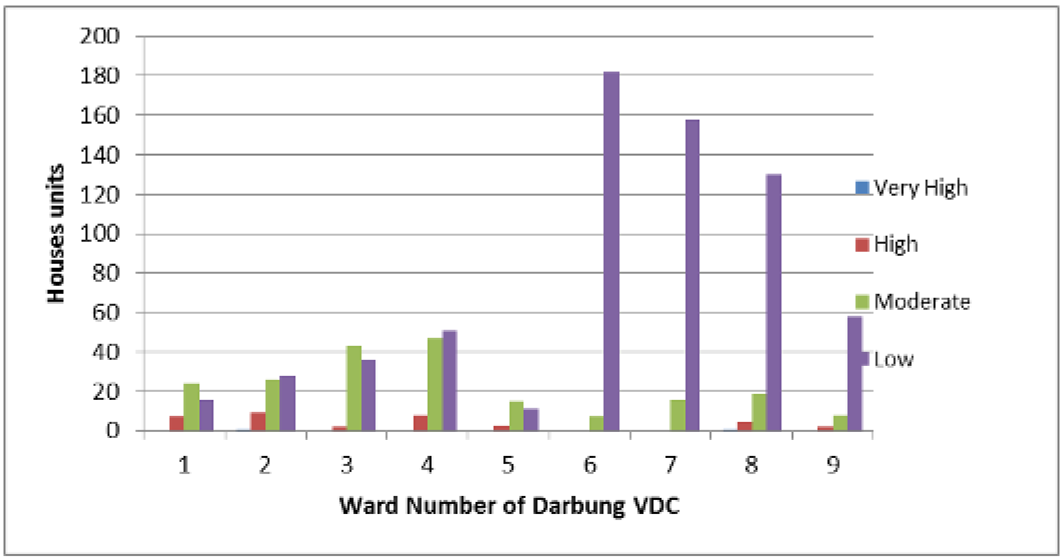


Figure 13: Household units located at respective susceptible zone

Similarly potential threat on cultivation land was also evaluated and presented below in Figure-14, link with annex 2. The threat in cultivation land of ward no 1 and 2 was found more than in other wards. Cultivation land of ward no 6 were potentially less threatened due to landslide.

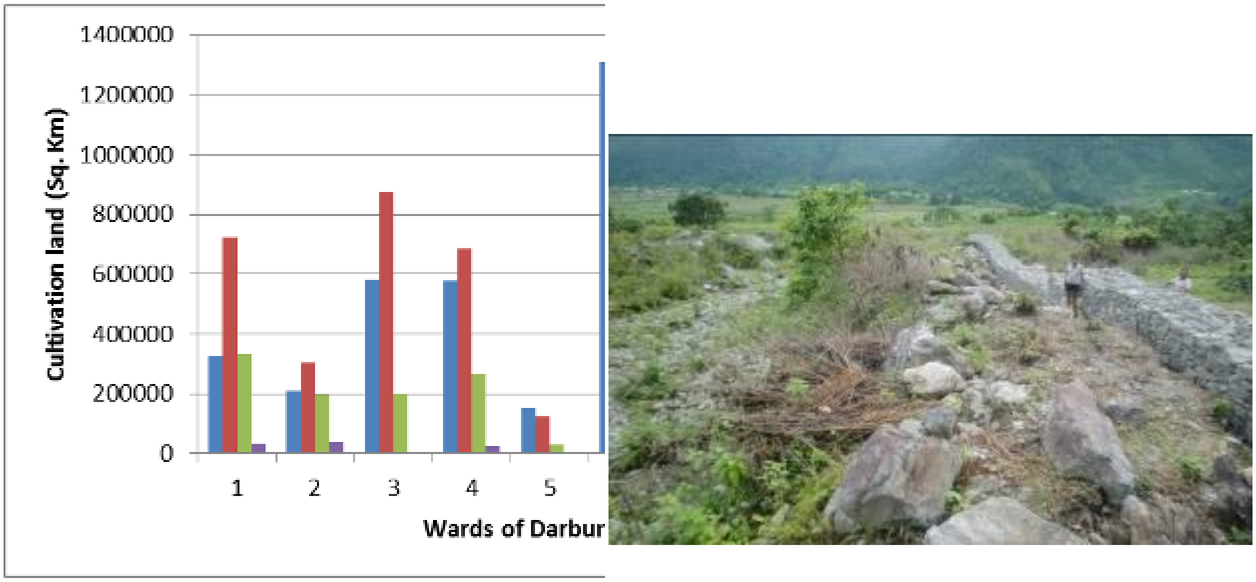


Figure 14: Cultivation land of each ward located in respective susceptible zone

3.3 Debris Flow

The devastating debris flow and deposited along Darbung-7, Magadi in Khani Khola basin which was originally created by the landslide occurred in upper reach in 6th Shrawan 2059 BS. The debris were delineated in the form of polygon in Arc GIS Environment, taking references of field marked GPS boundaries and recent Google Earth images of 2013. Meanwhile location of swept and damaged houses were marked in field and presented in digital map.

The map presented above shows the current mitigation works that is construction of gabion walls along banks of existing flow path of Khani khola. The construction of gabion wall was completed with the initiation of locals and support from DAO.

Boundary points were collected through GPS with the participation of locals. Boundary of each damage area was also collected. During the survey, certain portion of damaged land was found recovered into cultivation land. However the productivity has been lowered by half or even more than 50% of the previous production in recovered land. As local resident recognize this phenomenon of debris flow and deposition as flood which influence the social hazard ranking (table 9). More over damaged and partially recovered land can be tabulated as table8 and figured 15:

Table 9: Debris deposited and land cover statistic

Land cover affected debris flow &deposited (m^2)	**Debris deposited Area**	**Partially Recover**
Cultivation land	138180.2	27512.0
Bushes Area	68677.8	1627.4
River	5480.5	0.0
Total	212338.4	29139.3

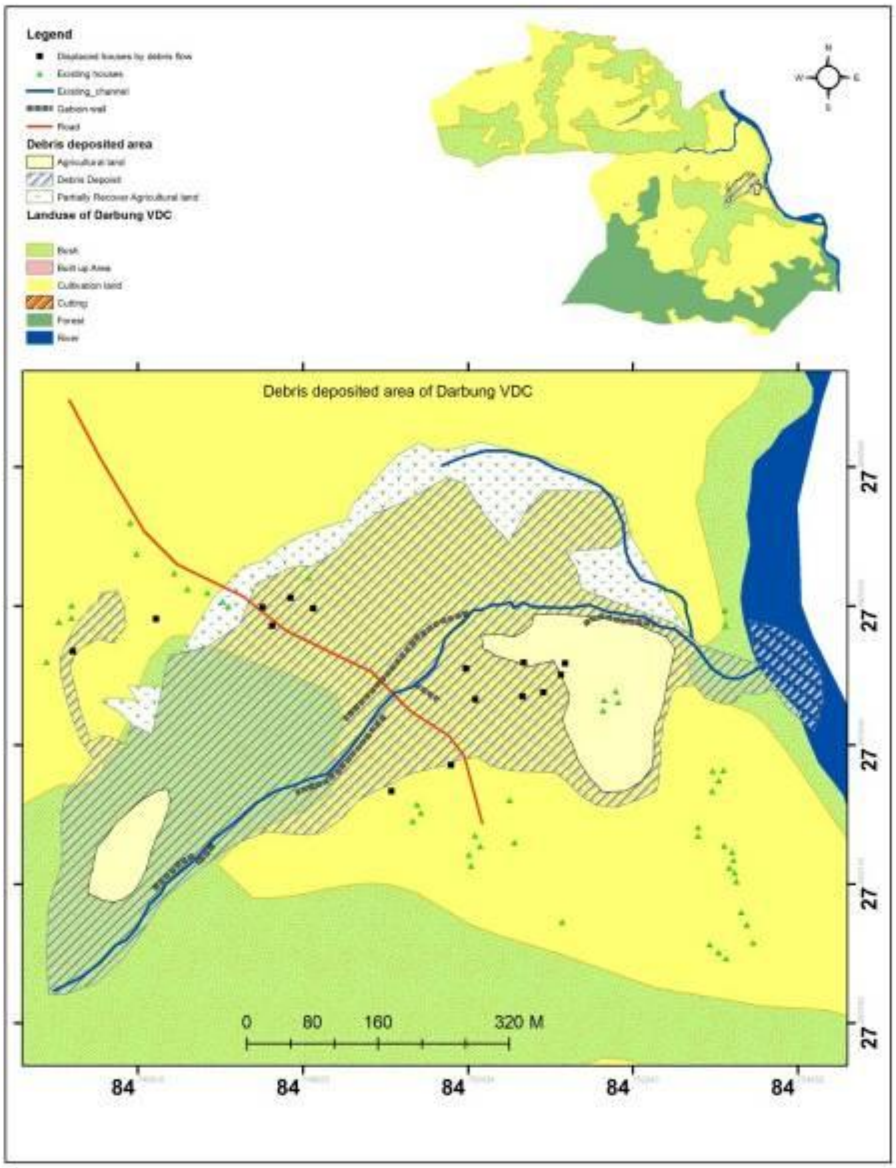


Figure 15: Debris hazard map of Khani Khola, Darbung VDC

The debris flow was initiated by the continuous rain that started the previous day of the incident. It was started with a bang sound which made most people aware about the probable disaster. Most of the forest area of ward no 9 and 7 were badly damaged by the flow. As explained by the locals, debris flow swept away all the valuables along with livestock making the cultivated land paralyzed with small as well as big boulders. The study area was affected by heavy flood in 1990 and 2028 and by drought in 2069 as per the locals.

4. Conclusion

In recent years, an increasing number of global and local initiatives have been launched to measure risk and vulnerability with a set of indicators and indices (Birkmann, 2006). Identifying and measuring risks and vulnerability before a disaster occurs—and also after disasters have happened— are essential tasks for effective and long-term disaster risk reduction. This study-adopting both science and community base knowledge; identified that the area is vulnerable to various disasters where weightage method for hazard ranking, found, drought as the most hazardous event having weightage of 15.75 followed by landslide (14), flood (13), forest fire (11.75), wildlife encroachment (5.5), epidemic (5.25), windstorm (2.25), crop disease (1.5) and thunderbolt (0.75) respectively. This report further showed that the debris flow of 2059 had affected the area and the people in the worst way it could. Many people were forced to leave their houses and lost their properties. People still have fare to settle in the same place. Most of the cultivated areas are still completely covered with debris which had decreased the production of the area. The vulnerability assessment of the area pointed toward the necessity of diverting the concern towards other disaster as well beside than debris flow or landslide. As the drought was seen to be one of the important issues in the place, study about the possible impact and mitigation measures would be very important.

In a nutshell, both science and community base knowledge revealed ward no. 7 as a most vulnerable ward. Community they themselves now can reduce the vulnerability in more extent due to their direct involvement in vulnerability assessment. Hence, if we link science and community base knowledge, disaster reduction efforts in more extents gain the sustainability

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Annex-1: Training content and Schedule

Day	Date	Heading	Resource person
1	16 June 2013 (Asar-2) SUNDAY	**Introduction to Disaster, Hazard, Vulnerability and Risk** • Types of Hazard • Casual factors of Hazard • Steps of risk management • Hazard Assessment methods and tools • DM cycle • Command, control and coordination mechanism	Dr Meen Bahadur Paudyal Chhetri, DPNet
2	17 June 2013 (Asar-3) MONDAY	**Community Based Hazard, Vulnerability and Risk Mapping** • Inventory of Major Disasters-frequency, magnitude and impact in the past • Resource mapping • Mapping of hazard prone areas and its quantification • Mapping of elements exposed and its damage probability • Institutional mapping and networking • Exercise	Prof Narendra Raj Khanal
3	18 June 2013 (Asar-4) TUESDAY	**Disaster Risk Management Planning** • Introduction • Steps • Major mitigation/adaptations • Cost/benefit analysis of mitigation and adaptation ptions • Lesson learns • Mainstreaming DRM into Development • Integrating DRM and CCA;Gender and Disaster	Mr. Ram Chandra Neupane, ECO-Nepal
4	19 June 2013 (Asar-5) WEDNESDAY	**Landslide Hazard Mapping** • Approaches of landslide hazard assessment • Key parameters/factors and scoring • Deterministic and statistical methods • Data layers preparation • Hazard Mapping • Exercise in GIS	Dr Govinda Acharya, IOE, Pulchowk
5	20 June 2013 (Asar-6) THURSDAY	**Drought, Fire and Earthquake Hazard** • Drought, fire and earthquake hazard scenario • Techniques and tools on drought, fire, and earth quake hazard and vulnerability assessment	Dr Jib Raj Pokharel, IOE, Pulchowk
6	21 June 2013 (Asar-7) FRIDAY	**Flood hazard mapping** • Introduction • parameters and data/information needs • Available models-HEC-RAS & HBV • Inundation mapping • Exercise	Dr Padam Khadka, IOE, Pulchowk
7	22 June 2013 (Asar-8) SATURDAY	**Disaster management Act, Policies and Institutions** • DM Act and Policies, -Gaps and constraints in policy • Institutional arrangement and networking (Formal/Informal) • Hyogo Framework, NSDRM & DRR Flagship Programme • I/NGOs working in the field of DM • Exercise	Dr Meen Bahadur Paudyal Chhetri, DPNet

8	23 June 2013 (Asar-9) SUNDAY	**Exposure and Vulnerability assessment** • Elements exposed to different hazards • Quantification • Monetary value • Exercise on calculation of vulnerability index • Orientation and preparatory exercise for field visits	Dr Govinda Acharya, IOE, Pulchowk Dr. Motilal Ghimire
9	24 June 2013 (Asar-10) TUESDAY	**Departure to Darbung VDC, Gorkha District: 7.15 A.M and arrival at 12.30 P.M** • Meeting and informing local community, • Socio-economic and damage data collection through group discussion • Short transect walk to observe damaged and risk sites on the downstream (fan) of KhaniKhola,	Dr. Motilal Ghimire Mr. Amrit Sharma
10	25 June 2013 (Asar-11) WEDNESDAY	**Transect field survey of the KhaniKhola watershed, Darbung VDC** • Landslide, debris flow inventory • Identification of landslide and flood hazard and risk areas • Cross section survey of the Khani Khola Fan using Laser Range meter • Measurement of sediment size, channel profile and slope • GPS data on location of damaged houses	Dr. Motilal Ghimire
11	26 June 2013 (Asar-13) THURSDAY	**Community approach of hazard and vulnerability assessment using VCA tool** • Hazard identification and prioritization • Vulnerability and coping capacity assessment • Resource and social mapping	Mr. Amrit Sharma
12	27 June 2013 (Asar-14) FIRDAY	**Field report summarization and presentation** • Compilation and summary report preparation • Reporting findings of field and community survey to community	
13	28 June 2013 (Asar-15) SATURDAY	**The return journey** • Presentation of electronic microscope to Ratneshawar Higher Secondary school. • Departure to Kathmandu	Dr Motilal Ghimire
14	29 June 2013 (Asar-16) SUNDAY	**RS and GIS activities and report preparation** • Hazard Mapping and Terrain analysis of the Study area • Group report preparation for the closing ceremony	Dr. Motilal Ghimire
15	30 June (Asar-17)	**Closing Ceremony** • Group report presentation • Poster and wall reporting • Closing remarks and	

Annex

Annex 1: Landslide index calculation

Factors		Area map (Sq km)	Landslide occurrences Area (Sq km)	wi
Accumulation (Cell)	1	8.22	0.04	0.117761
	3	4.04	0.01	-0.2089
	5	2.21	0.01	-0.1716
	10	2.68	0.01	0.069269
	20	2.04	0.01	-0.23519
	50	1.73	0.01	0.151179
	1000	1.58	0.01	0.081934
	>1000	0.46	0.00	-0.2615
Aspect				
	F	0.0023	0	0
	NE	5.7051	0.0184	-0.20765
	E	4.1255	0.0136	-0.18576
	SE	2.7786	0.0076	-0.37244
	SE	1.9499	0.0095	0.204874
	SW	1.1557	0.0085	0.61672
	W	1.0494	0.0034	-0.20308
	NW	2.2183	0.0098	0.107001
	N	3.9711	0.0203	0.252938
Drainage Distance (m)				
	<50	8.0846	0.0546	0.531433
	50-100	6.2637	0.027	0.082426
	100-200	5.6253	0.0089	-0.91986
	200-500	2.7009	0.0006	-2.88305
	>500	0.2814	0	0
Elevation (m)				
	<500	3.9073	0.0025	-1.8252
	500-750	6.3561	0.0104	-0.88625
	750-1000	7.0884	0.045	0.469563
	1000-1250	3.525	0.0181	0.257392
	>1250	2.0791	0.0151	0.60412
Landuse				
	Built up Area	0.0139	0	0
	Cutting	0.0037	0.0003	3.01681

	Cultivation land	11.991	0.0281	-0.52703
	Forest	4.7395	0.0288	0.425804
	Bhushes	5.869	0.0339	0.375091
	River	0.3386	0	0
Road distance (m)				
	<50	3.525	0.0225	0.474995
	50-100	2.478	0.0071	-0.326
	100-200	3.8838	0.0017	-2.20483
	200-500	7.2195	0.0408	0.353257
	>500	5.8496	0.019	-0.20057
Slope (in degree)				
	<7	1.63	0.0006	-2.37805
	7-15.	2.098	0.0007	-2.4763
	15-25	4.7415	0.0042	-1.49991
	25-35	5.5123	0.0117	-0.62603
	35-45	4.0274	0.0228	0.355
	45-55	1.9181	0.0132	0.550242
	55-65	0.8355	0.0077	0.842305
	>65	2.1931	0.0302	1.243886

Annex 2: Potential threat of cultivation land

Ward	Cultivation land with respective susceptible zone			
	Low	Moderate	High	Very High
1	325300	723900	334300	31300
2	207000	301100	197800	38600
3	582800	872200	200300	3300
4	579000	684000	264500	24100
5	152400	123000	28800	4300
6	1309100	129400	6300	0
7	1143200	577700	193200	23900
8	1021600	402700	190700	19900
9	684000	467900	130500	12800

Annex 3: Houses units within Different Susceptible zone

	Houses in susceptible zone			
Ward	Very High	High	Moderate	Low
1	0	7	24	16
2	1	9	26	28
3	0	2	43	36
4	0	8	47	51
5	0	3	15	11
6	0	0	7	182
7	0	0	16	158
8	1	5	19	130
9	0	2	8	58

Annex 4: weightage

Hazard types	Rank/ Frequency				Total weight
	1st	2nd	3rd	4th	
Drought	2	3	0	3	15.75
Landslide	2	2	2	0	14
Flood	3	1	1	0	13
Forest fire	0	2	4	1	11.75
Wildlife encroachment	1	1	0	0	5.5
Epidemics	1	0	0	3	5.25
Windstorm	0	0	1	1	2.25
Crop disease	0	0	1	0	1.5
Thunder storm	0	0	0	1	0.75