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Landslide hazard assessment using UAV imagery and GIS for road planning and development in Chure area: Sindhuli-Hetauda Section.

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Abstract

Chure hills are formed with the highly fragile, weak young sedimentary rocks and are environmentally sensitive. Road construction in this region is a big challenge to conserve the Chure from landslide. Occurrence of landslide hazard along the highway is the threat to the objective of timely, efficient and qualitative construction of highway. Landslide hazard map can greatly help in fixing and shifting of the alignment to reduce the loss of life and property.

This study “Landslide hazard assessment using UAV imagery and GIS for road planning and development in Chure area: Sindhuli-Hetauda section” aims at creating the hazard map, landslide inventory map and designation of hazard levels in one of the sensitive areas: Chure section. With the use of the Unmanned Aerial Vehicles (UAVs) as the primary means of carrying out the topographical surveying, the study used the Digital Surface Model (DSM) and the orthomosaic map produced from the UAV survey in acquiring the relevant results for fulfilling the study objectives. The survey area being ~100Km in length along the road alignment, four of the most crucial sites on the basis of existing landslide area and impact of those landslide in road, cultivation and settlement in the study area were selected for surveying. The study concluded that use of UAV for hazard mapping has good, accuracies and high resolution data. The Root Mean Square Error (RMSE) of the survey for the individual sites were found to be 0.001m, 0.045 m, 0.044 m and 0.804 m, respectively. A detailed topographical map of the area was created, along with the hazard map, including the factors such as slope, aspect, curvature, elevation, lithology, distance to road, distance to river and soil type. Furthermore, the hazard levels for the surveyed area were also obtained: the largest area being medium 60.68%, 57.45%, 71.21% and 71.16 %, respectively, followed by high 32.59%, 18.91%, 17.03% and 11.54% respectively and low 6.73%, 23.64%, 11.76% and 17.30%, respectively in Chattiwan, Bhawanchuli, Gurji and Hakpara. It was also concluded that the forest area is at high risk followed by the bush and the settlement area in the Chattiwan, Bhawanchuli and Hakpara site and the cultivable land followed by the bush and the settlement area were found to be in high risks in the fourth site (Gurji).

Keywords: UAV, DEM, Chure, Landslide Hazard, Risk Assessment

Introduction

1.1 Background

Landslides are gravity- dominated mass movement that transport soils, rock, dumped waste material and artificial fills from elevated position to the down slope. Landslide generally occurs when extreme events like heavy rainfall, seismic activity, movement of mass of ground which is marginally stable take place. Landslides are common natural hazards in mountain region which are accelerated by the development processes.

Landslide hazard mapping is a basic tool which can be used to represent the hazard area with the magnitude of hazard (High, Moderate, Low). It is important to assess and ensure the year round functioning of the mountainous road for a country like Nepal where most of the terrain is occupied by hills and mountain (Pathak, 2015). Landslide hazard map indicate the areas susceptible to landslide which requires careful evaluation of hazard condition and its possible impact before road alignment is finalized. During construction of highway, alignment fixation plays important role. Occurrence of landslide hazard along the highway is the threat to the objective of timely, efficient and qualitative construction of highway (Pathak, 2015). Landslide also increases the maintenance and operation cost of highway. The ultimate aim of any road construction is to avoid landslide prone area for which landslide hazard map of that area is absolutely necessary.

Chure region is environmentally sensitive due to its loose structural nature of stone, gravel, coarse sands, mudstone and sandstones (Singh, 2017). Recently, Nepal Government announced to develop the alternative highway to connect east and west which passes through the Chure region, named Madan Bhandari Highway. This project will drastically change the area to urbanization which might lead to increase in pressure on the available resources in the Chure region. Land use pattern will be changed that may cause negative impact on the land. The improper land management along the Chure might aggravate the chances of landslide in already fragile landscape. The president of Chure- Terai Madhesh Conservation Development Board, which was formed in 2016, takes the highway construction as a challenge to conserve Chure from the aforementioned disasters (PCTMCD/GoN, 2018).

1.2 Statement of the Problem

Chure hills are formed with the highly fragile, weak and young sedimentary rocks which are highly weathered and deformed, and inter-bedding of soft mudstone and hard sandstone beds provide differential weathering providing plenty of options for slope instabilities and occurrence of different types of landslides (Dhakal, 2016). Landslides in Chure are caused by both natural and human interferences. Change of land use system and land cover due to deforestation, haphazard road construction and over exploitation of raw materials have triggered landslide in Chure area. Madan Bhandari Highway, a new road project from east to west is proposed for construction in Chure area, having length of 1200km, connecting Jhapa of eastern Nepal to Dadeldhura of western Nepal (Poudel, 2018). The new highway proposed

on geologically fragile Chure area will create adverse impact on the environment (Acharya, 2018). Sindhuli- Hetauda section is one section of Madan Bhandari Highway which is under construction without hazard mapping and risk assessment. Road contributes to the largest surface erosion and landslide losses (per unit area disturbed) compared to other land use (Sidle, et al., 2006). Land use has direct impact on the soil erosion and slope stability in tropical mountain including timber harvesting, road trails, various agro-forestry practices, and conversion of forest to agricultural land and to grazing land.

There is lack of detail study of landslides and related phenomena in Chure area that creates dilemma about the landslide hazard, its distribution, and possibility of future occurrences, landslide risks and mitigation measures (Dhakal, 2016). Occurrence of landslide hazard along the highway is the threat to the objective of timely, efficient and qualitative construction of highway (Pathak, 2015). Landslide also increases the maintenance and operation cost of highway. The ultimate aim of any road construction is to avoid landslide prone area for which landslide hazard map of that area is absolutely necessary.

1.2 Significance of the study

Unmanned Aerial Vehicle (UAV) was used to collect high resolution aerial images, which portray the features that can be obtained from the satellite imagery but with higher detail of data, to produce highly accurate Digital Elevation Model (DEM) and Ortho-photo maps. The Ortho-photo map can be used for inventory mapping of landslide and the Digital Elevation Model (DEM) for landslide hazard map. Use of UAV for collection of aerial imagery to produce DEM is cost-effective as well as time efficient. Landslide hazard is a map that includes topographic and geographic information that can be used to compare against the inventory. This can greatly help in fixing and shifting of the alignment to reduce the loss of life and property. Landslide risk analysis has been used to quantify landslide risk along the road surrounding areas. As a final output, direct risk can be quantified for properties (alignments, vehicles, buildings, and plantations) and people (commuters and residents) (Jaiswal & Westen, 2012).

1.3 Scope of the Study

Landslide hazard map along Sindhuli- Hetauda road section of the Chure Area (Sindhuli-Hetauda Section) has been prepared using GIS. Weight of Evidence Model has been used during preparation of landslide hazard map with different parameters such as: Lithology, Land Use, Topography, Drainage, and Road Construction. UAV and SfM technology have been used to get the efficient DEM of the study area along with the ortho-photo map which is useful to identify the actual condition of road construction of the area. Landslide hazard map, together with information on existing or expected vulnerability, have been used to estimate the risk associated with the road networks.

Results and Discussion

2.1 Landslide Inventory in the study area

Landslide inventory map along the Hetauda - Sindhuli Road section contains the information about landslides occurred in that study area, such as landslide phenomena locations, type, volume and damages. Landslides are presented as area coverage by landslide. 100km of the Hetauda- Sindhuli road section was visited during site visit. Road alignment passes through plain as well as hill side. Mainly road contains the cut area at one side, left side as well as right side as shown in figure 2.1. Length of road containing cut at right side was 15.1km and at left side was 40.78km. Road has box cutting in some point. In cut slope along the road alignment, there are landslides visible in slope which exhibit both shallow as well as deep slide.

Figure 2-1 Cut slope zone along the Study area

During the field visit, SW Map was used to track the alignment which was also helpful to mark the cut slope in different location. Cut slope was separated by marking start and end of the cut slope for the remarks to know the point of change in cut and fill. During the field visit, major landslides were marked by GPS in which some were active. The main reason of those slides was construction of new road alignment in fragile geology.

The major landslides available in the study area are shown in table 2.1. In preparing this table, a deliberate effort has been made to set it up according to features that are observed at the time of site visit. Mainly location, soil type, type of landslide, state of activity etc. was tabulated to provide the information of landslides which were caused by the road construction (Sindhuli-Hetauda Road Section).

Table 2-1 Landslide Information

ID	Rural Municipality / Municipality	Ward No.	Tole Name	Soil Type	Type of Landslide	State of Activity	Distance from Road (m)	Distance from Drainage (m)	Land Use	Remarks
LS-1	Bakaiya Rural Municipality	3	Syaulebazar	GC	Debris Slide	Active	10		Forest /Road	Road Construction is cause
LS-2	Bakaiya Rural Municipality	3	Chhatiwan	GC	Debris Fall	Active	40		Forest /Road	Road Construction is cause
LS-3	Bakaiya Rural Municipality	4	Pandure	GC	Rotetional	Dormant	30	5	Forest /Road	Road Construction is cause
LS-4	Bakaiya Rural Municipality	4	Aajingare	GC	Debris Slide	Active	20		Forest /Road	Road Construction is cause
LS-5	Bakaiya Rural Municipality	5	Bhawanchuli	GC	Fall	Active	20	50	Forest /Road	Road Construction is cause
LS-6	Bagmati Rural Municipality	7	Lamitar	GC	Fall	Active	10	20	Forest /Road	Road Construction is cause
LS-7	Bagmati Rural Municipality	7	Lamitar (Near Bagamti)	GC	Slide	Active	40	50	Cultivation/ Road	Road Construction is cause
LS-8	Hariharpurga di Rural Municipality	2	Dande	GC	Fall	Active	20		Cultivation/ Building/Road	Road Construction is cause
LS-9	Hariharpurga di Rural Municipality	3	Banauli	OH	Fall	Active	20		Cultivation/ Road	Road Construction is cause
LS-10	Hariharpurga di Rural Municipality	3	Sakun	OH	Fall	Active	10	Seepage at point	Cultivation/ Road	Road Construction is cause
LS-11	Hariharpurga di Rural Municipality	3	Sakun	GP	Fall	Active	10	Seepage at point	Forest /Road	Road Construction is cause
LS-12	Hariharpurga di Rural Municipality	4	Hakpara	GC	Fall	Active	10	Seepage at point	Forest /Road	Road Construction is cause
LS-13	Hariharpurga di Rural Municipality	2	Gurji/Pipalmadi	GC	Slide/ Fall	Active	20	50	Cultivation/ Building/Road	Road Construction is cause

The Unified Soil Classification System (USCS) is a soil classification system used in describing the texture and grain size of soil in study area. The classification system can be applied to most unconsolidated materials, and is represented by a two-letter symbol as shown in table 4.2.

Table 2-2 The Unified Soil Classification System

Major Divisions			Group Symbols	Typical Names
Coarse grained soils, more than 50% retained on 0.075 mm seive and passing 75 mm sieve	Gravels 50% or more of coarse fraction retained on 4.75 sieve	Clean Gravel	GW	Well-graded gravel, fine to coarse gravel
			GP	Poorly graded gravel
		Gravels with fines	GM	Silty gravel
			GC	Clayey Gravel
	Sands more than 50% of coarse traction passes 4.75 mm sieve	Clean sands	SW	Well-graded sand, fine to coarse sand
			SP	Poorly graded sand
		Sands with fines	SM	Silty sand
			SC	Clayey sand
Fine grained soils 50% or more passes 0.075 mm	Silts and clays liquid limit 50% or less		ML	Silt
			CL	Clay of low plasticity, lean clay
			OL	Organic silt, organic clay
	Silts and clays liquid limit Greater than50%		MH	Silt of high plasticity, elastic silt
			CH	Clay of high plasticity, fat clay
			OH	Organic clay, organic silt
Highly organic soils			PT	Peat

Source (Dahal, 2006)

Types of landslides observed at study area were classified on the basis of type of landslide proposed by Varnes (1978). The type of landslides was determined by a short period of observation or by the shape of the slide and arrangement of debris. Landslide types are shown in figure 2.1.

The states of activity of landslides in the study area were classified on the basis of moving nature observed. An active landslide is the one which currently moving whereas dormant landslides are inactive landslide which can be reactivated by its original causes or other causes. In study area, major landslides observed were active in state due to the higher cut slope of road in hill side and lack of protective measures in those area.

The location of the landslides in the study area were surveyed with GPS which is presented in table 2.3. In table 2.3, landslide status has been categorized into small and big on the basis of area covered by landslide on that location. Big landslide has two or more than two landslides near about the point Land use available near those existing landslides in road alignment has been presented as the vulnerable land use.

Table 2-3 Vulnerable Information

ID	GPS Point			Landslide Status	Vulnerable			Remarks
	Easting	Northing	Height		Building	Road	Cultivation	
LS-1	319795	3026905	490	Small				
LS-2	319951	3026690	444	Big				
LS-3	324241	302588	280	Small				
LS-4	325222	3026472	288	Small				
LS-5	330456	3026852	356	Small				
LS-6	340977	3024517	257	Small				
LS-7	345351	3020108	211	Small				
LS-8	348273	3018875	199	Small				
LS-9	350898	3016058	199	Small				
LS-10	352559	3013661	208	Small				
LS-11	352552	3015993	212	Big				
LS-12	359813	3016981	234	Small				
LS-13	343599	3020573	217	Small				

The thirteen landslides areas are shown along the proposed highway in figure 2.2.

Considering the size, type and impact of the landslide in the study area, four sites were selected as the critical section for the study in which UAV was used to survey the area. The orthomosaic, output of the UAV survey, was used to identify the existing landslide in the selected specific study area of the road section. Major land use of area was also digitized to identify the impact of landslide in those areas. Table 2.4 shows the detail information about the selected site of study area for hazard map. All data of table 2.4 are collected through field visit.

Table 2-4 Details of each site in the study area

Site-1 (CHATTIWAN)	Site-2 (BHAWANCHULI)
<p>Land Use:</p> <ul style="list-style-type: none"> • Forest • Road <p>Feature Damage:</p> <ul style="list-style-type: none"> • Road • Natural Channel in valley Side of the road • Forest <p>Kind of Damage: Partially Collapse Length of study Section: 2 Km</p> <p>Major point having landslide are as below:</p> <ul style="list-style-type: none"> • GPS Point: <ul style="list-style-type: none"> E: 319319 m N: 3027124 m Z: 532 m Right Side from road Soil Depth: 50 cm Below soil: PattreChattan Soil Type: GC Landslide Type: Debris Slide • GPS Point: <ul style="list-style-type: none"> E: 319424 m N: 3026998 m Z: 549 m Left Side from road Soil Depth: 40 cm Below soil: Rock Soil Type: GC Landslide Type: Soil and Rock Fall • GPS Point: <ul style="list-style-type: none"> E: 319755 m N: 3026939 m Z: 522 m Left Side from road Soil Depth: 50 cm Below soil: Rock Soil Type: GC 	<p>Land Use:</p> <ul style="list-style-type: none"> • Forest • Road • Cultivation • Building <p>Feature Damage:</p> <ul style="list-style-type: none"> • Road • Natural Channel • Forest • Cultivation • Electric Pole: Three Phase <p>Kind of Damage: Partially Collapse Length of study Section: 2 Km</p> <p>Major point having landslide are as below:</p> <ul style="list-style-type: none"> • GPS Point: <ul style="list-style-type: none"> E: 330444.71 m N: 3026845.34 m Z: 399 m Right Side from road Soil Depth: 60 cm Below soil: PattreChattan Soil Type: GC Landslide Type: Debris Slide • GPS Point: <ul style="list-style-type: none"> E: 330613.06 m N: 3026887.73 m Z: 433 m Left Side from road Soil Depth: 40 cm Below soil: Rock Soil Type: GC Landslide Type: Soil and Rock Fall • GPS Point: <ul style="list-style-type: none"> E: 330696.72 m N: 3026818.64 m Z: 458 m

<p>Landslide Type: Soil and Rock Fall</p> <ul style="list-style-type: none"> GPS Point: <p>E: 320222 m N: 3026622 m Z: 445 m Left Side from road Soil Depth: 50 cm Below soil: Rock Soil Type: GC Landslide Type: Debris Fall</p>	<p>Right as well as Left Side from road Soil Depth: 20 cm Below soil: Soil Type: Boulder Mix Soil Landslide Type: Soil and Boulder Fall</p>
<u>Site-3 (GURJI)</u>	<u>Site-4 (HAKPARA)</u>
<p>Land Use:</p> <ul style="list-style-type: none"> Forest Road Building Cultivation <p>Feature Damage:</p> <ul style="list-style-type: none"> Road Natural Channel (Bagmati River) in valley Side of the road Forest Cultivation Building <p>Protection: Gabion wall at site 3(b) but not sufficient height to protect the landslide</p> <p>Kind of Damage: Partially Collapse Length of study Section: 1.5 Km</p> <p>Major point having landslide are as below:</p> <ul style="list-style-type: none"> GPS Point: <p>E: 345304.13 m N: 3020179.94 m Z: 243 m left Side from road Soil Depth: 45 cm Below soil:</p>	<p>Land Use:</p> <ul style="list-style-type: none"> Forest Road Barren Land <p>Feature Damage:</p> <ul style="list-style-type: none"> Road Natural Channel in valley Side of the road Forest <p>Kind of Damage: Partially Collapse Length of study Section: 2 Km</p> <p>Major point having landslide are as below:</p> <ul style="list-style-type: none"> GPS Point: <p>E: 356258 m N: 30169663 m Z: 224 m Left Side from road Soil Depth: 30 cm Below soil: PatreChattan Soil Type: GC Landslide Type: Soil and Rock Slide</p> <ul style="list-style-type: none"> GPS Point: <p>E: 356211 m N: 3016879 m Z: 206 m</p>

<p>Soil Type: GC Landslide Type: Soil and Rock fall</p> <ul style="list-style-type: none"> GPS Point: <p>E: 345565.14 m N: 3020477.30 m Z: 238 m Left Side from road Soil Depth: 40 cm Below soil: Rock Soil Type: GC Landslide Type: soil slide</p> 	<p>Left Side from road Soil Depth: 35 cm Below soil: Rock Soil Type: GC Landslide Type: Soil and Rock Fall</p> <ul style="list-style-type: none"> GPS Point: <p>E: 356152 m N: 3016830 m Z: 206 m Left Side from road Soil Depth: 20 cm Below soil: PatreeChattan Soil Type: GC Landslide Type: Soil and Rock Fall</p> GPS Point: <p>E: 356005 m N: 3016748 m Z: 206 m Left Side from road Soil Depth: 50 cm Below soil: Patree Chattan Soil Type: GC Landslide Type: Debris Fall</p> GPS Point: <p>E: 355886 m N: 3016621 m Z: 211 m Left Side from road Soil Depth: 30 cm Below soil: Boulder Mix Soil Soil Type: GC</p> GPS Point: <p>E: 355474.95 m N: 3015943.73 m Z: 230 m Left Side from road Soil Depth: 25 cm Below soil: Patree Chattan Soil Type: GC</p>
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2.1.1 Chattiwan site

Chattiwan site was selected on the basis of existing landslide area along the road alignment and junction of the two major road (Proposed Madan Bhandari Highway and Fast Track). The study mainly focused on the Madan Bhandari highway section but newly cut area of fast track also has seen impact on the section. Orthomosaic in figure 2.3 provides the picture of the site at the time of survey. Land use of that area was obtained by digitizing the orthomosaic presented in figure 2.4. The major land use has been found to be forest which covers the 0.725 sq. km. Other land use on Chattiwan site were cultivation, settlement, stream, wall, landslide, fill, road etc. The land use, landslide indicates the existing landslide in the study area which covers the 0.883 sq.km. Table 2.5 provided information of land use with area cover by individual land use in the study area.

Figure 2-3 Orthophoto of Chattiwan

Figure 2-4 Landuse map of Chattiwan

Table 2-5 Area of land use in Chattiwan

SN	Land Use	Area (sq. m)
1	Cultivation	45078.14
2	Fill	100792.46
3	Forest	725266.03
4	Landslide	88282.85
5	Road	28300.07
6	Settlement	3481.67
7	Stream	18207.69
8	Wall	64.59

2.1.2 Bhawanchuli site

Bhuwnchuli site was selected on the basis of existing landslide area along the road alignment and impact of landslide on settlement and cultivable land. Orthomosaic in figure 2.5 provides the picture of the site at the time of survey. By using orthomosaic, land use of the study area was digitized which is presented in figure 2.6. The major land use was found out to be forest which covers the 0.298 sq. km. Other land use on Bhawanchuli site were cultivation, settlement, stream, bagar, Barren land, river, landslide, fill, road etc. The parameter landslide indicates the existing landslide in the study area which covers the 0.229 sq.km. Table 2.6 provides the area covered by the land use pattern in surveyed area.

Figure 2-5 Orthophoto of Bhawanchuli

Figure 2-6 Land use map of Bawanchuli

Table 2-6 Area of land use in Bhawanchuli

SN	Land use	Area (Sq.m)
1	Bagar	1119.99
2	Barren land	17016.96
3	Bush	79750.55
4	Cultivation	533023.08
5	Fill	9457.93
6	Forest	298053.21
7	Landslide	22943.37
8	River	39350.43
9	Road	64304.66
10	Settlement	19168.77
11	Stream	14883.21

2.1.3 Gurji site

Gurji site was selected on the basis of existing landslide area along the road alignment and impact of landslide on settlement and cultivable land. Orthomosaic in figure 2.7 provides the picture of the site at the time of survey. By using orthomosaic, land use of the study area was digitized which is presented in figure 2.8. The major land use was cultivation which covers the 0.520 sq. km. Other land use on Gurji site were cultivation, settlement, stream, bagar, Barren land, river, landslide, fill, road etc.

Figure 2-7 Orthophoto of Gurji

Figure 2-8 Land use map of Gurji

The parameter landslide indicates the existing landslide in the study area which covers the 0.066 sq.km. The table 2.8 provides the area covered by the land use pattern in surveyed area.

Table 2-7 Area of different land use in Gurji

SN	Land use	Area (sq.m)
1	Bagar	95465.08
2	Barren land	84159.07
3	Bush	334112.92
4	Cultivation	519529.53
5	Fill	32460.09
6	Landslide	6605.13
7	River	36547.21
8	Road	25726.34
9	Settlement	29055.56
10	Stream	27133.43

2.1.4 Hakpara site

Hakpara site was selected on the basis of existing landslide area along the road alignment and impact of landslide on road. Orthomosaic in figure 2.9 provides the picture of the site at the time of survey. By using orthomosaic, land use of the study area was digitized which is presented in figure 2.10. The major land use was forest which covers the 0.452 sq. km. Other land use on Gurji site were cultivation, settlement, stream, bagar, Barren land, river, landslide, fill, road, pond etc. The parameter landslide indicates the existing landslide in the study area

which covers the 0.451 sq.km. Table 2.8 provides the area covered by the different land use pattern in surveyed section i.e. site IV.

Figure 2-9 Orthophoto of Hakpara

Figure 2-10 Land use of Hakpara

Table 2-8 Area of different land use in Hakpara

SN	Land Use	Area (sq.m)
1	Barren land	413774.04
2	Cultivation	213809.20
3	Fill	30891.62
4	Forest	513887.96
5	Landslide	45172.42
6	Pond	1776.37
7	River	51673.84
8	Road	22391.05
9	Settlement	16497.36
10	Stream	4639.13

2.2. Topographical map preparation for hazard mapping

For topographic map preparation, GIS based technique was used to process the DEM generated by the PixdD mapper. PixdD Mapper uses Structure from Motion algorithm (SfM) to reconstruct the actual surface from a large number of overlapping photos. The software locates matching features on each image and uses iterative bundle block adjustment to estimate image orientation, exterior orientation parameters and building model geometry. The GCPs are entered to aero triangulation which enables precise calculation of the exterior orientation parameters and improves spatial geo-referencing accuracy. The final step generates the digital surface model (DSM) by building the model texture and exporting a 3D model (mesh) or orthomosaic.

Photogrammetry produces only a surface envelope and cannot capture terrain under vegetation cover. So, UAV point cloud data were manually classified in different classes for filtering vegetation cover and buildings. The elevation model generated from all point cloud data was labelled the digital surface model (DSM) and the model from ground point cloud data was termed the digital terrain model (DTM).

Plate 1: GCP setup

Plate 2: Data recording using DGPS

From the finding, it can be observed that the accuracy of the topographical survey is formidable, with the Root Mean Square Error (RMSE) of the survey for the individual sites as 0.001m, 0.045 m, 0.044 m and 0.408 m respectively. Meanwhile, the errors in the X, Y and Z of the sites are good enough, and the survey conducted can hence be said to be of the survey-grade accuracy. For the absolute accuracy of the survey, the Differential GPS (DGPS) played the vital role. Table 2.9 shows the co-ordinate of ground control point used during process of UAV imagery. After completion of processing of image PixdD mapper provided the mean root mean square error (RMS) of the geo-referencing as presented in figure 2.11 and error calculation also presented in figure 2.12.

Table 2-9 Co-ordinate of ground control point

Point	Easting	Northing	Z	Remarks	Site
2015	320267.2631	3026996.484	402.5869	GCP-1	Chattiwan
2016	319406.3871	3026951.777	467.9689	GCP-2	Chattiwan
2017	319869.7026	3026401.22	415.0704	GCP-3	Chattiwan
2020	330379.9078	3026877.302	312.1119	GCP-4	Bhawanchuli
2021	330623.4246	3027002.017	353.7346	GCP-5	Bhawanchuli
2022	330721.9609	3026695.83	385.9781	GCP-6	Bhawanchuli
2025	345648.568	3020631.688	165.5747	GCP-7	Gurji
2026	345588.3088	3020318.824	169.1284	GCP-8	Gurji
2027	345587.9736	3020318.376	167.0681	GCP-9	Gurji
2030	355626.2952	3016145.932	154.7943	GCP-11	Hakpara
2031	355514.7932	3015838.767	150.4054	GCP-12	Hakpara
2032	355763.8028	3016396.631	161.8068	GCP-13	Hakpara
2033	356252.32	3016952.48	155.8397	GCP-14	Hakpara

Images	median of 54137 keypoints per image
Dataset	544 out of 576 images calibrated (94%), all images enabled, 2 blocks
Camera Optimization	0.36% relative difference between initial and optimized internal camera parameters
Matching	median of 8601.32 matches per calibrated image
Georeferencing	yes, 3 GCPs (3 3D), mean RMS error = 0.001 m

Images	median of 71457 keypoints per image
Dataset	727 out of 728 images calibrated (99%), all images enabled
Camera Optimization	0.65% relative difference between initial and optimized internal camera parameters
Matching	median of 14186.1 matches per calibrated image
Georeferencing	yes, 3 GCPs (3 3D), mean RMS error = 0.044 m

Figure 2-11 Mean RMS error

Ground Control Points						
GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1 (3D)	0.020/ 0.020	0.000	0.001	0.001	0.386	6 / 6
2 (3D)	0.020/ 0.020	0.001	-0.001	-0.002	0.290	6 / 6
3 (3D)	0.020/ 0.020	-0.002	-0.000	0.003	0.343	6 / 6
Mean [m]		-0.000131	0.000057	0.000868		
Sigma [m]		0.001165	0.000674	0.001892		
RMS Error [m]		0.001172	0.000677	0.002081		

Ground Control Points						
GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
3 (3D)	0.020/ 0.020	-0.042	-0.057	0.020	0.489	9 / 9
2 (3D)	0.020/ 0.020	0.027	0.138	0.003	0.271	6 / 6
1 (3D)	0.020/ 0.020	0.020	-0.065	0.006	0.503	9 / 9
Mean [m]		0.001411	0.005578	0.009588		
Sigma [m]		0.031031	0.093886	0.007544		
RMS Error [m]		0.031063	0.094052	0.012200		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Figure 2-12 Calculation of RMS error

2.2.1 Elevation

Topographic relief of the study area divided into different classes is often used to describe and reflect the macroscopic features of the terrain surface, which is of great significance for landslide sensitivity analysis. Elevation model is one of the major outputs of this study. Whole study area can be generalized with reference of the elevation model. The study area lies in the range of 95-533 m from the mean sea level.

Four different sites have different elevation range. The elevation difference of first selected site (Chattiwan) is 268.15 m starting from 264.52 m to 532.87 m. Similarly, second, third and fourth site have the elevation difference of 213.07 m, 137.872 m, 296.56 m. Fourth surveyed area lies in the lowest elevation range where first site lies on the highest elevation range. Four different sites have different elevation difference values which directly impact the accuracy and final output of the result as well as the details that are visible in the final Orthomosaic. The resolution of output is based on the ground sampling distance (GSD). In this study resolution of the orthomosaic is one times of GSD and DTM/DEM is three times of GSD. Because of the unequal elevation difference in four different sites, they have different GSD as well as resolution of output. GSD of first, second, third and fourth site is 6.08 cm/pixel, 5.6 cm/pixel, 4.42 cm/pixel, 7.25 cm/pixel respectively.

Elevation model is often used to describe and reflect the macroscopic features of the terrain surface, which is of great significance for landslide sensitivity analysis (Wang, et al., 2017). DEMs of different site of study generated by PixdD software were reclassified to derive the elevation model. Chattiwan site was reclassified into six classes where other sites, Bhawanchuli, Gurji and Hakpara were reclassified into five, three and five classes

respectively as shown in figure 2.13 (a), figure 2.13 (b), figure 2.13 (c) and figure 2.13 (d) respectively. Area of existing landslide occurred in the different class of elevation are shown in table 2.10, 2.11, 2.12 and 2.13 for Chattiwan, Bhawanchuli, Gurji and Hakapara site respectively. Moreover, in tables aforementioned (2.10, 2.11, 2.12 and 2.13), area of individual class of elevation were calculated on the basis of number of cell (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

Figure 2-13 Elevation class of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakapara

Table 2-10 Occurrence of landslide with elevation in Chattiwan site

OID	Class	Count	Area	Lanslide Count	Landslide Area	% of Landslide
1	264.52-300	3006237	100104.54	0	0.00	0.00
2	300-350	8835361	294208.25	141	2468.60	4.87
3	350-400	9450595	314694.89	662	11590.18	22.84
4	400-450	8318476	276996.52	1574	27557.32	54.31
5	450-500	5496379	183023.65	521	9121.58	17.98
6	500-532.87	3477220	115787.78	0	0.00	0.00
Total			1284815.63		50737.67	100.00

Table 2-11 Occurrence of landslide with elevation in Bhawanchuli site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	205.726-250	10648623	300940.44	0	0.00	0.00
2	250-300	14169477	400443.19	136	3068.25	10.56
3	300-350	6272317	177261.78	402	9069.40	31.21
4	450-500	5746558	162403.32	750	16920.52	58.23
5	500-418.803	660594	18669.03	0	0.00	0.00
Total			1059717.75		29058.17	100.00

Table 2-12 Occurrence of landslide with elevation in Gurji site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	146.29-150	21437	376.13	0	0.00	0.00
2	150-200	47255212	829123.49	823	21526.44	82.38
3	200-250	22447863	393862.38	83	2170.95	8.31
4	250-284.14	3180753	55808.38	93	2432.51	9.31
Total			1279170.38		26129.91	100.00

Table 2-13 Occurrence of landslide with elevation in Hapkara site

OID	Class	Count	Aera	Landslide Count	Landslide Area	% of landslide
1	97.89-150	11737564	555311.20	0	0.00	0.00
2	150-200	5764728	272732.74	800	27846.08	61.44
3	200-250	6758379	319742.97	282	9815.74	21.66
4	250-300	3409414	161301.42	171	5952.10	13.13
5	300-394.437	3510992	166107.14	49	1705.57	3.76
Total			1475195.46		45319.50	100.00

2.2.2 Slope

In our study area, slope was classified in six categories as very gentle, gentle, moderate, moderately steep, steep, and very steep are shown in figure 2.14 (a), 2.14 (b), 2.14 (c) and 2.14 (d) respectively, for site Chattiwan, Bhawanchuli, Gurji and Hakpara respectively. Due to the steep road side slope, there were many landslides active in the study area. In Chattiwan site around 2 km of road section has the steep roadside slope and Bhawanchuli, Gurji and Hakpara also have steep slope. The slope angle map was extracted from the DEM.

The slope map was re-classified into six classes: (1) 0°–5° (Very gentle), (2) 5°–10° (Gentle), (3) 10°–15° (Moderate), (4) 15°–25° (Moderate Steep), (5) 25°–35° (Steep), and (6) > 35° (Very steep). The maximum slope gradient is 86.56 in Hakpara. The result shows that maximum percentage of landslides occurred when the slope is between greater than 35° (Very Steep). In Chattiwan 45.96 % of existing landslide lied in steep slope and in Bhawanchuli,

Gurji and Hakpara, 37.73 %, 37.14%, 68.51% of landslide lies in steep slope as shown in table 2.14, 2.15, 2.16 and 2.17 respectively. Moreover, in tables aforementioned (2.14, 2.15, 2.16 and 2.17), area of individual class of slope were calculated on the basis of number of cell (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

Figure 2-14 Elevation class of (a) Chattiwadan (b) Bhawanchuli (c) Gurji (d) Hakpara

Table 2-14 Occurrence of landslide with slope class

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Very gentle	1851187	61642.58	165	2888.79	5.69
2	Gentle	2192795	73017.77	285	4989.73	9.83
3	Moderate	2151681	71648.72	184	3221.44	6.35
4	Moderate Steep	6414175	213585.30	379	6635.47	13.08
5	Steep	9281175	309053.39	553	9681.83	19.08
6	Very Steep	8424394	280523.48	1332	23320.42	45.96
Total			1009471.23		50737.67	100.00

Table 2-15 Occurrence of landslide with slope class

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Very gentle	10877641	307412.71	51	1150.60	3.96
2	Gentle	6097483	172320.80	91	2053.02	7.07
3	Moderate	3744409	105820.64	109	2459.12	8.46
4	Moderate Steep	6069614	171533.19	249	5617.61	19.33
5	Steep	5782191	163410.34	302	6813.33	23.45
6	Very Steep	4926231	139220.08	486	10964.50	37.73
Total			1059717.75		29058.17	100.00

Table 2-16 Occurrence of landslide with slope class

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Very gentle	27300304	479001.62	58	1517.05	5.81
2	Gentle	9368153	164370.35	57	1490.90	5.71
3	Moderate	6253277	109717.82	69	1804.77	6.91
4	Moderate Steep	11629539	204047.84	171	4472.69	17.12
5	Steep	10757931	188754.91	273	7140.61	27.33
6	Very Steep	7596061	133277.84	371	9703.90	37.14
Total			1279170.38		26129.91	100

Table 2-17 Occurrence of landslide with slope class

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Very gentle	2967808	140408.78	3	104.42	0.23
2	Gentle	8963870	424086.07	21	730.96	1.61
3	Moderate	4599666	217612.96	55	1914.42	4.22
4	Moderate Steep	5210155	246495.56	121	4211.72	9.29
5	Steep	4624231	218775.14	210	7309.60	16.13
6	Very Steep	4815343	227816.77	892	31048.38	68.51
Total			1475195.28		45319.50	100.00

2.2.3 Aspect

The aspect includes nine faces, which are flat, north, northeast, east, southeast, south, southwest, west, and northwest. The aspect map is derived by using the spatial tool of GIS software which classified the aspect on the basis of slope with respect to the north. Aspect (slope orientation) affects the exposure to sunlight, wind and precipitation thereby indirectly affecting other factors that contribute to landslides such as soil moisture, vegetation cover and soil thickness (Meten & Bhandary, 2015).

In Chattiwan, maximum 31.92 % of landslide lies in the south and 26.64% on the southeast. In Bhawanchuli, maximum 18.63% of landslide lies on the west and 14.60% on the north. In Gurji, maximum percentage of landslide (28.53%) was observed in south where in Hakpara, maximum % of landslide (45.39%) was observed in southeast. Table 2.18, 2.19, 2.20 and 2.21 shows the percentage of existing landslide in each class of aspect in Chtriwan, Bhawanchuli, Gurji and Hakpara site respectively. Moreover, in tables aforementioned (2.18, 2.19, 2.20 and 2.21), area of individual classes of aspect were calculated on the basis of number of cell (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

With the reference of all results in study area more landslides were seen in the south and southeast direction than in other direction. Aspect map of Chattiwan site, Bhawanchuli site, Gurji site and Hakpara site are shown in figure 2.15 (a), (b), (c), (d).

Figure 2-15 Aspect class of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Table 2-18 Occurrence of landslide with aspect class

OID	Class	Count	Area	Landslide Count	Landslide Area	%of area
1	Flat	3082	102.63	0	0.00	0.00
2	North	1340362	44632.65	37	647.79	1.28
3	Northeast	4653157	154945.24	134	2346.05	4.62
4	East	4792464	159584.02	315	5514.96	10.87
5	Southeast	4687386	156085.03	772	13516.04	26.64
6	South	6404393	213259.56	925	16194.74	31.92
7	Southwest	4122951	137289.94	471	8246.19	16.25
8	West	2090301	69604.83	182	3186.42	6.28
9	Northeast	1460731	48640.81	48	840.38	1.66
10	North	760582	25326.58	14	245.11	0.48
Total			1009471.30		50737.67	100

Table 2-19 Occurrence of landslide with aspect class

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Flat	1499	42.36	0	0.00	0.00
2	North	3523352	99573.35	188	4241.41	14.60
3	Northeast	3739953	105694.71	184	4151.17	14.29
4	East	2204684	62306.51	138	3113.38	10.71
5	Southeast	1632629	46139.68	28	631.70	2.17
6	South	1647701	46565.63	43	970.11	3.34
7	Southwest	3745322	105846.44	139	3135.94	10.79
8	West	5803959	164025.52	240	5414.57	18.63
9	Northeast	10308545	291329.50	210	4737.74	16.30
10	North	4889927	138194.09	118	2662.16	9.16
Total			1059717.81		29058.17	100.00

Table 2-20 Occurrence of landslide with aspect class

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Flat	12566	220.48	0	0.00	0.00
2	North	3209145	56306.54	8	209.25	0.80
3	Northeast	8633171	151474.61	63	1647.83	6.31
4	East	10745813	188542.29	150	3923.41	15.02
5	Southeast	11122644	195154.04	220	5754.33	22.02
6	South	11104278	194831.79	285	7454.48	28.53
7	Southwest	10115802	177488.34	106	2772.54	10.61
8	West	8406274	147493.55	124	3243.35	12.41

9	Northeast	6522922	114448.92	37	967.77	3.70
10	North	3032650	53209.82	6	156.94	0.60
Total			1279170.38		26129.91	100

Table 2-21 Occurrence of landslide with aspect class

OID	Class	Count	Area	Landslide Count	Landslide Area	% of landslide
1	Flat	84665	4005.55	0	0.00	0.00
2	North	474731	22459.81	0	0.00	0.00
3	Northeast	2110806	99863.50	68	2366.92	5.22
4	East	8041478	380447.15	362	12600.35	27.80
5	Southeast	14567361	689190.59	591	20571.29	45.39
6	South	3229026	152767.16	239	8319.02	18.36
7	Southwest	1224187	57917.02	41	1427.11	3.15
8	West	663194	31376.11	1	34.81	0.08
9	Northeast	504244	23856.09	0	0.00	0.00
10	North	281385	13312.49	0	0.00	0.00
Total			1475195.46		45319.50	100.00

2.2.4 Curvature

The plan curvature is defined as the rate of change of the slope angle, which directly affects surface runoff and the development of landslides (Wang, et al., 2017). Plan curvature is classified in three categories such as concave, flat and convex. In this study Arc GIS with its spatial analysis tool was applied to derive plan curvature in which negative curvatures value represents concave, around zero (-0.1 – 0.1) curvatures value represent flat and positive curvatures value represent convex surface. Concave and convex surfaces of the earth are more influential in boosting landslide to occur.

DEM produced by PixdD mapper was used to derive plan curvature of the study area. Figure 2.16 (a), (b), (c), and (d) respectively shows the curvature map of Chattiwan, Bhawanchuli, Gurji and Hakpara respectively. In Chattiwan, curvature map has a range between (-6832.5205-2052.60) and other site Bhawanchuli, Gurji and Hakpara has a range between -9648.43 to 2388.418, -21820.94 to 4162.69 and -9313.7666 to 8246.3730 respectively. Among four study site, maximum area of existing landslide in concave area was higher in Chattiwan, Gurji and Hakpara while convex was higher in Bhawanchuli site.

Figure 2-16 Curvature class of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

The percentage of existing landslide in three class of Curvature are presented in table 2.22, 2.23, 2.24 and 2.25 for four site, Chattiwan, Bhawanchuli, Gurji and Hakpara. Moreover, in tables aforementioned, area of individual classes of curvature were calculated on the basis of number of cells (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

Table 2-22 Occurrence of landslide with curvature class in Chattiwan site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Concave	13824794	460351.13	1638	28677.82	56.52
2	Flat	95602	3183.45	2	35.02	0.07
3	Convex	16395012	545936.69	1258	22024.84	43.41
Total			1009471.27		50737.67	

Table 2-23 Occurrence of landslide with curvature class in Bhawanchuli site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Concave	19401493	548305.05	642	14483.96	49.84
2	Flat	14303	404.22	0	0.00	0.00
3	Convex	18081774	511008.51	646	14574.21	50.16
Total			1059717.78		29058.17	100.00

Table 2-24 Occurrence of landslide with curvature class in Gurji site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Concave	39167655	687222.03	500	13078.03	50.05
2	Flat	81766	1434.64	0	0.00	0.00
3	Convex	33655842	590513.68	499	13051.88	49.95
Total			1279170.34		26129.91	100

Table 2-25 Occurrence of landslide with curvature class in Hapkara site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Concave	15336007	725555.69	659	22938.21	50.61
2	Flat	139884	6618.00	1	34.81	0.08
3	Convex	15705186	743021.77	642	22346.48	49.31
Total			1475195.46		45319.50	100.00

2.2.5 Distance from road

The study area encompasses Madan Bhandari Highway which passes through the Chure area. Chure is the most fragile area. Changing of land use system and land cover due road construction have triggered landslide in Chure area. Due to rugged terrain, roads in the chure are characterized by high gradient, steep slopes, sharp curves including unstable geological features, mass movements, debris flow, etc. There are frequent provision/occurrence of heavy cut and fills in the hill roads which are not mechanically compacted. These loose materials cause numerous landslides in the hills. Equally, the excessive cut areas are exposed to heat and rain effects which causes slope instability, ultimately landslides are inevitable.

The layer of the road from the land use map was used to generate the distance from the road. The distance from road was classified into the separate classes to identify the impact of the road in the landslide. Figure 2.17 (a), (b), (c) and (d) respectively shows the distance from road map for Chattiwan, Bhawanchuli, Gurji and Hakpara respectively. Road network layer was developed by digitizing the road from orthomosaic. The vector layer of road was used to create Euclidean distance raster. In this study Arc GIS with its spatial analysis tool was applied to derive the Euclidean distance. The distance from road was reclassified into six classes which represent the range of distance from road. In the study area, it was observed that the landslides generally occur near the road. In Chattiwan, Bhawanchuli, Gurji and Hakpara,

higher percentage of landslides were seen near the road (0-50m). The percentage of existing landslide in different interval of distance from road are presented in table 2.26, 2.27, 2.28 and 2.29 for four site, Chattiwan, Bhawanchuli, Gurji and Hakpara. Moreover, in tables aforementioned, area of individual classes of distance from road were calculated on the basis of number of cell (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

Figure 2-17 Distance from road map of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Table 2-26 occurrence of landslide with distance from the road in Chattiwan						
OID	Class	Count	Area	Landslide Count	Landslide Area	% of landslide
1	0-50	25304	478404.11	2728	47761.34	94.13
2	50-100	21781	411797.34	170	2976.33	5.87
3	100-200	28417	537259.31	0	0.00	0.00
4	200-300	9691	183220.61	0	0.00	0.00
5		2790	52748.48	0	0.00	0.00
6		1016	19208.76	0	0.00	0.00
Total			1682638.60		50737.67	100.00
Table 2-27 Occurrence of landslide with distance from the road in Bhawanchuli						
OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	0-50	20314	555207.33	683	17864.59	70.12
2	50-100	14376	392914.28	193	5048.12	19.82
3	100-200	18456	504425.84	33	863.15	3.39
4	200-300	8012	218978.10	65	1700.14	6.67
5	300-400	2832	77402.14	0	0.00	0.00
Total			1748927.69		25476.01	100.00
Table 2-28 Occurrence of landslide with distance from the road in Gurji						
OID	Class	Count	Area	Landslide Count	Landslide Area	% of landslide
1	0-50	14193	539150.18	617	21476.29	51.55
2	50-100	10914	414590.65	243	8458.25	20.30
3	100-200	15670	595257.05	163	5673.64	13.62
4	200-300	10897	413944.87	174	6056.52	14.54
5	>300	9181	348759.09	0	0.00	0.00
Total			2311701.83		41664.70	100.00
Table 2-29 Occurrence of landslide with distance from the road in Hakpara						
OID	Class	Count	Area	Landslide Count	Landslide Area	% of landslide
1	0-50	24075	455168.31	3953	69208.43	83.80
2	50-100	19982	377784.97	427	7475.84	9.05
3	100-200	29001	548300.56	337	5900.14	7.14
4	200-300	10254	193864.83	0	0.00	0.00
5		3354	63411.61	0	0.00	0.00
6		1834	34674.09	0	0.00	0.00
Total			1673204.37		82584.41	100.00

2.2.6 Distance from stream

The Madan Bhandari Highway crosses the lot of stream in sindhuli- Hetauda section. In this study, stream layer was developed by digitizing the stream and river from orthomosaic. The vector layer of stream and river was used to create Euclidean stream distance raster. In this study Arc GIS with its spatial analysis tool was applied to derive the Euclidean distance. The distance from stream was reclassified into six classes which represent the range of distance from stream. Figure 2.18 (a), (b), (c) and (d) respectively shows the distance from stream map for Chattwan, Bhawanchuli, Gurji and Hakpara respectively.

The role played by rivers in creating a conducive environment for landslide occurrence has great significance. The maximum number of landslides in the close proximity of rivers, as can be seen in table 2.30, 2.31, 2.32 and 2.33 for different site, shows how rivers are contributing to land sliding. Moreover, in tables aforementioned, area of individual classes of distance from stream were calculated on the basis of number of cell (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

Figure 2-18 Distance from stream map of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Table 2-30 Occurrence of landslide with distance from the stream in Chattiwan site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	0-100	20742	392153.73	59	1032.96	2.04
2	100-200	22298	421571.88	2012	35225.74	69.43
3	200-300	17702	334678.69	564	9874.41	19.46
4	300-400	12561	237481.58	156	2731.22	5.38
5	400-500	8260	156165.74	34	595.27	1.17
6	500-600	7436	140586.98	73	1278.07	2.52
Total			1682638.60		50737.67	100.00

Table 2-31 Occurrence of landslide with distance from the stream in Bhawanchuli site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	0-100	39121	915753.58	506	11415.71	40.03
2	100-200	23491	549882.86	621	14010.19	49.13
3	200-300	11460	268258.38	46	1037.79	3.64
4	300-400	4274	100046.80	69	1556.69	5.46
5	400-500	1814	42462.54	22	496.34	1.74
6	500-600	339	7935.39	0	0.00	0.00
Total			1884339.54		28516.71	100.00

Table 2-32 Occurrence of landslide with distance from the stream in Gurji site

OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	0-100	22133	604922.90	159	4158.81	16.32
2	100-200	10563	288700.16	29	758.53	2.98
3	200-300	10725	293127.82	151	3949.57	15.50
4	300-400	10961	299578.00	509	13313.44	52.26
5	400-500	8271	226056.90	126	3295.66	12.94
6	500-600	2844	77730.12	0	0.00	0.00
Total			1790115.91		25476.01	100.00

Table 2-33 Occurrence of landslide with distance from the stream in Hapkara site

OID	Class	Count	Area	Landslide Count	Landslide area	% of landslide
1	0-100	22211	843730.33	736	25618.40	61.49
2	100-200	13579	515826.13	456	15872.27	38.10
3	200-300	11271	428152.02	5	174.04	0.42
4	300-400	10009	380212.37	0	0.00	0.00
5	400-500	8917	338730.51	0	0.00	0.00
Total			2506651.36		41664.70	100.00

2.2.7 Geology Map

The lithology of the study area comprises three lithological units. These are

- Quaternary (Q): Alluvial boulders, gravels, sands and clay
- Middle Siwaliks (MS1): Fine to medium grained friable, arkosic sandstones and hard, compact massive sandstone intercalated with green to greenish grey clays, thin bands of pseudo-conglomerates and mudstones, plants and animal's fossils are present in clay.
- Lower Siwaliks (LS): Fine grained hard, grey, sandstones interbedded with purple and chocolate coloured shades, nodular, maroon clays and psedo conglomerates.

From figure 2.19, it can be seen that Chattiwan site has two lithological units: Middle Siwalik and Quaternary, in which 97.38% of existing landslides were found in Middle Siwalik. In Bhawanchuli site, 92.8 % of existing Landslides were found in Middle Siwalik while others were in Quaternary. All area of Gurji site were found in Quaternary. In Hakpara Site, 82.12% of existing landslides were found in Lower Siwalik. Occurrence of landslide with lithology are presented in table 2.34. Moreover, in table 2.34, area of individual classes of geology were calculated on the basis of number of cell (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

Figure 2-19 Geological map of the study area

Table 2-34 Occurrence of landslide with geology for sites Chattiwan, Bhawanchuli & Hakpara

Site Chattiwan						
OID	Class	Count	Area	Landslide Count	Area	% of Landslide
1	Q	47179646	1571032.69	2822	49407.08	97.38
2	MS1	3002122	99967.51	76	1330.59	2.62
Total			1671000.20		50737.67	100.00
Site Bhawanchuli						
OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	Q	19474	455851.98	91	2053.02	7.20
2	MS1	61026	1428510.97	1173	26463.69	92.80
Total					28516.71	100.00
Site Hakpara						
OID	Class	Count	Area	Landslide Count	Landslide Area	% of landslide
1	Q	30343	1152641.01	214	7448.83	17.88
2	LS	50657	1924309.91	983	34215.87	82.12
Total			3076950.92		41664.70	100.00

2.2.8 Soil Map

In this study area, in Chattiwan and Bhawanchuli have Dystric Regosols (RGd) soils whereas Gurji and Hakpara have DystricRegosols (RGd) in both, but also GleyicCambisols (CMg)in Gurji and HaplicPhaeozems(PHh) in Hakpara as shown figure 2.20. In three selected site of study area Chattiwan, Bhawanchuli and Hakpara, all landslides were in DystricRegosols (RGd) but in Gurji 31.19 % of landslides were in GleyicCambisols (CMg). Percentage of existing landslide with each soil type in study area are presented in table 2.36. Moreover, in table 2.36, area of individual classes of geology were calculated on the basis of number of cell (Count) and existing landslide area in respective class which were calculated on the basis of number of cells (Landslide count) of landslide present in the individual class.

Figure 2-20 Soil map of the study area

Table 2-20 Occurrence of landslide with soil type in Gurji and Hakpara

Site Gurji						
OID	Class	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	RGd	17836	490786.69	150	3923.41	68.81
2	Cmg	48914	1345769.02	68	1778.61	31.19
Total			1836555.72		5702.02	100.00
Site Hakpara						
OID	OID	Count	Area	Landslide Count	Landslide Area	% of Landslide
1	RGd	51280	2245891.29	207	1098.88	100
2	CMg	14752	261347.98	0	0.00	0
3	PHh	5968	646178.01	0	0.00	0
Total			3153417.28		1098.88	100

2.2.9 Rainfall Map

The rainfall data required for the analysis was obtained from Department of Hydrology and Meteorology. The monthly average precipitation of the collected data around area varies between 69.862 mm (Nepalthok) and 206.645 mm (MakawanpurGadi).

The rainfall data of eight stations available in Sindhuli and Hetauda district were collected from Department of Hydrology and Meteorology. The average monthly data of those stations were used in preparation of isohyets map known as rainfall map. The rainfall map was

classified into nine classes as in figure 2.21. The mean monthly rainfall data used in preparation of rainfall map were shown in table 2.36.

Table 2-36 Rainfall data

Latitude	Longitude	Rainfall (mm)	Remarks
27.183	86.167	153.607	BahunTilpung
27.420	85.849	69.682	Nepalthok
27.294	85.456	206.419	HariharpurGadhi Valley
27.560	85.139	161.602	ChisapaniGadhi
27.619	85.150	112.411	MarkhuGaun
27.416	85.156	206.645	MakwanpurGadhi
27.535	84.809	160.4722	Beluwa(Manahari)
27.467	84.882	172.577	Rajaiya

From figure 2.21, Chattiwan, Bhawanchuli, Gurji and Hakpara sites were situated on range of 171.40 mm-268.85 mm rainfall. In Hakpara, the average rainfall varies from 171.40 mm to 236.36 mm and in other three sites varies from 236.37 mm - 268.85 mm. So, the average rainfall of the study area is insignificant for proper analysis. As a result, rainfall is not regarded as the most important factor in sensitivity mapping.

Figure 2-21 Rainfall map of the study area

2.3. Landslide Hazard Map

For hazard map preparation, WoE method was used in this study, positive weight (W^+), negative weight (W^-) and contrast value were calculated. All values were joined in each class of influencing factor and the weight map of each influencing factor were developed by using the spatial analysis tool in GIS. During preparation of weight of each influencing factor of contrast value of each classes were used. Prepared weight maps were combined with raster calculator in GIS to develop landslide hazard map. The magnitude of the contrast C was determined from the difference, W^+ and W^- , and provided a measure of the spatial association between a set of points and the patterns. C is positive for a positive spatial association, and negative for a negative spatial association.

In table 2.37, table 2.39, table 2.41 and table 2.43, positive weight (W^+), negative weight (W^-), Contrast (C) and other pixel information of landslide and non- landslide for different classes of individual influencing factor was shown.

Where,

$W^+ =$ Positive weight

$W^- =$ Negative weight

$L_{pixi} =$ Number of landslide pixel in i class

$TL_{pix} =$ Total number of landslide pixel (according to each factor)

$NL_{pixi} =$ Number of non-landslide pixel in i class

$TNL_{pix} =$ Total number of non-landslide pixel (according to each factor)

$L_{pixothers} =$ Number of landslide pixel in the other classes

$NL_{pixothers} =$ Number of non-landslide pixel in the other classes

Table 2-37 weightage table for various influencing factors for Chattiwan site

Inflencing Factor	OID	Class	Lpixi	Tlpixi	NLpixi	TNLpix	Lpixother	NLPixother	W+	W-	C
Slope	1	Very gentle	165	2898	3325	54749	2733	51424	-0.065	0.004	-0.069
	2	Gentle	285	2898	3937	54749	2613	50812	0.313	-0.029	0.342
	3	Moderate	184	2898	3877	54749	2714	50872	-0.109	0.008	-0.117
	4	Moderate Steep	379	2898	11847	54749	2519	42902	-0.504	0.104	-0.607
	5	Steep	553	2898	17101	54749	2345	37648	-0.493	0.163	-0.656
	6	Very Steep	1332	2898	14662	54749	1566	40087	0.540	-0.304	0.844
Aspect	1	Flat	0	2898	7	54749	2898	54742	0.000	0.000	0.000
	2	North	37	2898	2526	54749	2861	52223	-1.285	0.034	-1.319
	3	Northeast	134	2898	8677	54749	2764	46072	-1.232	0.125	-1.357
	4	East	315	2898	8823	54749	2583	45926	-0.394	0.061	-0.454
	5	Southeast	772	2898	8120	54749	2126	46629	0.586	-0.149	0.735
	6	South	925	2898	11295	54749	1973	43454	0.436	-0.153	0.590
	7	Southwest	471	2898	7353	54749	2427	47396	0.191	-0.033	0.224
	8	West	182	2898	3742	54749	2716	51007	-0.085	0.006	-0.091
	9	Northeast	48	2898	2766	54749	2850	51983	-1.115	0.035	-1.150
	10	North	14	2898	1440	54749	2884	53309	-1.695	0.022	-1.716
Curvature	1	Concave	1638	2898	24704	54749	1260	30045	0.225	-0.233	0.458
	2	Flat	2	2898	190	54749	2896	54559	-1.615	0.003	-1.618
	3	Convex	1258	2898	29855	54749	1640	24894	-0.228	0.219	-0.447
Distance from road	1	0-50	2728	2898	20615	54756	170	34141	0.916	-2.364	3.280
	2	50-100	170	2898	16707	54756	2728	38049	-1.649	0.304	-1.952
	3	100-200	0	2898	16207	54756	2898	38549	0.000	0.351	-0.351
	4	200-300	0	2898	1227	54756	2898	53529	0.000	0.023	0.000
Distance from stream	1	0-100	59	2898	19262	54756	2839	35494	-2.849	0.413	-3.262
	2	100-200	2012	2898	15911	54756	886	38845	0.871	-0.842	1.713
	3	200-300	564	2898	9464	54756	2334	45292	0.119	-0.027	0.145
	4	300-400	156	2898	5603	54756	2742	49153	-0.642	0.053	-0.695
	5	400-500	34	2898	3159	54756	2864	51597	-1.593	0.048	-1.640
	6	500-600	73	2898	1357	54756	2825	53399	0.016	0.000	0.017
Elevation	1	264.52-300	0	2898	4116	54756	2898	50640	0.000	0.078	-0.078
	2	300-350	141	2898	12906	54756	2757	41850	-1.578	0.219	-1.797
	3	350-400	662	2898	14590	54756	2236	40166	-0.154	0.051	-0.204
	4	400-450	1574	2898	10300	54756	1324	44456	1.060	-0.575	1.635
	5	450-500	521	2898	8145	54756	2377	46611	0.189	-0.037	0.227
	6	500-532.87	0	2898	4699	54756	2898	50057	0.000	0.090	-0.090
Geology	1	Q	2822	2898	50643	54756	76	4113	0.052	-1.052	1.104
	2	MS1	76	2898	4113	54756	2822	50643	-1.052	0.052	-1.104

According to the table 2.39, 25.19 % (0.28 sq.km) of the area lies in the low hazard whereas the area under moderate and high hazard are 46.39% (0.505 sq.km) and 28.47% (0.31 sq.km) respectively.

The maximum area of Chattiwan site is formed with alluvial boulders, gravel, sands and clay. From figure 2.22, maximum area of high level hazard is near about the road. Due to the presence of slope cut more than 35 degrees with south and southeast facing aspect has more influence to cause landslide near the newly constructed road alignment.

Figure 2-22 Hazard map of Chattiwan

Table 2-38 Hazard level classification in the Chattiwan site

OID	Hazard Level	Count	Area (Sq.m)	Percentage
1	Low	14495	274046.30	25.14
2	Medium	26741	505572.41	46.39
3	High	16412	310289.61	28.47
Total			1089908.31	100.00

Table 2-39 Weightage table for influencing factors in Bhawanchuli site

Influencing Factor	OID	Class	Lpixi	Tlpixi	NLpixi	TNLpix	Lpixother	NLPixother	W+	W-	C
Slope	1	Very gentle	51	1288	13612	45685	1237	32073	-2.018	0.313	-2.332
	2	Gentle	91	1288	7475	45685	1197	38210	-0.840	0.105	-0.945
	3	Moderate	109	1288	4608	45685	1179	41077	-0.176	0.018	-0.193
	4	Moderate Steep	249	1288	7377	45685	1039	38308	0.180	-0.039	0.219
	5	Steep	302	1288	6930	45685	986	38755	0.435	-0.103	0.538
	6	Very Steep	486	1288	5683	45685	802	40002	1.110	-0.341	1.451
Aspect	1	Flat	0	1288	2	45685	1288	45683	0.000	0.000	0.000
	2	North	188	1288	4240	45685	1100	41445	0.453	-0.060	0.513
	3	Northeast	184	1288	4599	45685	1104	41086	0.350	-0.048	0.398
	4	East	138	1288	2611	45685	1150	43074	0.628	-0.054	0.683
	5	Southeast	28	1288	2003	45685	1260	43682	-0.702	0.023	-0.724
	6	South	43	1288	1987	45685	1245	43698	-0.265	0.011	-0.275
	7	Southwest	139	1288	4556	45685	1149	41129	0.079	-0.009	0.088
	8	West	240	1288	6982	45685	1048	38703	0.198	-0.040	0.239
	9	Northeast	210	1288	12754	45685	1078	32931	-0.538	0.149	-0.687
	10	North	118	1288	5951	45685	1170	39734	-0.352	0.043	-0.395
Curvature	1	Concave	642	1288	23698	45685	646	21987	-0.040	0.041	-0.081
	2	Flat	0	1288	17	45685	1288	45668	0.000	0.000	0.000
	3	Convex	646	1288	21970	45685	642	23715	0.042	-0.041	0.083
Elevation	1	205.726-250	0	1288	13346	45685	1288	32339	0.000	0.345	-0.345
	2	250-300	136	1288	17604	45685	1152	28081	-1.295	0.375	-1.670
	3	300-350	402	1288	7448	45685	886	38237	0.649	-0.196	0.846
	4	450-500	750	1288	6455	45685	538	39230	1.416	-0.721	2.137
	5	500-418.803	0	1288	832	45685	1288	44853	0.000	0.018	-0.018
Distance from Road	1	0-50	1205	1258	16170	44019	53	27849	0.958	-2.709	3.668
	2	50-100	53	1258	12735	44019	1205	31284	-1.927	0.298	-2.225
	3	100-200	6	1258	13193	44019	1252	30826	-4.141	0.351	-4.492
	4	200-300	0	1258	1921	44019	1258	42098	0.000	0.045	-0.045
Distance from Stream	1	0-100	506	1264	32229	44019	758	11790	-0.604	0.806	-1.410
	2	100-200	621	1264	8093	44019	643	35926	0.983	-0.473	1.456
	3	200-300	46	1264	2040	44019	1218	41979	-0.242	0.010	-0.252
	4	300-400	69	1264	942	44019	1195	43077	0.936	-0.035	0.971
	5	400-500	22	1264	577	44019	1242	43442	0.284	-0.004	0.288
	6	500-600	0	1264	138	44019	1264	43881	0.000	0.003	-0.003
Geology	1	MS1	91	1264	3347	44019	1173	40672	-0.055	0.004	-0.059
	2	LS	1173	1264	40672	44019	91	3347	0.004	-0.055	0.059

Figure 2.23 shows the landslide hazard map of Bhawanchuli site. According to the table 2.40, 23.64 % of the area lies in the low hazard whereas the area under moderate and high hazard are 57.45% and 18.91% respectively. table 2.41 depicts the areal relationship of the hazard level along with the percentage of landslide occurrence in the zones.

The maximum area of Bhawanchuli site is formed with fine grained hard, grey, sandstones interbedded with purple and chocolate coloured shades, nodular, maroon clays and psedo conglomerates. From figure, maximum area of high level hazard is near about the road. Due to the presence very steep slope has more influence to cause landslide near the newly constructed road alignment.

Figure 4-23 Hazard map of Bhawanchuli site

Table 2-40 Hazard level classification in the Bhuwanchli site

OID	Hazard Level	Count	Area (Sq. m)	Percentage
1	Low	10705	250585.16	23.64
2	Medium	26011	608871.61	57.45
3	High	8563	200444.72	18.91
Total			1059901.49	100.00

Table 2-41 Weightage table for various influencing factors for Gurji site

Influencing Factor	OID	Class	Lpixi	Tlpixi	NLpixi	TNLpix	Lpixother	NLPixother	W+	W-	C
Slope	1	Very gentle	58	999	16924	43758	941	26834	-1.896	0.429	-2.326
	2	Gentle	57	999	5505	43758	942	38253	-0.791	0.076	-0.866
	3	Moderate	69	999	3674	43758	930	40084	-0.195	0.016	-0.211
	4	Moderate Steep	171	999	6892	43758	828	36866	0.083	-0.016	0.100
	5	Steep	273	999	6377	43758	726	37381	0.629	-0.162	0.790
	6	Very Steep	371	999	4386	43758	628	39372	1.310	-0.359	1.668
Aspect	1	Flat	0	999	4	52608	999	52604	0.000	0.000	0.000
	2	North	8	999	1824	52608	991	50784	-1.465	0.027	-1.493
	3	Northeast	63	999	5160	52608	936	47448	-0.442	0.038	-0.480
	4	East	150	999	6500	52608	849	46108	0.195	-0.031	0.226
	5	Southeast	220	999	6834	52608	779	45774	0.528	-0.110	0.637
	6	South	285	999	6848	52608	714	45760	0.785	-0.196	0.981
	7	Southwest	106	999	6133	52608	893	46475	-0.094	0.012	-0.106
	8	West	124	999	4910	52608	875	47698	0.285	-0.035	0.320
	9	Northeast	37	999	3833	52608	962	48775	-0.677	0.038	-0.715
	10	North	6	999	1712	52608	993	50896	-1.690	0.027	-1.717
Curvature	1	Concave	500	999	23919	43758	499	19839	-0.088	0.097	-0.185
	2	Flat	0	999	20	43758	999	43738	0.000	0.000	0.000
	3	Convex	499	999	19819	43758	500	23939	0.098	-0.089	0.187
Elevation	1	146.29-150	0	999	15	43756	999	43741	0.000	0.000	0.000
	2	150-200	823	999	28583	43756	176	15173	0.232	-0.677	0.909
	3	200-250	83	999	13128	43756	916	30628	-1.284	0.270	-1.554
	4	250-284.14	93	999	2032	43756	906	41724	0.695	-0.050	0.746
Distance From Road	1	0-50	683	4717	17966	48699	4034	30733	-0.935	0.304	-1.239
	2	50-100	193	4717	11128	48699	4524	37571	-1.720	0.218	-1.938
	3	100-200	33	4717	10706	48699	4684	37993	-3.448	0.241	-3.689
	4	200-300	65	4717	1798	48699	4652	46901	-0.986	0.024	-1.009
	5	300-400	0	4717	232	48699	4717	48467	0.000	0.005	-0.005
Distance From Stream	1	0-100	159	974	16559	41830	815	25271	-0.886	0.326	-1.212
	2	100-200	29	974	6994	41830	945	34836	-1.726	0.153	-1.878
	3	200-300	151	974	6649	41830	823	35181	-0.025	0.005	-0.030
	4	300-400	509	974	6153	41830	465	35677	1.268	-0.580	1.848
	5	400-500	126	974	4921	41830	848	36909	0.095	-0.013	0.108
	6	500-600	0	974	554	41830	974	41276	0.000	0.013	-0.013
Geology	1	MS1	4970	5046	48495	52608	76	4113	0.066	-1.647	1.713
	2	LS	76	5046	4113	52608	4970	48495	-1.647	0.066	-1.713
Soil	1	RGd	150	218	11387	52608	68	41221	1.157	-0.921	2.078
	2	Cmg	68	218	7009	52608	150	45599	0.851	-0.231	1.082

According to the figure 2.24, 11.76 % of the area lies in the low hazard whereas the area under moderate and high hazard are 71.21% and 17.03% respectively. table 2.43 depicts the areal relationship of the hazard along with the percentage of landslide occurrence in the zones.

The maximum area of Gurji site is formed with fine to medium grained friable, arkosic sandstones and hard, compact massive sandstone intercalated with green to greenish grey clays, thin bands of pseudo-conglomerates and mudstones, plants and animal's fossils are present in clay. From figure, maximum area of high level hazard is near about the road. Due to the presence very steep slope and south facing aspect has more influence to cause landslide near the newly constructed road alignment.

Presence of Bagmai river near this study area also has significant impact on the landslide hazard.

Figure 2-24 Hazard map of Gurji site

Table 2-42 Hazard level classification for Gurji site

OID	Hazard Level	Count	Area (Sq.m)	Percentage
1	Low	5450	150201.34	11.76
2	Medium	33005	909613.82	71.21
3	High	7892	217502.57	17.03
Total			1277317.72	100.00

Table 2-43 Weightage table for influencing factors for Hapkara site

Influencing Factor	OID	Class	Lpixi	Tlpixi	NLpixi	TNLpix	Lpixother	NLPixother	W+	W-	C
Slope	1	Very gentle	3	1302	2621	36468	1299	33847	-3.440	0.072	-3.512
	2	Gentle	21	1302	11583	36468	1281	24885	-2.980	0.366	-3.346
	3	Moderate	55	1302	5570	36468	1247	30898	-1.285	0.123	-1.408
	4	Moderate Steep	121	1302	6044	36468	1181	30424	-0.578	0.084	-0.662
	5	Steep	210	1302	5331	36468	1092	31137	0.098	-0.018	0.116
	6	Very Steep	892	1302	5319	36468	410	31149	1.547	-0.998	2.545
Aspect	1	Flat	0	1302	0	36468	1302	36468	0.000	0.000	0.000
	2	North	0	1302	472	36468	1302	35996	0.000	0.013	-0.013
	3	Northeast	68	1302	2050	36468	1234	34418	-0.074	0.004	-0.078
	4	East	362	1302	9861	36468	940	26607	0.028	-0.011	0.038
	5	Southeast	591	1302	18115	36468	711	18353	-0.090	0.082	-0.172
	6	South	239	1302	3324	36468	1063	33144	0.700	-0.107	0.807
	7	Southwest	41	1302	1045	36468	1261	35423	0.094	-0.003	0.097
	8	West	1	1302	722	36468	1301	35746	-3.249	0.019	-3.269
	9	Northeast	0	1302	561	36468	1302	35907	0.000	0.016	-0.016
	10	North	0	1302	318	36468	1302	36150	0.000	0.009	-0.009
Plan Curvature	1	Concave	659	1302	18049	36468	643	18419	0.022	-0.022	0.045
	2	Flat	1	1302	13	36468	1301	36455	0.768	0.000	0.768
	3	Convex	642	1302	18406	36468	660	18062	-0.023	0.023	-0.047
Elevation	1	97.89-150	0	1302	14727	36468	1302	21741	0.000	0.517	-0.517
	2	150-200	800	1302	6863	36468	502	29605	1.183	-0.745	1.928
	3	200-250	282	1302	8387	36468	1020	28081	-0.060	0.017	-0.077
	4	250-300	171	1302	3975	36468	1131	32493	0.186	-0.025	0.212
	5	300-394.437	49	1302	2516	36468	1253	33952	-0.606	0.033	-0.639
Distance from Road	1	0-50	617	1197	12892	33410	580	20518	0.290	-0.237	0.527
	2	50-100	243	1197	8254	33410	954	25156	-0.196	0.057	-0.253
	3	100-200	163	1197	8008	33410	1034	25402	-0.565	0.128	-0.693
	4	200-300	174	1197	2995	33410	1023	30415	0.483	-0.063	0.547
	5	>300	0	1197	1261	33410	1197	32149	0.000	0.038	-0.038
Distance from Stream	1	0-100	736	974	18658	41830	238	23172	0.527	-0.818	1.346
	2	100-200	456	974	7670	41830	518	34160	0.937	-0.429	1.366
	3	200-300	5	974	4128	41830	969	37702	-2.956	0.099	-3.055
	4	300-400	0	974	2492	41830	974	39338	0.000	0.061	-0.061
	5	400-500	0	974	462	41830	974	41368	0.000	0.011	-0.011
Geology	1	Q	214	1197	8853	33410	983	24557	-0.393	0.111	-0.504
	2	LS	983	1197	24557	33410	214	8853	0.111	-0.393	0.504
Soil	1	RGd	207	207	12808	12818	0	10	0.001	0.000	0.001
	2	Cmg	0	207	10	12818	207	12808	0.000	0.001	-0.001

According to the table 2.45, 17.30 % of the area lies in the low hazard whereas the area under moderate and high hazard are 71.16% and 11.54% respectively. Table 2.45 depicts the areal relationship of the hazard along with the percentage of landslide occurrence in the zones.

The maximum area of Hakpara site is formed with fine grained hard, grey, sandstones inter-bedded with purple and chocolate colored shades, nodular, maroon clays and psedo conglomerates but also significant part have alluvial boulders, gravel, sands and clay. In both geological formations, there are landslides. From Figure, maximum area of high level hazard is near about the road. Due to the presence very steep slope and south facing aspect has more influence to cause landslide near the newly constructed road alignment.

Presence of Marin Khola near by the study area also possesses significant impact on the landslide hazard.

Figure 2-25 Hazard map of Hakpara site

Table 2-44 Hazard level classification for Hakpara site

OID	Hazard Level	Count	Area(Sq.m)	Percentage
1	Low	5771	255126.56	17.30
2	Medium	23736	1049330.12	71.16
3	High	3850	170202.26	11.54
Total			1474658.95	100.00

2.4. Risk Assessment

For risk assessment, hazard map was combined with land use raster map by using combine tool of GIS software which is very useful for calculating the presence of hazard level in existing land use. Land use map obtained from digitizing the orthomosaic was used to produce raster map with feature to raster tools in GIS is combined. The areas under the high and medium hazard were calculated to find the risk level on existing land use.

Chattiwan

The high risk and medium risk area of Chattiwan site on the basis of presence of hazard level on land use as shown in table 2.45. The forest area of 0.143 sq. km was found to be in high risk while 0.408 sq. km of the forest areas was found to be in medium risk of landslide hazard in the Chhattiwan site. The 0.0210 sq. km of road was observed to be high risk while 0.0089 sq. km of road was observed to be in medium risk. The settlement area of .00247 sq. km was found to be in high risk and 0.000812 sq. km was found to be in medium risk. The cultivable area of 0.0232 sq. km was prone to high risk of landslide hazard and 0.0176 sq. km of cultivable areas prone to the medium risk. The big portion of the forest area in the study section is prone to the high risk of landslide hazard. The greater portion of the total settlement area is prone to the high risk of landslide hazard as compared to area bearing medium risk. The larger portion of the total cultivation area is prone to the medium risk of landslide hazard in the study area.

Table 2-45 Risk classification for Chattiwan site

OID	Landcover	Count	Area (Sq.m)	OID	Value	Count	Area (Sq.m)
1	Forest	7608	143838.857	1	Forest	21619	408734.52
2	Road	1113	21042.6719	2	Road	472	8923.7566
3	Settlement	131	2476.720592	3	Settlement	43	812.96935
4	Cultivation	1229	23235.79853	4	Cultivation	934	17658.451
5	Fill	1822	34447.21312	5	Fill	2417	45696.44
6	Deposit	539	10190.47633	6	Deposit	313	5917.6607
7	Road slope cut	3955	74774.27437	7	Road Slope Cut	594	11230.321
Total			310006.0119	8	Stream	296	5596.2542
				Total			504570.38

High Risk

Medium Risk

Bhawanchuli

The high risk and medium risk area of Bhawanchuli site on the basis of presence of hazard level on land use is shown in table 2.46. The forest area of 0.082982 sq. km was observed to be in medium risk of landslide hazard while the forest area of 0.183614 sq. km was in medium risk. The cultivation area of 0.065519 sq. km was in high risk and 0.317649 sq. km was in medium risk. The road area of 0.011587 sq. km was in high risk and 0.01374 sq. km in

medium risk. The river area of 0.000397 sq. km was in high risk while 0.018258 sq. km in medium risk. The settlement area of 0.00599251 sq. km was found to be in high risk whereas the area of 0.011025 sq. km was in medium risk. The greater portion of total cultivation, settlement, road and river area are in medium risk while the greater portion of forest area in this section is in high risk.

Table 2-46 Risk classification for Bhawanchuli site

OID	Land cover	Count	Area (Sq.m)	OID	Land cover	Count	Area
1	Cultivation	2799	65519.65	1	Cultivation	13570	317649.75
2	Settlement	256	5992.51	2	Road	587	13740.63
3	Road	495	11587.08	3	Settlement	471	11025.28
4	Bush	300	7022.47	4	Forest	7844	183614.20
5	Forest	3545	82982.19	5	Stream	376	8801.50
6	River	17	397.94	6	River	780	18258.42
7	Barren Land	69	1615.17	7	Road Cut Slope	315	7373.59
8	Fill	357	8356.74	8	Fill	54	1264.04
9	Road Cut Slope	660	15449.44	9	Bush	1514	35440.07
10	Stream	24	561.80	10	Bagar	40	936.33
11	Bagar	9	210.67	11	Barren Land	331	7748.13
Total			199695.66	Total			605851.95
High Risk				Medium Risk			

Gurji

The high risk and medium risk area of Gurji site on the basis of presence of hazard level on land use is shown in table 2.47. In the Gurji study section, 0.004078 sq. km. of the road area was found to be in high risk and 0.021193 sq. km was found to be in medium risk. 0.081081 sq. km of total cultivation area in the Gurji study section was found to be in high risk while 0.359573 sq. km of it was in medium risk. The river area of 0.000992 sq. km was in high risk and 0.031197 sq. km was in medium risk.

Table 2-47 Risk classification for Gurji site

OID	Land cover	Count	Area (Sq.m)
1	Bagar	13	358.28
2	Road	148	4078.86
3	Cultivation	2942	81081.16
4	Stream	87	2397.71
5	Bush	3621	99794.32
6	Barren Land	129	3555.22
7	Fill	319	8791.60
8	River	36	992.16
9	Road Cut Slope	175	4822.98
10	Settlement	362	9976.68
Total			215848.97

High Risk

OID	Land cover	Count	Area (Sq.m)
1	Bagar	2810	77443.26
2	Road	769	21193.55
3	Cultivation	13047	359573.74
4	Stream	881	24280.25
5	Bush	7748	213533.94
6	Barren Land	2421	66722.47
7	Fill	841	23177.86
8	River	1132	31197.78
9	Landslide	53	1460.67
10	Settlement	684	18850.96
Total			837434.5

Medium Risk

The settlement area of 0.009976 sq. km was in high risk of the landslide hazard in the Gurji section while the remaining 0.01885 sq. km was in medium risk of the landslide hazard. The larger portion of total area remained in medium risk of landslide hazard in Gurji section of the study area.

Hakpara

The high risk and medium risk area of Hakpara site on the basis of presence of hazard level on land use is shown in table 2.48. In Hakpara section of the study area, the road area of 0.001503 sq. km was found to be in high risk of landslide hazard and 0.019407 sq. km was in medium risk.

Table 2-48 Risk classification for Hakpara site

OID	Land cover	Count	Area (Sq.m)
1	Road	34	1503.08
2	Barren Land	63	2785.13
3	Forest	2426	107249.53
4	Stream	22	972.58
5	Cultivation	200	8841.68
6	River	4	176.83
7	Pond	9	397.88
8	Road Cut Slope	682	30150.12
9	Fill	281	12422.55
10	Settlement	22	972.58
Total			165471.97

High Risk

OID	Land cover	Count	Area (Sq.m)
1	Road	439	19407.48
2	Barren Land	7042	311315.42
3	Forest	7967	352208.17
4	Stream	71	3138.80
5	Cultivation	3959	175020.98
6	River	812	35897.20
7	Pond	36	1591.50
8	Landslide	362	16003.43
9	Fill	400	17683.35
10	Settlement	310	13704.60
Total			945970.93

Medium Risk

The forest area of 0.107249 sq. km was prone to high risk of landslide hazard and 0.352208 sq. km was prone to medium risk. The cultivation area of 0.008841 sq. km was in high risk and remaining 0.175020 sq. km was in medium risk. The river area of 0.000176 sq. km was in high risk and 0.035897 was in medium risk. The pond area of 0.000397 was prone to the landslide with high risk in the study area while 0.001597 sq. km was in medium risk. The settlement area of 0.000972 sq. km was in high risk whereas 0.013704 sq. km area of the settlement zone was in medium risk of landslide hazard in the Hapkara section of the study area.

2.5 Discussion on results

Although this study has not explored and discussed the different topographic data collection method for landslide hazard mapping method, it shows that perhaps, photogrammetric techniques and aerial photographs promise to be more efficient for discerning boundaries of recently active landslides and prepare a topographic factor map (slope, aspect, curvature and elevation. Classical surveying techniques can only provide data measurements with a very low sampling, and may not provide detailed information for deformation description in the landslide area along the road. UAV have alternative advantages in capturing high-density 3D point cloud data that opens substantial potential for the applications of natural hazards assessment like landslides (Pirasteh & Li, 2017). Pirasteh & Li, 2017 also shows that 3D with high-resolution data with centimeter in pixel size and detailed information can perform a better quality of generating DEM derivatives and further landslide susceptibility maps and motivates to prepare hazard assessment via '3D point clouds' that enables us to generate detail information about topography and geomorphology.

Landslide hazard map was developed by weight of evidence method which calculated the positive weight($W+$), negative weight($W-$) and contrast value (C) to show the existence or non-existence of influencing factor in the landslide and correlated power of the factor. As higher value for $W+$, as stronger is the positive correlation. High positive correlations to landslides are obtained for slope more the 35-degree slope and nearer from road alignment. This category has also a greater predictive power ($C>1$). Hazard map was classified in three class high medium and low with equal interval classification basis.

Land use map of the study are shows that the road alignment mainly passes through forest, cultivable land and some settlement area. In Chattiwan and Hakpara site the there was a forest in hill side which was under the high risk where in Bhawanchuli and Gurji site forest was lied in higher risk followed by cultivation and settlement area. In this study, risk assessment carried out with overlaying the landslide hazard map and current land use map. The major factor of landslide in the study area was road construction in highly fragile area with making high slope cut that leads to the high risk in surrounding road alignment. One of the most important ways that can minimize landslide risk is to minimize road mileage and to the fullest extent possible, locate necessary roads on the more stable portions of the landscape. Structural support such as masonry retaining wall, gabion wall can be used to along the hill slope for the toe protection. In Hakpara site, there is vertical cliff in several locations that can be avoid by shifting the alignment.

Conclusion

3.1 Conclusion

This study “Landslide hazard assessment using UAV imagery and GIS in the Sindhuli-Hetauda section of Chure Area” mainly aimed at finding the risk area in the Hetauda-Sindhuli road section of proposed Madan Bhandari Highway acts as one of the baselines in disaster management. Acting as a preventive medium to minimize landslide risks in the affected area, these processes could facilitate other steps in disaster management such as landslide risk mapping (which involves the assessment of loss of lives and property) and its integration with road planning and development. This study used Weight of Evidence (WOE) method to prepare landslide hazard map, and led to the following conclusions:

- Relating to the accuracy of the topographical survey, the Root Mean Square Error (RMSE) of the survey for the individual sites were found to be 0.001m, 0.045 m, 0.044 m and 0.804 m respectively. Meanwhile, the errors in the X, Y and Z of the sites were found to be 0.001172 m, 0.000677 m and 0.002081 m in the first site, 0.052234 m, 0.037494 m and 0.052226 m in the second site, 0.031062 m, 0.094952 m and 0.012200 m in the third site, and 0.239665 m, 0.939586 m and 1.321983 m in the fourth site. The Ground Sampling Distance (GSD) for the respective sites is 6.08 cm/pixel, 5.6 cm/pixel, 4.42 cm/pixel, 7.25 cm/pixel. Since the RMSE is very less and resolution of the data is very high, the use of UAV was found to be fruitful in preparing the topographic map.
- Majority of landslide along the road in the study area were found to be active, with only one being dormant. The active landslides were mainly of the type fall owing to the steep road cut slope while small number of the landslide was slide and rotational.
- The study area (consisting of four individual sites within the area) was categorized into three landslide hazard levels as low, medium and high. In all the four sites, the obtained hazard levels are unique, owing to the uniqueness in the influencing factors. As per the results obtained from hazard map, the largest area being medium 46.39%, 57.45%, 71.21% and 71.16 % respectively, followed by high 28.47%, 18.91%, 17.03% and 11.54% respectively and low 25.14%, 23.64%, 11.76% and 17.30% respectively in Chattiwan, Bhawanchuli, Gurji and Hakpara.
- The land use map is combined with landslide hazard map to prepare inventory of the elements at risk. In all three sites Chattiwan, Bhawanchuli and Hakpara, forest is at high risk followed by cultivation and settlement, while in Gurji, mainly cultivable land is in risk followed by bush and settlement.

In order to maintain the balance between the development and the its impact in environment in Chure area of Nepal, in which land degradation is primarily contributed by different types of landslides and mass wasting phenomena which are collectively controlled by the lithospheric plate dynamics, geology, topography, intense precipitation

and human interference, hazard assessment and proper planning before road construction is absolutely necessary.

Methodology

4.1 Research Design

This study utilized the quantitative methodology. High resolution imagery were used to get topographic data, landslide data and land use data by using UAV and SfM software and some other data such as geological, rainfall, land use data were obtained from the Department of Mines and Geology(DMG), Department of Hydrology and Meteorology(DHM), SOTER. For landslide hazard assessment weight of evidence method (Statistical method) was used. In this method, each factor maps (slope, geology, land use etc.) was combined with the landslide distribution map, and weight values, based on landslide densities, was calculated for each parameter class (slope class, lithological unit, land use type, etc.). For risk assessment quantitative method was used. Risk area of the land use was quantified by combining hazard map with land use map. Risk over the settlement, forest, cultivation, road and other natural resources near the road have been identified with spatial analysis tool in GIS. Overall research design to obtain the research objective is shown in figure 4.1.

Figure 4-1 Research Design

4.2 Hazard map preparation

In this study WoE method is used to prepare the landslide hazard map. The method was originally developed for mineral potential mapping but recently the method has been used in landslide susceptibility analysis by several researchers in which evidence maps are generally converted to binary predictor maps in order to apply the model (Mezughhi, et al., 2011). Weights were calculated for the initial categorization of the parameters derived from DEM (Slope, Aspect, Curvature, Elevation) and for other parameter such as distance from road, distance from stream, geology, soil. As per following equation, positive weight (W+) as well as negative weights (W-) were calculated (Barbieri & Cambuli, 2009).

$$W+ = \ln \left(\frac{LPix_i}{TLpix_i} \right) / \left(\frac{NLPix_i}{TNLpix} \right) \dots \dots \dots (1)$$

$$W- = \ln \left(\frac{LPix_{other}}{TLpix_i} \right) / \left(\frac{NLPix_{other}}{TNLpix} \right) \dots \dots \dots (2)$$

Where,

W_i + = Positive weight

W_i - = Negative weight

Lpix_i = Number of landslide pixel in i class

TLpix = Total number of landslide pixel (according to each factor)

NLPix_i = Number of non-landslide pixel in i class

TNLpix = Total number of non-landslide pixel (according to each factor)

Lpix_{others} = Number of landslide pixel in the other classes

NLPix_{others} = Number of non-landslide pixel in the other classes

The contrast (C) is calculated as the difference between the two weights (C = W₊ - W₋) where C is positive for a positive spatial association indicating the factor is favorable for the landslides, but C is negative if the spatial association is negative indicating that the factor is unfavorable. The magnitude of the contrast indicates an overall of spatial association between the causative factor and landslides whereas C equal to zero when a class has no spatial relationship with landslides occurrence. The weights and contrast value of all influencing factor is shown in table below. In GIS, the calculated weights and contrast have been assigned with join and relate in the existing thematic layer to produce multi-class weighted maps for all evidences. Then, raster map of all influencing factor named as contrast class raster were generated with the lookup tools in spatial analysis tool. For the final hazard map raster calculator was used to combine all contrast class raster map. Figure 4.2 shows the flowchart of hazard map preparation in this study.

Figure 4-2 Hazard Map Preparation Flowchart

4.3 Risk assessment

Figure 4.3 shows the risk assessment process used in this study. The landslide hazard map and land use map were combined to get the area of different hazard level on the individual land use. In all four site Chattiwan, Bhawanchuli, Gurji and Hakpara, area of land use on high risk, medium risk and low risk is calculated.

Figure 4-3 Risk Assessment Flowchart

Abbreviations and Acronyms

DEM	: Digital Elevation Model
DGPS	: Differential Global Positioning System
DHM	: Department of Hydrology and Meteorology
DMG	: Department of Mine and Geology
DSM	: Digital Surface Model
DTM	: Digital Terrain Model
GC	: Clayey Gravel
GCP	: Ground Control Point
GIS	: Geographic Information System
GoN	: Government of Nepal
GP	: Poorly Graded Gravel
GPS	: Global Positioning System
IDF	: Intensity Duration Curve
NDVI	: Normalized Difference Vegetation Index
OH	: Organic Clay, Organic Silt
PCTMCD	: President Chure Terai Madesh Conservation Development Board
SfM	: Structure from Motion
Sq.km	: Square kilometer
Sq.m	: Square meter
SRTM	: Shuttle Radar Topography Mission
SW	: SoftWel
UTM	: Universal Transverse Mercator
WGS	: World Geodetic System

Availability of data and material

- The datasets generated and/or analyzed during the study are not available in any public domain and remain the sole property of the author. However, the datasets could be available from the authors upon request.

Competing Interest

Financial competing interest:

- The authors declare no financial competing interests.

Non- Financial Competing interest:

- Authors assured that there are no any non-financial competing interests include such as political, personal, religious, ideological, academic, and intellectual competing interests

The authors declare that they have no competing interests

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Author's Contribution

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Figures

Figure 1

Figure 2-1 Cut slope zone along the Study area

Figure 2-2 Landslide inventory map

Figure 2

Figure 2-2 Landslide inventory map

Figure 3

Figure 2-3 Orthophoto of Chattiwan

Figure 4

Figure 2-4 Landuse map of Chattiwan

Figure 5

Figure 2-5 Orthophoto of Bhawanchuli

Figure 6

Figure 2-6 Land use map of Bawanchuli

Figure 7

Figure 2-7 Orthophoto of Gurji

Figure 8

Figure 2-8 Land use map of Gurji

Figure 9

Figure 2-9 Orthophoto of Hakpara

Figure 10

Figure 2-10 Land use of Hakpara

Figure 11

Plate 1: GCP setup

Figure 12

Plate 2: Data recording using DGPS

Images	median of 54137 keypoints per image
Dataset	544 out of 576 images calibrated (94%), all images enabled, 2 blocks
Camera Optimization	0.36% relative difference between initial and optimized internal camera parameters
Matching	median of 8601.32 matches per calibrated image
Georeferencing	yes, 3 GCPs (3 3D), mean RMS error = 0.001 m

Images	median of 71457 keypoints per image
Dataset	727 out of 728 images calibrated (99%), all images enabled
Camera Optimization	0.65% relative difference between initial and optimized internal camera parameters
Matching	median of 14186.1 matches per calibrated image
Georeferencing	yes, 3 GCPs (3 3D), mean RMS error = 0.044 m

Figure 13

Figure 2-11 Mean RMS error

Ground Control Points						
GCP Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1 (3D)	0.020/ 0.020	0.000	0.001	0.001	0.386	6 / 6
2 (3D)	0.020/ 0.020	0.001	-0.001	-0.002	0.290	6 / 6
3 (3D)	0.020/ 0.020	-0.002	-0.000	0.003	0.343	6 / 6
Mean [m]		-0.000131	0.000057	0.000868		
Sigma [m]		0.001165	0.000674	0.001892		
RMS Error [m]		0.001172	0.000677	0.002081		

Ground Control Points						
GCP Name	Accuracy XY/Z [m]	Error X[m]	Error Y[m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
3 (3D)	0.020/ 0.020	-0.042	-0.057	0.020	0.489	9 / 9
2 (3D)	0.020/ 0.020	0.027	0.138	0.003	0.271	6 / 6
1 (3D)	0.020/ 0.020	0.020	-0.065	0.006	0.503	9 / 9
Mean [m]		0.001411	0.005578	0.009588		
Sigma [m]		0.031031	0.093886	0.007544		
RMS Error [m]		0.031063	0.094052	0.012200		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified v.s. manually marked.

Figure 14

Figure 2-12 Calculation of RMS error

Figure 15

Figure 2-13 Elevation class of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Figure 16

Figure 2-14 Elevation class of (a) Chattiwdan (b) Bhawanchuli (c) Gurji (d) Hakpara

Figure 17

Figure 2-15 Aspect class of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Figure 18

Figure 2-16 Curvature class of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Figure 19

Figure 2-17 Distance from road map of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Figure 20

Figure 2-18 Distance from stream map of (a) Chattiwan (b) Bhawanchuli (c) Gurji (d) Hakpara

Figure 21

Figure 2-19 Geological map of the study area

Figure 22

Figure 2-20 Soil map of the study area

Figure 23

Figure 2-21 Rainfall map of the study area

Figure 24

Figure 2-22 Hazard map of Chattiwan

Figure 25

Figure 4-23 Hazard map of Bhawanchuli site

Figure 26

Figure 2-24 Hazard map of Gurji site

Figure 27

Figure 2-25 Hazard map of Hapkara site

Figure 28

Figure 4-1 Research Design

Figure 29

Figure 4-2 Hazard Map Preparation Flowchart

Figure 30

Figure 4-3 Risk Assessment Flowchart