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Research Article

Climate-induced Vulnerability Assessment: A Case of Seti River Corridor, Central Nepal

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Abstract

There are greater consensus among the climate scientists that the global warming and associated climate change has triggered the hazards and increased community vulnerability in the recent years. As river corridors are the active resources and energy flow regimes, the vulnerability concentrated along the river corridors are likely to hamper the regulatory mechanisms of biological, physical and anthropogenic systems. This paper focuses on multi-criteria based vulnerability mapping along the Seti River corridor. For the purpose, different physical and social parameters like altitude, aspect, slope, climatic condition, land-use and land-cover, and population distribution and its demographic characteristics were used. All measurable parameters were assigned with intensity of occurrences of impact factor according to their respective scales. The domination of those impact factors was measured with respect to the total area of Village Development Committee/Municipality scale (the lowest administrative units). The sum of the computed value was classified in five-point scale in relative degree of severity, i.e. very high, high, medium, low and very low. The integration process was based on GIS Environment and all the data were spatially referenced. The results show up-stream region of the corridor is at higher risk, where 5.1% of the total area is under the very high category. The mid-stream area covers 2.2% under very high category, and none of the down-stream area falls within this category. The combination of both physiographic complexities and human activities determines the vulnerability of the landscape. The outcome of the mapping is recommended for adoption during disaster risk reduction and management and climate change adaptation practices at the community level.

Keywords: Climate-induced hazard, Disaster risk reduction and management, Multi-criteria based vulnerability

Introduction

Nepal is highly diverse in terms of geographical, physiographical and geological setting. Consequently, various types of hazard and vulnerabilities are common, and people are living at risk. Such hazards are different in origin, but climate-induced hazards are considered to be the most frequent in the recent years putting the country at high risk (Gurung & Rai, 2009). Rivers are the lifelines for several biotic and abiotic components of ecosystems. Specifically, in the mountainous region, river corridors are the most fertile areas with high population due to availability of water resource. These river corridors provide accessible paths for the movement of wildlife and aquatic animals across the difficult terrain. However, the occurrence of natural, human and climate-induced hazards and vulnerabilities across the river corridor create risk to human as well as flora and fauna. Therefore, assessment of hazard and vulnerability in a river corridor has great significance for potential disaster risk reduction strategies. The Sendai Framework for Disaster Risk Reduction (UNISDR, 2015), UN conference on Sustainable Development 2012 (UN, 2012) and Sustainable Development Goals (SDGs) 2015-2030 (UN, 2015) strongly emphasize

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climate-induced disaster and risk reduction and management agendas in different perspectives.

Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm, and lack of capacity to cope and adapt (IPCC, 2014). The vulnerability is measured in terms of parameters such as economic condition (lack of livelihoods options), self-protection, social protection, poor governance, physiography (altitude, aspect and slope), climatic condition and land-use/land-cover change, to name a few (IPCC, 2014). However, this study has considered the physiographic conditions such as altitude, aspect and slope as the basic determinants for understanding vulnerability. In the Seti River corridor of the Central Nepal, such type of study seems to be limited (Poudel, 1996a; Poudel, 1996b; Poudel, 2000; Poudel & Thakur, 2002). Therefore, the present study has focused on assessing vulnerability in the river corridor integrating the above-mentioned parameters and computing their scores at spatial context, which provides relative scale of severity of vulnerability. The key hazards in the study area are flash floods, riverine floods, landslides, soil erosion, earthquakes, drought, forest fire, deforestation, heavy winds, extreme rainfall, lightening and hailstorms (Poudel & Thakur, 2002). In this study, only the climate-sensitive hazards such as floods and landslides were taken into account. However, the study did not consider the hazard parameters such as occurrence, frequency, scope, severity and physical coverage. In addition, vulnerability parameters such as relations, linkages of governance structure and economic status were also not included.

Materials and Methods

Study Area

General Characteristic

The Seti River, one of the tributaries of Gandaki River, merges with Trishuli at Gaighat which again merges with Kaligandaki and named as Narayani draining the warm Tarai plain constituting complete corridor connecting Tarai, the Middle Hills and the High Himalayas. The corridor has high diversity with respect to various natural ecosystems, plants and animal species.

The Seti River corridor is located in the central part of the Gandaki River basin and has a very active geo-hydrological regime. The most of the areas within the corridor face south, with higher precipitation and several wetlands. The corridor includes the immediately raised concave-shaped Annapurna Mountain range. The corridor, extending from the warmer Tarai (100 m msl) up to the Himalayan region (8091 m msl at Annapurna I), has diverse physiography, climate, ecosystems, socio-culture and biodiversity, imparting the unique social and ecological characteristics (Fig. 1, Table 1, Fig. 2). With respect to climate-induced disasters, landslides in the upper part and flooding in the low-lands are common forms of disasters.

The Seti River is the trunk river originating at the southern flank of the Annapurna Himalayan range and flows towards the south and south-east direction until it confluences with the Trishuli

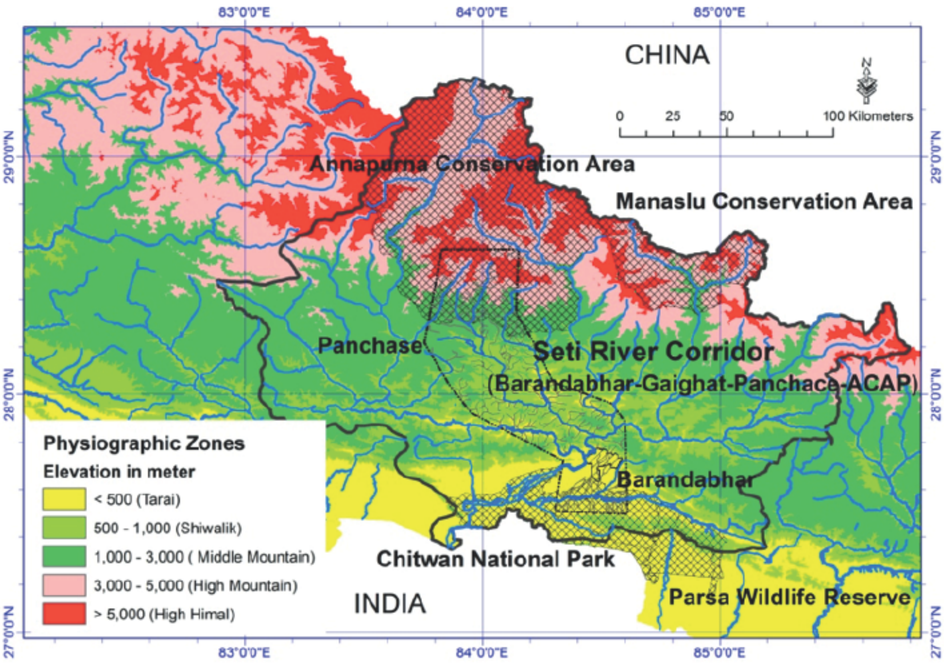

Figure 1 Location of Seti River corridor (Data source: Department of Survey, 1998)

River at Gaighat (Tanahu and Chitwan Districts). This is a perennial river system and several tributaries confluence with the trunk river including the Madi River, which is also a glacial fed system. This is one of the major sub-systems of the river Narayani (Gandaki) system. Due to its water volume and flow, and geography, it influences diverse aquatic lives. The Seti River system has, though contains small irrigation project, it has no large dams and barriers constructed so far, which is favorable for the free movement of aquatic life through the channel. Due to the deep and narrow gorges and the valley formed by the river channel, several river-induced hazards and disasters are associated with it. Among others, sidewall collapse, river water blockade during monsoon and landslides over narrow and steep valleys and side hill-slopes are frequent throughout the channel. In recent years, excavation of river sand and stone for construction purposes has resulted in the river developing deep and intense down cutting, causing further slides.

Climatic condition

The corridor exhibits great variation in geographical setting resulting into variability of temperature, precipitation, sunshine, humidity and wind direction. Therefore, the region reveals micro-climatic variation. The permanent snow line lies at the altitude of 4800 m msl. However, the snow line varies with the extent of hill-slope inclination, aspect and prevailing wind direction. The climatic data (temperature and rainfall) of different stations in the corridor was obtained from the Department of Hydrology and Meteorology, Government of Nepal.

The data of January, from 2007 to 2013, shows that the mean minimum and mean maximum temperature at Bharatpur (205 m msl) varies respectively between 8.8°C and 22.1°C. In June, the mean minimum and maximum value varies respectively between 25.8°C and 35.1°C. In Damauli (358 m msl), during the same period, the mean minimum and maximum temperature in January varies respectively between 8.7°C and 21.3°C and the values in June varies respectively between 22.5°C and 35.1°C. Likewise, in Khairenitar (500 m msl), the mean minimum and maximum temperature varies respectively between 9.0°C and 22°C in January, and 22.9°C and 33.8°C in June. In Lumle (1740 m msl), the mean minimum and maximum value in January varies respectively between 4.9°C and 14.9°C, and in June, it varies respectively between 16.8°C and 24.8°C. This shows that the temperature in the corridor gradually declines with the elevation (Table 2).

With respect to rainfall, the total annual average rainfall of Bharatpur (from 2001 to 2013) was found to be 2400.0 mm with the maximum value (704 mm) in August, 2009, July, 2010, and in July, 2013 (735 mm). The average annual rainfall in Damauli (from 1974 to 2013) was recorded to be <2000 mm with peak value (757 mm) in July, 1989 (highest record, with total annual value 1783 mm) followed by June, 1974 (2774 mm). For 2013, the total annual rainfall value is 1940 mm and in June, it is 586 mm. Similarly, in Khairenitar (from 1972 to 2013), the annual average rainfall was found to be about 2400 mm with a peak value (1023 mm) in July, 1972 (annual 2517 mm) followed by 949 mm in July, 2002 (total annual 3058 mm). In 2013, the total annual rainfall was 2345 mm. Likewise, in Lumle, annual average (from 1970 to 2013) rainfall was recorded to be around 5500 mm. The highest annual record was 6561 mm in 1995 (Table 2). This shows that there is no uniform distribution of rainfall in the corridor. However, there seems peak rainfall in up-stream region and lower rainfall in the down-stream region. The study from the Panchase area has shown an uncertain trend of rainfall (Dixit, Karki & Shukla, 2015). Sometimes, the cloud burst was reported to be confined within the small area coverage in the corridor causing heavy damage (Poudel, 2003).

Table 1 General characteristics of the Seti River corridor

Characteristics	Down-stream	Mid-stream	Up-stream	Total	Reference
Local units (No.)	6 VDCs* 1 Municipality	23 VDCs* 1 Municipality	28 VDCs* 1 Sub-Metropolis	57 VDCs* 1 Municipality 1 Municipality	CBS (2011) 1 Sub- Metropolis 3 Municipality
Total area (km²)	431.2	836.3	1087.6	2355.1	HMG-N (1998)
Total household (No.)	53844.0	48232	114276	216,352	CBS (2011)
Total population (No.)	216502.0	197500	437659	851,661	CBS (2011)
Total male population (No.)	105933.0	87598	208532	402,063	CBS (2011)
Total female population (No.)	110569.0	109902	229127	449,598	CBS(2011)
Population density (No./ha)	502.1	236.2	402.4	361.6	CBS(2011)
Male population/1000 female	958.1	797.1	910.1	894.3	CBS(2011)

*VDC = Village Development Committee (the then administrative units have been adopted)

Data collection method

Intensive field visit was done to identify and assess the impacts of different hazards and vulnerability status at all levels of the corridor. Household interview was performed to understand the perspective of local people from each section of the river

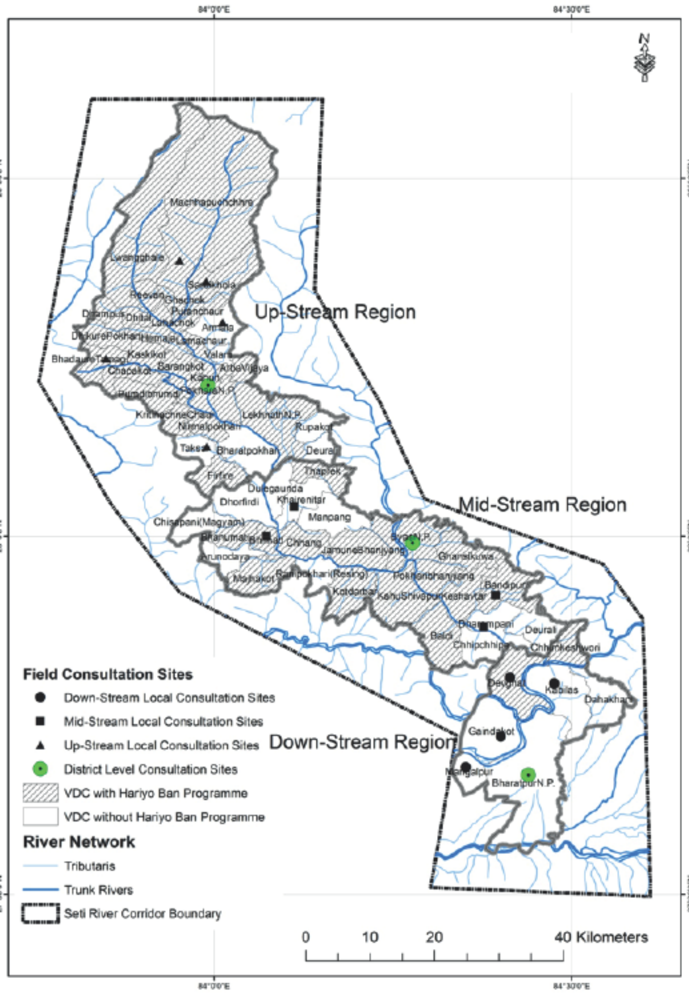

Figure 2 Distribution of local units in different stretches of the corridor

Table 2 Climatic condition of the Seti River corridor

Catchment	Station	Elevation (m)	Temp. Jan (°C) (2007-2013)		Temp. June (°C) (2007-2013)		Rainfall (mm)				
			Mean Min.	Mean Max.	Mean Min.	Mean Max.	Time period	Annual average	Highest average	Max. monthly average	Max. in 2013
Up-Stream	Lumle	1740	4.9	14.9	16.8	24.8	1970-2013	5416 in last 44 years	6561.4 in 1995	1818 in July 2010	1588 in July
Mid-Stream	Damauli	358	8.7	21.3	22.5	35.1	1974-2013	1770 in last 38 years	2276 in 1998	865.8 in July,2003	585.8 in June
Mid-Stream	Khairenitar	500	9.0	22.0	22.9	33.8	1972-2013	2227 in last 42 years	3057.5 in 2002	1022.5 in July, 1972	595.3 in June
Down- Stream	Bharatpur	205	8.8	22.1	25.8	35.1	2001-2013	2408 in last 40 years	3269 in 2003	1225.8 in July, 2003	797.6 in July

corridor. Altogether, 399 households were determined following Arkins and Colton (1963). However, to be on the safe side and to have a reasonable number of households in each of 13 VDCs of all the three sections of the basins, 35 households from each VDC were determined. Therefore, a total of 456 households from the corridor were randomly selected ensuring proportional representation of different section of the corridor (175 from up-stream, 140 from each mid-stream and down-stream) with due consideration of ethnic and caste groups from each VDC. During the field survey, nine Focus Group Discussions (FGDs) were held at community, VDC and district levels. In such events, information collected from survey was triangulated. Topographic maps and satellite images were respectively collected from the Department of Survey, Government of Nepal, and International Centre for Integrated Mountain Development (ICIMOD) and from open sources.

Data analysis and interpretation

The present study has adopted the 'Multi-criteria' approach for the data collection and analysis. GIS-based Multi-Criteria Decision Analysis (MCDA) approach is the process that transforms and combines geographical data and value judgments to obtain information for decision making (Malczewski, 1999). The ranking is carried out with respect to an overall goal, which is broken down into a set of criteria such as objectives or attributes (Boroushaki & Malczewski, 2008). Scale or intensity of importance (Vulnerable categories) and judgment of preference in this paper is based on the reference given by Kavzoglu et al. (2013). The Multi-criteria analysis of the spatial variables provides the data integration capability in the GIS software environment.

The assessment of vulnerability at the corridor scale was carried out by using spatial data acquired from different maps and satellite imageries. The basin is divided into three sections, i.e. upper stretch (approximately 500 m msl and above, at the river bed follows water divides of tributaries), middle stretch (approximately 300 to 500 msl at the river bed follows water divides of tributaries) and lower stretch (approximately 100 to 300 m msl at the river bed follows water divides of tributaries). The acquired data were compiled and Multi-criteria analysis was carried out in the Geographic Information System (GIS), ArcGIS. The relative impact factors were given in each parameter across the VDCs and Municipalities accordingly. The different parameters considered are as follows:

i. Aspect

In Nepal, east, south-east, south and south-west facing hill-slopes are exposed to high intensity of sunshine and precipitation in comparison to the north-west, north, north-east and flat directions. Those faces have dense human settlement and land is intensively used for agriculture. Thus, these aspects are relatively highly exposed to climate-induced hazards and vulnerability due to physiographic factors. The distribution of area of a VDC/ Municipality by aspect was determined by using ASTER DEM (Satellite imageries) and by giving higher score to the area with higher exposure.

ii. Slope

Slope is one of the major physiographic parameters. The area with steeper slope is more exposed to climate-induced vulnerability. The distribution of area within VDC/Municipality by slope, particularly beyond steep to very steep slope categories (>25^0 slope inclination has been categorized as critical hill-slope) was determined using slope map (LRMP, 1986). The VDCs/ Municipalities with larger area beyond this critical slope were given higher score.

iii. Cultivated land across exposed aspect and critical hill-slope

Land cultivation is the most notable human activity in the rural areas. Therefore, the percentage distribution of such land in a VDC/Municipality under exposed aspect and critical hill-slope was determined by aspect and slope map. The VDC/Municipality with higher percentage of area under this class was given higher score.

iv. Settlement location over the critical slope

Spatial distributions of settlements were determined by counting the settlement units in Topo-sheet map-1998 (scale 1:25,000) of the Department of Survey, Government of Nepal. Based on the counting, share of settlement of a VDC/Municipality over the critical hill-slope was determined. The VDC/Municipality with higher settlement number in the critical hill-slope was considered to be more vulnerable.

v. Per-capita forest coverage

The per-capita forest in a VDC/Municipality gives the relative degree of the measurement of environmental condition. Therefore, it is taken as the measurement criterion, where lower the value, higher will be the pressure on the forest resources, and more prone to disaster and vulnerability. Thus, area with low per-capita forest was given a higher score.

vi. Crude density of population

This is a common measurement for people to land ratio, where higher number of people per unit area exerts larger pressure on land, which provides greater possibility of hazard and vulnerability, and thus was given higher score.

vii. Physiologic density

The ratio of the total population to the cultivated land gives the information about population pressure on cultivated land. A higher ratio exerts more pressure on agriculture land leading to a relatively high probability of hazard and vulnerability. The VDC/Municipality with higher value of physiologic density was given higher score.

viii. Male to female (sex) ratio: The ratio of male to female is measured by the number of males to 1000 females. Where, number of males is less compared to females, the pressure is higher on females creating more social vulnerability.

In the present study, the above-mentioned parameters have been assessed as an impact factor for vulnerability. The score value of each parameter was ranked at the VDC/Municipality level. The ranked scores of individual parameters of multi-criteria (above parameters) were normalized using the equation given by Carroll et al. (2002):

$$Z = X_i - \frac{\overline{X}}{s}$$

Where;

Z = Normalized score

X_i = Observed value

$\overline{X}$ = Mean value

s = Standard deviation

The normalized scores were naturally classified into five categories, i.e. very high, high, medium, low and very low relative scale of hazard and vulnerability across the VDCs/Municipalities within the Seti River corridor.

Results and Discussion

Physiography

Elevation

Geologically, the upper part of the corridor has the influence of the Main Central Thrust (MCT), middle part of the corridor has the influence of Main Boundary Thrust (MBT) and lower part has influence of Main Frontal Thrust (MFT). The upper part of the corridor is the major zone of displacement of the Indian continental block in the south and the Tibetan continental block in the north. Because of the colloidal zone of these two huge and thick continental masses, this zone is very sensitive to endogenic activities (Bhandary, 1987). The altitudinal gradient has resulted in extreme variation in several ecosystem parameters from the lower bottom to the summit of the hills and mountain (Table 3, Fig. 3).

Table 3 Corridor area across elevation zone

Elevation Zone (m)	Total area (km²)	%
100- 500	519.0	22.0
500 - 1000	971.8	41.2
1000 – 1500	336.7	14.3
1500 – 2500	189.5	8.0
2500 - 3500	108.3	4.6
3500 - 4500	110.8	4.7
4500 - 6000	110.7	4.7
6000 – 8091	13.9	0.6
Total	**2360.7**	**100.0**

Data source: Department of Survey (1998).

The data shows that 22.0% of the corridor area falls below 500 m elevation with the maximum area being within the 500 and 1000 m elevation zone (41.3%). The corridor has a substantial area (5.3%) above the permanent snowline (>4500 m) (Table 3). In the corridor, human settlements are mostly located up to 1500 m elevation. However, seasonal grazing goes up to the snowline (4500 m).

Aspect

The trunk river (Seti) channels from north to south direction, gradually bending towards the south-east. The water divide of the corridor is elongated parallel to the trunk channel. A small portion (0.5%) of the area is flat (Fig. 3). Likewise, north, north-east and north-west aspects constitute 34.5%, while the west facing aspect constitutes 14.3% of the total area. The rest (50.6%) includes east, south-east, south and south-west facing slopes, which have longer sun-shine period and higher monsoon rainfall along with relatively high human inhabitants and intensive anthropogenic activities with sparse vegetation cover (Table 4, Fig. 4). The parameters associated with aspect such as exposure to sunlight, drying winds, degree of intensity and saturation of rainfall and its discontinuities are important factors in triggering the various hazards and the risks. The south-west facing slopes of the up-stream basin of Seti River have been found to be more susceptible to landslide and soil erosion.

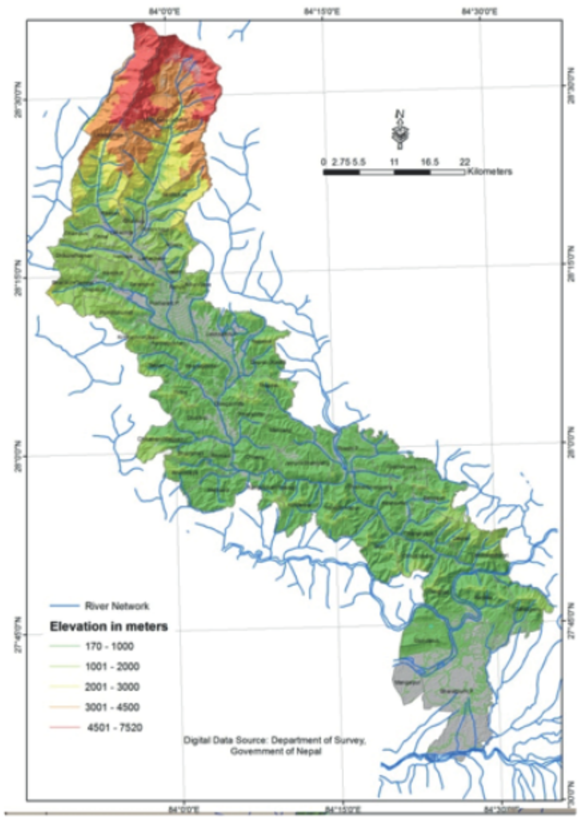

Fig. 3 Elevation zone map of the corridor

Table 4 Corridor area (km^2) by aspects (hill-slope facing direction)

Aspect direction	Down-stream	Mid-stream	Up-stream	Total	%
Flat	3.3	2.7	5.9	11.9	0.5
Northeast	49.0	108.3	103.6	261.0	11.1
East	49.6	103.3	113.3	266.2	11.3
Southeast	49.0	86.2	123.0	258.2	11.0
South	57.3	106.4	155.3	319.0	13.5
Southwest	63.1	120.5	165.1	348.6	14.8
West	56.4	114.4	165.6	336.4	14.3
Northwest	56.6	103.6	145.4	305.6	13.0
North	47.1	90.8	110.3	248.2	10.5
Total	431.2	836.3	1087.6	2355.1	100.0
%	**18.3**	**35.5**	**46.2**	**100.0**	

Data Source: Computed from ASTER DEM (Open Source) (August 27, 2015)

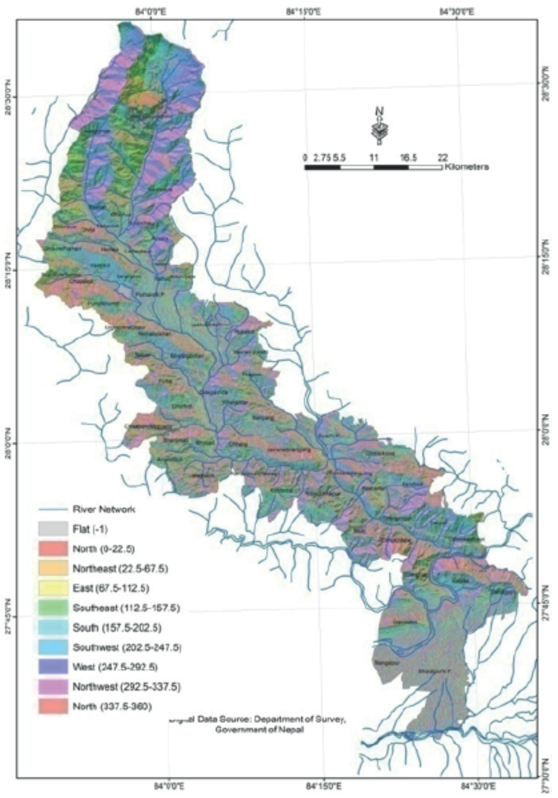

Figure 4 Aspect map of the corridor

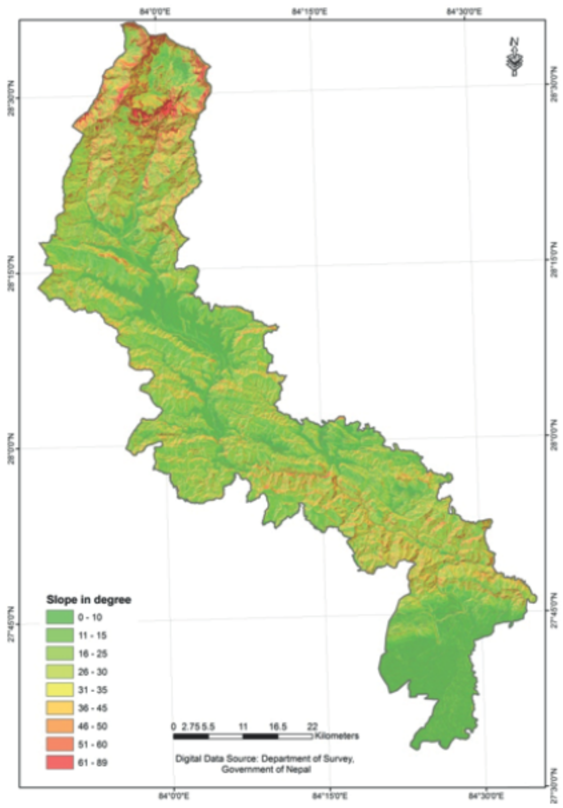

Figure 5 Slope class map of the corridor

Slope

Another basic physiographic character of the corridor is hill-slope. In this respect, nearly half of the total area falls above 25° inclination (Fig. 5, Table 5), which is categorized as the critical slope for the human activities (Gurung, 1965). Only 18.1% of the total area falls below 10° slope. Similarly, 32.6% area is in between 10° and 25°, which is the major area for cultivation in the hills. Overall, the corridor has domination of steep to very steep slope with higher possibility of land degradation due to slope steepness (Fig. 5).

Land-use/Land-cover change

Land-use/cover data shows that 33.1% of the corridor area is cultivated and about half is forest, including shrub/bush. The rest of the area includes snow/glacier (6.7%), barren land (3.3%), built-up area (2.2%), grassland (2.1%) and water bodies-lakes and rivers (1.0%) (Table 6, Fig. 6).

Table 5 Distribution of area in the corridor by slope class

Slope Class (degree)	Corridor (area in hectare)				
	Down-stream	Mid-stream	Up-stream	Total	%
< 10	185.41	92.9	148.6	426.9	18.1
10-15	87.59	140.9	137.6	366.1	15.5
15-25	43.31	176.8	182.1	402.2	17.1
25-35	73.63	309.4	356.2	739.2	31.4
35-45	26.37	76.1	120.1	222.8	9.5
> 45	14.92	40.2	143.0	198.1	8.4
Total	431.23	836.3	1087.6	2355.1	100.0
%	**18.3**	**35.5**	**46.2**	**100.0**	

Data Source: Computed from ASTER DEM (Open Source) (August 27, 2015)

Table 6 Land use/cover distribution in the corridor

Land Use/Cover	Total Area (km²)	%
Cultivated land	793.9	33.1
Broad-leaved closed forest	671.1	28.0
Broad-leaved open forest	273.5	11.4
Needle-leaved closed forest	97.4	4.1
Needle-leaved open forest	151.5	6.3
Shrub land	42.0	1.7
Grassland	51.6	2.1
Built-up area	53.6	2.2
Barren land	78.9	3.3
Lakes	8.3	0.3
River	17.6	0.7
Snow/Glacier	161.8	6.7
Total	**2401.1**	**100.0**

Data source: ICIMOD (2010)

The data shows that forest, shrub/bush, grassland and cultivated area cover over 80% of the total corridor coverage. For the last few decades, Nepal has been experiencing substantial changes in land-use/cover pattern. Specifically, change in cultivated land, forest, shrub and bush plays an important role in the local environment. Land-use/cover change in the Seti River corridor in the past 16 years, i.e. between 1994 and 2010, shows a significant change, where cultivated land has declined by 9.03%. Over the same period, forest area seems to have increased by 3.23%, and grassland decreased by 44.5% most likely due to increment of forest area. Grassland has declined (69.6%) mainly in the down-stream region of the corridor (Table 7). The maximum (15.1%) cultivated land has declined in the mid-stream of the corridor coinciding with the low sex ratio (797.1 males per 1000 females) (Table 1). In the same period, forest area has increased, which is shown by the increase in per-capita forest coverage (Table 8). The data shows, nearly 57.6% of the total forest coverage lies under the critical slope, which is a good indicator of reduced vulnerability (Table 9). The average per-capita forest area including dense forest and shrub is relatively less than the national average, 0.25 ha (FRA Nepal, 2016).

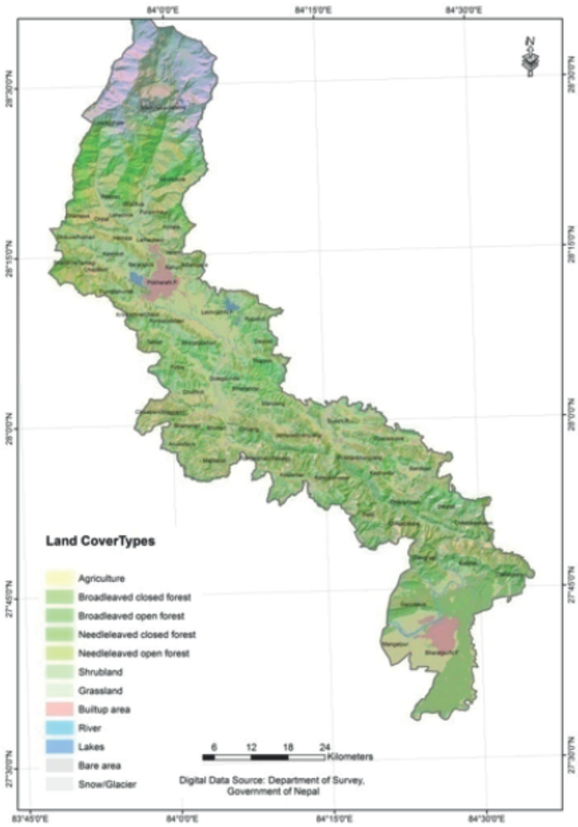

Figure 6 Land cover type of the corridor

In the lower part of the corridor, built-up area is increasing with dense human settlement and encroachment upon open fallow grassland and bush/shrub areas in accessible areas along motorable roadsides. Many such settlements seem to have high risk of flood, sedimentation of mass-waste, specifically in the break-of-bulk of sloping landscape, and improper sanitation due to congestion. Cultivated land is another major land-use/cover type in the corridor, which shares 77575.9 ha (33.1%) of the total area. Out of the total cultivated land, 20948.4 ha (27.0%) is confined within the critical hill-slope (>25 degree). In the mid-stream region, 35.5% of the cultivated land falls in the critical slope, indicating the vulnerable status (Table 10).

Table 7 Land use/cover (km²) change in the corridor between 1994 and 2010

Land Use/Cover	Down-stream	Mid-stream	Up-stream	Total
Cultivated land, 2010	127.3	335.9	312.6	775.8
Cultivated land, 1994	136.3	455.6	337.9	929.8
Total area change between 1994 and 2010	-9.0	-119.7	-25.3	-154.1
Percent change between 1994 and 2010	-3.4	-15.1	-3.9	-9.0
Forest land, 2010	260.5	466.7	479.3	1206.5
Forest land, 1994	261.2	416.8	452.9	1130.9
Total area change between 1994 and 2010	-0.8	49.9	26.4	75.5
Percent change between 1994 and 2010	-0.1	5.6	2.8	3.2
Grass land, 2010	1.6	4.2	45.8	51.6
Grass land, 1994	8.8	10.8	114.5	134.1
Total area change between 1994 and 2010	-7.2	-6.6	-68.7	-82.6
Percent change between 1994 and 2010	-69.6	-43.9	-42.9	-44.5

Data source: Department of Survey (1998); ICIMOD (2010)

Table 8 Per-capita agriculture and forest area across the corridor

Characteristics	Corridor			
	Down-stream	Mid-stream	Upper	Total
Cultivated land (ha)	12725.9	34358.5	30491.6	77575.9
Per-capita cultivated land (ha)	0.06	0.17	0.07	0.091
Total forest area including bush/shrub (ha)	26047.6	46666.0	47931.5	120645.1
Per-capita forest land (ha)	0.12	0.24	0.11	0.14

Source: Computed from the land-use/cover maps (Fig. 5), ICIMOD (2010)

Table 9 Distribution of forest coverage (km²) in the critical slope (>25⁰)

Land use	Down-stream	Mid-stream	Up-stream	Total
Total forest area	26047.6	46666	47931.5	120645.1
Forest in critical slope (>25⁰)	7474.9	31476.71	30580.6	69532.2
%	28.7	67.5	63.8	57.6

Source: Computed from overlaid land-use and slope map (Fig. 4 and Fig. 5)

Table 10 Distribution of cultivated land (km²) in the critical slope (>25⁰)

Land use	Down-stream	Mid-stream	Up-stream	Total
Total cultivated land	12725.9	34358.5	30491.6	77575.9
Cultivation over in critical slope (>25⁰)	1597.5	12213.5	7137.4	20948.4
%	12.6	35.5	23.4	27.0

Source: Computed from overlaid land-use and slope map (Fig. 4, Fig. 5)

Social status

The mid-land river valleys of Nepal were not preferred for human inhabitation for a long period. History unveils that the valleys became attractive only after the eradication of malaria in the early 1950s, along with the construction of roads and other infrastructural facilities such as health, education, market, and irrigation canal. At present, the corridor includes one sub-metropolitan city (Pokhara) and three municipalities (Lekhnath, Byas and Bharatpur). Pokhara and Lekhnath are located in the up-stream region, Byas in the mid-stream region and Bharatpur in the down-stream region of the corridor. The population density is high within these urban centers and along the river terraces. The corridor has a total population of 851,661 and 216,352 households (3.94 persons per household) (CBS, 2012). These four urban centers cover only 15.1% area of the corridor, but include 60.7% of the households with 58.7% of the population, and 1413 persons per km² population density. In the down-stream region, Mangalpur has the highest and Kabilas has the lowest population density, i.e. 900 and 93 persons per km², respectively. Likewise, in the mid-stream region, the highest population density (815 persons per km²) is in the Byas Municipality and the least in the Deurali VDC (72 persons per km²). Similarly, in the up-stream region, the highest population density is in Pokhara Sub-Metropolitan City and the lowest in the Machhapuchhre VDC, i.e. 4,636 and 6 persons per km^2, respectively. The low population density in Machhapuchhre is due to the presence of high mountain range without settlements. With respect to per-capita cultivated land, on an average, the cultivated land area covers 0.091 ha with variation in the different stretches: 0.06 ha in the down-stream region, 0.17 ha in the mid-stream and 0.07 ha in the up-stream region (Table 8).

The ratio of male to female gives a measurement of pressure over females. Relatively high absentees male population in the community hamper the environmental management activities. The lesser number of male members in the community results in higher probability of social vulnerabilities as per discussion with the local people during the FGD. It was found that the corridor has a low sex ratio (894.3 males per 1000 females), with the down-stream value being 958.1, the mid-stream value being 797.1 and the up-stream value being 910.1, depicting large number of male absentees in the mid-stream region. As a result, females in the corridor are under high pressure to maintain their livelihood and local environment. With respect to the settlement, large numbers of human settlements are confined within the critical hill-slopes. Results show that 42.2% of human settlements area in the up-stream region, 39.8% in the mid-stream region and 18.0% in the down-stream region are located within critical hill-slopes.

Relative vulnerability status

The multi-criteria based assessment result shows different relative scale of vulnerability categories in the corridor (Table 11). The up-stream region of the corridor is more vulnerable where 5.2% of the total area is under the very high category. Similarly, the downstream corridor has no area within very high category. This indicates that the combination of the both physiographic complexities and the human activities determines vulnerability of the landscape. The upper part of the corridor is complex in physiography with relatively less human inhabitation because of the high altitude, steep slope and cold climate. Similarly, the down- stream region has more flat land with lesser complexities in physical condition.

In connection to the spatial distribution by VDCs/Municipalities, Puranchaur, Armala, Valam and Arva-Vijaya in the eastern side, Dhikurpokhari, Pumdi-Bhumdi and Kristi in the western side, and Rupakot in the eastern side seem to be in relatively high vulnerability category (Fig. 7). The Pokhara Sub-metropolis and

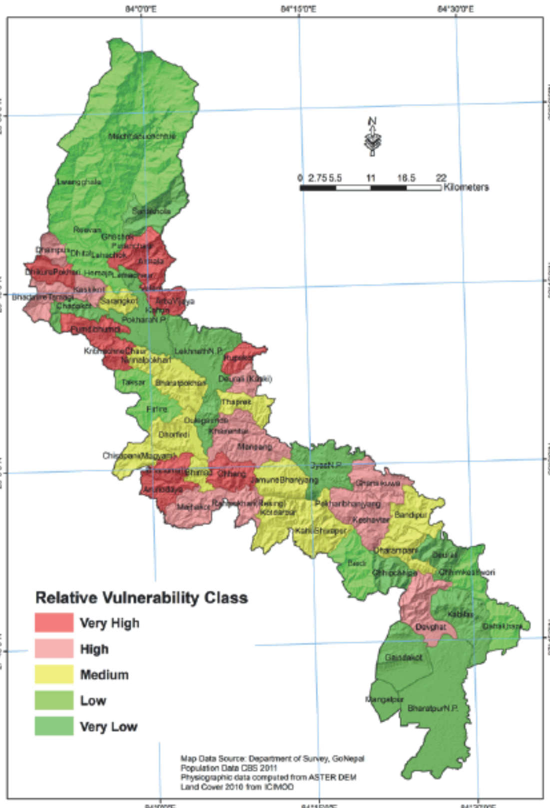

Figure 7 Relative vulnerability classes in the corridor

Lekhnath Municipality have shown very low vulnerability. The VDCs lying in the upper part of the mid-stream region: Chhang, Arunodaya and Bhanumati are in very high hazard and high vulnerability category, while the mid and lower parts fall under low to high vulnerability categories (Table 11, Fig. 7).

In the down-stream region, because of low altitude and homogeneous physical parameters, the VDCs (except Devghat) fall under low to very low hazard and vulnerability categories. Also the adaptive capacity of downstream region was found to be stronger than up-streams and mid-streams, with risk reducing plan, provision of early warning system and relatively high economic status. The formation of sinkholes in the lower part of Armala VDC, landslide and flood in Lumle and Bhadaure-Tamagi in 2015 (due to cloud burst), the Seti River Flash Flood of May 2012, the Seti River blockade during the monsoon in Pokhara Sub-Metropolitan City, landslides and floods in Kabilas and many VDCs of Tanahun in August 2003 (due to cloud burst), and flood and side-cutting at Mangalpur and Devghat are the some instances of local events. Therefore, from climate-induced disaster resilience perspective, such local events need to be considered at micro-level planning.

Table 11 Distribution of area across the relative vulnerability class in the corridor

Vulnerability class	VDC/Municipality (No.)	Up-stream	%	Mid-stream	%	Down-stream	%	Total Area	%
Very High	8	120.5	5.1	52.4	2.2	0.0	0.0	172.9	7.3
High	12	89.4	3.8	184.1	7.8	55.2	2.3	328.7	14.0
Medium	14	71.1	3.0	364.1	15.5	0.0	0.0	435.1	18.5
Low	18	668.4	28.4	151.0	6.4	128.9	5.5	948.3	40.3
Very Low	9	138.1	5.9	84.8	3.6	247.2	10.5	470.0	20.0
Total	**61**	**1087.6**	**46.2**	**836.3**	**35.5**	**431.2**	**18.3**	**2355.1**	**100.0**

Source: Computed from the analyzed relative vulnerability class map (Fig. 6)

Conclusion

The present results reveal 7.3% of the total area and nearly 5% population in the corridor is confined within the very high risk category. Likewise, 12 VDCs with an area of 14.0% fall in the high risk category. The medium risk category encompasses 14 VDCs with 18.5% of the total area and the low class covers 18 VDCs and Municipalities with 40.3% area. The very low category includes only 9 VDCs with 20.0% area of the corridor. This result provides the ground level information for future planning to identify appropriate risk reduction and management measures. The VDCs/Municipalities within very high and high risk categories require serious attention for disaster risk reduction and management interventions. Due to such geo-environmental and spatial characteristics, a proper scrutiny of the corridor morphology for future development activities is essential.

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