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Bank erosion and lateral instability hazard status of Kodku Khola, southeast Kathmandu, central Nepal

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ABSTRACT

The northward flowing fifth order Kodku Khola confluences with the Manahara River in the southeast of Kathmandu, and has about 16.49 km stretch with 35.67 sq km watershed area. Many large civil engineering structures such as irrigation cannels, bridges, highways and roads are under construction, and are located along and around the river in the urbanizing Kodku Khola valley. Some sections of the river are of high erosion potential due to various reasons. Many human activities together with natural processes have led to bank erosion and channel shifting of the Kodku Khola. Thus, study of the river bank erosion and lateral instability is of great concern as unstable segments of the river may pose threat on civil engineering structures and adjacent agricultural lands. The river bank hazard potential and its variations were assessed in terms of its bank erosion and lateral instability (BELI) hazard indices by considering four parameters namely, bank erosion hazard index (BEHI), near bank stress index (NBSI), lateral instability hazard index (LIHI), and anthropogenic disturbance factors (ADF). For this, thirty nine locations were surveyed throughout the river and assessed the BELI hazard levels. This paper evaluated the BELI hazard levels and channel shifting condition of the Kodku Khola.

Key words: Bank erosion, Planform geometry, Flood prone areas, Channel shifting

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INTRODUCTION

Stream bank erosion is a natural process, however, in many places the rate of stream bank erosion accelerates noticeably because of poor hydraulic and geotechnical processes (Rosgen 2001). Stream bank erosion can be taken as the sum of bank erodibility and bank erosivity. The former is directly related to material properties, slope protection against gravitational and lateral force, whereas the latter to near bank stress and boundary stress, which are hydraulic properties. Stream bank erosion removes the lateral toe support of the slope and generates slope instability (Shrestha and Tamrakar 2007). Many human activities together with natural processes have led to bank erosion and channel shifting of the Kodku Khola. The extensive bank erosion in the river basin has led to numerous social and economic consequences such as loss of agricultural land, settlement and other essential engineering infrastructures. High human intrusion on the natural landscape of the river corridor can also extends erosion rate in the river basin.

The Kodku Khola originating from Majhgau is one of the major tributaries of the Manahara River from southern part of the Kathmandu Valley (Fig. 1).

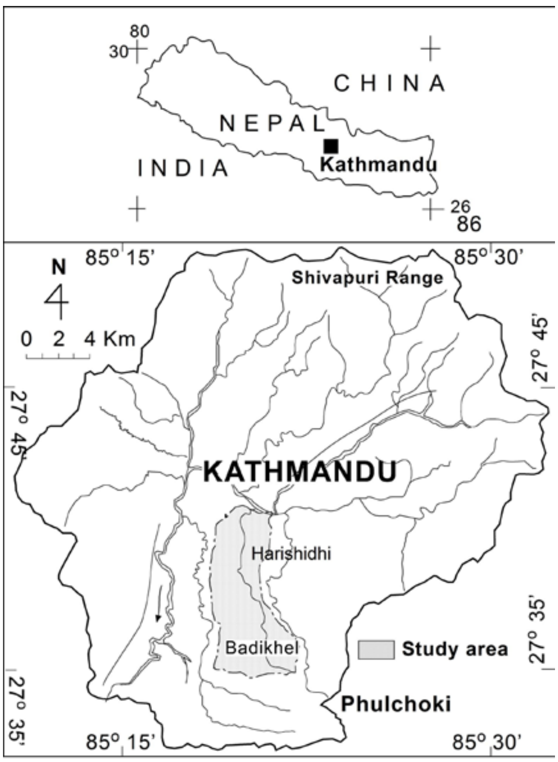

Fig. 1: Location map of the Kodku Khola basin.

KODKU KHOLA BASIN

Most of the floodplains areas are used for farming and settlement. Some parts are covered by forest and some of the parts are used for quarry sites for brick industries. Due to rapid urbanisation of the Kodku valley the land used pattern has been changed around the river corridor. The water quality has been highly degraded due to contamination of sewer and solid waste disposed to the lower portion of the Kodku Khola.

Relative relief is extremely high in the Majhgau and Badikhel, high in the Muldol area and moderate to moderately low in the Taukhel, Dhapakhel, Harisidhi and Khumaltar. Relative relief decreases from south to north of the Kodku Khola watershed.

The Kodku Khola is the fifth order river. There are altogether twenty two 2nd order, six 3rd order and two 4th order streams in the watershed. The third order main stem stretches for about 3,440 m from Majhgau up to the confluence of the Kodku Khola with the Guhe Khola. The fourth order main stem river stretches for 793 m up to Tasinchok where it confluences with the major tributaries extending from the Muldol sub-watershed. The fifth order main stem river stretches for about 11,886 m and finally confluences with the Manahara River.

Planform geometry of the river is controlled by various parameters. Sinuosity (K), meander wavelength (lm), meander belt with (Wblt), and radius of curvature (Rc). All these parameters were calculated from the topographic map enlarge to 1:10,000 scale. The results of these parameters are calculated for 3rd and 5th order stream. Sinuosity indices of the third, fourth and fifth order main stem stretches of the Kodku Khola are 1.13, 1.29, and 1.36, respectively showing sinuous nature according to the classification of Leopold and Wolman (1957). The Meander wavelength, belt width and radius of curvature of the fifth order main stem river are 161.2 m, 223.1 m, and 53.3 m, respectively. Both Lm and Wblt gradually increase from the 3rd to the 4th order stream, but increase drastically to the 5th order stream. Radius of curvature however slightly diminishes and increases again from the 3rd to the 5th order stream. Increasing size of the 5th order stream possibly has caused increase in Planform parameters.

Geologically, the Kodku watershed comprises three types of sediments and rocks; Cambro-Ordovician bedrocks and Plio-Pleistocene fluvial-lacustrine sediments, Quaternary sediment (after DMG 1998) (Fig. 2). The Kodku watershed comprises Cambro-Ordovician metasedimentary rocks of the Phulchoki Group i.e., the Sopyang and the Chandragri formations in the southernmost portion. The Sopyang Formation comprises dark to yellowish brown thinly bedded calcareous slate, argillaceous limestone and grey metasiltstone. It is well exposed at the left bank of the Kodku Khola near the Badikhel. The Chandragiri Formation comprises bluish grey to brown, finely crystalline limestone, phyllite and metasandstones. The beds extend NW-SE, and dip southwestward in the southern portion and northeastwards in the northern portion, thus forming the portion of the anticline. A ridge forming bedrock of the Chandragiri Limestone also exists at Jharuwarasi, where river incises forming a hanging valley towards the south. Adjacent to the bedrocks of the above two formations are distributed the colluvial sediments and the alluvial fan deposits. The western half portion of the watershed is occupied by the Chapagaon Formation. It comprises of subrounded to rounded silty sandy gravel occasionally intercalated with silty sand, clayey silt, and boulder beds. The portion of the western part of the watershed is occupied by the Lukukdol Formation characterised by sandy clayey silt interbedded with gravel, sand, and peat layers. The majority of the northeastern or the eastern half portion of the watershed constitutes the Kalimati Formation.

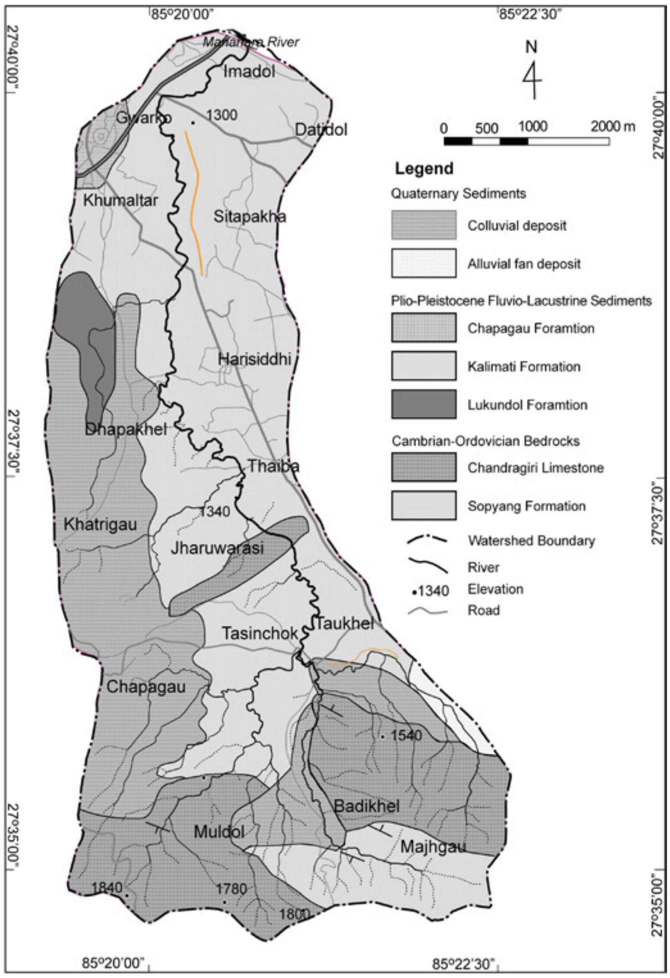

Fig. 2: Geology of the Kodku Khola basin.

BANK EROSION AND LATERAL INSTABILITY HAZARD ASSESSMENT

Stream bank erosion is basically controlled by two parameters which influence erodibility and erosivity of the banks. These parameters are respectively Bank Erosion Hazard Index (BEHI) and Near Bank Shear Stress Index (NBSI). Six parameters of bank features; bank height ratio (BHR), bank angle (BA), root depth ratio (RDR), root density (RD), surface protection (SP) and bank material characteristics (BMC) are considered for BEHI (Rosgen 2001). Similarly near bank maximum depth (D_{nb}), bankfull depth (D_{bkf}), near bank slope

(S_{nb}) and average slope (S_{avg}) are considered in terms of NBSI. Shrestha and Tamrakar (2007) proposed some other parameters which are responsible for lateral instability of channels. These parameters are expressed in trems of lateral instability hazard index (LIHI) and anthropogenic disturbance (AD). Altogether these four parameters, i.e., BEHI, NBSI, LIHI and AD were assessed to generate a bank erosion and lateral instability (BELI) hazard indices for the Kodku Khola.

To generate the BELI hazard map, thirty nine locations at the Kodku Khola were surveyed. The Ushikata theodolite and staff were used to measure the cross-section and the longitudinal section of the Kodku Khola. Planform geometry and hydraulic parameters were assessed from the field survey and topographic map. Eventually, BEHI, NBSI, LIHI, and AD were determined and their values were transformed into corresponding ratings based on Rosgen (2001) and Shrestha and Tamrakar (2007) using the Table 1. The BELI rating for a given location was then determined by summing up of the corresponding values of the four parameters. Finally, it was further classified in to very low, low, moderate, high, very high, and extreme hazard categories based on these categories, and then BELI hazard indices were obtained for the river corridor within the flood prone width.

Table 1: Criteria for evaluating bank erosion and lateral instability hazard levels.

Parameters	Attributes	Hazard levels						
			Very high	low	Moderate	High	Very high	Extreme
Bank erosion hazard index (BEHI)	Bank height ratio	Value	1.0-1.1	1.1-1.2	1.2-1.5	1.5-2	2.2.8	>2.8
		Index	1-2	2-4	4-6	6-8	8-9	10
	Root depth ratio (%)	Value	100-80	80-55	55-30	30-15	15-5	<5
		Index	1-2	2-4	4-6	6-8	8-9	10
	Root density (%)	Value	100-80	80-55	55-30	30-15	15-5	<5
		Index	1-2	2-4	4-6	6-8	8-9	10
	Bank angle (degree)	Value	0-20	20-60	60-80	80-90	90-120	>120
		Index	1-2	2-4	4-6	6-8	8-9	10
	Surface protection (%)	Value	100-90	90-50	50-30	30-15	15-5	<5
		Index	1-2	2-4	4-6	6-8	8-9	10
	Total BEHI		<10	10-20	20-30	30-40	40-45	>45
Near bank stress index (NBSI)	Near bank stress index	Value	<0.8	0.8-1.05	1.06-1.14	1.15-1.19	1.20-1.60	>1.60
		Index	<2	2-4	4-6	6-8	8-9	>9
Lateral instability hazard index (LIHI)	Sinuosity (K)	Value	<2..1	2.1-1.4	1.4-1.6	1.6-1.8	1.8-2.0	>2.0
		Index	1-2	2-4	4-6	6-8	8-9	>9
	Meander width ratio	Value	<2	2-5	5-10	10-15	15-20	>20
		Index	1-2	2-4	4-6	6-8	8-9	>9
	Meander length ratio	Value	<10	10-15	15-20	20-25	25-30	>30
		Index	1-2	2-4	4-6	6-8	8-9	>9
	W/D ratio	Value	<1.4	1.4-2.0	2-10	10-20	20-40	>40
		Index	1-2	2-4	4-6	6-8	8-9	>9
	Total LIHI		<8	8-16	16-24	24-32	32-36	>36
Anthropogenic disturbance	Percentage disturbance	Value	<5	5-10	10-15	15-20	20-25	>25%
		Index	1-2	2-4	4-6	6-8	8-9	>9
	Total rating		**<22**	**22-44**	**44-66**	**66-88**	**88-99**	**>99**

River itself shows dynamic nature by shifting its channel in space and time. The shifting of channel can however be aggravated by effects of natural and human activities. The channel shifting of the Kodku Khola was determined by comparing the topographic map of 1999 and satellite image of 2013 of the Kodku watershed (Fig. 3). The river channel is more shifted in Imadol and Khumaltar.

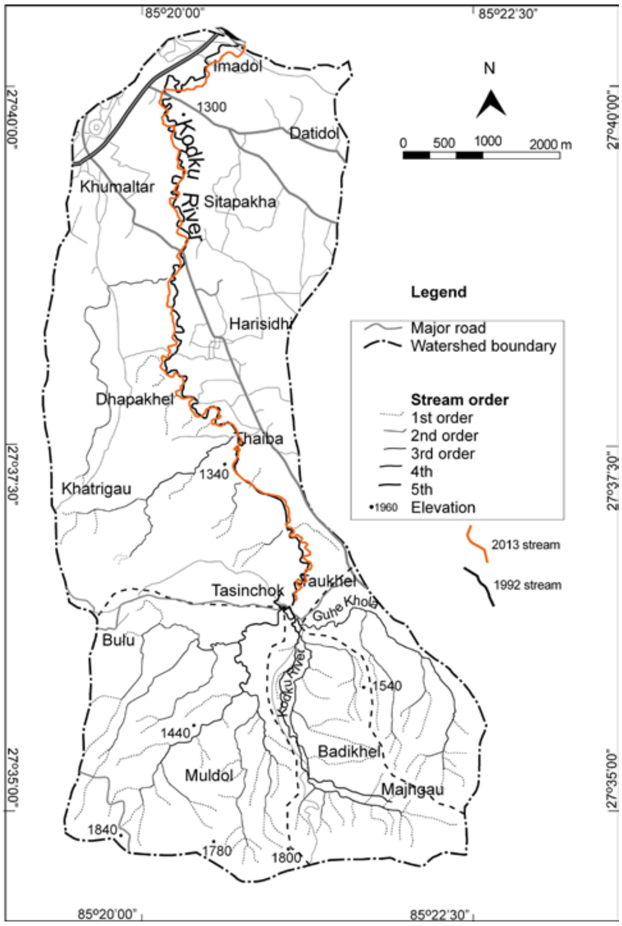

Fig. 3: Comparison of streams of two episodes: 1992 and 2013.

Bank erosion hazard index

Five parameters of stream bank features were assessed following the Rosgen. The variables includes Bank height ratio (BHR), bank angle (BA), root depth ratio (RDR), root density (RD), surface protection (SP) (Table 2). The assessed stream bank variables were transformed in to their corresponding rating by using the Table 1. Hazard rating ranges from 0-10 corresponding to very low, low, moderate, high, very high and extreme. Apart from the above five parameters according to the Rosgen (1996) bank material type, its stratification, texture and stiffness were also considered for determining the BEHI. Bank height ratio, bank angle and root depth ratio were calculated quantitatively in the field at each location. But root density and surface protection percentage were obtained qualitatively by estimating the vegetation present on banks of the Kodku Khola throughout thirty nine locations.

The status of erosion is largely controlled by the steepness of the slope of the stream bank. Vertical and cantilever banks often show high erosion rates. Generally, higher BHR value represents greater susceptibility to stream bank erosion Rosgen (2001). In the Kodku Khola, BHR ranges from low value 1 to high value 8. The lowest values observed were repeatedly throughout the river whereas the highest values were observed from Jharuwarasi near the gorge. The Badikhel, Thaiba, Dasghare and Gwarko sites of the Kodku Khola fall on moderate to high hazard level. Majgau and Jharuwarasi sites of the river fall on extreme hazard level.

The result of BEHI is indicated in Table 2 and Fig. 4. The result shows that Erosion potentiality of the Kodku Khola banks fall on low to very high hazard level. The Harishidhi (BE26, BE27, and BE28) and Thaiba (BE20) areas exhibit very high potential of stream erosion. More than half of the sample stations exhibit the high to very high hazard level. The hazard level increases towards downstream region.

Near bank stress index

Near bank stress index (NBSI) is the ratio of near bank shear stress and boundary shear stress. To find NBSI each stream width at a selected station was divided into three equal parts. The near bank shear stress was estimated by taking the depth and slope of near bank region.

$$\tau_{nb} = \gamma d_{nb}.S_{nb} \qquad (1)$$

Where τ_{nb} = near bank shear stress (kN/m^2), γ= unit weight of water (kN/m^2), d_{nb} = near bank maximum depth (m), S_{nb} = near bank slope

Boundary shear stress (τ) was calculated using the following expression of Shields (1936).

$$\tau = \gamma RS \qquad (2)$$

Where τ = boundary shear stress, γ = Unit weight of water, R = Hydraulic radius of the riffle cross-section at bank full stage and S = Average stream slope.

Finally NBSI was calculated, and the values of NBSI were then transformed into their corresponding hazard rating based on Table 1. The greater values of NBSI indicate greater power of stream flow to erode the stream banks (Table 3).

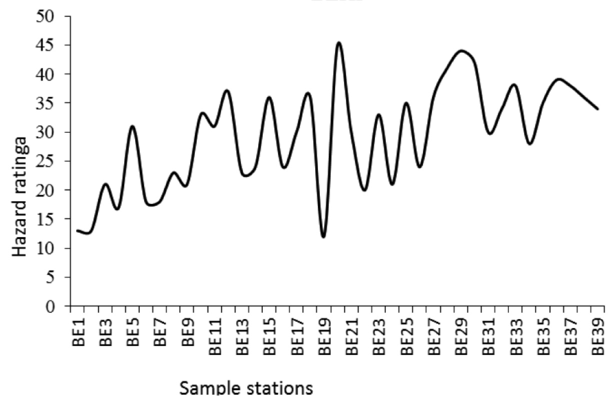

Fig. 4: Bank erosion hazard status of the Kodku Khola.

Table 2: Field data of BEHI and their corresponding hazard ratings.

Sample Station	Field measured values					Bank erosion hazard index rating							
	BHR	RDR	RD	BA	SP	BHR	RDR	RD	BA	SP	Adjustment	Total BEHI	BEHI Level
BE1	5	0.14	95	30	95	10	8	1	3	1	-10	13	L
BE2	1.5	0.5	80	85	50	6	4	2	7	4	-10	13	L
BE3	1.3	0.31	20	110	50	6	6	8	9	4	-10	21	M
BE4	1.4	0.33	22	120	20	6	6	7	10	8	-10	17	M
BE5	1.2	0.29	70	90	75	6	6	3	8	3	5	31	H
BE6	1.7	0.16	70	85	40	6	7	3	7	5	-10	18	L
BE7	3	0.27	85	75	60	10	6	2	6	4	-10	18	L
BE8	1.9	0.19	45	80	60	7	7	4	6	4	-5	23	M
BE9	1	0.88	50	95	80	1	2	4	8	2	5	21	M
BE10	2.7	0.31	40	70	70	9	6	5	5	3	5	33	H
BE11	1	0.55	20	85	25	1	4	7	7	7	5	31	H
BE12	1.3	0.47	15	110	25	4	4	8	9	7	5	37	H
BE13	1	0.56	30	110	70	1	4	6	9	3	0	23	M
BE14	1.2	0.75	30	85	55	4	3	6	7	4	0	24	M
BE15	1	0.5	20	110	10	1	4	8	9	9	5	36	H
BE16	1.1	0.79	25	83	60	2	2	7	7	4	2	24	M
BE17	1.5	0.17	60	105	50	6	7	4	9	4	0	30	H
BE18	8	0.03	45	78	60	10	10	5	7	4	0	36	H
BE19	1	0.85	40	75	75	1	2	5	6	3	-5	12	L
BE20	1.3	0.4	20	110	10	4	5	8	9	9	10	45	VH
BE21	1	0.42	20	105	10	1	5	8	8	9	-2	30	H
BE22	1	0.3	60	105	75	1	6	4	8	3	-2	20	M
BE23	1.4	0.34	35	105	40	4	6	5	8	5	5	33	H
BE24	1.4	0.33	50	100	55	4	6	4	8	4	-5	21	M
BE25	1.9	0.2	65	95	45	8	7	3	8	4	5	35	H
BE26	1.5	0.35	68	85	90	6	6	3	7	2	0	24	M
BE27	1	0.38	20	105	10	1	5	8	8	9	5	36	H
BE28	1.2	0.13	10	87	10	2	8	9	8	9	5	41	VH
BE29	1.5	0.1	10	95	20	6	8	9	8	8	5	44	VH
BE30	1	0.1	10	105	5	1	8	9	9	10	5	42	VH
BE31	1.4	0.17	80	85	85	4	7	2	7	5	5	30	H
BE32	1.9	0.14	75	85	80	7	8	2	7	5	5	34	H
BE33	1.3	0.32	25	95	8	4	6	6	8	9	5	38	H
BE34	1.8	0.15	78	65	86	6	8	2	5	2	5	28	M
BE35	2.7	0.14	65	88	70	9	8	3	7	3	5	35	H
BE36	2.5	0.09	40	90	55	9	8	5	8	4	5	39	H
BE37	1.9	0.12	40	90	55	8	8	5	8	4	5	38	H
BE38	2.3	0.09	45	80	55	8	8	5	6	4	5	36	H
BE39	2.5	0.13	40	90	60	9	8	5	8	4	5	34	H

The banks of the Kodku Khola are subject to very high to extreme near bank stresses (Table 3 and Fig. 5). Sample stations around the Majhgau areas (BE1, BE2, and BE3), Thapagau (BE7), Jharuwarasi (BE16) and Harishidhi areas are subject to very high hazard level and the remaining sample stations fall on extreme hazard level.

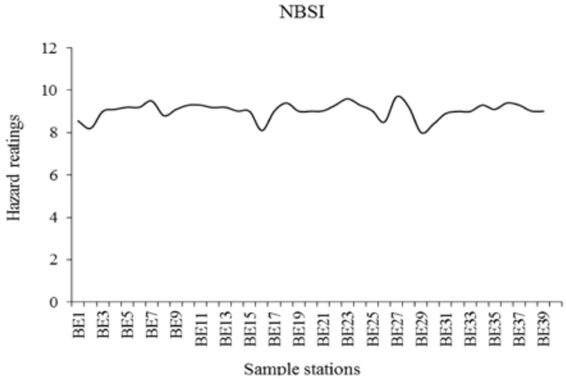

Fig. 5: NBSI hazard status of the Kodku Khola.

Lateral instability hazard index

Sinuosity (K: Sinuosity is the ratio of the channel length to the distance of the valley), meander width ratio (MWR: the ratio of the meander length to bank full depth of the river), meander length ratio (MLR: ratio of the meander length to bank full depth of the river) and width depth ratio (W/D: ratio of meander width to the bank full depth of the river) are the hazard indices which influence the lateral instability of the river. Laterally unstable stram banks have higher values of all above indices. The sinuosity of the river is progressively developed by the result of the bank erosion. MWR and MLR represent lateral containment of the river. Higher values of W/D indicate unstable stream banks. The cross-section survey and Planform results were used to calculate the above all lateral instability hazard indices of all study sites.

The result (Table 4 and Fig. 6) shows that lateral instability condition of the banks of the Kodku Khola fall on low to moderate hazard levels. Moderate LIHI is due to high values of almost all the Planform parameters. Sinuosity (K), meander width ratio (MWR) and meander length ratio (MLR) of the river largely influence the value of LIHI, and hence its fluctuation. The result shows that the area of Badikhel and the downstream sites from the Harishidhi to the Manahara River Bridge fall on low lateral instability hazard index level. The low values of LIHI are due to the extreme channelisation and human encroachment of the river. The channelisation directly affects the K, MWR and MLR of the river. Such planform parameters are frequently altered due to many anthropogenic disturbances and discharge variation of the river.

Table 3: Result of the near bank stress index (NBSI).

Sample Station	Near Bank Stress Level III (5)				
	Near bank max. depth, D_{nb} (m)	Bankfull depth, D_{bkf} (m)	NBSI= D_{nb}/D_{bkf}	Rating	NBS hazard level
BE1	1.3	0.9	1.44	8.55	VH
BE2	1.2	0.9	1.33	8.2	VH
BE3	1.3	0.8	1.60	9	VH
BE4	1.7	1.0	1.70	9.1	E
BE5	1.4	0.6	2.33	9.2	E
BE6	1.5	0.7	2.14	9.2	E
BE7	1.6	0.7	2.29	9.5	E
BE8	1.2	0.8	1.5	8.8	VH
BE9	1.6	0.8	2.00	9.1	E
BE10	1.3	0.5	2.60	9.3	E
BE11	1.5	0.6	2.50	9.3	E
BE12	1.6	0.7	2.29	9.18	E
BE13	1.1	0.5	2.20	9.2	E
BE14	1.0	0.6	1.73	9.02	E
BE15	1.3	0.5	2.60	9	E
BE16	0.5	0.4	1.25	8.1	VH
BE17	1	0.5	2	9.01	E
BE18	1.3	0.5	2.56	9.4	E
BE19	1.2	0.6	2.00	9.01	E
BE20	1.0	0.5	2.00	9.01	E
BE21	1.3	0.6	2.17	9.03	E
BE22	1.3	0.5	2.60	9.3	E
BE23	2.0	0.6	3.33	9.6	E
BE24	1.5	0.6	2.50	9.3	E
BE25	1.1	0.6	1.83	9.04	E
BE26	0.8	0.6	1.33	8.5	E
BE27	1.0	0.3	3.33	9.7	E
BE28	1.1	0.5	2.20	9.2	E
BE29	1.2	1.0	1.20	8	VH
BE30	1.2	0.9	1.33	8.4	VH
BE31	1.5	0.9	1.67	8.9	E
BE32	1.5	0.8	1.88	9	E
BE33	2.3	0.9	2.56	9	E
BE34	2.5	1.0	2.50	9.3	E
BE35	2.3	1.1	2.09	9.1	E
BE36	2.9	1.2	2.42	9.4	E
BE37	2.5	1.0	2.50	9.3	E
BE38	2.7	1.3	2.08	9.02	E
BE39	2.4	1.2	2.00	9.01	E

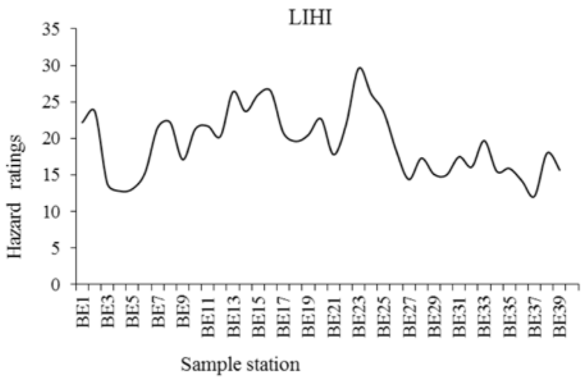

Fig. 6: LIHI hazard status of the Kodku Khola.

Anthropogenic disturbances

The river bank erosion is also influenced by natural as well anthropogenic factors. Flood and landslide are main natural factors that directly affect the river bank stability condition. The major anthropogenic activities such as bank encroachment, river channel excavation and unplanned cultivation on the river corridors are also responsible for bank erosion hazard. Disturbance percentage of each location was assessed qualitatively from the field and rating was assigned from 1 to 10 into six hazard classes from very low to extreme by using the Table 2.

At the Majhgau area, banks of the Kodku Khola have been less disturbed by human activities whereas natural factors moderately affect stability condition of river banks (Fig. 7 and Table 5). Some areas of the Thaiba and Harishidi belong to very high hazard levels. The sample stations located downstream from the Harishidhi to the Gwarko areas are highly disturbed by human activities. River has extremely lost its natural status by extreme channelization and pollutions in these areas. The Taukhel, Jharuwarasi, Dasghare and Imadol areas fall on high hazard levels. The sample station downstream from the Thapa Gau to Dashgare areas are seriously affected by the anthropogenic disturbances such as unplanned cultivation, disposal of sewage and livestock.

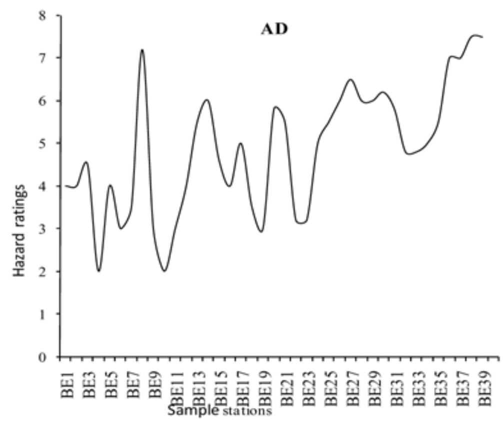

Fig. 7: Anthropogenic disturbance (AD) status of the Kodku Khola.

Table 4: Result of lateral instability hazard indices and there corresponding ratings.

Location	K	Rating	MWR	Rating	MLR	Rating	W/D ratio	Rating	Total rating	Hazard level
BE1	1.09	1	10.77	7.1	30.77	9	7.22	5.1	22.2	M
BE2	1.2	2	13.33	7.8	30.00	9	5.00	4.9	23.7	M
BE3	1.2	2	6.04	4.5	7.99	0.8	12.34	6.5	13.8	L
BE4	1.2	2	5.52	4	7.30	0.7	10.10	6.1	12.8	L
BE5	1.2	2	5.98	4.1	7.91	0.8	10.79	6.2	13.1	L
BE6	1.2	2	7.00	4.9	9.26	1.9	12.42	6.5	15.3	L
BE7	1.5	5	12.33	6.9	13.70	3.1	10.43	6.5	21.5	M
BE8	1.28	2	8.65	5.6	27.16	8.5	10.13	6.1	22.2	M
BE9	1.3	3	8.66	5.7	11.73	2.2	12.03	6.2	17.1	L
BE10	1.3	3	13.83	7.2	18.73	5.1	10.00	6	21.3	M
BE11	1.3	3	14.67	7.3	19.88	5.9	8.45	5.5	21.7	M
BE12	1.3	3	13.83	7.3	18.73	5.1	7.03	4.9	20.3	M
BE13	1.7	7	13.36	7.2	19.44	5.8	13.58	6.4	26.4	M
BE14	1.7	7	9.72	5.8	14.14	3.8	15.71	7.1	23.7	M
BE15	1.7	7	12.83	6.9	18.67	5.5	13.89	6.6	26	M
BE16	1.7	7	12.49	6.8	18.18	5.3	17.50	7.4	26.5	M
BE17	1.45	4	10.25	5.9	16.95	4.7	11.80	6.2	20.8	M
BE18	1.3	3	8.63	5.6	13.04	2.9	23.00	8.1	19.6	L
BE19	1.2	2	11.99	7.1	17.81	4.8	13.83	6.6	20.5	M
BE20	1.2	2	14.63	7.4	21.74	6.4	14.47	6.9	22.7	M
BE21	1.2	2	8.36	5.2	12.42	2.7	19.51	7.9	17.8	L
BE22	1.2	2	13.63	7.2	20.25	6.2	13.77	6.5	21.9	M
BE23	1.8	8	18.37	8.5	19.41	5.6	16.33	7.5	29.6	M
BE24	2	9	11.46	6.7	8.34	1.8	32.00	8.6	26.1	M
BE25	1.7	8.5	6.96	4.8	9.53	1.9	26.33	8.4	23.6	M
BE26	1.68	6	2.77	2	5.23	1.3	41.67	9	18.3	L
BE27	1.2	2	4.23	1.7	4.80	1.2	73.00	9.5	14.4	L
BE28	1.2	2	8.58	5.1	9.74	1.8	20.38	8.4	17.3	L
BE29	1.2	2	4.66	3.3	5.29	1.4	20.52	8.4	15.1	L
BE30	1.2	2	8.28	5.1	9.40	1.7	12.17	6.2	15	L
BE31	1.08	1	8.24	4.9	18.74	5.5	10.11	6.1	17.5	L
BE32	1.2	2	6.86	4.7	7.60	1.8	18.13	7.6	16.1	L
BE33	1.5	5	6.03	4.6	3.62	1.3	33.58	8.8	19.7	L
BE34	1.2	2	5.81	3.4	2.64	1.2	39.50	8.9	15.5	L
BE35	1.15	3	3.33	2.9	4.14	1.5	24.64	8.5	15.9	L
BE36	0.15	0	9.64	5.6	11.87	2.3	11.25	6.3	14.2	L
BE37	0.9	0	2.97	2.8	7.92	1.9	15.20	7.4	12.1	L
BE38	0.7	0	10.61	6.1	20.81	6.1	8.08	5.8	18	L
BE39	1.3	3	6.76	4.6	4.88	1.6	15.42	6.5	15.7	L

Table 5: Result of anthropogenic disturbance.

Sample station	Average values AD	AD ratings	Hazard level
BE1	10.7	4	M
BE2	11.7	4	M
BE3	11.0	4.5	M
BE4	3.0	2	L
BE5	11.3	4	M
BT6	7.5	3	L
BE7	9.6	3.5	L
BE8	18.8	7.2	H
BE9	8.3	3	L
BE10	4.2	2	L
BE11	6.7	3	L
BE12	10.0	4	M
BE13	12.5	5.5	M
BE14	15.0	6	H
BE15	12.3	4.6	M
BE16	10.0	4	M
BE17	14.3	5	M
BE18	9.3	3.5	L
BE19	7.1	3	L
BE20	13.3	5.8	M
BE21	12.5	5.5	M
BE22	8.8	3.2	L
BE23	12.3	3.2	L
BE24	11.9	5	M
BE25	14.4	5.5	M
BE26	15.0	6	H
BE27	16.9	6.5	H
BE28	15.0	6	H
BE29	15.0	6	H
BE30	16.1	6.2	H
BE31	14.7	5.8	M
BE32	12.3	4.8	M
BE33	12.7	4.8	M
BE34	13.7	5	M
BE35	13.7	5.5	M
BE36	16.0	7	H
BE37	16.3	7	H
BE38	17.0	7.5	H
BE39	17.7	7.5	H

BANK EROSION AND LATERAL INSTABILITY HAZARD STATUS

Above mentioned four major parameters namely BEHI, NBSI, LIHI, AD were combined to prepare the BELI hazard map (Fig. 8) of the Kodku Khola. This shows that the river has moderate to high hazard level except in one sample station (BE4) near Badikhel. The stream bank with high hazard are observed near Taukhel (BE12, BE15), Gorge (BE18), Thaiba (BE20), Dashghare (BE23), Harishidhi (BE25, BE28, BE29, BE30) and downstream from Los Angel School (BE33, BE36, BE37, BE38, BE39). The remains out stations indicate the stream banks are moderately hazardous (Table 6, Figs. 8 and 9).

Table 6: Result of the bank erosion and lateral instability hazard.

Locations	Distance	AD	BEHI	LIHI	NBSI	BELI	Hazard
BE1	0.65	4	13	22.2	8.55	48.2	M
BE2	1.15	4	13	23.7	8.2	49.7	M
BE3	1.71	4.5	21	13.8	9	48.3	M
BE4	1.9	2	17	12.8	9.1	40.8	L
BE5	1.96	4	31	13.1	9.2	57.1	M
BE6	2.08	3	18	15.3	9.2	45.3	M
BE7	3.29	3.5	18	21.5	9.5	52	M
BE8	3.75	7.2	23	22.2	8.8	61.4	M
BE9	4.32	3	21	17.1	9.1	50.1	M
BE10	4.44	2	33	21.3	9.3	65.3	M
BE11	4.5	3	31	21.7	9.3	64.7	M
BE12	4.57	4	37	20.3	9.18	70.3	H
BE13	5	5.5	23	26.4	9.2	63.9	M
BE14	5.06	6	24	23.7	9.02	62.7	M
BE15	5.17	4.6	36	26	9	75.6	H
BE16	5.37	4	24	26.5	8.1	63.5	M
BE17	6.12	5	30	20.8	9.01	64.8	M
BE18	7.05	3.5	36	19.6	9.4	68.1	H
BE19	7.15	3	12	20.5	9.01	44.5	M
BE20	7.25	5.8	45	22.7	9.01	82.5	H
BE21	7.32	5.5	30	17.8	9.03	62.3	M
BE22	8.02	3.2	20	21.9	9.3	54.1	M
BE23	8.52	3.2	33	29.6	9.6	74.8	H
BE24	9.02	5	21	26.1	9.3	61.1	M
BE25	9.55	5.5	35	23.6	9.04	73.1	H
BE26	10.16	6	24	18.3	8.5	57.3	M
BE27	10.56	6.5	36	14.4	9.7	65.9	M
BE28	10.71	6	41	17.3	9.2	73.3	H
BE29	10.85	6	44	15.1	8	73.6	H
BE30	11.2	6.2	42	15	8.4	71.6	H
BE31	11.83	5.8	30	17.5	8.9	62.3	M
BE32	12.38	4.8	34	16.1	9	63.9	M
BE33	12.94	4.8	38	19.7	9	71.5	H
BE34	13.56	5	28	15.5	9.3	57.5	M
BE35	14.11	5.5	35	15.9	9.1	65.4	M
BE36	14.74	7	39	14.2	9.4	69.2	H
BE37	15.39	7	38	12.1	9.3	66.1	H
BE38	15.93	7.5	36	18	9.02	70.5	H
BE39	16.49	7.5	34	15.7	9.01	66.2	H

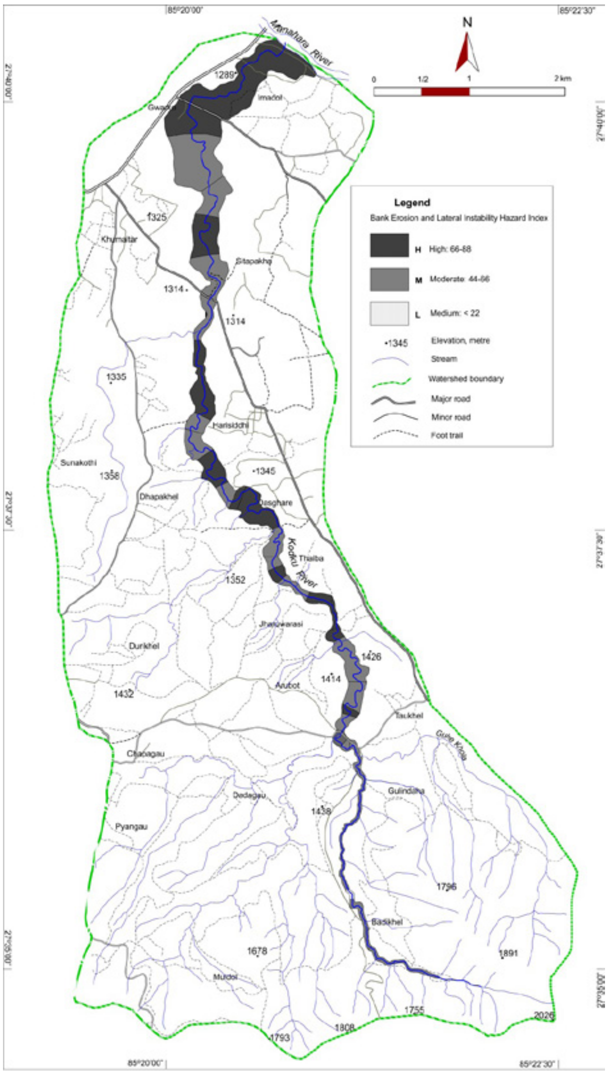

Fig. 8: BELI hazard status of the Kodku Khola.

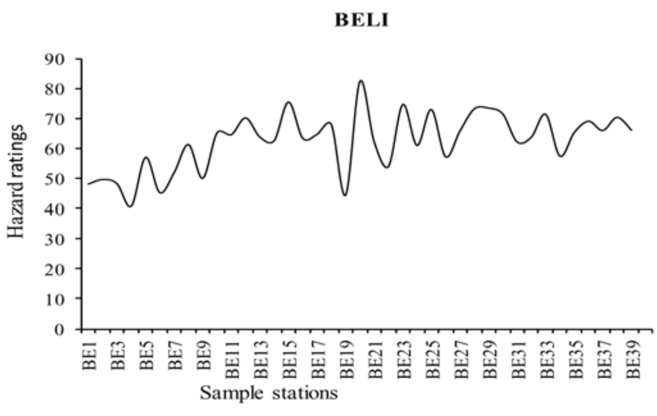

Fig.9: Bank erosion and lateral instability hazard map of the Kodku Khola.

CONCLUSIONS

The Kodku Khola falls in a moderate to high level of BELI hazard. The hazard level is found higher while moving from the upstream (Badikhel) to the downstream. BELI hazard level is moderate in the Majhgau, Badikhel and Taukhel areas. From Arubot to Los Angel School, the hazard levels fall in moderate to high level. The river has more hazardous in the Thaiba, Harishidi and Gwarko areas. BEHI and AD plays great roles for increasing the BELI hazard levels in the Kodku Khola. Minimising the hazard level of the Kodku Khola is very essential for the peoples, infrastructures around river corridors and to keep the river's natural beauty. Minimising the human disturbance such as by prohibiting channelisation, encroachments, direct sewage input and mining are best way to minimise the hazard levels in the Kodku Khola. To reduce stream bank erodibility, riparian vegetation buffer zones with suitable bioengineering measures should be established soon.

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