Journal of Nepal Geological Society, 1998, Vol. 18, pp. 309-318

Erosion and sedimentation problems in Nepal from the viewpoint of morphological development

Daisuke Higaki
Water Induced Disaster Prevention Technical Centre, Lalitpur, Nepal

ABSTRACT

Three cases of disasters such as landslides, debris flows and unstable river courses are presented from the viewpoint of morphological development in Nepal. In the Tukuche village in the Higher Himalaya, shallow landslides occur in moraine deposits covered with recent fluvial deposits promoting bank erosion of the Kali Gandaki River. The slope towards the river bank composed of Quaternary glacial deposits should be noticed as landslide-prone areas in this region.

Alluvial fans are less developed and widths of river courses are larger on the rivers originating from the Upper Siwaliks than those from the Middle/Lower Siwaliks in the eastern Churia hills. Because material size produced from hill slopes is smaller in the former case than the latter case, less tractive force by river stream can transport river bed materials and erode river banks. Consequently, the river topography is altered dramatically. River course control works are very important for the former case. Countermeasures for the torrents affected by debris flows in 1981 are also discussed in this paper. Distribution and volume of unstable deposits depend on the stage of morphological development of a torrent watershed. Analysis of morphological development was carried out on the basis of mapping and volume estimation of unstable deposits on the slopes and valley floors in two torrent watersheds of the Nallu Khola in the Mahabarat Range.

INTRODUCTION

Erosion and sedimentation processes often create disasters in mountanious countries. Types and scales of these morphological processes are usually controlled by topography, geology and its structure, which are the consequence of the past development of geological/geomorphological formations. Therefore, analysis of disaster phenomena and planning/designing of countermeasures against erosion and sedimentation problems should be based on geohistorical analysis of the target area (Higaki and Yoshida, 1996). Especially, investigation on Quaternary morphological development, which is often affected by neotectonics and climatic changes, plays an important role in assessment of hazards due to erosion and sedimentation in the mountainious countries like Nepal.

Mountain hazard mapping as well as analysis of various types of disasters have been carried out in this context in Nepal (Fort, 1987; Bichsel et. al., 1985; Saijo et.al., 1991). In this paper, not only causes of disastrous phenomena but also basic concept of countermeasures are discussed for three cases located in different physiographic areas of Nepal (Fig. 1) from the viewpoint of morhological development.

BANK UNDERCUTTING IN TUKUCHE VILLAGE, MUSTANG IN HIGHER HIMALAYA

The Tukuche village located at the right bank of the Kali Gandaki River in the western central part of Nepal has been suffering from serious bank erosion, because the braided river with heavy sediment load forms wide flood plain and frequently changes its course (Fig. 2). Shallow rotaional slides due to toe cutting by the river also occur along the river bank even on very gentle slopes (< 5°) between the river and the lower river terrace surface on which

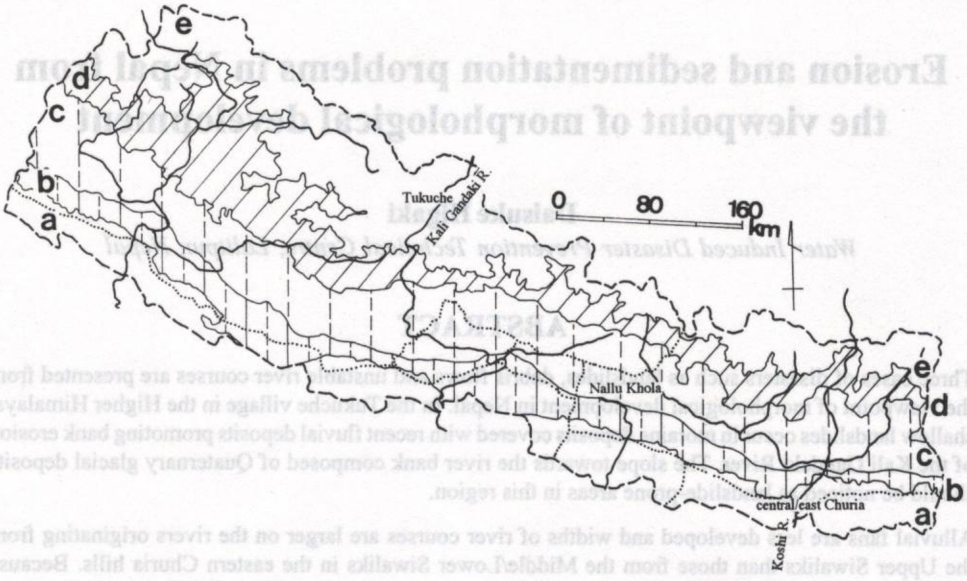

Fig. 1: Physiographic regions and study areas (modified after WECS, 1987) Tukuche, Nallu Khola, central/east Churia, Koshi River, Kali Gandaki River. Legend: a: Terai Plain, b: Siwalik(Churia) hills, c: Middle mountains, d: High mountains, e: Higher Himalaya Kali Gandaki River. Landslide Mound, Lower terrace, Moraine Topography, southwest part of Trijuga river basin ,Topography of the east side of Dharan Landslide, Debris flow deposits, and Alluvium Torrent Numbering are same as in table.

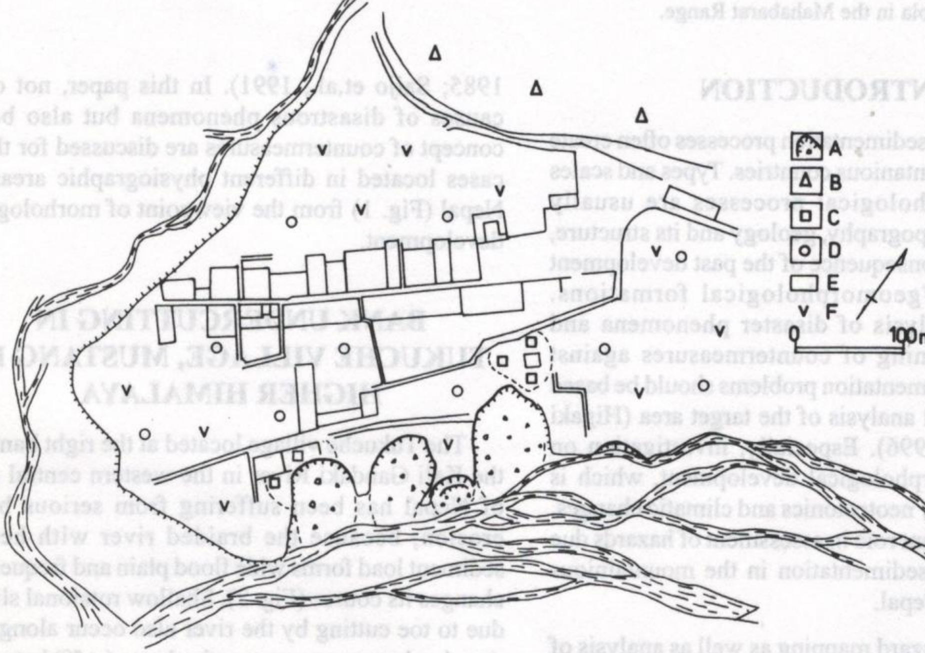

Fig. 2: Topograhy of Tukuche village. Legend: A: Landslide, B: Morainic hill, C: Mound, D: Lower river terrace, E: house, F: Cultivated land.

the Tukuche village is standing. Loose slid materials are easily washed away by stream. Since this village has long history of trade between Nepal and Tibet and now important function for tourism, it has to be protected from the erosion problems. As the surrounding steep slopes of the village are composed of the Palaeozoic schists prone to slumps and debris flows with limestones, flood and lateral erosion by river stream were pointed out to be major hazards along the Kali Gandaki River (Fort, 1987). Since this village is located at high altitude (2,600 m) and is surrouded by the Higher Himalayan Mountains, late Pleistocene glaciation could advance to the Kali Gandaki River and form morainic hills composed of clayey or sandy angular/sub-angular boulder deposits behind the village (Iwata,1984). These glacial deposits are considered to extend under the lower river terrace, where some isolated small hills can be found above the terrace surface and are composed of angular breccia or boulder with clayey matrix simlar to moraine deposits. Rotational soil slides which erode the lower terrace often occur in these deposits (Fig. 3).

These glacial deposits overlaid by lower fluvial terrace deposits can be a cause of landslides. Plenty of groundwater, which is indicated by many spring points in the sliding slopes, easily concentrates near the undulated boundary between moraine deposits with clayey matrix and loose gravelly ones of the river terrace due to the difference in permeability. Since these landslides have retrogressively expanded toward the terrace behind, toe protection works from river bank erosion and retaining walls to protect the head scarps of the landslides are proposed as appropriate countermeasures.

Minor slumps or debris slides/flows are common on cut slopes in moraines (Rib and Liang,1978). Some landslides along the Arniko Highway in central Nepal are considered possibly to originate in the Quaternary glacial deposits (ICIMOD, 1996). Since some landslides are found at the locaions geologically similar to the Tukuche village along the bank of the upper Kali Gandaki River, the land composed of glacial deposits of the Quaternary ice age accompanied with bank undercutting is landslide prone areas in the Higher Himalaya.

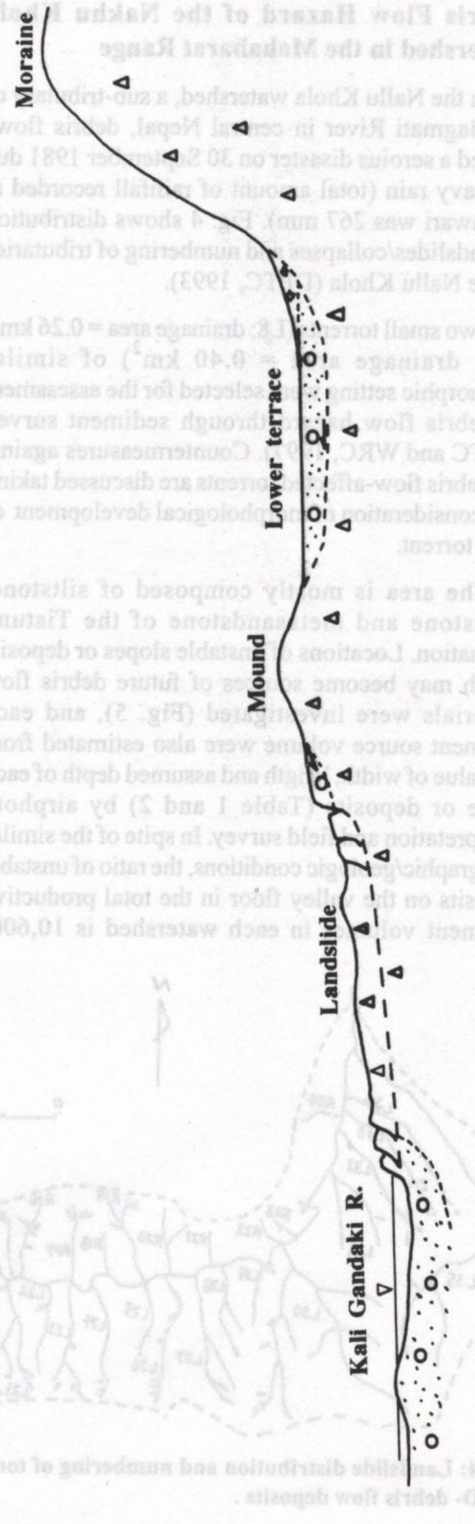

Fig. 3: Idealised section between morain hills and the Kali Gandaki River.

Debris Flow Hazard of the Nakhu Khola Watershed in the Mahabarat Range

In the Nallu Khola watershed, a sub-tributary of the Bagmati River in central Nepal, debris flows caused a seroius disaster on 30 September 1981 due to heavy rain (total amount of rainfall recorded at Godawari was 267 mm). Fig. 4 shows distribution of landslides/collapses and numbering of tributaries of the Nallu Khola (DPTC, 1993).

Two small torrents (L8: drainage area = 0.26 km^2, L11: drainage area = 0.40 km^2) of similar geomorphic setting were selected for the assessment of debris flow hazard through sediment survey (DPTC and WRC, 1997). Countermeasures against the debris flow-affected torrents are discussed taking into consideration of morphological development of each torrent.

The area is mostly composed of siltstone, sandstone and metasandstone of the Tistung Formation. Locations of unstable slopes or deposits which may become sources of future debris flow materials were investigated (Fig. 5), and each sediment source volume were also estimated from the value of width, length and assumed depth of each slope or deposits (Table 1 and 2) by airphoto interpretation and field survey. In spite of the similar topographic/geologic conditions, the ratio of unstable deposits on the valley floor in the total productive sediment volumes in each watershed is 10,600/ 21,580 m^3 (49.1%) in L8 and 9985/70,420 m^3 (14.2%) in L11. This fact indicates not only the difference of sediment yield volume but that previous debris flow deposits remaining on the valley floor may contribute to future debris flow in L8 than L11.

Morphological development of the torrent L11 is at more progressive stage as gullies are more active and dissect the valley and the landslides/collapses and numbers of unstable slopes are more. Therefore, debris flow countermeasures is priotised higher at L11 than L8 based on the difference in the total possible sediment yield. Rehabilitaion works for the debris flow-affected torrents can be classified into protection of unstable slopes, prevention of secondary movement of previous debris flow deposits and check or control of future debris flow in the downstream part (Ikeya, 1980). More emphasis should be given to stabilisation of previous debris flow deposits on the valley floor at L8 than L11 depends on the difference of morphological deveopment stage. Channel works and check dams to control down-cutting and side erosion of existing debris flow deposits by the stream are proposed for that purpose.

Unstable River Courses and Bank Erosion in Churia hills

The Churia hills are composed of mollassic sedimentary rocks of Miocene-Pleistocene. The

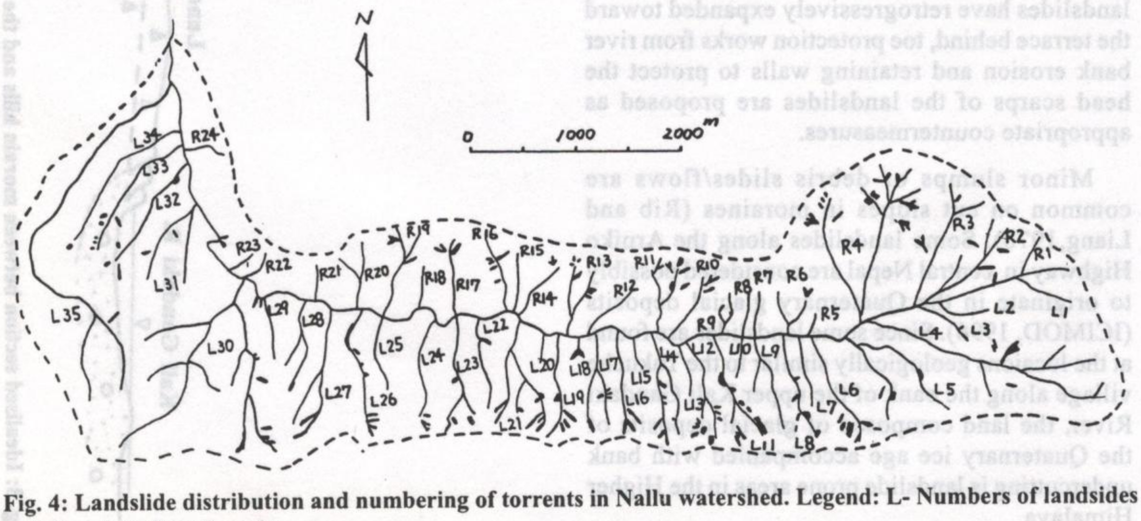

Fig. 4: Landslide distribution and numbering of torrents in Nallu watershed. Legend: L- Numbers of landsides and D- debris flow deposits .

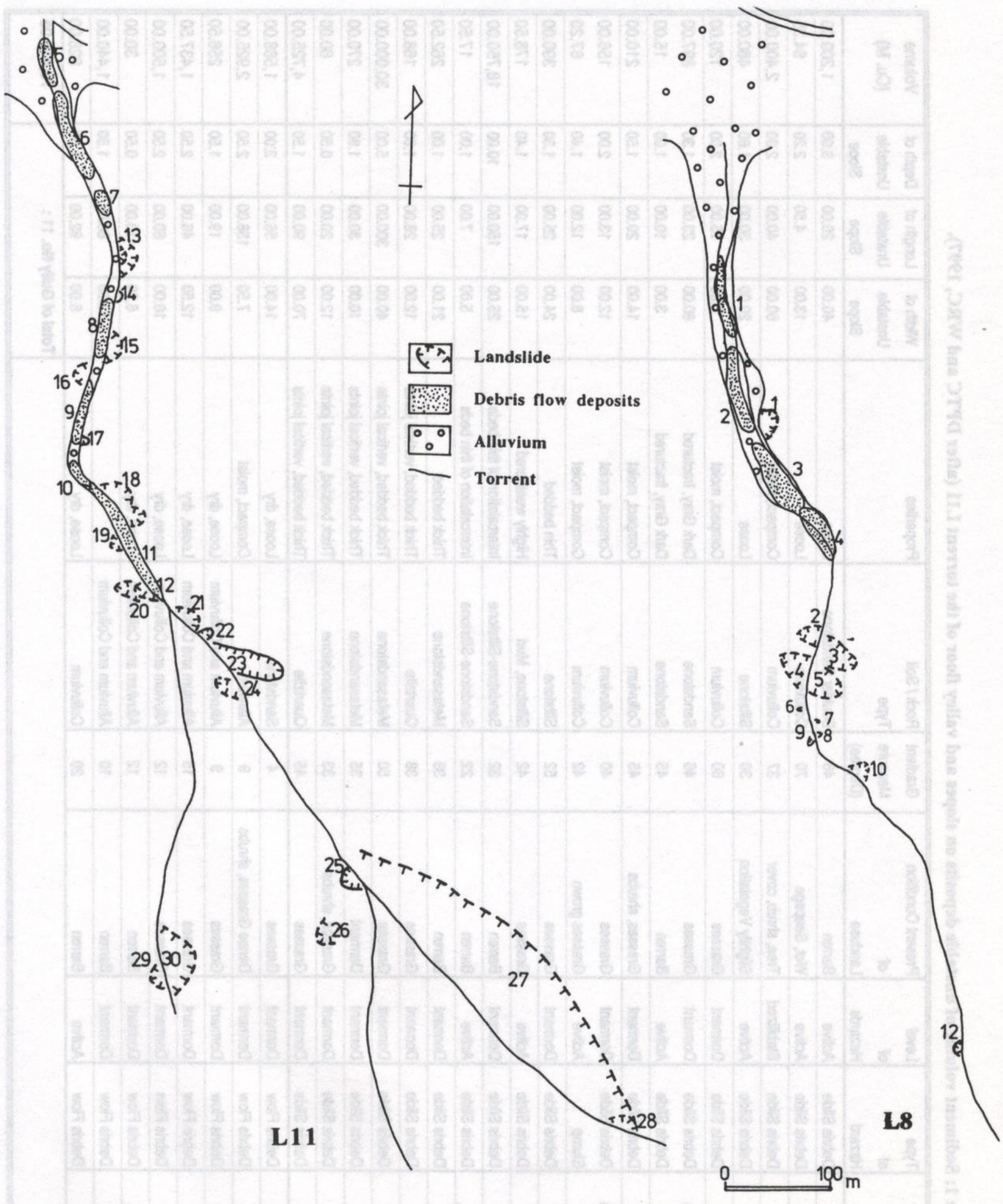

Fig. 5: Distribution of unstable slopes and deposits in the drainage areas of L8 and L11.

Table 1: Sediment volume of unstable deposits on slopes and valley floor of the torrent L11 (after DPTC and WRC, 1997).

Item No.	Type of Hazard	Level of Hazards	Present Condition of Landuse	Gradient Measure (Degree)	Rock / Soil Type	Properties	Width of Unstable Slope	Length of Unstable Slope	Depth of Unstable Slope	Volume (Cu. M)
L13	Debris Slide	Active	Barren	46	Boulder Sandstone	Loose	40.00	20.00	3.00	1,200.00
L14	Debris Slide	Active	Wet, Seepage	70	Colluvium	Loose	13.00	4.50	2.20	64.35
L15	Debris Slide	Stabilized	Tree, shrub, cover	37	Colluvium	Compact, moist	60.00	40.00	2.00	2,400.00
L16	Debris Slide	Active	Slightly Vegetation	30	Siltstone	Loose	20.00	30.00	1.60	480.00
L17	Debris Slide	Dormant	Grasses	60	Colluvium	Compact, moist	8.00	15.00	2.00	120.00
L18 A	Debris Slide	Dormant	Grasses	46	Sandstone	Dark Gray, fractured	60.00	23.00	1.30	897.00
	Debris Slide	Active	Barren	45	Sandstone	Dark Gray, fractured	3.00	10.00	1.00	15.00
L19	Debris Slide	Dormant	Grasses, shrubs	45	Colluvium	Compact, moist	14.00	20.00	1.50	210.00
L20 A	Debris Slide	Dormant	Grasses	40	Colluvium	Compact, moist	12.00	13.00	2.00	156.00
	Slump	Active	Grasses grown	42	Colluvium	Compact, moist	8.00	12.00	1.40	67.20
L21	Debris Slide	Dormant	Grasses	52	Siltstone	Thin bedded	24.00	25.00	1.30	390.00
L22	Debris Slide	Active	Grasses	42	Siltstone, Mud	Highly weathered	15.00	17.00	1.40	178.50
L23	Debris Slide	Dormant	Barren	32	Sandstone-Siltstone	Intercalation of thin beds	25.00	150.00	10.00	18,750.00
L24	Debris Slide	Active	Barren	22	Sandstone-Siltstone	Intercalation of thin beds	5.00	7.00	1.00	17.50
L25	Debris Slide	Dormant	Barren	38	Metasandstone	Thick bedded	21.00	25.00	1.00	262.50
L26	Debris Slide	Dormant	Grasses	38	Quartzite	Thick bedded, vertical joints	12.00	28.00	1.00	168.00
L27	Debris Slide	Dormant	Grasses	50	Metasandstone	Thick bedded, vertical joints	40.00	300.00	5.00	30,000.00
L28	Debris Slide	Dormant	Dormant	35	Metasandstone	Thick bedded, vertical joints	10.00	30.00	1.80	270.00
L29	Debris Slide	Dormant	Grasses, shrubs	33	Metasandstone	Thick bedded, vertical joints	12.00	20.00	0.50	60.00
L30	Debris Slide	Dormant	Grasses	45	Quartzite	Thick bedded, vertical joints	70.00	90.00	1.50	4,725.00
D5	Debris Flow	Dormant	Grasses	4	Sandstone	Loose, dry	14.00	56.00	2.00	1,568.00
D6	Debris Flow	Dormant	Dense Grasses, shrubs	9	Alluvium	Compact, moist	7.50	156.00	2.50	2,925.00
D7	Debris Flow	Dormant	Grasses	9	Alluvium and Colluvium	Loose, dry	9.00	19.00	1.50	256.50
D8	Debris Flow	Dormant	Grasses	15	Alluvium and Colluvium	Loose, dry	12.50	46.00	2.50	1,437.50
D9	Debris Flow	Dormant	Grasses	12	Alluvium and Colluvium	Loose, dry	10.00	60.00	2.50	1,500.00
D10	Debris Flow	Dormant	Barren	12	Alluvium and Colluvium	Loose, dry	6.00	10.00	0.50	30.00
D11	Debris Flow	Dormant	Barren	10	Alluvium and Colluvium		12.00	80.00	1.50	1,440.00
D12	Debris Flow	Active	Barren	20	Colluvium	Loose, dry	6.00	92.00	1.50	828.00
							Total of Gully No. 11 :			70,416.05

Table 2: Sediment volume of unstable deposits on slopes and valley floor of the torrent L8 (after DPTC and WRC, 1997).

Item No.	Type of Hazard	Level of Hazards	Present Condition of Landuse	Gradient Measure (Degree)	Rock / Soil Type	Properties	Width of Unstable Slope	Length of Unstable Slope	Depth of Unstable Slope	Volume (Cu. M)
L1	Debris Slide	Dormant	Grasses	38	Siltstone	Light gray highly Jointed	27.90	18.30	2.70	689.27
	Debris Slide	Active	Barren	36	Siltstone	Highly weathered	2.20	6.00	1.20	7.92
L2	Debris Slide	Dormant	Grasses	45	Metasandstone	Highly fractured	10.00	12.70	4.50	285.75
	Rock Fall	Active	Barren	45	Metasandstone	Highly fractured	2.50	6.00	1.50	11.25
L3	Slump	Dormant	Grasses	42	Metasandstone	Highly fractured	31.00	29.00	4.00	1,798.00
	Debris Slide	Active	Barren	42	Colluvium	Loose, moist	12.00	14.00	3.00	252.00
L4	Debris Slide	Dormant	Grasses	40	Siltstone	Thin bedded	47.00	56.00	3.00	3,948.00
	Rock Fall	Active	Barren	42	Siltstone	Thin bedded	14.80	12.50	1.50	138.75
	Rock Creep	Active	Barren	80	Siltstone	Thin bedded	12.00	17.30	2.00	207.60
L5	Debris Slide	Dormant	Grasses	40	Colluvium	Compact, moist	41.00	50.00	2.50	2,562.50
	Rock Fall	Active	Barren	30	Siltstone	Thin bedded	6.00	8.60	1.90	49.02
	Rock Fall	Active	Barren	45	Colluvium	Loose, dry	6.00	9.40	2.00	56.40
L6	Rock Fall	Active	Barren	30	Siltstone	Thin bedded	9.60	7.50	1.20	43.20
L7	Rock Fall	Active	Barren	45	Siltstone	Thin bedded	8.00	10.70	2.00	85.60
L8	Slump	Dormant	Grasses	35	Sandstone	Highly fractured	5.90	9.00	2.50	66.38
L9	Debris Slide	Dormant	Grasses	30	Colluvium	Compact, moist	12.00	10.00	2.00	120.00
L10	Debris Slide	Dormant	Grasses	80	Metasandstone	Thick bedded	21.80	37.00	1.50	604.95
L11	Land Creep	Dormant	Grasses, shrubs	70	Colluvium	Compact, moist	5.40	4.00	2.00	21.60
L12	Talus Creep	Active	Barren	35	Metasandstone	Thin bedded	8.40	6.40	1.00	26.88
D1	Debris Flow	Dormant	Barren	11	Pebble and boulder of siltstone, sandstone	Loose, dry	28.50	88.00	2.50	6,270.00
D2	Debris Flow	Dormant	Dense Grasses	13	Pebble and boulder of siltstone, sandstone	Loose, dry	24.00	68.00	1.50	2,448.00
D3	Debris Flow	Dormant	Dense Grasses	4	Pebble and boulder of siltstone, sandstone	Loose, dry	17.00	45.00	2.00	1,530.00
D4	Debris Flow	Dormant	Dense Grasses	7	Colluvium	Loose, dry	8.00	30.00	1.50	360.00
							Total of Gully No. 8 :			21,583.06

rocks of this zone are divided into the Lower, Middle and Upper Siwaliks. In the central to eastern region of Nepal, dominant rocks are mudstones and sandstones in the Lower and Middle Siwaliks and less consolidated conglomerates in the Upper Siwaliks (Herail et al., 1986).

The rivers originating from the Churia hills have been inducing problems of bank erosion and frequent river course changes in Terai plain and the inner Churia basins called Dun. They are flash type rivers and transport heavy sediment load produced from steep hill slopes with shallow soil (WECS,1987). Consequently, river coureses are mostly wide. However, according to the comparison of topography and widths of the rivers from the Lower/Middle Siwaliks and the Upper Siwaliks at the piedmont zone of the Chria hills, alluvial fans are less developed and width of river courses is larger in the former case. These differences are studied from the morphological development processes of the Siwaliks and piedmont areas.

Fig. 6 shows the typical difference of piedmont topography. The Upper Siwalik rivers (US) have not formed typical alluvial fans and are gentler in gradient than the Middle and Lower Siwalik rivers (MLS). Width of the US and MLS) is compared in the western Kamala River basin, eastern part of the Trijuga River basin and east side of Dharan (Fig. 1). Average width of a river course at sedimentation area where basement rocks and valley width do not affect river width are measured on the 1:25,000 topographical map.

The relation between drainage area (A) and river width (B) are discussed, as width of an alluvial river are correlative with drainage area as follows:

$$B = Q \text{ (Regime theory of Lacey, 1929)} \quad (1)$$

$$Q = kCIA \text{ (Rational formula)} \quad (2)$$

where B = river width

Q = bankfull discharge

I = rainfall intensity during the time of concentration

A = drainage(catchment) area

μ, k, C = coefficient

Fig. 7, which compares the rivers (US) and the rivers (MLS) indicates following facts:

1) Widths of the rivers (US) are higher correlative with drainage areas than the rivers (MLS).
2) Widths of the rivers (US) are larger than the rivers (MLS).

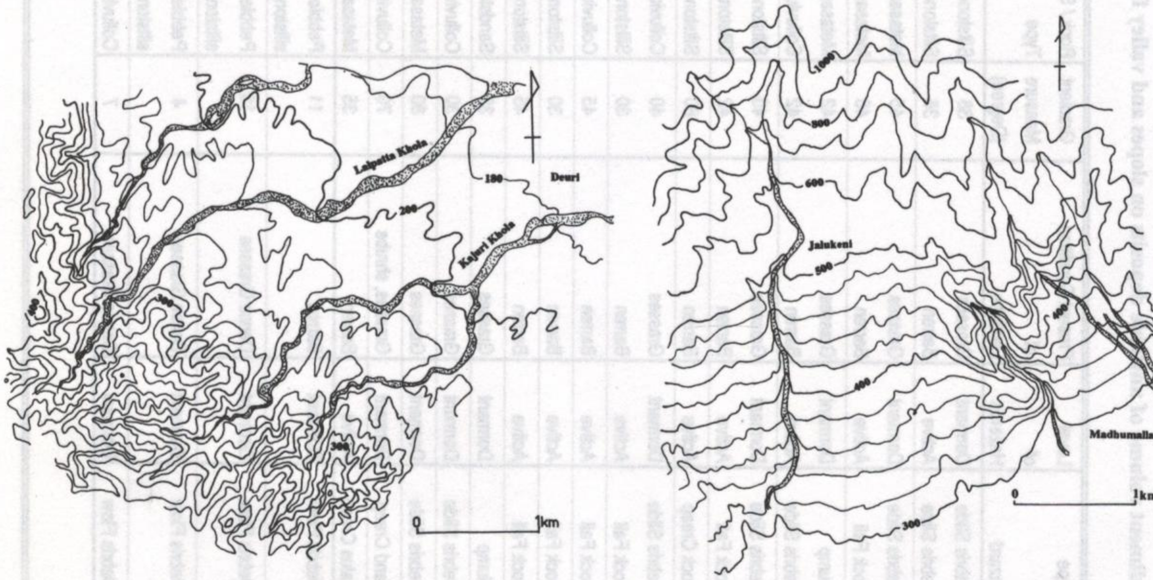

Fig. 6: Topography of (a) southwest part of Trijuga drainage basin(upper Siwaliks) and (b) east Dharan (lower Siwaliks). 180 200 300 400 Kajuri Khola Lalpatta Khola Deuri Churia hills, 300 400 500 600 800 1000 Madhumalla Jalukeni Sokhare.

Width of the rivers (US) is also larger than those of gravel/sand bed rivers in Japan. Ashida et al. (1975) suggested that of the formula (1) varies 3.5-7. For example at the downstream of the Kajuri Khola ($A = 6\ km^2$) flowing into the Trijuga River the river width varies 50-120 m. Since the bankfull discharge of this river is estimated to be 50 m^3/s by Manning's formula, the river width is expected only 25-50 m in case of Jthe apanese rivers which is twice smaller than that of the Kajuri Khola.

Since drainage basins of the rivers (US) are mostly composed of unconsolidated conglomerates interbedded by sand layers and terrace deposits of fluvial origin (Delcaillau et al,1987), size of the materials produced from the hill slopes is relatively smaller and more uniform than that of the rivers (MLS) which can produce sandstone boulders. The facts (1) and (2) and difference in alluvial fan formation can be explained by this defference as follows:

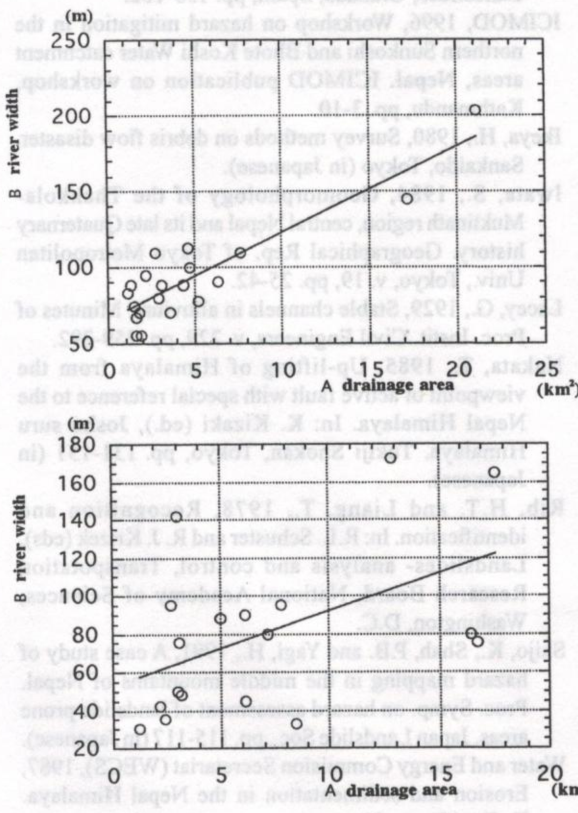

Fig. 7: Relation between width (B) and drainage areas (A) of the US and MLS rivers.

Alluvial fans are favourably developed at the foot of uplifted mountain/hills. Crustal movement along the frontal zone of the Churia hills is so active in the central-east Nepal (Nakata, 1985; Delcaillau et al., 1987) that alluvials fans are also expected for the rivers (US). However, the unconsolidated deposits of the Upper Siwaliks are highly erodable and even small tractive force by river stream can transport small size materials, and the gradient of riverbeds becomes smaller at both valley floors and piedmont areas. Consequently, alluvial fans are hardly developed on the rivers (US).

Similarly, river width is also controlled by erodibity of river banks (Yamamoto, 1996). Erodibity of the river bank deposits from the Upper Siwaliks is higher than that of alluvial fan deposits from the Middle/Lower Siwaliks, because former deposits are more rich in fine materials like sand/silt and gravels transported by sediment flow processes while big boulders can be produced and transported from the Middle/Lower Siwaliks. Hence, frequent bank erosion occurs and river width becomes wider in the rivers (US). Erosion control measures in the uppr catchment area and bank protection works in the downstream area are, therefore, necessary especially to control courses of the rivers (US).

CONCLUSIONS

Causes of different types of disastrous phenomena such as landslides, debris flows and unstable river courses are studied focusing on the morphological development of three studied areas (Tukuche, Nallu Khola, central-east Churia hills) from different physiographic condition in Nepal. Based on it concept of countermeasure planning are also discussed.

In the Higher Himalaya, the land composed of Quaternary glacial deposits, which is accompanied with recent river bankundercutting should be noticed as landslide prone areas, because clayey materials, which have rlatively low shear strength easily slide in case of less supporting mass at toe part. These deposits covered with more permeable layer can concentrate underground water flow between two layers. Therefore, morphological development due to Quaternary climatic changes are important for hazard assessment in high mountain areas in Nepal.

In the Nallu Khola watershed, basic concept of countermeasures for the debris flow-affected torrents are considered by investigating the distribution of unstable slopes or deposits and their volume in two torrent catchemnt areas (L8 and L11). The fact that the volume of unstable deposits are much larger and unstable debris deposits on the valley floor is less in the watershed of L11 than L8 indicates that the morphological development of the torrent L11 is at more progressive stage than L8. It also means that the L11 has more debris flow hazard. Therefore, priority of counermeasures are higher for L11, and more emphasis should be given to stabilisation of debris deposits on the valley floor for L8. Countermeasures should be considered based on the morphological development stage of a torrent.

Differences in alluvial fan formation and widths of rivers originating from the Churia hills are compared with the rivers from the Upper Siwaliks and those from the Middle/Lower Siwaliks. Since the Upper Siwaliks are composed of highly erodable unconsolidated conglomerates, materials produced from there are so small in size that they are easily transported to downstream even on very gentle riverbeds. On the other hand the Middle/Lower Siwaliks can produce boulders which make rivers steeper in gradient and alluvial fans are easily formed. Erodibility of river bank deposits are also higher along the rivers from the Upper Siwaliks. Therefore, frequent bank erosion occurs and river course becomes wider in the rivers from the Upper Siwaliks.

REFERENCES

Ashida, K., Takahashi, T. and Mizuyama, T., 1975, Hydraulic study on planning of channel works. Shin-sabo Jour. Japan Erosion Cotrol Soc., v. 97, pp. 9-16.

Bichsel, M., Grunder, M., Kienholz, H. and Mool, P., 1985, Mountain hazards and slope stability, Kathmandu-Kakani area, Nepal in 1:10000. UN Univ., Mountain Hazard Mapping Project map No. 4.

Delcaillau, B., Herail, G. and Mascle, G., 1987, Evolution geomorphostructurale de fronts de chevauchement actifs: le cas des chevauchements intrasiwaliks du Nepal central. Zeit. Geomorph., v. 31, pp. 339-360.

DPTC, 1993, Review of 1981 flood/debris flow in the Nakhu Khola basin in central Nepal. 15 p.

DPTC and Water Resources Consult (P.) Ltd. (WRC), 1997, Study and mapping of unstable slopes and estimation of sediment volume in the gully 8 and 11 of the model site of the Nallu Khola. Unpubl. Report, Lalitpur, Nepal, 18 p.

Fort, M., 1987, Geomorphic and hazard mapping in the dry, continental Himalaya: 1:50,000 maps of Mustang district, Nepal. Mountain Research and Development, v. 7, pp. 222-238.

Herail, G., Mascle, G. and Delcaillau, B., 1986, Les Siwaliks de l'Himalaya du Nepal: un example d'evolution geodynamique d'un prisme d'accretion intracontinental. Livre Jubilaire P. Bordet, Les orogenes de l'Asie du Sud-est. Mem. Sc. de la Terre, No. 47, pp. 155-182.

Higaki, D. and Yoshida, K., 1996, Geological structure and movement of landslide slopes from the viewpoint of slope evolution processes. Proc. of the eighth International Conference and Field Workshop on Landslides, Granada, Spain, pp. 153-162.

ICIMOD, 1996, Workshop on hazard mitigation in the northern Sunkoshi and Bhote Koshi Water catchment areas, Nepal. ICIMOD publication on workshop, Kathmandu, pp. 3-10.

Ikeya, H., 1980, Survey methods on debris flow disaster. Sankaido, Tokyo (in Japanese).

Iwata, S., 1984, Geomorphology of the Thakkola-Muktinath region, central Nepal and its late Quaternary history. Geographical Rep. of Tokyo Metropolitan Univ., Tokyo, v. 19, pp. 25-42.

Lacey, G., 1929, Stable channels in alluvium. Minutes of Proc. Instit. Civil Engineers, v. 229, pp. 259-292.

Nakata, T., 1985, Up-lifting of Himalaya from the viewpoint of active fault with special reference to the Nepal Himalaya. In: K. Kizaki (ed.), Josho suru Himalaya. Tukiji Shokan, Tokyo, pp. 131-151 (in Japanese).

Rib, H.T. and Liang, T., 1978, Recognition and identification. In: R.L. Schuster and R. J. Krizek (eds). Landslides- analysis and control, Transpotation Research Board, National Academy of Sciences, Washington, D.C.

Saijo, K., Shah, P.B. and Yagi, H., 1991, A case study of hazard mapping in the middle mountains of Nepal. Proc. Symp. on hazard assessment of landslide prone areas. Japan Landslide Soc., pp. 115-117 (in Japanese).

Water and Energy Commision Secretariat (WECS), 1987, Erosion and sedimentation in the Nepal Himalaya. Kefford Press, Singapore.

Yamamoto, K., 1994, Chuseki kasen gaku (Alluvial river science). Sankaido, Tokyo, 470 p. (in Japanese).