

# River degradation problems along the Bishnumati River corridor in the Kathmandu Basin

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## ABSTRACT

River channel scouring, bank erosion, dilution of riparian vegetation, contamination of river by waste disposal are the major problems in the Bishnumati River corridor. To access potential factors contributing river degradation, and to identify severely degraded reaches and impacts on these, the Bishnumati River was selected for pilot study. Basinwide morphometric parameters, fluvial morphology, sedimentology, hydraulic parameters and surface water quality were analyzed. Four segments; Bishnumatigau, Okhaltar, Mahadevtar and Tamsipakha from upstream to downstream of the Bishnumati River corridor were studied in detail for their fluvial morphological parameters, substrate sediments (level I and II), and existing stream condition (level III) of Rosgen's designation of classifying stream and identifying potential disturbing factors and impacts.

The Bishnumati River is sixth order perennial stream fed by spring and storm flows. Bishnumatigau, Okhaltar, Mahadevtar and Tamsipakha segments are classified as A4-, C4-, F5- and F4-type streams. Entrenchment ratio is less than 1.4 in Bishnumatigau, Mahadevtar and Tamsipakha segments. Bank height ratio of all the segments exceeds 1.5, and therefore they are vertically unstable. Okhaltar and Tamsipakha segments bear high values of meandering width ratio, bank erosion hazard index and bankfull width/ depth ratios, which suggest high risk of lateral accretion. Overall channel stability scoring places Bishnumatigau and Okhaltar segments in fair category, and other two segments in poor category. F-factor versus M-factor plots indicate that the Bishnumati River segments are in degrading state. Surface water quality diminishes abruptly in Tamsipakha segments and downstream segments. Domestic and industrial effluent discharges are responsible for affecting the water quality.

Potential disturbing factors are sediment excavation, channelization and damming, landuse changes, encroachment of river banks and vegetation clearing, discharge of effluents and garbage dumping. Fifth and sixth order streams are the most severely contaminated, degraded and impacted segments in the Bishnumati River corridor. Mitigative measures should be immediately implemented to rehabilitate river environment.

Key words: Bishnumati River, fluvial geomorphology, river environment, surface water quality, river degradation

## INTRODUCTION

Civilization in the Kathmandu Basin was associated with the holy rivers in the basin where many temples, religious structures and shelters were built up on and near the river banks. People depended largely on rivers for

domestic and agricultural purposes. With growing population and urbanization, river sediments have been excavated for building structures. With rapid urbanization during the last two decades, efficiency of exploiting river resources has increased tremendously. Unplanned building and encroachment,

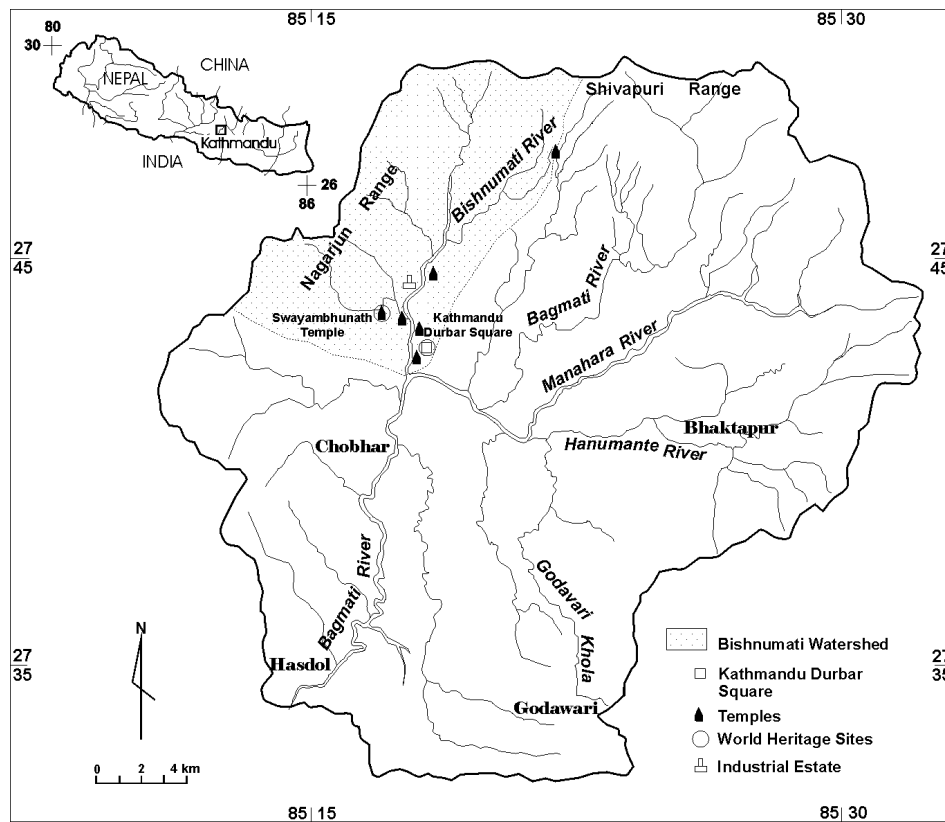


Fig. 1: Location map of the Bishnumati River basin in the northwest part of the Kathmandu Valley

vegetation clearing along the river banks, unwise mining of construction material from rivers, and waste disposal in rivers are thought to be disturbing activities in the Bishnumati and other rivers in the Kathmandu Basin (Fig. 1).

Generally, riverflow tends to maintain a dynamic equilibrium. Sediment load and size tend to balance stream discharge and slope (Lane, 1955). If one of these variables alters, the adjustment in other variables is required to maintain the balance. Any activity which affects the balance may bring about several consequences. The Bishnumati River is one of the severely affected rivers, in the Kathmandu Basin. Some of the major problems which are faced by the river are alteration of its morphologic features, flow regime, scouring

of river bed, erosion of banks, dilution of riparian vegetation zone, contamination of river from effluent and solid waste directed towards the river. Inadequate sewerage, on-site sanitation, and wastewater treatment facilities as well as discharging industrial and domestic effluents and dumping solid wastes are some of the severe causes of environmental degradation of the Bishnumati River (Shrestha et al., 2002).

Disturbances in river corridor can be both natural and man-induced and consequently bring about system wide and local instabilities in the river system. Man-induced disturbances are quite evident along the Bishnumati River corridor, and if the river is disturbed in the present trend, the disturbance will aggravate system instability and will bring about

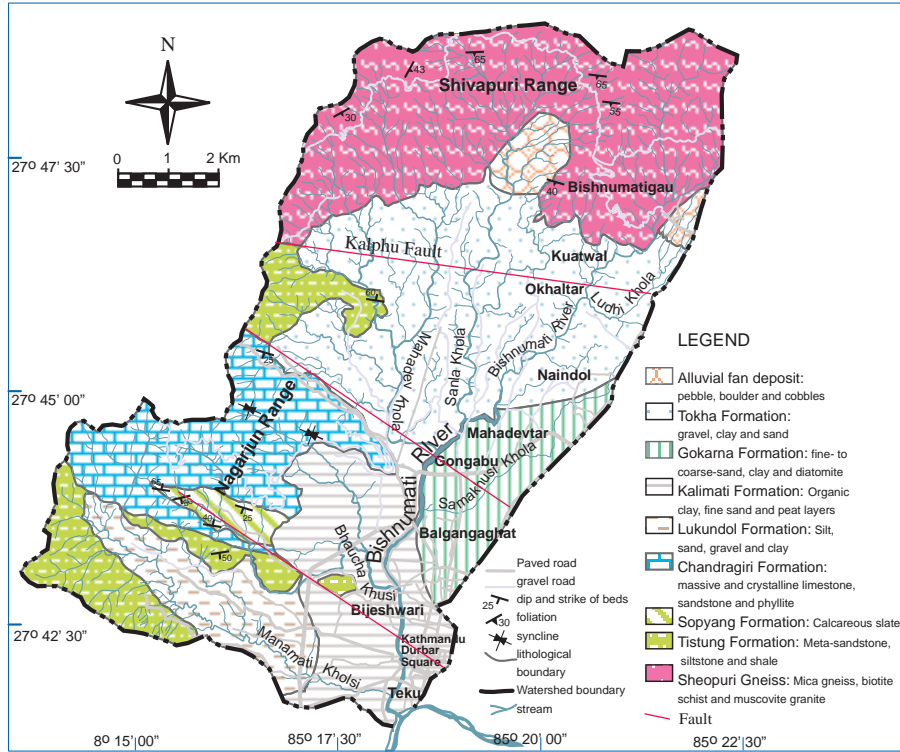


Fig.2: Geologic map of the Bishnumati River basin (compiled from Stocklin 1980; DMG 1998; Kalphi Fault after Arita et al. 1973)

unrecoverable deterioration to river environment. Therefore, it is necessary to identify problems and present status of the Bishnumati River corridor to rehabilitate the river in the future, because many people live around it and the two UNESCO world heritage sites, many temples, industrial estate and city's biggest bus park are also situated nearby the river (Fig. 1). This study therefore, aims in surveying existing condition of the river, identifying disturbances and potential factors causing instabilities, severely degraded reach and tracing clues for rehabilitation.

### BISHNUMATI RIVER BASIN

The Bishnumati River basin is located in the northwest part of the Kathmandu Valley (Fig. 1). The basin is bounded in north and west by high relief mountains. The northern mountain is composed of Sheopuri Gneiss

(DMG, 1998) comprising mica gneiss, biotite schist, and muscovite granite (Fig. 2) and granitic gneiss, banded gneiss, and augen gneiss (Ohata, 1973). Foliation of rock outcrop extends roughly E-W and dips southwards. The western region is formed up of meta-sedimentary rocks (siltstone, sandstone, limestone, phyllite and schist) of the Phulchoki Group consisting of the Tistung Formation, Sopyang Formation, and Chandragiri Formation of Cambrian to Ordovician periods (Stocklin, 1980). The central, southern and eastern regions of the river basin are occupied by fluvio-lacustrine sediments (silt, clay, sand and gravel) of the Pleistocene to Recent epochs (Yoshida and Igarashi, 1984; Dongol, 1985; DMG, 1998). The Recent alluvial flood plain deposits compose stratified sand, gravel and clay. Two large fans originate from the southern face of the Shivapuri Range. These fans contain angular mega gravel, gravel, sand and clay mixtures which overlie

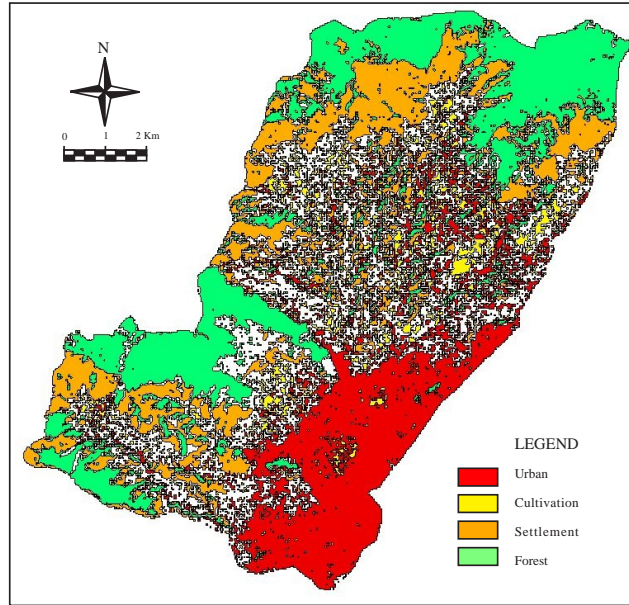


Fig. 3: Landuse landcover map of the Bishnumati watershed

Sheopuri Gneiss and in some part fluvio-lacustrine sediments. Three major lineaments extend NW-SE, in northern, central and southern parts of the Bishnumati watershed area (Fig. 1). These lineaments are responsible for vertical dislocation.

### Drainage

The summit of the Shivapuri Range forms the highest elevation (2300 m) and the flood plain in Teku forms the lowest land (1280 m). The Shivapuri and Nagarjun ranges pose steep sloped high lands while the central, southern and eastern regions produce flat and wide flood plains and older terraces (Fig. 2).

The Bishnumati River originates in the northwest of the Kathmandu Valley and flows southwards confluencing the Bagmati River at Teku. The drainage area contributing third, fourth, fifth and sixth order segments of the Bishnumati River are respectively 5.09 sq. km, 10.78 sq. km, 18.33 sq. km, and 67.89 sq. km. The total drainage area of the Bishnumati River is 102.09 sq. km. The Sanla and Mahadev

kholas (5th order) originate from the Shivapuri Range whereas the Baucha Khushi and Manamati Kholasi originate from the Nagarjun Range. Few tributaries such as Ludhi Khola and Samakhushi Khola originate from the fluvio-lacustrine terraces. All these rivers contribute the Bishnumati River and produce a dendritic pattern.

### Population and household

Total population of the Bishnumati River watershed during 1991 and 2001 were 225681 and 170854, respectively. Total household during 1991 and 2001 were 45889 and 85586 respectively. Population and household increment was about 40% in Kathmandu municipality alone. Increase of these in Gongabu and Manamaiju areas (river areas) is also remarkable.

### Landuse

Considering the watershed, urban, cultivation, settlement and forest lands cover 18%, 6%, 16% and 22%, respectively. Patches

of forest distribute in National Park (Shivapuri) and reserved forest (Nagarjun Range) (Fig. 3). A huge patch of urban areas locates in the southern part. The central, southern and eastern regions show mosaics of settlements, urban, cultivation, forest and unclassified lands (Fig. 3). Proportion of urban and settlement areas increase noticeably in the regions that contribute sixth order segment of the Bishnumati River.

### **Hydro-meteorology**

Yearly and monthly discharges recorded during 1969-1985 in Budhanilkantha station (DHM, 1998), located in the northern part of the Bishnumati watershed, were analysed. The yearly extreme maximum discharge varied between 1.04 and 3.40 m<sup>3</sup>/s. The yearly extreme minimum discharge remained below 0.028 m<sup>3</sup>/s. The monthly average maximum discharge was greatest in August (3.40 m<sup>3</sup>/s) and least in February (0.024 m<sup>3</sup>/s) during 1965-1985.

The maximum and minimum average monthly rainfall were respectively 559 mm (July) and 8.65 (November) during 1987-2003. Generally, June, July and August experienced high rainfall. November, December and January experienced low rainfall. The total monsoonal rainfall (1987-2003) was slowly increasing. Therefore, the discharge should have also increased at present.

Monthly means of maximum and minimum temperatures recorded during 1987-2003 exhibited somewhat constant range. Averages of mean-maximum and that of mean-minimum temperature ranged from 17.3 to 27.4°C and 3.8 to 19.7°C, respectively. June, July, August and September possessed high temperature whereas December, January and February possessed low temperature. Temporal variation of maximum and minimum

temperatures in January and July during year 1987-2003 was almost constant and varied within 5°C.

### **MORPHOMETRIC PARAMETERS**

The Bishnumati River is a sixth order stream (Fig. 4a) having a total length of 18.4 km. First to sixth order stream segments of the Bishnumati River corridor extending from Bishnumatigau to Teku have lengths respectively 0.19 m, 0.92 m, 2.32 m, 8.03 m, 0.77 m and 6.17 m. The river shows a meandering pattern.

Isopach maps of drainage texture, relative relief and dissection index of the Bishnumati River basin are shown (Fig. 4b, 4c and 4d). Drainage texture (calculated using equation of Singh, 1981) varies from 0.25 to 8.00. Relative relief (Singh, 1999) ranges from 8 to 560. Dissection index, which is a ratio of relative relief to absolute relief (Singh, 1999), varies between 0.001 and 0.280, and is extremely low to moderate (Fig. 4d). Shivapuri and Nagarjun ranges possess fine drainage texture, high relative relief and moderate dissection index. The southeastern fluvio lacustrine terrain possesses extremely coarse drainage texture, extremely low relief and low dissection index.

Four stream segments (third, fourth, fifth and sixth orders) which were analyzed for pattern yielded parameters as shown in Table 1. Meander wavelength, belt width and radius of curvature are highest for 6th order stream followed by fourth, fifth and third order segments. Considering sinuosity (K), the fourth order segment is more sinuous compared to other segments which bear more or less same sinuosity values. However, all the segments exhibit meandering pattern.

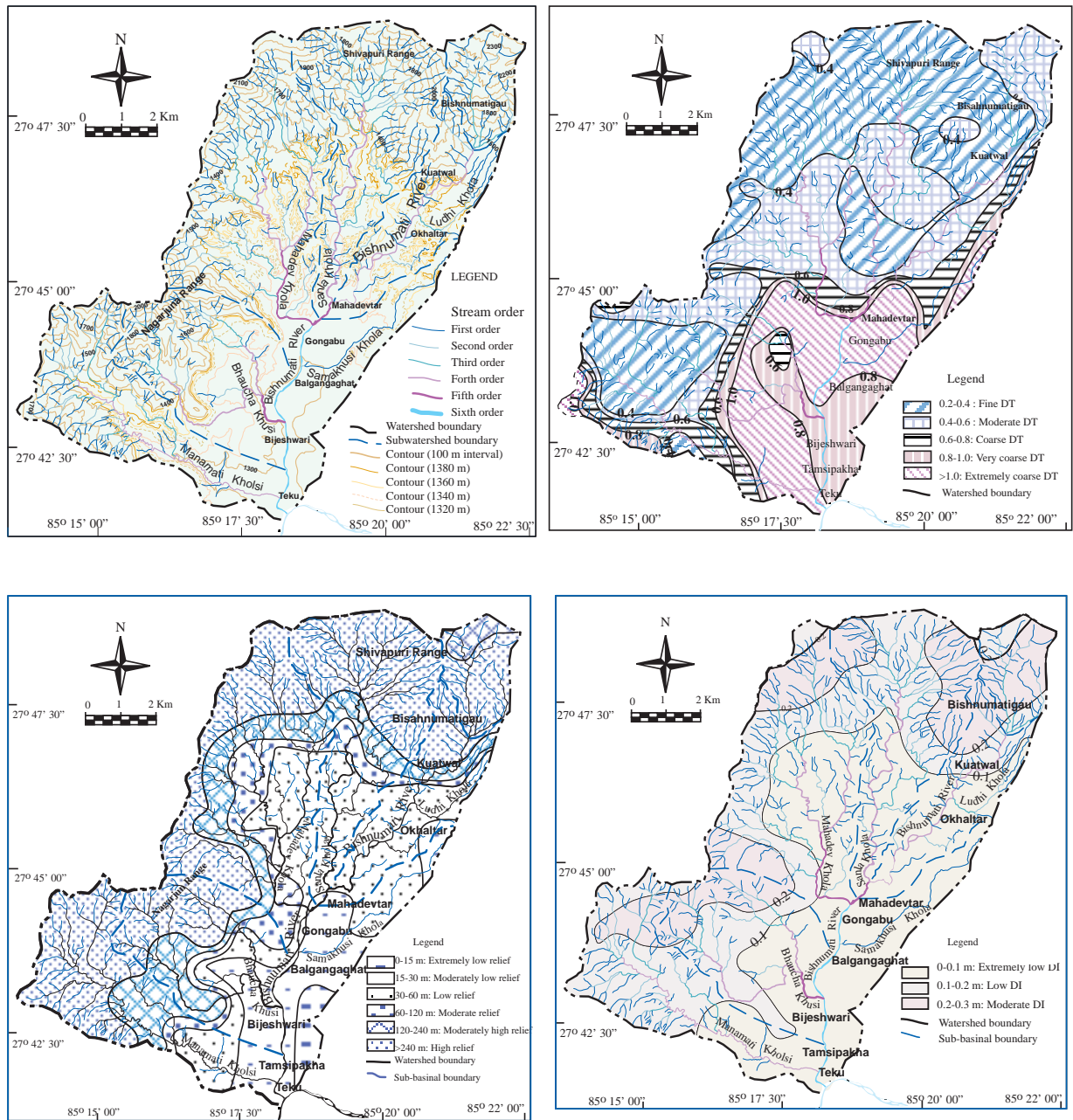


Fig. 4: Isoleth maps showing morphometry of the Bishnumati River basin; (a) Topography and drainage, (b) Drainage texture, (c) Relative relief and (d) Dissection index

## MORPHOLOGIC FEATURES

Segments such as Bishnumatigau, Okhaltar, Mahadevtar and Tamsipakha belonging to third, forth, fifth and sixth order streams, respectively were surveyed for morphological parameters, substrate characteristics and stream condition.

Morphologic parameters were derived using dimensional data obtained from cross-sectional analysis of stream segments and measurement from topomap. Both riffle and pool were surveyed and measured using Abney level, staff and tape. Four to six cross-sections were traversed in each stream segment of the Bishnumati River corridor. Cross-sections of

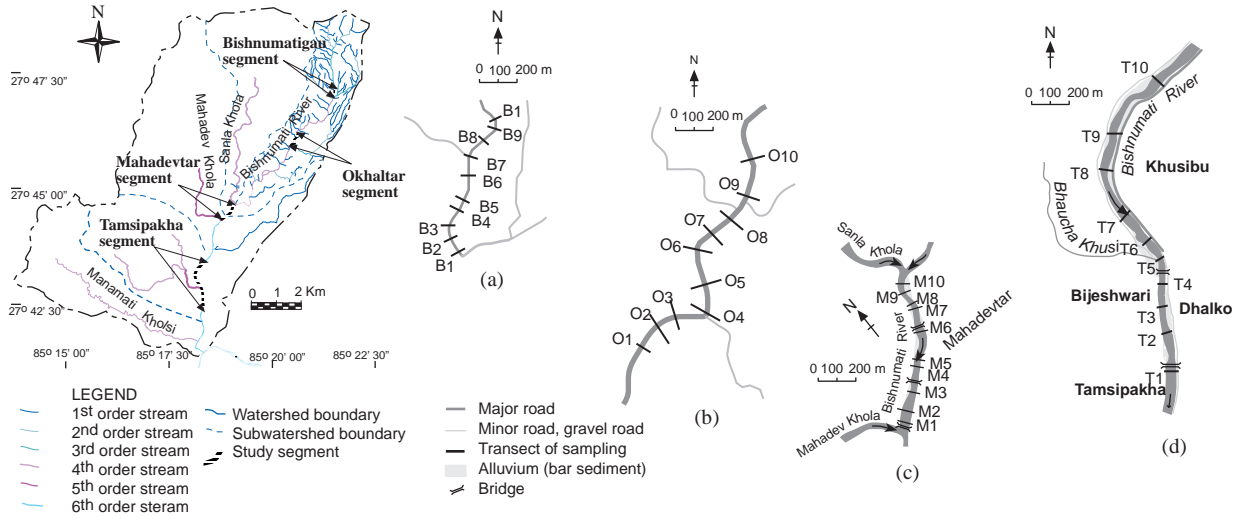


Fig. 5: Location of study segments; (a) Bishnumatigau segment, (b) Okhaltar segment, (c) Mahadevtar segment and (d) Tamsipakha segment. B1 to B10, O1 to O10, M1 to M10 and T1 to T10 represent transects.

Bishnumatigau, Okhaltar, Mahadevtar and Tamsipakha segments are indicated in Fig. 5. Cross-sectional survey of riffles in each stream yielded data for calculating bankfull elevation, depth, width, area, height of bank, etc which were further used for calculating other dimensionless ratios. Morphologic parameters are shown in Table 1.

Mean bankfull elevation ranges between 0.83 m and 0.98 m. Maximum width at bankfull ( $W_{bkf}$ ) ranges between 6.08 m and 13.8 m, being lowest in Bishnumatigau segment and highest in Mahadevtar segment. Mean bankfull cross-sectional area ( $A_{bkf}$ ) varies from 3.52 m<sup>2</sup> to 7.37 m<sup>2</sup>, the highest in Mahadevtar segment and the lowest in Bishnumatigau segment. The mean of maximum depth of top of low bank ( $D_{TOB}$ ) ranges from 1.6 m (in Okhaltar segment) to 2.58 m (in Tamsipakha segment).

Entrenchment ratio (ER), which is the ratio of width of flood prone area to width at bankfull stage varies from 1.08 (in Mahadevtar segment) to 4.78 (in Okhaltar segment) and is less than 1.4 in all the three segments except

Okhaltar segment. Therefore, Bishnumatigau, Mahadevtar and Tamsipakha segments are entrenched segments.

W/D ratio ranges from 10.7 to 26.2, being lowest in Bishnumatigau segment and highest in Mahadevtar segment. Bank height ratio (BHR), the ratio of depth of top of bank to maximum depth at bankfull stage, for Bishnumatigau, Okhaltar, Mahadevtar, and Tamsipakha segments are 2.53, 1.79, 2.44, and 3.11, respectively. Mean BHR is relatively low in Okhaltar segment. Bank height in Mahadevtar and Tamsipakha segments have been increased by human activities such as waste dumping and road building along the river banks.

Means of maximum depth ratio, which is a ratio of maximum depth at bankfull to average depth at bankfull, from upstream to downstream segments are respectively 1.72, 1.41, 1.68 and 0.93. These show that mean maximum depth ratios gradually decrease downstream.

Mean pool area ranges from 3.01 sq. m to 6.45 sq. m being highest in Okhaltar segment

Table 1: Morphological data from segments of the Bishnumati River

Morphological data	Bishnumatigau			Okhaltar			Mahadevtar			Tamsipakha		
	min	max	mean	min	max	mean	min	max	mean	min	max	mean
<b>Riffle cross-section:</b>												
Bankfull x-section area, $A_{bkf}$ (m <sup>2</sup> )	2.20	4.75	3.52	3.59	6.53	4.89	5.28	8.55	7.37	3.26	10.7	6.98
Width at bankfull, $W_{bkf}$ (m)	4.00	7.70	6.08	5.50	11.50	7.67	8.80	15.7	13.8	6.4	15.30	10.9
Width flood prone area, $W_{fpa}$ (m)	5.50	9.00	7.68	12.6	77.8	36.8	11.7	22.6	19.1	9.7	16.50	13.1
Max. depth bankfull, $D_{max}$ (m)	0.90	0.95	0.98	0.87	0.90	0.89	0.90	0.90	0.90	0.80	0.85	0.83
Max depth top low bank, $D_{TOB}$ (m)	1.26	3.10	2.44	1.47	1.90	1.60	1.50	3.60	2.20	2.10	3.05	2.58
Mean depth at bankfull, $D_{bkf} = A_{bkf}/W_{bkf}$ (m)	0.51	0.72	0.58	0.56	0.75	0.64	0.46	0.60	0.54	0.51	0.51	0.51
Entrenchment ratio, $ER = W_{fpa}/W_{bkf}$	1.17	1.38	1.28	2.29	12.2	4.78	1.33	1.45	1.37	1.08	1.52	1.30
Width-depth ratio, $W/D = W_{bkf}/D_{bkf}$	7.27	15.2	10.7	8.09	20.3	12.2	14.7	33.9	26.2	12.6	30.0	21.3
Bank height ratio, $BHR = D_{TOB}/D_{max}$	1.33	3.33	2.53	1.67	2.11	1.79	1.67	4.00	2.44	2.63	3.59	3.11
Max. depth ratio, $D_{max}/D_{bkf}$	1.32	2.17	1.72	1.20	2.01	1.41	1.50	1.94	1.68	0.20	1.67	0.93
<b>Pool cross-section:</b>												
Pool area, $A_{pool}$	2.38	4.36	3.01	3.00	6.45	4.60	4.01	5.57	4.75	7.77	2.93	5.35
Pool width, $W_{pool}$	3.10	5.40	4.75	5.70	8.70	7.38	4.40	10.0	7.13	16.5	5.80	11.2
Pool max. depth, $D_{pool}$	0.90	1.10	0.95	0.90	1.00	0.94	1.10	1.40	1.23	0.80	0.80	0.80
Pool area ratio = $A_{pool}/A_{bkf}$	0.68	1.24	0.85	0.60	1.72	1.01	0.54	0.76	0.64	0.99	0.88	0.94
Pool width ratio = $W_{pool}/W_{bkf}$	0.51	0.89	0.78	0.76	1.25	0.93	0.32	0.72	0.52	1.08	0.91	0.99
Pool max depth ratio = $D_{pool}/D_{bkf}$	1.55	1.90	1.64	1.20	1.66	1.62	2.04	2.59	2.27	1.56	1.57	1.57
<b>Pattern survey:</b>												
Meander wavelength, $L_m$ (m)	70.0	480	167	240	850	100	230	240	235	340	1950	998
Radius of curvature, $R_c$	10.0	106	29.0	15.0	507	89.0	36.3	72.5	51.4	75.0	975	465.0
Meander wavelength ratio, $MLR = L_m/W_{bkf}$	12.2	83.5	29.0	13.0	111	31.3	16.6	17.4	17.0	31.3	180	92.0
Radius of curvature ratio, $R_c/W_{bkf}$	1.74	18.4	5.04	2.0	66.1	11.61	2.62	5.24	3.72	6.9	89.9	42.9
Belth width, $W_{blt}$ (m)			170			540			160			800
Meander width ratio = $W_{blt}/W_{bkf}$			29.6			70.4			11.6			73.7
Sinuosity, $K = L_{tw}/L_{valley}$ (m/m)			1.15			1.34			1.16			1.15
<b>Slope of channel:</b>												
$\Delta$ Elev (m)			60			10			20			10
Slope of channel, $S_{avg} = \Delta \text{ Elev}/L_{tw}$ (m/m)			0.133			0.008			0.004			0.005

and lowest in Bishnumatigau segment. Maximum pool depth varies from 0.80 m to 1.23 m and mean pool width from 4.75 m to 11.2 m. Pool width increases from upstream to downstream segments. Pool depth is relatively higher in Mahadevtar segment probably because of scouring of clayey channel bed. Pool area ratio is highest in Okhaltar segment. Pool width ratio and pool depth ratio are large in Tamsipakha and Mahadevtar segments, respectively.

Meander width ratio (MWR) of Tamsipakha and Okhaltar segments are of same magnitude (70.4-73.7), and that of Bishnumatigau segment is higher (29.6) than

that of Mahadevtar segment (11.6). Mahadevtar segment possesses low dimensionless ratios because of its confinement along the clayey substrate and banks, and also due to encroachments along the river banks.

The Bishnumati River shows concave up river profile (Fig. 6). Slope of the third order segment is 0.133 and of other segments is below 0.004. The river shows three knick points which exist between third and 4th order segment, 5th and 6th order segments and in Bijeswari area reach. Therefore, head cutting and disequilibrium condition are occurring towards third, 5th and upstream segment of the 6th order stream.

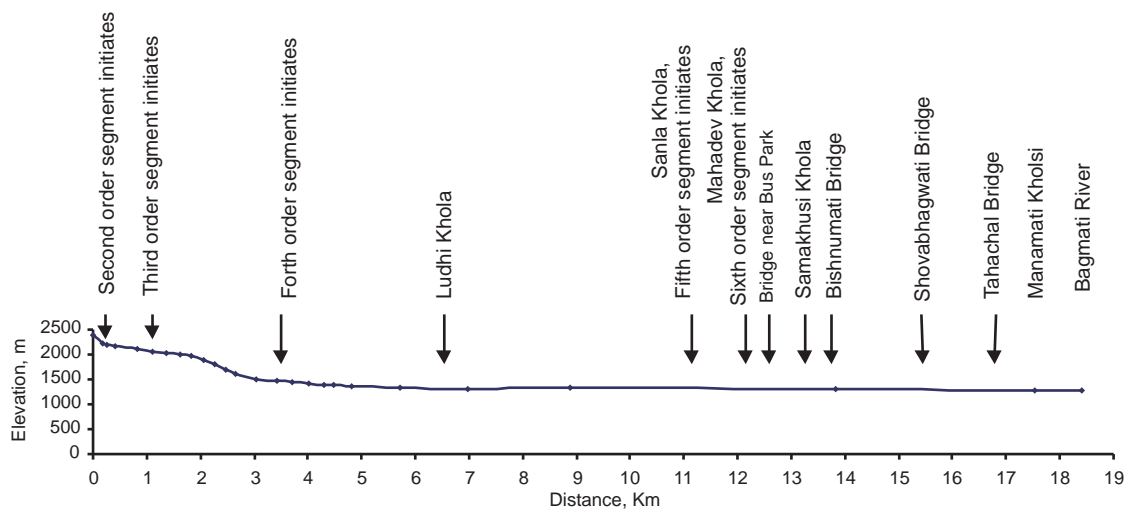


Fig. 6: Profile of the Bishnumati River

## SUBSTRATE CHARACTERISTICS

Ten transections in each of four segments of the Bishnumati River (riffle and pool) were traversed to obtain about 400 particles following the modified Wolman's (1954) method. A template of 1 phi intervals was used for measuring particle size. For the particles larger than 180 mm, a measuring tape was used for size determination. All the size measured are equivalent to intermediate diameter.

### Particle size distribution and statistical measures

Particle size distribution curves of Bishnumatigau segment indicate four distinct sub-populations, which are rolling and creeping, saltation, intermittent suspension, and suspension, respectively from coarse to fine size grades (Fig. 7). Plots of Okhaltar, Mahadevtar and Tamsipakha segments indicate three distinct sub-populations of which coarser and finer sub-populations are more well sorted while intermediate sub-populations are poorly sorted. The coarse sub-population travelled by saltation whereas intermediate sub-population as intermittent suspension (saltation plus suspension) and the fine sub-population

travelled as wash load. The plot of Mahadevtar segment although shows four segments, the intermediate poorly sorted segments are almost similar in transport mode.

The coarsest particle ( $d_{max}$  values) were obtained by extrapolating the curve representing coarse sub-population. The  $d_{max}$  is two to three times higher in substrate of Bishnumati segment compared to other segments (Table 2). Median particle size ( $d_{50}$ ) is high in Bishnumatigau segment (-4.8 phi) and Tamsipakha segment (-4.65 phi), whereas it is least in Mahadevtar segment (0.2 phi). The high  $d_{50}$  in the former is due to nearness of source rocks and in the latter can be due to contribution by the fifth order Mahadev Khola. All the samples show poor sorting according to the sorting categories of Folk and Ward (1957). Sediments of both Bishnumatigau and Tamsipakha segments are very finely skewed while those of Okhaltar segment is finely skewed, and Mahadevtar segment is coarsely skewed (Table 2). Median size and skewness parameters of Mahadevtar segment are anomalous and are due to excavation of sediments in upstream segment.

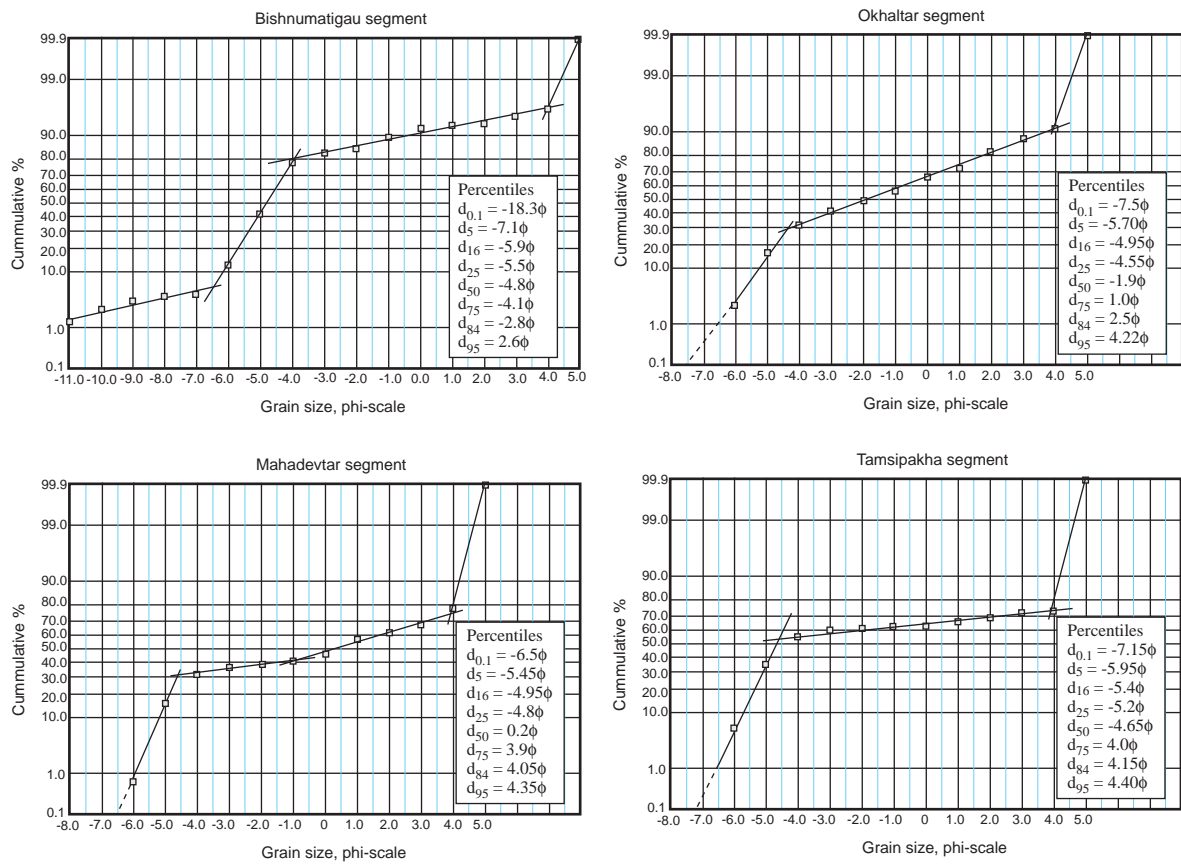


Fig. 7: Probability plots showing nature of curves; each straight line segment represents sub-population travelled in different modes of transport, and estimation of percentiles

### Composition and shape of gravel

Gravel obtained in Wolman’s pebble count was observed for composition and texture. Majority of the gravel is composed of gneissic rock fragments, followed by mica-quartz-feldspar aggregates, granites, meta-sedimentary and other clasts (Table 3 and Fig. 8). Composition of gravel from Bishnumatigau segment is limited to gneissic and granitic categories. Gravel from Tamsipakha segment is more diverse than that of other segments. Few metasedimentary clasts also contribute Okhaltar, Mahadevtar and Tamsipakha segments. These clasts were supplied from the fluvio-deltaic deposits (Tokha Formation) and the Phulchoki Group of rocks. Proportion of meta-sedimentary gravel increases in Tamsipakha segment because these have been

brought by the Mahadev Khola and the Bhauchakhusi Khola.

Axial ratios, oblate prolate index (OPI), settling sphericity ( $\Psi_p$ ) and roundness ( $\rho$ ) were calculated for each gravel obtained in each transect. Settling sphericity was calculated using axial data. For estimating roundness-value of Folk (1955), Power’s (1953) roundness chart was used. Axial ratios were plotted on Sneed and Folk’s (1958) diagram to compare forms (Fig. 9). Plots indicate that forms of gravel are compact bladed and few bladed and compact platy. All the means of gravel data plot on compact bladed field of the diagram.

Average settling sphericity values are 0.71, 0.70, 0.71 and 0.71, respectively for gravel in Bishnumatigau, Okhaltar, Mahadevtar and

Table 2: Percentiles and statistical parameters of size distribution of surface sediment in the Bishnumati River

	Bishnumatigau	Okhaltar	Mahadevtar	Tamsipakha
Dmax, $\phi$	-18.3	-7.5	-6.5	-7.15
D5, $\phi$	-7.1	-5.75	-5.45	-5.95
D16, $\phi$	-5.9	-4.95	-4.95	-5.4
D25, $\phi$	-5.5	-4.55	-4.8	-5.2
D50, $\phi$	-4.8 (27.86 mm)	-1.9 (3.73 mm)	0.2 (0.871 mm)	-4.65 (25.11 mm)
D75, $\phi$	-4.1	1	3.9	4
D84, $\phi$	-2.8	2.5	4.05	4.15
D95, $\phi$	2.6	4.22	4.35	4.4
Mean, $M_z$ , ( $\phi$ )	2.63	3.12	2.93	4.73
Median, $D_{50}$ , ( $\phi$ )	-4.8	1.9	-0.2	4.65
Sorting, $\sigma_I$ , ( $\phi$ )	2.24 VPS	3.37 VPS	3.73 VPS	3.96 VPS
Skewness, $SK_I$	0.41 VFS	0.20 FS	-0.15 CS	0.80 VFS
Graphic Kurtosis, $K_G$	2.84 VLK	0.74 PK	0.46 VPK	0.46 VPK

Table 3: Composition of gravel from the Bishnumati River

Stream segment	Composition of gravel-cobble particle (%)									
	Gneiss	Granite	MQF Agg.	Quartzite	Siltstone	Sandstone	Shale	Limestone	Quartz	Others
Bishnumatigau	64	5	29	-	-	-	-	-	2	-
Okhaltar	46.10	8.51	28.37	0.71	4.26	2.13	-	-	9.93	-
Mahadevtar	42.9	10.7	39.3	0.7	-	4.3	-	-	-	2.1
Tamsipakha	42.2	11.1	20.1	1.0	13.6	2.0	0.5	3.0	3.5	3.0

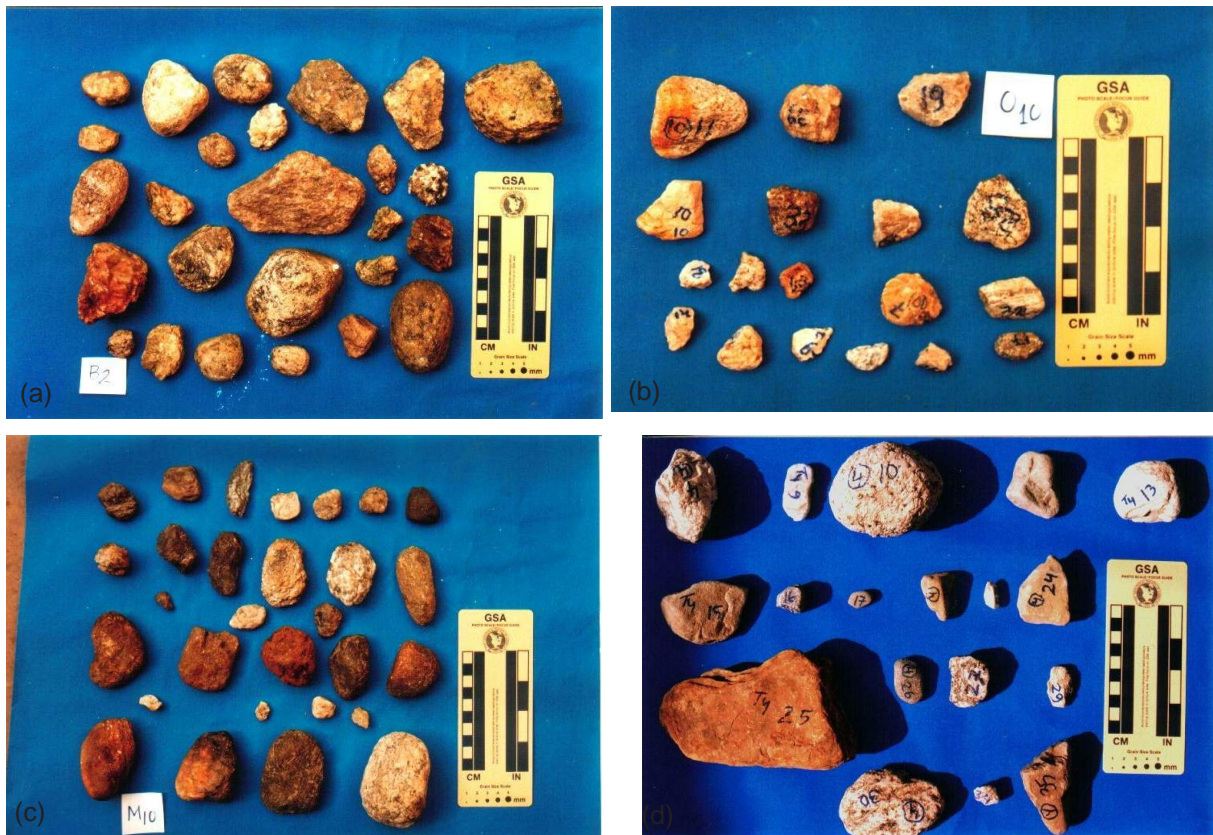


Fig. 8: Gravel sub-samples from (a) Bishnumatigau segment; transect-B2, (b) Okhaltar segment; transect-O10, (c) Mahadevtar segment; transect-M10, and (d) Tamsipakha segment; transect-T4

Tamsipakha segments. OPI data show that clasts from Tamsipakha segment are more oblate than those from other segments. This is probably due to bundance of metasedimentary gravel. Therefore, form of gravel from the Bishnumati River is not so diverse and is abundantly compact bladed. Settling sphericity decreases in Tamsipakha segment and becomes more oblate (negative values of OPI) than

prolate.

Average roundness values of gravel are 2.47, 2.82, 2.5, and 3.05, respectively for upstream to downstream segments. Roundness of gravel develops from subangular to subrounded due course of transport. However, subrounded gravel of Tamsipakha segment was resulted by weathering meta-sedimentary gravel.

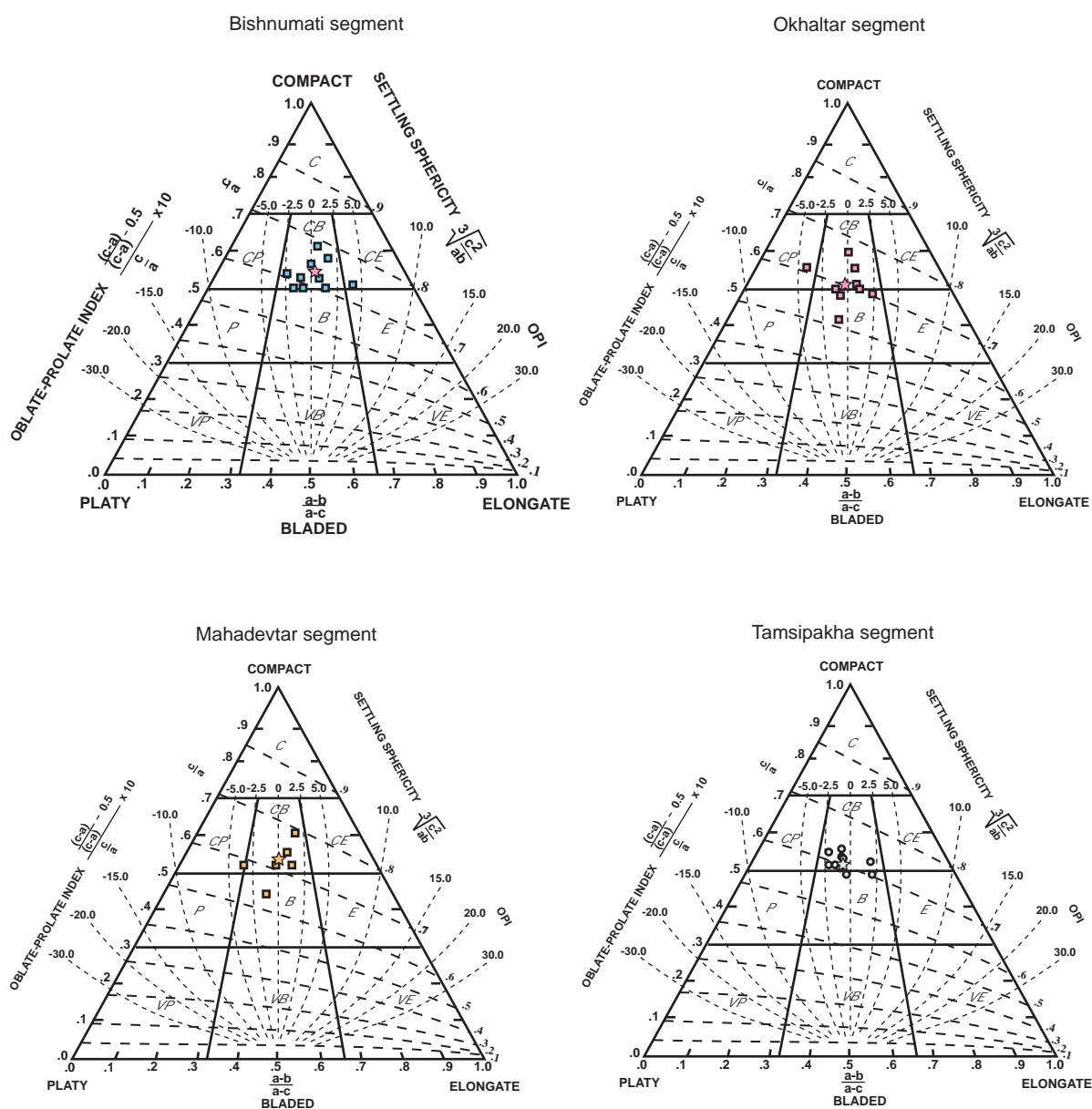


Fig. 9: Form diagrams indicating plots of axial ratios of gravel from (a) Bishnumatigau segment, (b) Okhaltar segment, (c) Mahadevtar segment, and (d) Tamsipakha segment; C = compact, CP = compact platy, CB = compact bladed, CE = compact elongate, P = platy, B = bladed, E = elongate, VP = very platy, VB = very bladed, and VE = very elongate

Overall shape analysis indicates that there is no remarkable downstream variation of shape parameters of gravel. The shape parameters seem to be influenced much by initial composition rather than by transport. One of the main causes could be relatively soft nature of riverbed material.

### CLASSIFICATION OF BISHNUMATI RIVER SEGMENTS

Classification of rivers is an organization of data on stream features into discrete combinations so that one can predict a river's behavior from its appearance and develop specific hydraulic and sediment relations from a given morphological channel type and state (Rosgen, 1994). There are three levels of classification; the broad geomorphic characterization (level I), the morphological description (level II), which incorporates the general character of channel form and related interpretations, and stream state or condition (level III).

Plan view morphology, longitudinal profiles of river, field measurement of channel cross-sectional parameters and substrate characteristics provided information required for level I and II classification. The following

basic criteria were followed for delineating the stream types of four segments of the Bishnumati River surveyed.

1. Entrenchment ratio (a value that indicates degree of vertical containment)
2. Width/depth ratio (W/D ratio; a value that indicates the shape of the channel cross-sections)
3. Sinuosity (value indicating degree of sinuosity)
4. Slope, and
5. dominant channel materials (median grain size in substrate)

The results of Rosgen stream classification are presented in Table 4. Bishnumatigau, Okhaltar, Mahadevtar and Tamsipakha segments are A4, C4, F5 and F4-type streams, respectively.

#### Bishnumatigau segment

Bishnumatigau segment possesses ER of less than 1.4, meaning that the segment is considerably entrenched. W/D ratio is also not so high and is about half of the Mahadevtar and Tamsipakha segments. Sinuosity is 1.15 which is low compared to other stream types. Slope is 0.133 m/m and is highest among the segments surveyed. The river segment is

Table 4: Summary of Rosgen stream classification (level I and II) of the Bishnumati River

	Bishnumatigau	Okhaltar	Mahadevtar	Tamsipakha
Bankfull x-section area, $A_{bkf}$ (m <sup>2</sup> )	3.52	4.89	7.37	6.98
Width at bankfull, $W_{bkf}$ (m)	6.10	7.67	13.8	10.85
Width flood prone area, $W_{fpa}$ (m)	7.68	36.80	19.05	13.10
Max. depth bankfull, $D_{max}$ (m)	0.98	0.89	0.90	0.83
Max depth top low bank, $D_{TOB}$ (m)	2.44	1.60	2.20	2.58
Mean depth at bankfull, $D_{bkf} = A_{bkf} / W_{bkf}$ (m)	0.58	0.64	0.54	0.51
Entrenchment ratio, $ER = W_{fpa} / W_{bkf}$	1.28 (A)	4.78 (C, E)	1.37 (F, G)	1.30 (F, G)
Width-depth ratio, $W/D = W_{bkf} / D_{bkf}$	10.69 (A, E, G)	12.19 (C)	26.16 (F, C)	21.29 (C, F)
Sinuosity, K	1.15 (A)	1.34 (C, F)	1.16 (F, E)	1.15 (C, F, G)
Slope (m/m)	0.133 (A)	0.008 (F, E, C)	0.004 (F, E, C)	0.005 (F, E, C)
Dominant channel material, $D_{50}$	27.86 mm (pebble)	3.73 mm (pebble)	0.87 (sand)	25.11 mm (pebble)
Rosgen stream type	A4	C4	F5	F4

characterised by step, riffle and pool. The substrate is composed dominantly of pebble although huge mega boulder and clay also exist in the substrate (Fig. 10). All the above criteria place the Bishnumatigau segment in A4-type stream.

The river banks are lined with mostly shrubs and grass, and few trees. Banks in B1, B7 and B10 transects are mostly covered with megagravel (Fig. 10). Right bank of B2 is confined with a concrete wall. Left bank of B8

is steep whereas right bank is stepped for cultivation. The banks in B8 are composed of sandy soil. Distribution of boulder and megagravel in channel and banks can be noticed (Fig. 11). Vegetation in the banks is well distributed.

### Okhatar segment

Okhatar segment shows large ER (4.78) and is less entrenched than any other segments. It shows affinity towards C or E-type stream. However, it has W/D ratio more than 12 and sinuosity (1.34) comparatively less than that of E-type stream. Okhatar segment also possesses low slope angle (0.008 m/m) and contains dominantly pebble sized sediment on the substrate. All the criteria place this stream in C4-type category.

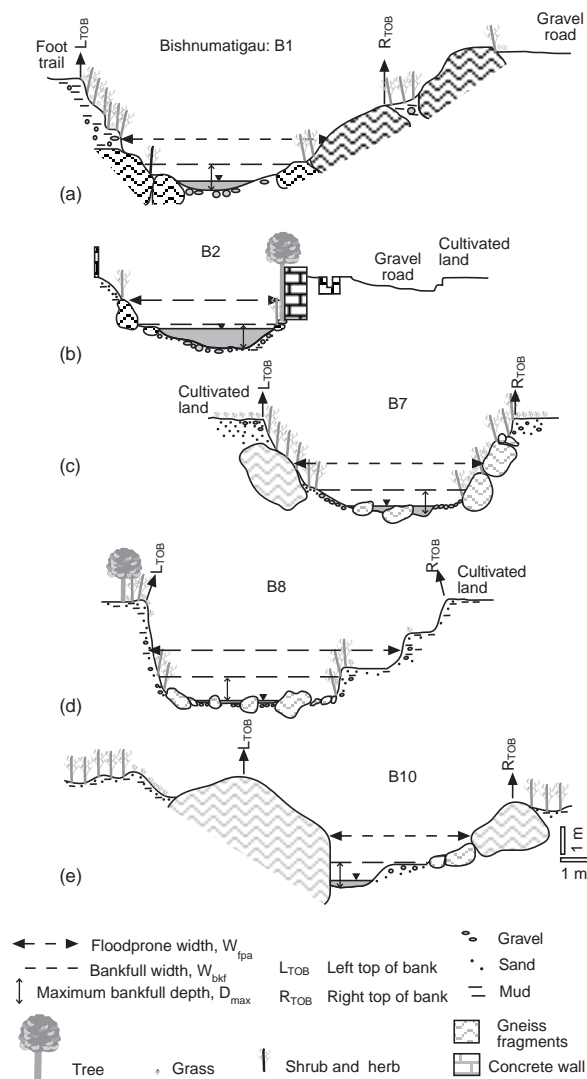


Fig. 10: Cross-sections of transects in Bishnumatigau segment; (a) B1, (b) B5), (c) B7, (d) B8, and (e) B10



Fig. 11: An upstream view from B5 showing stream bank sediments and vegetation

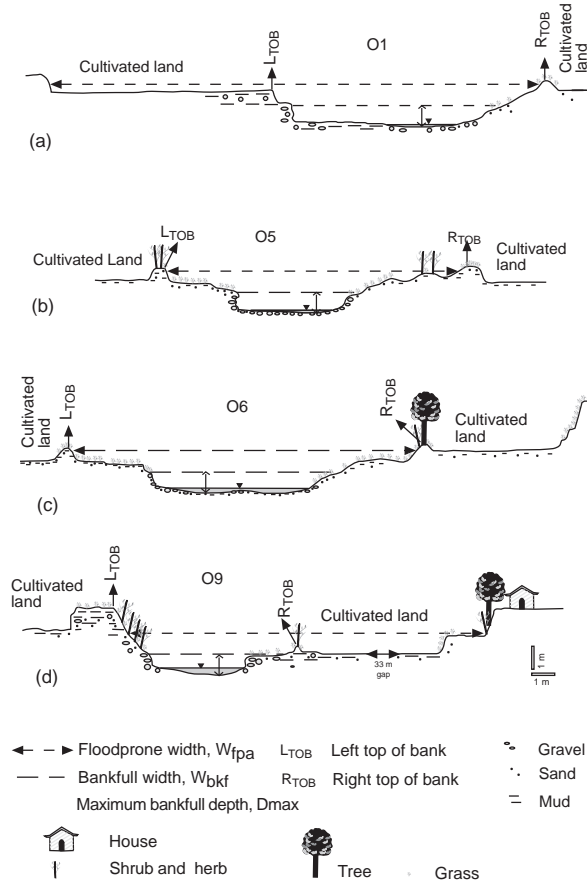


Fig. 12: Cross-sections of transects in Okhaltar segment; (a) O1, (b) O5, (c) O6, and (d) O9

Transects O1, O5, O6 and O9, from downstream to upstream portion have wider floodprone width than the average bankfull depth (Fig. 12). Average depth does not deviate much from  $D_{max}$ . Substrate materials are abundantly gravel and sand (Fig. 13). Bank materials are stratified muddy sand and gravel. Lower banks are mostly eroded. Banks are covered by grass and in some places by shrubs. Few trees are distributed on levees. Riparian vegetation is weak in the downstream segments compared to the upstream one. The banks have been eroded by flows (Fig. 13). In some instances, banks have been protected by bamboo

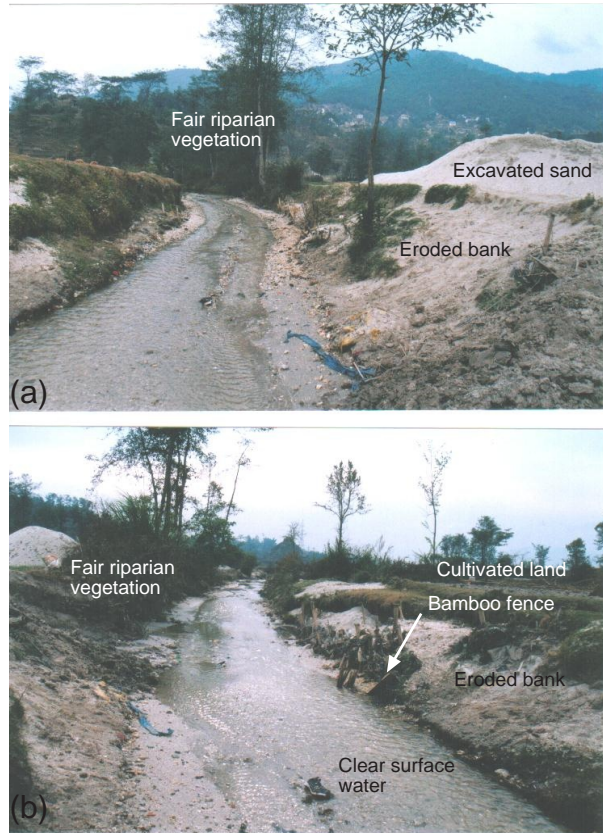


Fig. 13: Views from transect O9 showing fair development of riparian vegetation, low turbidity of water, gravelly channel substrate, bamboo fence used for protecting bank scouring, and excavated sand mounds; (a) upstream view and (b) downstream view

fences. The landuse at both banks of the stream is mainly cultivation. Extensive excavation of sand and gravel from the channel can be noticed.

### Mahadevtar segment

Mahadevtar segment shows lower ER (1.37) and higher W/D ratio (26.16) than the Okhaltar segment. Sinuosity does not exceed 1.2. Slope of channel also decreases from 0.008 to 0.004. The dominant bed material is sand although there exists gravel and clay. Therefore, Mahadevtar segment is classified as F5-type stream.

River flows over fluvio-lacustrine clay

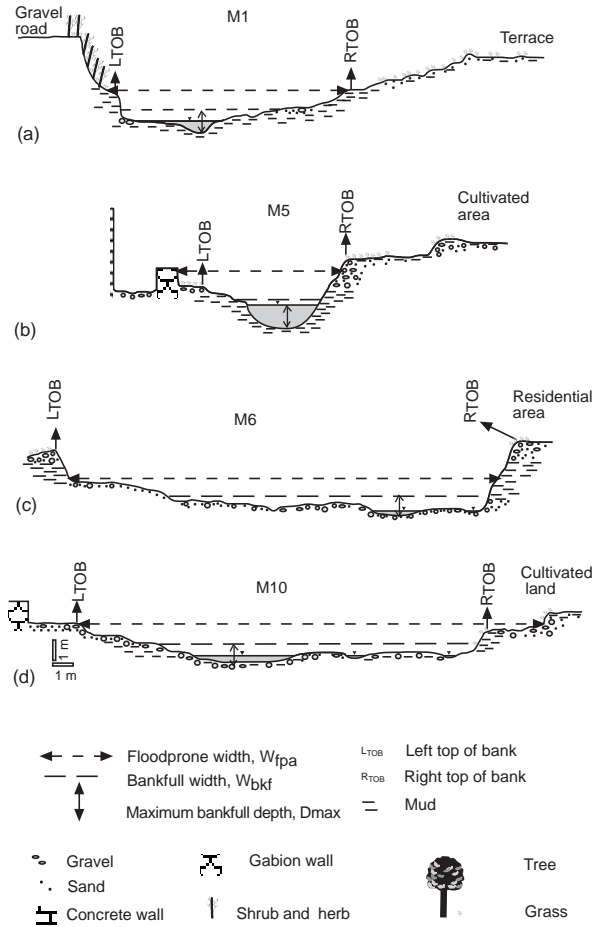


Fig. 14: Cross-sections of transects in Mahadevtar segment; (a) M1, (b) M5, (c) M6, and (d) M10

deposits and incises clayey channel bed in Tamsipakha segment (Fig. 14). Substrate materials are often clay and sand in pool, and gravel and sand on the bank and riffles. Bank materials are composed of gravel and sand overlying fluvio-lacustrine clay deposits, and are stratified. Riparian vegetation is poor. Few shrubs and some grass serve very narrow zone and patches. Pools are deep exceeding 1 m at some places due to channel scouring, and their width is narrower compared to width of riffle cross-sections.

Upstream and downstream views from transects M1 and M3 are shown in Fig. 15.



Fig. 15: (a) Upstream view from transect M1, and exposure of clayey bank, erosion scars and poor riparian vegetation, and (b) Downstream view from M3, showing channel scouring, exposure of clayey channel bed, and poor riparian vegetation

Right and left banks exhibit erosion scars. Riparian vegetation along both banks are poor. The channel width here is not so wide, but the channel is scoured forming deep pools.

### Tamsipakha segment

As Mahadevtar segment, ER (1.3), W/D ratio (21.29), sinuosity (1.15) and slope (0.005) place Tamsipakha segment into F-type category. However, the median channel material in this segment is pebble sized particles. Therefore, Tamsipakha segment is classified as F4-type stream.

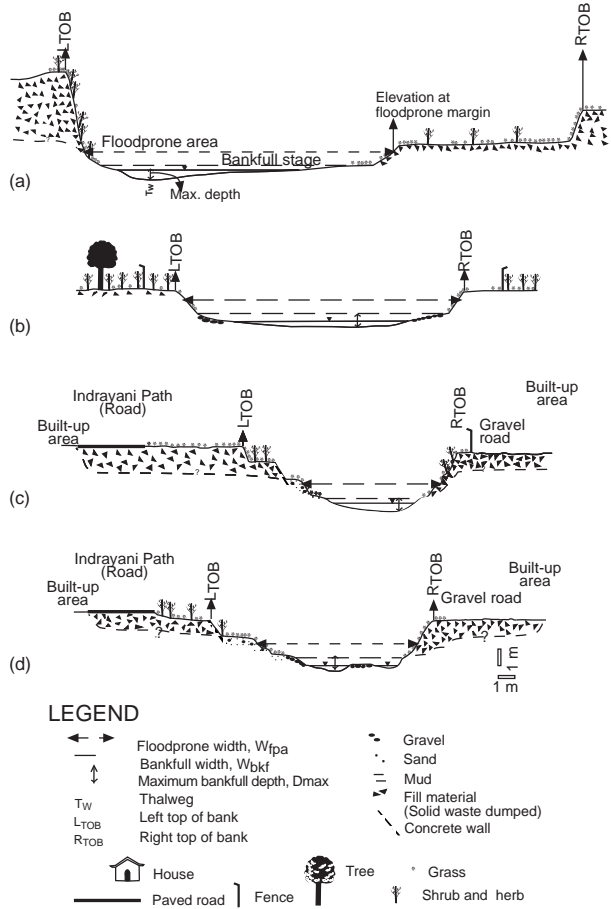


Fig. 16: Cross-sections of transects in Tamsipakha segment; (a) T1, (b) T2, (c) T8, and (d) T9

Height of the top of low bank approaches 3 m in transection T1 (Fig. 16). Increase in height is resulted by incision as well as by infilling of waste materials. Solid waste materials are dumped along the both sides of the river banks and can be observed in T2, T8 and T9 (Fig. 16) as well. On the left bank, a black topped road has been built over the dumped material, whereas on the right bank, a gravel road has been extended. In a reach between Tamsipakha and Bijeswari, the right bank is preserved as a narrow riparian zone (Fig. 17).

Between Bijeswari and Balgangaghat, slope of the left bank of river has been benched

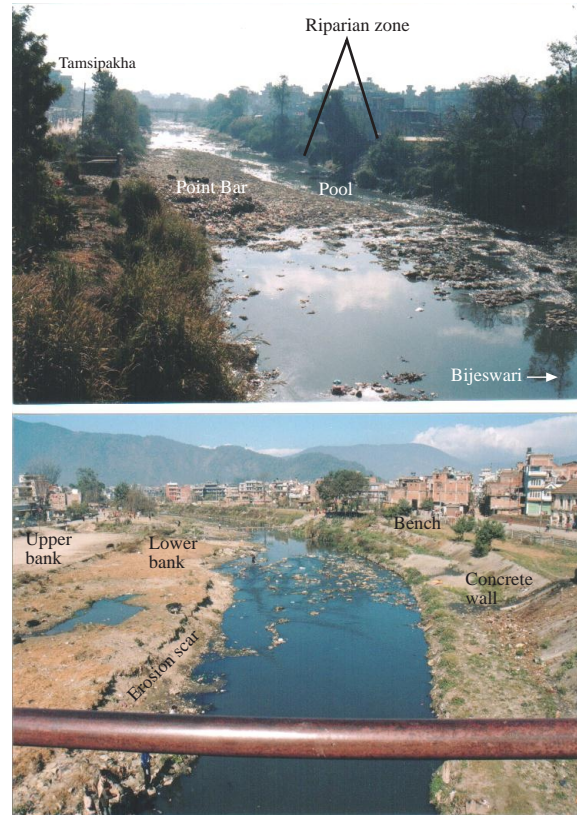


Fig.17: View from the Bijeswari bridge, 50 m upstream of transect T4 in Tamsipakha segment; (a) Downstream view and (b) Upstream view

and walled frequently (Fig. 16 b). Few grass and shrub exist along the banks. But on the right bank, except some gabion walls in some places, the slope is unmanaged and solid waste is dispersed everywhere. Few trees line up along the right bank in transect T6 (Fig. 16a), but most of the vegetation is cleared off in the right bank. The same is the case for left bank between Bijeswari and Tamsipakha. The right bank, from T6 to the Bijeswari bridge, is eroded by high flow and the area represents poor riparian vegetation (Fig. 17b). Flat muddy terrace represents former flood plain and indicates leftward shifting and lowering of river bed at present condition.