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River dynamics and existing stability condition of the Manahara River, Kathmandu basin, Central Nepal Himalaya

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ABSTRACT

Five representative segments of the river were surveyed in detail for evaluating its dynamics and stability condition. The first (downstream) to the fifth (upstream) segments are classified as ‘F4’, ‘C4’, ‘C4’, ‘B4’ and ‘B4’ streams characterised by gravelly substrates. All these streams are competent enough to transport their bed material (d_{90}) as shown by the exceeding dimensionless shear stress over critical dimensionless shear stress of the river segments. The existing depth and slope of the river is far enough to carry d_{90} of the substrate grain size. Stream power of segments 1 to 5 are respectively, 622.6, 79.0, 146.6, 354.6 and 15617.0 KN/s. The ‘B4’ streams show greater stream power, i.e., transport capacity compared to ‘F4’ followed by ‘C4’ streams. Therefore, the ‘B4 streams (3rd and 4th order streams) are potential to degradation, and the ‘C4’ and ‘F4’ (both 5th order) streams are potential to aggradation depending on river morphology and dynamics. Meander geometry of the Manahara River exhibit deviation of variables (meander wavelength vs channel width, and meander belt width vs channel width) from the stability, suggesting existence of instability to some extent in the river.

INTRODUCTION

Rosgen (1996) defined stream channel stability as the ability of a stream over time, in the present climate, to transport the sediment and water in such a manner that the stream maintains its dimension, pattern and profile without aggrading or degrading. Dynamics of a river is indeed closely related to stability of river, flow competence, aggrading/degrading potential of channel, channel planform changes, etc. Determining these parameters require extensive fieldwork and gathering of morphological, hydraulic, and sedimentological data. Several authors have shown fruitful results over treatment on competence (Andrew, 1983, 1984), aggrading/degrading relationship (Schumm, 1963), meander geometry relationship (Leopold and Wolman, 1960), etc. This paper attempts to gather field information from existing river, and to assess dynamics of the Manahara River in order to recognise instability in the river.

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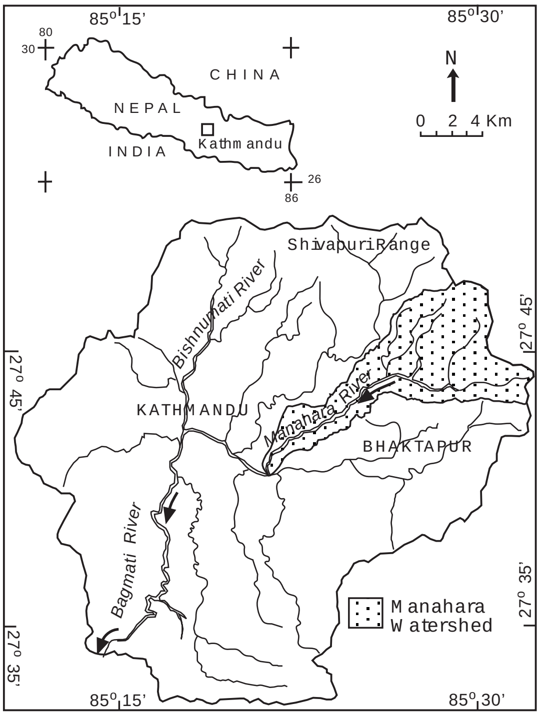

Fig. 1 Location map of study area.

GEOLOGY OF CATCHMENT

The Manahara River, located in the northeast of Kathmandu, stretches for about 28 km, and is one of the largest tributaries of the Bagmati River (Fig. 1). It has a short headed high gradient segment (about 5 km), and a long low gradient downstream segment (23 km).

Gneiss and granitic pegmatites of the Sheopuri Injection Gneiss Zone (Ohta, 1973), and schist and quartzite of the Kulekhani Formation (Stöcklin and Bhattarai, 1977) form major rock types in the northern divide (Fig. 2). Meta-sandstone, siltstone and phyllite of the Tistung Formation (Stocklin and Bhattarai, 1977) occupy the eastern and southeastern divides. The strata generally extend E-W and dip towards north. The fluvio-lacustrine deposits cover the central, western and southwestern parts of the watershed (Fig. 2). The Gokarna Formation that comprises gravel, pebbly sand, coarse sand, silt, clay and lignite crops out along the river for the relative height varying between 1.5 and 35 m. The Thimi Formation exposes in the southern region and comprises arkosic sand, silt and silty clay. The river bars and flood plain elements constitute cobble to silt/clay.

METHODOLOGY

Regional watershed parameters and planform were measured on topographic maps (1:25,000 and 1:10,000) and reconnaissance field survey were made. Then five representative segments of the Manahara River (Fig. 2) based on their planform, nature of channel, and stream order, were surveyed for cross-sections and longitudinal profiles. To characterize grain size of each of five segments in reach-scale and in cross-section scale, Wolman's (1954) pebble counting was adopted in eight transects in each of these five segments. The volumetric bar surface samples were sieve analysed separately for grain size parameters.

Each surveyed segment was classified based on the scheme of Rosgen (1994). Results of hydraulic and morphologic analyses were used to evaluate competency, aggrading/degrading potential and stability

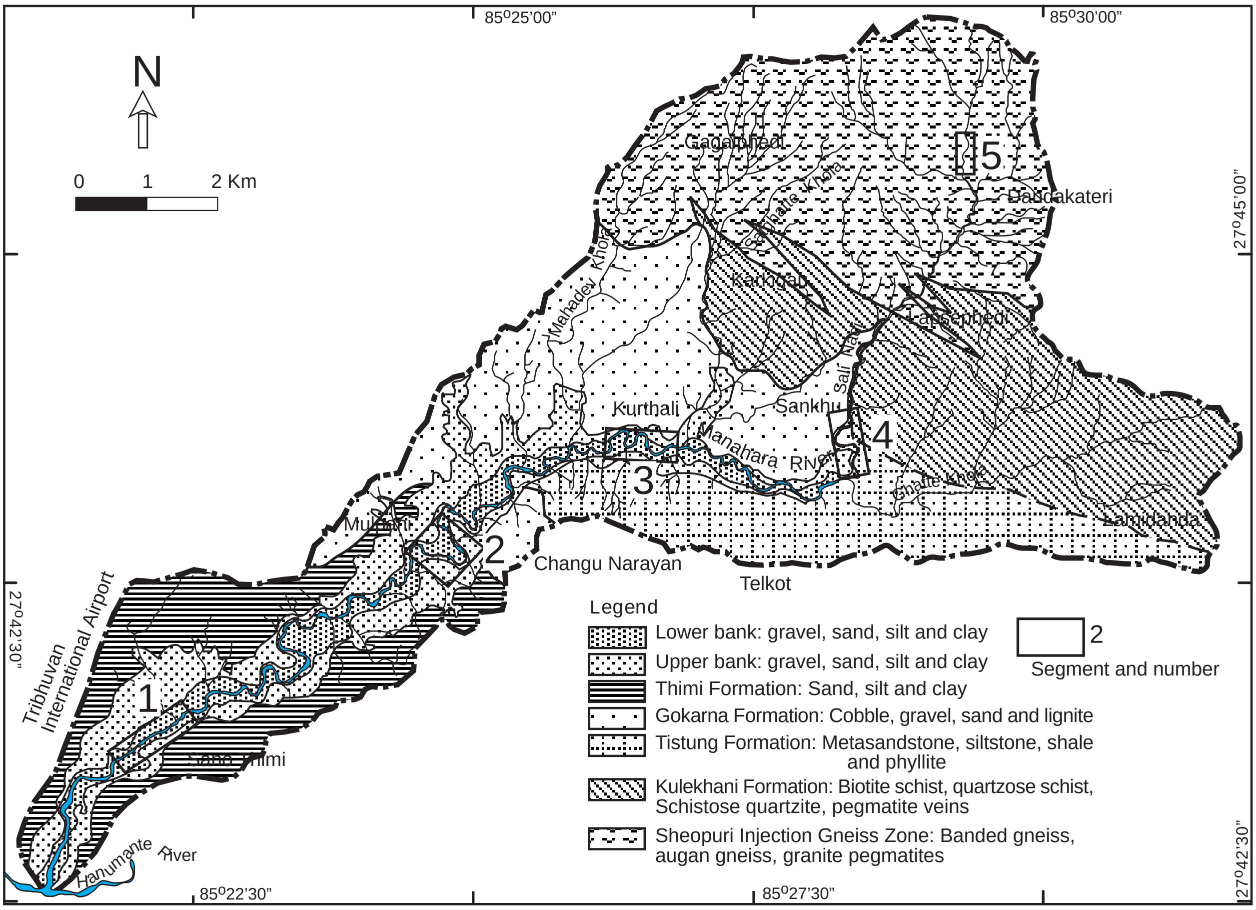

Fig. 2 Geology of the Manahara watershed.

of the river. Furthermore, the meandering geometry of the existing river was compared with the established relationships to diagnose stability of the river.

MORPHOLOGICAL AND HYDRAULIC PARAMETERS

Planform geometry

The Manahara basin is elongated NE-SW, and covers about 83 km^2. It's 4th order streams incise bedrock and terrace deposits, while main stem channel (5th order) incises the fluvio-lacustrine terrace deposits, and widens the valley, in geomorphic time-scale, against upliftment of terraces that has been probably continuing since late Pleistocene due to neotectonic activities (Bajracharya, 1992; Bajracharya, 2001).

Sinuosity (K) exceeds 1.4 in Segments 3, 4 and 5, except in somewhat straight Segments 1 and 5 (Table 1). Segment 2 is potential in lateral accretion with large meander length (L_m) and meander belt width (W_{blt}). The Segments 1, 3 and 4 bear somewhat similar magnitude of L_m and W_{blt}. Segment 3 exhibits the highest degree of radius of curvature (R_c) and Segment 5 shows the least.

Morphology

Morphological parameters are indicated in Table 1. Riffle and pool cross-sectional areas range from 5.50 to 13.09 m^2 and from 0.67 to 2.78 m^2, respectively. Width (W_{blt}), depth (D_{blt}), maximum depth (D_{max}), and flood prone width (W_{fpa}) are of higher magnitude in Segment 1 and 2 compared to the remaining segments. The cross-sectional areas and widths decrease from Segment 2 to 5 (Fig. 3).

Segment 1 is entrenched, Segments 4 and 5 are moderately entrenched, and Segments 2 and 3 are slightly entrenched (Table 1; Fig. 3). Width/Depth ratio (W/D ratio) progressively decrease from Segments 1 to 5 (Table 1; Fig. 3) indicating decrease lateral instability towards upstream segments. Bank height ratio of segment 4 is the greatest, whereas those of 1, 2, and 3 are low. Therefore, the latter are vulnerable to lateral shifting of river and flooding.

Table 1: Planform, morphologic and hydraulic parameters of the Manahara River

Attribute	Segment				
	1	2	3	4	5
Pattern					
Thalweg length, L_{tw} (m)	730	2430	970	570	230
Valley length, L_{valley} (m)	640	1160	630	400	210
Sinuosity, K = $L_{thalweg}/L_{valley}$ (m/m)	1.14	2.11	1.53	1.43	1.09
Meander length, L_m (m)	450	760	550	400	160
Belt width, W_{blt} (m)	160	670	170	210	20.0
Radius of curvature, R_c (m)	112	103	125	97.8	69.6
Meander length ratio, L_m/W_{bkf}	14.8	26.0	19.9	25.3	16.1
Meander width ratio, W_{blt}/W_{bkf}	5.25	22.9	6.15	13.3	2.01
Riffle cross-section					
Bankfull cross-sectional area, A_{bkf} (m^2)	11.8	13.1	10.6	6.37	5.50
Width at bankfull, W_{bkf} (m)	30.5	29.3	27.6	15.8	9.93
Width of flood prone level, W_{fpl} (m)	50.3	347	206	22.8	14.3
Maximum depth at bankfull, D_{max} (m)	1.38	1.46	1.16	0.74	1.16
Maximum depth at top of low bank, D_{TOB} (m)	2.23	1.88	1.38	1.73	1.65
Mean depth at bankfull, $D_{bkf} = A_{bkf}/W_{bkf}$ (m)	0.41	0.46	0.38	0.40	0.56
Hydraulic radius, R (m)	0.38	0.43	0.37	0.38	0.50
Entrenchment ratio, ER	1.39	12.2	7.71	1.43	1.45
Width/depth ratio, W/D = W_{bkf}/D_{bkf}	85.4	69.8	65.9	47.6	24.8
Bank height ratio, BHR, D_{TOB}/D_{max}	1.63	1.30	1.19	2.33	1.42
Maximum depth ratio, MDR = D_{max}/D_{bkf}	3.46	3.22	3.06	2.18	2.65
Pool cross-section					
Pool cross-sectional area, A_{pool} (m^2)	1.98	2.61	2.78	0.67	0.73
Pool width, W_{pool} (m)	16.6	15.4	12.7	6.65	3.55
Pool maximum depth, D_{pool} (m)	0.42	0.71	0.74	0.38	0.65
Slope of channel, $S_{average} = Delta_{Elv}/Delta_{Lthalweg}$ (m/m)	0.024	0.006	0.011	0.030	0.700

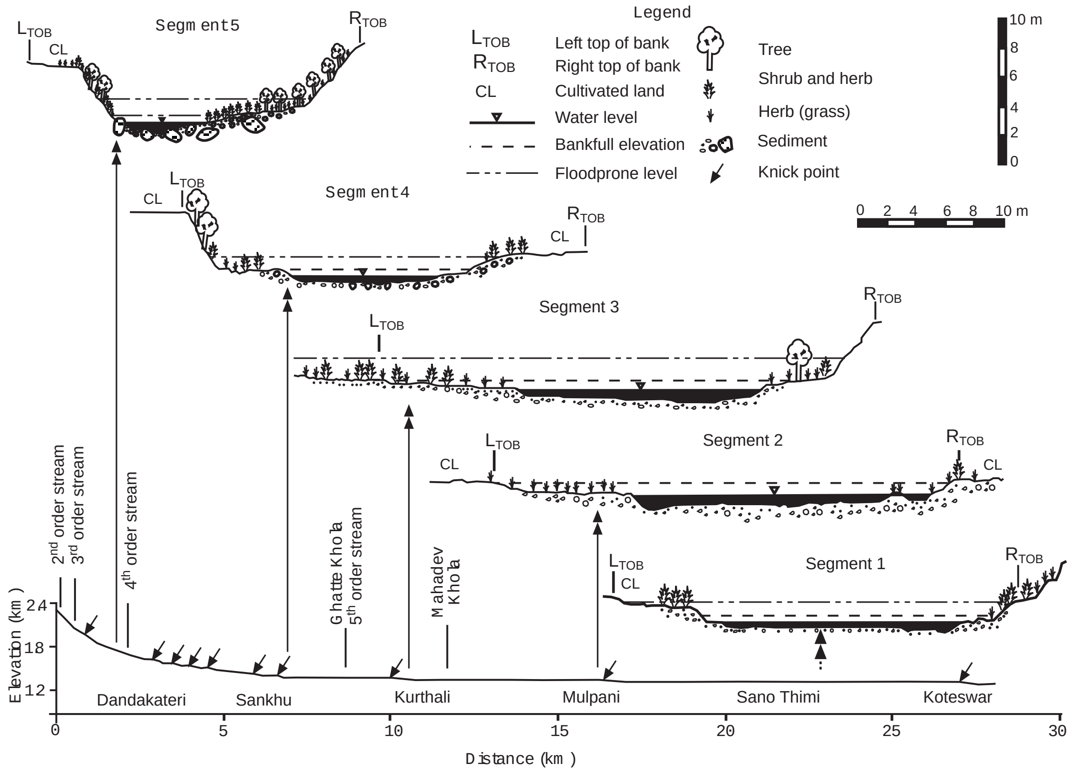

Fig. 3 A longitudinal profile of the Manahara River and its five study segments.

Meander length ratio extends from 14.75 to 25.98 and indicates that this ratio of downstream segments is nearly twice this ratio of the upstream segment. Meander belt width ratio ranges from 2.01 to 22.9 showing that the middle to lower segments have generated remarkably wide belts compared to their widths, while the upstream segments (4 and 5) have narrow belts compared to widths.

Longitudinal profile

The Manahara River profile exhibits concavity (Fig. 3). Slopes of low order stream decline abruptly when the 3rd order stream begins with slope of 0.70 m/m. From 3rd to 4th order stream slope gradually diminishes but from the begining of 5th order segment, the slope becomes gentle. Several knick points exist particularly in forth order segments.

Hydraulic parameters

The Manning's roughness coefficient (n) was estimated from field survey, and parameters were after Cowan (1959) and correction factors were from Aldridge and Garrett (1973). The n-values are 0.04 in segments 1, 2 and 3, 0.05 in Segment 4, and 0.13 in Segment 5 (Table 2). The Manahara River is a perennial river fed by spring and storm flow. Generally, rainfall is high during June-September and is lean during November-February. The discharge of the river is expected to be high during high rainfall period and varies seasonally.

Bankfull discharge (Q) and velocity (V) were estimated using Manning's equation (Chow 1959) and continuity equation, respectively. The discharge extends from 6.95 m^3/s (in Segment 5) to 25.19 m^3/s (in Segment 1) (Table 2) showing downstream increase of discharge probably due to increase in cross-sectional area of stream and decrease in n-value. Discharge may also increase upon increase of drainage area and contribution from different tributaries. Bankfull velocity is the highest in Segment 1 (2.13 m/s), medium in Segments 3, 4, and 5 (1.26–1.27 m/s), and is the least in Segment 2 (1.04 m/s). Velocity in Segment 1 is influenced by increased discharge due to increased slope, low roughness and low sinuosity. In Segment 2, increased channel cross-sectional area reduces velocity.

River sediments

Median diameter of the reach-scale pebble counted samples falls on fine- to medium-gravel (Table 2). The d_{50} of the riffle samples falls on very coarse sand to

Table 2: Summary of classification of the Manahara River based on Rosgen (1994)

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Entrenchment ratio, ER	1.39 (F, G)	12.22 (C, E)	7.71 (C)	1.43 (B)	1.45 (B)
W/D ratio	85.42 (F)	69.77 (C)	65.87 (C)	47.59 (B)	24.78 (B)
Sinuosity, K (m/m)	1.14 (A)	2.11 (C, E)	1.53 (C, E)	1.43 (B)	1.09 (B)
Slope (m/m)	0.024 (F)	0.006 (C)	0.011 (C, E)	0.030 (B)	0.70 (B)
Bed material, median size (mm)	0.003	0.002	0.003	0.012	0.007
Rosgen stream type	F4	C4	C4	B4	B4
Manning's roughness coefficient, n	0.037	0.041	0.043	0.049	0.13
Bankfull discharge, $Q = (A R^{2/3} S^{1/2})/n$ (m^3/s)	25.94	14.11	13.33	11.82	22.31
Bankfull velocity, V = Q/A (m/s)	2.198	1.077	1.258	1.856	4.056

fine gravel. The proportion of gravel and matrix of sand and mud is almost equal up to Segment 3 and then gravel increases in upstream portion of the river probably because of proximity to the source rocks where slope and boundary shear stress are enough to carry gravel.

Stream categories

Segment 1, 2, 3, 4 and 5 are classified as 'F4', 'C4', 'C4', 'B4' and 'B4', respectively (Table 2).

'F4' stream

Segment 1 is entrenched (<1.4) with high W/D ratio (>12) and somewhat low sinuosity (>1.2). Its bed material is of pebble size grade. This segment gradually narrows down with reduced ER. Point bars, point bars with few mid channel bars, and side bars characterise deposition pattern (Table 3).

'C4' stream

Segments 2 and 3 are less entrenched (Fig. 3) with W/D ratio greater than 12. These are highly sinuous with very gentle slopes, and constitute numerous point bars and mid channel bars. The bed material is composed of fine gravel. The banks frequently exhibit erosion scars and in places landslides. Channel shifting is quite remarkable.

'B4' stream

Segments 4 and 5 are moderately entrenched with large W/D ratio (Fig. 3). Segment 4 is somewhat meandering but Segment 5 is slightly straight. Slopes of both segments are large. Bed material consists of gravel. Side bars and few point bars constitute the channel elements. Erosion scars are commonly found on steep and high banks showing mass failure.

RIVER DYNAMICS

The morphology of the river itself reflects the dynamics of river. For instance, a passive river flowing of a gentle slope is sinuous, whereas rivers flowing on steep slope is much active as they can transport huge amount and large sized sediments, and thus form several mid-channels bars and braiding pattern. There are other measures of dynamism, i.e., stability condition, competence of river, aggrading/degrading potential, deviation of meandering geometry relations, etc.

Flow competence and dynamics

The boundary shear stress was obtained using the expression of Shields (1936):

$$\tau = \gamma RS \qquad (1)$$

where, γ is density of water (1,000 kg/m^3), τ is a

Table 3: Stability parameters of the Manahara River

Stream segment	Stream type	Stream order	[a]Flow	[b]Depositional pattern	Riparian vegetation	Vertical stability: BHR	Vertical stability: ER	Vertical stability: Condition	Lateral stability: MWR	Lateral stability: W/D ratio
1	F4	5th	P-2, 4, 8	B-1, 2, 4	Poor	1.63 (HU)	entrenched	Aggrading	MS	HU
2	C4	5th	P-2, 4	B-1, 2, 4	Poor	1.30 (U)	Slightly entrenched	Aggrading	U	HU
3	C4	5th	P-2, 4	B-1, 2, 4	Poor	1.18 (MU)	Slightly entrenched	Aggrading	U	HU
4	B4	4th	P-2, 4	B-1, 4	Fair	2.33 (HU)	Moderately entrenched	Degrading	MS	HU
5	B4	3rd	P-2, 4	B-1, 4	Good	1.42 (U)	Moderately entrenched	Degrading	S	HU

[a] P = Perennial, P-2 = storm flow dominated, P-4 = spring fed and P-8 = flow altered by development;
[b] B = Bar, B-1 = point bars, B-2 = point bars wit hfew mid-channel bars and B-4 = side bars; HU = highly unstable, U = unstable, MU = moderately unstable, MS = moderately stable and S = stable

Table 4: Flow competence and capacity of the Manahara River

Parametres	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Largest size, d_{max} (m)	0.084	0.099	0.145	0.183	1.020
Coarse 90th percentile size, d_{90} (m)	0.021	0.018	0.034	0.049	0.065
Median size of riffle sediment, d_{50} (m)	0.003	0.002	0.002	0.012	0.007
Median size of bar sediment, d_{s50} (m)	0.004	0.003	0.007	0.01	0.204
Boundary shear stress, τ (N/m^2)	9.840	2.576	4.180	12.000	392.00
Critical dimensionless shear stress, τ_{ci}*	0.021	0.019	0.021	0.021	0.201
Dimensionless shear stress, τ_i*	0.259	0.080	0.073	0.150	3.655
Threshold depth, D_t (m)	0.030	0.101	0.107	0.056	0.035
Threshold slope, S_t (m/m)	0.002	0.001	0.003	0.004	0.043
Stream power, ω (KN/s)	622.6	79.0	146.6	354.6	15617.0

boundary shear stress (N/m^2), R is a hydraulic radius (m), and S is a channel slope (m/m). Boundary shear stresses in Segment 1 and 5 are much greater compared to the remaining segments (Table 4).

Shields (1936) showed that the hydraulic conditions required to entrain particles could be explained by the dimensionless shear stress (Shields constant), τ_i* as below:

$$\tau_i^* = DS/(S_s–1)d_i \qquad (2)$$

where, d_i is the particle diameter which is coarser than ith % of the riverbed material and S_s is specific gravity of the sediment (2.65). Bradley and Mears (1980) used Shields constant between 0.45 and 0.06 for computation of bedload transport using Shields criteria. As dimensionless shear stress varies with bed material size distribution, for armored beds, Andrews (1983) derived the relationships as below:

$$\tau_{ci}^* = 0.0834\ (d_i/d_{s50})^{–0.872} \qquad (3)$$

where, τ_{ci}* is a threshold dimensionless shear stress required to entrain d_i of the riverbed material and d_{s50} is a median grain diameter of subsurface bed or bar material. In gravelly stream the τ_{ci}* value may range from 0.02 to 0.25, and for the ratio d_i /d_{s50} greater than 4.2, τ_{ci}* becomes 0.02 but it may be as low as 0.01 for eroding stream (Andrew, 1983). In this instance, the d_i of the equation (4) and (5) was replaced by the d_{90} to get threshold dimensionless shear stress for the bed material of coarse percentile, and then parameters were calculated (Table 4).

The calculated τ_i* from equation (2) ranges from 0.073 and 3.655. In all the five segments of the Manahara River, dimensionless shear stress values are significantly greater than the calculated τ_{ci}*that extends from 0.019 to 0.201, suggesting that the bankfull flow is capable of mobilizing the riverbed material as large as the 90th percentile fraction. Considering this condition, what would be the threshold bankfull depth, D_t and threshold slope, S_t required to initiate movement of d_i are expressed as:

$$D_t = (1.65\tau_{ci}^*\ d_i)/S \qquad (4)$$

$$S_t = (1.65\tau_{ci}^*\ d_i)/D \qquad (5)$$

where, D is the existing depth at bankfull and S is the existing slope. The existing depth and slopes in all the segments are significantly greater than the calculated threshold depth and slope (Table 4), therefore suggesting that bed materials in the Manahara River are prone to entrainment and transport.

Flow dynamics of stream is the power contained in stream. Stream power can be obtained by using following relation:

$$\omega = \gamma QS \quad ....(6)$$

Where,

ω=Stream power, Q=Bankfull discharge, γ = density of water, and S=Stream slope.

Stream power (ω) is highest (15617 KN/s) in Segment 5, and lowest in Segment 2 (79 KN/s). These values indicate that, Segment 5 has the highest stream power and has high erosive capacity (Table 4), Segments 4, 3 and 1 have moderate flow competencies showing lateral vertical erosion potential. Segment 2 has least stream power indicating the lowest erosional potential but the greatest depositional potential.

STABILITY CONDITION OF THE RIVER

Morphology versus stability

BHR and ER are two important measures of vertical stability of river. Banks of the river becomes highly unstable when BHR exceeds 1.5 (Rosgen, 2001). In this regards, banks of Segments 1 and 4 are highly unstable (Table 3), those of Segments 2 and 5 are unstable, and Segment 3 are moderately unstable. The entrenched streams have ER less than 1.4 ± 0.2 (Rosgen, 1994). In this respect, Segments 1, 4 and 5, having ER less than 1.4 are vulnerable to channel degradation.

MWR and W/D provide information on lateral stability of channel. High W/D ratio is associated with bank erosion and channel widening (Rosgen, 1996). MWR shows that Segments 2 and 3 are vulnerable to lateral instability. Segments 1 and 4 are moderately stable, and Segment 5 very stable. Considering the W/D ratio, all the segments are vulnerable at different degrees to bank erosion depending on bank material involved, vegetation covering and BHR.

Aggrading/degrading potential

Aggradation/degradation potential of the Manahara River was evaluated using Schumm's (1963) relationship,

$$F = 255\, M^{-1.08} \quad (7)$$

where, F and M are defined as:

$$F = W_{bkf}/D_{bkf} \quad (8)$$

$$M = [(S_c \,.W_{bkf})+(S_b \,.\, 2D_{bkf})]/(W_{bkf}+2D_{bkf}) \quad (9)$$

where, S_c is % silt and clay in wetted perimeter of a riffle cross-section and S_b is % silt and clay in a bar material.

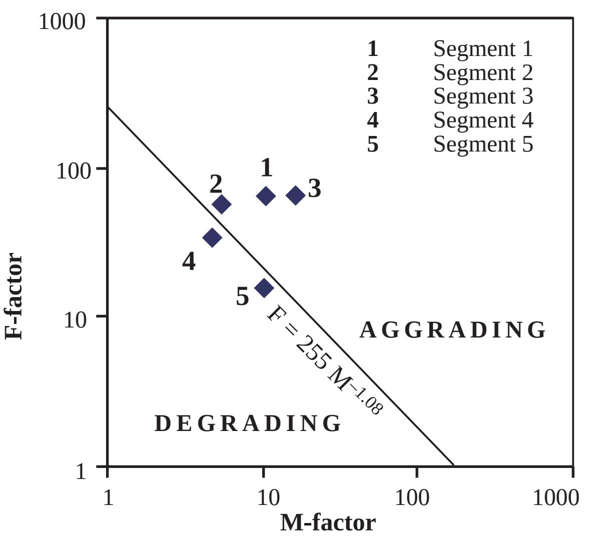

Fig. 4 F-versus M-factor showing aggrading/degrading potential of the Manahara River segments.

Using the plot of F versus M factors (Fig. 4), in which Segments 1, 2 and 3 plot on the aggrading field and Segments 4 and 5 plot on the degrading field, 3rd and 4th order streams have degradation potential, while 5th order stream has aggradation potential.

Deviation of meandering geometry versus stability condition of the river

Many regional and planform relationships have been formulated for large number of natural and artificial streams by various researchers. For instance, L_m = 10.9W1.01 (Leopold and Wolman, 1960) and W_{blt} = 4.4W1.12 (Williams, 1986), where L_m is a meander

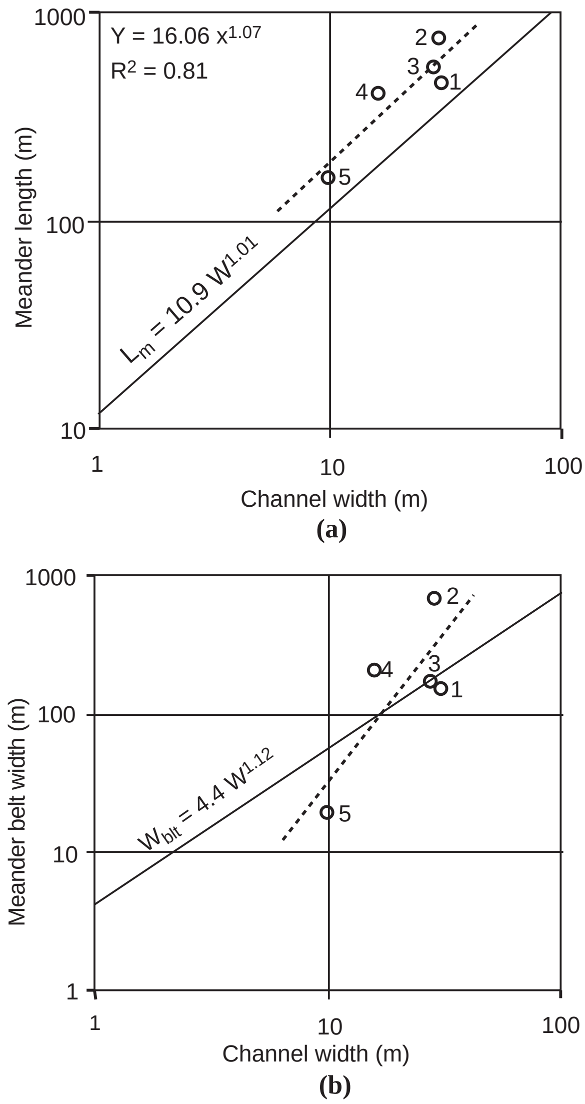

Fig. 5 Meander geometry relationships showing deviation of the Manahara river channels from stability. The established relationships are after Leopold and Wolman (1960).

length, W is a bankfull width, and W_{blt} is a meander belt width. These relationships were used as references, in order to find out deviation of the existing river channel from stability. Considering Fig. 5a and b, both relationships are positive. In Fig. 5a, Segments 2, 3 and 4 plot farther from the indicating deviation of their meander length from stability. In Fig. 5b, Segment 2, 4 and 5 plot away from the curve indicating deviation of their meander belt width from the stability.

CONCLUSIONS

1. Segments 1, 2, 3, 4 and 5 of the Manahara River are classified as ‘F4’, ‘C4’, ‘C4’, ‘B4’ and ‘B4’ streams, respectively. Morphologic analyses suggest that ‘F4’ and ‘C4’ streams are potential to aggradation and ‘B4’ are potential to degradation. Boundary shear stress and Shields number exceed critical dimensionless shear stress of every segment suggesting for enough competency of river segments in transporting their bed materials. Stream power ranging from 79 to 15617.0 KN/s, shows huge fluctuation along the stream of transporting capacity influenced probably by change in slope and stream pattern.

2. Deviation of meander geometry of the segments from stability suggest for existence of systemwide instability. This would produce imbalance of discharge against sediment load and size, and induce changes in planform.

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REFERENCES

Aldridge, B.N. and Garrett, J.M., 1973. Roughness coefficients for stream channels in Arizona, U.S. Geological Survey Open-File Report, U. S. Geological Survey.

Andrews, E.D., 1983. Entrainment of gravel from natural sorted riverbed material. Geological Society of America Bulletin, v. 94, pp. 1225–1231. http://dx.doi.org/10.1130/0016-7606(1983)94<1225:EOGFNS>2.0.CO;2

Andrews, E.D., 1984. Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. Geological Society of America Bulletin, v. 97, pp. 1012–1023. http://dx.doi.org/10.1130/0016-7606(1986)97<1012:DEOFGR>2.0.CO;2

Ohta, Y., 1973. Geology of the Nepal Himalayas, In: K. Arita, Y. Ohta, C. Akiba and Y. Mauro, (Eds.), Geology of Himalayas. Saikon Publication Co. Ltd., pp. 235–259.

Bajracharya, K.R., 2001. Geology of Bhaktapur-Nagarkot area. M. S. Thesis submitted to Central Department of Geology, Tribhuvan University, Kathmandu, Nepal, 76p.

Bajracharya, S.R., 1992. Fluvial system of Kathmandu valley in relation to neotectonics. Bulletin of Department of Geology, Tribhuvan University, Kathmandu, v. 2, no. 1, pp. 173–179.

Bradley, W.C. and Mears, A.I., 1980. Calculations of flows needed to transport coarse fraction of Boulder Creek alluvium at Boulder, Colorado. Geological Society of America Bulletin, Part II, 91, pp. 1057–1090.

Chow, V.T., 1959. Open channel hydraulic. McGraw-Hill, Inc. New York.

Cowan, J., 1959. 'Pre-fab' wire mesh cone gives doves better nest than they can build themselves. Outdoor California, v. 20, pp. 10–11.

Leopold, L.B. and Wolman,, M.G., 1960. River meanders. Geological Society of America Bulletin, v. 71, pp. 769-794. http://dx.doi.org/10.1130/0016-7606(1960)71[769:RM]2.0.CO;2

Rosgen, D.L., 1994. A classification of natural rivers, Cantenna, v. 22, pp. 169–199. http://dx.doi.org/10.1016/0341-8162(94)90001-9

Rosgen, D.L., 2001. A stream channel stability assessment methodology. In Proceedings of the Seventh International Sedimentation Conference, Reno, Nevada, March, pp. 25–28.

Schumm, S.A., 1963. A tentative classification system of alluvial rivers. Circular 477, U. S. Geological survey, Washington, D. C.

Shields, A., 1936. Application of similarity principles and turbulence research to bed-load movement. In: W.P. Ott and J.C. Uchelen (translators), Mitt. Preuss. Verschsanst., Berlin. Wasserbau Schiffbau. California Institute of Technology, Pasadena. CA, Report No. 167, 43p.

Stocklin, J., and Bhattarai, K.D., 1977. Geology of the Kathmandu area and Central Mahabharat range, Nepal Himalaya. Report of Department of Mines and Geology/UNDP (unpublished report), 86p.

Williams, G.W., 1986. River meanders and channel size. Journal of Hydrology, v. 88, pp. 147–164. http://dx.doi.org/10.1016/0022-1694(86)90202-7

Wolman, M.G., 1954. A method of sampling coarse river bed material. Trans. American Geophysical Union, v. 35, pp. 951–956.