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Deterioration of the Nakhu River: impairment on dynamic and recreational functions of the river

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ABSTRACT

The NakhuRiver, which stretches about 25.98 km from the south to the north, drains the southeast part of the Kathmandu Valley and is a fifth order drainage with an average gradient of 0.052m/m and watershed area of 58 km^2. Like other rivers of the Kathmandu Valley, the Nakhu River is threatened by rapid changes in landuse and watershed hydrology, resulting in deteriorated and unstable stream with poor environmental condition was investigated for fluvial morphological and hydraulic parameters, and the whole segments of the river was surveyed for assessing various disturbances to the river.

The overall segments are vertically and laterally unstable as bank height ratio (BHR) and width depth ratio (W/D) ratio exceed 1.5 and 1.4, respectively. Entrenchment ratio of the river segments ranged between 2.87 to 4.00 and thus river segments are not much entrenched. W/D ratio ranged between 30.19 to 49.06 showing that the Nakhu River is more laterally unstable. Many segments of the river are deteriorating day by day due to excess erosion of stream banks and channels, river encroachment, sewer disposal, vegetation clearing on banks etc. Encroachment of channel, clearing of vegetation, pollution of surface water by waste disposal, increase in sediment load due to mines, landuse change and waste dumping and disposal of solid waste along the river banks are major causes for reduction in the dynamic function of the river and degrading river environment. To bring back the river close to its natural function and to gain optimum advantages from the river resource, all the concerning government and non-governmental authorities are required to come with prospective vision on the advanced academic platform to establish a long-term program for river rehabilitation.

Keywords: Nakhu River,rivers of Kathmandu,river environment, river morphology, riverstability condition, river deterioration

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INTRODUCTION:

A river comprises a dynamic environment where different components like flood plain, channel and bed form evolve through various processes that erode, transport, sort and deposit sediments (Leopold and Wolman 1960). River and its processes are related to its watershed area, geology, rocks, soil types, topography and climate. A stable river is one that maintains its dimension pattern and profile over time, without degrading or aggrading. Landuse change in the watershed such as removal of riparian vegetation, channelisation, and encroachment can change the river dynamic equilibrium. A new equilibrium may eventually result but not before the occurrence of large adjustments in channel form such as extreme bank erosion or incision (Lane 1955; Schumm 1960). These adjustment processes can transmit throughout the whole watershed and lead to system wide instability.

The Nakhu River and its tributaries were instrumental in developing the Nakhu River watershed agriculture and civilization. The river system servers as the source of water supply for people living in the watershed. Within the past few years, the river systems have deteriorated rapidly as a result of rapid and unmanaged urbanization. There is heavy pollution of the river as a result of dumping raw sewage, uncontrolled extraction of river sediments like sand, gravel, and bank encroachment, Sediment dumping along the river banks at quarry site in the Nallu River, over withdraws of river water, and bank encroachments are notable disturbances to river in whole segment. While channelisation by constructing gabion wall at river banks is another disturbing factor in the downstream segment. Sedimentation, channel shifting and rapid bank erosion are notable events during high discharge destroying cultivated lands. In order to protect river banks and improve river environment either by applying natural methods or by engineering works, it is important firstly to recognize existing stability conditions and function of the river. Therefore the objectives of the study are to evaluate the existing condition and the stability condition and function of the river.Tamrakar (2004),Adhikariand Tamrakar (2006),Shrestha and Tamrakar (2007), and Tamrakar and Bajracharya (2009) evaluated stability condition of the Bishnumati and the Manahara rivers, the major tributaries of the Bagmati River. As the existing stability condition of the southern tributaries of the Bagmati River is not yet worked out for the Nakhu River, which the largest southern tributary and selected for the study.

NAKHURIVER BASIN

The Nakhu River, which is one of the major tributaries of the Bagmati River (Fig.1) in the Kathmandu basin, flows from the southern ranges of the southern part of the valley. The watershed of the Nakhu River lies from latitude 27°32'15"N to 27°40'40"N and from longitude between 85°17'10"E to 85°24'30"E. The Nakhu River watershed extends about 16 km N-S and about12 km E-W with an altitude ranging from 1266 m to 2625 m above mean sea level. The watershed is surrounded by the Mahabharat Range in the SE -SW while other parts of watershed by quaternary deposits of valley sediments. It is surrounded by Phulbaridada in east (2590m), Gothdada in south (2083m) and Deurali in west (2075m).

The Nakhu River is the perennial river fed by storm and seepage and its watershed has an area of about 58 km^2. The Nakhu River is fifth-order river contributed by two 4th order and one 3rd order major tributaries with three sub-basins viz. the Nallu River, the Lele River and the Burunchuli River sub basin region. Among these sub basins, the Nallu River sub basin is the largest of about 22.64 km^2. The Lele River sub-basin 14.92 km^2, and the Burunchuli River, the smallest is about 4.457 km^2.

The southern part of the watershed, which is surrounded by hills, has high relative relief and northern part with low lying area has low relative relief (Fig.2a). The higher relief in the southern part is due to presence of ridges with hard rock. The drainage texture of the watershed is fine to moderate at the southern part with bed rocks and coarse to very coarse at the central and northern part (Fig. 2b).

The NakhuRiver originates from the Chandragiri Limestone in the south east region, the Tistung and the Sopyang Formations in the south and basinfill sediment of the Kathmandu basin at the north of thewatershed(Fig.3).The Tistung Formation, which consists of meta-sandstone, meta-siltstone and phyllite, is the dominant rock at the southern part of the watershed. Vertical fault trending NW, SE and a few lineaments are also reported from the Nallu River area (Stöcklin and Bhattarai 1977).At the Tikabhairav gorge, the river flows through the thick sequence of the Chandragiri Limestone. The main rock type is yellow to brown weathered limestone of massive appearance from a distance but well bedded, quite platy at close view (Stöcklin 1981). After flowing through gorge, the Nakhu River flows over thefluvio-lacurtrine deposit of the Lukundol Formation,the Chapagaon Formation, the Kalimati Formation and the Kobgaon Formation which covers the central and northern part of the Nakhu River watershed (DMG 1998).

Trend of the precipitation in watershed

The precipitation condition of the Nakhu River watershed area was studied by using the rainfall data obtained from Chapagaon (1986-2008) and Lele (1994-2008) meteorological stations, obtained from Department of Hydrology and Meterology (DHM).

The temporal variation of precipitation shows that the rainfall also varies with altitude and mostly occurs during monsoon period (June to September) and low rainfall occurs during dry period at both stations. The rainfall trend during both dry and monsoon period at both stations is in decreasing trend with time (Fig.4a and b).

Comparing the monthly average rainfall in two stations during 1995-2008(Fig. 5), Lele station receives the largest amount of rainfall and the Chapagaon station receives least amount during June-September. Since theLele River (fourth order stream)receives the greatest rainfall during monsoon period based on the data obtained from the Lele station (Fig. 4a and b)

EXISTING CONDITION OF RIVER

Planiform Pattern

The meander length ratio varies from 18.05 to 34.43 in 1 segment. The meander belt width ratio ranges from 14.91 to 20.02 showing that magnitude of meandering is large in the middle segments 2, 3, then segment 4 and finally least in segment 1(Table 1).

Hydraulic parameters

Four representative segments of the Nakhu River were investigated for plan-form and hydraulic parameters based on resembling more or less morphological patterns, riparian vegetation, stream order and distribution position of the stream stretch (Fig. 6).The entrenchment ratio in all the four segments has nearly same value and all segments are moderately entrenched. Segment 2 has greatest value showing greater affinity towards flooding than other segments. Width depth ratio (W/D) is in the range of 30 to 40 for segments 1, 2 and 4. Segment 3 has the greatest W/D ratio compared to other segments. Segment 3 also has the greatest bank height ratio (BHR) of 5.28. The downstream segments possess comparatively low value of BHR and are vulnerable to lateral shifting of river and flooding.

The Manning's roughness coefficients of four surveyed segments were evaluated following the criteria suggested by Chow (1959), and the results are given in Table1. The higher values are obtained at upstream segment mainly due to channel irregularities, sinuosity, river bed sediment size and instream vegetation. A low Manning's roughness coefficient in lower segment probably helps in high-velocity flow indicating a possibility of bank erosion.

The bankfull discharge ranged from 2.970 m^3/s for Segment 4 to 10.236 m^3/s for Segment 1. The bankfull velocity were also least for Segment 4 (0.511 m/s) and greatest for Segment 1 (0.881 m/s). The downstream increase of discharge is probably due to an increase in cross-sectional area of stream and decrease in Manning's roughness coefficient. Increase in discharge may be due to contribution from additional tributaries.

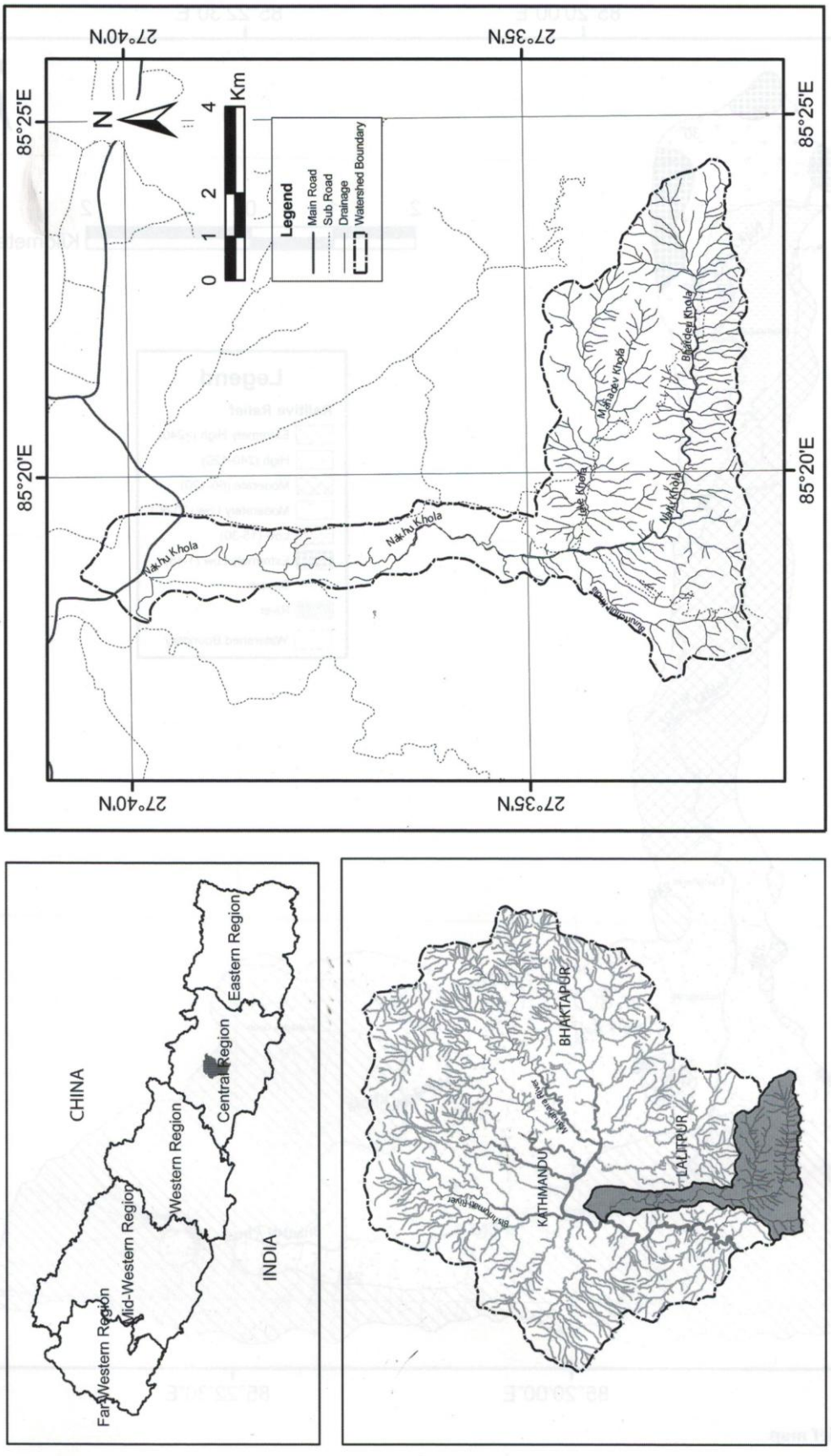

Fig. 1: Location map of study area

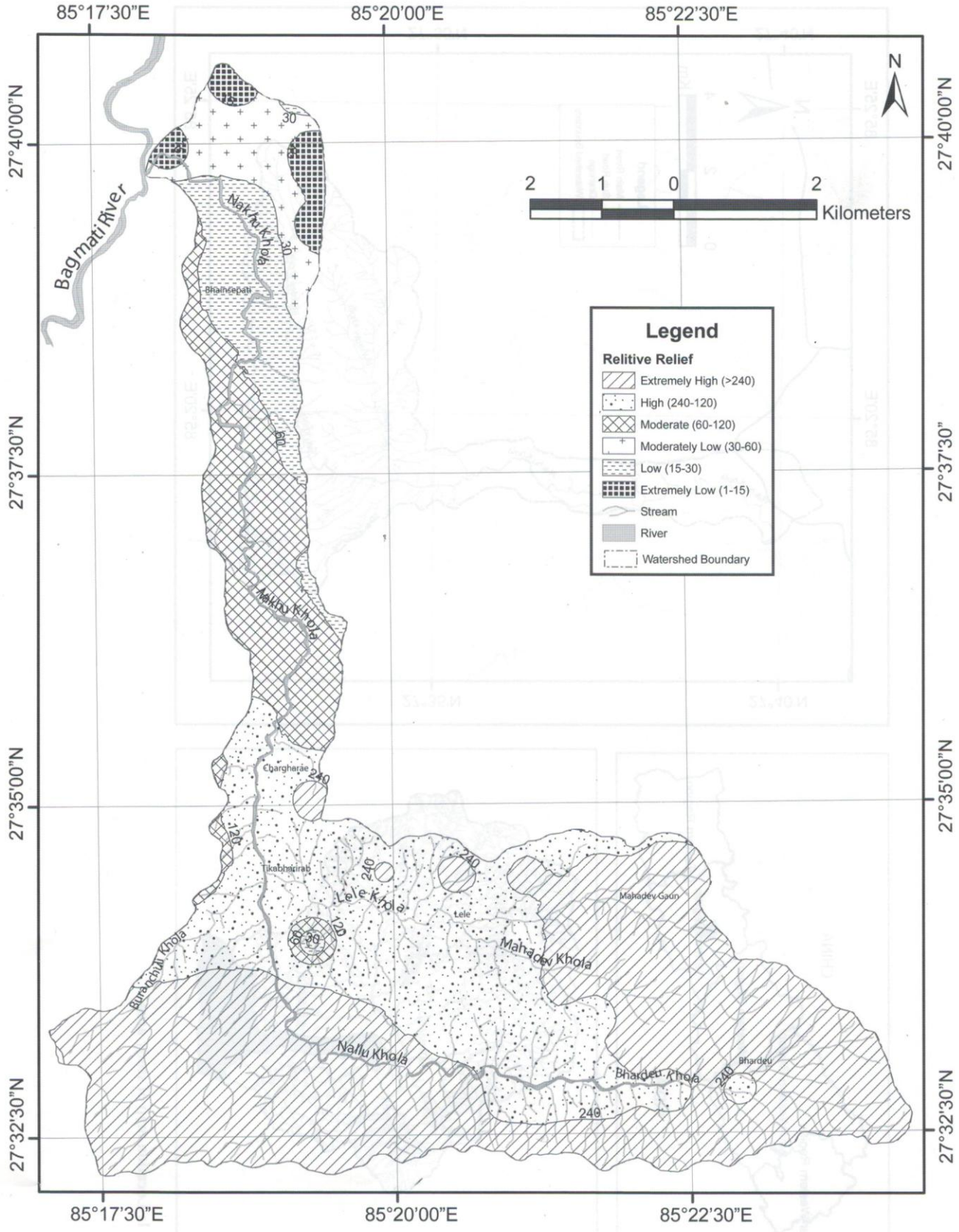

Fig. 2: (a) Relative relief map

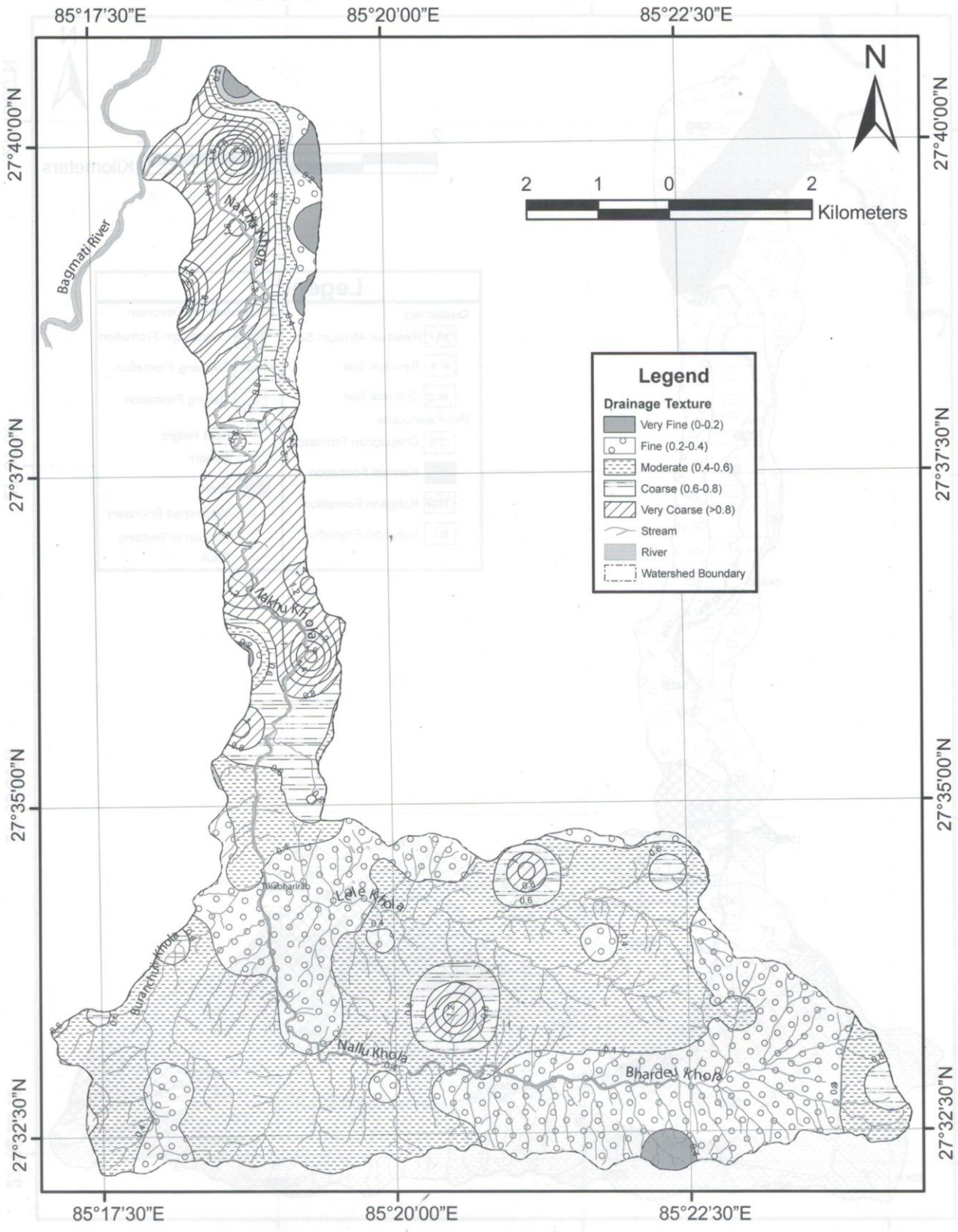

Fig. 2: (b) Drainage texture map of the Nakhu River watershed

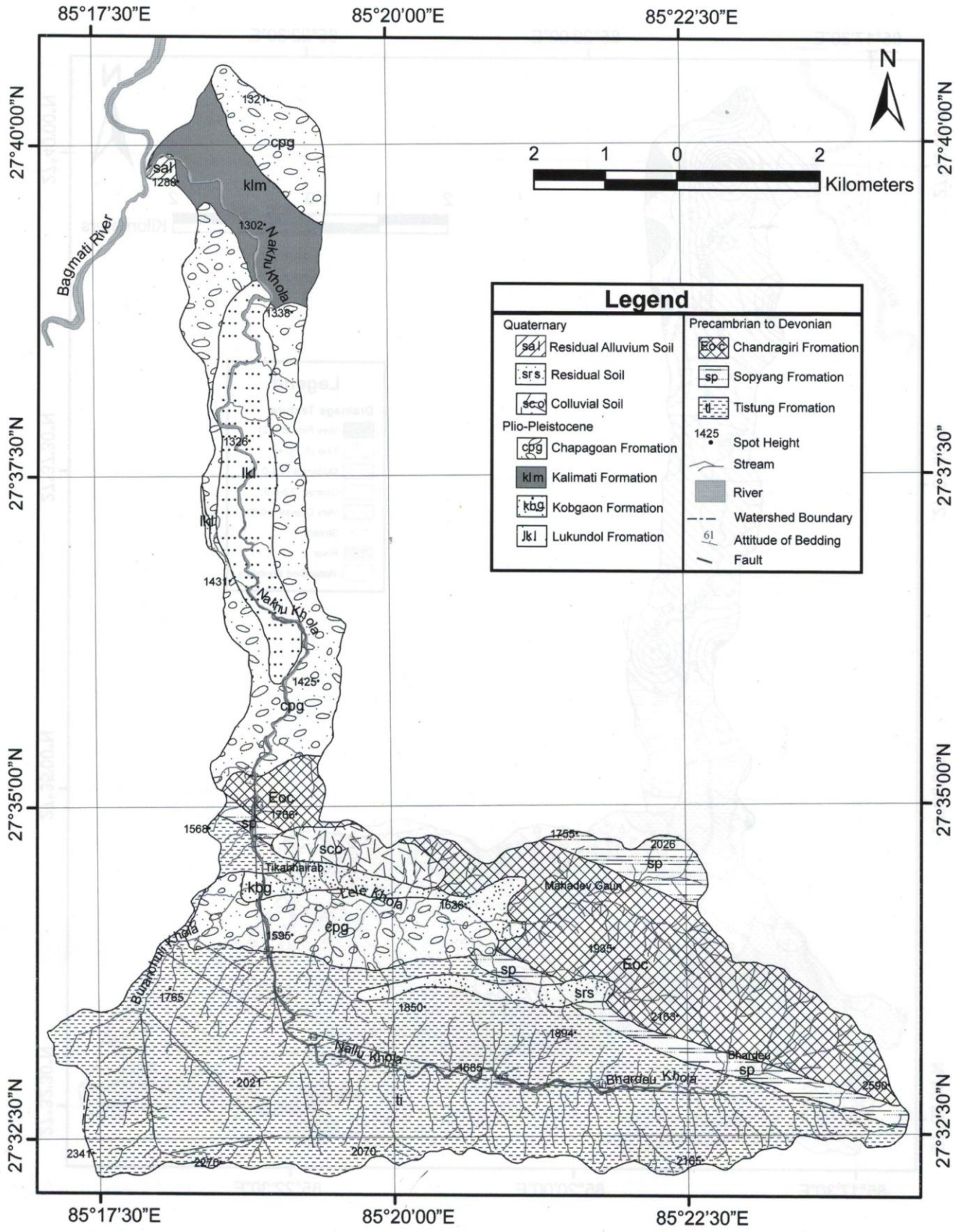

Fig. 3: Geological map of the theNakhu River watershed (modified from DMG , 1998 and Stöcklin and Bhattrai, 1977).

Longitudinal profile

The longitudinal profile of the Nakhu River is concave upward (Fig.7). The average slope of the Nakhu River is 0.052 m/m. The slope of lower order streams decline abruptly when the fourth order stream begins with slope 0.017m/m. The slopes of the segments from 4 to 1 segment gradually decreases from 0.017m/m to 0.012m/m.

Stream categories and habitat

C5 stream type:

On the basis of Rosgen (1994) Segment 1 and 2 fall under C5 stream category with broad valleys with terraces associated with broad well defined flood plains, alluvial soil. These Segmentsare less to slightly entrenched (>1.4) with well-defined meandering channel, high W/D ratio (>12), very low gradient (<0.02 m/m), low sinuosity (1.2). The median diameter of bed material composed of fine sand size grade with gravel. Riparian vegetation is represented by grass and shrubs with few trees.Both the river segments have been affected by clearing of the riparian vegetation, bank encroachment for cultivation and road construction at right

Table 1: Planiform and hydraulic parameters of the Nakhu River

Attribute	Segment 1	Segment 2	Segment 3	Segment 4
Pattern				
Sinuosity,K=L_{tw}/L_{valley} (m/m)	1.17	1.52	1.19	1.25
Meander length, L_m (m)	607.30	574.84	460.22	400.00
Belt width, W_{blt}	263.11	356.36	255.29	211.43
Radius of curvature, R_c	177.62	201.94	137.53	107.09
Manderlenth ratio, L_m/W_{bkf} (m)	34.43	32.26	18.05	31.05
Meander width ratio, W_{blt}/W_{bkf}	14.92	20.00	25.50	16.41
Riffle Crossection				
Width at bankfull,W_{bkf}(m)	17.64	17.82	19.53	12.88
Bankfull x-section area, A_{bkf} (m^2)	11.62	8.39	9.20	5.82
Max depth bankfull, D_{max} (m)	1.00	0.77	0.77	0.72
Flood prone height, W_{fph}	2.00	1.53	1.53	1.44
Width flood prone area ,W_{fpa} (m)	57.52	72.12	51.83	36.92
Max depth top low bank, d_{tob} (m)	2.44	1.81	4.24	1.98
Mean depth at bankfull, $D_{bkf}= A_{bkf}/W_{bkf}$	0.62	0.44	0.40	0.42
Entrenchment ratio, ER= Wf_{pa}/W_{bkf}	3.05	4.00	2.87	3.37
Width depth ratio, W/D= W_{bkf}/d_{bkf}	30.19	39.94	49.06	31.26
Bank height ratio, BHR= d_{tob}/d_{max}	2.62	2.52	5.28	2.79
Max depth ratio, D_{max}/d_{bkf}	1.68	1.70	1.85	1.75
Pool cross-section				
Pool width, W_{pool}(m)	11.86	12.48	13.38	10.03
Pool area, $A_{pool}(m_2)$	5.51	4.25	5.92	5.78
Pool max depth, d_{poo}l(m)	0.85	0.70	0.91	0.91
Slope of Channel,				
Average slope = $\Delta elv/\Delta L_{tw}$ (m/m)	0.012	0.013	0.015	0.017
Wetted perimeter (m)	18.88	18.71	20.41	13.73
Hydraulic radius (m)	0.62	0.45	0.45	0.42
Slope (m/m)	0.012	0.013	0.015	0.017
Manning's roughness coefficient, η	0.090	0.125	0.121	0.144
Bankfull discharge Q (m^3/s)	10.236	4.478	5.473	2.970
Bankfull Velocity, V(m/s)	0.881	0.534	0.595	0.511

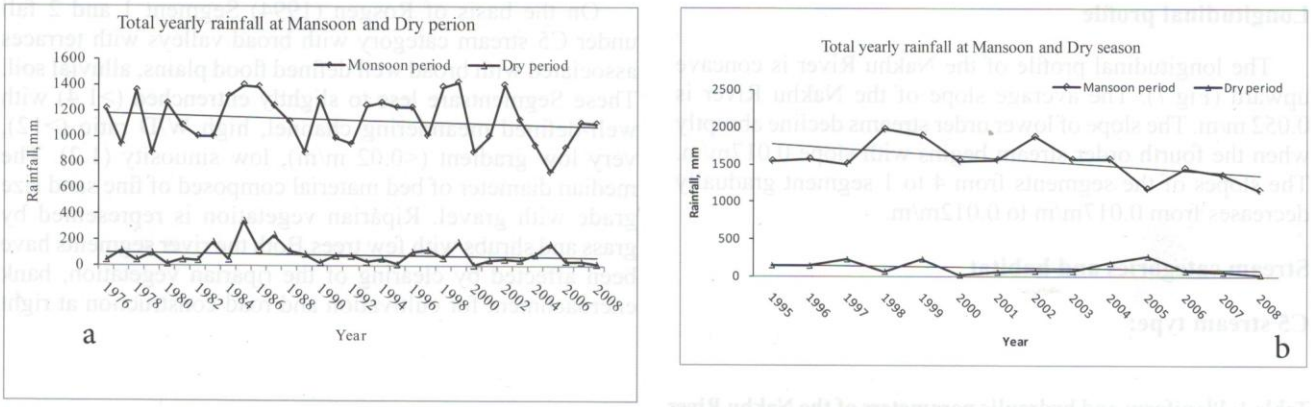

Fig. 4: Total yearly rainfall during Mansoon and dry season at Chapagaon (a) and Lele station (b)

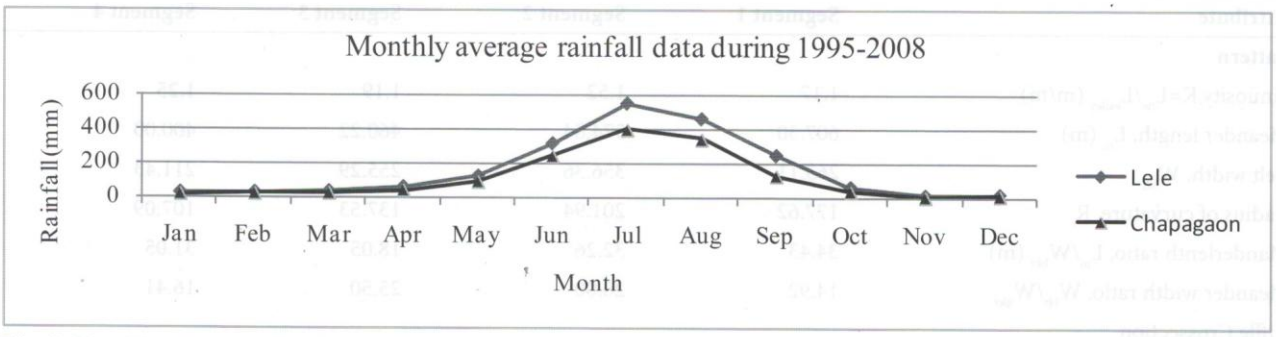

Fig. 5: Monthly average rainfall data during 1995-2008

bank. Segment 1 is even much degraded due to extremely high effluent discharge from settlement since most flood plains of the downstream segment of the Nakhu River is used for built up areas.

C4 Stream type:

Segment 3 and 4 fall under the C4-stream category and are slightly entrenched with W/D ratio greater than 1 and well defined meandering channel with low sinuosity (>1.2) and with very gentle slope. Therefore segments have broad valleys with terraces and flood plains. The bed materials are composed of fine gravel. Abundant point bars and mid channel bars constitute depositional channel elements. Riparian vegetation is represented by grasses, shrubs, and few trees. Major disturbances are channel mining, cultivation of banks and bars, and grazing.

Stability Condition

The aggrading Nakhu River, which is capable of transporting bed material even in normal flow,is very much influenced by human activities is degraded, and is unstable (Maharjan and Tamrakar 2010).

Deviation from the stability condition of the Nakhu River is represented in Figs.8 a and b. The plots of all four segments of the Nakhu River deviate from the predicted curve for stable river after Leopold and Wolman (1960). This suggests deviation of stability of stream from dynamic equilibrium.

Causes of Impairment

Disturbances is defined as the detectable change to the natural sedimentation processes of erosion, transport and deposition that alters the physical characteristics of the stream channel, flood plain and riparian zone. Activities that are causing disturbance to the river corridor includes the construction of diversion, roads and bridges, bank protection, removal of riparian vegetation, grazing, gravel mining and quarrying, and settlement. Disturbance to the river is an event with the potential to harm the natural river environment and are mainly of two types; natural and human induced

Both natural and human induced disturbances cause degradation to river environment. But human induced disturbances are more frequent than natural disturbances.

Natural Cause

The natural factors influencing the NakhuRiver are the gradual change in rainfall and river discharge pattern. Analysis of precipitation and discharge data from available stations within the Nakhu river basin shows that there is gradual decrease in river discharge with decreasing rainfall trend (Maharjan 2010). Though, the average yearly precipitation and discharge shows decreasing trend, but the instantaneous high rainfall during monsoon season causes high discharge and hence sever erosion occurred in the banks. Also the Nakhu River bank consists of unconsolidated muddy gravel and lacks vegetation so banks are easily eroded.

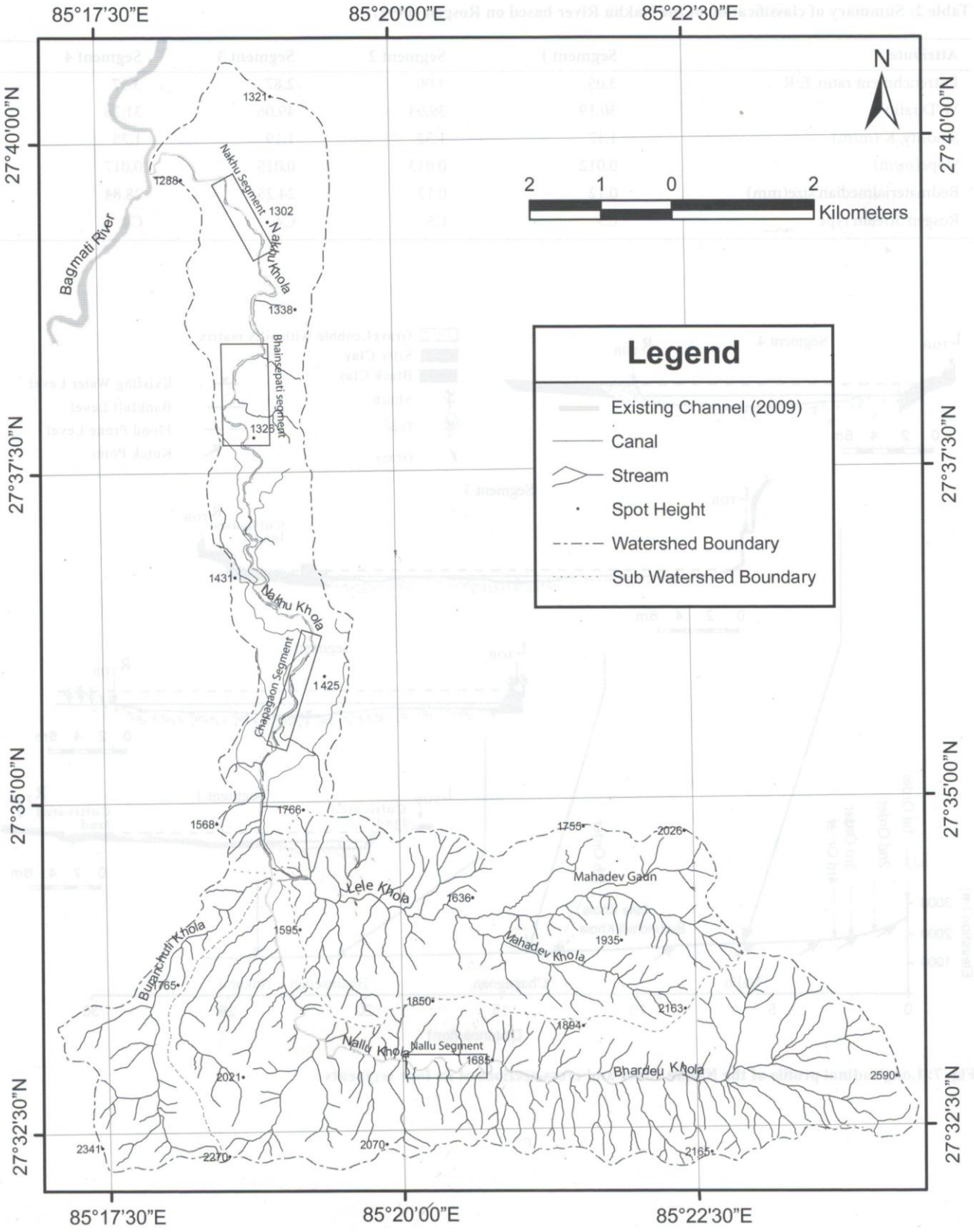

Fig. 6: Four surveyed segments of the Nakhu River

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

Attribute	Segment 1	Segment 2	Segment 3	Segment 4
Entrenchment ratio, E/R	3.05	4.00	2.87	3.37
W/D ratio	30.19	39.94	49.06	31.26
Sinosity, K (m/m)	1.17	1.52	1.19	1.25
Slope(m/m)	0.012	0.013	0.015	0.017
Bedmaterialmedian size(mm)	0.12	0.12	24.25	28.84
Rosgen Stream type	C5	C5	C4	C4

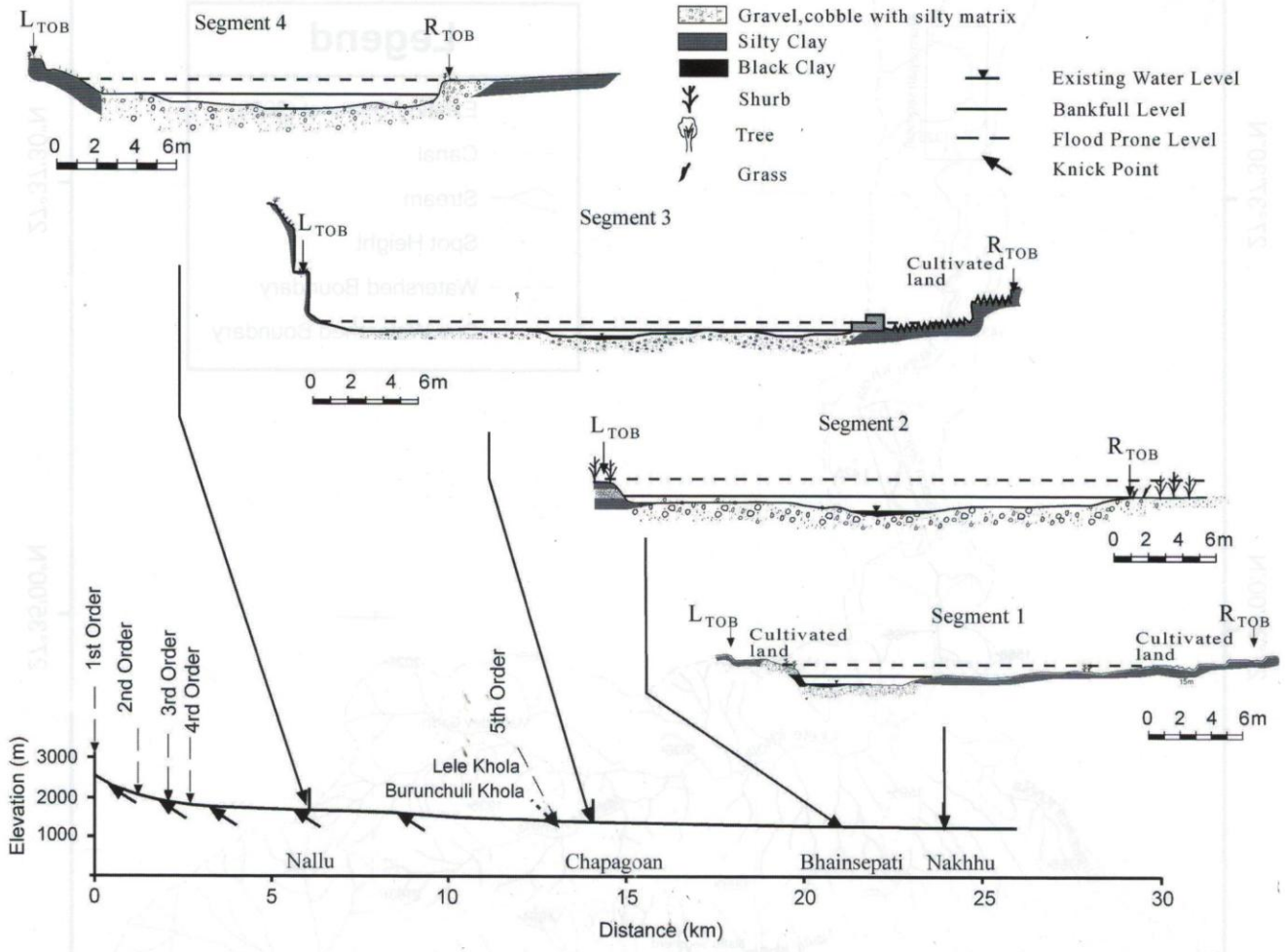

Fig. 7: Longitudinal profile of the Nakhu River and cross-sections of its four segments

Erosion at the meander bend of the Nakhu River in concave bank is higher, where stream dissipate energy, than at other parts of bank. Such meander bend erosion is pronounced in all four segments.

Anthropogenic causes

Anthropogenic causes include bank encroachment, vegetation clearing, dump of sewage, construction of gabion wall to channelise river, mining, landuse change, etc.

Bank Encroachment and channelisation

With the rapid urbanization demand for the living space and cultivating land have increased. Since river consists of fertile floodplain deposits and river terrace, people are attracted towards cultivating in flood plain and river terraces. Therefore, bank encroachment by clearing riparian vegetation is increased along the Nakhu River. Consequently, erosion problem has triggered. In order to control erosion, structures such as gabion walls have been constructed(Fig.9) by government agency. These structures channelize the river and hence cause river instability. Scouring of river bed during high discharge is caused due to upstream channelisation (Fig.10).

Removal of Riparian Vegetation

Riparian vegetation is referred to those plants that grow in the stream bank. Riparian plants play an important role in river ecosystems by providing shade to control water temperature, regulating microclimates, stabilizing stream banks, controlling sediment inputs from surface erosion, and trapping excess nutrient and pollutants helping keep the water clean. In the Nakhu River removal of riparian vegetation for cultivation and settlement is the major problem along the whole river channel.The effect of the riparian vegetation clearing is excess erosion at concave bank and along with decrease in the aquatic lives and deterioration of aquatic habitat.

Livestock Grazing

Livestock grazing is one of the causes that degrade the river environment and also cause instability. Vegetation along the river is destroyed due to grazing and water is contaminated by animal excreta accumulated in the banks. The Nakhu River consists of only few river segments which are influenced by livestock grazing, e.g. in segments 1 and 2. These segments however suffer from vegetation clearing and pollution. Many pig farms are located at the downstream of the Nakhu River along the river banks and flood plains. Sewage and excretory are dumped in the river channel and hence polluting water and impairing recreational function of the river.

Water intake

Most of the river banks and flood plains of the Nakhu River is cultivated. For good cultivation irrigation is very important. In order to irrigate cultivated land, different intakes and water storage tanks have been constructed within river banks. Because of these intakes, there is significant reduction in the water flow in the river. Due to water reduction in the river, river could not support survival condition for aquatic life. Hence this has caused reduction of aquatic lives and river habitat. Reduction in river habitat not only destroys ecosystem but also decreases the recreational value of the river.

Obstructions in stream

Obstructions in the Nakhu River include bridge piers, debris, temporary damming, concrete pipes and improper stream crossings (Fig.11). They constrict the channel, alter the normal flow, create eddies and increase the velocity upstream. The obstruction causes erosion upstream and also downstream from deflection of normal stream flow. In the Nakhu River obstructions at different parts along the whole river are observed.

Road Extension

Extension of road at the right bank along the river segment from Nakhu to Tika Bhairabis another major deteriorating cause of the Nakhu River. Due to untechnical road extension, the river channel and bank are encroached destroying riparian vegetation and consequently, increasing bank erosion (Fig. 12). Construction of road has also channelised and increased the depth and slope of the channel. Several cut banks for road have also suffered from excessive erosion during high discharge, thus washing away cultivated lands.

Landuse change

With the rapid urbanization in the Kathmandu Valley, scarcity of land for settlement forced people to live in the river banks and flood plains. Bank encroachment for cultivation and settlement increased. The transformation of productive cultivated land to nonproductive settlement also increased (Figs.13a and 13b). Within 14 years, cultivated land has decreased from 30.65% (1995) to 24.9% (2009) and settlement area has increased from 1.3% (1995) to 6.12% (2009) of the watershed area. Though lands of the watershed have been modified to cultivate and other purposes from the past decades, current rates, extents and intensities of landuse changes are far greater than past, driving unprecedented changes in ecosystems and environmental processes inthe watershed. Vegetation removal in the watershed leaves soils vulnerable to massive increases in soil erosion by wind and water, especially on steep slopes of quarry area, also releases pollutants to the atmosphere. This not only degrades soil fertility over time, reducing the suitability of land for future agricultural use, but also releases huge quantities of nitrates, phosphorus from fertilizer and sediments to streams and other aquatic ecosystems, causing a different negative impacts such as increased sedimentation and turbidity. In the Nakhu River watershed quarries have increased from 0.04% (1995) to 0.6% (2009) of the total area which have directly reduced the forest area.

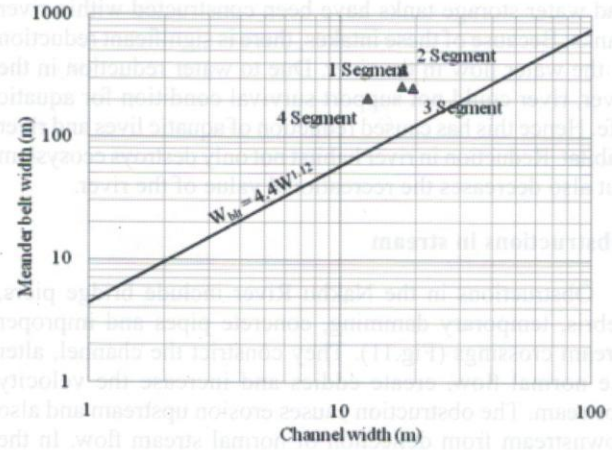

Fig. 8a channel Stability

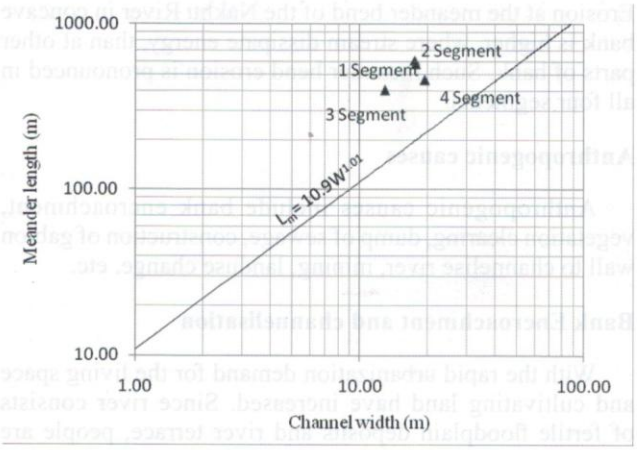

Fig. 8b channel Stability

Quarry and mining

Huge quarry for aggregates and few gravel mining activities are operating along the Nakhu River at Nallu village development committee. Sediments from the quarry are dumped in the river channel and river bank. These sediments dumped in the river have increased turbidity in the river water and hence no aquatic lives can survive and have destroyed river ecosystem. Other impact of quarrying is the channelization and bank encroachment for road in the quarry area. The purpose of such road is to transport quarried material from the site. Vegetation clearing along the river channel and hills of the quarry area has also reduced the recreational value of the river landscape.

Dump of sewage pipe and garbage

River is used as the easy means of disposing of solid waste and sewer in the cities. These are the potential factor for decreasing water quality and river habitat. This is one of the major causes of degrading habitat in the downstream part of the Nakhu River from the Nakhipot Bridge to the confluence with the Bagmati River. The change of water colour from light grey to black, bad odor of water, and increase in suspended solid organic waste from upstream to downstream the of the Nakhu River also indicate degradation of the water quality. The pH of the river water ranges from 8.3 to 6.4, EC ranges from 15.1 to 115.4 ms/m, NH_4 from 0.16 to 10 mg/l, NO_3 from 0.23 to 0.46 mgNO_3–/l and COD from 20 to 75 mgO/l from upstream to downstream. This degradation of the water quality and habitat of the Nakhu River is a main cause in reduction of aquatic lives and recreational value of the river.

DISCUSSION

The Nakhu River segments are C5- and C4- stream types with aggrading nature. The river is also competent in transporting bed material since boundary shear stress and Shield number exceeds the critical dimensionless shear stress in all segments (Maharjan and Tamrakar 2010). The upstream segments have greater bed roughness and hence low discharge while downstream segments have low roughness and high discharge. The Nakhu River segments are slightly entrenched and has high W/D ratio accelerating lateral shifting. The meander geometry relationship also shows deviation of the river segment from stability.

The river is deviated from stability by different anthropogenic activities like channelisation, obstruction to river flow, vegetation clearing, bank encroachment, grazing etc. The channelisation at upstream cause scouring and erosion in the river bed and bank at downstream which increase sediment load in the river. Dump of sewage and solid waste is frequent in downstream segments flowing through cities causing degraded water quality of river. Vegetation clearing for cultivation, quarry and settlement along the river bank is another cause of deterioration or river. Sediment input and turbidity of river has increased due to quarry which has decreased aquatic life and hence decreased recreational value of river. Vegetation clearing has not only created erosion problem but also has reduced river habitat due to lack of shade to regulate river water temperature. Road extended by encroaching right bank is the recent notable disturbing factor. Because of haphazard road construction, unstable cut banks has created excess bank erosion and also reducing recreational value of river. Beside these, natural causes as local erosion at cut banks also impairs river.

The Nakhu River is deteriorating day by day both due to natural and human cause. Impacts due to natural cause may not be stopped but can be minimized by using different protective techniques. But human induced causes disturbing river environment can be controlled by stopping and prohibiting these activities. Since the Nakhu River is very much deteriorated, steps towards protecting river environment should be implemented in time. River bioengineering and implementation of rules and regulation

are important factors for rehabilitation and protecting river environment.

CONCLUSION

The Nakhu River draining the southern part of the Kathmandu basin is the fifth order river fed by three main tributaries viz. the Nallu River, the Lele River and the Buranchuli River. The river segments belong to C4- and C5- type stream and are of aggrading nature.

Like the other river flowing though the Kathmandu valley, the Nakhu River is also deteriorating day by day due to natural and human induced causes. Human-induced causes are more frequent and contribute more for deteriorating the river than natural causes. Quarrying,channelisation and channel modification, riparian vegetation clearing, over withdrawal of river water are main causes which are impairing the river currently. In order to rehabilitate the Nakhu River into natural condition, human induced disturbances should be reduced and river restoration works like river bio-engineering, creating riparian vegetation buffer zone, etc should be implemented. Beside prevention steps, people should be educated about importance of river environment and recreational values of river.

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Fig.9: Bank encroachment and channelization for settlement

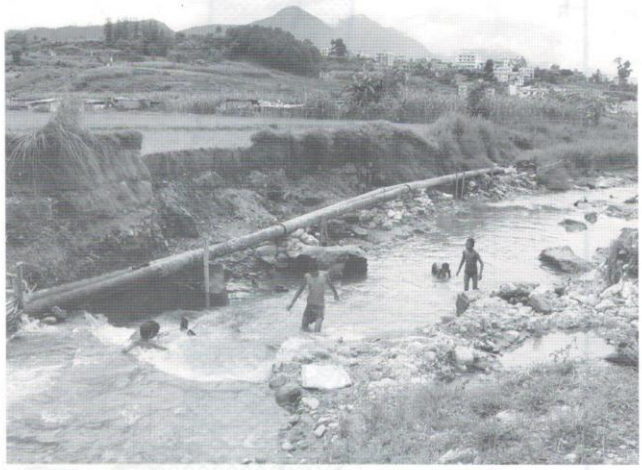

Fig.10: Scour of the river channel due to channelization at up-stream

Fig. 11: Sediments from quarry dumped along river channel and obstruction to river flow

Fig. 12: Excessive erosion in cut bank and road extended at right bank or river

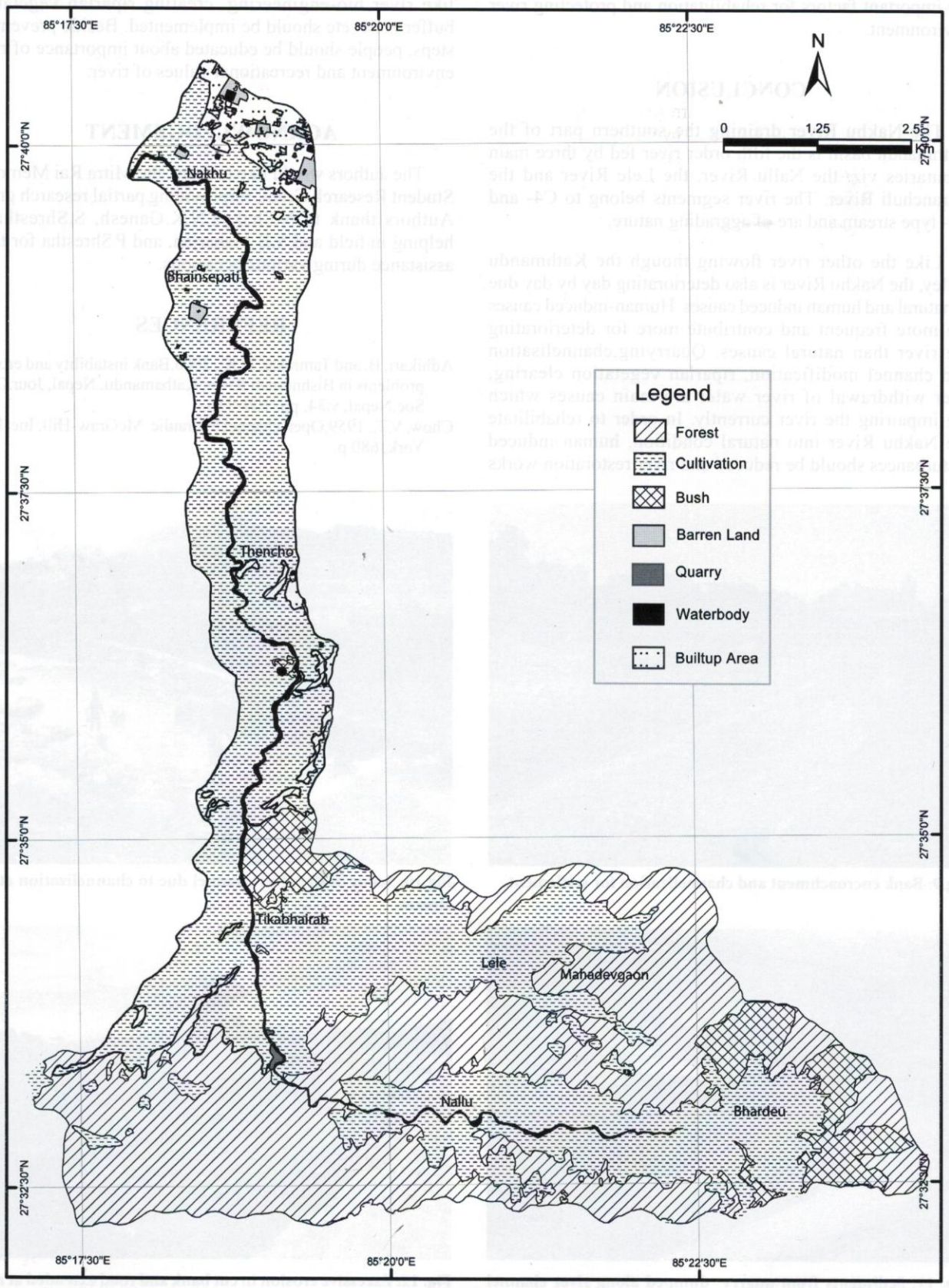

Fig. 13a: Landuse map of Nakhu River watershed (a) based on topo-sheet 1995

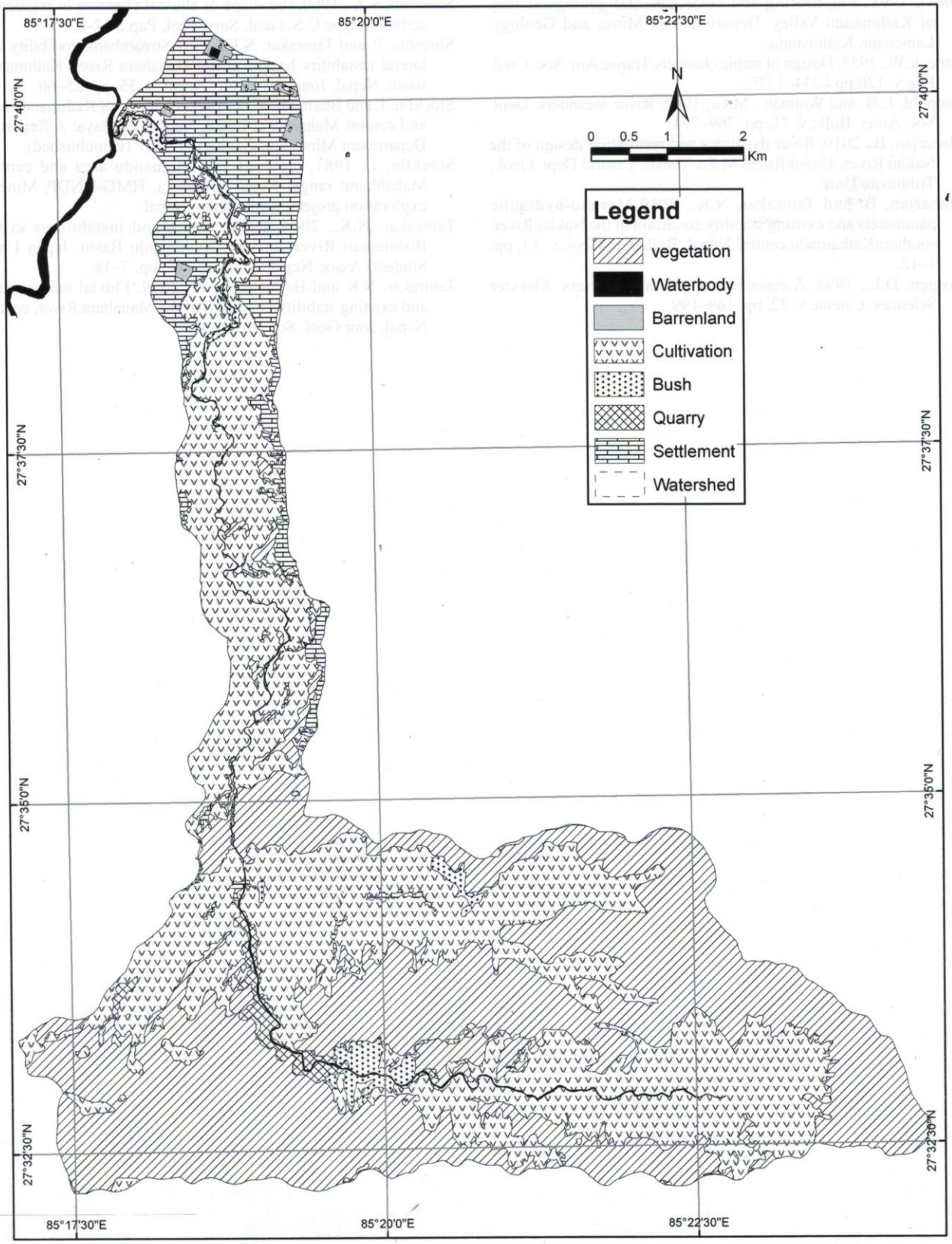

Fig. 13b: Landuse map of Nakhu River watershed (b) Google Earth 2009

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