RIVER DYNAMICS AND RESTORATION DESIGN OF THE NAKHU KHOLA

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Recommendation

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River Dynamics and Restoration Design of the Nakhu Khola

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ABSTRACTS

The fifth order Nakhu Khola, flowing from the south towards north direction drains southeastern part of the Kathmandu Valley and functions as major tributary of the Bagmati River. Like other rivers of the Kathmandu Valley, the Nakhu Khola is also threatened by changes in watershed hydrology and land use, resulting in unstable streams with poor habitat and water quality. Impacts include eroding stream banks, unsafe water supply, impaired habitat, fish kills, flooding, and loss of flood plain functions. Causes of stream impairment include channelization, increased sediment loads and loss of riparian vegetation.

In order to restore the degrading the Nakhu Khola into its natural condition, its present conditions is identified and river is classified by following Rosen's designation of classifying stream. Four representative segments: Nakhu Segment, Bhainsepati Segment, Chapagaun Segment, and Bhardew Segment from downstream to upstream of the Nakhu Khola were studied in detail for their fluvial morphological parameters, substrate sediment and existing stream conditions. The overall segments are vertically and laterally unstable as the value of BHR and W/D ratio exceeds 1.5 and 1.4, respectively. Since the slope and velocity exceeds critical values, the Nakhu Khola is competent for transporting the channel sediments present in the channel and bar even during normal flow. The Chapagaon Segment is most vertically and laterally unstable with greatest bank height ratio and width depth ratio than other segments The channel modification map shows no change in the primary river meandering pattern but only in the secondary meandering pattern. Encroachment of channel, clearing of vegetation, increase in sediment load due to mines, landuse change and waste dumping and

disposal are major causes for degrading river environment. Aggrading and degrading potential of the Nakhu Khola is evaluated by using F versus M graph. All the segments of the river lies in the aggrading field. When channel width, meander length and meander wavelength of the segments are plotted to find stability, the Bhainsepati Segment deviates most from stability than the other segments. Parallel erosion, sheet erosion, impinging flow erosion, slump, rill and gully erosion are major erosion processed in the watershed. Bank erosion hazard in the river segment is very high at quarry site, low at gorge where as other parts show moderate to high erosion.

Like other rivers of the Kathmandu Valley, the Nakhu Khola is also very much degraded and impaired due to different anthropogenic causes as well as due to natural cause. But human causes are more frequent and degrading river more than due to natural cause. Human disturbances like bank encroachment, channelization, cultivating flood plains, vegetation clearing and obstruction to natural flow are present in whole river segment. Therefore, to protect river from further degrading, mitigation measures as well as restoration works of river should be done. Mitigation measures such as reconstruction of natural channel; riparian vegetation zone establishment etc. should be implemented. River restoration and establishment of vegetation zone can be done by different methods such as vegetation works, bioengineering works, engineering works and channel design. The Nakhu River has poor vegetation so vegetation zone should be established in the whole segment. Channel design is needed only in quarry sites where quarrying caused the Nakhu Khola to flow without distinct channel. Beside restoration works to bring back the river close to its natural function and to gain optimum advantages from the river resourse, all the concerning government and non-government authorities are required to come with long term program for river rehabilitation and restoration.

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Abbreviation

AD	Anno Domino
BS	Bikram Sambat
BEHI	Bank Erosion Hazard Index
BHR	Bank Height Ration
DMG	Department of Mines and Geology
ER	Entrenchment Ratio
EU	European Union
ER	Entrenchment Ratio
ICIMOD	International Center for Integrated Mountain Development
MLR	Meander Length Ratio
MWR	Meander Wavelength Ratio
NE	Northeast
NW	Northwest
SE	Southeast
SW	Southwest
TIN	Triangulated Irregular Network
TU	Tribhuvan University
UNDP	United Nation Development Program
VDC	Village Development Committee
W/D	Width Depth Ratio

CHAPTER ONE

INTRODUCTION

BACKGROUND

A river is a flowing body of water in an open channel, which is most wide spread, and most effective erosional agents in the earth. From the earliest times in the history of humankind, water, in the form of lakes, seas, and especially rivers, has played an essential role in the development of civilization. Rivers have been a source of food since pre-history.

Most of the rivers of The Kathmandu Valley like the Bagmati River, the Bishnumati River, and the Manahara River etc are being polluted and degraded day by day due to the bank erosion, mining of construction material, encroachment of the channel area, disposing of municipal and industrial wastes and artificial modification of channel. Generally, these problems have evolved due to the unplanned urbanization, poor infrastructure for sewage disposal and sanitation, poor plan and policy of the municipality and lack of awareness in people. Therefore, the present condition of the most of the river of the Kathmandu Valley is environmentally deteorated.

Like other rivers of The Kathmandu Valley the Nakhu Khola, which is one of the major tributaries of the Bagmati River and draining southern part of the Kathmandu Valley, is also threatened by changes in watershed hydrology and land use. Impacts include eroding stream banks, unsafe water supply, impaired habitat, flooding, and loss of flood plain functions. Causes of stream impairment include channelization, increased sediment loads, loss of riparian vegetation, bank encroachment and over withdraw of water for irrigation and drinking. With the over population in the Kathmandu Valley, bank and floodplain encroachment rate are increasing causing unstable and degrading channel. Anthropogenic cause like disposal of sewage, solid waste and chemical waste from the nearby settlement area and industries is also polluting river. Hence, most of the banks and segments have altered remarkably.

Water of the Nakhu Khola has been used for various purposes mainly for irrigation and drinking. It is acting as the main source of water for irrigating fertile flood plains and river terraces of the Nakhu Khola watershed. It is also main source of drinking water for some parts of Lalitpur and Kathmandu. Historically, important canal, known as *Raj Kulo*, which is main source of water for Dhunge Dhara of Lalitpur, is also fed by water of Nakhu Khola. The Nakhu Khola being such an important natural resource for the Kathmandu Valley, it is degrading rapidly with rapid unplanned urbanization. So if the river degrading continuous and not restored to its natural condition it may bring serious problems to the river environment, human health and reductions in bio diversities and natural flow of river. In order to know present condition of the Nakhu Khola and identify methods for restoring river into natural conditon, Nakhu Khola has been selected for the study.

PREVIOUS WORKS

Many geologists have undertaken exploration and research project to find out basement geology as well as surface geology of the Kathmandu Valley. Some geologists have carried out researches focusing on rock while some focusing on soft basin sediment of Kathmandu Basin. Despite many works related to rocks and basin fill sediments of The Kathmandu Valley only few geologist have conducted researches based on river, river erosion processes and river environment condition of valley. This nature of work has been conducted only in the Bishnumati and the Manohara River of The Kathmandu Valley.

Stöcklin and Bhattarai (1977) have investigated the geology of the basement rocks of the Kathmandu Valley in detail. They have included all the rocks of Kathmandu area into the Kathmandu Complex, which is divided into the Bhimphedi Group and the conformably overlying the Phulchoki Group. These Groups are again subdivided into several formations.

The hills to the north and northeast are composed mainly of gneisses, schist and granites belonging to the Precambrian Bhimphedi Group and the southern western hills are made of the lower Palaeozoic the Phulchoki Group consisting of limestone, metasandstone, slates and quartzites. The Nakhu Khola watershed lies in the Phulchoki Group of the Kathamandu Complex with rocks belonging to the Tistung Formation, the Sopyang Formation and Chandriagiri Formation along the river banks of Nallu and the Nakhu Khola. Many lineaments, parallel to the Nallu Khola, are developed in the Tistung Formation.

Hagen (1969) developed the concept of nappe structure in the Nepal Himalaya. He first delineated the Kathmandu Nappe with its root zone to the Langtang Himalaya through the Gosainkund Tectonic Bridge. In which he described the shale found in the south of the Kathmandu as “the Chitlang Series” and prescribed the age to be of Cambrian, as trilobite fossils were found for the first time. At the same place, other fossils also occur; then exact determination, however, has still to be carried out. In the limestone overlying the Chitlang Series, Bowman found, a long time ago, crinoids, which he considered to be of upper Silurian age.

Sharma (1977) studied the geotectonic of the Kathmandu block based on lithology, stratigraphy and structures. According to the study there exists an anticlinorium to the north and a synclinorium to the south of the valley which itself is a faulted anticline. The Nakhu Khola watershed lies in the southern part of valley where synclinorium is developed.

Fluvial system of the Kathmandu Valley in relation to neotectonics was studied by Bajracharya, 1992. He concluded that most of faults and joints developed within the Kathmandu Valley are of Plio-Pleistocene age and some are still active.

Third order drainage basins of the Kathmandu Valley have been analyzed by Bajracharya (1996) and concluded that the morphometric parameters of the fluvio-lacustrine sediment are highly correlated with the basement rocks of the basin.

Yagi et al. (2000) and Saijo et al. (1995) have studied recent activities of active faults in and around the valley. Isolated mounds, scarps and depressions express the fault morphology. The faults dislocate the colluvial slopes and terraces of the late Pleistocene. The Quaternary sediments near the fault zone are tilted. The field evidences suggest the downthrow of the footwall along the southwestward dipping fault plane. They estimated an average vertical displacement rate of 1 mm/yr on the Kathmandu South Fault running along the southern margin of the Kathmandu Basin (Yagi et al., 2000).

Maharjan, D.K and Tamrakar, N.K, studied the quality of siltstones from The Tistung Formation for concrete aggregate from the Nallu Khola area, the Kathmandu Valley. The test on siltstone from The Tistung Formation indicates that the aggregates are physically, mechanically, and chemically sound.

P.C.L. Rajbhandari studied the extent, nature and causes of the disaster caused by a debris flow in the Nallu Khola watershed on 30 September 1981 A.D. The debris flow killed 70 persons and destroyed many houses, and agriculture land. He estimated the volume of debris deposited in the L-8 stream of the Nallu Khola which is estimated to be about 14700 cu m, 60% of which was contributed by the four landslides of the catchment.`

The first engineering and environmental map (1:50,000) of the Kathmandu Valley has been published by Department of Mines and Geology (DMG, 1998) under the technical cooperation with Federal Institute of Geosciences and Natural Resources. According to the map published, the Nakhu Khola watershed consists of basement rocks belonging to The Tistung Formation, the Sopyang Formation, and the Chandragiri Limestone of Phulchoki Group at southern part of watershed. While watershed consists of soft sediment of the Kobgaon Formation, the Chapagaon Formation, the Lukundol Formation, and the Kalimati Formation belonging to age Pliocene to Pleistocene. Recent colluviums, residual soil and alluvium

Yoshida and Igarashi, 1984; Dongol, 1985; Yoshida and Gautam, 1988; Sakai, H., 2001 studied valley sediments of the Kathmandu Valley. However, Yoshida and Igarashi (1984) have conducted most detailed statigraphic study of the valley sedimentsbased on surface geological survey and paleomagnetic studies. They classified valley sediments into eight stratigraphic units (Table 1.1).

Table 1.1: Stratigraphic units of the Kathmandu Valley (after Yoshida and Igarashi, 1984)

Age	Stratigraphic unit	Composition	Distribution
Holocene	Recent Flood Plain	Sand, silt and clay	Along the BagmatiRiver and its tributaries
	Lower Terrace deposits	Micaceous sand and gravel	Along the BagmatiRiver and its tributaries
	Patan Formation	Laminated arkosic sand ,silt clay and peat layers	Mainly around Patan and Kathmandu cities
	Thimi Formation	Arkosic sand, silt clay, peat and gravel	Around Kathmandu at Pashupati, Airport, Thimi and Bhaktpur
	Gokarn Formation	Laminated arkosic sand silt clay and peat	North part of the KathmanduValley around Gokarna area
	Boregaon Terrace Deposit	Rounded gravel with silt and sand laminated	Southern area of the KathmanduValley near Chapagaon and Boregaon village
Pleistocene	Chapagaon Terrace Deposits	Subrounded gravel of phyllite and metasandstone	Southern area of the KathmanduValley near Chapagaon village
	Pyangaon Terrace Deposit	Sub rounded gravel of metasandstone and phyllite	Southern areas of the KathmanduValley near Pyangaon and Godavary village
Pliocene	Lukundol Formation	Weakley consolidated clay, silt and and beds with lignite layers	Along terrace, scarps near Chapagaon village, probably widely distributed in the subsurface of the KathmanduValley

Sakai (2001) studied the Kathmandu basin sediment and reclassified into the different stratigraphic schemes for southern, central and northern parts of the basin. The southern parts was divided into Tarebhir redefined the Lukundol and the Itaiti Formations in ascending order. The northern part was divided into the Bagmati, Kalimati and Patan Formations from bottom to top. He also correla6ted this newly proposed stratigraphy of the Kathmandu Basin sediments with that by previous workers, as Yoshida and Igarashi (1984), Yoshida and Gautam (1988), Shrestha et al. (1998) and Sakai et al. (2001).

Sakai (2001) mentioned that the Kalphu–Dhauwarr Khola Fault and Chandragiri Fault bound the northern and southern margins of the Kathmandu basin, respectively. Both are active faults cutting the late Pleistocene sediments. Between these two major faults, there are some unnamed faults in lacustrine deposit in Kathmandu valley. Among these, one of the faults runs parallel along the Nakhu Khola near confluence with the Bagmati River and Nakhu Bazaar.

Some of the previous works done on the different rivers of Kathmandu are:

Tamrakar (2004) studied degradation problems of Bishnumati River and concluded that River channel scouring, bank erosion, dilution of riparian vegetation, contamination of river by waste disposal are the major problems in the Bishnumati River corridor.

Bajracharya (2006) studied environmental condition of the Manahara River and concluded that river environment is degrading due to human induced as well as natural causes. This river is vertically as well as laterally unstable and river has shifting its course continuously, and magnitude of shift is variable at different segments.

Adhikari, B. and Tamrakar, N.K. (2007) studied bank instability and erosion problems in Bishnumati River, Kathamandu. They found high bank erodabiligy and channel in stabiligy in this river.

Shrestha (2007) also studied stability and erodibility of the Manahara River and found that the river has been suffering from severe bank erosion problem due to human as well as natural causes.

Shrestha and Tamrakar (2007) studied the stream erodability and latral instabiligy hazard in Manahara River, Kathmandu basin, Nepal. The river is known for itshigh bank erosion and lateral instability, which is caused by anthropogenic disturbancs and near bank stress.

Tamrakar (2010) studied the Bishnumati River gave different bioengineering works to restore impaired river into natural condition.

OBJECTIVES

Some of the rivers of the Kathmandu have been studied by different researchers for river environment, disturbing factors and bank erosion hazard. Yet the study on the river restoration has not been focused in earlier studies. Therefore, study attemps to design restoration model for the Nakhu Khola using vegetation, hydraulic structures and geomorphic adjustments.

The main objectives of the present study are:

- To identify the existing condition of the Nakhu Khola
- To identify the impaired river reaches that needs to be restored into natural condition.
- To suggest restoration methods that can to be applied in the impaired river reaches of the Nakhu Khola to restore back into natural condition.

APPLICATION OR BENEFIT

Benefits of the present study includes

- Information on status of river and its banks provide current situation of the Nakhu Khola Watershed in terms of environment, hazard, flow competency, and tendency of bank erosion loss.
- By understanding, the river dynamics and trend of river lateral shifting and bank erosion would be helpful for elucidating future phenomenon of instability and hence take preventive measures for bank protection.
- Suggesting for proper management of flood plain by using them for economic and recreational value. E.g.: construction of fishery pound, parks etc.
- By understanding, the river dynamics and trend of river lateral shifting and bank erosion would be helpful for elucidating future phenomenon of instability and hence take preventive measures for bank protection.
- Flood hazard map, the bank erosion hazard map will be useful for organization working on preservation of soil erosion and river management for landowner, farmer, planner and developer.

LIMITATIONS

Few limitations exist in present research, however such were overcome.

- The map of scale 1:25,000 and aerial photograph 1:50,000 available from topographic survey department lacks recent information such as changed drainage, newly constructed structures, etc. So, satellite photos of Google earth will be used to overcome problems.
- Only two gauge station for rain fall measurement within water shed. So, it may not be enough for accurate analysis.
- There is lack of data on river discharge and sediment load from 1980 to recent. So correlation between rainfall and discharge in the Nakhu Khola watershed is not possible in current study.

CHAPTER TWO

THE NAKHU KHOLA BASIN

LOCATION

The Nakhu Khola watershed is located in the southern part of the Kathmandu Valley. The Nakhu Khola flows from SE towards NW within the Lalitpur district (Toposheets 2785 06A, 2785 06C, 2785 06D). It extends from latitude 27°32’15”N to 27°40’40”N and in longitude 85°17’10”E to 85°24’30”E (Figure: 2.1).

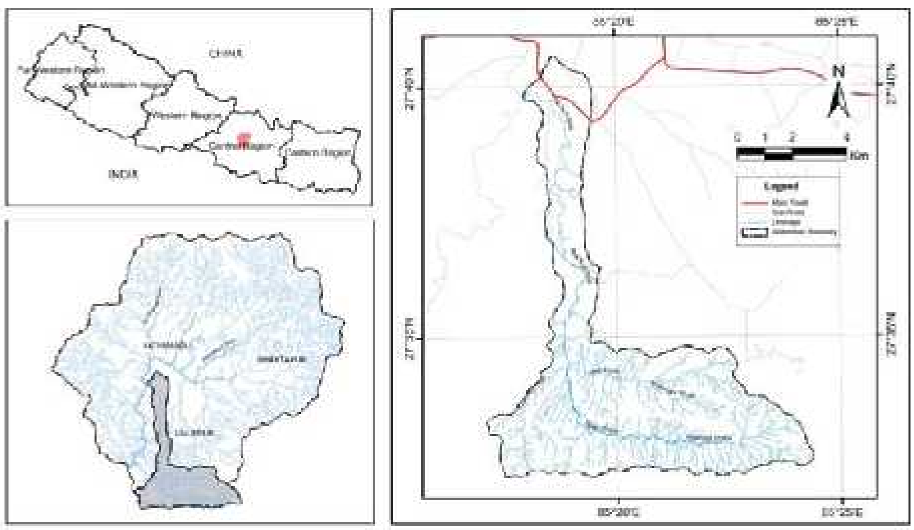


Figure 2.1:Location map of the study area

MAJOR RIVER SYSTEM

The Nakhu Khola watershed, elongating about 16 km NW to SW and about 12 km SW to SE direction, has an area of about 58 km^2.The Nakhu Khola originates from the Phulbaridada of the Phulchowki Range which lies at SE of the watershed. At origin point, it is known as the Bhardeu Khola, which is known as the Nallu Khola at the NakhuVillage and finally it is called The NakhuKhola after it meets the Burunchuli and the Lele Khola at Tikabhairab.

The Nakhu Khola is fifth Order River and contributed by two fourth order and third order major tributaries with three sub- basins viz the Nallu Khola, the Lele Kholaand the Burunchuli Khola sub basin region. Among these sub basisns, the Nallu Khola sub basin is largest about 22.64 km^2. The Lele Khola with 14.922 km^2 and Burunchuli Khola is the smallest of about 4.457 km^2.

The Nakhu Khola has total length of 25.98 km, which extends from Southeast towards North-West and meets with the Bagmati River near the Chobar gorge. It is sinuous river with high meandering at some parts with flood plains along its course. It has deposited pebble, cobble, gravel and boulder with mud matrix. It has several tributaries major are the Lele, theNallu and the Buranchuli Khola. The Nakhu Khola originates from the Phulbaridada of the Phulchoki Range which lies at SE of watershed. At origin point, it is known as Bhardeu Khola, which is known as the Nallu Khola at Nallu village and finally it known as the Nakhu Khola after it meet Burunchuli and Lele Khola at Tika-Bhairab.

The fifth order the NakhuKhola is fed by two fourth order streams viz Nallu Khola and Lele Khola, and one 3rd orderBurunchuli Khola with three sub-basins. Among these sub-basins, Nallu Khola sub-basin is largest of about 22.64 km^2, Lele Khola with 14.92 $km^2$and Burunchuli Khola is the smallest of about 4.46 km^2. The Nakhu Khola watershed has area of about 58 km^2. The drainage order of the Nakhu Khola watershed area ranges from first order to fifth order. The fifth order stream has greater length extending about 14 km. The first, second, third, and fourth order stream extend for 1.19 km, 0.89 km, 0.59 km, 9.31 km, which is measured along the main stream respectively.

In the Nakhu Khola watershed, there are mainly three kinds of drainage pattern viz Dendritic, Trellis and Barbed drainage pattern. The trellis drainage pattern is observed at Nallu area at southern part of watershed. The dendritic drainage pattern is observed in the hills of Bhardeu, Lele, and Burunchuli. The barbed drainage pattern is observed at the confluence of the Nakhu Khola with the Bagmati River.

TOPOGRAPHY

The highest altitude of the study area is 2625 m and the lowest altitude is 1260m above mean sea level. The watershed is surrounded by Mahabharat Range in the SE to SW while other parts of watershed by quaternary deposits of valley sediments (Figure 2.2). It is surrounded by Phulbaridada in East (2590 m), Gothdada in South (2083 m) and Deurali in west (2075 m).

Table 2.1: Physical characteristics of the Nakhu Khola watershed

	Catchment area (km^2)	Highest elevation (m)	Lowest elevation (m)	Main stream length (km)
Nallu Khola	22.64	2625	1417	11.05
Lele Khola	14.92	2377	1417	7.4
Burunchuli Khola	4.46	2301	1417	5.6
Nakhu Khola	58.34	2625	1230	25.98

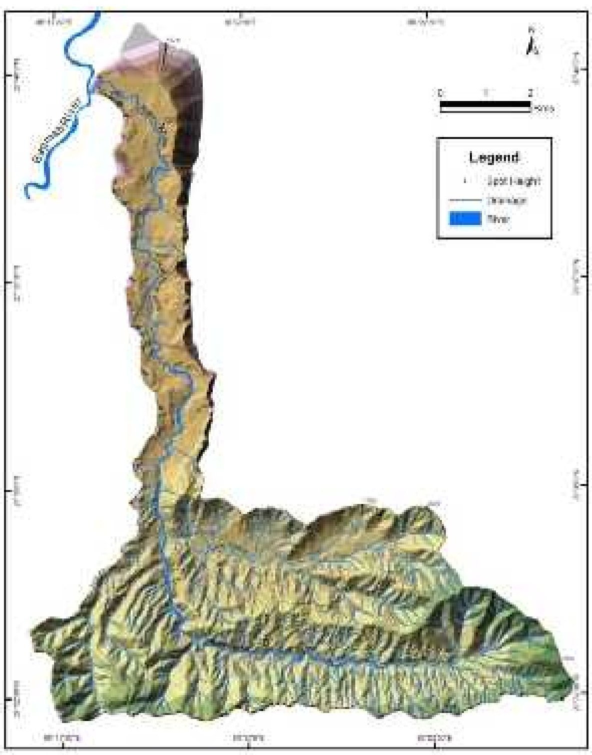


Figure 2.2: Tin image showing topography of the study area

Shape and Dimension of Drainage Area

The Nakhu Khola basin spreads from south, southwest and southeast of Lalitpur district. It is narrow in south west to north of watershed. The watershed has nearly elliptical shape at southern part, which gradually becomes narrow towards southwest and north part of watershed. It covers an area of 58 km^2 with three major sub basins *viz*.the Burunchuli Khola, the Lele Khola, and the Nallu Khola. Among these sub-basins, the Nallu Khola sub-basin is largest with area of about 22.64 km^2, the Lele Khola with 14.92 km^2 and the Burunchuli Khola is the smallest of about 4.46 km^2 (Figure 2.3). The Nakhu Khola watershed has area of about 58 km^2. The drainage order of the Nakhu Khola watershed area ranges from first order to fifth order.

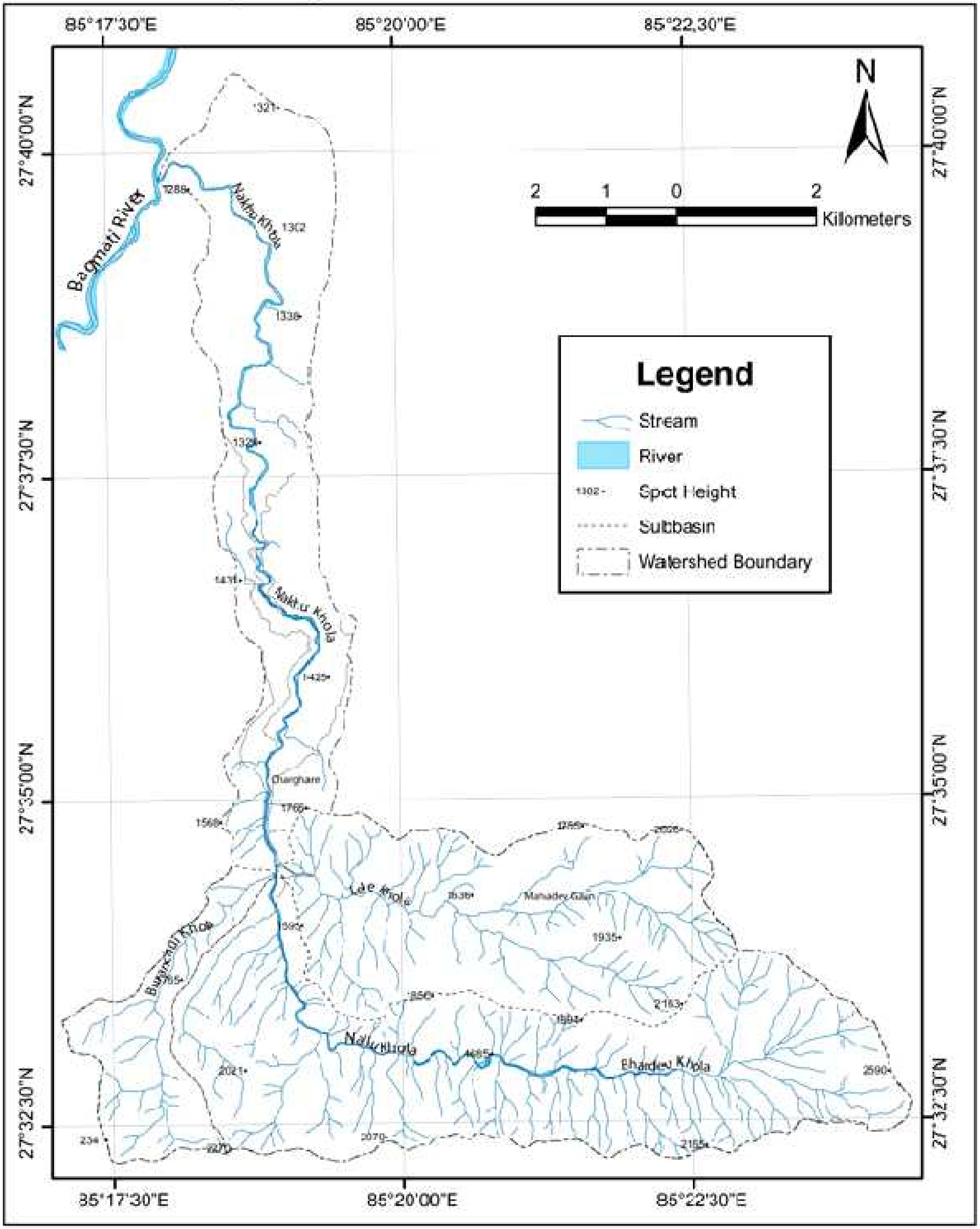


Figure 2.3: Drainage map with sub-drainage basin of the study area

GEOLOGY

The Nakhu Khola watershed comprises of meta-sedimentary rocks of Phulchoki group and soft sediments of The Kathmandu Valley. The Nakhu Khola originates from the Chandragiri Limestone and traverses basin fill sediment at Bhardeu in the southeast, rocks of the Tistung and the Sopyang Formation of the Phulchoki Group of rock in the south and basinfill sediment of the Kathmandu basin at the north of watershed (Figure 2.4). Therefore, the geology of watershed area can be studied under following titles as

- Geology of basement rock
- Geology of soft sediments

Geology of basement rock

The basement rock of The Nakhu Khola watershed belongs to the rocks of Paleozoic Kathmandu Complex (Stöcklin and Bhattarai, 1977, Stöcklin 1980). The lithostratigraphic nomenclature in the present study area is used after Stöcklin (1980). This area occupies the very core stratigraphic position of the entire Mahabharat Synclinorium and consist the rocks of the Kathmandu Complex (Figure 2.4). The Kathmandu Complex has been divided into the Precambrian Bhimphedi Group (Nadir et al., 1968-73), consisting of relatively high grade rocks, and the Phulchoki Group consisting of un-metamorphosed or weakly metamorphosed rocks containing fossils of early-middle Palaeozoic age (Table 2.2). The Nakhu Khola watershed consists of unmetamorphosed rocks of the Phulchoki Group of Cambrian to Ordovician age. The south-eastern parts of watershed consist of the Chandragiri Limestone and while the Sopyang and The Tistung Formation covers southern part of watershed which consists of metasandstone, siltstone and quartzite. The rocks are fractured, foliated and faulted. The general trend of rocks is NW-NE.

Table 2.2: Stratigraphic subdivisions of the Kathmandu Complex

Rock unit	Group	Formation	Thickness (m)	Main Lithology	Age
Kathmandu Complex	Phulchoki Group	Godavari Limestone	300	Limestone, dolomite	Devonian
		Chitlang Formation	1000	Slate	Silurian
		Chandragiri Limestone	2000	Limestone	Ordovician
		Sopyang Formation	200	Slate, Calc-phyllite	Cambrian
		Tistung Formation	3000	Metasandstone	
	----------------Transitional Zone----------------------				
	Bhimphedi Group	Markhu Formation	1000	Marble, Schist	Precambrian
		Kulikhani Formation	2000	Quartzite, Schist	
		Chisapani Formation	400	White quartzite	
		Kalitar Formation	2000	Schist, Quartzite	
		Bhainsedobhan Marble	800	Marble	
		Raduwa Formation	1000	Garnetiferous Schist	

(Source: Stöcklin and Bhattarai, 1977, Stöcklin, 1980)

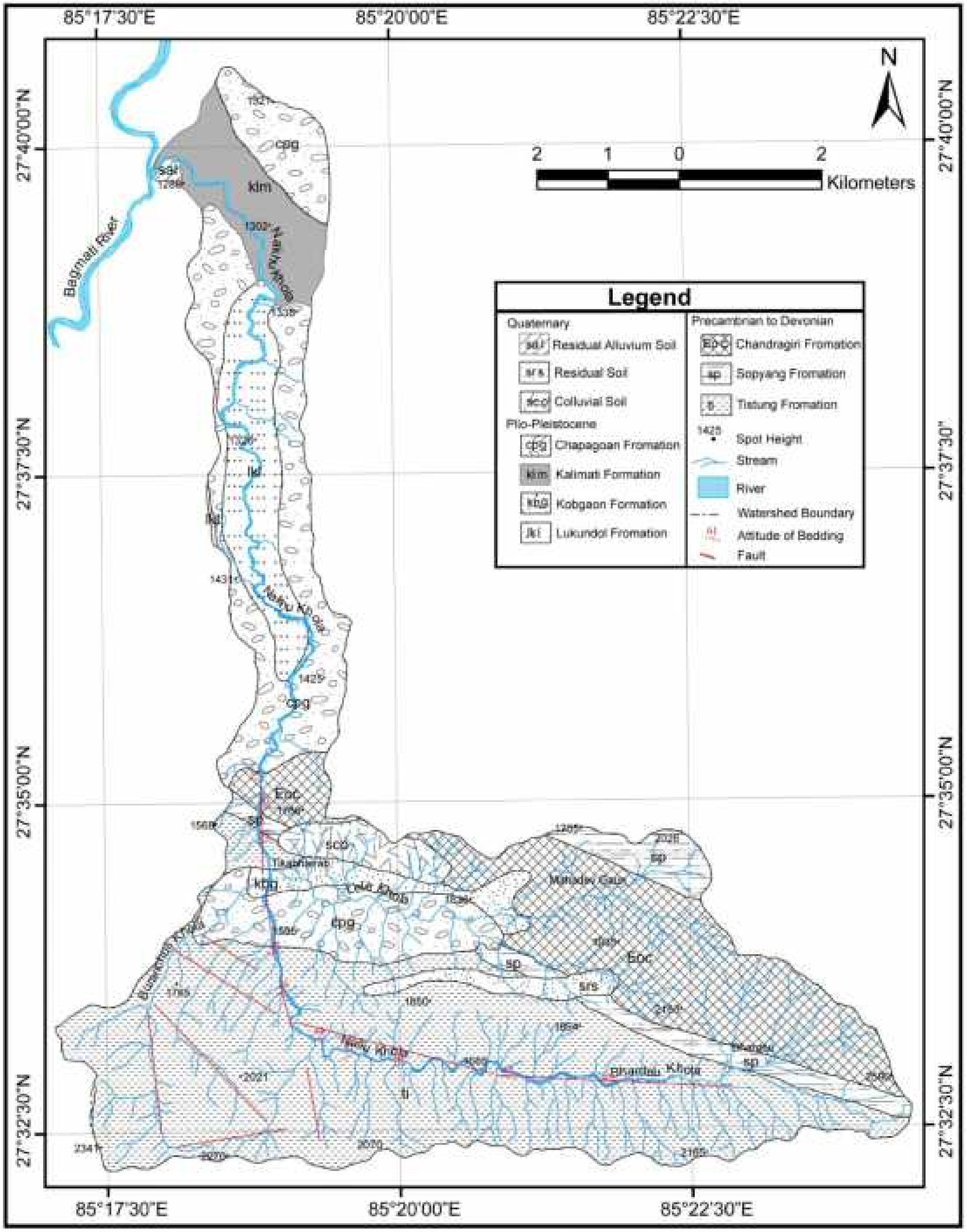
The Tistung Formation is composed of weakly metamorphosed fine to medium-grained sedimentary rocks (Stöcklin and Bhattarai, 1977). The rocks of this formation comprises medium-bedded, light to dark grey metasandstone and siltstone at its lower parts whereas thin to medium bedded sandstone intercalated with thin-bedded slate and phyllite at its upper portion. The southern part of the study area consist the Tistung Formation which is distributed along the banks of Nallu Khola and around the hills of Nallu, Bhardeu, Buranchuli, and near the Tikabhairab temple. The rock exposure is grey-dark grey (brown in weathered), fine-grained, massive to fracture siltstone with metasandstone and slate is also present in some parts. A vertical fault trending NW-SE and a few lineaments are also reported from the Nallu Khola area (Stöcklin and Bhattari, 1977).Attitudes of bedding are 236°/57°NW, 176°/36°NW at southern part of watershed near quarry site located along the Nallu Khola.

The Sedimentary structures like ripple marks and cross laminae are present in siltstone and metasandstone (Figure 2.5).

The Sopyang Formation is a transitional zone with mixed lithology of both, the Tistung Formation and the thick The Chandragiri Limestone (Stöcklin and Bhattarai, 1977). The rocks of this formation is distributed in the Khatrigau on the right bank of the Mahadev Khola at quarry site, at the some parts of road cut section along the road from Lele to Bhardeu, east of Tikabhairab Temple along the Lele Khola. The rock exposure consist of grey-brown-yellow, fine- to medium-grained, thick-bedded metasandstone, and siltstone.

Attitudes of bedding measured are 165°/29°NE, 42°/44°NE

The Chandragiri Limestone is the most prominent formation of the Phulchoki Group. The main rock type is yellow or brown, weathered limestone of massive appearance from a distance but well-bedded quite platy at a close view (Stöcklin and Bhattarai, 1977). Attitudes of Bedding measured are 282°/61°NE, 269°/48°N This formation is distributed at the southeastern part of watershed in the hills of Pulbari Dada, Bhardeu, along the Mahadev Khola near Mahadev Gaon and gorge near Chargare.



(Compiled from Stocklin and Bhattarai 1977, Engineering and Environmental Geological Map of Kathmandu Valley, Published by DMG)

Figure 2.4: Geological map of the the Nakhu Khola watershed (modified from DMG , 1998 and Stöcklin and Bhattrai, 1977)

Geology of soft sediments

The fluvio lacurtrine deposit covers the central and northern part of the watershed (Figure 2.4). The fluvio lacustrine deposits in the watershed are the Chapagoan Formation, the Kalimati Formation, the Kobgaon Formation and the Lukundol Formation (DMG, 1998) (Table 2.3).

Table 2.3: Stratigraphic units of the Kathmandu Basin (after Shrestha et al,1998)

S.N.	Formation	Description
i.	Tokha Formation (tka)	The formation mainly consists of dark grey clay, brownish grey sand and poorly sorted, sub angular to rounded sandy gravel with occasional peaty clay and lignite layers. The thickness of the formation is up to 200 m or more.
ii.	Gokarna Formation (gkr)	It comprises light grey; fine laminated and poorly graded silty sand, intercalation of clay of variable thickness as well as in upper part Thimi diatomite (1m) present. The total thickness is up to 300 m and more. The sediment of this formation is considered to be fluvio-deltaic facies.
iii.	Chapagoan Formation (cpg)	It consists of sub-rounded to rounded silty sandy gravel, occasionally with boulder beds sometime with thin (<1m) clayey silt and silty sand, and at some places lignite pockets. The total thickness is up to 110 m.
iv.	Kalimati Formation (klm)	The formation is exposed in the central part of the valley around the main cities of Kathmandu, Lalitpur and Bhaktapur. It consisits of grey to dark silty clay and clayey silt, at places calcareous nature and phosphate mineral (vivianite). Organic clay, fine sand beds and peat layers are common. Occasionally lignite seams upto 20m is also present. In Kharipati area quartzite and biotite schist boulder beds with sandy gravel and minor clayey and sandy silt layers are present. The total thickness of the formation is 450 m or more.
v.	Kobgaon Formation (kbg)	It exposed along the western bank of the Bagmati River and the Nakhu Khola in the southern part of the valley around Yutiki, Pharping, Bansbari and Tika Bhairab area. The formation consists of light grey to grey laminated fine sand, occasionally with sandy clay, silty sand and sub rounded to rounded, poorly graded gravel. The thickness is up to 50 m or more.
vi.	Lukundol Formation (lkl)	It is exposed around the Sunakothi, Bungmati, Khokana and Saibhu Bhaisepati area. It is composed of semi-consolidated sandy, clayey silt interbedded with gravel and clayey sand, peat and lignite of upto 3 m thickness. The total thickness of the formation is up to 80 m.
vii.	Basal Boulder Bed (bbd)	It is the oldest basin fills sediments, which unconformably overlie the basement rock of the Valley. The formation is exposed at the southwestern part of the valley near Katuwal Daha around the Bagmati River. It consists of mainly of compact boulder conglomerate mixed with silt and sand. Boulders are of quartzite, granite, gneiss and meta-sandstone. The thick of this formation is up to 300 m.

(Source: Shrestha et al., 1998, DMG)

The Chapagoan Formation found in the central part of study area, consists of sub-rounded to rounded silty sandy gravel, occasionally with boulder beds sometime with thin (<1m) clayey silt and silty sand, and at places lignite pockets. The total thickness is up to 110 m.

The Kalimati Formation is exposed in the northern part of the watershed around the Nakhuarea. It consists of grey to dark silty clay and clayey silt, at places calcareous nature and phosphate mineral (vivianite). Organic clay, fine sand beds and peat layers are common. Occasionally lignite seams up to 20m also occurs. The total thickness of the formation is 450 m or more. This formation shows purely a lacustrine facies.

The Kobgaon Formation consists of lightgrey-to-grey laminated fine sand, occasionally with sandy clay, silty sand and sub rounded to rounded, poorly graded gravel. The thickness is up to 50 m or more.

The Lukudol formation is a mud dominant sequence of marginal lacustrine formation. It also contains common occurrence of lignite beds ranging 1 to 50 cm (Figure 2.6 and 2.7). The Lukundol Formation is also composed of black to gray organic mud, rythmite sand and silt and cobble granite, sand and granite (Figure 2.7). It exposed along the bank of the Nakhu Khola in the middle part of the watershed.

The gravelly river sediment of The Nakhu Khola is distributed along the river channel, point bar, flood plain. In the upsteam segment, at Bhardeu, few boulders with gravely silty mud are dominant. At left bank of the Nallu Khola near Nallu village there is thick debris deposit with angular clast and mud deposited by recent debris flow.

Figure 2.5: Ripple mark observed in the rocks of the Tistung Fromation exposed along the Nallu Khola.

Figure 2.6: Exposure of thick lignite bed in the Lukundol Formation

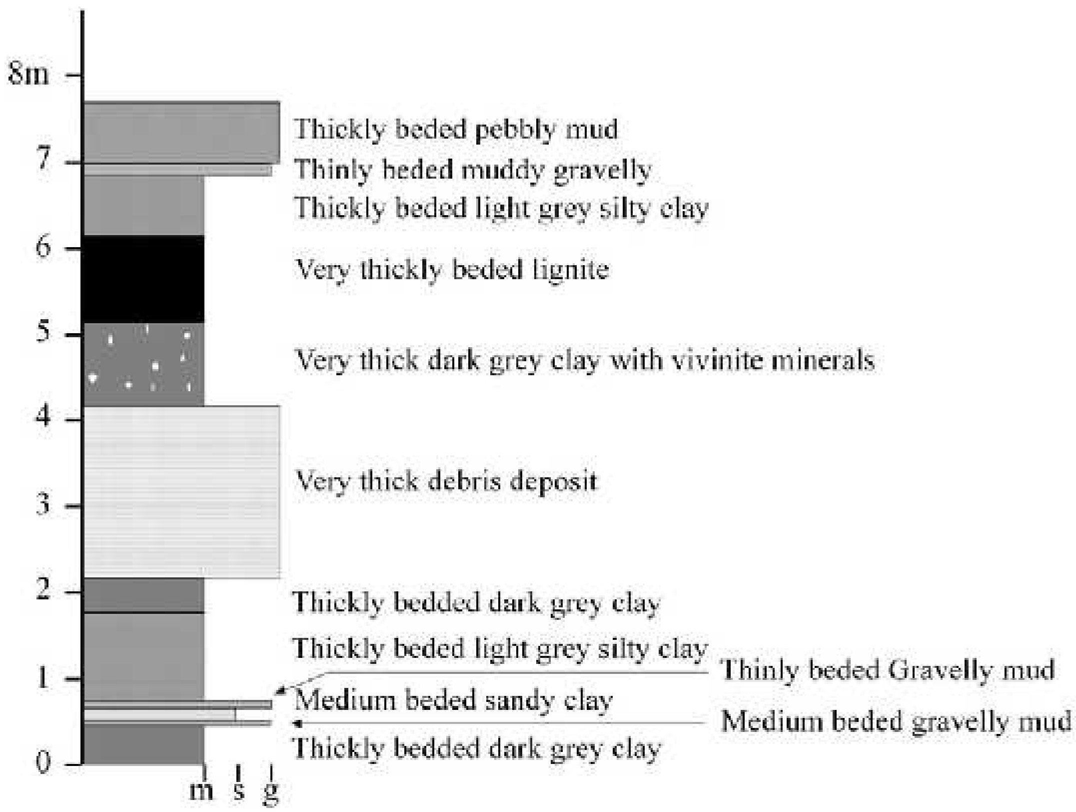


Figure 2.7: Litholog of the Lukundol Formation exposed at left bank of the Nakhu Khola near Chapagaon.

CLIMATE

Climate is an aggregate of prevailing environment for a considerable span of time. Koeppen (1998) has classified the climate into five major categories (Table 2.4) based on vegetation, temperature, rainfall and their seasonal characteristics as:

Table 2.4: Classification of climate according to Koeppen (1998)

S.N.	Category	Description
1.	A	Tropical forest climates, hot all seasons
2.	B	Dry climate
3.	C	Warm temperature rainy climates, mild winters
4.	D	Cold forest climates, server winter
5.	E	Polar climate

According to the classification system of Koeppen, the climate of the Kathmandu Valley falls under category C, i.e., warm temperate rainy climate; mild winters.

The Nakhu Khola watershed lies in the Kathmandu Valley which lies in a warm temperate climatic zone (elevation ranging from 1200-2300m) where the climate is fairly pleasant. The climate of the study area is similar to the other parts of the Midlands of Nepal. It is rather cold in winter and relatively hot to warm in summer. The average temperature is 18 °C and the mean minimum temperature of the coldest month is 1°C. Freezing and frost are rare. The annual precipitation ranges from 1300 to 1800 mm. In this study area, Indian southwest monsoon normally begins in mid-June and continues up to the end of September. In this period the relative humidity and temperature are high end experience nearly 80% of the annual rainfall and during this period the Nakhu Khola flows in bankfull flow condition. March and April are categorized as dry months and July and August are humid months.

HYDRO-METEOROLOGY

The hydro-meteorological condition of the Nakhu Khola watershed area was studied by using the rainfall data obtained from Chapagaon (1986-2008) and Lele (1994-2008) metrological stations, obtained from Department of Hydrology and Meterology (DHM) and is given in Annex I. The data have been analyzed to evaluate average monthly rainfall and maximum rainfall. This hydro-metrological condition of the watershed influences several factors such as river flow, river erosion, and sediment yield and transport and water quality.

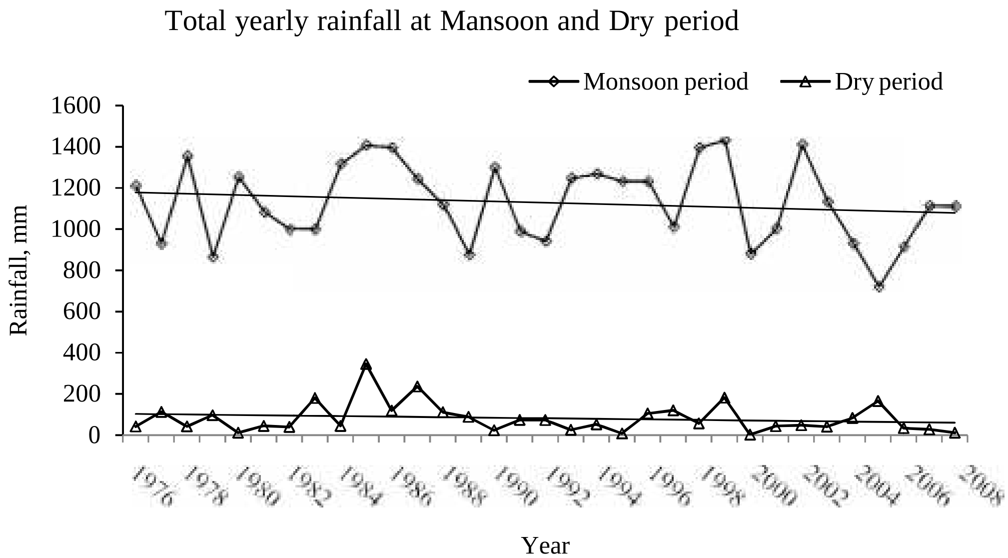
Rainfall Analysis

The Kathmandu district is divided into three zones based on precipitation occurence (ICIMOD, 1993)

1) Valley floor below 1600 m altitude receives less than 1500 mm of rainfall.
2) Lower mountain slopes between 1600-2000 m altitudes receives 1500-2500 mm of rainfall.
3) The area above 2000 m in the Phulchoki range receives more than 2000 mm of precipitation.

The precipitation of the watershed area was recorded at two different stations (Annex I). 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 (Figure. 2.8a and b).

Comparing the monthly average rainfall in two stations during 1995-2008 (Figure. 2.9), Lele station receives the largest amount of rainfall and the Chapagaon station receives least amount during June-September. Since the fourth order stream the Lele Khola locates near Lele station these, receive the greatest rainfall during monsoon period.



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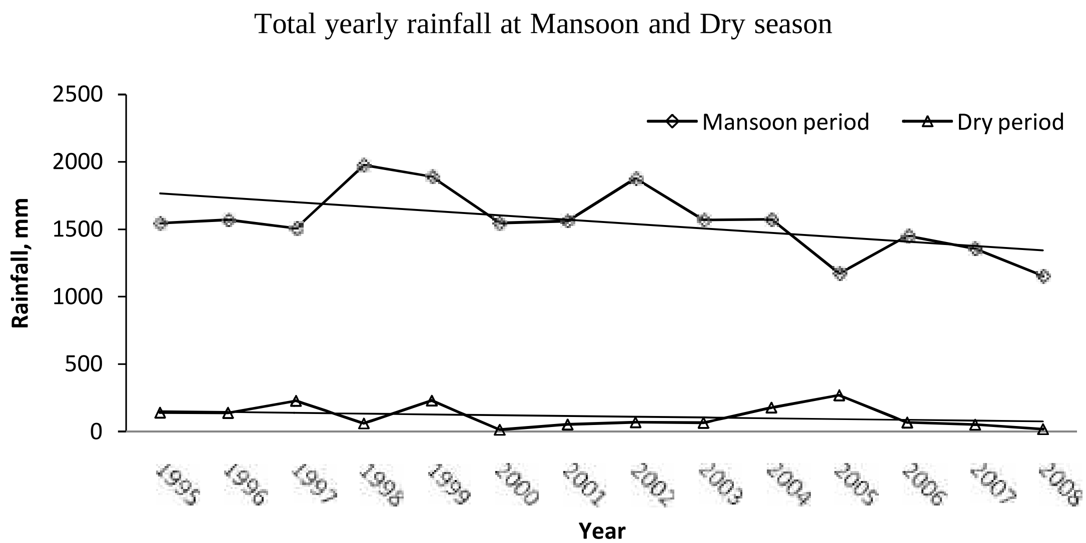


(b)

Figure 2.8: Total yearly rainfall during mansoon and dry season Chapagaon and Lele station

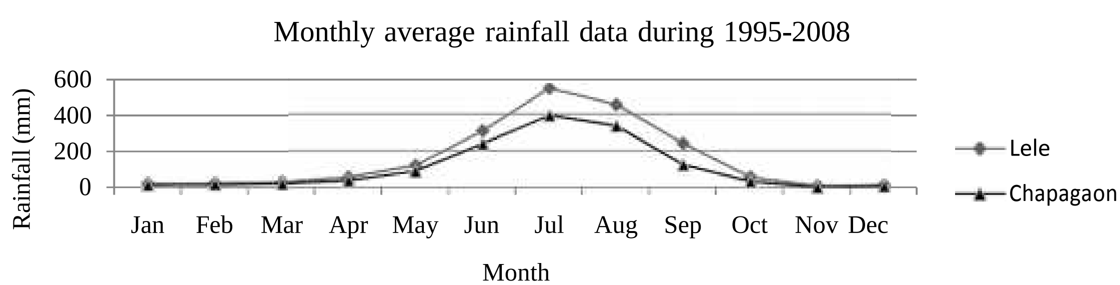


Figure 2.9 : Monthly average rainfall data during 1995-2008

Stream Flow Analysis

A flood is usually high stage in a river, normally the level at which the river overflows its bank and inundates the adjoining area. In other word, flood is an unusual large flow of runoff resulting from rainfall or due to melting of snow, causing high stage of flow in the river at which the stream/channels are completely filled and if runoff exceed, then excess runoff amount tends to overflow by the riverbank and also spread in the adjoining areas.

Estimation of flood: Estimation of flood volume or rate is an important task for planning and design of flood regulation works and control measures. To design the flood control measures, the knowledge of Probable Maximum Flood (PMF) and its corresponding stage are essential. There are various methods for estimation of PMF.

Probability method: Usually, the probable maximum flood is estimated by the statistical method. The recurrence interval and probability of occurrence of an event is calculated based upon the long time series data. The data are arranged in descending order by their magnitude of peak flood constituting a satisfied array. The probability of occurrence of the flood whose magnitude is equal or greater than a specific magnitude is referred as probability (P). The recurrence interval or return period (T) is reciprocal of probability (i.e T=1/P). There are three methods for calculating the return period. They are; Weibull's Method, California Method and Hazen's Method.

Weibull Method: This method involves the following equation for computing the return period.

$T= (n+1)/m$ 2.1

Where,
T= Return periods in years
n= Total numbers of events and
m= Rank assigned to the event

The flood data are arranged in ascending order i.e highest magnitude is ranked as 1 and so on.

California Method: This method was originated around 1923 and return period is calculated as follow

T= n/m 2.2

Where,

T= Return periods in years

n= Total numbers of events and

m= Rank assigned to the event

Hazen's Method: This method was originated around 1930 and return period is calculated as follow

T=2n/(2m-1) 2.3

Where,

T= Return periods in years

n= Total numbers of events and

m= Rank assigned to the event

Following steps are involved for the calculation of recurrence interval and probability.

The rainfall data is arranged in descending order.

The rank number is assigned to each event.

The recurrence interval of each event is determined by using equation 2.3

The probability of each event is calculated by using equation P= (1/T) ×100%

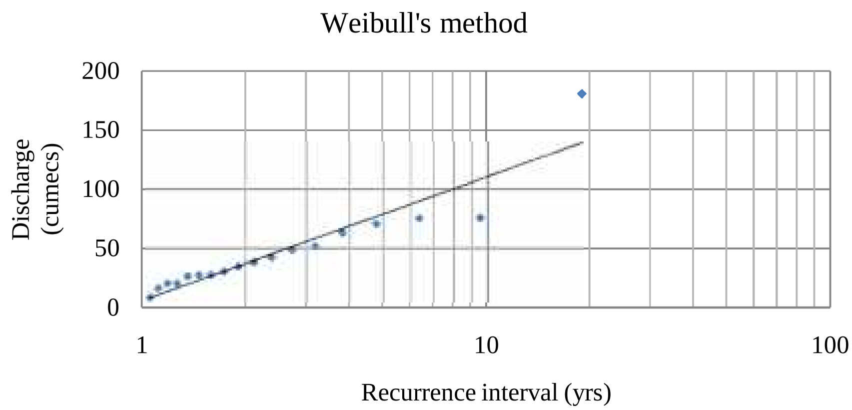
The annual discharge versus recurrence interval and annual discharge versus probability curves are plotted on log-log graph and trend is also plotted.

The line is extended for finding the value of discharge corresponding to any desired recurrence interval.

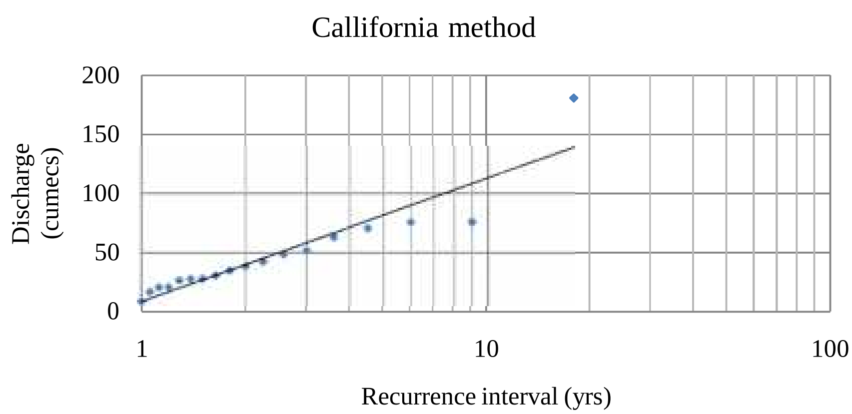
Table 2.5 gives the detail calculation of the recurrence interval of peak floods and their respective probabilities. The peak floods and recurrence interval of each are shown in Figure 2.10 and 2.11

Table 2.5: Calculations for recurrence interval and probability of occurrence of any event by different methods.

Year	Discharge (m3/s)	Rank (m)	Weibull's method		Callifornia method		Hazen's method	
			T=(n+1)/m	P=(1/T)*100	T=n/m	p=(1/T)*100	T=2n/(2m-1)	P=(1/T)*100
1966	181	1	19.00	5.26	18.00	5.56	36.00	2.78
1965	76	2	9.50	10.53	9.00	11.11	12.00	8.33
1979	75.6	3	6.33	15.79	6.00	16.67	7.20	13.89
1974	70.8	4	4.75	21.05	4.50	22.22	5.14	19.44
1971	63.2	5	3.80	26.32	3.60	27.78	4.00	25.00
1975	52	6	3.17	31.58	3.00	33.33	3.27	30.56
1970	48.6	7	2.71	36.84	2.57	38.89	2.77	36.11
1973	42.4	8	2.38	42.11	2.25	44.44	2.40	41.67
1969	38.6	9	2.11	47.37	2.00	50.00	2.12	47.22
1967	35	10	1.90	52.63	1.80	55.56	1.89	52.78
1978	30.8	11	1.73	57.89	1.64	61.11	1.71	58.33
1972	28	12	1.58	63.16	1.50	66.67	1.57	63.89
1963	27.9	13	1.46	68.42	1.38	72.22	1.44	69.44
1968	26.6	14	1.36	73.68	1.29	77.78	1.33	75.00
1976	20.8	15	1.27	78.95	1.20	83.33	1.24	80.56
1964	20.7	16	1.19	84.21	1.13	88.89	1.16	86.11
1980	16.8	17	1.12	89.47	1.06	94.44	1.09	91.67
1977	8.7	18	1.06	94.74	1.00	100.00	1.03	97.22



(a)



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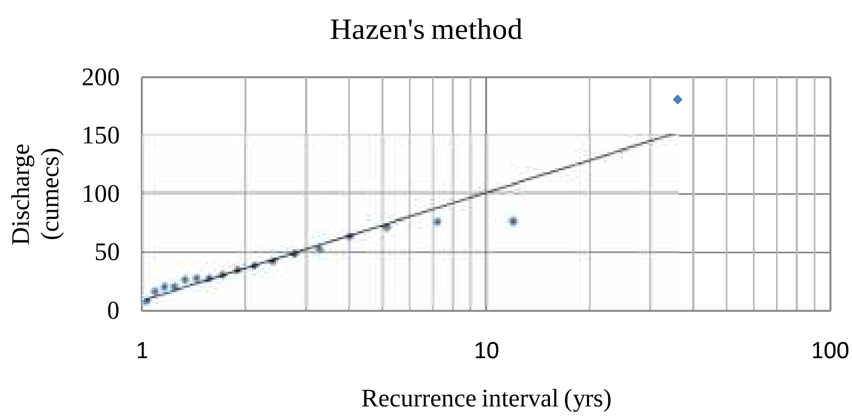


(c)

Figure 2.10: Peak flood versus recurrence interval cures(a) Weibull's method (b) California method and (c) Hazen's method

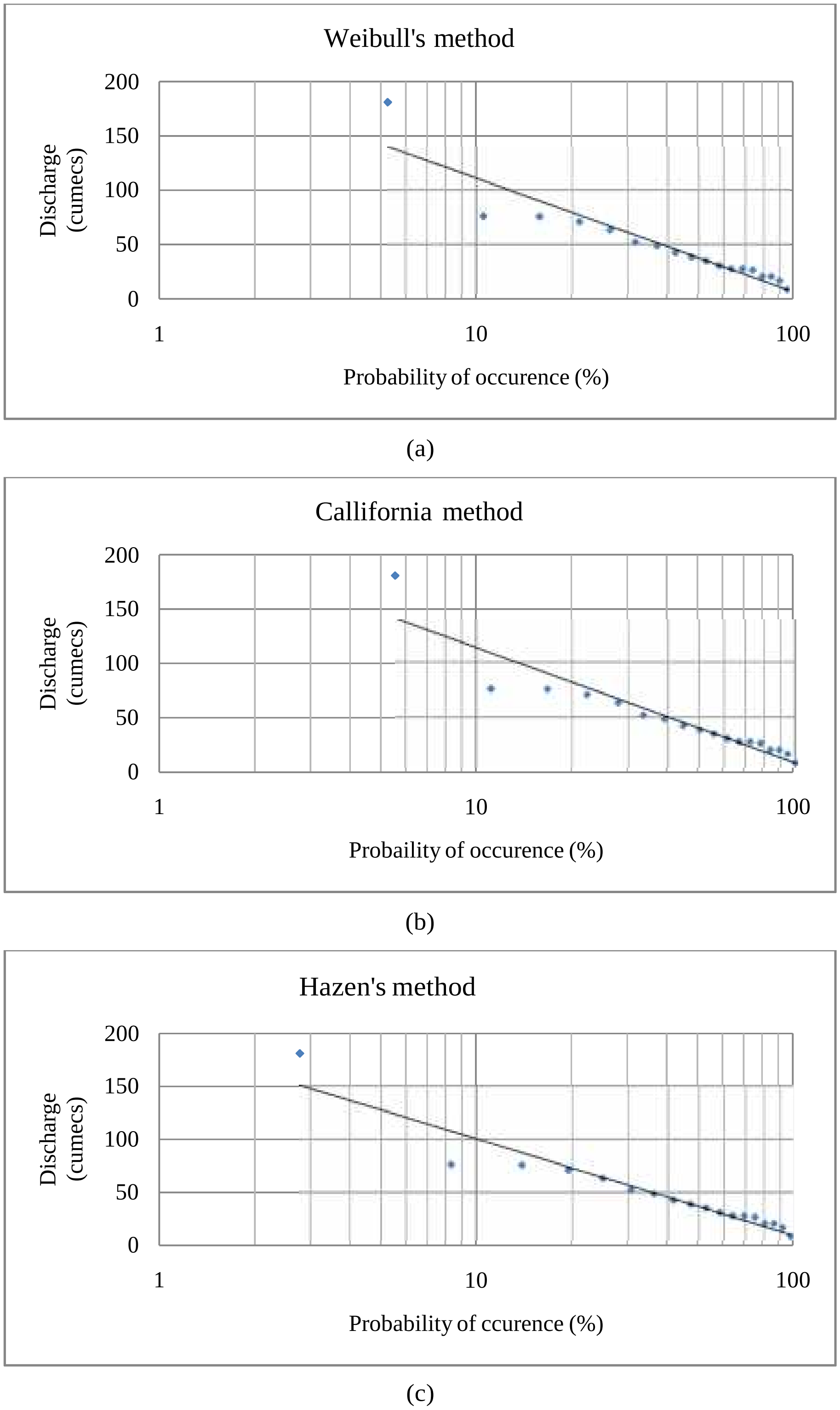


Figure 2.11: Peak flood versus probability of occurrence curves (a) Weibull's method (b) California method and (c) Hazen's method

Now using the above curves, the value of rainfall at desired recurrence intervals and probabilities could be read out. The obtained values are shown in Table 2.6 as follows.

Table 2.6:The values of discharge at desired recurrence intervals and probalities

Recurrence Interval	Weibul's Discharge (cumsec)	California's Discharge (cumsec)	Hazen's Discharge (cumsec)	Probabilities (%)
10	110	115	100	10
20	140	145	130	5
30	160	165	145	3.3
40	172	175	152	2.5
50	182	190	162	2
60	190	195	170	1.67
70	200	205	175	1.43
80	205	210	180	1.25
90	210	215	188	1.11
100	215	220	190	1

Estimation of maximum discharge magnitude within a specified time p eriod is done by the three different methods. Among all three methods, Hazen's method gives the lowest value while the California's method gives the highest values. The values for each recurrence intervals are estimated from the graph by extending the trend line and the value at desired recurrence is read out.

Log-Pearson method: In Log-Pearson method of determining the return period of the flood, all the data series are converted into the log-domain. Mean, standard deviation and skew coeffiecent are calculated from the log converted values. Thus mean, standard deviation and skew coeffiecent are obtained by

Mean ($\log \bar{Q}$) = $\sum \log Q/n$ 2.4

Standard deviation ($\sigma_{\log Q}$) = $\{ \sum(\log Q - \log \bar{Q}))^2/(n-1)\}^{1/2}$ 2.5

Skew coeffiecient (G) = $n \sum(\log Q - \overline{\log Q})^3/(n-1)(n-2)(\sigma_{\log Q})^3$ 2.6

The value of Q for any Return period and probability level is computed by

$\log Q = \overline{\log Q} + K\,\sigma_{\log q}$ 2.7

Where K is obtained from the Table (given below), the detail about the computation of Log-Pearson method is presented in the table

Table 2.7: Values of K for Log-Pearson method

Skew coefficient (G)	Recurrence Interval					
	2	5	10	25	50	100
	Percent Chance					
	50	20	10	4	2	1
	K					
1	-0.164	0.758	1.34	2.043	2.542	3.022
0.8	-0.132	0.78	1.336	1.993	2.453	2.891
0.6	-0.099	0.8	1.328	1.939	2.359	2.755
0.4	-0.066	0.816	1.317	1.88	2.261	2.615
0.2	-0.033	0.83	1.301	1.818	2.159	2.472
0	0	0.842	1.282	1.751	2.054	2.326

Table 2.8: Flood probability analysis by Log-Pearson method

Year	Discharge, Q (m3/s)	LogQ	LogQ-Log$\bar{Q}$	(LogQ-Log$\bar{Q}$)2	(LogQ-Log$\bar{Q}$)3
1966	181	2.25768	0.67808	0.45979	0.31177
1965	76	1.88081	0.30121	0.09073	0.02733
1979	75.6	1.87852	0.29892	0.08935	0.02671
1974	70.8	1.85003	0.27043	0.07313	0.01978
1971	63.2	1.80072	0.22112	0.04889	0.01081
1975	52	1.71600	0.13640	0.01861	0.00254
1970	48.6	1.68664	0.10704	0.01146	0.00123
1973	42.4	1.62737	0.04777	0.00228	0.00011
1969	38.6	1.58659	0.00699	0.00005	0.00000
1967	35	1.54407	-0.03553	0.00126	-0.00004
1978	30.8	1.48855	-0.09105	0.00829	-0.00075
1972	28	1.44716	-0.13244	0.01754	-0.00232
1963	27.9	1.44560	-0.13400	0.01795	-0.00241
1968	26.6	1.42488	-0.15472	0.02394	-0.00370
1976	20.8	1.31806	-0.26154	0.06840	-0.01789
1964	20.7	1.31597	-0.26363	0.06950	-0.01832
1980	16.8	1.22531	-0.35429	0.12552	-0.04447
1977	8.7	0.93952	-0.64008	0.40970	-0.26224
Total		28.43348	0.00068	1.53641	0.04812

From computation in table

Mean **(**log$\bar{Q}$) =1.579638

Standard deviation **(**σ_{logq}**)=** 0.300628

Skew coefficent **(**G**)** **=** 0.131

Table 2.9 shows the recurance interval and peak flow predicted by Log-Pearson method for the Nakhu Khola. The peak discharge measured by DHM during the year 1966 with discharge of 181 cumsec when compared with the Table 2.9, the observed value lies between 50-100 years discharge.

Table 2.9: Recurrance interval and peak flow discharge

Recurance interval	K	LogQ	Discharge, Q (cumecs)
2	-0.017	1.575	37.553
5	0.863	1.839	69.027
10	1.292	1.968	92.859
25	1.785	2.116	130.623
50	2.107	2.213	163.235
100	2.399	2.301	199.866

LANDUSE

Most of the floodplains, the low-lying land and gentle slope area of the watershed are used for farming and settlement. While the other major parts are covered by forest, some of the parts as quarry site for construction materials. Most of the southern parts of watershed consist of steep slope to gentle slope, which are covered by forest. Also most of the quarry in the area is located in these hills of southeastern to south-western part of watershed.The sediments of the Nakhu Khola been exploited for construction material near the confluence of Nallu and Lele Khola and flood plains are cultivated (Figure 2.12).

The siltstone of the Tistung Formation distributed in vicinity of Nallu Khola, and limestone of the Chandragiri Limestone distributed along the hills of Bhardeu, Lele, and Mahadevgau are being quarried for aggregates. Because of these unplanned quarries different environmental problems like air pollution, dump of sediments from quarry site into river, bank encroachment and artificial river course changing are major problems in the segment of river. Due to increase in sediment load from quarry sites is increaseing turbidity of river, which causes reduction in aquatic life. Temporary damming is other problem, which might be caused due the uncontrolled quarrying during heavy rainfall.

After Tika Bhairab Gorge most of the land is used for agriculture. However, with demand for settlement for growing population, the land use pattern has changed rapidly in watershed area. Most of the huge flood plains of The Nakhu Khola from Bhaisepati downstream segment (confluence with Bagmati) that is used for agriculture have changed rapidly to build up area, for animal farming and few industries. Because of these, the banks of Nakhu Khola are suffering from human encroachment and the water quality is highly degraded due to contamination of sewer and solid waste.

POPULATION

The ethnic/caste distribution is not uniform throughout the study area. Newars are the major residents in the 6 VDCs, Tamangs in the 3 VDCs and Brahmins and Chhetris in other VDCs of study area. Brahmins and Chhetris, are the other major ethnic groups living in the area.

Table 2.10: Population data of different VDCs of the the Nakhu watershed

VDC	No of HH	Census 2001			Projected for 2008		
		Total	Male	Female	Total	M	F
Bhardev	369	2068	1012	1056	2497	1222	1275
Bungamati	1067	5667	2831	2836	6843	3418	3424
Chapagaon	2390	12448	6234	6214	15031	7527	7503
Champi	868	4192	2068	2124	5602	2497	2565
Devichour	487	2734	1390	1344	3301	1678	1623
Dukuchap	480	2501	1240	1261	3020	1497	1523
Lele	1516	7921	3877	4044	9565	4681	4883
Khokana	818	4542	2246	2296	5484	2712	2772
Nallu	385	2165	1090	1075	2614	1316	1298
Sainbu	1789	8337	4243	4094	10067	5123	4943
Sunakoti	1149	6199	3035	3164	7485	3665	3820
Thecho	1550	8020	4021	3999	9684	4855	4829
Lalitpur UMNP	34996	162991	84502	78489	196809	102035	94774
Choughare	333	1925	931	994	2324	1124	1200

SOCIOECONOMIC ACTIVITIES

The study area consists of 13 village development committees (VDC) and part of city of the Lalitpur district. The socio-economic condition is influenced by various factors such as climate, topography, mode of transportation etc. The construction material quarry sites in Chapagaon, Lele and Nallu VDCs is the major source of income for the people in the watershed. The quarry sites located along the Nallu Khola of Nallu VDC is the biggest quarry site of Nepal. Agriculture is the main occupation of the majority of the population within the VDC. Rice, maize, mustard seed and millet are the main agro-production and this area is a good supplier of agricultural. Now days mushroom production as cash crop is also gaining popularity in Chapagaon VDC.Beside agriculture, a large number of local inhabitants are involved in business, civil services and craftsmanship in city of Lalitpur. Still some people are labor in quarry sites and other industries.

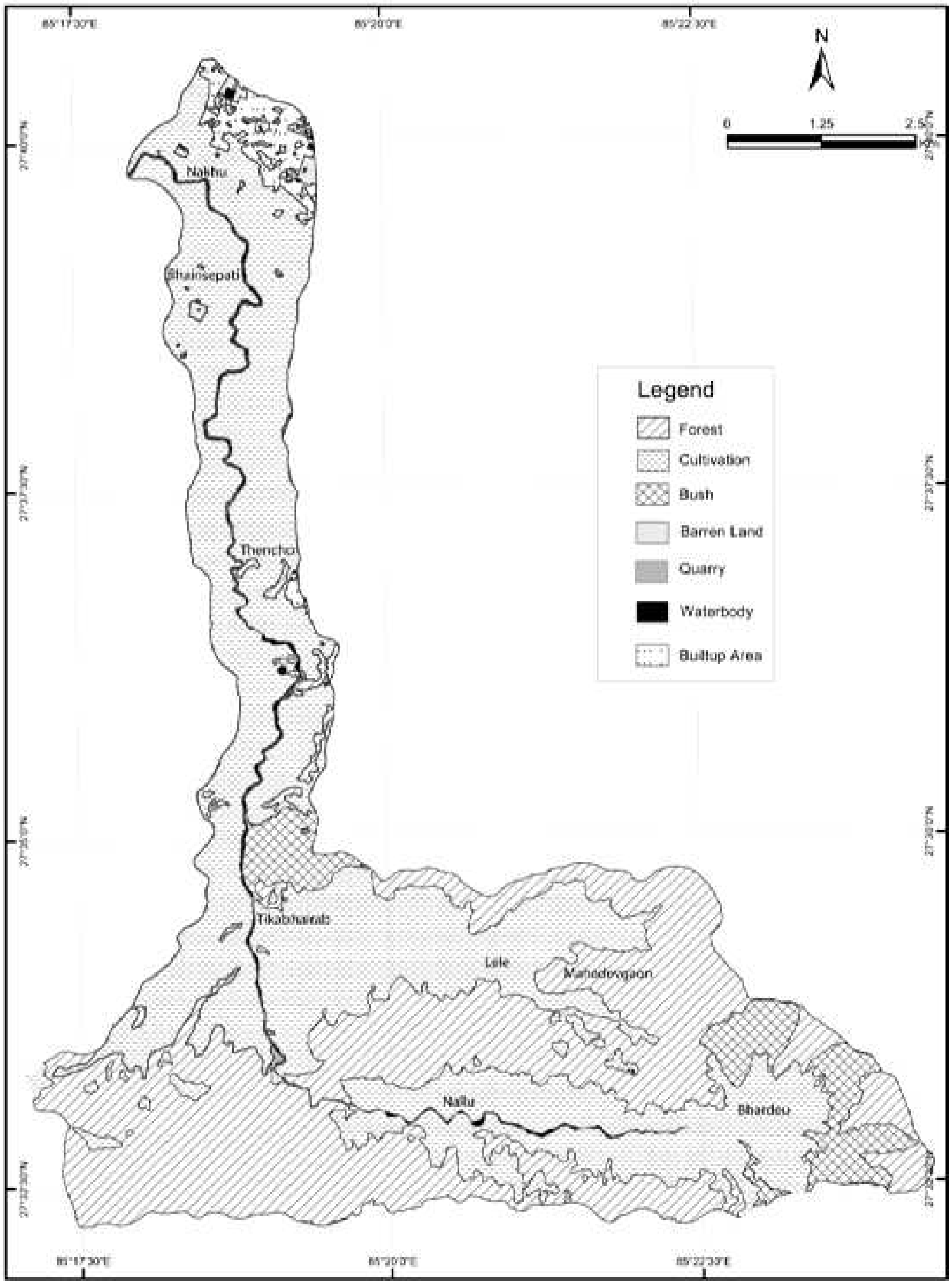


Figure 2.12: Land use map of the Nakhu Khola Watershed based on Topo-shee(1992)

CHAPTER THREE

METHODOLOGY

The present study was carried out in the following phases:

LITERATURE REVIEW

Desk study was carried out by reviewing various published and unpublished maps and reports and secondary data which were collected by consulting various reports, journals, and related research papers. The reports, thesis, journals, and research papers were collected from the Central Department of Geology, Central Library, and Department of Geology and Mine.

Literature review covered the following aspects:

a. Study of topographic maps of study area (1:25,000)
b. Study of aerial photographs (1:50,000, year 1992) of the study area
c. Study of geological and geo-environmental maps of the study area
d. Review of published and unpublished reports, journals and books
e. Collection of preliminary database from previous works e.g.: Metro and hydrological data from department of metrology and hydrology.

FIELD AND LAB WORK

The fieldwork was carried out in the study area focusing on the following targets:

a. Mapping of channel and flood plain elements of the Nakhu Khola from Bardev to the Nakhu Khola and the Bagmati River confluence near Chobar gorge
b. Cross-sectional survey at different transects of stream segments during
c. Mapping of riparian vegetation buffer zone, stream bank material, erosional process and present environmental condition of the river,
d. Preparation of flood hazard map along the Nakhu khola.

e. Study of river bank erosion from field survey.

f. Collection of river water for quality test in lab.

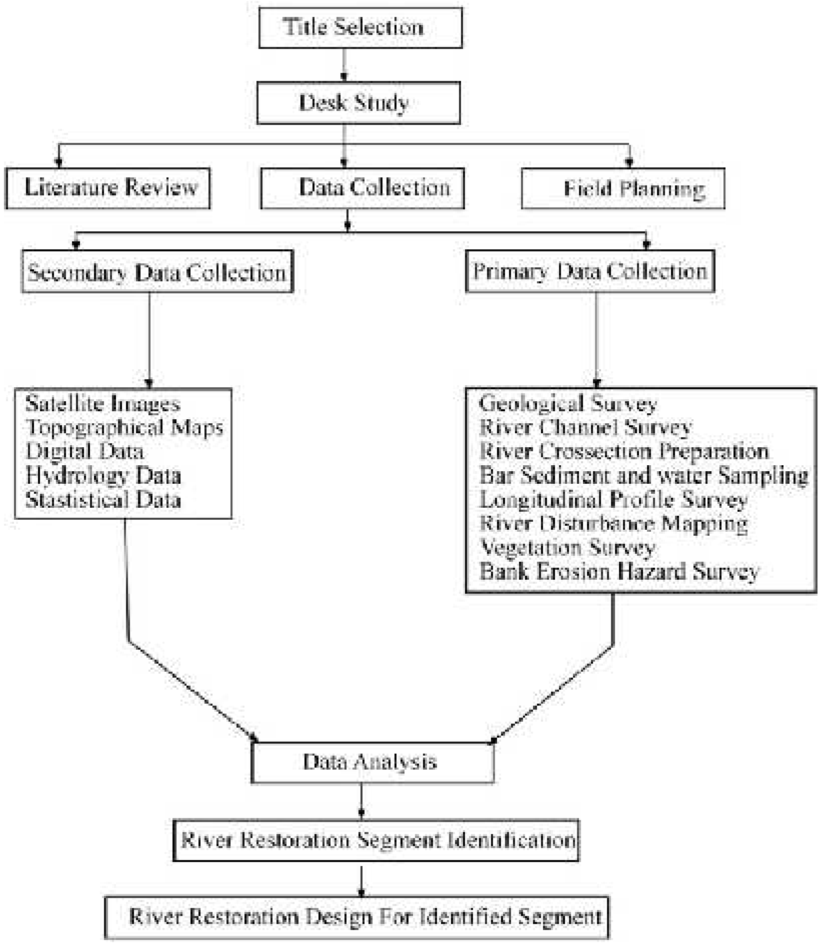


Figure 3.1: Detail flow chart of research process

DATA ANALYSIS

Analysis of the data and information obtained from both field and lab works, represented, and interpreted.

The M. Sc. thesis was compiled using both the primary as well as secondary data. The final report was prepared by the detail study of the primary data, secondary data, laboratory analysis as well as the thorough supervision from the supervisor.

Chapter Four

Morphology and Planiform Geometry

Morphometry

Drainage Order

Streams are classified or ordered according to the hierarchy of natural channels within in watershed. The upper most channels in the drainage network (i.e headwater channels with no upstream tributaries) are designated as first order stream down to their first confluence (Strahler, 1952). A second order stream is formed below the confluence of two first-order channels. Third order streams are created when two second order channels join and so on.

The drainage order of the Nakhu Khola water shed areas ranges from first to fifth order. The first, second, and third ordered steams are numerous. The Nakhu Khola is the fifth order river and its major tributaries like the the Lele Khola and the Nallu Khola are fourth order steams and the Burunchuli Khola, is third order stream (Figure 4.1). The fifth order river has greater length, extending for about14 km. The first, second, third and fourth order stream extend for 1.19 km, 0.89 km, 0.59 km, and 9.31 km respectively.

Drainage Texture

Drainage texture is defined as the number of stream segments passes across per unit length within the square kilometer area.The drainage texture of the Nakhu Khola watershed at the southern part of watershed shows fine, moderate fine, coarse and again moderate fine from south-east to south-west direction. While drainage texture from south to north of watershed shows very coarse at some part and coarse at major part. Drainage texture is fine in the southern ridges containing high resistant bed rock with thick forest cover, and little infiltration and very coarse in the north-west low lying areas with soft sediment cover, very little vegetation and high water infiltration in soil (Figure 4.2). Fine texture means very dense stream distribution and coarse texture means very sparse stream distribution.

Drainage Frequency

Drainage frequency is the measure of number of stream per square kilometer, ranges from very poor toward northern and very high towards southern region of watershed (Figure 4.3). The difference in the drainage frequency within watershed shows the change in geological condition. The northern region of watershed consists of soft sediments with low relative relief, so very poor drainage frequency. The southern part of watershed has high relative relief with basement rocks which produce numerous lower order streams from the joints on rock. So, drainage frequency is high at southern part.

Relative Relief

Relative relief is the difference in height on the grid of square of a kilometer. The relative relief map of watershed area shows that at the southern part of watershed including origin point of river has high relative relief. The southern part of watershed, which is surrounded by hills, has high relative relief and low relief in the north low-lying areas of the watershed (Figure 4.4).The middle part of watershed has very low relative relief. The relative relief map shows that at the southern part of watershed high elevation peaks dominate area while at Northern part and middle part by low elevated plains.Higher relative relief means more erosional activities in the southern part.

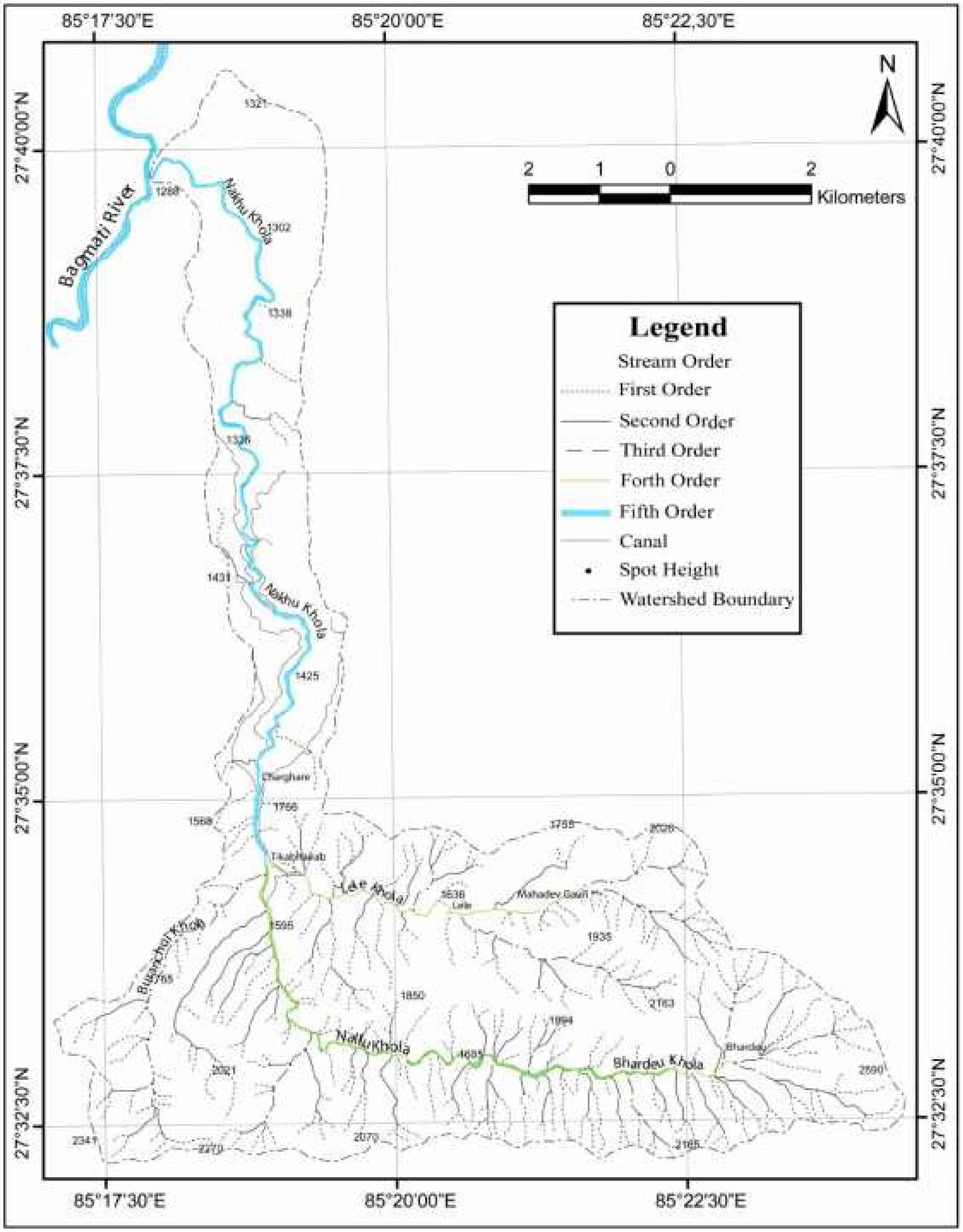


Figure 4.1: Drainage order map of the Nakhu watershed.

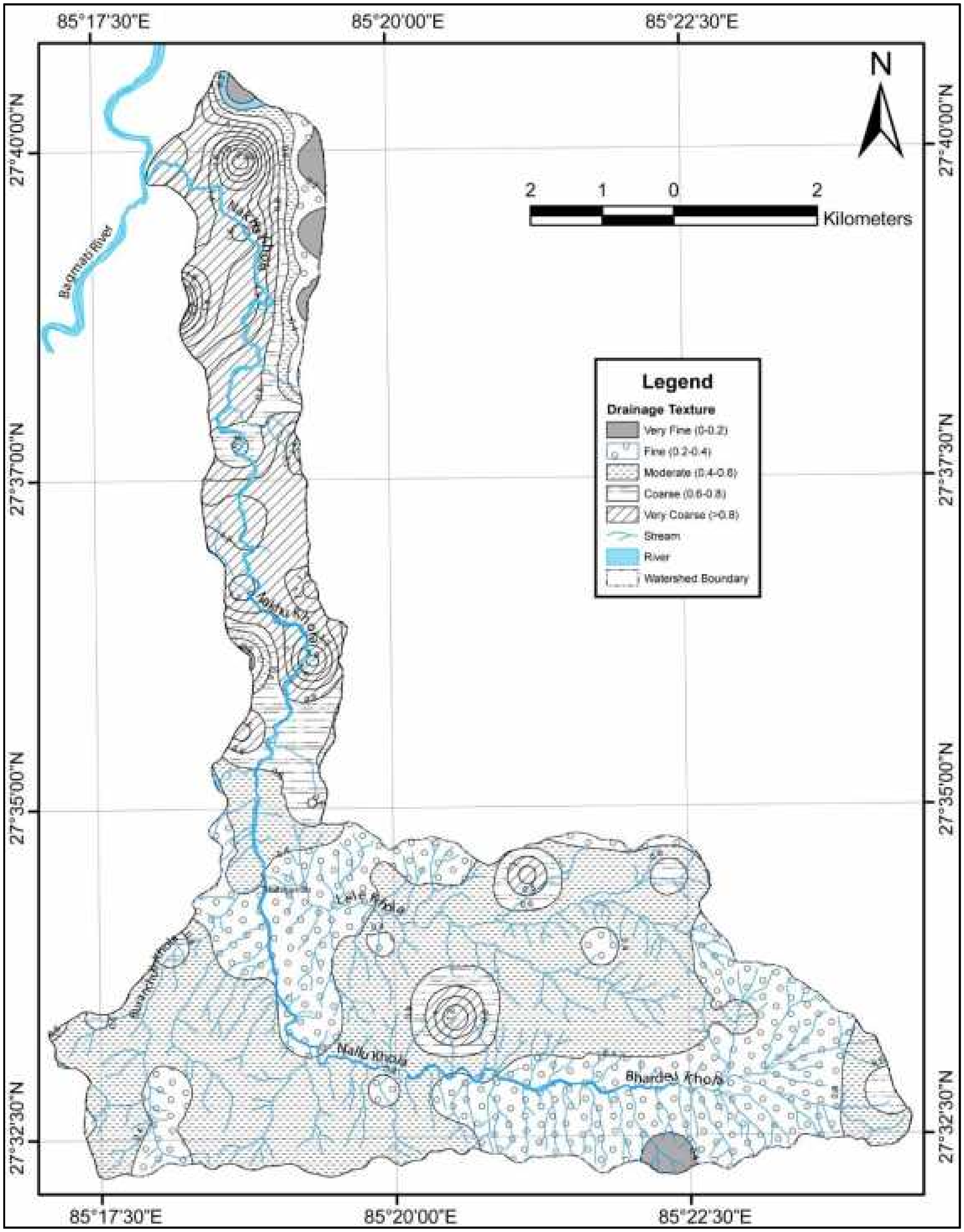


Figure 4.2: Drainage texture map of the Nakhu watershed.

Drainage Pattern

The drainages in the Nakhu Khola watershed flows through the hills made of metasedimentary rocks and the plains of fluvio lacustrine sediments. As the streams cut into the underlying rocks and structures of the region, they give rise to certain drainage pattern. There are mainly three types of drainage pattern within the Nakhu Khola watershed. They are Dendritic, Trellis, Barbed drainage pattern (Bajracharya, 1991). The dendritic drainage pattern is observed in the hills of Bhardeu, Lele and Burunchuli. The trellis drainage pattern is observed at Nallu area at southern part of watershed. The barbed drainage pattern is observed near the confluence of the Bagmati River forming boat-hooked shaped bend. The formation of this special drainage pattern is due to accumulation of alluvial deposit at the centre of the valley, which caused the reflection of The Nakhu Khola towards west to join the main river in hook-shaped bend forming air gap in centre of valley (Bajracharya, 1988).

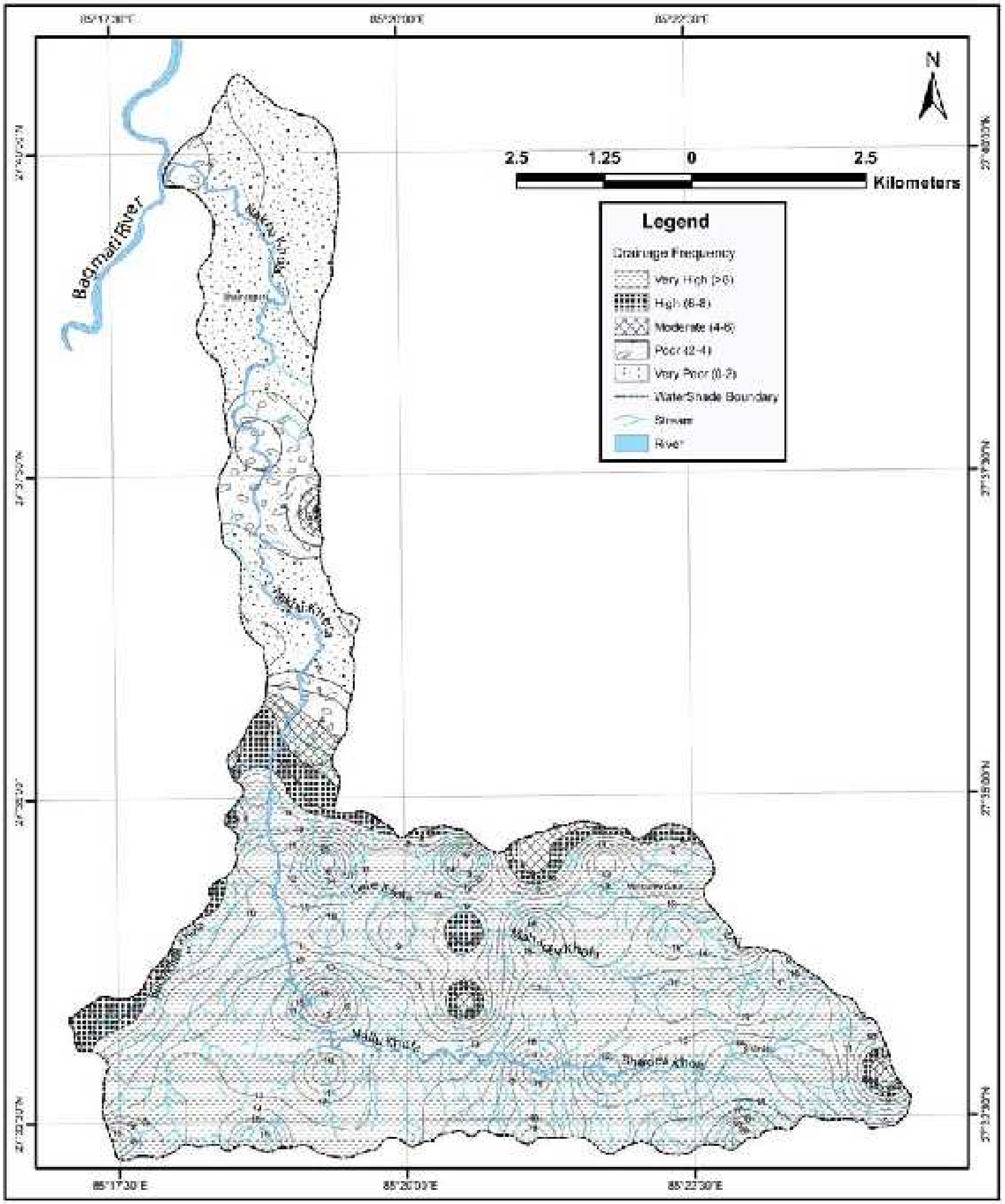


Figure 4.3: Drainage frequency map of the Nakhu watershed.

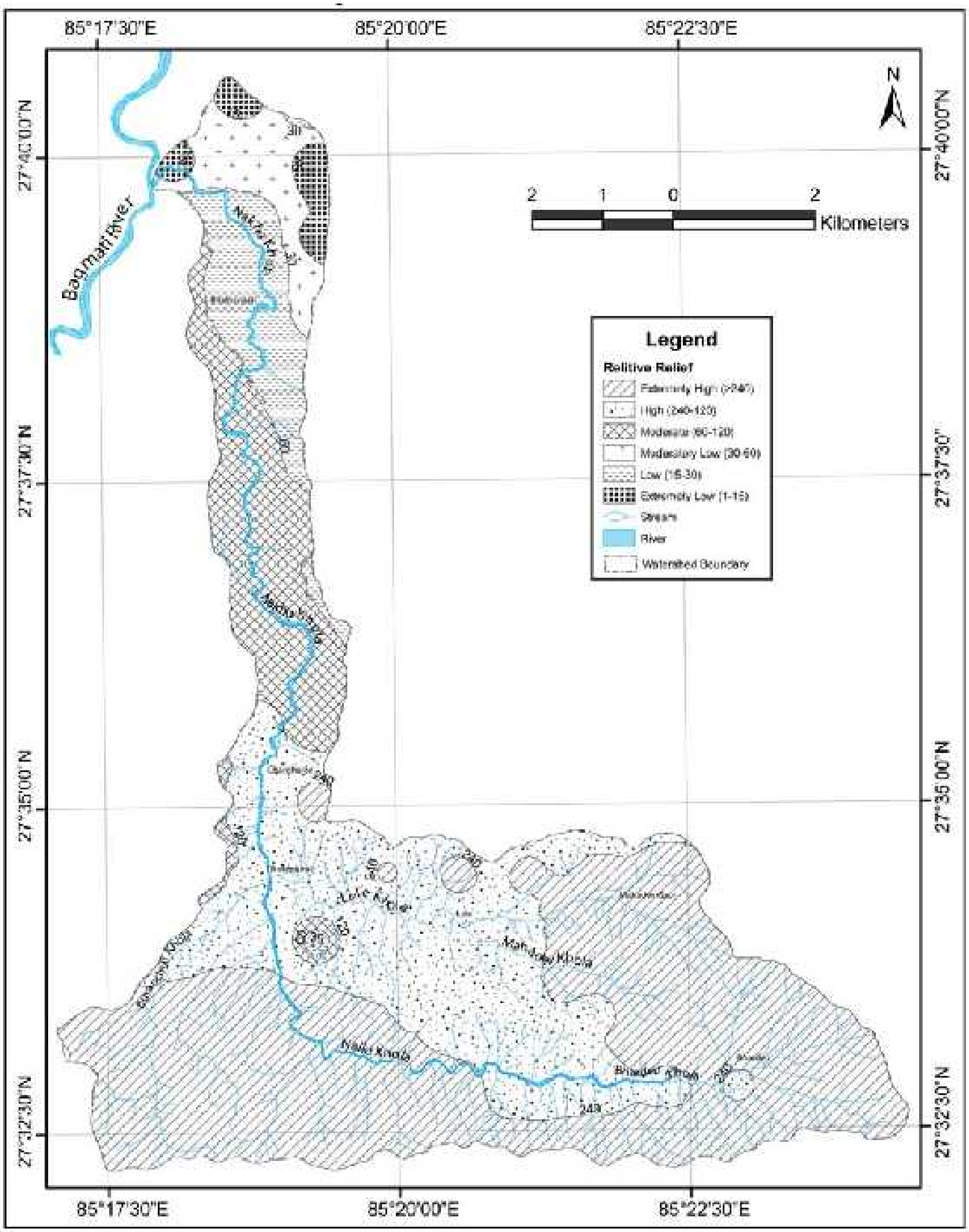


Figure 4.4: Relative Relief map of the Nakhu watershed.

MORPHOLOGICAL PARAMETERS

Planiform Patterns

Planiform geometry is described as the term, which defines stream pattern and plain view of river such as sinuosity, radius of curvature, meander channel belt, wavelength, meander length and slope.

In order to measure planiform geometry of the Nakhu Khola, different representative segments of the Nakhu Khola were selected. They are Nakhu Segment, Bhainsepati Segment, Chapagoan Segment and Nallu Segment. The Nallu Segment is 4^{th} ordered stream; where as other segments are 5^{th} ordered steams. Planiform geometry such as sinuosity, radius of curvature and meander channel belt width were measured from large scale topographic map (1:10,000), the results are given in Table 4.1

a. Sinuosity

Sinuosity (K) of a stream is the ratio of channel length to the valley length. Stream with steep slope has low sinuosity and stream with gentle slope has high sinuosity. Sinuosity of the Nakhu Khola is calculated from the 1995 topographic map and recent field surveyed map for old and recent sinuosity. Sinuosity measured from the topographic map of The Nakhu Segment showe 1.170 where as recent surveyed map gives 1.171. Similarly Bhainsepati, Chapagoan and Nallu show 1.52 and 1.524, 1.18 and 1.19 and 1.24 and 1.246. Among these Bhainsepati segment shows the high sinuosity (K=1.52). This value indicates that this segment is matured and meandering compared to upstream segments. The Nakhu Segment has the lowest sinuosity indicating that the segment is immature and has high eroding potential (Table 4.1).

b. Radius of Curvature

Radius of curvature (Rc) is defined as the curved surface formed by the meandering stream channel. It is calculated as bellow (Rosgen, 1998):

$$Rc = C^2/8M + M/2 \quad \text{......} \quad 3.1$$

Where, C = Chord length between inflection points

M = Middle ordinate distance between the curve crest and the chord

The mean value of the Rc is highest in Bhainsepati segment (201.94) and lowest in Nallu segment (107.1).

c. Meander Belt Width and Wave Length

Meander belt width (W_{blt}) is a straight line between the crest of the bend to the crest of the next bend lying downstream. The values of mender belt width of four segments are shown in Table 4.1. This ranges from 211m (Nallu Segment) to 356.36m (Bhainsepati Segment). The Bhainsepati shows the highest magnitude of river wandering and lateral instability. Nallu segment has the low river wandering compared to other segments.

Meandering wavelength (Lm) of the stream is the distance between two successive creast and two successive trough of the curved channel. The values of all 4 segments obtained range from 400m (Nallu segment) to 607m (Nakhu Segment).

d. Meander Width Ratio and Meander Length Ratio

Meander width ratio is the ratio of meander belt width to bankfull channel width of river. Values obtained from the downstream to upstream viz the Nakhu Segment, the Bhainsepati segment, the Chapagaon segment and the Nallu segment are 14.91, 20.00, 19.53 and 16.41 respectively (Table 4.1). Among these values, the Bhainsepati segment has highest values indicating highest potential of lateral instability.

Meander length ratio is the ratio between meander wavelength and bankfull channel width of river. Meander length ratio is the measure of lateral channel stability of river. Calculated values of meander length ratio of the Nakhu Segment, the Bhainsepati segment, the Chapagaon segment and the Nallu segment are 34.43, 32.26, 23.56 and 31.05respectively (Table 4.1). From the values obtained by calculation, it shows that The Nakhu Segment has highest MLR values and this segment is laterally highly unstable and the Chapagoan segment has lowest value so this segment is laterally stable.

e. Slope

Slope of the steam is the ratio of elevation difference to distance of river. Slope of the Nakhu Khola is determined from a river profile which is concave upward in shape (Figure 4.5). The average slope of the Nakhu Khola is 0.05 m/m the slope in between 1st order and 2nd order, it is very steep and between 2nd and 4th has moderate slope. The slope from 4th order stream onward is gentle.

Planifrom geometry of river is directly related with sinuosity. Stream with steep slope has low sinuosity where as stream with gentle slope has highsinuosity. The slope of fourth ordered Nallu segment is 0.017m/m, and the fifth ordered streams are 0.015m/m (Chapagoan segment), 0.013m/m (Bhainsepati segment) and 0.012m/m (Nakhu Segment).

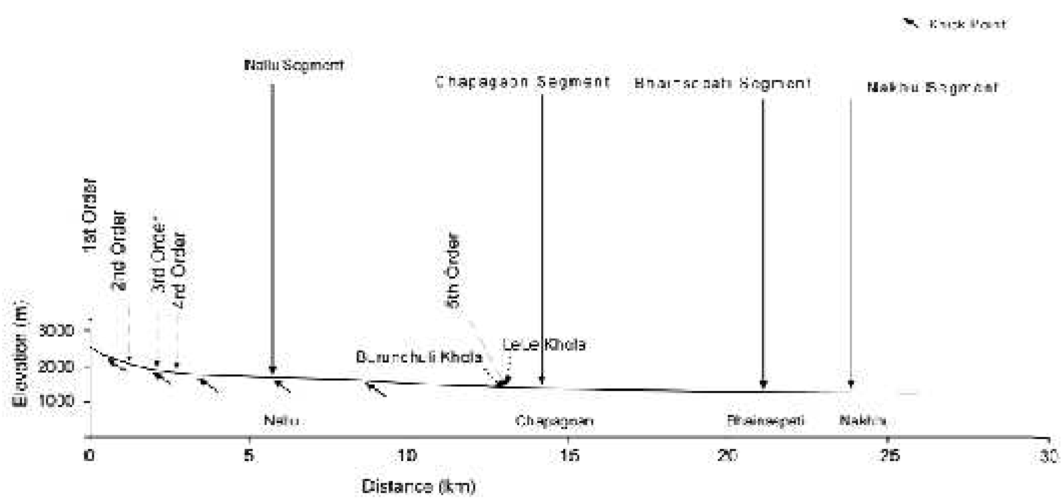


Figure 4.5: Longitudinal Profile of the Nakhu Khola

Cross-section Parameters

For the study of river geometry and geomorphology of the Nakhu Khola four different segments in different parts of river were selected, with the help of topographic map of scale 1:25000 and field surveyed map of scale 1:10000 scale. The four segments are the Nallu segment, the Chapagaon segment, the Bhainsepati segment and the Nakhu Segment.Nallu segment lies in the fourth order and other three segments are in fifth ordered stream. During cross-section preparation bed composition and grain size distribution along each transects were also surveyed. Altogether 40 transect, each segment with ten transect were prepared. The result of cross-section analysis is shown in Table 4.1.

a. Riffle Cross-section

In each, segment four to six riffile crossection segments were prepared. From this riffle crossection crossectional area, bankfull elevation, width/depth ratio, entrenchment ratio, maximum depth ratio, bankfull height ratio, mean depth at bankfull were calculated (Table 4.1).

b. Bank-full Elevation

Bankfull discharge is the flow that transports the majority of stream's sediment load over time and maintains the channel. Any flow that exceeds the stage of the bank-full flow will move onto the flood plain. Bank-full elevation is the incipient point of flooding. Bank-full elevation is measured from the deepest part of channel cross-section which may or may not be the top of the bank. The bank-full elevation is near the top of the bank for slightly entrenched stream but too less that the top of bank for deeply entrenched stream. If the stream has become incised due to changes in the watershed or stream side vegetation, the bank-full stage is considered to be entrenched. Bank-full elevation can be identified in the field by using different indications such as break in slope of the bank, the elevation associated with the top of the highest depositional features, exposed root hair below intact soil an changes in vegetation pattern. For defining the channel form, identification of the bank-full elevation is the most important step in the study of river character. The bank-full elevation was identified and measured in the both banks of river. With the help of these data's other parameters were calculated.

c. Bank-full Width

Bank-full width is the horizontal distance between right and left bank-full point which is measured in field. Flood prone height which is the twice of the bank-full elevation; flood prone width and the mean depth of the bank-full (D_{bkf}) i.e. the ratio of bank-full cross-sectional area to bank-full width were also measured with the help of level instrument, staff and measuring tape. The mean bank-full depth varies from 0.42m (Nallu Segment) to 0.62 m (Nakhu Segment). Bank-full width ranges from 12.88m (Nallu segment) to 19.53 m (Chapagaon Segment). Mean bank-full cross-sectional area is range from 5.82 m^2 (Nallu Segment) to 11.62 m^2 (Nakhu Segment). These data shows that the high ordered streams (Nakhu, Bhainsepati, and Chapagoan Segments) have large width and cross-sectional area compared to low order stream (Nallu Segment). The bank-full width in the Nakhu Khola varies from segment to segment. It increases from the Nallu segment to the Chapagoan Segment and decreases from the Chapagoan Segment to the Nakhu Segment. These calculated parameter shows that the drainage area increases with increased width.

d. Entrenchment Ratio

Entrenchment ratio is defined as the ratio of flood prone width to bankfull width. A stream is said to entrenched if the value of entrenchment ratio is less than 1.4 and the stream having higher than 1.4 shows affinity of flooding. (Rosgen 1994).

Entrenchment ratio in the Nakhu Khola varies from 2.87 (Chapagoan segment) to 4.00 (Bhainsepati segment) (Table 4.1). In the Nakhu Khola, entrenchment ratio is highest in the Bhainsepati Segment which indicates that the flows of water over top their banks and extend onto the surrounding flood plain during flooding. This shows lateral migration of Bhainsepati segment more easily than other segments.

e. Width Depth Ratio

Width depth ratio is defined as the ratio of bank-full width to mean depth at the bank-full channel. This ratio gives the quick idea about the lateral channel stability. High width depth ratio places stress on the near bank region and indicates erosion hazard. The width depth ratio of the Nakhu Khola ranges from 31.26 (Nallu segment) to 49.06 (Chapagaon segment). The high value of width depth ratio in the Chapagaon segment shows lateral instabilities and possibility of bank erosion due to high velocity. Hence, the increase in bank erosion may increase sediment supply to the channel and widens stream channel.

f. Bank Height Ratio

Bank Height Ratio (BHR) is defined as the ratio of depth of top of bank to maximum depth at bank-full elevation stage. The value of BHR ranges from 2.52(Bhainsepati Segment) to 5.28 (Chapagoan Segment) (Table 4.1). The higher value of BHR in Chapagoan Segment indicates the chances of bank failure but at the same time it prevents from overspread of flow level during high flow period. But other segments of the Nakhu Khola having low BHR suffer from flooding during high flow.

g. Maximum Depth Ratio

Maximum depth ratio is defined as the ratio of maximum depth at bankfull stage to average depth at bankfull condition. The ratio ranges from 1.68 (Nakhu Segment) to

1.85 (Chapagaon Segment). The high value of D_{max} in the Nakhu segment indicates the high depth of water in the channel.

Pool Cross-section

Four to five cross-sections were prepared in the each segment. Pool area, pool width and maximum pool depth were measured. The mean pool area varies from 4.25m^2(Bhainsepati segment) to 5.92 m^2 (Chapagoan segment). Mean pool width and depth are ranges from 10.03m (Nallu segment) to 13.38 m (Bhainsepati segment) and 0.70m (Bhainsepati segment) to 0.91m (Chapagaon and the Nallu segment) respectively. The mean pool width increases from upper to downstream up to Chapagoan segment, which again decreases from the Bhainsepati to Nakhu Segment. Maximum pool depth is relatively higher in the Nallu segment due to scouring of channel bed and due to gravel mining along the river channel.

Dimensionless ratio

The dimensionless ratio was calculated dividing pattern survey parameters such as meander wavelength, radius of curvature, and belt width by bankfull width (Table 4.1). Meaner wavelength ratio (MLR) of the Nakhu Segment has highest magnitude of 34.43. The lowest value is obtained in the Chapagoan Segment of magnitude 23.56. Meander width ratio (MWR) is highest in Bhainsepati segment of magnitude 20 followed by Chapagaon segment 19.53, Nallu segment 16.41, the Nakhu Segment 14.91. Radius of curvature ratio is the highest in Bhainsepati segment 11.33 and lowest in Chapagoan Segment 7.04. The Bhainsepati segment shows highest value of MWR and the highest radius of curvature ratio due to highly meandering bends.

Table 4.1: Morphological data of the Nakhu Khola.

Morphological data	Nakhu Segment										
	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10	Mean
Riffel cross-section											
Width at bankfull, W_{bkf} (m)	20.40		22.80		13.20		13.20		18.60		17.64
Bankfull x-section area, A_{bkf} (m^2)	14.50		16.81		4.30		5.78		16.73		11.62
Max depth bankfull, D_{max} (m)	1.10		1.15		0.65		0.80		1.30		1.00
Flood prone height, W_{fph}	2.20		2.30		1.30		1.60		2.60		2.00
Width flood prone area, W_{fpa} (m)	99.50		54.00		14.30		20.80		99.00		57.52
Max depth top low bank, d_{tob} (m)	2.60		1.80		2.00		3.40		2.40		2.44
Mean depth at bankfull, $Dbkf= A_{bkf}/W_{bkf}$	0.71		0.74		0.33		0.44		0.90		0.62
Entrenchment ratio, $ER= Wf_{pa}/W_{bkf}$	4.88		2.37		1.08		1.58		5.32		3.05
Width depth ratio, $W/D= W_{bkf}/d_{bkf}$	28.70		30.92		40.52		30.15		20.68		30.19
Bank height ratio, $BHR= dt_{ob}/d_{max}$	2.36		1.57		3.08		4.25		1.85		2.62
Max depth ratio, D_{max}/d_{bkf}	1.55		1.56		2.00		1.83		1.45		1.68
Pool cross-section											
Pool width, W_{pool}		12.30		13.50		9.80		9.40		14.30	11.86
Pool area, A_{pool}		7.89		6.52		4.00		4.40		4.73	5.51
Pool max depth, d_{pool}		1.15		1.00		0.70		0.80		0.60	0.85
Pattern Survey											
Meander wavelength, lm(m)											607.30
Belth width, W_{blt} (m)											263.11
Radious of curvature, Rc											177.62
Meander wavelength ratio, $MLR=l_m/W_{bkf}$											34.43
Radius of curvature ratio, Rc/W_{bkf}											10.07
Meander width ratio, W_{blt}/W_{bkf}											14.91
Length of channel thalwage, L_w (m)											1510.90
Length of valley, L_{vally} (m)											1290.00
Sinuosity, $K=L_{tw}/L_{valley}$ (m/m)											1.171
Slope of channel, S_{avg}=d elv/ltw (m/m)											0.012

Morphological data	Bhiansepati Segment										
	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	Mean
Riffel cross-section											
Width at bankfull, W_{bkf} (m)	17.00	30.40			14.20		12.70		15.30	17.30	17.82
Bankfull x-section area, A_{bkf} (m^2)	7.80	17.66			5.56		3.83		5.67	9.79	8.39
Max depth bankfull, D_{max} (m)	0.70	1.30			0.80		0.50		0.50	0.80	0.77
Flood prone height, W_{fph}	1.40	2.60			1.60		1.00		1.00	1.60	1.53
Width flood prone area, W_{fpa} (m)	44.20	136.00			130		26.20		20.80	75.50	72.12
Max depth top low bank, d_{tob} (m)	1.70	2.10			1.70		1.50		1.50	2.35	1.81
Mean depth at bankfull, $Dbkf= A_{bkf}/W_{bkf}$	0.46	0.58			0.39		0.30		0.37	0.57	0.44
Entrenchment ratio, $ER= Wf_{pa}/W_{bkf}$	2.60	4.47			9.15		2.06		1.36	4.36	4.003
Width depth ratio, $W/D= W_{bkf}/d_{bkf}$	37.05	52.33			36.27		42.11		41.29	30.57	39.94
Bank height ratio, $BHR= dt_{ob}/d_{max}$	2.43	1.62			2.13		3.00		3.00	2.94	2.52
Max depth ratio, D_{max}/d_{bkf}	1.53	2.24			2.04		1.66		1.35	1.41	1.70
Pool cross-section											
Pool width, W_{pool}			12	12.60		13.90		11.40			12.48
Pool area, A_{pool}			4.91	5.53		4.44		2.10			4.25
Pool max depth, d_{pool}			0.70	0.90		0.70		0.50			0.70
Pattern Survey											
Meander wavelength, lm(m)											574.84
Belth width, W_{blt} (m)											356.36
Radious of curvature, Rc											201.94
Meander wavelength ratio, $MLR=l_m/W_{bkf}$											32.26
Radius of curvature ratio, Rc/W_{bkf}											11.33
Meander width ratio, W_{blt}/W_{bkf}											20.00
Length of channel thalwage, L_w (m)											2605.00
Length of valley, L_{vally} (m)											1708.88
Sinuosity, $K=L_{tw}/L_{valley}$ (m/m)											1.524
Slope of channel, S_{avg}=d elv/ltw (m/m)											0.013

Morphological data	Chapagaon Segment										
	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9	3-10	Mean
Riffel cross-section											
Width at bankfull, W_{bkf} (m)	21.10	18.50	21.00	18.00		28.00		10.60			19.53
Bankfull x-section area, A_{bkf} (m^2)	6.65	5.36	6.39	9.34		23.12		4.33			9.20
Max depth bankfull, D_{max} (m)	0.70	0.63	0.60	0.80		1.10		0.77			0.77
Flood prone height, W_{fph}	1.40	1.26	1.20	1.60		2.20		1.54			1.53
Width flood prone area, W_{fpa} (m)	45.20	85.60	48.00	56.60		36.00		39.60			51.83
Max depth top low bank, d_{tob} (m)	3.20	3.60	1.20	7.35		7.40		2.70			4.24
Mean depth at bankfull, $Dbkf= A_{bkf}/W_{bkf}$	0.32	0.29	0.30	0.52		0.83		0.41			0.44
Entrenchment ratio, $ER= Wf_{pa}/W_{bkf}$	2.14	4.63	2.29	3.14		1.29		3.74			2.87
Width depth ratio, $W/D= W_{bkf}/d_{bkf}$	66.95	63.85	69.01	34.69		33.91		25.95			49.06
Bank height ratio, $BHR= dt_{ob}/d_{max}$	4.57	5.71	2.00	9.19		6.73		3.51			5.28
Max depth ratio, D_{max}/d_{bkf}	2.22	2.17	1.97	1.54		1.33		1.88			1.85
Pool cross-section											
Pool width, W_{pool}					17.00		12.00		12.50	12.00	13.38
Pool area, A_{pool}					9.57		6.15		4.40	3.57	5.92
Pool max depth, d_{pool}					1.20		1.10		0.75	0.6	0.91
Pattern Survey											
Meander wavelength, lm(m)											460.22
Belth width, W_{blt} (m)											255.29
Radious of curvature, Rc											137.53
Meander wavelength ratio, $MLR=l_m/W_{bkf}$											23.56
Radius of curvature ratio, Rc/W_{bkf}											7.041
Meander width ratio, W_{blt}/W_{bkf}											19.533
Length of channel thalwage, L_w (m)											1792.24
Length of valley, L_{vally} (m)											1500.48
Sinuosity, $K=L_{tw}/L_{valley}$ (m/m)											1.194
Slope of channel, S_{avg}=d elv/ltw (m/m)											0.015

Morphological data			Nallu Segment								
	4-1	4-2	4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	Mean
Riffel cross-section											
Width at bankfull, W_{bkf} (m)		19.00		14.60		17.30	10.70	8.10	7.60		12.88
Bankfull x-section area, A_{bkf} (m^2)		11.19		8.01		7.12	2.61	3.63	2.34		5.82
Max depth bankfull, D_{max} (m)		0.93		0.82		0.62	0.50	0.80	0.65		0.72
Flood prone height, W_{fph}		1.86		1.64		1.24	1	1.60	1.30		1.44
Width flood prone area, W_{fpa} (m)		23.00		46.60		40.10	19.80	59.50	32.50		36.92
Max depth top low bank, d_{tob} (m)		2.90		2.10		1.80	1.80	1.90	1.40		1.98
Mean depth at bankfull, $Dbkf= A_{bkf}/W_{bkf}$		0.59		0.55		0.41	0.24	0.45	0.31		0.42
Entrenchment ratio, $ER= Wf_{pa}/W_{bkf}$		1.21		3.19		2.32	1.85	7.35	4.28		3.37
Width depth ratio, $W/D= W_{bkf}/d_{bkf}$		32.26		26.61		42.04	43.87	18.07	24.68		31.26
Bank height ratio, $BHR= dt_{ob}/d_{max}$		3.12		2.56		2.90	3.60	2.38	2.15		2.79
Max depth ratio, D_{max}/d_{bkf}		1.58		1.49		1.51	2.05	1.79	2.11		1.75
Pool cross-section											
Pool width, W_{pool}	8.60		15.00		8.20					8.30	10.03
Pool area, A_{pool}	5.46		13.53		2.17					1.97	5.78
Pool max depth, d_{pool}	0.9		1.40		0.70					0.65	0.91
Pattern Survey											
Meander wavelength, lm(m)											400.00
Belth width, W_{blt} (m)											211.43
Radious of curvature, Rc											107.09
Meander wavelength ratio, $MLR=l_m/W_{bkf}$											31.05
Radius of curvature ratio, Rc/W_{bkf}											8.312
Meander width ratio, W_{blt}/W_{bkf}											16.41
Length of channel thalwage, L_w (m)											1570.00
Length of valley, L_{vally} (m)											1260.00
Sinuosity, $K=L_{tw}/L_{valley}$ (m/m)											1.246
Slope of channel, S_{avg}=d elv/ltw (m/m)											0.017

CHAPTER FIVE

GRAIN SIZE AND COMPOSITION OF RIVER SEDIMENT

The river sediment distributed along the river channel, and bar of the Nakhu Khola were studied. The reachwide river sediments were studied by using the method of reach-scale Wolman Pebble count during river cross section survey. Sieve analysis of bar sample was done.

REACH WIDE GRAIN SIZE ANALYSIS

Reach wide grain size analysis was done by application of Wolman pebble count. This is the most efficient method developed by Wolman (1954) and modified by Rosgen (1996). This method gives the quantitative description of the river bed material. Total 400 pebbles were counted from the ten transects both on the riffle and pool throughout the longitudinal reach of the each four segments of the river and the median diameter (d_{50}) of the pebble were measured (Annex II).

The result obtained from the pebble count data gives the composition of gravel as well as the proportion of the pebble, sand and silt/clay for each segment of the Nakhu Khola. The proportion is nearly same in downstream the Nakhu and Bhainsepati segments and in upstream Chapagaon and Nallu segments. The size of gravel decreases gradually from Nallu segment to the Nakhu Segment. Large boulder, cobble and pebble observed in the stream channel shows that the low order streams could not transport large particle due to the low velocity. The upstream segments; Chapagaon and Nallu have greater and nearly same proportion of gravel (55.24-55.4%), silt/clay and sand percentage is lower. The two downstream segments: Bhainsepati and the Nakhu Segment have nearly same proportion of gravel (44.5 to 39.51%); silt/clay and sand percentage is lower. Since downstream segments have comparatively small grain size, these segments have low riverbed roughness, which may influence for high velocity. The greater percent of silt/clay in the channel could cause increase in suspended material and turbidity of water

GRAIN SIZE ANALYSIS OF BAR SAMPLE

Bar sample of the Nakhu Khola were analyzed by sieving in the field and in laboratory and aplotted on probability paper (Annex III). Bulk samples were collected from eight different locations. Two samples from each four segments were analyzed in field up to certain grain size and then collected samples were analyzed in laboratory. Locations of sediment sampling spot are given in the Figure 5.1.

The result obtained from the grain size analysis give different composition of gravel, sand and silt in each different samples used. The gravel percentage in bar sample ranges from 93.24% (SA4) to 60% (SA8). The sand percentage ranges from 29.50% (SA6) to 6.01% (SA4) and silt percentage range from 2.06% (SA7) to 0.76% (SA4). On average, the upstream segment Chapagaon and Nallu segment has nearly same proportion of gravel (74.80% to 72.29%), sand (23.26% to 23.13%) and silt clay. The downstream segments, the Bhainsepati segment and the Nakhu Segment, has nearly same percentage of silt (1.35% to 1.016%). Though the grain size of the river generally decreases from the upstream to downstream, the bar samples sieved does not show this trend in the Nakhu Khola. The result of sieve analysis show that in the Nakhu Segment and Chapagaon segment, grain size increases for upstream to downstream segment, which might be due to sediment mining from the bar of the Nakhu Khola for construction purposes and sediment dump from crusher and quarry area.

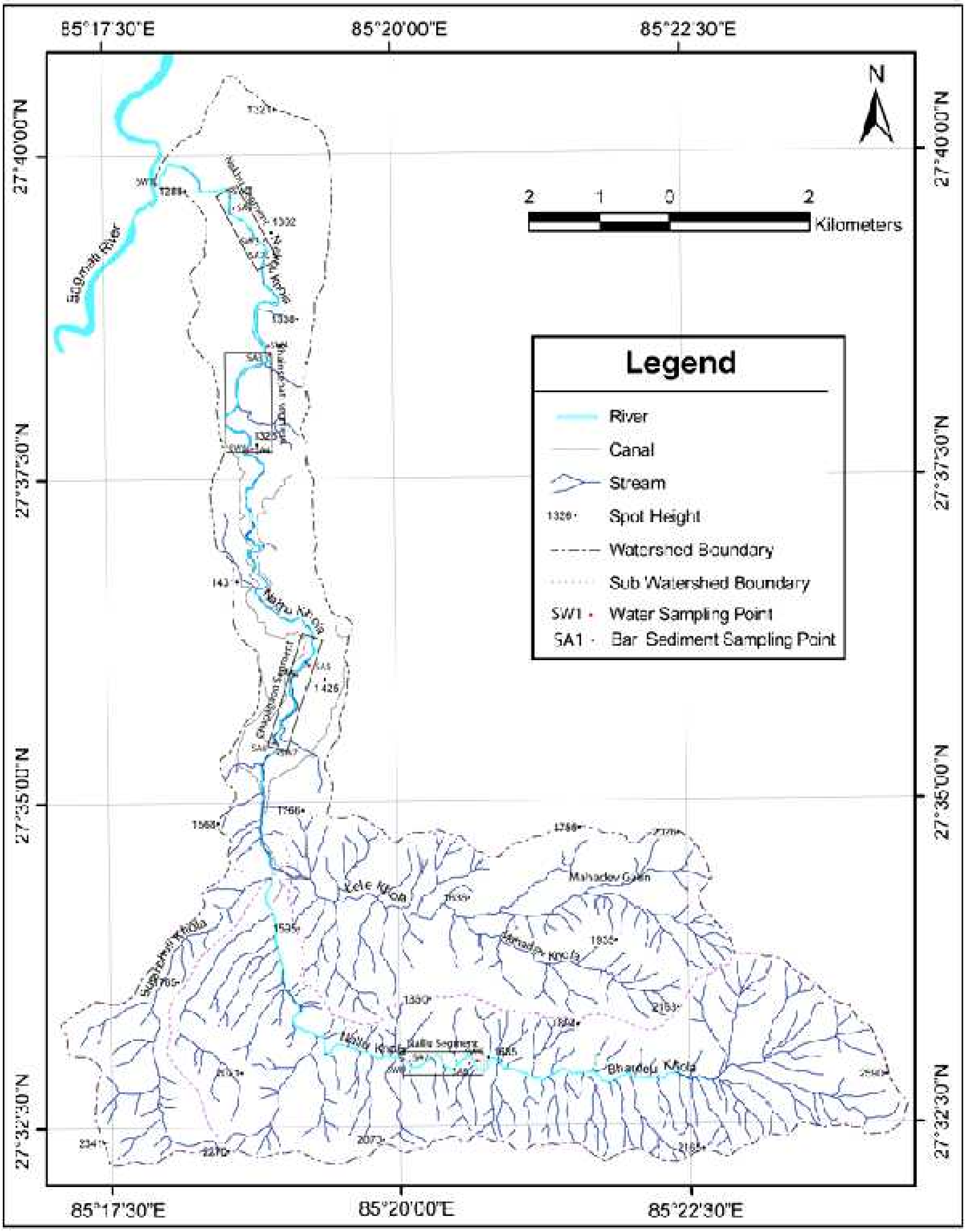


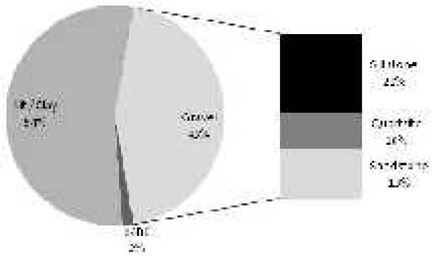
Figure 5.1: Location map of bar and water sampling point.

COMPOSITION OF CHANNEL SEDIMENTS

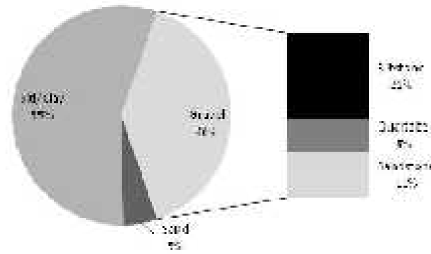
The study of gravel obtained from the pebble count data shows that gravels are mainly composed of slit stone, quartzite, sandstone and few limestones. The composition of gravel in all four segments is nearly same. The Nallu segment is composed of few limestones with siltstone, sandstone and quartzite. These gravels in all four segments are supplied from the Tistung Formation, the Sopyang Formation and the Chandagiri Limestone. The gravels of downstream segments, after Tikabhairab gorge, also belong to the Chapagaon gravel deposit. This Chapagaon gravel deposit deposited as alluvial fan, during upliftment period of Mahabharat range is now reworked and transported by the Nakhu Khola. The compositon of gravel sediment from upstream to downstream is same. This composition variation also gives the composition variation of the Nakhu Khola. (Table 5.1)

Table 5.1: Compositional variation of the Nakhu River

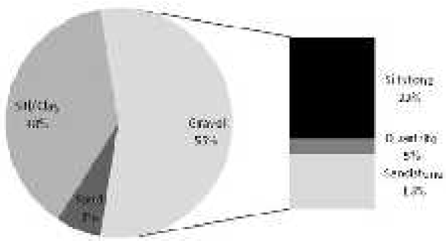
Composition	%	Stream Segment			
		Nakhu	Bhainsepati	Chapagaon	Nallu
Gravel	Siltstone	21.36	20.54	32.59	22
	Quartzite	9.79	7.9	4.97	6.8
	Sandstone	13.35	11.06	17.68	26
	Limestone	-	-	-	0.6
Sand		1.75	5	6.5	4
Sitl/Clay		53.75	55.5	38.25	40



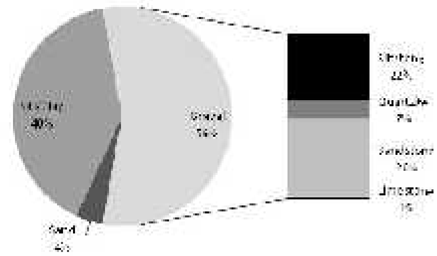
(a) Nakhu Segment



(b) Bhainsepati Segment



(c)



(d)

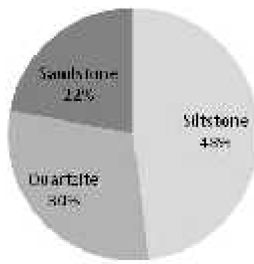
Figure 5.2 : Pie chart of composition of channel sediment of (a) NakhuSegment (b) Bhainsepati Segment (c) Chapagaon Segment and (d) Nallu Segment of the Nakhu Khola

COMPOSITION OF BAR SEDIMENTS

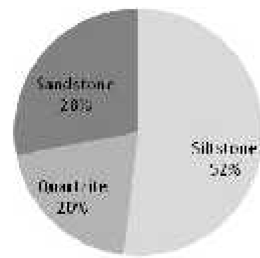
The composition of bar sediment is also mainly siltstone, quartzite, sandstone and limestone belonging to the Tistung Formation, the Sopyang Formation and the Chandragiri Limestone and some sediment are reworked from the Chapagaon Gravel Deposit. The composition of gravel, sand and silt/ Clay is different in each segment based on the sediment source. Majority of gravel in all segments is composed of siltstone, which is followed, by sandstone, quartzite and limestone. The gravel obtained from the Nallu segment consists of siltstone, sandstone, quartzite and limestone, which are derived from the surrounding hills. The gravel observed at downstream segments, the Bhaisepati segment and the Nakhu Segment are also composed of siltstone, sandstone and quartzite. These segments also have few mud balls, which are produced due to reworking of older soft sediment of fluvio lacustrine deposit of the Lukundol Formation by the Nakhu Khola. The gravel of limestone is observed only in the Nallu Segment but not observed in other segments.

Table 5.2: Gravel compositional variation of bar sample of the Nakhu River

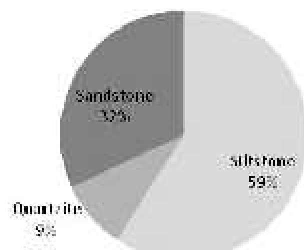
Composition %	Stream Segment			
	Nakhu	Bhainsepati	Chapagaon	Nallu
Siltstone	48	52	59	40
Quartzite	30	20	9	12
Sandstone	22	28	32	47
Limestone	-	-	-	1



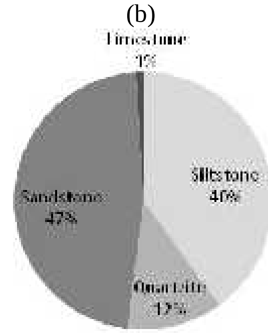
(a)



(b)



(c)



(d)

Figure 5.3 : Pie chart of composition of bar gravel of (a) Nakhu Segment (b) Bhainsepati Segment (c) Chapagaon Segment and (d) Nallu Segment of the Nakhu Khola

CHAPTER SIX

HYDRAULIC PARAMETERS

6.1 WETTED PERIMETER AND HYDRAULIC RADIUS

Wetted perimeter is the sum of full width and twice the depth at bankfull. It is highest in Chapagaon Segment (20.42 m) and least in Nallu Segment (13.73 m). The Nakhu and Bhainsepati Segment have nearly equal value of wetted perimeter, which are 18.88 m and 18.71 m respectively. The Chapagaon segment has wider channel due to lower slope and addition of many tributaries. Therefore, it has high wetted perimeter. It increased from upstream to downstream segments of river. It indicates that high order stream has high wetted perimeter suggesting wide channel and low order stream has low wetted perimeter due to narrow channel.

Hydraulic radius is the ratio of the cross sectional area to its wetted perimeter. It is highest in The Nakhu Segment (0.62 m) and least in the Nallu segment (0.42 m). The hydraulic radius in three segments, the Nallu segment (0.42 m), the Chapagaon segment (0.45 m) and the Bhainsepati segment (0.45 m) have nearly equal hydraulic radius. The fourth order Nallu Segment has the least cross sectional area and the wetted perimeter and hence least hydraulic perimeter (Table 6.1).

Table 6.1: Calculated values of Hydraulic Parameters

Attributes	Nakhu	Bhainsepati	Chapagaon	Nallu
Bankfull cross-section area, $A_{bkf}(m^2)$	11.62	8.39	9.20	5.82
Width at bankfull, W_{bkf}(m)	17.64	17.82	19.53	12.88
Mean depth at bankfull, D_{bkf}(m)	0.62	0.44	0.44	0.42
Wetted Perimeter	18.88	18.71	20.42	13.73
Hydraulic radius,R(m)	0.62	0.45	0.45	0.42
Manning's roughness coeficient,n	0.090	0.125	0.121	0.144
Slope, S_e(m/m)	0.0120	0.0130	0.015	0.017
Bankfull discharge, $Q(m^3/s)$	10.23775	4.48	5.47	2.97
Bankfull Velocity,V(m/s)	0.88	0.53	0.59	0.51
d_{50}(m)	0.00012	0.00012	0.02425	0.02884

Attributes	Nakhu	Bhainsepati	Chapagaon	Nallu
ds_{50}(m)	0.02042	0.03407	0.01743	0.024415
d_{10}(m)	0.094	0.135	0.155	0.201
d_{50}/ds_{50}	0.0059	0.0036	1.3913	1.1812
d_{10}/d_{S50}	4.60	3.96	8.89	8.23
$\tau(N/m^2)$	7.386	5.827	6.761	7.200
Critical dimensionless shear stress, τ_{cr}	0.0220	0.0251	0.0124	0.0133
D_r	0.2847	0.4301	0.2115	0.2588
S_r	0.0055	0.0126	0.0072	0.0104
Sc	53.75	55.50	38.25	40.00
Sb	1.200	1.020	1.930	4.032
F-factor=W/D	28.35	40.05	44.02	30.32
M-factor= $\{(S_c X W_{bkf})+(S_b X 2D_{bkf})\}/(W_{bkf}+2D_{bkf})$	50.29	52.91	36.67	37.77

6.2 MANNING ROUGHNESS COEFFICIENT

The value of Manning's roughness coefficient depends on the different factors such as channel irregularity, surface roughness, vegetation, seasonal change and channel materials (Chow, 1986). The value of n can be calculated by following equations

$n= (n_b+n_1+n_2+n_3+n_4)\ m$ .... (6.1)

Where,

n_b= value for a straight, uniform, smooth channel in the natural material involved

n_1= value of the surface irregularity

n_2= value for variation in shape and size of the channel cross-section

n_3=value for obstruction

n_4= value for vegetation and flow condition

m= correction factor for meandering of the channel

The Manning's roughness value was used for calculating the velocity at the bankfull stage. The Manning roughness coefficient was estimated for the Nakhu Khola by comparing the n value given by Chow (1986)(Annex IV) and the present obstruction produced by channel condition and boundary material observed in each segments during field survey.During field survey, Manning's roughness coefficient was estimated for each segment. These are 0.090 in the Nakhu Segment, 0.125 in the Bhainsepati segment, 0.121 in the Chapagaon segment and 0.144 in the Nallu segment (Table 6.2). In undisturbed channel, it increases from downstream to upsetream. But in the case of the Nakhu Khola, value increases from the Nakhu Segment to the Bhainepati segment and decreases in the Chapagaon segment and again increases in the Nallu segment. The low n value suggests that bed materials of lower segment are fine with low obstruction and low vegetation compare to upstream segments. The value of coefficient in the second segment is greater due to human influence in river due to artificial channel obstruction and vegetation in the flood plain and river channel and also due high meander bend. The low n value in the lower segment directly influences the high velocity with greater possibility of bank erosion. The obstruction in the Chapagaon segment and the Bhainsepati Segment is nearly same.

Table 6.2: Calculated Roughness Parameters

Segment	Parameters of roughness						
	n_b	n_1	n_2	n_3	n_4	m	n
Nakhu	0.035	0.01	0.015	0.02	0.01	1	0.090
Bhainsepati	0.035	0.01	0.010	0.025	0.02	1.3	0.125
Chapagaon	0.04	0.01	0.015	0.03	0.015	1.1	0.121
Nallu	0.04	0.015	0.015	0.035	0.02	1.2	0.144

Manning roughness (n=nb+n1+n2+n3+n4)m (nb=0.035 for Nakhu)

DISCHARGE

Discharge is the volume of water flowing through a stream channel cross section per unit time. Bank-full discharge was estimated by using Manning's equation (Chow, 1959).

$$Q = (A.R^{2/3}.\ S^{1/2})/n \quad .... 6.2$$

Where,

A = cross-sectional area at bankfull stage
Q = bankfull discharge
S = average channel slope
n = Manning's roughness coefficient
R = hydraulic radius

The bank-full discharge is highest in the Nakhu Segment (10.236 m^3/s) and lowest in the Nallu segment (2.97 m^3/s). Decrease in roughness and increase in slope, hydraulic radius and cross-sectional area increases discharge. Discharge increases from upstream to downstream segments due to decrease in roughness and contribution of its tributaries at downstream. (Table 6.1). The Nakhu Segment has the highest discharge due to low roughness in the channel and located in the downstream of the river, collecting water from all regions and contributing tributaries to the watershed. So, the Bhainsepati segment and the Chapagaon segment has also greater discharge than the Nallu segment.

VELOCITY

It is the velocity of the stream at bank-full stage. The bank-full velocity was calculated from cross-sectional area and discharge using the equation:

V=Q/A .... (6.3)

Where,

V = bankfull velocity (m/s)
A = cross-sectional area (m^2)
Q =bankfull discharge, (m^3/s)

The bank-full velocity is greatest at the Nakhu Segment 0.88m/s followed by Chapagaon (0.59 m/s), Bhainsepati (0.534 m/s) and Nallu segment (0.511 m/s). The high velocity in The Nakhusegment is influenced by the low slope, low roughness in the channel and high discharge (Table 6.1). Bank erosion is themajor problem caused by high velocity in the Nakhu Segment. The velocity depends on the discharge, slope, roughness and cross-sectional area. Velocity increases with increase in discharge and decreases with increase in cross sectional area of channel. The Nallu segment and Bhainsepati segment has the least velocity due to high roughness. Therefore, this channel suffers from maximum channel meandering due to low slope and poor riparian vegetation.

CHAPTER SEVEN

RIVER CLASSIFICATION

Rivers are complex natural system. In order to make study easy, rivers are stratified into groups that share common physical characteristics. The stream classification system provides better communication among those studying river systems and promotes a better understanding of river processes.The Classification of rivers is an organization of data of stream features into categories so that one can predict a river behavior from its appearance and specific hydraulic and sediment relation from a given geomorphic channel type and state (Foggen 1998). Rogen stream classification consists of three levels, which are intended for planning purpose. Four different segment of the Nakhu Khola was classified following the criteria of Rosgen (1994) (Annex V).

Level-I classification is based on geomorphic characteristics such as basin relief, landform and valley morphology. This is board characterization level used only where general classification is required. The dimensions, pattern and profile are based on information from topographic, landform maps and aerial photographs. In this level, streams are categorized into nine types: Aa+, A, B, C, D, DA, E, F, and G.

Level II classification process provides a more detained morphological description of the stream based on field-collected data such as entrenchment ratio, width depth ration, sinuosity, and meander. This level classification provides information needed for sediment supply, stream sensitivity to disturbance, potential for natural recovery, channel responses to disturbance, potential for natural recovery, channel responses to changes in flow regimes. In this level, dominant channel material is determined by using the numeric indicators based on D_{50} size. The channel material is classified into one of six particle size categories which is shown in table 7.1

Table 7.1: Channel material classification

S.N.	Particles	Size (mm)
1.	Bed Rock	>2048
2.	Boulder	256 to 204
3.	Cobble	64 to 255.9
4.	Gravel	2 to 63.9
5.	Sand	0.062 to 1.99
6.	Silt/ clay	<0.062

So, stream segments can be classified at 42 categories of level II classification.

Level III classification evaluates the existing stream condition and stability. For describing existing condition of the stream, riparian vegetation, stream flow regime, stream size and order, disturbance to the channel meander pattern and channel stability etc are required.

For the classification of four segment of the Nakhu Khola, five morphological characteristics (Rosgen, 1994) viz. entrenchment ratio, width depth ratio, Sinuosity, slope and dominant channel materials D_{50} were considered. The results of river classification of four segments are shown in Table: 7.2 and respectively classified as C_{5b}, C_{5b}, C_{4b} and C_{4a} in which small letter indicate the slope range.

Table 7.2: Summary of classification of the Nakhu River based on Rosgen(1994)

Attribute	Nakhu Segment	Bhainsepati Segment	Chapagoan Segment	Nallu Segment
Entrenchment ration,E/R	3.05	4.00	2.52	3.37
W/D ratio	30.19	39.94	75.66	31.26
Sinosity, (Km/m)	1.17	1.52	1.19	1.25
Slope(m/m)	0.012	0.013	0.015	0.017
Bedmaterial,median size(mm)	0.120	0.122	24.250	28.840
Rosgen Stream type	C_5	C_5	C_4	C_4

NAKHU SEGMENT

This segment is slightly entrenched with entrenchment ratio 3.05, which is greater than 1.4. The width depth ratio is 30.19. Slope measured from longitudinal profile is 0.012m/m, whichis least among all segments. Sinuosity (k) is 1.17 with bed material of gravel and silt/

clay mixture with little sand and the median channel material is sand sized particle. This segment is slightly entrenched with low sinuosity. So, the segment is classified as C_{5b}. Cross section prepares in this segment is shown in Annex V-2.The deposition pattern of segment is characterized by the presence of point bars, point bars with few mid channel bars and side bars. Cross-sctions prepared during field survey are shown in Annex V-2.

Riparian vegetation along the river corridor is poor. Along the whole segment banks are covered mainly by grass, and shrubs and some small trees are present at downstream of segment. Most of the flood plain of the segment is cultivated and built up areas. Some civil engineering structures like dyke, spurs and gabion walls are built to protect the cultivated and built up areas from the erosion. This segment has been affected by clearing of the riparian vegetation, bank encroachment, extremely high effluent discharge from the settlement areas and pig farms.

BHAINSEPATI SEGMENT

This segment has broad valley with terraces associated with well-defined flood plains. The entrenchment ratio is 4.603 which is highest than all other segments. This high entrenchment ratio indicates that flooding occurs outside stream easily. So, this segment have flood prone width. The Nallu and Nakhu Segment and sinuosity is 1.524 which depth ratio 39.94 which is slightly greater than The Nakhusegment. The bed materials composed of finesand grade particle with gravel. Deposition pattern in stream is characterized by abundant channel bar and point bars. The segment is slightly entrenched with well-defined meandering channel and high W/D ratio and low gradient (<0.02 m/m) so it is classified as C_{5b} stream.Cross-sctions prepared during field survey are shown in Annex V-2.

Riparian vegetation is represented by grass, shrubs, cultivated land. Distributed of tree is only in certain part in patchy and discontinuous pattern.

The banks exhibit erositional scraps and parallel erosion along the whole segment. Seasonal channel shifting of 10 to 20m is remarkable. Gabion wall, dykes built for erosion control and cultivation of banks, flood plains, grazing, bank encroachment, and riparian vegetation clearing are major problems.

CHAPAGAON SEGMENT

This segment is also slightly entrenched with entrenchment ratio of 2.87, which is lowest among all. The segment has highest W/D ratio among all which is equal to 49.06.Sinuosity is 1.94 which is nearly same with the Nallu and Nakhu Segment. The slope is 0.015 with bed materials dominantly composed of gravel. This segment is classified as C_4 type. Prepared cross section of both riffle and pool is shown in Annex V-2. Abundant point bars and mid channel bars constitute depositional channel elements.

Grasses, shrubs and linear to patchy isolated trees represent riparian vegetation. This segment also exhibits natural and seasonal channel shifting in wide flood plains and artificial temporary channel deflection and obstruction for irrigation is frequent along the channel. Banks of this segment exhibit erositional scraps and a few landslides.

Civil engineering structures built at the banks for erosion control is one of the disturbing factors of river. Excavation of gravel from channels, cultivation on the banks and bars and grazing activities are the major disturbances, which have been impairing the river segment. Road along the whole segment is extended by right bank.

NALLU SEGMENT

This segment is slight entrenched (3.37) with high width depth ratio (31.26) greater than 12. This segment have well defined meandering channel with low sinuosity (1.246) generally less than 1.5 with gentle slopes. This segment have also well developed valley with distinct flood plains. Abundant point bars and mid channel bars constitute depositional channel elements. The bed material is gravel with slit matrix. So, the segment is classified as C4b. Cross-sctions prepared during field survey are shown in Annex V-2.

Riparian vegetation is representation by grass, shrubs and linear to patchy isolated trees. Though the segment is in natural condition than others, it is also affected by human activities like over withdrawal of water and sediment mining. The high banks of this segment have erositional scraps and a few landslides. Cultivated Flood plains, poor vegetation in banks, over grazing in flood plains, road cut and cut slopes for mining are the major factors for high sediment contribution in segment. The abandoned and existing mines located in up and downstream of the segment are also impairing the segment.

CHAPTER EIGHT

RIPARIAN VEGETATION CONDITION

The word "riparian" is derived from Latin *ripa*, meaning riverbank. A riparian zone or riparian area is the interface between land and a river or stream. Plant habitats and communities along the river margins and banks are called riparian vegetation. Riparian zones are significant in ecology, environmental management, and civil engineering because of their role in soil conservation, their habitat biodiversity, and the influence they have on fauna and aquatic ecosystems.

These zones are important natural biofilters, protecting aquatic environments from excessive sedimentation, polluted surface runoff and erosion. They supply shelter and food for many aquatic animals and shade that is an important part of stream temperature regulation. The vegetation surrounding the stream helps to shade the water, mitigating water temperature changes.The riparian zones are also important in water quality improvement for both surface runoff and water flowing into streams through subsurface or groundwater flow. Absorption of nitrate from agriculture fields or denitrification of the nitrates from fertilizer in this buffer zone is important, which runoff would otherwise damage ecosystems and human health. The meandering curves of a river, combined with vegetation and root systems in riparian zone, dissipate stream energy, which results in less soil erosion. Sediment is trapped, reducing suspended solids to create less turbid water, replenish soils, and build stream banks. Pollutants are filtered from surface runoff, which enhances water quality via biofiltration.

Riparian vegetation of the Nakhu Khola was studied by traversing and mapping along the river from the Nallu VDC to confluence of the Nakhu Khola with the Bagmati River. For the vegetation study and distribution pattern, maps were prepared with the help of satellite images and Google Earth and verified during the field study. Also vegetation present along the river bank, flood plain as well as terrace was identified and located onto a map of 1:10000.

CLASSIFICATION

For making the study of vegetation, distribution easy, present vegetations are classified into three basic types as:

- Canopy (Overstory)
- Understory
- Ground cover

The canopy is made up of very tall trees that stand over the rest of the plants. The understory consists of underlying layer of vegetation, especially the vegetative layer and small trees, shrubs and grass between canopy and ground cover. The low growing vegetation as herbs, shrubs and grasses, which cover ground, are called the ground cover. The vegetation distribution pattern in the watershed is shown in the Figure 8.1. The northern part of the watershed consists of poor riparian vegetation dominantly of ground cover with scattered understory and canopy only in few parts. The central part of the watershed consists of mixed type of vegetation distribution. The vegetation distribution in this part is moderate and patchy with dominant of understory, groundcover and scattered canopy. The vegetation distribution in the southern part of the watershed is also moderate and very poor in the quarry sites located along the Nallu Khola. The vegetation distribution in the river corridor and flood plain is mostly ground cover and understory while surrounding hills consist of canopy.

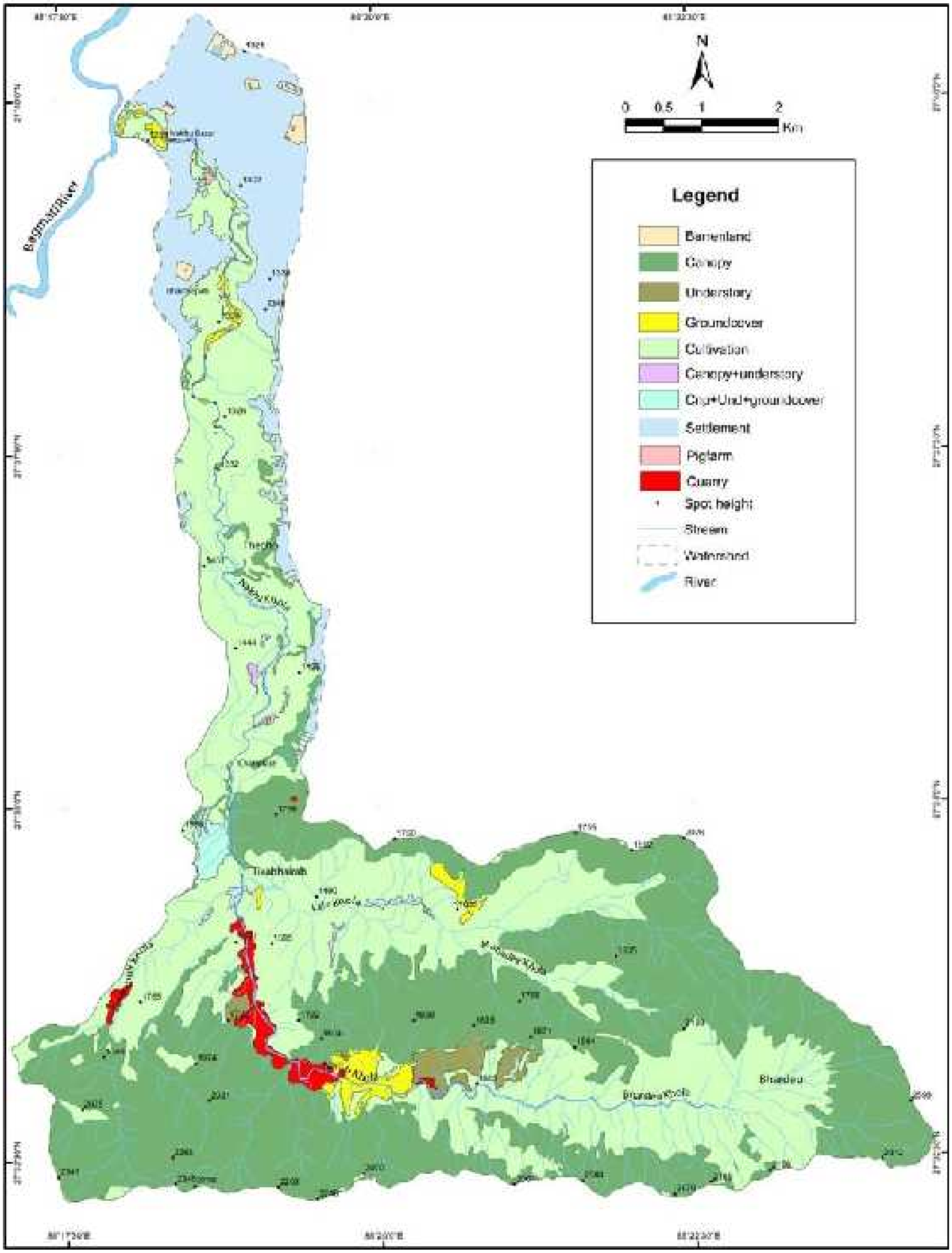


Figure 8.1: Map showing riparianvegetation and recent(2010) landuse pattern of the Nakhu Khola watershed

PATTERNS

The distribution of riparian vegetation depends on different factors like soil moisture level, distance from stream and native plant community mark up. The riparian vegetation are distributed into different patterns. The pattern of vegetation was identified with the help of satellite images, aerial photos and field visit. Patterns of riparian vegetation were categorized as:

- Matrix
- Corridor
- Patch

The riparian vegetation which has aerial coverage was grouped into matrix category. The array of vegetation which has linear feature was grouped into corridor and the vegetation present in form of cluster was grouped into patch. The distribution of types and pattern of vegetation is shown in Figure 8.1. The pattern of vegetation distribution in the northern and central part is matrix type for ground cover and patch and corridor type for the understory and canopy. Some of the parts also consist of mixed type and scattered pattern of vegetation distribution. In the southern part of the watershed, canopy is distributed in matrix pattern in the hills and patchy and corridor type in the riparian vegetation zone. Ground cover and understory is distributed in patch and matrix pattern.

SPECIES

The natural vegetation is dictated by the climatic conditions and accordingly five vegetation zones have been defined for Nepal, out of which Kathmandu and its valley fall under the Deciduous Monsoon Forest Zone (altitude range of 1,200–2,100 metres (3,900–6,900 ft)). The dominant species found in four segments of the Nakhu Khola watershed are given in Table 8.1

Table 8.1: Dominant plant species in four segment of the Nakhu Khola

S.N.	Common Name	Botanical Name	S.N.	Common Name	Botanical Name
		Nakhu Segment			
1	Dubo	*Cynodon dactylon*	11	Polygonace	*Polygonum barbatum*
2	Banmara	*Eupatorium adenophorum*	12	Kanda pul	*Lantana camara*
3	Kuro	*Compositae sp.*	13	Kantakari	*Solanum myriacanthum*
4	Tite pate	*Artemisia vulgaris*	14	Lattae	*Amaranthus sp.*
5	Kans	*Saccharum spontaneum*	15	Bhimsenpati	*Buddleja asiatica*
6	Sisnu	*Urtica diocia*	16	…..	*Solanum sp.*
7	Narkat	*Phragmites karka*	17	…..	*Labiateal sp.*
8	Ghodtaprae	*Centella asciatica*	18	…..	*Asteraceae*
9	…..	*Oxalix sp.*	19	Bottlebrush	*Callistemon citrinus*
10	Bhang	*Cannabis sativa*	20		
		Bhainsepati Segment			
1	Dubo	*Cynodon dactylon*	16	Nilkadha	*Durenta erecta*
2	Banmara	*Eupatorium adenophorum*	17	……	*Labiateal sp.*
3	Narkat	*Phragmites karka*	18	Lapsi	*Choerospandias*
4	Batulpate	*Cissampelos pareira*	19	Banchutro	*Berberis aristata*
5	Sisnu	*Urtica diocia*	20	Kanda pul	*Lantana camara*
6	Kantakari	*Solanum myriacanthum*	21	Ipilipil	*Leucaena leucocephala*
7	Kans	*Saccharum spontaneum*	22	…...	*Asteracea sp.*
8	Titepate	*Artemisia vulgaris*	23	…...	*Persicaria sp.*
9	Uniyu(Fern)	*Dryopteris*	24	……	*Zizypus sp.*
10	Kuro	*Compositae sp.*	25	Utish	*Ainus nepalensis*
11	Ghodtaprae	*Centella asciatica*	26	……	*Persicaria sp.*
12	Bans	*Bambusa sp.*	27		
13	Kantakari	*Solanum myriacanthum*			
14	Sisnu	*Urtica diocia*			
15	……..	*Solanum sp.*			
		Chapagaon Segment			
1	Ainselu	*Rubus ellipticus*	10	Tite pate	*Artemisia vulgaris*
2	Kantakari	*Solanum myriacanthum*	11	Kans	*Saccharum spontaneum*
3	Utis	*Ainus nepalensis*	12	Bakaina	*Melia azedarach*
4	Banchutro	*Berberis aristata*	13	Uniyu(Fern)	*Dryopteris sp.*
5	Narkat	*Phragmites karka*	14	……	*Zizypus sp.*
6	Bans	*Bambusa sp.*	15	Kuro	*Compositae sp.*
7	Salla	*Pinus sp.*	16	Nilkadha	*Durenta erecta*
8	Chilaune	*Schima wallichii*	17	Nigalo	*Arundinaria falcate*
9	Lapsi	*Choerospandias*	18	Kimbu	*Morus alba*
		Nallu Segment			
1	Dubo	*Cynodon dactylon*	11	Kimbu	*Morus alba*
2	Kanda pul	*Lantana camara*	12	Utis	*Ainus nepalensis*
3	Ainselu	*Rubus ellipticus*	13	……	*Persicaria sp.*

S.N.	Common Name	Botanical Name	S.N.	Common Name	Botanical Name
4	Salla	*Pinus sp.*	14	Uniyu	*Dryopteris sp.*
5	Kaiyo phul	*Grevillea sp.*	15	Laliguras	*Rhododendron arboretum*
6	Banmara	*Berberis aristata*	16	Banchutro	*Berberis aristata*
7	Nigalo	*Arundinaria falcate*	17	Kuro	*Compositae sp.*
8	Bhimsenpati	*Buddleja asiatica*	18	Salla	*Pinus sp.*
9	Nilkadha	*Durenta erecta*	19	……..	*Solanum sp.*
10	Polygonum	*Polygonum barbatum*	20	Tite pate	*Artemisia vulgaris*

SEGMENT WISE DESCRIPTION OF VEGETATION TYPE AND PATTERN

Riparian zones have been degraded throughout the Nakhu Khola. There are different causes of degradation in riparian vegetation mainly stream channelization, vegetation clearing, grazing and mining. Riparian vegetation pattern distributed in the Nakhu Khola is variable in width and density as well as vegetation type and their distribution. The distribution of riparian vegetation from confluence between the Nakhu Khola and the Bagmati River to Bungamati is poor. The Nakhu and the Bhainsepati Segments lying in this part of the Nakhu Khola are very sparse and thin while vegetation distribution pattern is small patchy ground cover along with sparsely distributed canopy and understory.

The riparian vegetation of the Nakhu Segment is mostly affected by bank encroachment and vegetation clearing for cultivation and settlement. Vegetation distribution in this segment is dominantly of ground cover type with sparsely distributed understory. This segment is the most degraded segment among all.

The Bhainsepati segment consists of matrix of ground cover in flood plains and patch of understory in the river terraces. Distribution of canopy in this segment is also rare and distribution pattern is very sparse and linear in some parts.

The riparian vegetation distribution is quite good from Thecho to Chapagaon. The vegetation in this part of stream consists of matrix, patches as well as linear distribution of canopy and understory. Ground cover in this part is less than other parts. As in other parts, this part is also in stage of degradation due to human induced as well as natural causes. Natural cause includes the steep unstable bank failure and erosion in meander bends.

The Chapagaon segment consists of patches of grass and shrubs in form of ground cover in the flood plain and canopy and understory in the patch as well as linear pattern in river terraces. The Chapagaon segment is degraded due to clearing of vegetation for cultivation. The distribution of vegetation along the gorge between Chapagaon and Tikabhariab consists of matrix of canopy at right bank and corridor and patch of understory on the hills.

The quarry sites distributed along the Nallu khola is located after the Tikabhairab temple at confluence of Lele, Nallu and Buranchuli Khola. Therefore, this part of river segment is much degraded and consist of very poor riparian vegetation along river corridor. In quarry sites, vegetation is totally cleared though unquarried area still consist of matrix of canopy and understory in the hills.

The distribution of vegetation in the Nallu segment, which lies just after the quarry sites, consists of patch of ground cover and understory in flood plains and matrix of understory and canopy in the hills.

Chapter Nine

River Channel Stability Condition

Rivers are natural eroding as well as depositing agent with number of geomorphic functions. They carve the channels in which they flow and form most of the relief available for slope process to act upon; they transport the debris of slope and produce different erosional and depositional landforms. A naturally stable river neither aggrades nor degrades. Stable channel migrates across alluvial landscape slowly over long periods of time while maintaining their form and function. Stability and equilibrium of river is disturbed by different human activities like channelization due to sediment mining, watershed land use change etc. River always flows with tendency to maintain its equilibrium, to maintain equilibrium, river erodes and deposits by lateral and vertical shifting.

The Nakhu Khola watershed consists of many low order tributaries, which are in youthful stage with tendency of high headward erosion. The high order streams like the Lele Khola, the Nallu Khola and the Nakhu Khola are in mature stage and have meandering channel pattern.

Stream Channel Condition

Regional or system-wide instability is often caused by the channel modification (channelization) and development activities in watershed. These are found in upstream, downstream and in basin wide of the segments of river. In the study area, the downstream of the Nallu segment, along the quarry site is most unstable area without any distinct channel due to channel modification and dump of byproduct of the quarry. The Nallu segment is also degraded due to gravel and boulder mining from the river channel and flood plain. The dumping of byproduct from quarry and channelization directly influences to dynamic equilibrium of the river and degrades the streambed level. In order to balance the equilibrium of the river, deposits and base level of channel should be increased. Thus, downstream segment suffers from frequent flooding. In order to protect downstream from the flooding river should be channelized by building gabion wall and increasing depth of river. This channelization causes the maximum bank erosion at downstream segment. Encroachment of flood plain for cultivation is observed along the river from Nallu to Bhainsepati. Urbanization and flood plain encroachment are observed at downstream of the Bhainsepati segment and in many parts of Chapagaon, Thecho, Bungamati and Sunakothi. The landuse change from agriculture land to urban area in all segments causes reduction of lag time and increase peak discharge due to low infiltration of storm water and high surface runoff (Dunne and Leopold, 1978). Such peak discharge severely erodes stream banks and channel and causes river degradation. This type of condition is found in the Bhainsepati segment and the Nakhu Segment where the flood plains are encroached and landuse are greatly changed into urban area. Most of the agricultural land of this segment is urbanized.

The Chapagoan Segment and the Nallu segment have also same type of cause for system wide instability. The main factor is land use change and vegetation clearing, over withdraw of water for water irrigation and gravel mining.

The Nallu segment is less unstable compared to the other segments though after this segment at quarry site is much degraded.

Local instability refers to erosion and depositional process not caused by un-stability in watershed. Most common form of local un-stability is erosion along outside bank in meander bend. The un-stability occurs in all four segments are result of channelization, channel modification, grazing of livestock, loss of riparian, vegetation and unconsolidated sediment.

All of the low ordered streams originates from the rocks of the Tistung Formation, the Sopyang Formation and the Chandragiri Limestone in the southern part of basin and flows over basinfill sediment of the Bhardev and Lele villages. While high ordered streams flow from hard rock up to the Tika Bhairab gorge and then flow over the basin fill sediments of

Kathmandu. Both low and high order streams meander when flowing over basinfill sediment. Trunk stream represent matured stage with wide river valley and well developed flood plain while youthful low order streams still widening river valley by eroding and meandering its channel in basinfill sediments. Many point bars, side bars, mid bars and flood plains are developed along its course.

VERTICAL STABILITY

Vertical stability is the measure of incision of channel, which is determined by using the value of Bank Height Ratio (BHR) and Entrenchment Ratio (ER). BHR represents degree of incision and ER shows the degree of incision with respect to the flood prone area. BHR of four segments are 2.62 in the Nakhu Segment, 2.52 in the Bhainsepati segment, 5.28 in the Chapagoan Segment and 2.79 in the Nallu segment. These values show that all the segments are highly unstable according to stability category (Annex VI). The BHR values exceed 1.5, which shows high degree of incision and high risk of degradation of stream channel. The Chapagoan Segment is most unstable since it has the greatest value of BHR among all segments and other segments have nearly same value.

Entrenchment Ratios of four segments are 3.05 in the Nakhu Segment, 4.00 in the Bhainsepati segment, 2.87 in the Chapagoan Segment and 3.37 in the Nallu segment. The Chanpagoan segment is most entrenched among four segments. Since, all segments have ER greater than 2.21, all the segments are slightly entrenched. Gravel mining in the Nallu segment and channelization by building gabion wall at river banks have resulted in lowering of river bed and increased BHR.

LATERAL STABILITY

Lateral stability is determined by usingWidth Depth Ratio (W/D), Meander wavelength ratio (MLR) and Meandering Width Ratio (MWR). W/D ratio is related with stream bank erosion, excessive sediment deposition, stream flow changes, channel widening due to lateral shifting and direct alteration of channel shape from channelization. Based on W/D ratio, four categories of rating can be obtained as suggested by Rosgen (1994, 1996) (Annex VI). The W/D ratios of four segments are 28.45 in the Nakhu Segment, 39.94 in the Bhainsepati segment, 44.38 in the Chapagoan Segment and 31.26 in the Nallu segment. Since all the segments have W/D ratio greater than 1.4, all the segments are highly unstable. Among these, the Chapagoan Segment is most highly unstable.

The MLR in the Nakhu Segment (34.43) followed by the Bhainsepati segment (32.26), the Nallu segment (31.05) and the Chapagoan Segment (23.56). It indicates that lateral shifting is potential in all four segments. Among them, the Nakhu Segment has high potential than other segments. The lateral shift of the Nakhu Khola can be observed by the presence of abandoned channel and presence of structures (spur) made to protect from bank erosion away from the recent channel.

From the graph (Figure 9.1), the Meander Length Plotted against Channel Width, the Bhainsepati segment is plotted away from the predicted curve (Lepold and Wolman, 1960) indicate stream instability.

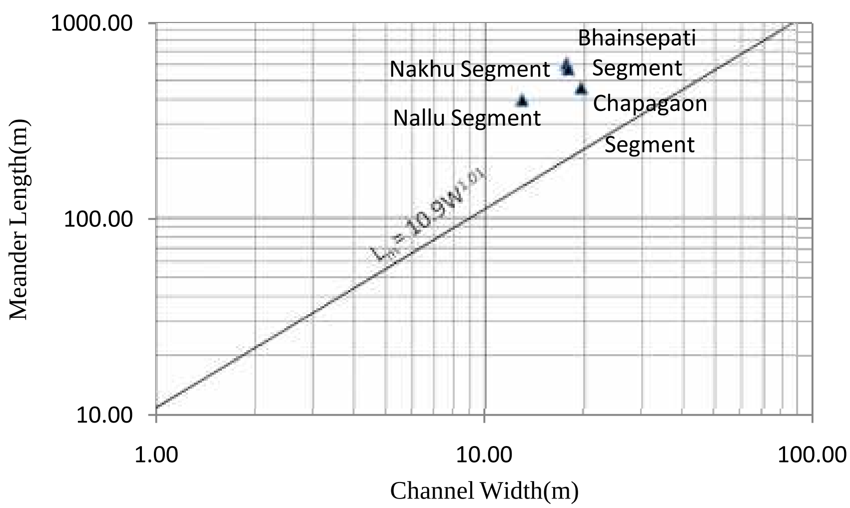


Figure 9.1: Meander geometry relations showing stability of the Nakhu Khola.

The MWR in the Bhainsepati segment (20.00), followed by the Chapagaon segment (19.53), the Nallu segment (16.41) and the Nakhu Segment (14.91). These values shows that lateral instability is possible in all four segments. But the Bhainsepati segment has high potential than other segment.

From the graph (Figur 9.2), the Meander Belth Width plotted against Channel Width, the Bhainsepati segment is plotted away from the predicted curve (Lepold and Wolman, 1960) indicate stream instability.

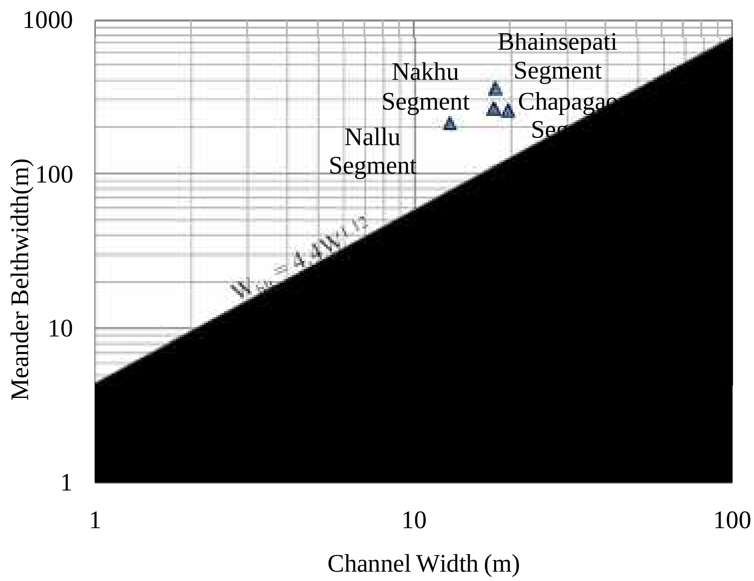


Figure 9.2: Meander geometry relations showing stability of the Nakhu Khola.

The modification map of river channel shows different patterns and magnitude of channel shifting in all four segments. The major shifting in the Nakhu Khola occurred only during major flood time and no major shifting occurred during low flood. There are no primary changes in river pattern but seasonal wondering of channel is frequent changing only in secondary river pattern during bank full flow. The channel shifting is distinct in the Bhainsepati segment where river have shifted 60-70 m towards right bank (Figure 9.3). The Nakhu Khola channel is shifting left and right seasonally eroding left bank at one season and right bank at other season. The high discharge directly influences the lateral shifting. By comparing the photograph of the same place for two successive monsoons gives the evidence of lateral shifting. The wide flood plains in the Nakhu Segment, the Chapagoan Segment and the Bhainsepati Segment with flow evidence suggest the channel shifting occurred during high discharge.

Lateral shifting generally occurs due to eroding of outside bend and depositing in inside bend. This king of erosion is also common in the Nakhu Khola which is main cause of lateral shifting. The spurs and gabion wall covered by grass at right bank about 500 m upstream from the Nakhipot bridge suggest left ward shifting of channel while at the Chapagoan Segment channel is shifting towards right of river course in middle segment and in lower part of segment seasonal variation in shifting is frequent without following distinct side. The main cause of channel shifting in the Bhainsepati segment and the Nakhu Segment is lack of vegetation and unconsolidated bank materials and due to high discharge during monsoon periods.

The channel shifting of the Nakhu Khola is not only caused by vegetation and high flow but also caused by neotectonic activities. Two major fault; Danwargoan fault running SW-NE and Chandragiri fault running NW- SE and other minor faults at southern part of basin developed during upliftment of Mahabharat Range; lies in the watershed. Sharp bending of the Nallu Khola at the Nallu village is due to these faults.

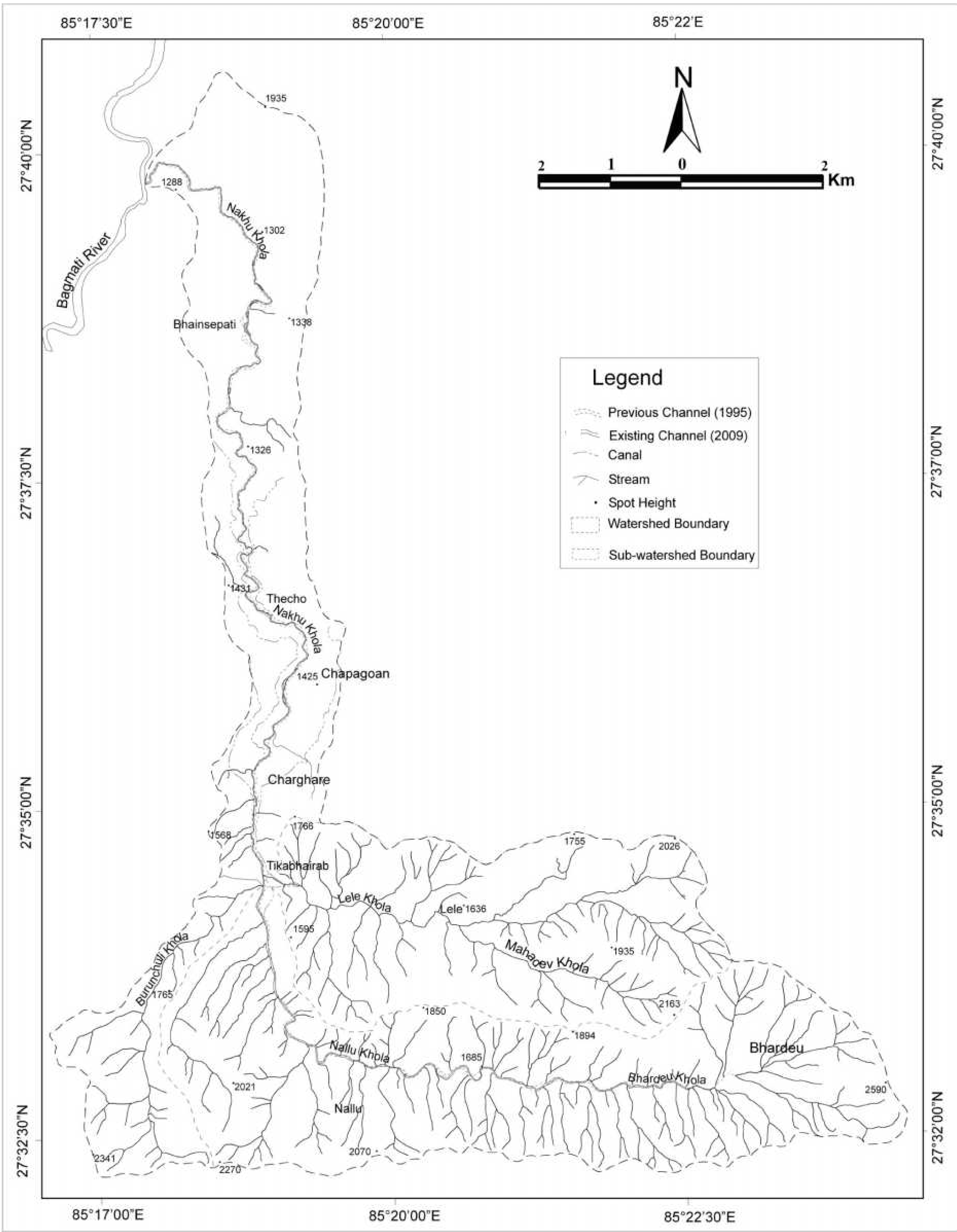


Figure 9.3: Channel modification map of the Nakhu Khola

EROSION PROCESS AND ITS DISTRIBUTION

Stream bank erosion is a naturally occurring process along the river bank. The agents of stream bank erosion are water contributing a significant amount of soil loss each year. Eroded soil particles carried by water often move into streams where sedimentation and suspended solids can lead to a number of problems. The stream bank erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of topsoil. Erosion is caused by natural processes and accelerated by land use changes, land development, overbank drainage, groundwater seepage, obstruction etc. The loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality and damaged drainage networks. The stream bank Erosion refers to hydraulic process where individual soil particles at the bank surface are carried away by the tractive force of the fluid flow.The tractive force increasesas the slope, velocity and water depth increases in the stream.Therefore, the erosive force is generally higher at higherflows. Stream impacts can be reduced by first preventing soil erosion and then by preventing the detached soil particles from leaving the site.

Rill and gully erosion, sheet erosion, scouring, impinging, parallel flow erosion, slumping, are the major erosional processes observed along the Nakhu Khola. Their distribution (Figure 9.8) and description is given below.

Rill and gully erosion

The rilling and gullying occurs when there is sufficient uncontrolled surface runoff over the bank to initialized erosion. This is especially likely where floodplain drainage has been controlled by human activities. In the study area rill erosion is mostly observed around quarry and crusher area in freshly dumped quarry waste near river and abandoned quarry area due to lack of vegetation.

9.4.2 Scouring

Bank scour is the direct removal of bank material by the physical action of flowing water and the sediment that carried. Scouring of riverbed and bank is common along the river bank of the Nakhu Khola. In the study area, scouring generally occurs due to impinging flow erosion and parallel flow erosion. Parallel erosion is dominant in the Nakhu Khola watershed. Channelization at upstream also cause scouring of riverbed at downstream. This kind of scour is observed in the Nakhu Khola near water intake site at the Nakhu Bazar (Figure 9.4)

Parallel flow erosion: Parallel flow erosion is detachment of grain from the bank face by flow along the bank. High flow velocity during bankfull stage and flooding scour the banks as well as channel bed. Undercutting of the toe/lower bank relative to the bank top is common in this type of erosion. In the study area, bank and bed erosion by scouring due to parallel flow is very common due to unconsolidated muddy gravel as bank material and lack of natural riparian vegetation zone. At upstream segment near Nallu area, scouring is also triggered by gravel mining from river channel of the Nallu Khola (Figure 9.5).

Impinging flow erosion: The impinging flow erosion is detachment and removal of grains or aggregateby a flow attacking a bank at steep angle. Impinging flow is caused by deflection of flow and striking of bank, meander bends where radius of curvature of outer bank is less than that of the channel centerline. It is observed in the Nakhu Khola wherein stream obstruction deflects and disturbs the orderly flow of water. Channelization by construction gabion walls at upstream also caused scouring at downstream (Figure 9.6).

9.4.3 Slumping

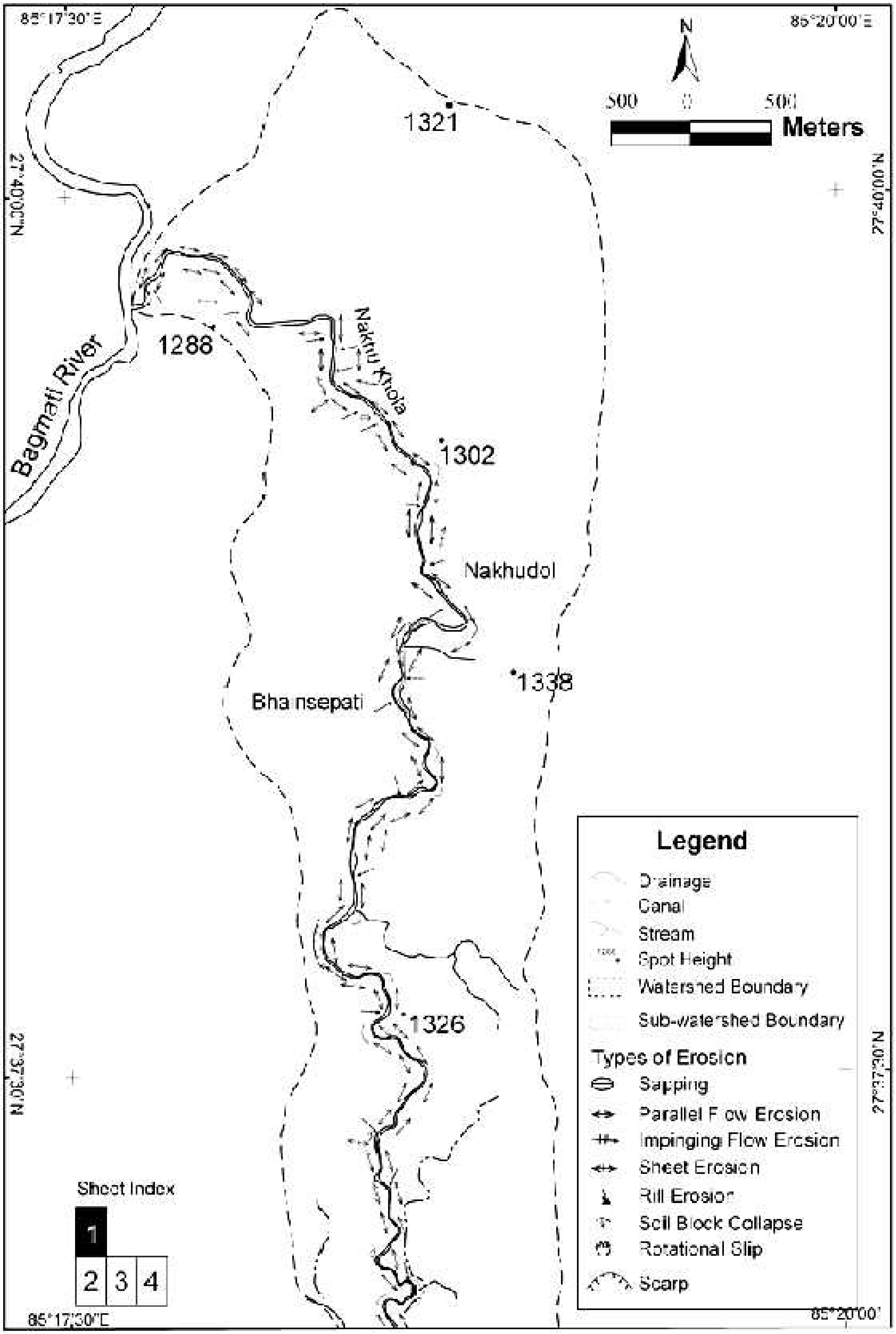
Slumping generally occurs in the banks having steep slopes (>60º) where grain, grain-aggregate and blocks fall into the channel. It generally occurs at the areas where there is pronounced toe undercutting of the sandy, gravelly banks. Slumping is also triggered by the groundwater seepage flow. Slumping is mostly observed in Thecho to Chapagaon area due to toe cutting of thick lacustrine clay, ground water seepage in the high bank and water seepage from irrigation canal (Figure 9.7).

Figure 9.4:Scour of the river near water intake site at Nakhu Bazar

Figure 9.5 : Parallel erosion at the right bank at the Nakhu Khola

Figure 9.6: Impinging erosion at the left bank of the Nakhu Khola near Nakhu Bazar

Figure 9.7: Earth slump at the left bank of Nallu Khola near Nallu VDC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Spot Height
Watershed Boundary
Sub-watershed Boundary
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Impinging Flow Erosion
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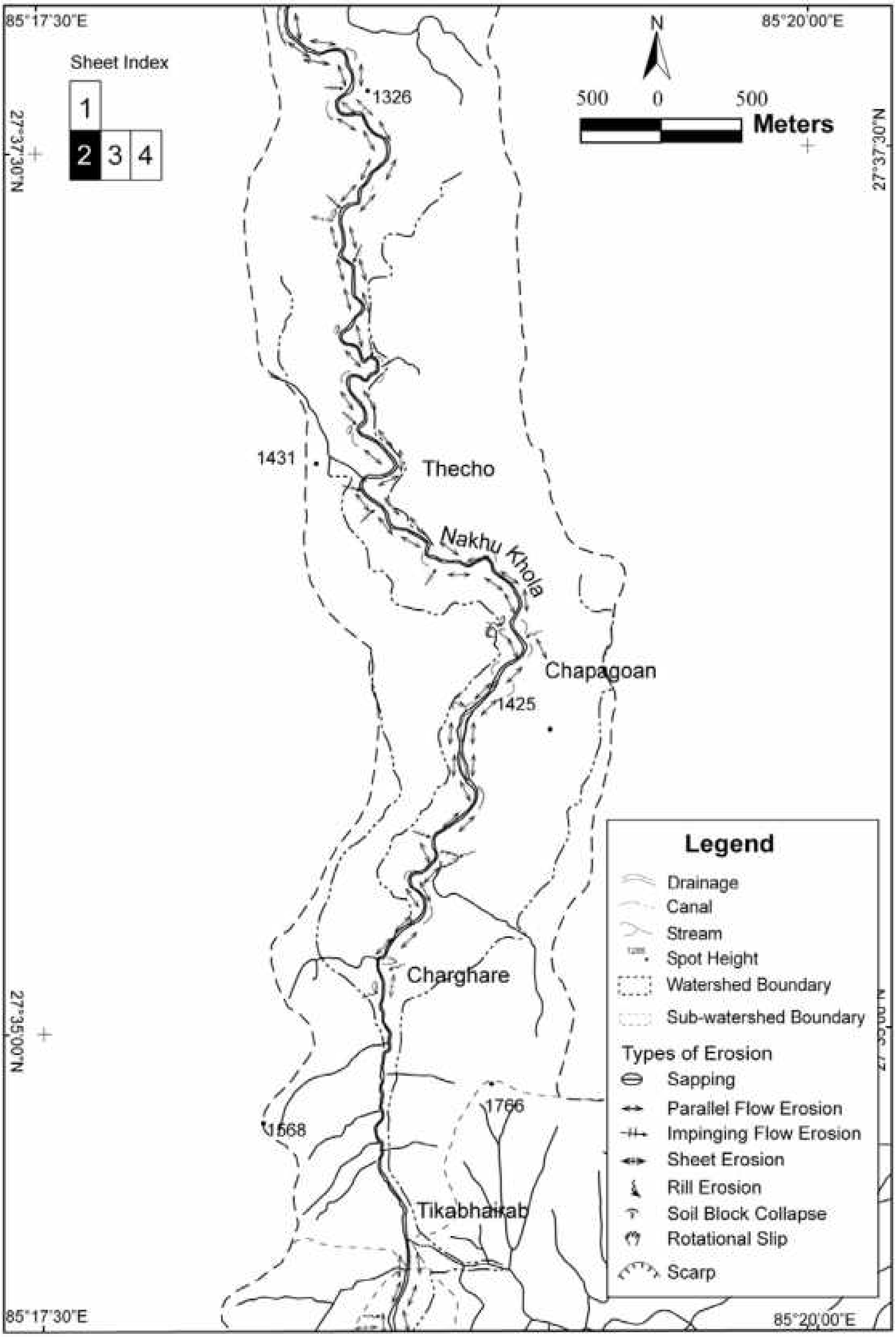
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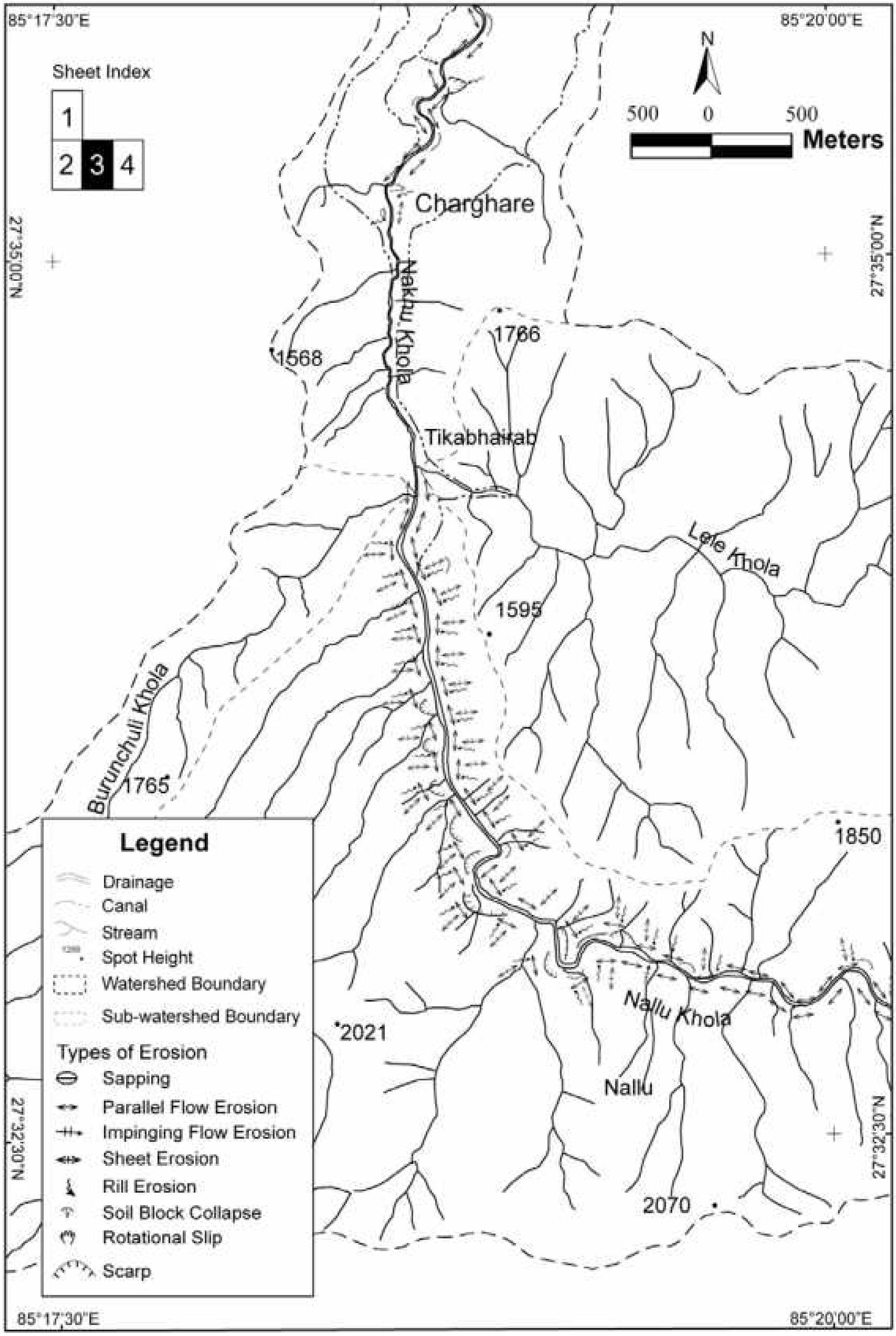
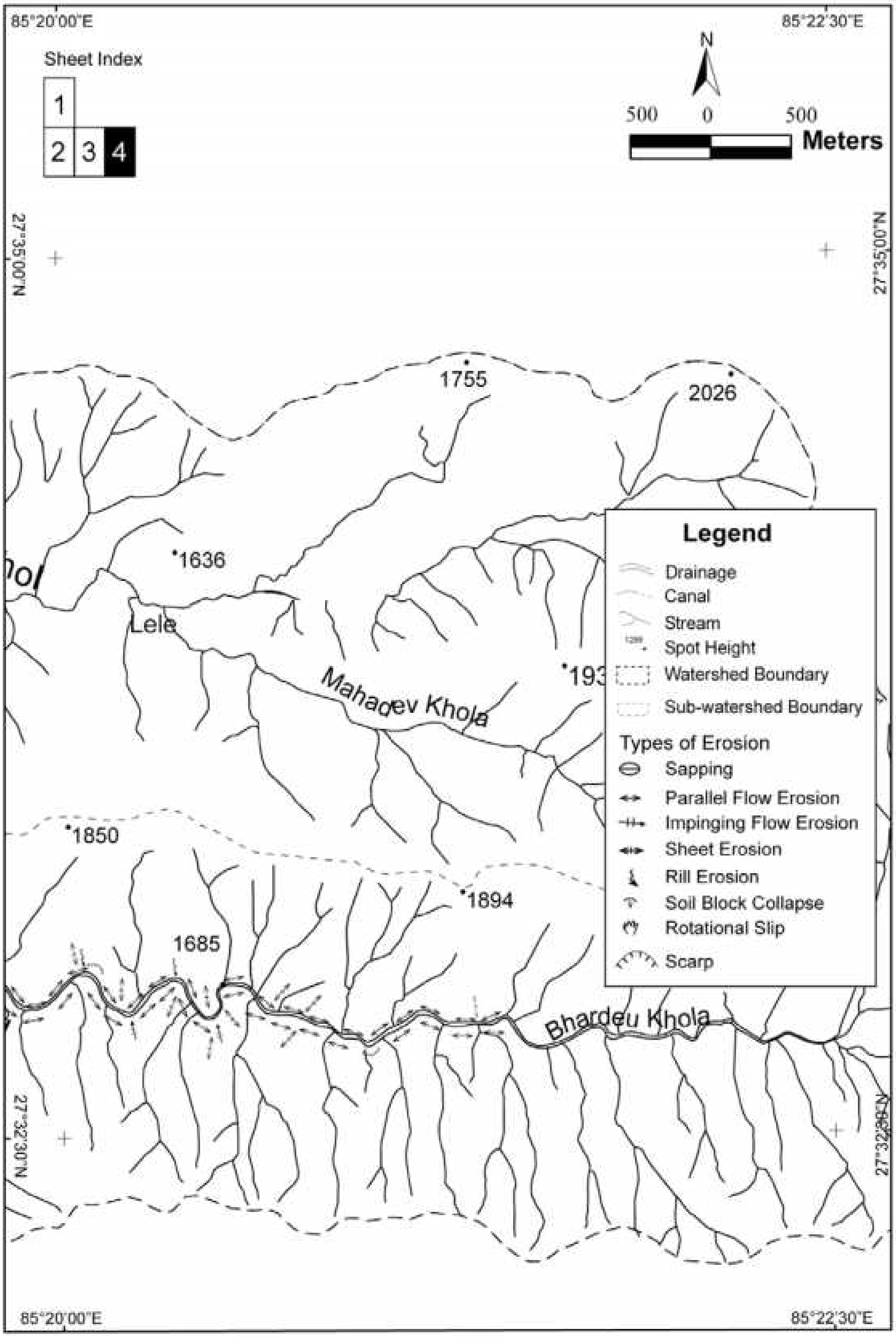
Canal
Stream
Spot Height
Watershed Boundary
Sub-watershed Boundary
Types of Erosion
Sapping
Parallel Flow Erosion
Impinging Flow Erosion
Sheet Erosion
Rill Erosion
Soil Block Collapse
Rotational Slip
Scarp

b



85°17'30"E
85°20'00"E
Sheet Index
1
2
3
4
N
500
0
500
Meters
Charghare
27°35'00"N
Nakhu Khola
1766
1568
Tikabhairab
Lele Khola
1595
Burunchuli Khola
1765
1850
Legend
Drainage
Canal
Stream
Spot Height
Watershed Boundary
Sub-watershed Boundary
Types of Erosion
Sapping
Parallel Flow Erosion
Impinging Flow Erosion
Sheet Erosion
Rill Erosion
Soil Block Collapse
Rotational Slip
Scarp
2021
Nallu Khola
Nallu
27°32'30"N
2070
85°17'30"E
85°20'00"E

c



d

Figure 9.8: a, b, c, and d Erosion process map along the Nakhu Khola

BANK EROSION POTENTIAL

Bank erosion potential of river is the capacity to erode banks and scour river bed by flowing river. Bank erosion is the natural process, which is accelerated by the land use change, overbank drainage, groundwater seepage, obstruction etc.

Erosion of stream banks has the following impacts:

a. Loss of land or poor quality uncompacted "new" land deposited from the eroded soils.

b. Re property boundary litigation if the stream serves as a boundary.

c. Water quality decreases when sediments and chemical compounds such as nitrogen or phosphorous are carried by stream flows. These chemicals cause rapid growth of noxious plants and organisms and declining water quality as they decay.

d. Damages to buildings, road, bridges etc.

e. Wildlife habitat is disturbed or destroyed.

Bank Erosion Hazard Index

River is one of the geomorphic agents which are eroding as well as depositing the bank materials producing different land forms. Stream bank erosion is one of the major hazards produced by the flowing river. The Nakhu Khola is also suffering from this stream bank erosion problem. So in order to identify the bank erosion hazard field analyses were conducted by traversing the river. During the field analysis parameters necessary for bank erodibility and lateral instability hazard map were collected and evaluated. For the assessment of river erosion along the Nakhu Khola,bank erosion hazard index (BEHI) method developed by Rogen(1996) is implemented.

The Bank Erosion Hazard Index (BEHI) is a method for assessing stream bank erosion potential. It assigns point values to several aspects of bank condition and provides an overall score that can be used to inventory stream bank condition over large areas and prioritize restoration efforts. For using BEHI, bank characteristics such as bank height, bank angle, bank materials, presence of layers, root depth, root depth, rooth density and percent of bank protection were used (Table 9.1). Following criteria were developed, using above bank characteristics, for assessment of BEHI.

Table 9.1: Stream bank characteristic used to develop Bank erosion Hazard Index (BEHI)

Category		Bank ht. ratio (m/m)	Rooth detpth ratio(%)	Root density (%)	Bank angle (degrees)	Surface protection	Total index
Very low	Value	1.0-1.1	100-80	100-80	0-20	100-90	
	Index	1-2	1-2	1-2	1-2	1-2	<10
Low	Value	1.1-1.2	80-55	80-55	20-60	90-50	
	Index						
	Index	2-4	2-4	2-4	2-4	2-4	10-20
Moderate	Value	1.2-1.5	55-30	55-30	60-80	50-30	
	Index						
	Index	4-6	4-6	4-6	4-6	4-6	20-30
High	Value	1.5-2	30-15	30-15	80-90	30-15	
	Index						
	Index	6-8	6-8	6-8	6-8	6-8	30-40
Very high	Value	2-2.8	15-5	15-5	90-120	15-5	
	Index						
	Index	8-9	8-9	8-9	8-9	8-9	40-45
Extream	Value	>2.8	<5	<5	>120	<5	
	Index						
	Index	10	10	10	10	10	>45
Field measure	Value						
	Index						

(After Rogen 1996)

For adjustment in points for specific nature of bank materials and stratification, the following is used:

Bank material: Bed rock (very low), Boulder (low), Cobble (Subract 10 points unless gravel/sand>50%, then no adjustment), Gravel (add 5-10 points depending on %sand), Sand (add 10 points), Silt/Clay (no adjustment)

Stratification: points depending on the number and position of layer 5-10 points were added.

For the BEHI thirty-five location (Figure 9.9) along Nakhu Khola from Nakhu-Bagmati River confluence to Bhardeu were selected. These field-measured variables assembled as prediction of erodibility (BEHI) were given risk-rating score of 1-10 (10 as highest level of risk). The risk rating value from one to ten indicates corresponding adjacent value of risk of low, very low, moderate, high, very high and extreme potential erodibility (Figure 9.10). The field data collected and converted for risk rating and their risk rating is given in Tables 9.2.

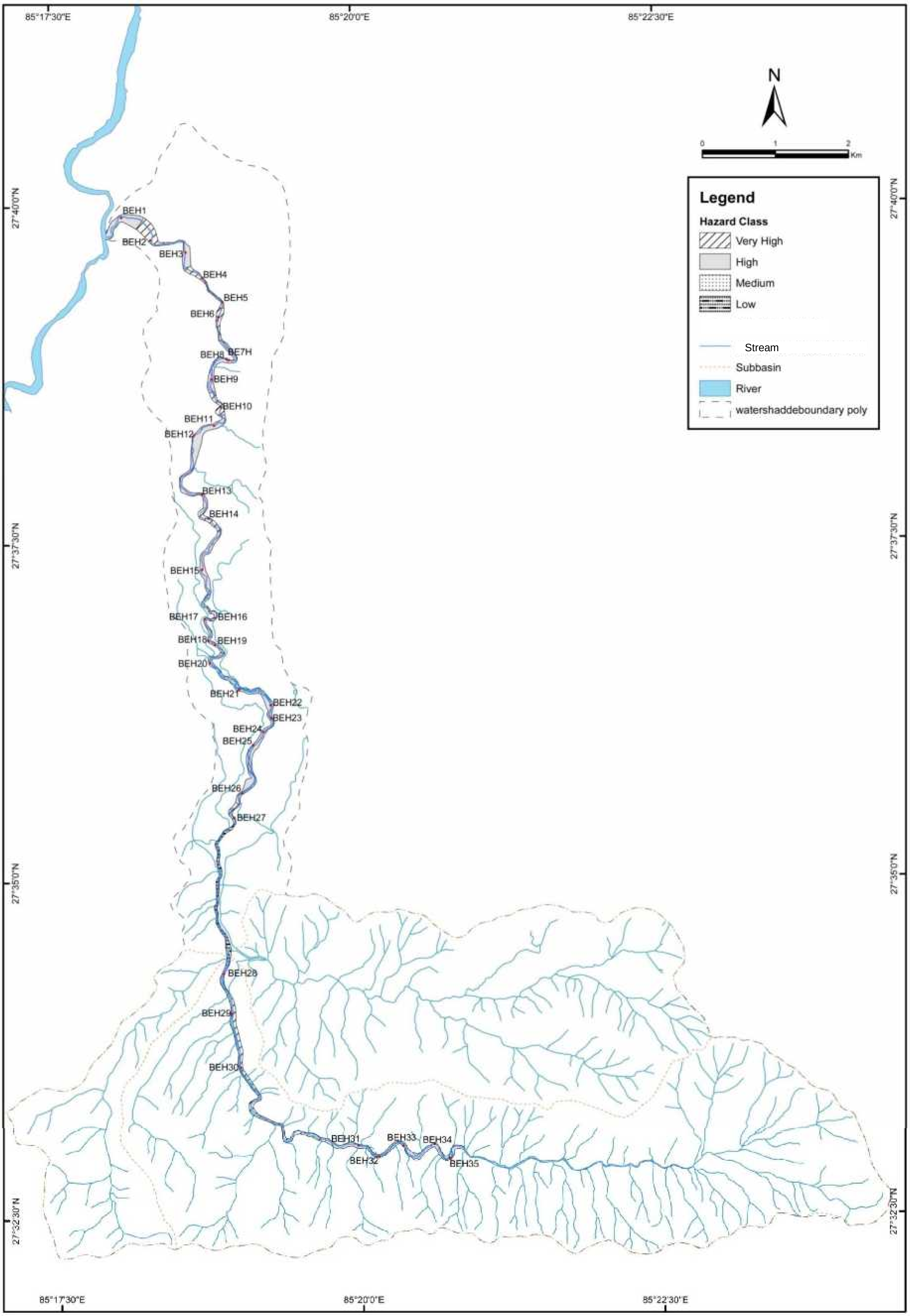


Figure 9.9: BEHI measurement station

Table 9.2: Data measured in field for bank erosion hazard index (BEHI)

Location	Left/Right Bank	Bank Height Ration(m/m)	Rooth depth ratio	Root Density (%)	Bank Angle(Degree)	Surface Protection(%)
BEH1	Left	1.38	0.14	5	81	10
BEH2	Left	2.63	0.06	5	68	10
BEH3	Right	1.72	0.15	4	104.5	60
BEH4	Right	7.69	0.05	5	70	15
BEH5	Right	10	0.04	5	60	40
BEH6	Left	1.54	0.05	6	95	10
BEH7	Left	4.86	0.29	6	82	80
BEH8	Left	7.14	0.32	4	84	85
BEH9	Left	2.13	0.47	3	99	20
BEH10	Left	4	0.35	1	90	10
BEH11	Left	4.17	0.36	2	85	20
BEH12	Left	2.29	0	3.5	68	70
BEH13	Left	2.38	0	5	86	30
BEH14	Left	2.63	0.19	1	80	0
BEH15	Left	5.85	0.11	2	86	50
BEH16	Right	16.67	0.13	40	70	85
BEH17	Left	13.13	0.19	20	69	80
BEH18	Left	21.43	0.17	20	75	40
BEH19	Right	1.43	0.2	50	110	80
BEH20	Left	23.08	0.1	30	57	70
BEH21	Left	4.29	0.67	15	82	60
BEH22	Left	8.57	0.25	25	90	80
BEH23	Right	6.76	0.06	7	70	70
BEH24	Left	6.76	0.4	25	56	50
BEH25	Left	10.86	0.05	5	67	60
BEH26	Right	1.82	0.2	8	84	70
BEH27	Right	7.6	0.11	5	83	20
BEH28	Right	2.25	0.11	20	49	40
BEH29	left	2.73	0	0	80	0
BEH30	Right	3.45	0.04	2	60.5	0
BEH31	Right	2.29	0.13	10	113	60
BEH32	Left	114.29	0	4	96	40
BEH33	Left	1.43	0.1	5	116	30
BEH34	Right	7.14	0.06	3	71	40
BEH35	Right	2.33	0.18	3	84	50

Table 9.3: Bank erosion hazard index (BEHI) rating

Location	Left/Right Bank	Bank Height Ratio	Root Depth Ratio	Root Density	Bank Angle	Surface Protection	Total
BEH1	Left	5.93(H)	8.16(VH)	8.86(VH)	5.94(H)	8.87(VH)	37.76(H)
BEH2	Left	9.78(E)	8.78(VH)	8.86(VH)	4.43(M)	8.87(VH)	40.72(VH)
BEH3	Right	7.79(H)	7.78(H)	9.04(E)	8.50(VH)	3.50(L)	36.61(H)
BEH4	Right	10.00(E)	8.69(VH)	8.86(VH)	4.67(M)	7.85(H)	40.07(VH)
BEH5	Right	10.00(E)	9.18(E)	8.86(VH)	3.87(L)	5.03(M)	36.94(H)
BEH6	Left	6.82(H)	8.96(VH)	8.72(VH)	8.15(VH)	8.87(VH)	41.52(VH)
BEH7	Left	10.00(E)	5.93(H)	8.72(VH)	6.07(H)	1.87(VL)	32.59(H)
BEH8	Left	10.00(E)	5.56(M)	9.04(E)	6.42(H)	1.40(VL)	32.42(H)
BEH9	Left	9.10(E)	4.04(M)	9.28(E)	8.28(VH)	7.45(H)	38.15(H)
BEH10	Left	10.00(E)	5.18(M)	9.68(E)	7.90(H)	8.87(VH)	41.63(VH)
BEH11	Left	10.00(E)	5.05(M)	9.47(E)	6.99(H)	7.05(H)	38.55(H)
BEH12	Left	9.34(E)	6.37(H)	9.15(E)	4.43(M)	2.73(L)	32.02(H)
BEH13	Left	9.36(E)	6.22(H)	8.86(VH)	7.08(H)	5.92(H)	37.44(H)
BEH14	Left	9.78(E)	7.26(H)	9.68(E)	5.88(M)	10.00(E)	42.60(VH)
BEH15	Left	10.00(E)	8.34(VH)	9.47(E)	7.08(H)	4.19(M)	39.08(H)
BEH16	Right	10.00(E)	8.04(VH)	5.02(M)	4.67(M)	1.40(VL)	29.13(M)
BEH17	Left	10.00(E)	7.26(H)	6.99(H)	4.53(M)	1.87(VL)	30.65(H)
BEH18	Left	10.00(E)	7.56(H)	6.99(H)	5.16(M)	5.03(M)	34.74(H)
BEH19	Right	6.27(H)	7.14(H)	4.26(M)	8.61(VH)	1.87(VL)	28.15(M)
BEH20	Left	10.00(E)	8.04(VH)	5.86(M)	3.67(L)	2.73(L)	30.66(H)
BEH21	Left	10.00(E)	3.00(L)	7.77(H)	6.07(H)	3.90(L)	30.74(H)
BEH22	Left	10.00(E)	6.37(H)	6.36(H)	7.82(H)	1.87(VL)	32.42(H)
BEH23	Right	10.00(E)	8.88(VH)	8.62(VH)	4.67(M)	2.73(L)	34.9(H)
BEH24	Left	10.00(E)	4.82(M)	6.36(H)	3.62(L)	4.19(M)	28.99(M)
BEH25	Left	10.00(E)	9.04(E)	8.86(VH)	4.36(M)	3.9(L)	36.16(H)
BEH26	Right	8.22(VH)	7.14(H)	8.54(VH)	6.42(H)	2.73(L)	33.05(H)
BEH27	Right	10.00(E)	8.34(VH)	8.68(VH)	6.23(H)	7.05(H)	40.30(VH)
BEH28	Right	9.307(E)	8.29(VH)	6.99(H)	3.25(L)	5.03(M)	32.87(H)
BEH29	Left	8.7(VH)	10(E)	10(E)	5.97(H)	10(E)	44.67(VH)
BEH30	Right	10(E)	10(E)	9.47(VH)	3.9(L)	10(E)	43.37(VH)
BEH31	Right	9.38(E)	7.96(VH)	8.37(VH)	8.67(VH)	3.90(L)	38.28(H)
BEH32	Left	7.75(H)	7.96(VH)	9.04(E)	8.19(VH)	5.03(M)	37.97(H)
BEH33	Left	6.27(H)	8.4(VH)	8.86(VH)	8.75(VH)	5.92(H)	38.2(H)
BEH34	Right	10.00(E)	8.82(VH)	9.28(E)	4.72(M)	5.03(M)	37.85(H)
BEH35	Right	9.43(E)	7.42(H)	9.28(E)	6.42(H)	4.19(M)	36.74(H)

From the result, most of the locations along the Nakhu khola has high bank erosion hazard index. At middle parts of Nakhu Khola near Thecho at location BE20, BE21 and BE23 exhibits moderate BEHI value, hence has moderate potential of stream bank erosion which is due to good condition of riparian vegetation with good root depth and density. AT few parts along the Nakhu Khola, where riparian vegetation condition is poor and poor rood depth and root density, has very high BEHI. Along the gorge where riparian vegetation is good and bank consists of bedrock, has low BEHI. At quarry site where riparian vegetation is cleared and sediment from quarry is dumped in riverbank has extreme bank erosion potential due to human cause like dumping of sediments from quarry along river bank and clearing of riparian vegetation for mining.

Flood Prone Area Mapping

Floods are an inevitable natural phenomenon occurring from time to time in all rivers and natural drainage systems. A flood is an overflow of an expanse of water that submerges land.The EU Floods directive defines a flood as a temporary covering by water of land not normally covered by water. Flooding may result from the volume of water within a body of water, such as a river or lake, which overflows or breaks levees, with the result that some of the water escapes its usual boundaries.Floods occur when either the rainfall rate exceeds the infiltration rate or the cumulative infiltration exceeds the storage capacity of a drainage basin. Floods can also occur in rivers, when flow exceeds the capacity of the river channel, particularly at bends or meanders. Flooding can not only disrupt baseline riparian habitat functions, but also is responsible for long term damage to infrastructure, affects local economies and threatens human health. The flood prone area is defined on the basis of the so-called risk map. The flood prone area map is referred as the map that graphically provides information on predicted inundation areas, inundation depth etc. in an easy to understand format. The method of preparing flood prone area map with the help of satellite imageries as well as field techniques is called flood prone area mapping. The main purpose of the flood prone map is to identify the areas that are in risk of flood disaster. Flood-prone Area Maps are used as basic information for producing Flood Hazard Maps.

The Figure 9.10 shows the flood prone area map of the Nakhu Khola from the confluence of the Nakhu Khola with the Bagmati River. For the flood prone area mapping, existing river cross-sections areas are prepared identifying bankfull levels at various spots along the river channel that accommodate discharge without flooding. After preparing cross-section possible flooding spots are identified and define the target floodplain. After defining, topographic features of the target flood plains are identified and flood prone area are defined and flood prone map is prepared.

In the Nakhu Khola watershed, flood prone width is not so wide untill river crosses gorge. At upstream confinement of channel and narrrow, river valley is the main cause for reduced flood prone width. After crossing the gorge, the river flows by reworking over the lacustrine and fluvio-lacustrine sediments and developing river valley river terraces. Though flood prone width is wider than upstream Flooding is still protected from spreading over by river terraceces and protect sourounding from flooding.This confinement due to terraces continues untill reaching river section with wide flood plains. After Bungamati, the flood plains are wider with poor canopy. So excessive erosion and channel shifting during flooding may caues bank slumping and destroy cultivated lands. The flooding again confine into small width after reaching the Nakhipot bridge due to channelization.Though this channelization and gabion wall protect area from flooding, it may bring disaster at downstream after river crosses this channelization. Channel scouring and destroying of infrastructures may be caused. From Log Pearson method of flood estimation, discharge of flood is expected to be high even in 10 years reccurance interval. The landslide damming and flooding during 1981 A.D killed 70 people and destroyed huge property (P.C.L. Rajbhandari, 1981). Most of the flood plains of the Nakhu Khola is used for settlement and cultivation, which can bring huge loss during flooding. Unplanned settlement, cultivation and other activitiesin the flood prone zone should be stopped or other preventive measures should be impliemented.

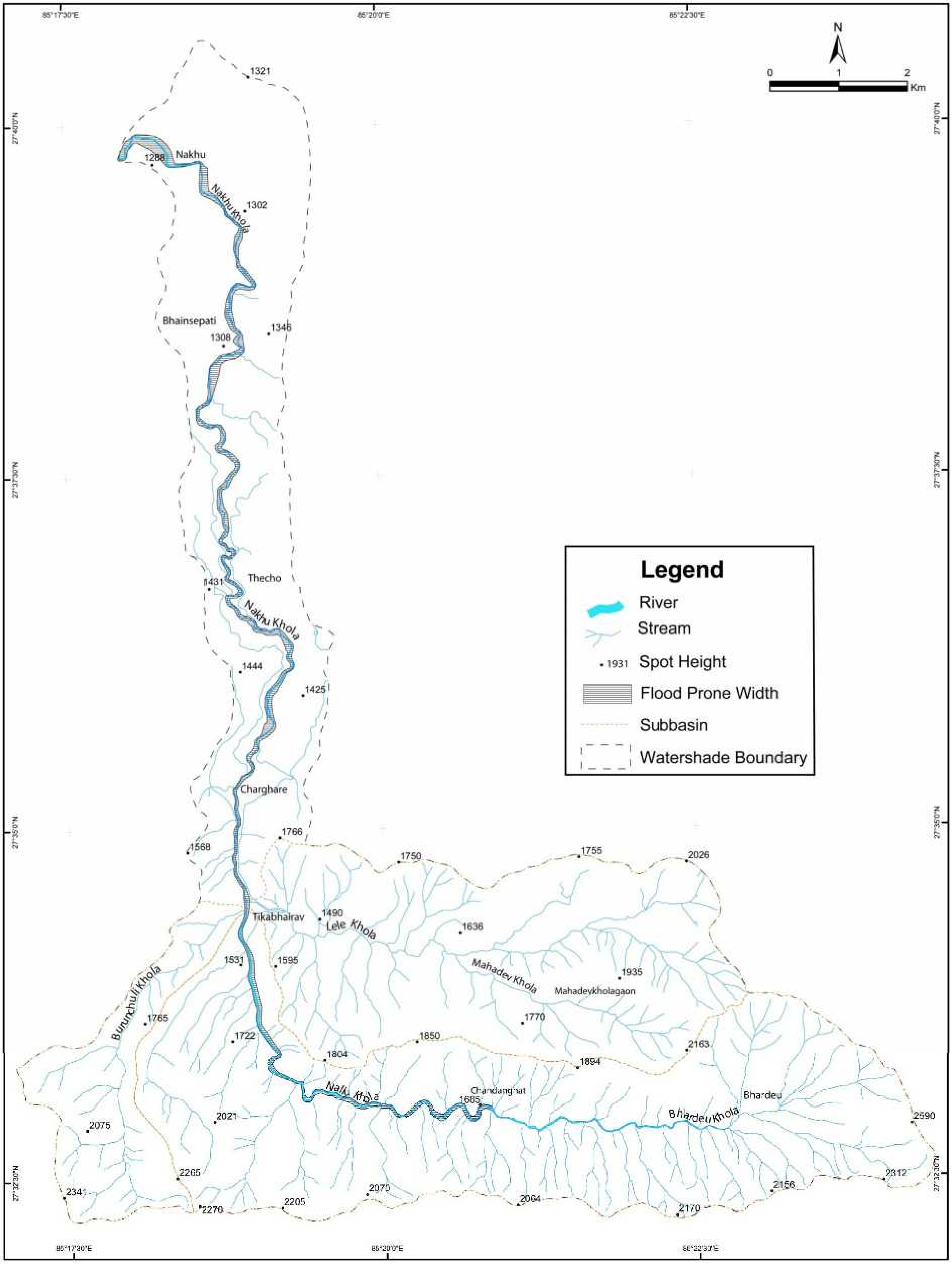


Figure 9.10 : Flood prone area map of the Nakhu Khola from the confluence of the Nakhu Khola with the Bagmati River

DEPARTURE OF CHANNEL PATTERN

Channel dimension relation of river is studied by calculating width depth ratio. Width depth ratio is the ratio of bankfull width to mean depth at the bankfull channel. The ratio indicated departure from the reference reach and is very sensitive and diagnostic of instability. Increase in W/D ratio is related with stream bank erosion, excessive sedimentation, stream flow changes, channel widening due to evolutionary shifts from one stream type to another and direct alteration of channel shape from channelization etc. The width depth ratio of four segments is 28.45 in the Nakhu Segment, 39.94 in the Bhainsepati segment, 44.32 in the Chapagaon segment and 31.26 in the Nallu segment. Since all the segments have W/D ratio greater than 1.4 all the segments are highly unstable. Among these Chapagaon segment is most unstable.

The channel pattern of the river is studied with the help of dimensionless ratio. For calculating dimensionless ratio detail survey of bankfull channel dimension, pattern and profile of river is done. The dimensionless ratio was calculated by dividing each parameter by bankfull width. The information collected is converted into dimensionless ratios that are used to develop designs for streams with different drainage areas. A common pattern measurement is the meander wavelength ratio, meander width ratio and ratio of radius of curvature to bankfull width. Meander wavelength ratio, meander width ratio and radius of curvature ratio is obtained by dividing meander wavelength, meander width and radius of curvature by bankfull width respectively.

Meander wavelength ratio (MLR) of Nakhu Segment has highest magnitude of 34.43 followed by Bhainsepati 32.26, Nallu 31.05 and Chapagaon with lowest magnitude of 23.56. A common range for the meander wavelength ratio is 10 to 14 times bankfull width (Leopold and Wolman, 1960, Carlston, 1965, Schumm, 1968). However, in the Nakhu Khola the range is much lower between 1.2 to 2.4 times bankfull widths. Meander width ratio (MWR) is highest in Bhainsepati segment of magnitude 20.00 followed by Chapagaon 19.53, Nallu 16.41 and Nakhu with lowest magnitude of 14.91. Radious of curvature ratio is hihest in Bhainsepati segment with magnitude 11.93 followed by Naku 10.07, Nallu 8.312 and Chapagaon with lowest magnitude of 7.041.

STREAM CHANNEL SCOUR/ DEPOSITIONAL POTENTIAL

Boundary Shear Stress

Boundary shear stress is the energy available to transport bed load in a stream. Shield's (1936) equation gives the shear stress acting on the sediment particles:

$\tau = \gamma RS$ .... (9.1)

Where,

τ = Tractive shear stress

γ=Unit weight of water

R=Hydraulic radius of the riffle cross-section at bankfullstage

S = Average stream slope

In order to evaluate the flow competency of The Nakhu Khola, boundary shear stress (τ) of all four segments were calculated. (Table 9.4). The boundary shear stress of Nakhu Segment is highest (7.386 N/m^2) followed by Nallu (7.200 N/m^2), Chapagaon(6.76N/m^2) Nallu segment (5.827 N/m^2). This shows that Nakhu and Nallu segment have nearly same competency to transport bed load and greater potential of scouring stream than other segments.

Critical Boundary Shear Stress

Critical shear stress (τ_{cr}) is measure of force required to mobilize and transport a given grain sized particle resting on the channel bet. It is used to evaluate flow competency of the channel. For evaluation of flow competency of four segments of

Nakhu Khola, sediment size data of both bar sample and stream bed were analyzed and relation modified from Andrew (1984) was used.

$$\tau_{cr} = 0.0834(d_i/ds_{50})^{-0.872} \text{.......................} (9.2)$$

Where,

d_i=diameterofinterestofrifflesample(usuallycoarsefraction d_{10}

ds_{50}= median diameter of bar sample

The values obtained from the calculation are given in Table 9.4.

Stream Competency and Flow Dynamics

In order to find whether the given size particle are transported during bankfull flow only or even during normal flow, critical depth (D_c) and critical slope (S_c) is computed. Critical bankfull depth and critical slope is the minimum depth and slope required to mobilize and transport the large particles made available annually to the channel. The critical bankfull depth and critical slope required to move d_i particle present in bed are calculated by using following equation khown as Shield's criteria,

$$D_c = (1.65.\ \tau_{cr}.d_i)/S_e \text{..........} (9.3)$$

$$S_c = (1.65.\ \tau_{cr}.d_i)/D_e \text{..........} (9.4)$$

Where,

D_c = bankfull mean depth required

S_c=bankfullsloperequired

1.65=sedimentdensity (submergedspecificweight)=density of sediment (2.65 g/cm^3) - density of water (1.0 g/cm^3)

τ_{cr} =criticaldimensionlessshearstress

d_i= particle of interest from riffle sample (usually coarse d_{10})

D_e=existingordesignmeanbankfulldepth

S_e = existing bankfull water surface slope

Critical dimensionless shear stress (τ_{cr}) and shield parameter was calculated at four segment and values obtained are given in (Table 9.4). According to the result, values of τ_{cr}ranges from 0.022 (Nakhu Segment) to 0.149 (Nallu Segment).The highest value in the Nakhu Segment indicate large force required to mobilize and transport particle size present in stream. The least value obtained in Nallu segment show that lowest force is required to mobilize and transport particles resting on stream bed. Also the critical slope (S_c) and critical depth (D_c) is less than the existing slope and depth of channel which indicate that Nakhu Segment are competent enough to mobilize the river bed materials currently distributed in the river. Hence currently distributed river bed materials are mobilized not only in the bankfull flow but also in normal flow condition.

Table 9.4: Calculated values of Hydraulic Parameters

Attributes	Nakhu	Bhainsepati	Chapagaon	Nallu
Hydraulic radius,R(m)	0.62	0.45	0.45	0.42
Slope, S_e(m/m)	0.0120	0.0130	0.015	0.017
d_{50}(m)	0.00012	0.00012	0.02425	0.02884
ds_{50}(m)	0.02042	0.03407	0.01743	0.024415
d_{10}(m)	0.094	0.135	0.155	0.201
d_{50}/ds_{50}	0.0059	0.0036	1.3913	1.1812
d_{10}/d_{S50}	4.60	3.96	8.89	8.23
$\tau(N/m^2)$	7.386	5.827	6.761	7.200
Critical dimensionless shear stress,τ_{cr}	0.0220	0.0251	0.0124	0.0133
D_r	0.2847	0.4301	0.2115	0.2588
S_r	0.0055	0.0126	0.0072	0.0104
Sc	53.75	55.50	38.25	40.00
Sb	1.200	1.020	1.930	4.032

Schumm's F-M Relationship

The Nakhu Khola watershed comprises of meta-sedimentary rocks at southern part where most of the quarry sites are located along the banks of the Nakhu Khola. These quarry sites produce tones of byproducts of aggregates, which are dumped along the route of the Nakhu Khola. These are carried by river and hence turbidity and sediment discharge is increased in water. For the construction materials, gravel and boulders along the channel are excavated. Because of these changes, stability of river is changed. In order to evaluate the stream channel condition Schummis (1963) F-factor versus M-factor plot (Figure: 9.11) was used. F and M factor of each segment was calculated by following formula,

$$F \, \mathrm{X} W_{bkf} / D_{bkf} \quad \text{....................} \ (9.5)$$

$$M \, \mathrm{X} \sum (S_c \, | W_{bkf}) \, \Gamma (S_b \, | 2D_{bkf}) \ast / (W_{bkf} \, \Gamma \, 2D_{bkf}) \quad \text{.............} \ (9.6)$$

Where,

S_c = Percentage silt-clay in bed material

S_b = Percentage silt-clay in bank material

W_{bkf} = Width at bankfull

D_{bkf} = Depth at bankfull

The plot shows that all four segments of the Nakhu Khola are in aggradation condition. Excessive sediment input at upstream segment from quarry site and high bank erosion might be cause of agragadation in the Nakhu Khola.

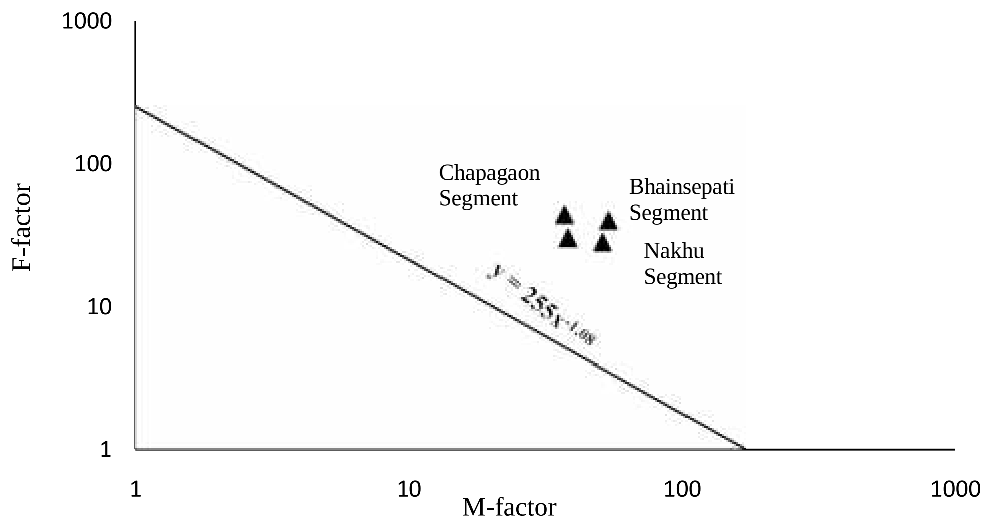


Figure 9.1: Schummis (1963) F-factor versus M-factor plot

9.8 CHANNEL EVOLUTION

A naturally stable stream must be able to transport the water and sediment load supplied by its watershed while maintaining dimension, pattern, and profile over time so that it does not degrade or aggrade (Rosgen, 1994). Stable streams migrate across alluvial landscapes slowly over long periods of time while maintaining their form and function. Instability occurs when scouring causes the channel to incise (degrade), excessive deposition causes the channel bed to aggrade, or lack of stream vegetation allows rapid channel migration. In river, the product of sediment load and sediment size is proportional to the product of stream slope and discharge or stream power. A change in any one of these variables causes a rapid physical adjustment in the stream channel. This adjustment process is often referred to as channel evolution.

The channel evolution process is initiated once a stable, well-vegetated stream that interacts with the floodplain frequently is disturbed. Disturbance commonly results in an increase in stream power that causes degradation, often referred to as channel incision (Lane, 1955). Incision eventually leads to over-steepening of the banks and when critical bank heights are exceeded, the banks begin to fail and mass wasting of soil and rock leads to channel widening. Incision and widening continue moving upstream in the form of head cut. Eventually the mass wasting slows and the stream beings to aggrade. The Simon (1989) stream evolution model characterizes evolution in six steps: 1) sinuos, premodified, 2) channelized, 3) degradation, 4) degradation and widening, 5) aggradation and widening, and 6) quasi equilibrium

Table 9.5: Probable evolution trend of the Nakhu KHola

Segment	Stream	Current stage of CEM	Evolutionary scenarios			Remarks
			Past	Present	Future	
Nakhu	C5	V (Aggrading)	F	C	F or E	With bank channelization and increase in depth W/D ratio and slope increases, K and MWR decreases, with increasing downstream disturbance, C change to F. If over withdraw of water continues and excess sediment deposits then C change to E
Bhainsepati	C5	V (Aggrading)	F	C	Cbar	With bank instability W/D ratio of slope increases, K and MWR decreases, bar deposition and bank erosion may accelerate; with increasing downstream disturbance, C may change to F or E
Chapagaon	C4	V (Aggrading)	F	C	Cbar	With bank instability W/D ratio of slope increases, K and MWR decreases, bar deposition and bank erosion may accelerate; with increasing downstream disturbance, C may change to F or E
Nallu	C4	V (Aggrading)	F	C	E or F	With bank channelization and increase in depth W/D ratio and slope increases, K and MWR decreases, with increasing downstream disturbance, C change to F or E

In Nakhu Khola disturbances like channelization, removal of riparian vegetation, over withdraw of water and mining activates as well as other changes are negatively affecting it stability. The Nakhu Khola is aggrading in regional scale but locally in some parts it is incising as well due to channelization, vegetation clearing and channel modification. Table 9.5 indicates evolutionary scenarios of the segments of the Nakhu Khola, which is recognized by analyzing the cross-sections of individual segments and existing condition of river. Comparing with the Simon's (1989) six-stage channel evolution models, the three downstream fifth-order segments and one upstream fourth-order segment can be represented by stage V (aggrading). All the segments are aggrading with notable bank instability and lateral instability. They may potentially transfer from 'C5' and 'C4' stream types to Cbar stream type with enhanced W/D ratio and slopes, but decreased MWR.The downstream Nakhu Segment and the upstream Nallu segment may change to F or E type since disturbing factors like channelization, increase in channel depth and over withdraw of water influence the stream. Over withdraw of water can cause reduction in capacity to transport sediments due to which sinusity may increase also W/D ratio may decrease.

CHAPTER TEN

DISTURBANCES IN RIVER

A stream naturally flowing meanders and goes through stages as it matures and adjusts to changing conditions often caused by new construction, changing weather patterns, sand and gravel mining or even uncontrolled cattle grazing or improper stream crossings.As a stream adjusts or stabilizes for the changing events, erosion and streambed scour or sedimentation may occur. When a stream is in a stable condition, it will exhibit relatively unchanging or constant bed elevations and widths.

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 cause disturbance to the river corridor includes the construction of dams, diversion, levees, roads and bridges, bank protection, removal of large woody debris, deforestation, grazing, gravel mining, urbanization and recreation. Disturbance to the river is an event with the potential to harm the natural river environment. Disturbances are mainly of two types:

- Natural cause
- Human induced

Both natural and human induced disturbances cause degradation to river environment.

NATURAL CAUSE

Natural causes of disturbances are the naturally occurring disturbances due character of bank material and natural process such as erosion process, meandering of river, poor vegetation etc. Natural cause includes a long-term temporal variation of catastrophic events and geologic phenomena. Change in the river environment due to natural cause takes several years. One of the natural disturbing factors is neotectonics activity. Two faults in the Tistung Formation extend parallel to Nallu Khola at the southern part of watershed (Sotöcklin and

Bhattarai, 1977).A Naturally flowing stream erodes and scour river bank and bed.The rate of erosion depends on many factors. Climatic factors include the amount and intensity of precipitation, the average temperature, as well as the typical temperature range, and seasonality, the wind speed, storm frequency. The geologic factors include the sediment or rock type, its porosity and permeability, the slope (gradient) of the land, and whether the rocks are tilted, faulted, folded, or weathered. The biological factors include ground cover from vegetation or lack thereof, the type of organisms inhabiting the area, and the land use. In general, given similar vegetation and ecosystems, areas with high-intensity precipitation, more frequent rainfall, more wind, or more storms are expected to have more erosion. Sediment with high sand or silt contents and areas with steep slopes erode more easily, as do areas with highly fractured or weathered rock. Porosity and permeability of the sediment or rock affect the speed with which the water can percolate into the ground. If the water moves underground, less runoff is generated, reducing the amount of surface erosion. Sediments containing more clay tend to erode less than those with sand or silt. Erosion rate is high in unconsolidated sediments, poorly vegetate banks. Erosion at the meander bend in concave bank is higher, where stream dissipate energy, than at other parts of bank.

HUMAND INDUCED (ANTHROPOGENIC) DISTURBANCE

Anthropogenic disturbances are the human induced disturbance such as bank encroachment, vegetation clearing, dump of sewage, construction of gabion wall to channelize river, pesticides run off, **e**utrophication etc.

Bank Encroachment and channelization

With the rapid urbanization demand for the living space and cultivating land are increases. Since river consist of fertile flood plain deposits and river terrace so people are attracted towards cultivating in flood plain and river terraces. So bank encroachment by clearing riparian vegetation has increased. After clearing vegetation along bank erosion problem is triggered and in other to control erosion structures such as gabion walls are constructed (Figure 10.1). These structures channelize the river and hence cause river instability.

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 (Annex VIII). This is one of the major disturbances in the downstream part of the Nakhu Khola, along whole Nakhu Segment (Figure 10.2).

Removal of Riparian Vegetation

Riparian vegetation is referred to those plants that grow in the stream bank. Riparian plants play an important role in stream ecosystems by providing shade, 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 Khola removal of riparian vegetation for cultivation, quarry and settlement is the major problem along the whole river channel(Figure 10.3).

Livestock Grazing:

Livestock grazing is one of the causes that degrade the river environment and also cause instabiliy. Due to grazing vegetation along the river are destroyed and also contaminate water by their excreta accumulated in the banks. Along the Nakhu Khola few parts of the river segment is influences by livestock grazing.

Pesticides and fertilizer run off

Pesticides are used in nearly every home, business, farm, school, hospital and park and are found almost everywhere in our environment. Pesticides run off have also been found to be a cause of amphibian declines and deformities and are also implicated in the decline of pollinator species and other beneficial insects. Pesticides accumulate in the bottom sediments of streams, rivers, lakes and coastal areas, and are most commonly found in the fatty tissues of fish.

Fertilizers are soil amendments applied to promote plant growth. The main nutrients present in fertilizer are nitrogen, phosphorus, and potassium and other nutrients are added in smaller amounts. Water quality decreases when sediments and chemical compounds of nitrogen or phosphorus are carried by stream flows. This chemical cause eutrophication.Eutrophication is the overgrowth of invasive plants (algae, periphyton attached algae, and nuisance plants weeds), caused by the increase of nutrients, typically nitrogen or phosphorus, in the environment. And is often the result of runoff from fertilizers, livestock and the discharge of sewage treatment plants. This enhanced plant growth, often called algal blooms, blocks the water surface, which reduces light penetration in the water column, reducing photosynthesis and dissolved oxygen in the water. This causes severe reductions in water quality and biodiversity. Since floodplains and river terraces along the Nakhu Khola are heavily, cultivated and chemical fertilizers are extensively used for the high crops production. The excessive chemicals fertilizers not consumed by plants are being washed away during rainfall and mix with river water of the Nakhu Khola. The water quality analysis done at different parts of the Nakhu Khola, shows increase in chemical parameters like nitrate, ammonia, NaCl towards downstream (Annex VIII).

Quarry and mining

Huge quarry for aggregates and few gravel mining activities is operated along the Nakhu River at Nallu VDC. 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 destroyed river ecosystem. Other impact of quarrying is the channelization and bank encroachment for road in the quarry area. Vegetation clearing along the river channel and hills of the quarry area also reduced the recreational value of the river landscape (Figure 10.4).

Obstructions in Stream

Obstructions include bridge piers, boat docks, fallen trees, sand bars, trash, debris, and improper stream crossings. They constrict the channel, alter the normal flow, create eddys and increase the velocity upstream and through the obstruction causing erosion upstream and also downstream from deflection of normal stream flow. In the Nakhu Khola obstructions at different parts along the whole river is observed. Obstruction in the Nakhu Khola includes bridge piers at some places, temporary damming in river channel, and channelizing concrete pipes etc (Figure 10.4).

Land use 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 (Figure 10.5). Within 14 years, cultivated land decreased from 30.65% (1996) to 24.9% (2010) and settlement area increased from 1.3% (1996) to 6.12% (2009) of the watershed area. Though land 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 in 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 variety of negative impacts (increased sedimentation, turbidity, and eutrophication). In the Nakhu River watershed quarry are increased from 0.04% (1996) to 0.6% (2010) of the total area which have directly reduced the forest area. Due to pig farms at river banks and concentration of livestock and their manures within small areas, have substantially increased the pollution of surface water by runoff.

Figure 10.1: Bank encroachment and channelization for settlement

Figure 10.2 Sewage and solid waste dumped in river channel

Figure 10.3:Vegetation destroyed and river landscape changed in quarry area

Figure10.4: Sediments from quarry dumped along river channel and obstruction to river flow

a *b* *c* *d*

Figure 10.5 : Landuse change at (a) and (b) Nakhu bazaar area (2004 and 2010) and (c) and (d) near confluence of the Bagmati and Nakhu River (2003 and 2010)

DISTURBANCES ALONG THE NAKHU KHOLA

With the rapid urbanization in the Nakhu Khola watershed, stream is under ever increasing pressure through the growing demands of water abstraction, and suffer recurrent disturbance through diffuse and point source pollutants, channel modification and bank encroachment for cultivation and settlement. Naturally flowing stream is interrupted by human activities like encroachment, vegetation clearing e.t.c. Increased urbanization, more roofs and paving and clearing of vegetation without proper conservation management create erodible land areas, speed up runoff and remove areas available for rainfall infiltration. Poor vegetation and unconsolidated muddy gravelly bank at a stream accelerated more erosion and siltation.

Distribribution of disturbance along the Nakhu Khola is given belo in Table 10.1 and shown in figure

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
0 to 0+500	Unconsolidated muddy gravel as bank material. Meander bends.	Bank encroachment, solid wastes dump and clearing of vegetation for the cultivation .Construction of gabion wall and dikes channelized the river.	Bank encroachment destroyed riparian vegetation. Parallel and impinging erosion along the river bank. Loss of fertile soil and increasing turbidity due to erosion. Pollution of water due to solid waste dump	For natural channel condition, width of channel should be increased, establishment of riparian vegetation zone for controlling erosion. At the meandering bend bank protecting structures like gabion wall should be constructed.
500 to 1+000	Unconsolidated muddy gravel as bank material. Poor vegetation	Bank encroachment, solid waste dump, sewage pipe disposing municipal waste and channelization. Channel modification by construction of gabion wall.	Bank encroachment destroyed riparian vegetation. Parallel, impinging and sheet erosion along the river bank and flood plain. Increase in turbidity and pollutants in the water and hence destroying aquatic lives.	Natural Channel construction by increasing channel width and establishment of riparian vegetation belt for certain distance along both banks. Disposing of sewage and solid waste is needed to be stopped.
1+000 to 1+500	Unconsolidated muddy gravel as bank material. Poor vegetation.	Bank encroachment, solid waste dump, sewage pipe disposing municipal waste. Channelization and channel modification by construction of gabion wall.	Bank encroachment destroyed riparian vegetation. Parallel and impinging erosion due to poor vegetation. Increase in turbidity and pollutants in the water and destroying aquatic lives.	Establishment of riparian vegetation belt along both banks, Disposing of sewage and solid waste is needed to be stopped. Construction of bank protecting structures at meander bends.
1+500 to 2+000	Unconsolidated muddy gravel as bank material. Poor vegetation. Meandering bends	Bank encroachment at both banks for cultivation and building. Road construction at right bank by filling gravel. Gabion wall at left bank.	Increase in turbidity and pollutants in the water and destroying aquatic lives. Due to cultivation and road construction at right bank increased the bank erosion hazard. Parallel and sheet erosion is triggered due to road construction by filling unconsolidated gravel.	Shifting road away from river channel for the construction of riparian vegetation belt near river to protect bank erosion. Construction of bank protection structures like gabion wall, rootwads etc.
2+000 to 2+500	Unconsolidated muddy gravel as bank material. Poor vegetation.	Bank encroachment at both banks. Road construction at right bank by filling gravel. Water intake point for drinking purpose by 'Kathmantdu Upateka Kahanepani Ltd.' is also located in this section.	Parallel, sapping and impinging erosion due to poor vegetation, and unconsolidated bank materials. Over withdraw of water from river destroys aquatic lives habitat. River channelization at upstream caused formation of knick point and step pool in this section due to scour and erosion (Photo…..).	Gabion wall which is channelizing should either be removed or by modifying left bank height should be reduced and widen channel in other to increase channel width and reduce impact of water in downstream due to high velocity.

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
2+500 to 3+000	Unconsolidate muddy gravel. Poor vegetation	Bank encroachment at both banks for cultivation. Road construction at right bank by filling gravel. Vegetation clearing.	Easy erosion of banks due to poor vegetation and recent road construction along bank. Due to cultivation and road construction at right bank increased the bank erosion hazard. Parallel erosion ,sheet erosion along the bank and impinging erosion at some clay bank	Construction of riparian vegetation belt near river to protect bank erosion on both bank.
3+000 to 3+500	Unconsolidate muddy gravel. Poor vegetation Meandering of river.	Bank encroachment at both banks for cultivation. Channelization by construction of gabion wall at right bank. Road construction at right bank by filling gravel. Vegetation clearing.	Easy erosion of banks due to poor vegetation and recent road construction along bank. Due to cultivation and road construction at right bank increased the bank erosion hazard. Parallel erosion ,sheet erosion along the bank and impinging erosion at some clay bank	Road should be shifted away from river and establish riparian vegetation zone. Construction of riparian vegetation belt near river to protect bank erosion on both banks. In order to minimize the impact of river at right bank, bank protection structures should be used at right meandering bank along with modification of left bank by widening.
3+500 to 4+000	Unconsolidate muddy gravel. Poor vegetation Meandering of river.	Bank encroachment at both banks for cultivation. Road construction at right bank by filling gravel. Sewer pipe and from the pig farm. By constructing wall at right bank river is channelized	Easy erosion of banks due to poor vegetation and unconsolidated muddy gravel at right bank along road. Erosion is excessive at meander bend. Impinging erosion at some clay bank. Parallel and sheet erosion at right bank is triggered due to road construction by filling gravel along river bank. Water quality is degraded due to sewer pipe.	Construction of riparian vegetation belt near river by shifting road away from river channel to protect bank erosion on both bank. Construction of gabion wall at the meander bend is needed along with left bank modification for reducing bank height and widen river channel.
4+000 to 4+500	Unconsolidate muddy gravel. Poor vegetation	Bank encroachment at both banks for cultivation by vegetation clearing Livestock Grazing Road construction at right bank by filling gravel	Erosion at banks due to poor vegetation and unconsolidated muddy gravel at right bank along road. Slump of clay bank due to toe cutting. Presence of parallel, impinging erosion at both banks. Small escarps are also present in clayey left bank due to poor vegetation.	Construction of gabion wall at the meander bend to stop toe cutting. Construction of riparian vegetation belt near river to protect bank erosion on both bank by shifting road away from river.
4+500 to 5+000	Unconsolidate muddy gravel.	Vegetation clearing Livestock Grazing	Erosion of banks due to poor vegetation and unconsolidated muddy gravel at right bank along	Construction of riparian vegetation belt near river to protect bank erosion on both

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
	Poor vegetation Meandering of river.	Dump of sewer from pig farm. Bank encroachment at both banks for cultivation and road by vegetation clearing Livestock Grazing Road construction at right bank by filling gravel	road. Water quality is degraded due to sewer pipe. Slump of clay bank due to poor vegetation and water seepage from cultivated land. Presence of parallel, impinging erosion at both banks due to unconsolidated bank materials and recently constructed road section.	bank. At the right bank in meander bend, gabion wall is needed to protect bank erosion. Also to minimize the impact of river at right bank, channel should be widen at left bank by cutting. Road is needed to be shifted away for riparian zone at river bank.
5+000 to. 5+500	Unconsolidated muddy gravel. Poor vegetation	Bank encroachment at both banks for cultivation by vegetation clearing. Livestock Grazing Road construction at right bank by filling gravel.	Decrease of vegetation by grazing, and cultivation. Erosion on both banks due to poor vegetation and unconsolidated muddy gravel at right bank along road.	Construction of riparian vegetation belt near river to protect bank erosion on both banks. Shifting road about 10 to 15m away from the river channel.
5+500 to 6+000	Unconsolidated muddy gravel. Poor vegetation Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel. Construction of gabion walls at left bank Withdraw of water from river.	Presence of parallel, impinging erosion at both banks due to unconsolidated bank materials and vegetation clearing. Formation of cantilever bank structure due to erosion. Small scarp is formed at right bank near meander bend.	Construction of riparian vegetation belt near river to protect bank erosion on both banks. Shifting road about 10 to 15m away from the river channel. At the right bank in meander bend, gabion wall is needed to protect bank erosion. Also to minimize the impact of river at right bank, channel should be widening at left bank by cutting. Flow deflecting structures like dike can be kept in right bank. Road is needed to be shifted away for riparian zone at river bank.
6+00 to 6+500	Unconsolidated muddy gravel. Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing	Reduction in water flow due to water withdraws. Bank erosion is triggered due to poor vegetation and muddy gravel.	Construction of riparian vegetation belt near river to protect bank erosion on both banks. At meander bend bank protecting

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
	Poor vegetation	Road construction at right bank by filling gravel. Construction of gabion walls and dikes at left bank Withdraw of water from river.	Scarp is present at left bank due to high bank height and toe cutting.	structures like gabion wall, roodwads is needed along with cutting of left bank to widen the river channel Road is needed to be shifted away for riparian zone at river bank.
6+500 to 7+000	Unconsolidated muddy gravel. Meandering of river. Poor vegetation	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel. Construction of gabion walls and dikes at left bank Withdraw of water from river.	Bank encroachment and clearing of vegetation due to cultivation. Bank erosion is triggered due to poor vegetation and muddy gravel. Withdraw of water cause instability caused due to reduction in water flow.	Construction of riparian vegetation belt near river to protect bank erosion on both bank. At meander bend bank protecting structures like gabion wall, roodwads is needed. Road is needed to be shifted away for river bank for riparian vegetation.
7+000 to 7+500	Unconsolidated muddy gravel. Meandering of river. Poor vegetation	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel. Construction of gabion walls and dikes at left bank Withdraw of water from river	Bank erosion due to poor vegetation and muddy gravel. Excessive erosion at right bank along the road filled section due to meander bend. Withdraw of water cause instability caused due to reduction in water flow. Formation of cantilever bank structure due to erosion.	For the reduction in erosion vegetation zone is needed to be constructed. AT right bank near meander bend, bank protection structure is needed along with vegetation. Road is needed to be shifted away for river bank for riparian vegetation.
7+500 to 8+000	Unconsolidated muddy gravel. Meandering of river. Poor vegetation	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel. Withdraw of water from river	Bank erosion due to poor vegetation and muddy gravel Excessive erosion at right bank near meander bend due to unconsolidated gravel fill for road. Withdraw of water cause instability caused due to reduction in water flow.	For the reduction in erosion vegetation zone is needed to be constructed. AT right bank near meander bend, bank protection structure is needed along with vegetation.
8+000 to 8+500	Unconsolidated muddy gravel. Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by	Bank erosion due to poor vegetation and muddy gravel Excessive erosion at right bank near meander bend due to unconsolidated gravel fill for road. Erosion in right bank along newly constructed road	For the reduction in erosion vegetation zone is needed to be constructed. AT meander bends bank protection structure is needed.

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
		filling gravel.	by filling unconsolidated gravel. Slump of clay bank due to seepage.	Road is needed to be shifted away from river bank for riparian vegetation. Where road shifting is not possible erosion protection structure like gabion wall, riprap in slope is needed to stabilize road section.
8+500 to 9+000	Unconsolidated muddy gravel in flood plain and bank with thick clay terraces. Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel.	Erosion in right bank along newly constructed road by filling unconsolidated gravel. Due to steep bank height in clay and toe cut due to meander bend slump and scarps are formed though this segment has good vegetation of canopy and understory at right bank	AT meander bends bank protection structure along with flow deflection structure is needed. Example vegetated gabion wall, roodwads, dike, fascine etc. Another way to stabilize slope problem is constructing steps of terraces by cutting thick clay.
9+00 to 9+500	Unconsolidated muddy gravel in flood plain and bank with thick clay terraces. Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel.	Erosion and slump at clayey meander bends due to high bank height, and poor vegetation. Erosion in right bank along newly constructed road by filling unconsolidated gravel. Slump at some parts due to steep bank height and cantilever bank erosion structure in muddy gravelly.	Vegetation belt should be established along the whole segment. AT meander bends bank protection structure along with flow deflection structure is needed. Example vegetated gabion wall, roodwads, dike, fascine etc.
9+500 to 10+000	Unconsolidated muddy gravel Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel.	Erosion along both banks due to unconsolidated bank materials Parallel and impinging erosion along both banks. Small scarp is present at left bank near meander bend	Increase in riparian vegetation zone along both banks. AT meander bends bank protection structure is needed.
10+000 to 10+500	Unconsolidated muddy gravel	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel.	Erosion along both banks due to unconsolidated bank materials and poor vegetation Bank encroachment and clearing of vegetation for cultivation increased vulnerability of bank erosion.	Construction of riparian vegetation zone along both banks. AT meander bends bank protection structure is needed.
10+500 to 11+000	Unconsolidated muddy gravel Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing	Erosion along both banks due to unconsolidated bank materials and poor vegetation. Construction of road along river bank is also	Construction of riparian vegetation zone along both banks. AT meander bends bank protection

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
		Road construction at right bank by filling gravel.	causing excessive bank erosion. Vegetation clearing at most of the parts for cultivation increased vulnerability of bank erosion.	structure such as gabion wall and flow deflecting structures like dike, vane structures are needed.
11+000 to 11+500	Unconsolidated muddy gravel Meandering of river. Seepage of sub surface water	Bank encroachment at both banks for cultivation by vegetation clearing Road construction at right bank by filling gravel. Seepage due to irrigation canal	Erosion along both banks due to unconsolidated bank materials, road construction and poor vegetation. Sapping erosion due to water seepage in clayey high bank created slumping and small slides.	Construction of riparian vegetation zone along both banks. For slump due to seepage, water should be drained properly from high banks which can be done by surface and subsurface drain along with bioengineering and structural techniques
11+500 to 12+000	Unconsolidated muddy gravel Meandering of river.	Bank encroachment at both banks for cultivation by vegetation clearing Gabion wall at left bank. Road construction at right bank by filling gravel.	Erosion along both banks. Parallel erosion forming cantilever bank structure at some parts. Toe cutting at meandering bends.	Construction of riparian vegetation zone along both banks. Construction gabion wall and root wads at meander bend.
12+00 to 12+500	Unconsolidated muddy gravel Meandering of river. Seepage of sub surface water. Seasonal channel shifting	Bank encroachment for cultivation Vegetation clearing Temporary channel modification. Road construction at right bank by filling gravel.	Erosion along both banks due to unconsolidated bank materials and poor vegetation. Construction of road along river bank is also causing excessive bank erosion. Parallel erosion along both banks due to lateral shifting. Toe cutting at meandering bends.	Construction of riparian vegetation zone along both banks. For slump due to seepage, water should be drained properly from high banks which can be done by surface and subsurface drain along with bioengineering and structural techniques
12+500 to 13+000	Unconsolidated muddy gravel Meandering of river. Seepage of sub surface water.	Bank encroachment for cultivation. Vegetation clearing. Temporary channel modification. Road construction at right bank by filling gravel. Seepage due to irrigation canal.	Erosion along both banks due to unconsolidated bank materials and poor vegetation. Toe cutting at meandering bends. Sapping erosion due to water seepage in clayey high bank created slumping and landslide (photo….).	Construction of riparian vegetation zone along both banks by shifting raod away from river. For slump due to seepage, water should be drained properly from high banks with the help of bioengineering techniques.
13+000 to 13+500	Unconsolidated muddy gravel Meandering of river.	Bank encroachment for cultivation. Vegetation clearing Water withdraws for irrigation	Erosion along both banks due to unconsolidated bank materials, road construction and poor vegetation.	Construction of riparian vegetation zone along both banks. AT meander bends bank protection

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
	Seepage of sub surface water.	canal. Temporary check dam. Road construction at right bank by filling gravel.	Sapping erosion due to water seepage in clayey high bank created slumping.	structure such as gabion wall and flow deflecting structures like dike, vane structures are needed. For erosion control bioengineering techniques is needed to be applied.
13+500 to 14+000	Steep rock slope	Road construction at right bank by cutting rock slope and filling gravel.	Construction of road at right bank, vegetation clearing, and channelization created erosion problem. Sheet erosion and small rock fall due to fracture is present near suspension bridge due to steep cliff, cut slope and lack of vegetation	Since it is located within gorge so for protecting road from erosion riprap of big boulders and rock should be kept along road. For stabilizing slope erosion application of bioengineering such as turfing, seeding slope etc is needed
14+000 to 14+500	Steep rock slope colluviums	Road construction at right bank by cutting rock slope and filling gravel.	Construction of road along river bank is also causing excessive bank erosion. Due to road river is channelized and instability is created.	To protect road from erosion riprap of big boulders and rock should be kept along road. For stabilizing slope erosion application of bioengineering is needed.
14+500 to 15+000	Steep rock slope with colluviums	Road construction at right bank by cutting rock slope and filling gravel. Crusher site. Sheet erosion from cultivated lands and crusher sites. Road construction at right bank by cutting rock slope and filling gravel.	Construction of road along river bank is also causing excessive bank erosion.	Due to road construction river is channelized so headward erosion might be created in upstream and bridge near confluence is in risk. So proper protection near bridge is required (photo…….)
15+00 to 15+500	Unconsolidated muddy gravel	Bank encroachment and vegetation clearing for cultivation and crusher located along river bank.	Vegetation clearing for cultivation and crusher located along river bank is contributing in excessive sediment supply. Parallel and sheet erosion due to unconsolidated bank materials.	Vegetation zone along both banks is needed. And Dump of sediments from crusher industry should be stopped. Bank erosion can be stabilized with the help of bioengineering technique live staking, brush mat, brush layering etc.

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
15+500 to 16+000	Fractured rocks, unconsolidated bank material and steep slopes with poor vegetation.	Bank encroachment and vegetation clearing for quarry and crusher located along river bank.	Fractured rocks, unconsolidated bank material and steep slopes with poor vegetation help in easy erosion along the river bank. Vegetation clearing in quarry sites and slope cuts trigger in different kinds of erosion and even temporary damming and debris flow is also recorded in the past.	Dumping of sediments from quarry and crusher industry should be stopped. Bank erosion can be stabilized with the help of bioengineering technique live staking, brush mat, brush layering etc. Since this segment is lacking distinct river channel geomorphic adjustment along with bioengineering like vegetated gabion wall, root wads, fascines for re-vegetating and erosion protection is needed. AT abandoned quarry sites bioengineering like jute netting, brush layering, etc is needed to protect slopes from erosion and mass movement.
16+000 to 16+500	Unconsolidated bank material and steep slopes with poor vegetation.	Bank encroachment and vegetation clearing for quarry and crusher located along river bank. Channelization with the help of concrete pipe at different parts.	Vegetation clearing in quarry sites and slope cuts trigger in erosion hazard. Temporary damming and debris flow due to landslide is also recorded in the past upstream of quarry site near Koldada. Channelizing stream and dumping of sediments from quarry is increasing turbidity in water due to which no aquatic life is possible. Scarps due to quarry can cause landslide during rainy season present.	Since this segment is lacking distinct river channel geomorphic adjustment along with bioengineering like vegetated gabion wall, root wads, fascines for re-vegetating and erosion protection is needed. AT abandoned quarry sites bioengineering like jute netting, brush layering, etc is needed to protect slopes from erosion and mass movement.
16+500 to 17+00	Unconsolidated bank material and steep slopes with poor vegetation.	Vegetation clearing for quarry and crusher located along river bank. Channelization with the help of concrete pipe at different parts. Dumping of sediments from quarry.	Vegetation clearing in quarry sites and cut slope trigger in erosion hazard. Temporary damming and debris flow due to landslide is also recorded in the past upstream of quarry site near Koldada. Channelizing stream and dumping of sediments from quarry is increasing turbidity in water due to which no aquatic life is possible.	Since this segment is lacking distinct river channel geomorphic adjustment along with bioengineering like vegetated gabion wall, root wads, fascines for re-vegetating and erosion protection is needed. AT abandoned quarry sites bioengineering like jute netting, brush layering, etc is needed to protect slopes from erosion and

Table 10.1: Disturbances alolng the Nakhu Khola

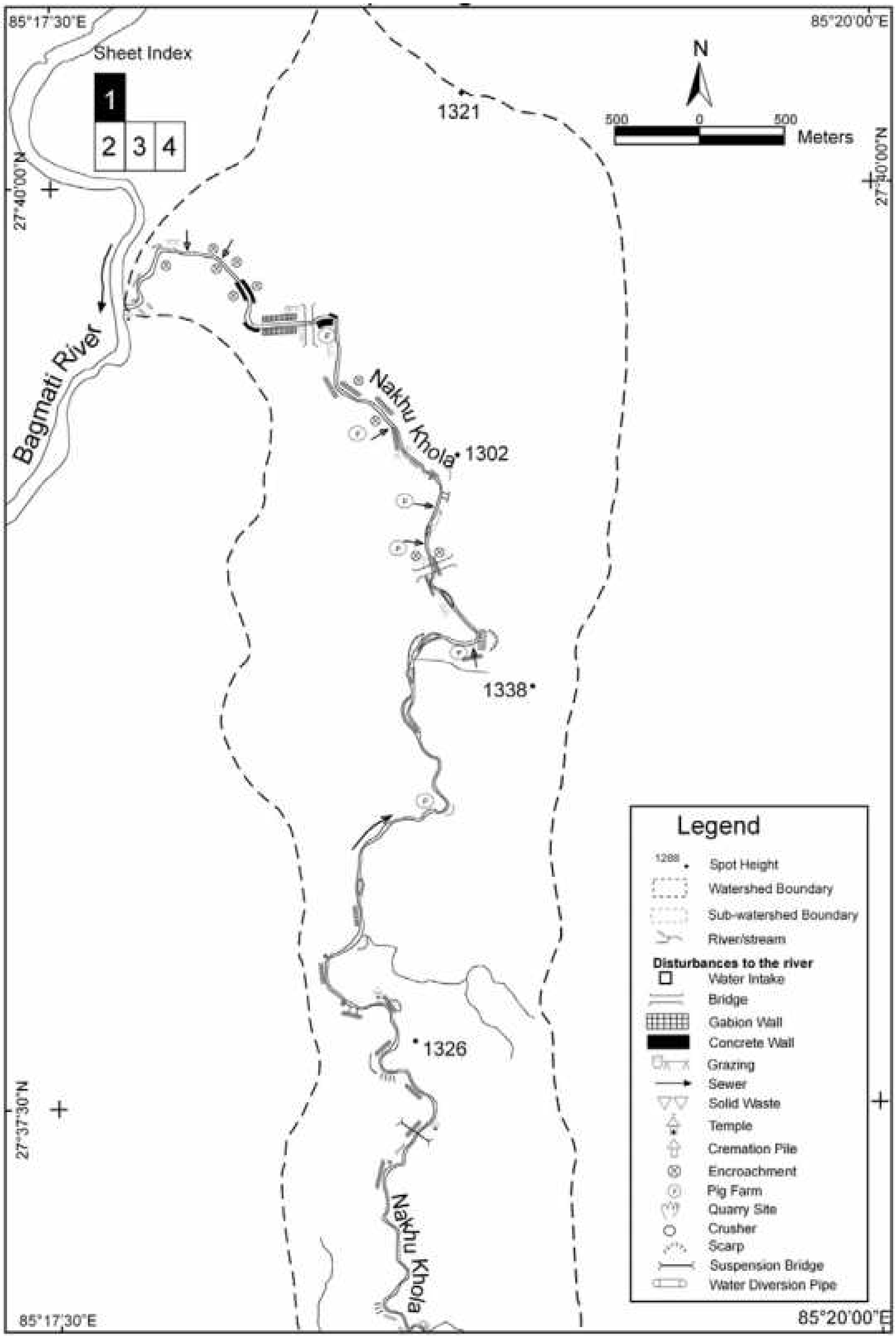
Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
			Scarps due to quarry can cause landslide during rainy season present.	mass movement.
17+000 to 17+500	Steep slopes with poor vegetation.	Vegetation clearing for quarry and road construction. Channelization with the help of concrete pipe at different parts.	Vegetation clearing in quarry sites and cut slope trigger in erosion hazard. Channelizing stream and dumping of sediments from quarry is increasing turbidity in water due to which no aquatic life is possible. Scarps due to quarry can cause landslide during rainy season present.	Since this segment is lacking distinct river channel and vegetation so some geomorphic adjustment is also needed along with riparian vegetation belt establishment. AT abandoned quarry sites bioengineering like jute netting, brush layering, etc is needed to protect slopes from erosion and mass movement.
17+500 to 18+000		Vegetation clearing for quarry and road construction (Figure 10.4).	Vegetation clearing in quarry sites and cut slope trigger in erosion hazard. Channelizing stream and dumping of sediments from quarry is increasing turbidity in water due to which no aquatic life is possible. Scarps due to quarry can cause landslide during rainy season present.	Since some part of this segment is lacking distinct river channel and vegetation so some geomorphic adjustment is also needed along with riparian vegetation belt establishment. AT abandoned quarry sites bioengineering like jute netting, brush layering, etc is needed to protect slopes from erosion and mass movement.
18+000 to 18+500	Steep slopes with poor vegetation.	Vegetation clearing and bank encroachment for quarry and road. Check dam and channelization with the help of concrete pipe. Water withdraw for irrigation and drinking. Quarry sediment dump in river.	Vegetation clearing in quarry sites and cut slope trigger in erosion hazard. Channelizing stream and dumping of sediments from quarry is increasing turbidity in water due to which no aquatic life is possible. Unstable slopes at quarry can cause landslide during rainy season. Water withdrawal reduced water flow in river.	Widening of channel and establishment of vegetation belt along both banks is required. AT abandoned quarry sites bioengineering like jute netting, brush layering, etc is needed to protect slopes from erosion and mass movement.
18+500 to 19+000	Unconsolidated muddy gravel	Bank encroachment and vegetation clearing for cultivation	Due to clearing of vegetation ground is exposed to erosion agents like water and wind.	Vegetation belt is required along both banks and bioengineering works can be applied to control erosion
19+000 to	Unconsolidated	Bank encroachment and vegetation	Due to clearing of vegetation ground is exposed to	Vegetation belt is required along both

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
19+500	gravel	clearing for cultivation. Gabion wall for erosion protection.	erosion agents like water and wind. Unconsolidated river banks are easily eroded Vegetation clearing for cultivation and gabion wall for bank protection. Construction of road along river channel.	banks.
19+500 to 20+000	Unconsolidated gravel. Meander Bend	Bank encroachment and vegetation clearing for cultivation. Construction of road along river channel.	Unconsolidated river banks are easily eroded. And due to cultivation ground is exposed to wind and water for erosion. Parallel and impinging erosion in unconsolidated river banks making cantilever structure erosion though ground cover is present.	Vegetation belt is required along both banks and bioengineering works can be applied to control erosion. AT meander bends bank protection structure such as gabion wall and flow deflecting structures like dike, vane structures are needed.
20+000 to 20+500	Unconsolidated gravel.	Bank encroachment and vegetation clearing for cultivation.	Clearing vegetation and unconsolidated river bank increased erosion hazard. Parallel and impinging erosion in unconsolidated river banks making cantilever structure erosion though ground cover is present. At steep slope small landslide is also present	Vegetation belt is required along both banks to protect erosion. Bank protecting structures like vegetated gabion wall and flow deflecting structures is required at meander bends is required.
20+500 to 21+000	Unconsolidated gravel Poor vegetation Colluvium deposit at Steep slope. Meander bend	Bank encroachment by clearing riparian vegetation. Gabion wall for bank protection.	Poor vegetation, unconsolidated river bank and steep slope help in easy erosion. AT meander bend erosion is high. Slope cut for road construction at uphill of bank contributing in small slides in hills.	Vegetation belt is required along both banks to protect erosion. Bank protecting structures like vegetated gabion wall and flow deflecting structures at left bank and bank adjustment at right bank is required at meander bends.
21+000 to 21+500	Unconsolidated muddy gravel Poor vegetation	Bank encroachment by clearing riparian vegetation. Gabion wall for channelization and bank protection from erosion. Temporary road along channel	Bank encroachment by clearing vegetation. Temporary road along channel not only caused erosion but also kill aquatic habitat. Channelizing with gabion wall at right bank cause instability in the stream due to disturbance in natural flow.	Vegetation belt is required along both banks to protect erosion and maintain temperature of water to support aquatic life.
21+500 to 22+000	Unconsolidated muddy gravel	Bank encroachment by clearing riparian vegetation.	Bank encroachment by clearing vegetation. Temporary road along channel not only caused	Vegetation belt is required along both banks to protect erosion and maintain

Table 10.1: Disturbances alolng the Nakhu Khola

Chainage (m) (Starts from the confluence of the Nakhu Khola with the Bagmati River)	Disturbance		Impact	Remarks
	Natural Cause	Human Induced		
	Meander bends	Gabion wall for channelization and bank protection from erosion. Temporary road along channel	erosion but also kill aquatic habitat. Parallel erosion in unconsolidated river bank and at meander bends. Scarp is formed due to slump in left river bank.	temperature of water to support aquatic life.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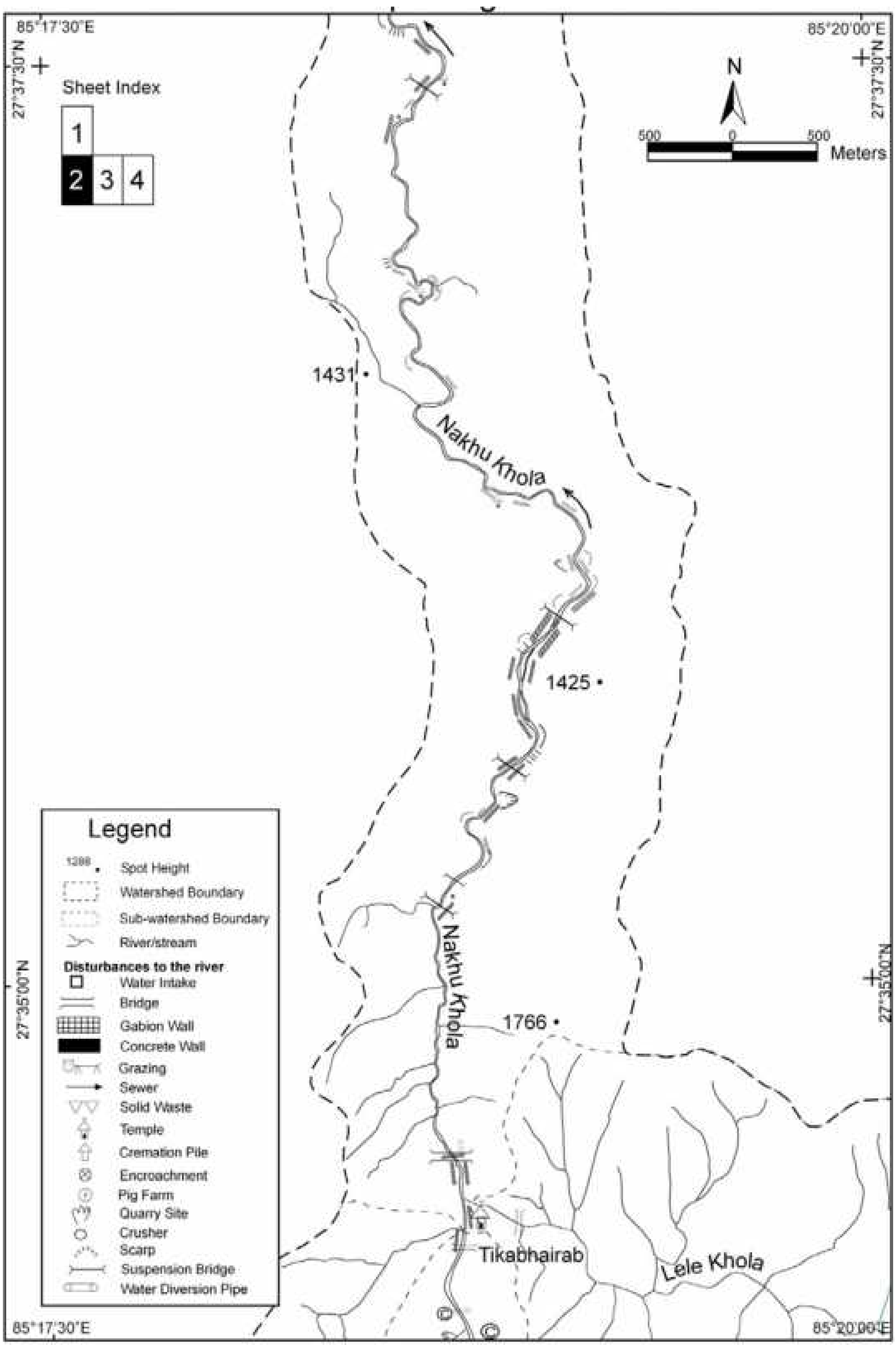
Legend
Spot Height
Watershed Boundary
Sub-watershed Boundary
River/stream
Disturbances to the river
Water Intake
Bridge
Gabion Wall
Concrete Wall
Grazing
Sewer
Solid Waste
Temple
Cremation Pile
Encroachment
Pig Farm
Quarry Site
Crusher
Scarp
Suspension Bridge
Water Diversion Pipe

a



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Nakhu Khola
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Sub-watershed Boundary
River/stream
Disturbances to the river
Water Intake
Bridge
Gabion Wall
Concrete Wall
Grazing
Sewer
Solid Waste
Temple
Cremation Pile
Encroachment
Pig Farm
Quarry Site
Crusher
Scarp
Suspension Bridge
Water Diversion Pipe
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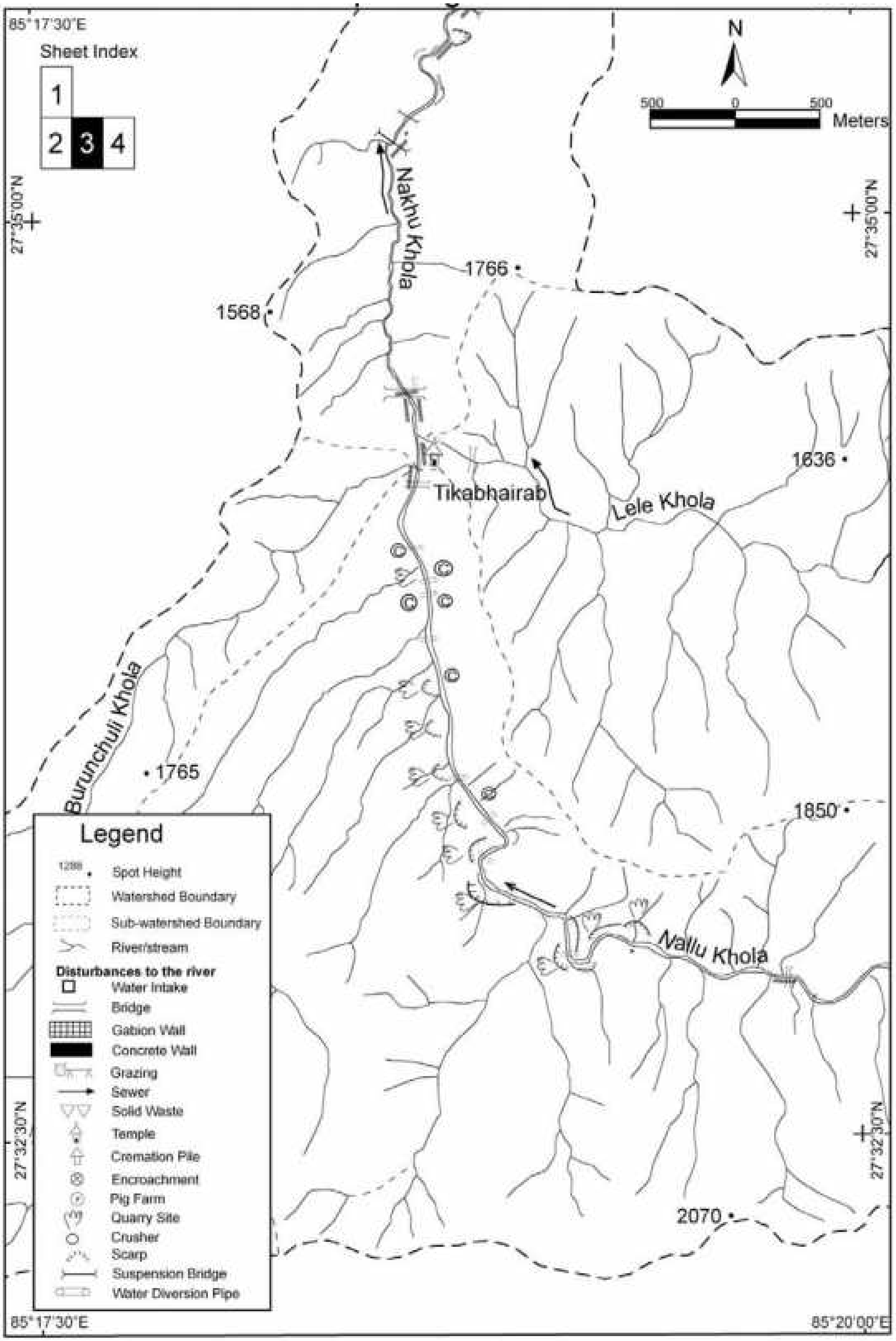
Tikabhairab
Lele Khola

b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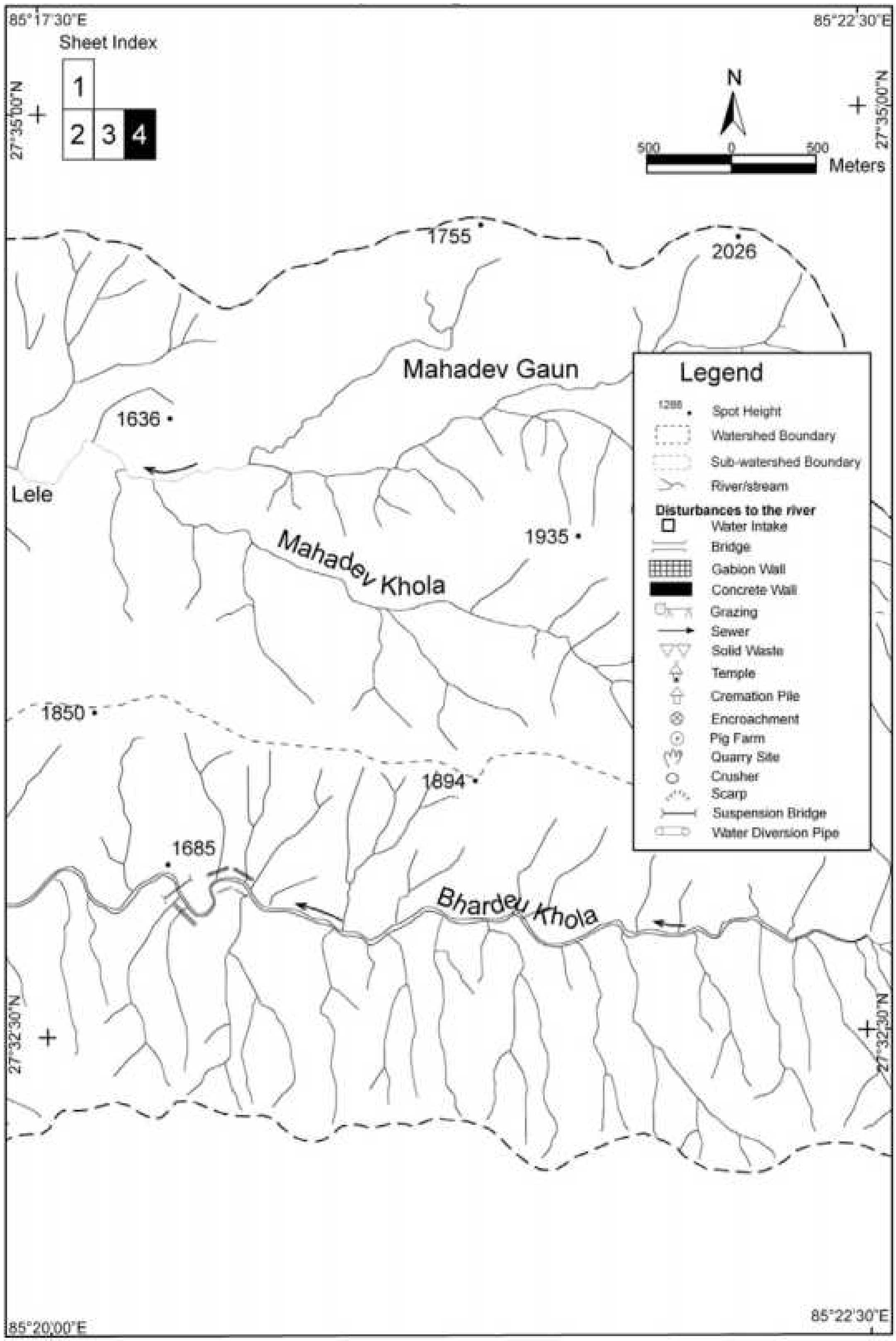
Legend
Spot Height
Watershed Boundary
Sub-watershed Boundary
River/stream
Disturbances to the river
Water Intake
Bridge
Gabion Wall
Concrete Wall
Grazing
Sewer
Solid Waste
Temple
Cremation Pile
Encroachment
Pig Farm
Quarry Site
Crusher
Scarp
Suspension Bridge
Water Diversion Pipe

c



d

Figure 10.7: a, b, c and d Distribution of disturbances long the Nakhu River

HYDRALIC GEOMETRY

A natural channel with no any disturbance generally has positive correlationbetween crossectional area and watershed area. Crossectional area of river increases with increase in watershed area. But this relation may or may not hold true for human influenced channel. Nakhu Khola is very much impaired due to human activities which are also shown by Figure 10.8 clearly shows that crossectional area does not have good correlation with watershed area. Most of the Nakhu Khola segments are channelized and modified for different purposes. Therefore hydraulic geometry relationship shows that the Nakhu Khola is impired and degraded and human activitie are one of the causes.

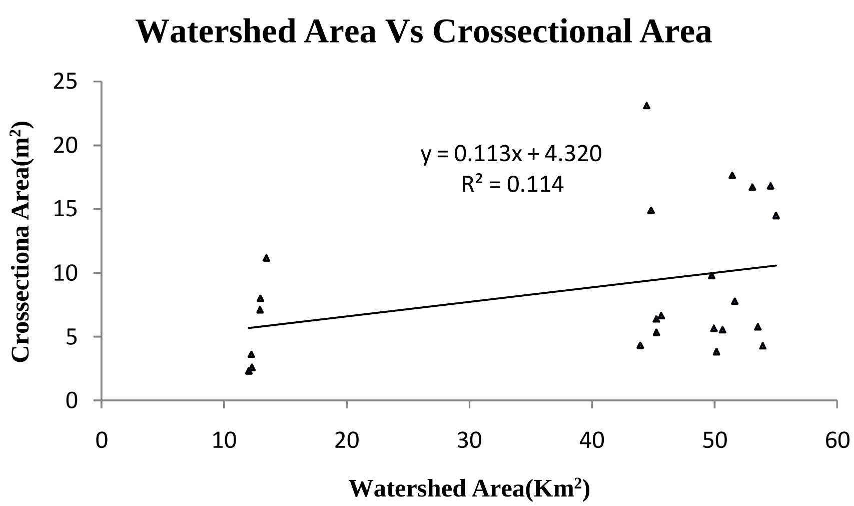


Figure 10.8: Graph showing crossectional area versus watershed area

CHAPTER ELEVEN

RESTORATION DESIGN

WHAT IS RESTORATION DESIGN?

Restoration is the reestablishment of the general structure function and self-sustaining behavior of the stream system that existed prior to disturbance. It is the special process that requires an understanding of all physical and biological components of stream system and its watershed. Restoration involve broad range of works such as removal of watershed disturbances that are causing instability, installation of structures and plantation of vegetation to protect stream banks and provide habitat: reshaping or replacement of unstable stream reaches into appropriately designed functional streams and associated floodplains.

Natural channel design is the process of applying fluvial geomorphic principles to transform unstable stream corridors into stable channels that maintain their dimension, pattern, and profile over time (Leopold, 1994; Rosgen, 1994). Additional goals include improving aquatic habitats and restoring native riparian vegetation along stream corridors with natural materials.

Over the past few years, a majority of the riparian areas in watersheds have been mismanaged and degraded by activities such as overgrazing, intensive agriculture, and indiscriminate logging. The primary focus of restoration design isinclude proper management of uplands adjacent toriparian areas, restoration and proper management of riparian buffer areas, andstabilization of stream banks.

RIVER REACHES SUBJECT TO RESTORATION DESIGN

Restoration Reaches Subjected to restoration is on the basis of the impact of disturbances the restoration required for different segment is different. Some segments are in sever condition requires special restoration work while most of the parts requires only few and easy restoration procedures like establishment of riparian vegetation buffer zone. On the basis of disturbances, river reaches for restoration procedure and model purposed are showing in the Figure 11.2 .Restoration models and special techniques required for restoring natural conditions of the Nakhu Khola are as follows.

From ch 0+000m to ch 3+500m

In this chainage for river restoration, bank encroachment should be stopped. Walls constructed for encroachment and channelization should be stopped and riparian vegetation zone should be established. At convex bend of river where impact is high requires special bank protecting structures like gabion walls, dike. On the basis of field condition Model 5 and Model 3 is purposed at meander bend and in whole segment model 1 is purposed which is shown in Figure 11.1. At places where model 5 is to be implemented, structure like gabion wall at right bank (conves bend) and widening left bank (concave bank) along with riparian vegetation can be used.

From CH 3+500 to CH 8+500m

Dumping of sewage and mixing of efficient from municipal, waste and farm needed to be prohibited and stopped for improvement in river water quality. Road extended from Nakhu Bridge to Tikabhairab gorge should be shifted away from the riverbank and flood plain.

This section of the river has flood plain with ground cover from 3+500 to 5+500m and cultivated river banks by clearing vegetation from chainage 5+500 to 8+800. Though this chainage consists of wide flood plains compare to other section, this section lacks any distinct canopy. So due to lack of distinct canopy in flood palin bank, bank erosion is major problem. For protecting bank erosion, vegetation zone should be established along both banks. At convex meander bends where erosion slump is problematic, Model 5 and Model 3 is purposed along with bank height reduction and channel widening. Flow deflection structures, rock boulders, dikes and logs are also needed at meander bed from chainage

5+500 to 8+500. Cultivated river banks and flood plains by clearing vegetation and road extension at right bank is major problem for excess erosion. For restoration of this segment, road should be shifted away from the river bank and establishment of vegetation zone is essential. Beside this river bio engineering Model 1 is needed along whole section. At meander beds where erosion is very distinct and slump due to high height is causing degradation Model 5 and Model 3 is purposed. At some convex bends, flow deflection structures like root walls, dike and channel widening by cutting opposite concave bank is also needed. All the purposed model and techniques required is shown in (Figure 11.1).

From CH 5+500 to CH 9+500m

This chainage of Nakhu Segment contains good vegetation along the river terraces and high than other segement with high bank. Because of high bank height and ground water seepage, slump and small landslide is also common at the chainage from 8+500 to 9+000m. So, protective structures like gabion walls are used and these are also not so effective in controlling slides. For controlling slides in high bank height, seepage should be drained by making drainage At meander bends Model 5 with flow deflecting structures can be used. Reducing high bank by making benches and vegetating those benches is another effective major for controlling erosion due to slides. Riparian vegetation zone should be established along the chainage from 9+000 to 9+500m. Model 2 along the chainage and model 5 and Model 3 is purposed at the convex meander bends (Figure 11.1).

From CH 9+500 to CH 11+000m

This section of the Nakhu River consists of cultivated flood plains and river terraces with linear pattern canopy and understory. This section also has poor riparian vegetation. Erosion along cultivated flood plains and banks due to poor vegetation can be controlled by Model 2using bioengineering model. Erosion at meander bends can be controlled by applying Model 5, which consists of flow deflecting structure like root, wads. At some bends besides applying Model 5, river channel is needed to be widened. At few cultivated river terraces, seepage due to irigation cannel is also causing slump problem. So, drainage and irrigation channel should be well managed and drained. Roadshould be shifted away from the bank to estalish vegetation (Figure 11.1).

From CH 11+000 to CH 12+000m

From chainage 11+000 to 12+000 contains cultivated flood plains at most of the part while gravelly flood plain from chainage 11+500 to 12+000. Due to lack of vegetation and muddy gravel banks are easily eroded. Another erosion triggering factor-degrading river is road extension at right bank. In other to restore river, extension of road should be shifted away to establish and riparian vegetation zone. For this chainage, Model 2 is purposed along the whole segment at meander bends, where erosion is excess Model 5, which consists of flow deflecting structure, is purposed (Figure 11.1).

From CH 12+000 to CH 13+500m

This chainage of the Nakhu Khola is dominated by cultivated flood plains and slumped meander bends in thick, clay dominated high river banks. Road constructed at right a bank is also causing disturbances due to the bank encroachment and vegetation clearing. For river restoring of this chainage Model 2 is purposed at riffle area where banks are of nearly same height and Model 3 is suggested for pool with unequal bank height. At convex meander bend model 5 is purposed and at river bank where bank height is high and nearly of same height Model 4 is suggested. Riparian vegetation zone should be established along both bank by shifting road away from be river bank (Figure 11.1).

From CH 13+500 to CH 15+000m

This chainage consists of gorge section of the Nakhu khola. So, banks are of bed rocks which are covered by vegetation at hills. No major erosion and natural disturbance are observed. However, few gully erosion is observed which are needed to be stablized by constructing gabion walls. Beside this, extension of road at right bank by confining river channel is main disturbance which also created unstable cut slope near suspension bridge. So, road should be shifted away from river channel. Near, Model 2 is suggested and walls constructed for bank protection should be removed (Figure 11.1).

From CH 15+000 to CH 15+500m

This chainage also consists of cultivated muddy gravel and clay bank with distinct river channel. This section of river banks also lacks vegetation. So riparian vegetation zone is needed and model 4 is suggested for this chainage. At meander bends, Model 5 is suggested (Figure 11.1).

From CH 15+500 to CH 18+500m

This section of river is most degraded section of the Nakhu River due to quarry and crusher. For quarry and mining activities vegetation is cleared, channel of river is modified and obstructed. To restore rivers, first river obstruction should be removed and channel should be well defined. Abandoned quarries and cut slopes should be stabilized and vegetated by armoring, jute netting at slopes and fascines brush layering etc. For these raw materials like seed, plants are available locally in the area. At gentle slope Fascines, live wattle fences, palisades can be used. Application of bioengineering model 4 is suggested along channel and model 5 at meander bends (Figure 11.1). From chainage 15+500m to 1700 m, river channel is also not distinct so distinct channel is needed to be defined. Detail of channel design based on stability condition is given in Table

From CH 18+500 to CH 19+500

From these chainage river disturbances due to human activities is quite low. But this section is still affected by cultivation and poor vegetation condition. Some parts of section are suffering from excess erosion at meander bend due to muddy gravel. For this section Model 2 is suggested along with Model 3 at meander bends (Figure 11.1).

From CH 19+500 to 21+000m

This section of river also lacks vegetation zone. Most of the flood plain are cultivated and some are barrer for grazing and gravel mining. Because of these activities, excess erosion is triggering. So, to reduce erosion rate these activities should be stopped. Beside this, Model 1 along the channel and Model 3 and Model 4 without riprap is purposed. which is shown in Figure 11.1

From CH 21+000 to 22+000m

This section of river is also dominated by cultivated flood plains and slopes with linear canopy and patchy canopy. Distinct riparian vegetation zone is absent in this section too. For this section, also model 2 is suggested for establishing vegetation along the channel and erosion control. At few parts where river channel meander, Model-3 is suggested for stabilizing bank erosion.

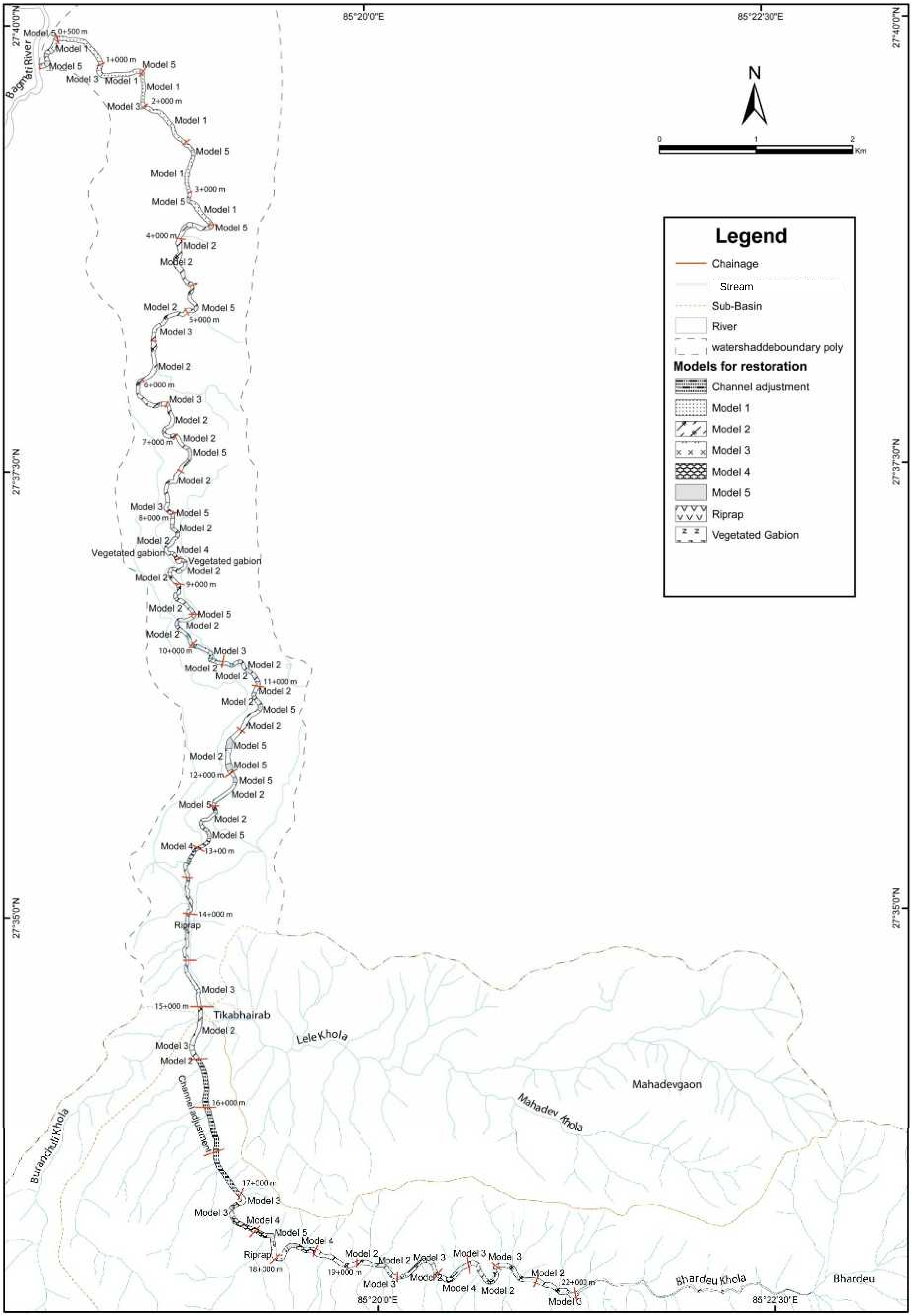


Figure 11.1: Map showing chainage and river section for purposed bioengineering model application

RESTORATION WORKS

Restoring degraded streams into natural condition by applying different principles is an extremely complex, expensive and delicate science. The ultimate aim of restoring rivers is to generate healthy, living streams with a diversity of habitats, which incorporate the essential elements of shade, hard leave sand tannin stained water. These ‘ingredients’ can be used to develop, as far as possible, a natural stream ecosystem and to keep the stream channel free of choking aquatic vegetation and algae. This concept can be applied at a simple scale, ie establishing fringing native vegetation along streamlines, through to the complex scale, where channel form, bank stability, in stream habitats and catchment management are all incorporated. Different works geomorphic, bioengineering and structural works are done for river restore. Some of the works are

- Vegetation works
- Bioengineering works
- Engineering Works
- Channel Adjustment Design

Vegetation works

Vegetation is one of the most commonly used methods for protecting river banks from erosion. Vegetation protects a stream bank with the roots and exposed branches, stems. The exposed plants defer flow by deforming the plant in place of removing soil. Over bank flow velocity is reduced and the capacity for infiltration and water withdrawal from the banks are increased. Woody plants provide greater erosion protection but on high banks the roots may not penetrate to the bank toe and a collapse will cause bank failure. The meandering curves of a river, combined with vegetation and root systems, dissipate stream energy, which results in less soil erosion and a reduction in flood damage. Sediment is trapped, reducing suspended solids to create less turbid water, replenish soils, and build stream banks. Pollutants are filtered from surface runoff which enhances water quality via bio-filtration. Revegetation along the river corridor is the most cheap and easy way of stabilizing banks, flood attenuation and habitat enhancement than other works. It utilizes different grass, herbs, shrub, and trees from nearby river corridor for vegetation. Natural undisturbed river generally have certain riparian vegetation zone which plays very important role. This zone provides shade to water which helps in maintaining water temperature.

Site-specific conditions must be considered to use vegetation. Success of vegetation depends on the stream flow characteristics, bank geometry, site preparation and compatibility with these conditions. It is relatively easy to maintain and establish and properly selected plants and grasses are self-maintaining. Erosion control matting may be necessary to hold the seed and soil in place until the vegetation is established. Eroded banks and undercut toes require grading prior to planting. If the toe is being undercut the toe should be protected with riprap or other non-erodible material or with the help of gabion wall. Slopes flatter than 1V to 1 ½ H can accommodate vegetation but slopes flatter than 1V on 2H or 3H are preferable especially for ease in maintenance.

With rapid urbanization in the Nakhu Khola watershed, banks and flood plains of stream is encroached by destroying riparian vegetation. Along the Nakhu Khola from downstream to upstream most of riparian vegetation is destroyed for cultivation and building. So lack of vegetation along the river bank has triggered bank erosion, reduction in aquatic habitat and water pollution. In other to restore Nakhu Khola into natural condition riparian vegetation zone along both of the river bank is needed to be established. For riparian vegetation, gravel road constructed at right bank is needed to be shifted further away from the river channel and at least 10 to 15m vegetation buffer zone is needed to be created. Riparian zones dissipate stream energy. For vegetation works, native plant species like Uttish, Sirish, Labshi, Chutro, Bamboo, Kandaphul, Kans, Dubo etc can be used. Despite these native plants other fruits and ornamental plants can be planted. At meander bends where erosion rate is high deep rooted plants and trees along with structures like gabion wall is needed. The banks and flood plains of Nakhu Khola has gravelly bed and thick clay bed. The clay bed has good vegetation but vegetation in the gravelly mud has only grass and herbs with poor root density. So vegetation work is very much needed in gravelly banks and flood plains.

Bioengineering Works

Bioengineering, also known as "soft engineering" is a technique, which uses native plant materials and erosion control products to stabilize eroding slopes, waterways, and banks. These techniques are used as an alternative to stone rip-rap, stone gabion baskets, concrete, or other "hard" engineering techniques. For bioengineering vegetation is carefully selected for the function it can serve in stabilizing roadside slopes and for its suitability to the site. It is usually used in combination with civil engineering structures. Some of the native vegetation used in bioengineering are Utis, Narkat, Bamboo, Nilkadha, Nigalo, Kandapul, Kans, Dubo. Bioengineering is basically used to protect slopes from erosion, reduce shallow planar sliding, and improve surface drainage and slumping. Bioengineering in river has two main functions: a) bank stabilization and b) establishment of vegetation zone to create bio-filter zone along river banks and maintain river habitat. Some of the bioengineering techniques commonly used for in river bioengineering are as follows:

Live staking: Live staking is a simple technique that installs a dormant cutting directly into the ground. This technique often provides a transition from a larger revegetation project to existing vegetation or is utilized where single stem plantings will provide adequate plant cover, slope stability and fish habitat. Live staking may be combined with other soil bioengineering techniques. Live stakes are often used as an anchoring device for bundles, brush mattress and erosion control mats. Planting sites should be selected carefully. Live staking requires moist soils; mortality will be high if the live stakes are planted at sites without adequate soil moisture.

Live siltation: Live siltation is a revegetation technique used to secure the toe of a slope and provide fish rearing habitat. This technique provides vegetative cover at the water level and can be constructed as either a sacrificial planting or as a live system.

Coir logs: Coir logs are constructed of interwoven coconut fibers that are bound together with biodegradable netting. Commercially produced coir logs come in various lengths and diameters. The product needs to be selected specifically for the site. Fiber logs composed of other sturdy biodegradable materials may function equally as well.

Brush layering: Brush layering is a revegetation technique which combines layers of dormant cuttings with soil to revegetate and stabilize both stream banks and slopes. Cuttings are placed on horizontal benches that follow the contour of the slope. The benches are cut to angle down and back into the slope. Construction of this technique can be easily mechanized, particularly on fill slopes.

Root Wads: Root Wads are ideal where water depth is too great for living bioengineering solutions or where flow velocities are high. Root Wads provide excellent cover for fish and deflect flows away from eroding or vulnerable banks.

Wattle fences: Wattle fences are short retaining walls built of living cuttings. Wattle fences are used on sites where over steepened slops is preventing growth of vegetation. As the cuttings are fairly well exposed, wattle fences work best where there is ample moisture available to sustain the growth of the cuttings. Wattle fences can be used on very steep slopes as long as the slope itself is globally stable. Bamboo wattle fence is common for slope protectin.

Engineering Works

Erosion along the stream can be controlled by vegetation works but requires some timeto grow the vegetation. Therefore, for the immediate protection of erosion along the bank, protective and slope stabilization structures such as gabion wall, retaining wall, concrete wall, riprap etc is required. These structures support the slopes along the stream and protect from toe cutting of slope, scouring and gulling. Some of the structural works that can be used along the stream bank and slope near stream are as follows:

Gabion walls:Gabions are free-draining walls constructed by filling large baskets usually made from galvanized, plastic coated, double twisted steel mesh with large crushed stone. Gabions are routinely used in river engineering to provide retaining structures, for scour and erosion protection, as channel lining and weirs. Depending on the height of the gabions, which defines the critical water velocity above which the rocks within the gabion start moving and the basket starts deforming, gabions can resist to water flows up to about 6 m/s, hence are suitable for the revetment of beds and banks of rivers with strong currents, including during flood conditions.

Along the Nakhu Khola gabion wall is needed in those place where erosion rate is high and only vegetation works cannot protect stream banks from erosion. E.g: at meander bends. Gabion wall along with vegetation of uttish can be used for long term and natural solution from erosion. Vegetated gabion wall is the combination of gabion wall and bioengineering technique, which is very useful in controlling erosion. It can be very effective in the bank erosion protection at meander bends of the Nakhu Khola because gabion provide immediate protection until vegetation grows.

Retaining Wall:Gabion retaining walls are constructed by placing rows of gabions in stepped courses. Normally, the walls are built inclined at 6°-8° to the vertical into the retained fill to enhance their stability as gravity walls. Retention is achieved from a combination of the stones weight, and its interlocking and frictional strength.

In Nakhu Khola retaining wall is needed only in river banks where bank height is too high and at meander bends where toe cutting is high. Generally thick lacustrine deposit of clay needs retaining wall for protection from slump and erosion.

Spur Dike: A spur dike is the flow deflecting structure which deflects water away from the eroding river banks. The spur dikes can be constructed with stone, rubble or even brush on a smaller scale and lower velocities.There are also permeable type dikes made from board fence and wire fences that permit deposition of sediment as the stream flows through them. They are most useful on stream carrying heavy sediment loads. The spur dikes have been recognized as riparian structures that have functions of retarding velocity near the riverbank and deflecting the main flow from the levee, and as environmental structures that can provide plentiful ecological surroundings by creating diverse flow fields.

In the Nakhu Khola the spur dikes are used as flow deflecting structures only in some meander bends where erosion problem is high and to protect cultivated land from being eroded.

Channel Adjustment Design

Channel adjustment design is the procedure of modifying unstable riverchannel by applying fluvial geomorphic principles to transfer unstable stream corridors into stable channel. A stable channel maintains its dimention, patterns and profile over time. This is one of the dedicated and expensive river restoring technique used for very much degraded and impaired stream.At the Nakhu Khola river segment in the quarry site is totally destroyed due to quarrying. River in this segment has lost its function.Erosion along this segment caused increase in turbidity in the water and hence no aquatic life is possible in this segment. So in other to restore river by implimentation of other bioengineering technique, channel with fixed width and sinuosity that will be stable and function should be designed in the quarry area. For channel desing geomorphic and hydraulic parametes should be considered.The basic criteria for the channel design is taken with the help of standard curve of the stable river given by Lepold and wolman 1960. On this basis channel width, meander lenghth and meander wave length that will be suitable for the Nakhu Khola is evaluated. (Table 11.1). These values are considered while designing tha stable channel for the river. Figure 11.2. shows the stable channel design of two meander wave lenth for the Nakhu River designed by considering ealuated values. For the restoration of the degraded segment from chainage 15+500m to 17+000 m, total of 20-meander wave lengthof 70 m is required.While designing channel bioengineering technique along with other structures may also require for developing natural channel.

Table 11.1: Design parameters for the channel design

parametes	Current Parameters	Design Parameters
Meander wavelength,lm(m)	335	70
Belth width,W_{blt} (m)	30	30
Length of channel thalwage,L_w (m)	1498	1974
Length of valley, L_{vally} (m)	1400	1400
Sinuosity, $K=L_{tw}/L_{valley}$ (m/m)	1.07	1.41

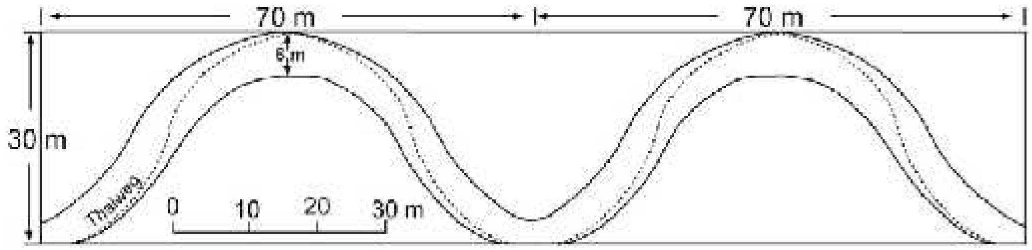


Figure 11.2: Channel design for the Nakhu Khola near quarry site

RESTORATION MODELS SUGGESTED FOR THE NAKHU RIVER

The Nakhu Khola is deteriorating day by day due to different humand as well as natural cause. Becaues of these activiteise in the river, there is significant reduction in the river habitat and water quality even reduction in the recreational values of the river. In other to protect river from total degradation the Nakhu Khola should be restored. River restoration can be done by the application of different methods such as vegetation works, engineering works etc. Application of these methods in any river depends upon the condition of the river and availability of local resources. Sinc the Nakhu Khola consists of many local resources such as boulders, rocks, vegetation etc that can be used to protect riverbank. Therefore, some of the bioengineering methods along with few engineering structures are implemented and river restoration model suitable for the Nakhu Khola is purposed. These models uses native vegetation that are available locally and rock riprap for temporary bank protection .Engineering sturctures are also purposed for critical riverbanks ard used for temporary protection until bioengineering works is well established. Based on these methods five bioengineering models are purposed. They are as follows

Model 1

The model 1 is suggested to the downstream segments of the Nakhu Khola with slight entrenchment ratio and lower bank height. Since vegetation along the river is poor. Gravelly bank material at top is easily eroded and scouring in the clay layer is common due to which gabion walls easily topple in this section. So to protect river bank erosion riprap of at low bank slope near water is suggested. At slopes of banks, live staking with vegetation mat is suggested (Figure 11.3). The vegetation matting provide surface protection from direct impact of rain and also reduce surface flow velocity. At upper portion pole planting of understory and canopy is suggested which will provide riparian vegetation zone for river.

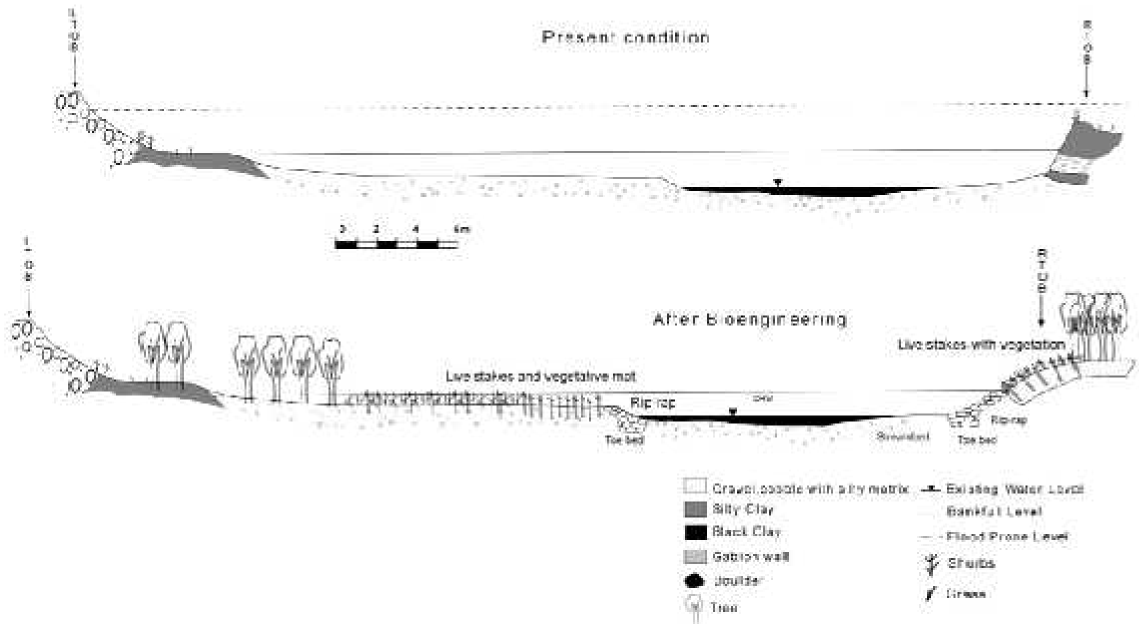


Figure 11.3: Bioengineering mode 1 suggested for the Nakhu Khola

Model 2

The model 2 applies to the stream segment with wide flood plain and bar deposit and low bar height. Fasihes of locally available plants like Banmara, Nilkado, Kandaphre etc is used near river. Fasine is near river helps reduce flow velocity and also provides hides for aquatic lives. Live staking with vegetation is used in the wide flood plains and banks away from river (Figure 11. 4). To provide biofilter for river and improve river echosystem vegetatiom zone of canopy and understory is required. Vegetation of understory at bank reduces water velocity due to roots and hence also protect water. This model is most river habitat friendly since no any engineering structure that disturb river ecosystem is used.

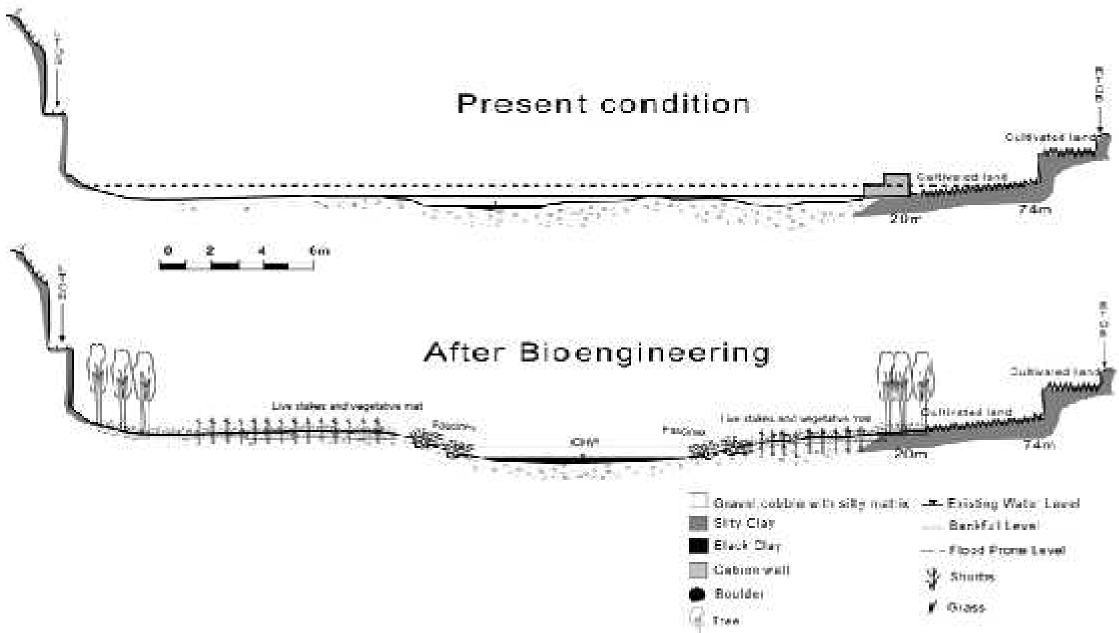


Figure 11.4: Bioengineering mode 2 suggested for the Nakhu Khola

Model 3

Model 3 is proposed at meander bends and at banks where impact of water is greater than other and weaker flow deflection is needed. Root wads suggested this model can protect riverbanks from erosions and deflects water away from bank towards the weg. Root wads are suggested at concave bank where impact of water is high and at covex bank rock riprap near water surface at slope is suggested (Figure 11.5). Riparap is used to provide temporary bank protection until plant is grow. Brush layering with coir wrap provides surface armor to slop and protect from erosion due to impac of rainwater. At upper banks riparian vegetation is required to provide hides for river habitat and food for river habitat. For establishment of riparian vegetation pole planting of trees are suggested. Riprap is suggested only at riverbanks where channel has greater bank height ration. For banks with low height and clay banks no riprap is required. Brush layering is suggested for these banks.

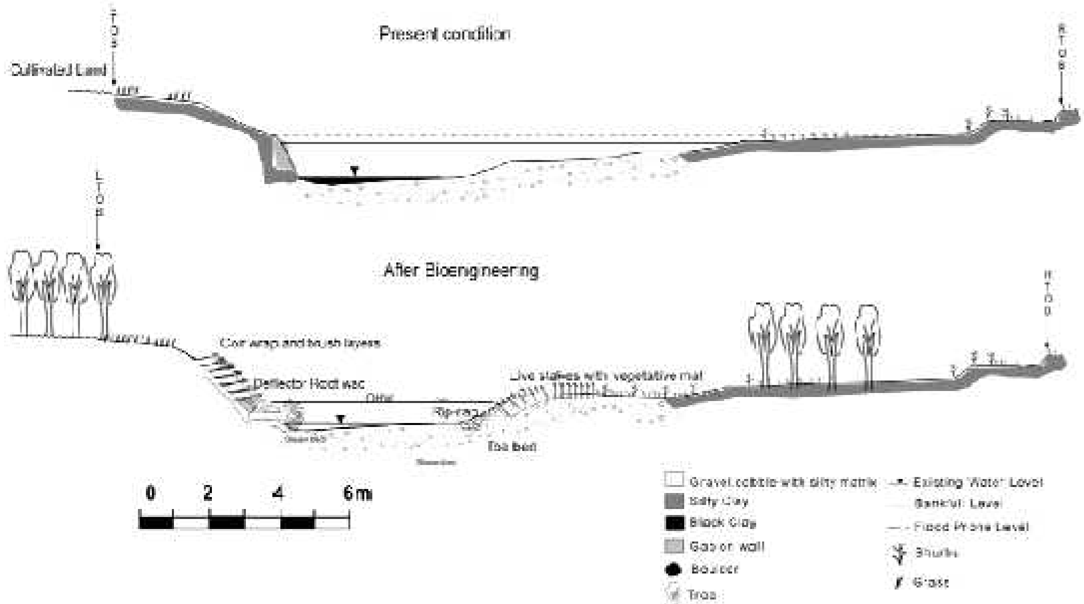


Figure 11.5: Bioengineering mode 3 suggested for the Nakhu Khola

Model 4

Model 4 is suggested for the stream starch with moderate bank height in the pool and low bank height in riffle. In this model for riprap revetment near water surface is suggested which can provide immediate bank protection and armor. Brush layering with coir wraps at slopes of medium bank and live staking with vegetation mat is at low bank height is suggested. At high bank height live wattle fence of bamboo can also be used to provide slope protection. For creating riparian vegetation zone along upper banks of the river planting of canopy and understory is suggested (Figure 11.6). For protecting, the vegetation from grazing and during early stage fencing is also required.

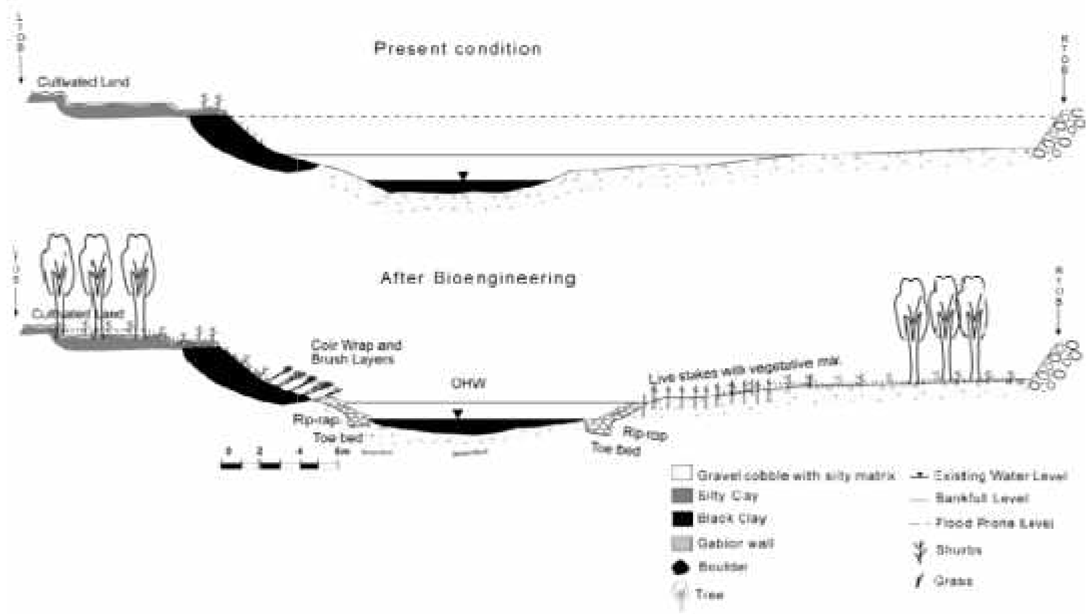


Figure 11.6: Bioengineering modes suggested for the Nakhu Khola

Model 5

This model is suggested for the concave meander bends with high bank height where water impact is high and other models cannot provide enough protection. At concave bends impact of water is very high and gravelly banks are easily eroded. So, root wads which deflects water away from the river banks is used in this model. Root wads not only protect banks but also provide hides for the aquatic lives and hence help in maintaining river ecosystem. Rock armor at toe used in this model also protects banks toe cutting and hence slump due to toe cutting is also reduced. Coir wrap and brush layering at slopes also reduce water impact on ground and provide protection from erosion. Live staking at low and wide banks at convex side with riprap to protect toe bed is suggested (Figure 11.3). At upper banks, planting of trees for vegetation zone is suggested. Applications of model 5 at narrow channel require channel widening by cutting convex side of bank for more stability. Some of the meander bens of the Nakhu khola need immediate protection from the erosion, whichis not achieved by bioengineering models alone. So for these bends vegetated gabion wall is suggested in combination with other bioengineering technique like vegetated benching. If the bank height is high and steep slope with stable upper slopes, vegetated benches at upper banks and applying model 5 at lower banks provide good stability for bank protection.

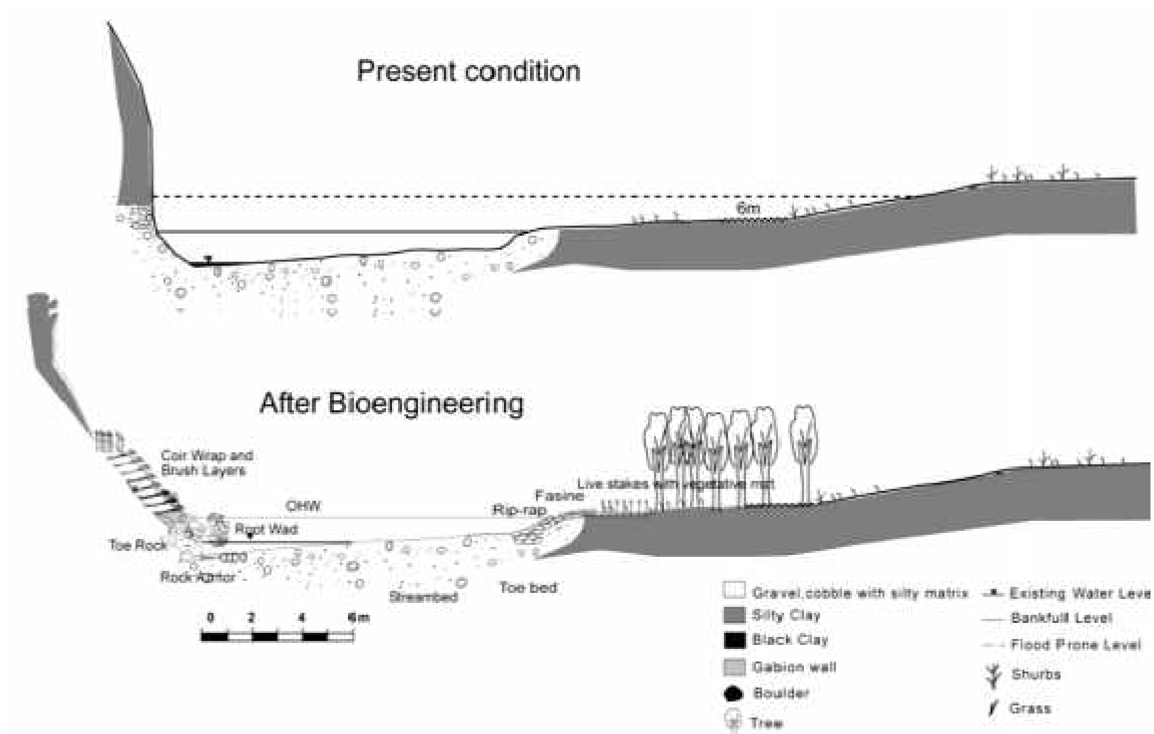


Figure 11.7: Bioengineering modes suggested for the Nakhu Khola

CHAPTER TWELVE

DISCUSSION

The Nakhu Khola which is one of the major tributaries of the Bagmati River, is the Perrinal River fed by storm and ground water seepage. The Nakhu Khola is aggrading river originating from southern hills of the Kathmandu Valley with rock belonging to the Chandragiri Limestone, The Tistung Formation and the Sopyang Formation of Kathmandu Complex. These ranges have been actively uplifting from last oneMa (Sakai, 2001). Therefore, huge amount of sediment is carried and transported by this aggrading river. During Himalayan Oregeny Kathmandu basin with different thrusts and fault running across the basin evolved. A vertical fault trending NW-SE and few linements were also reported(Stöcklin and Bhattrai, 1977). With rapid urbanization in the Kathmandu Valley, most of the river banks and flood plains of the rivers of the valley is encroached for settlement. Like other rivers of the valley, the Nakhu Khola is also suffering from different human induced as well as natural disturbances, which are deteriorating river environment. Rapid landuse change in recent decades causing instability and erosion hazard along the river. Quarries along the hills, gravel mining, cultivation, bank encroachment and vegetation clearing are some of notable disturbances in the watershed. Such activities have altered the natural balance of river environment as well as dynamic equilibrium system.

For the study of present condition and character of the Nakhu Khola morphology, planiform geometry, cross-sectional characteristics and hydraulic parameters of river were evaluates at four representative segments of the river. On the basis of result of study, main stem of the Nakhu Khola is sixth order which is contributed by three major sub-basins viz Lele, Nallu and Buranchuli Khola. The drainage texture of the river is fine to moderate at southern part where bedrocks exist and coarse to very coarse at central and northern parts of watershed. The drainage frequency of watershed is high at southern part with high relative relief and low in the northern part of low relative relief. The Nakhu Khola drains watershed by dendritic drainage pattern at hills, trellis at southern part and barbed pattern before contributing to the Bagmati River.

For cross-section parameters fourty cross-section on riffle and pool of each four segment were prepared. $D_{bkf,}$ $A_{bkf,}$ W/D ratio, ten on each segment, were obtained. The result of the crosssectional characteristics show that bankful depth and mean bankfull cross-section area increases from upstream Nallu segment indicating higher potential of lateral instability. Chapagaon segment has highest BHR, which indicate the chances of bank failure. But prevents from over spread of flow level during high flow period.

Hydraulic parameters like wetted perimeter, Manning's roughness coefficient, bankfull velocity, bankful discharge, bankfull crossectional area and basin area were evaluated for hydrodynamics of river. Since, the Nakhu Khola is very much influenced by human activities is no direct relation between A_{bkf} and basin area were observed. V_{bkf} is highest in down stream Nakhu Segment which is due to low roughness of river bed.

For the systematic and easy study of the Nakhu Khola four selected segments were classified on the basis of the Rosgen (1996). Based on this classification four studied segment are classified as $C_{5,}$ $C_{5,}$ C_4 and C_4 type river respectively for The Nakhu, Bhainsepati, Chapagaon and Nallu segments. According to the result of planiform geometry, all the segments are vertically as well as laterally unstable. However, Chapagaon is vertically most unstable and Bhainsepati is laterally unstable. In the Nakhu Khola, channel shifting is seasonal which erodes left bank during one season and right bank at other season. Comparing river channel of different years shows no evidence of major primary channel shifting but only secondary channel shifting. Because of the lateral shifting of river channel bank erosion in gravelly bank is triggered. Vegetation along the river is poor with only ground cover near river banks and patchy to linear canopy and ground cover at river terraces. Schumn (1963) is used to evaluate aggrading and degrading potential. On this basis all four studied segments are aggrading. Stability condition if Lepold (1960) evaluates the Nakhu Khola with the help of standatd curve of stable riverdrawn. When comparing The NakhuKhola with standard curve, the stability if river deviates from the stable curve.

Bank erosion in the Nakhu Khola was evaluated with the help of different parameters. These parameters were studied in whole river segment as well as banks and flood plains. Almost segment consists of muddy gravel as bank material, which is very much susceptible to erosion. Beside these high bank , height of clay, meander bends, poor riparian vegetation and bank encroachment for road extension are other causes for excessive bank encroachment. Bank erosion hazard ranges from low hazard at gorge to high to extreme hazard in minning and quary area.

High hazard at downstream and quarry area is due to poor riparian vegetation and low hazard at gorge is due to presence of bedrock. Erosion process in the watershed generally occurred in the form of parrallel erosion, slump, gully, rill erosion, scouring, and sheet erosion. Among this parallel erosion, the most common along the whole segment is sheet erosion at road and quarry area, and slump in the clay banks. These erosion processes are triggered due to human induced disturbances as well as due to natural causes. But human induced disturbances are most frequent and notable than natural cause. Disturbance to the river was surveyed along the whole The Nakhuriver segment. Most of the distrubing human induced factors to river enviroment are dumo of sewage, bank encroachment, for cultivation, settelement and road extension, vegetation clearing, over withdral of water and quarries. Dump of sewage is prominent from Bhainsepati to downstream. Bank encroachment is common on the whole river segment for cultivation and settlement. Road extension by the bank encroachment is the recent disturbance because of which excess bank erosion triggered and stability of river is also distrubed.

Over wthdraw of water irrigation and drinking purpose is also distrubing river enviroment during low flow and dry period. Because of reduction in water level aquatic habitat is also reduced. Reparian vegetation are bifilters that protects river from pollution and maintains river habitat by maintaing water temperature and when this zone is destroyed river habitat cannot survive. Because of these activities, recreational value of river is also reduced.

Different human induced and natural causes are causing deterioration of the Nakhu Khola day by day. So , to protect river from completely deterioration different mitigation measures can be applied. River restoration by implementation of river bioengineerring technique like live staking, fasine, palinates, root wads etc can be implemented. These bioengineering techniques not only improve river enviroment but also protect river banks from erosion. Though bioengineering is effective it takes some stablize untill plants grow. So for immidate bank protection at high eroding banks, engineering structures like gabion walls canbe used along with bio-engineering. At quarry sites river is very much distrubed by obstruction and channel modification. Therefore, to restore river in this area, channel adjustment design along with other river restoration techniques is required. Also quarrying should be done in enviroment friendly way and barren slopes of quarries should be vegetated. Though river restoration work can establish natural river encroachment but government polices and law to protect river and riparian vegetation zone is very important. Prohibiting activities, that distrub river enviroment is very important.

CHAPTER THIRTEEN

CONCLUSIONS

The fifte orderd The NakhuKhola draining the southern part of the Kathmandu valley is contributing the Bagmati River. Geologically the river is flowing over met sedimentary rocks of the Phulchoki Group and the soft basinfill sediments of the valley.

For the restoration design of the Nakhu Khola, its behavior, geomorphic characters and current condition of river has been identified. On the basis of Rogen (1994), four segments of the Nakhu Khola have been classified as $C_{5,}$ C_5, C4, C4, for Nakhu, Bhainsepati, Chapagaon and Nallu segments. This classification is based on ER, sinuosity, slope, and W/D ratio and channel material.

Since the Nakhu Khola is very much affected by human activities, hydraulic parameters of river do not show any correlation with basin area. Showing trend of increase as well as decrease in hydraulic parameters like A_{bkf}, Dbkf, and V_{bkf} even basin area is increased.

The Nakhu Khola watershed consists dominantly understory, but riparian vegetation condition along river corridor is poor and most of the river corridors are cultivated.

Schum’s F verses M-factor plot indicates that the dynamic equilibrium of all four segments of The NakhuRiver is aggrading condition.

All the four segments are laterally unstable as W/D ratio exceeds 1.4. Among these also Chapagaon and Bhainsepati segments are most unstable. Chapagaon segment is vertically most unstable since its bank height ratio, which indicates incision of channel, is high among all segments and most entrenched among all segments.

Bank encroachment and vegetation clearing for cultivation, building and quarry is observed. But Nallu, Bhainsepati segment and quarry area are most affected. The magnitude of channel shifting is high in Bhainsepati segment (60-70m) and in other segment only no primary channel shifting but only secondary shifting within channel valley and flood plain is observed, and in quarry site river channel is very much degraded and even no distinct channel.

Over withdraw of water for irrigation and drinking should be stopped in other to protect aquatic habitat and riparian vegetation along the river corridor.

Because of unconsolidated mudy gravel in channel and flood plain, lack of vegetation, change in landuse, lateral channel shifting and meander migration, quarry sites at upstream etc causing lateral instability and bank erosion hazard along the river. Rill erosion, gully erosion, sheet erosion, parallel and impinging flow erosion, slumping and cantilever structure bank erosion are major erosion processes along the river corridor triggered by different factors.

Most of the river bank has high to very high potential of bank erosion indicated by BEHI.

Critical boundary stress and flow competency evaluation indicate that force required mobilizing and transporting particle present in streambed and bank not only in bankfull flow condition but also during normal flow condition showing potential of bank erosion and lateral instability.

The Nakhu Khola can be restored into its natural condition by re-establishing riparian vegetation belt along river on both banks for at least 10-15m. AT the meander bends where impact of flow is high, bank protecting structures like gabion wall and flow deflecting structure such as dike and vane can be used in combination with bioengineering techniques to control erosion processes. The river segment near quarry sites where vegetation is totally cleared, no distinct channel and sediment is dumped into river needs geomorphic adjustment of channel along with vegetation works and engineering structures. Beside quarry area some of the parts of river, where channel width is low, also needs geomorphic channel adjustments.

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ANNEXES

Annex I

Annex I-1 Rainfall data recorded in Lele during 1994-2008(based on DHM)

Latitude(deg/min): 27°35'
Longitude(deg/min): 85°17'
Elevation(m):1590 m
Rainfall (mm) for LELE

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	516.4	0	0	0
1995	17.2	45.2	74	1	61	526	420.6	402.2	196.2	0	113.5	10
1996	77	22.2	24	6.2	48	335.4	499	502	235.8	61.8	0	0
1997	15.8	7.6	13.8	116	88.8	349.9	680.2	409.8	68.4	33.6	3.2	175.2
1998	0.4	24.8	88	42.4	82	265	873.6	615.3	223.6	46	13.6	0
1999	6	0	0	8.6	163.2	465	681.5	544.8	200.6	224	0	0
2000	0	6.6	33.1	104.2	218.9	350.2	362.8	557.3	277.4	11.6	0	2
2001	7	11.4	4.5	44.2	131.7	430.1	456.4	445.1	230.6	45.9	0	0
2002	47.3	39	15.8	112.2	215	173.7	843.2	473.5	388.4	13.2	8.4	0
2003	26.8	73.8	49.2	73.4	61.8	219.7	606.3	454.8	289.2	25.4	0	13.2
2004	41	2.5	0	64.6	203.2	240	735.7	333.5	265.8	117.4	18.6	0
2005	101.8	24.6	59.6	45.8	73.8	205	359.4	470.7	139	164.4	3	0
2006	0	0	31	110.4	152.5	272.7	342.3	488.6	348.9	23	4	40.5
2007	0	116.9	55.8	48	100.8	251.5	362.8	348.8	393.9	50.1	1.8	0
2008	10	2	19.7	41.6	111.8	286.7	398.1	325.4	144.4	8.5	0	0
Average	25.02	26.90	33.46	58.47	122.32	312.21	544.42	455.13	243.01	58.92	11.86	17.21

Annex I -2:Rainfall data recorded in Chapagoan during 1976-2008(based on DHM)

Latitude(deg/min):27°36'

Longitude(deg/min):85°20

Elevation(m):1448

Rainfall (mm) for CHAPAGAUN

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	29	7.4	0	35.7	80.7	395.7	338.6	277.6	201.2	13.5	0	0
1977	7.9	17.4	12.2	96.5	104.2	216.5	429.7	209.6	78.4	20	15	70.9
1978	2.5	21.5	55.3	61.1	135.9	253.7	319.1	492.7	290.1	37.4	0	3.1
1979	6.5	43.1	0.2	53.3	33.1	131.2	409.8	267.4	62	20.7	5.8	64.5
1980	0	5.2	30.3	9.4	91.3	385.5	384.5	239.4	245.6	8.2	0	4.4
1981	16.8	0	36.7	98.8	97.9	167.3	281.6	296.1	341.3	0	28.4	0
1982	14.1	19.9	42	33.2	74.3	166.6	238.4	393.9	202.3	11.2	11.7	3.5
1983	17.7	6.4	32.1	60.1	104.4	104.3	425.5	266.4	201.8	145.2	0	17.8
1984	16.5	18.4	11.5	53.6	62.4	291.1	261.3	333.9	425.6	14.7	0	14.2
1985	31	0	0	56.1	98.9	189.8	500.7	312.1	396.6	239.7	0.4	74.8
1986	0	28.7	13.1	68.4	102.1	369.6	371.6	358.5	287.7	56.3	7.1	56.3
1987	2.3	48.2	56.6	48.1	59.1	106.9	683	253.4	195.1	219.9	14.5	0
1988	1.5	23.4	72.2	54.2	138.9	172.6	391.9	358.8	193	14.6	0	95.9
1989	61.7	2	27	2.5	202.9	87.8	414.6	139.1	235.1	27.6	0	0
1990	0	50.8	41.8	61.5	98.7	272.1	504.9	353.2	163.3	22.4	0	1.5
1991	43.2	7.7	54.3	69	37.1	199.8	310.6	363.2	115	0	1.2	30.4
1992	9.5	14.4	0	32.8	143.2	151.3	369.3	266.6	154.4	48.9	15.5	0
1993	14.3	12	38.1	91.5	105.5	231.4	374.5	441.7	194.6	12.1	0	0
1994	41.2	25.1	36.6	12.8	146.6	243.8	296.3	376.9	345.5	0	6	6
1995	0	31.1	61.1	2.3	77	489.4	310.8	329.6	96.8	0.9	0	7.9
1996	64.7	8	4	16.2	35	276.8	397.8	372.5	179.4	41.1	0	0
1997	15.9	8.1	15.5	91.8	54.7	277.7	416.7	283.3	31.2	3.2	1.6	100.7
1998	0	18	102.7	36.4	90	212.9	689.4	409.3	76.1	28.8	28.9	0
1999	2.1	0	0	3.4	90	394	547.8	398.4	82.2	180	0	0.2
2000	0	2.7	18.7	84.1	127	211.1	219.8	392.2	58.9	2	0	1
2001	3.5	4.1	5.7	34.3	87.1	282.7	331.5	277.5	110.9	40.9	0	0
2002	43.3	25.2	10.4	74.2	184.4	79.1	581	453.6	288.6	0.2	5.2	0
2003	19.1	78.2	24.6	36	20.9	205.1	447.2	307.6	170.5	9.2	0	13.7
2004	23.5	0.4	0.1	52.4	138.3	166.1	454	194.5	116.6	53.9	6.8	0
2005	64.8	11	53.4	42.3	36.1	121.6	261.2	311.9	29.2	101.6	0	0
2006	0	0	25.0 1	5.7	99.1	176.5	237.8	402.3	99.5	9.3	0	25.6
2007	0	91.2	33.6	44.1	136.3	148.7	333.3	263.4	361.8	24	4.6	0
2008	6.9	16.5	7.3	51.1	106.1	347.3	327.3	360.9	68.3	5.4	0	0.1
Average	17.48	20.19	28.03	49.15	99.98	235.19	401.92	336.17	190.58	44.15	4.77	18.52

Annex I -3:Discharge data recorded at Tikabhairab Gorge from 1963-1980(based on DHM)

Station number: 540

Latitude: 27°34'30"

Longitude: 85°18'50"

Location: Tika Bhairab

River: The NakhuKhola

AVERAGE MONTHLY AND YEARLY DISCHARGE (in m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
1963	0.21	0.06	0.2	0.14	0.13	0.11	1.39	4.03	3.58	2.07	0.4	0.24	1.05
1964	0.16	0.14	0.11	0.16	0.41	0.38	2.37	3.31	4.6	1.22	0.66	0.47	1.17
1965	0.3	0.22	0.24	0.28	0.24	0.51	6.73	6.13	1.87	0.86	0.5	0.19	1.51
1966	0.26	0.2	0.1	0.07	0.08	0.05	0.81	7.74	3.27	0.91	0.45	0.25	1.18
1967	0.14	0.06	0.15	0.22	0.08	0.17	2.42	4.05	1.9	0.79	0.25	0.18	0.87
1968	0.09	0.06	0.13	0.07	0.16	1.65	3.14	3.1	1.18	3.24	0.43	0.13	1.12
1969	0.04	0.02	0.03	0.04	0.15	0.03	1	3.81	2.58	0.88	0.32	0.08	0.75
1970	0.09	0.09	0.07	0.08	0.06	0.65	4.4	4.99	2.27	1.47	0.8	0.49	1.29
1971	0.3	0.28	0.33	0.28	0.33	6.7	1.93	3.29	1.85	1.11	0.82	0.54	1.48
1972	0.39	0.45	0.42	0.29	0.19	0.23	2.62	1.06	1.22	0.53	0.45	0.36	0.68
1973	0.27	0.23	0.25	0.21	0.22	2.07	2.06	1.42	2.89	2.36	0.64	0.33	1.08
1974	0.23	0.15	0.15	0.15	0.17	0.15	0.54	4.32	5.32	0.45	0.25	0.23	1.01
1975	0.17	0.11	0.11	0.11	0.12	0.25	3.3	5.62	3.65	1.8	0.68	0.41	1.36
1976	0.25	0.21	0.15	0.12	0.13	0.79	2.83	2.35	2.51	0.98	0.46	0.26	0.92
1977	0.15	0.18	0.14	0.1	0.11	0.34	1.69	1.75	1.02	0.56	0.33	0.27	0.55
1978	0.25	0.16	0.3	0.23	0.21	1.22	3.78	5.76	5.22	1.31	0.46	0.21	1.59
1979	0.14	0.11	0.14	0.09	0.05	0.04	8.96	6.28	0.57	0.09	0.08	0.08	1.39
1980	0.07	0.06	0.06	0.05	0.04	2.88	3.73	1.85	0.81	0.47	0.18	0.13	0.86
Average:	0.19	0.15	0.17	0.15	0.16	1.01	2.98	3.94	2.57	1.17	0.45	0.27	1.1

Annex I -iv:Discharge data recorded at Tikabhairab Gorge from 1963-1980(based on DHM)

Station number: 540
Latitude: 27°34'30"
Longitude: 85°18'50"
Location: Tika Bhairab
River: Nakhu Khola

MAXIMUM MONTHLY AND YEARLY DISCHARGE (in m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
1963	0.41	0.14	0.53	0.21	0.2	0.24	5.35	21.3	24.6	5.85	0.74	0.29	24.6
1964	0.22	0.15	0.14	0.29	1.45	3.05	11.9	7.25	19.3	1.86	0.97	0.64	19.3
1965	0.45	0.26	0.36	0.41	0.34	2.45	70.5	24.3	3.61	1.02	0.67	0.26	70.5
1966	0.32	0.25	0.14	0.09	0.38	0.13	4.73	104	8.48	1.42	0.75	0.51	104
1967	0.2	0.1	0.46	0.38	0.24	0.75	26.6	12.6	5.1	1	0.42	0.29	26.6
1968	0.7	0.12	0.95	0.33	2.5	12.2	12.8	5.1	2.1	23.4	0.8	0.33	23.4
1969	0.06	0.03	0.1	0.06	1.82	0.06	2.4	32.6	6	1.82	0.51	0.24	32.6
1970	0.16	0.13	0.13	0.13	0.08	6.6	34.6	15	3.54	2.03	1.06	0.65	34.6
1971	0.32	0.29	0.64	0.46	0.52	45.2	2.88	5.16	2.3	1.45	0.92	0.6	45.2
1972	0.46	0.52	0.49	0.38	0.2	0.41	19.2	2.59	4.95	1.12	0.55	0.41	19.2
1973	0.32	0.25	0.55	0.23	0.26	15.7	23.2	3.17	17.4	9.9	0.92	0.52	23.2
1974	0.31	0.19	0.17	0.17	0.22	0.57	1.78	53.2	34.4	0.74	0.33	0.29	53.2
1975	0.25	0.12	0.12	0.12	0.21	1.98	38	21.1	9.2	3.3	1.02	0.67	38
1976	0.31	0.24	0.24	0.17	0.17	6.78	12.5	6.64	3.96	1.58	0.67	0.31	12.5
1977	0.2	0.26	0.24	0.11	0.26	1.06	5.24	7.32	1.72	0.7	0.4	0.33	7.32
1978	0.31	0.18	0.66	0.31	0.27	3.81	18.1	20.6	25.6	3.32	0.72	0.25	25.6
1979	0.22	0.25	0.19	0.19	0.09	0.08	72.8	30.8	2.36	0.13	0.09	0.09	72.8
1980	0.08	0.06	0.06	0.06	0.06	15	7.16	4.32	1.44	0.62	0.3	0.14	15
Extreme:	0.7	0.52	0.95	0.46	2.5	45.2	72.8	104	34.4	23.4	1.06	0.67	104

Annex I-v:Discharge data recorded at Tikabhairab Gorge from 1963-1980(based on DHM)

Station number: 540

Latitude: 27°34'30"

Longitude:
85°18'50"

Location: Tika Bhairab

River: Nakhu Khola

MINIMUM MONTHLY AND YEARLY DISCHARGE (in m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1963	0.06	0.04	0.03	0.07	0.08	0.01	0.02	1.19	0.93	0.53	0.27	0.16	0.01
1964	0.11	0.11	0.08	0.1	0.24	0.04	0.15	1.57	2.08	0.84	0.5	0.29	0.04
1965	0.21	0.16	0.18	0.22	0.2	0.09	0.21	1.51	1.1	0.77	0.26	0.15	0.09
1966	0.2	0.09	0.07	0.05	0.04	0.03	0.17	1.2	1.36	0.6	0.28	0.12	0.03
1967	0.08	0.05	0.05	0.04	0.04	0.04	0.05	1.91	1.05	0.42	0.12	0.06	0.04
1968	0.05	0.04	0.04	0.01	0.01	0.08	0.46	2.1	0.6	0.9	0.19	0.05	0.01
1969	0.03	0.02	0.02	0.02	0.03	0.01	0.02	0.65	1.19	0.42	0.24	0.03	0.01
1970	0.07	0.07	0.06	0.06	0.03	0.04	0.07	2.64	1.86	1.01	0.65	0.31	0.03
1971	0.28	0.26	0.18	0.19	0.25	0.25	1.6	1.6	1.5	0.89	0.6	0.41	0.18
1972	0.31	0.31	0.38	0.17	0.17	0.16	0.19	0.67	0.6	0.27	0.36	0.29	0.16
1973	0.23	0.22	0.22	0.19	0.2	0.2	0.44	0.67	0.71	0.96	0.44	0.28	0.19
1974	0.17	0.11	0.14	0.14	0.15	0.09	0.1	0.57	0.82	0.32	0.21	0.19	0.09
1975	0.11	0.1	0.1	0.1	0.1	0.09	0.31	2.67	1.84	0.98	0.49	0.22	0.09
1976	0.2	0.17	0.1	0.1	0.11	0.12	0.78	1.34	1.22	0.67	0.28	0.2	0.1
1977	0.12	0.12	0.1	0.1	0.07	0.04	0.78	0.95	0.73	0.42	0.29	0.22	0.04
1978	0.19	0.15	0.16	0.16	0.18	0.24	1.72	2.56	1.17	0.67	0.28	0.16	0.15
1979	0.1	0.09	0.06	0.05	0.04	0.03	0.03	0.37	0.16	0.08	0.08	0.06	0.03
1980	0.06	0.05	0.05	0.04	0.04	0.04	1.2	0.85	0.58	0.3	0.13	0.11	0.04
Extreme:	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.37	0.16	0.08	0.08	0.03	0.01

Annex I-6:Discharge data recorded at Tikabhairab Gorge from 1963-1980(based on DHM)

Station number: 540
Latitude: 27°34'30"
Longitude: 85°18'50"
Location: Tika Bhairab
River: Nakhu Khola

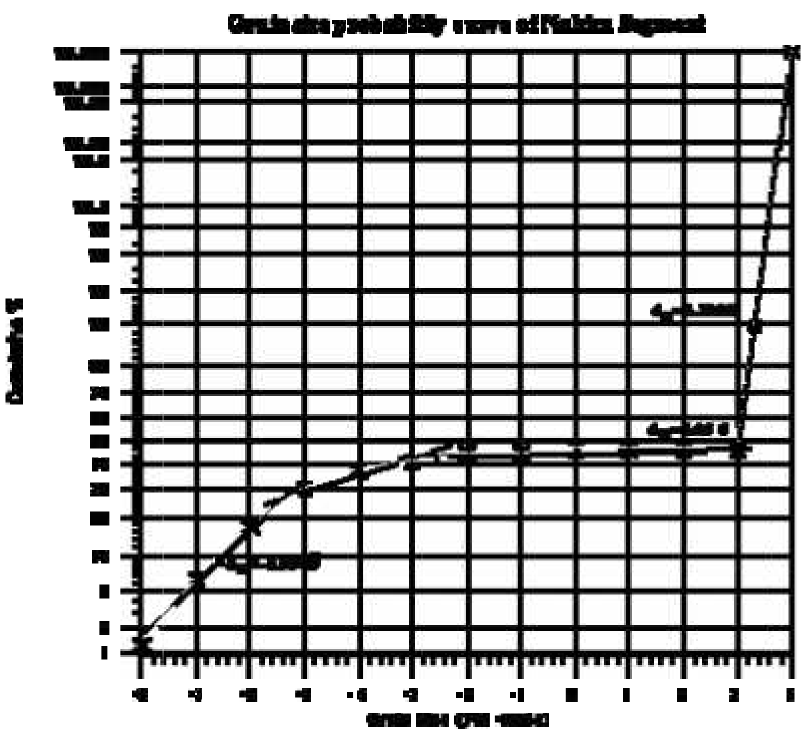
EXTREME DISCHARGES

Year	Maximum Instantaneous Discharge (m3/s)	Gauge height (m)	Date	Minumum Instantaneous Discharge (m3/s)	Gauge height (m)	Date
1963	27.9	3.13	29/09/63	0.01	1.12	28/06/63
1964	20.7	2.89	3/9/1964	0.05	1.22	10/6/1964
1965	76	4.22	8/7/1965	0.09	1.27	13/06/65
1966	181	5.75	24/08/66	0.02	1.59	12/5/1966
1967	35	3.75	10/7/1967	0.04	1.78	31/12/67
1968	26.6	3.51	5/10/1968	0.01	1.75	30/05/68
1969	38.6	3.8	2/8/1969	0.01	1.74	2/7/1969
1970	48.6	4.07	16/07/70	0.03	1.72	1/6/1970
1971	63.2	4.23	12/6/1971	0.17	1.96	27/03/71
1972	28	3.35	28/07/72	0.16	1.94	13/06/72
1973	42.4	3.71	26/09/73	0.19	1.98	21/04/73
1974	70.8	4.42	30/08/74	0.08	1.83	3/6/1974
1975	52	3.95	28/07/75	0.09	1.85	16/03/75
1976	20.8	3.06	2/7/1976	0.09	1.55	24/03/76
1977	8.7	2.75	13/08/77	0.02	1.4	11/6/1977
1978	30.8	3.42	14/09/78	0.14	1.73	2/2/1978
1979	75.6	4.54	24/07/79	0.03	1.87	9/6/1979
1980	16.8	3.05	19/06/80	0.04	1.96	5/6/1980

Annex II

Annex II-1: Data for Probability plot for the Nakhu Segment

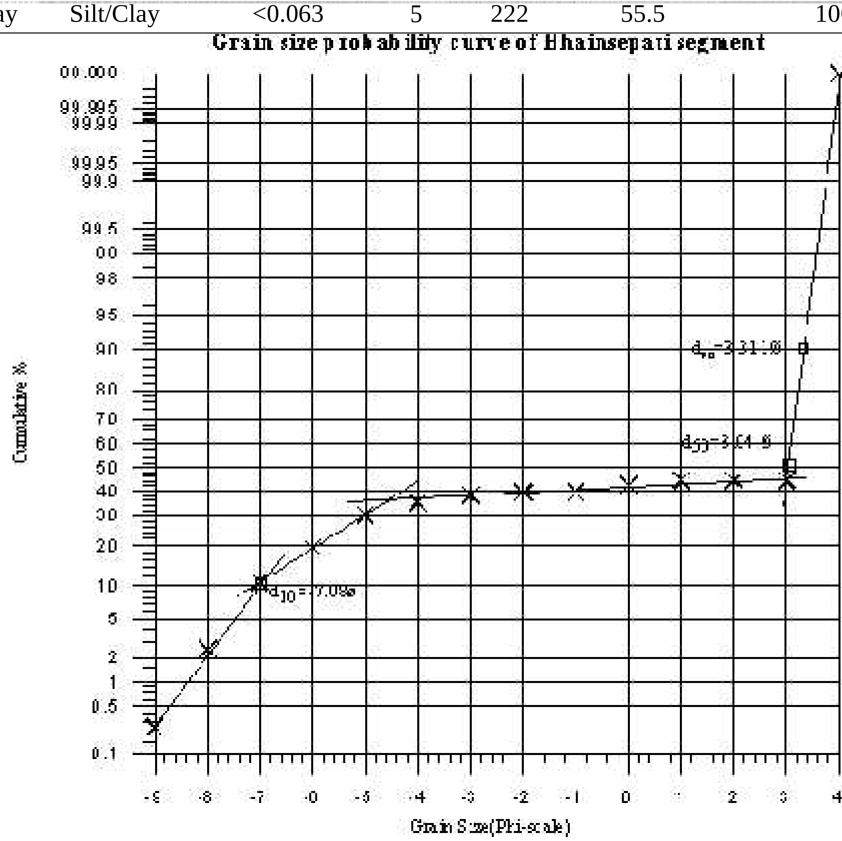
Particle	Description	Grain size				
		(mm)	(ϕ)	No of Particles	Frequency Percent	Cumulative freq. Percent
Bed-rock		>2048	-11			
Boulder	Large	1024-2048	-10			
	Medium	512-1024	-9			
	Small	256-512	-8			
Cobble	Large	128-256	-7	5	1.25	1.25
	Small	64-128	-6	21	5.25	6.5
Pebble	Very coarse	32-64	-5	43	10.75	17.25
	Coarse	16.0-32	-4	51	12.75	30
	Medium	8.0-16	-3	30	7.5	37.5
	Fine	4.0-8	-2	16	4	41.5
	Very fine	2.0-4	-1	12	3	44.5
Sand	Very coarse	1.0-2.0	0		0	44.5
	Coarse	0.5-1.0	1	7	1.75	46.25
	Medium	0.25-0.5	2		0	46.25
	Fine	0.125-0.25	3		0	46.25
	Very fine	0.063-0.125	4		0	46.25
Silt/Clay	Silt/Clay	<0.063	5	215	53.75	100



Probability plot for the Nakhu Segment

Annex II-2: Data for Probability plot for the Bhainsepati Segment

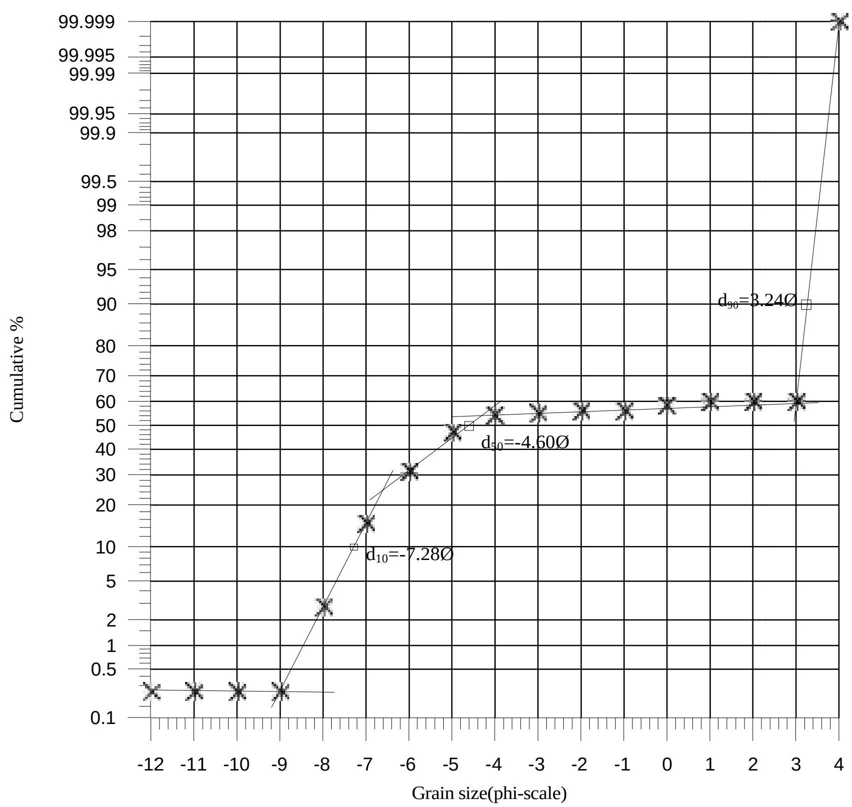
Particle	Description	Grainsize (mm)	(ϕ)	No of Particles	Frequency Percent	Cumulative freq. Percent
Bed-rock		>2048	-11			
Boulder	Large	1024-2048	-10			
	Medium	512-1024	-9			
	Small	256-512	-8	1	0.25	0.25
Cobble	Large	128-256	-7	9	2.25	2.5
	Small	64-128	-6	33	8.25	10.75
Pebble	Very coarse	32-64	-5	35	8.75	19.5
	Coarse	16.0-32	-4	44	11	30.5
	Medium	8.0-16	-3	19	4.75	35.25
	Fine	4.0-8	-2	12	3	38.25
	Very fine	2.0-4	-1	5	1.25	39.5
Sand	Very coarse	1.0-2.0	0		0	39.5
	Coarse	0.5-1.0	1	12	3	42.5
	Medium	0.25-0.5	2	8	2	44.5
	Fine	0.125-0.25	3		0	44.5
	Very fine	0.063-0.125	4		0	44.5
Silt/Clay	Silt/Clay	<0.063	5	222	55.5	100



Annex II-3: Data for Probability plot for the Chapagoan Segment

Particle	Description	Grain size (mm)	(ϕ)	No of Particles	Frequency Percent	Cumulative freq. Percent
Bed-rock		>2048	-11	1	0.25	0.25
Boulder	Large	1024-2048	-10		0	0.25
	Medium	512-1024	-9		0	0.25
	Small	256-512	-8		0	0.25
Cobble	Large	128-256	-7	10	2.5	2.75
	Small	64-128	-6	49	12.25	15
Pebble	Very coarse	32-64	-5	65	16.25	31.25
	Coarse	16.0-32	-4	63	15.75	47
	Medium	8.0-16	-3	29	7.25	54.25
	Fine	4.0-8	-2	4	1	55.25
	Very fine	2.0-4	-1	3	0.75	56
Sand	Very coarse	1.0-2.0	0		0	56
	Coarse	0.5-1.0	1	9	2.25	58.25
	Medium	0.25-0.5	2	6	1.5	59.75
	Fine	0.125-0.25	3	1	0.25	60
	Very fine	0.063-0.125	4		0	60
Silt/Clay	Silt/Clay	<0.063	5	160	40	100

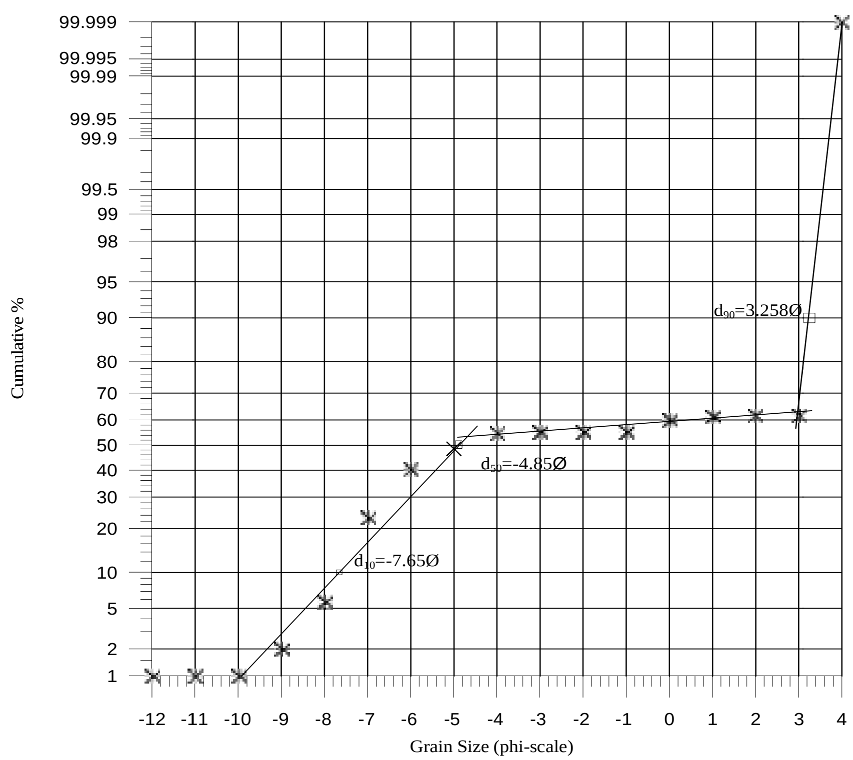
Grain size probability curve of Chapagaon segment



Annex II-4: Data for Probability plot for the Nallu Segment

Particle	Description	Grain size		Nallu Segment		
		(mm)	(ϕ)	No of Particles	Frequency Percent	Cumulative freq. Percent
Bed-rock		>2048	-11	4	1	1
Boulder	Large	1024-2048	-10		0	1
	Medium	512-1024	-9		0	1
	Small	256-512	-8	4	1	2
Cobble	Large	128-256	-7	15	3.75	5.75
	Small	64-128	-6	70	17.5	23.25
Pebble	Very coarse	32-64	-5	69	17.25	40.5
	Coarse	16.0-32	-4	32	8	48.5
	Medium	8.0-16	-3	25	6.25	54.75
	Fine	4.0-8	-2	2	0.5	55.25
	Very fine	2.0-4	-1		0	55.25
Sand	Very coarse	1.0-2.0	0		0	55.25
	Coarse	0.5-1.0	1	19	4.75	60
	Medium	0.25-0.5	2	6	1.5	61.5
	Fine	0.125-0.25	3	1	0.25	61.75
	Very fine	0.063-0.125	4		0	61.75
Silt/Clay	Silt/Clay	<0.063	5	153	38.25	100

Grain size probability curve of Nallu Segment

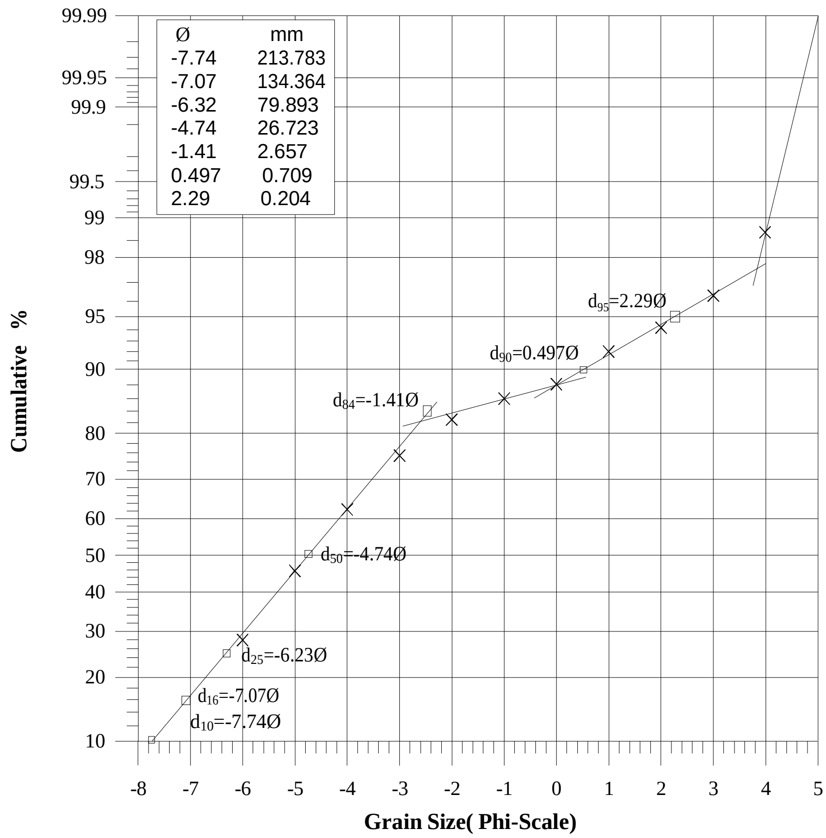


Annex III

Annex III-1: Result of sieve analysis of bar sample of SA1

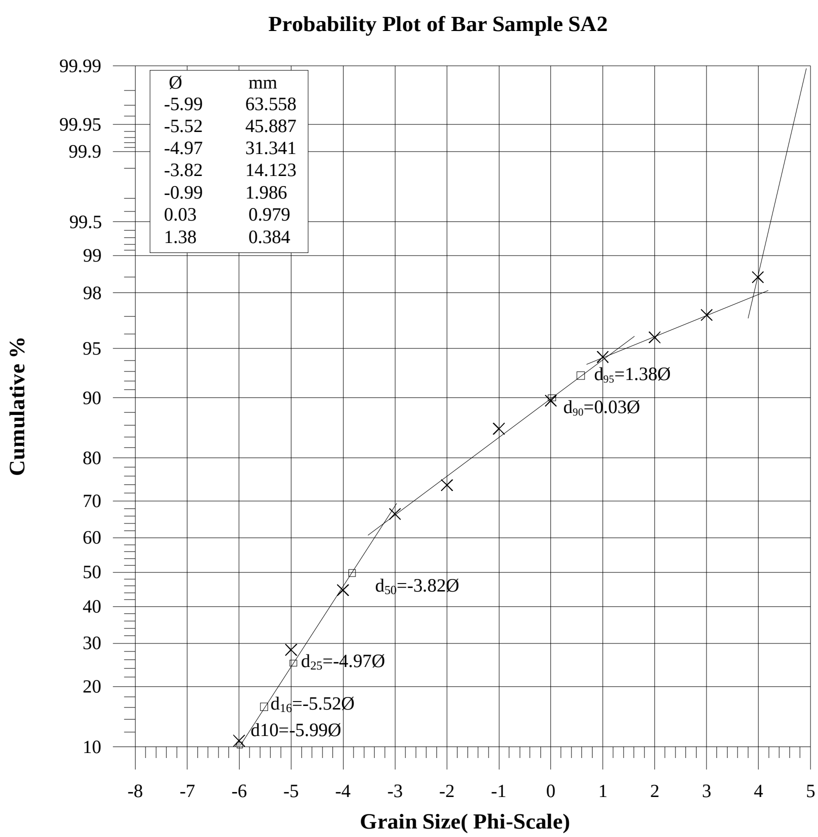
Sieve Size(mm)	Phi (ϕ) scale	Weight Retained(Kg)	F%	CF%	Composition	%
64	-6	94.000	27.905	27.905		
32	-5	60.000	17.812	45.716		
16	-4	56.000	16.624	62.341	Gravel	82.527
8	-3	44.000	13.062	75.403		
4	-2	24.000	7.125	82.527		
2	-1	11.636	3.454	85.981		
1	0	7.048	2.092	88.074		
0.5	1	13.179	3.912	91.986		
0.25	2	7.285	2.163	94.148	Sand	16.172
0.125	3	7.301	2.167	96.316		
0.063	3.99	8.028	2.383	98.699		
pan	>4	4.383	1.301	100.000	Silt	1.301

Probability Plot of Bar Sample SA1



Annex III-2: Result of sieve analysis of bar sample of SA2

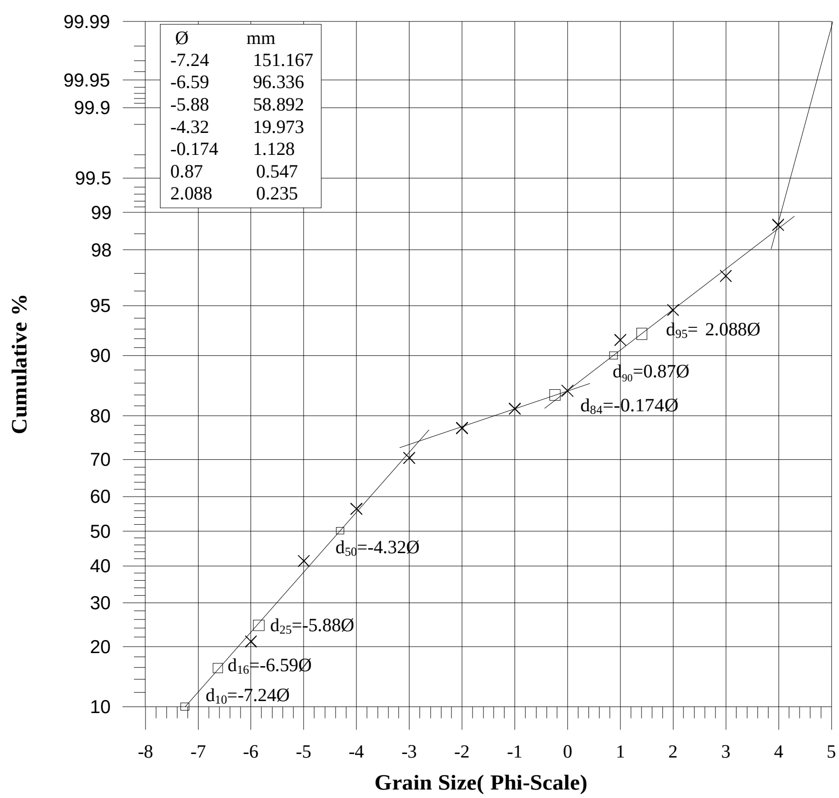
Sieve size (mm)	Phi (ϕ) scale	Weight retained (Kg)	F %	CF %	Composition	%
64	-6	66.000	10.776	10.776		
32	-5	108.000	17.634	28.410		
16	-4	100.000	16.328	44.738	Gravel	73.919
8	-3	134.000	21.879	66.617		
4	-2	44.725	7.303	73.919		
2	-1	70.273	11.474	85.393		
1	0	25.843	4.219	89.613		
0.5	1	28.789	4.701	94.313		
0.25	2	8.888	1.451	95.764	Sand	24.571
0.125	3	7.908	1.291	97.056		
0.063	3.99	8.789	1.435	98.491		
pan	>4	8.619	1.407	99.898	Silt	1.407



Annex III-3: Result of sieve analysis of bar sample of SA3

Sieve size(mm)	Phi (ϕ) scale	Weight retained(Kg)	F%	CF%	Composition	%
64	-6	137.000	21.063	21.063		
32	-5	132.000	20.294	41.357		
16	-4	98.600	15.159	56.517	Gravel	77.426
8	-3	90.000	13.837	70.354		
4	-2	46.000	7.072	77.426		
2	-1	25.957	3.991	81.417		
1	0	21.413	3.292	84.709		
0.5	1	46.479	7.146	91.855	Sand	21.301
0.25	2	18.228	2.802	94.657		
0.125	3	14.372	2.210	96.867		
0.063	3.99	12.100	1.860	98.727		
pan	>4	8.279	1.273	100.000	Silt	1.273

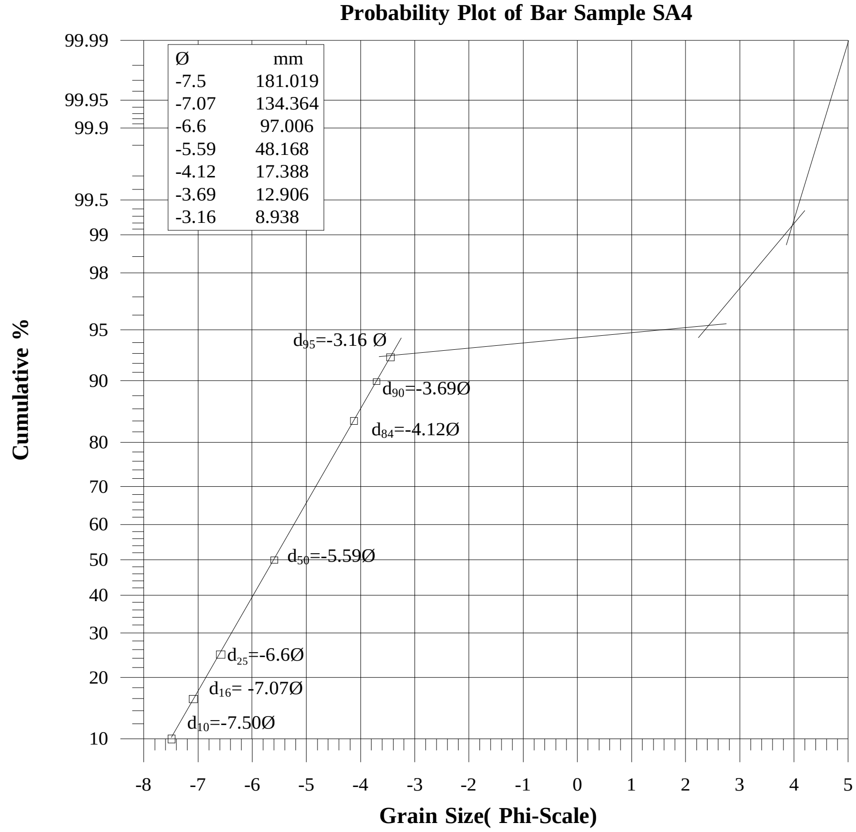
Probability Plot of Bar Sample SA3



Annex III-4: Result of sieve analysis of bar sample of SA4

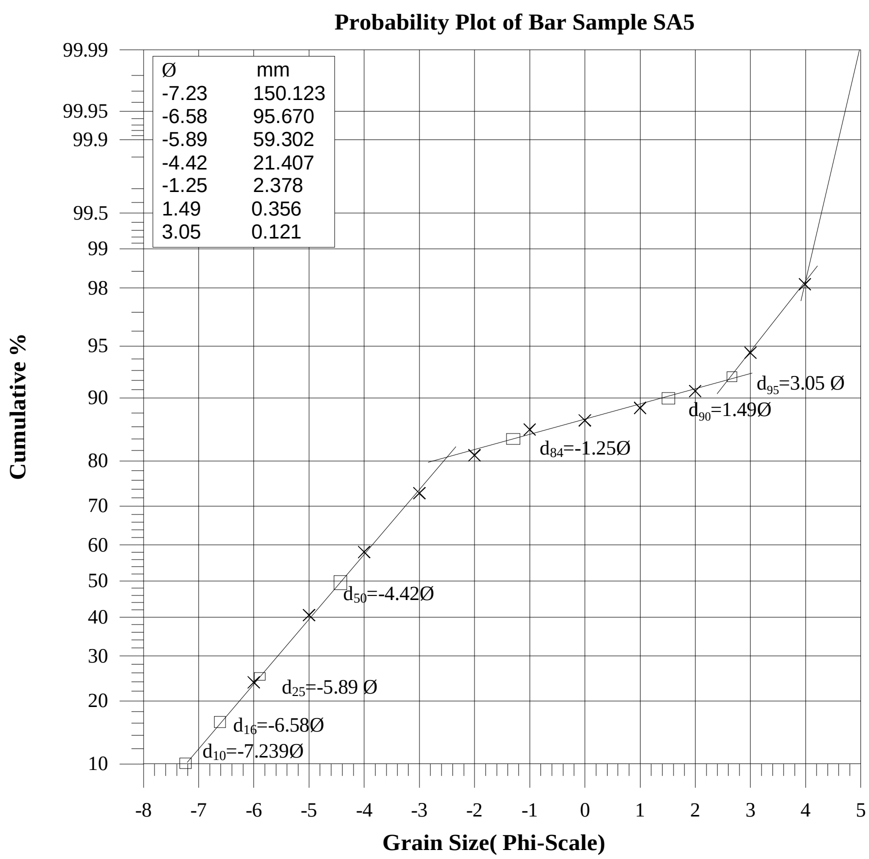
Sieve size (mm)	Phi (ϕ) scale	Weight retained (Kg)	F%	CF%	Composition	%
64	-6	187.000	35.959	35.959		
32	-5	171.000	32.882	68.841		
16	-4	84.000	16.153	84.994	Gravel	93.236
8	-3	38.000	7.307	92.301		
4	-2	4.863	0.935	93.236		
2	-1	6.619	1.273	94.509		
1	0	1.355	0.261	94.770		
0.5	1	0.839	0.161	94.931	Sand	6.006
0.25	2	1.274	0.245	95.176		
0.125	3	9.657	1.857	97.033		
0.063	3.99	11.487	2.209	99.242		
pan	>4	3.942	0.758	100.000	Silt	0.758

Probability Plot of Bar Sample SA4



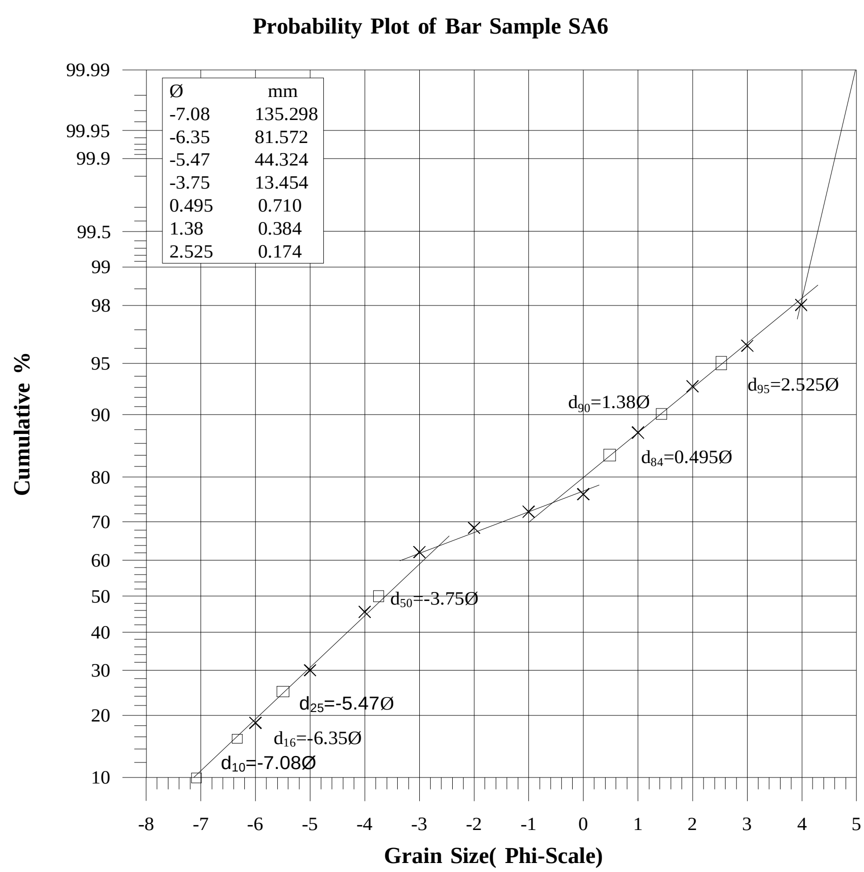
Annex III-5: Result of sieve analysis of bar sample of SA5

Sieve size(mm)	Phi(φ) scale	Weight retained (Kg)	F%	CF%	Composition	%
64	-6	176.000	23.868	23.868		
32	-5	123.000	16.680	40.548		
16	-4	129.000	17.494	58.042	Gravel	81.096
8	-3	111.000	15.053	73.095		
4	-2	59.000	8.001	81.096		
2	-1	32.970	4.471	85.567		
1	0	10.356	1.404	86.972		
0.5	1	13.065	1.772	88.743	Sand	17.017
0.25	2	15.506	2.103	90.846		
0.125	3	26.974	3.658	94.504		
0.063	3.99	26.610	3.609	98.113		
pan	>4	13.915	1.887	100.000	Silt	1.887



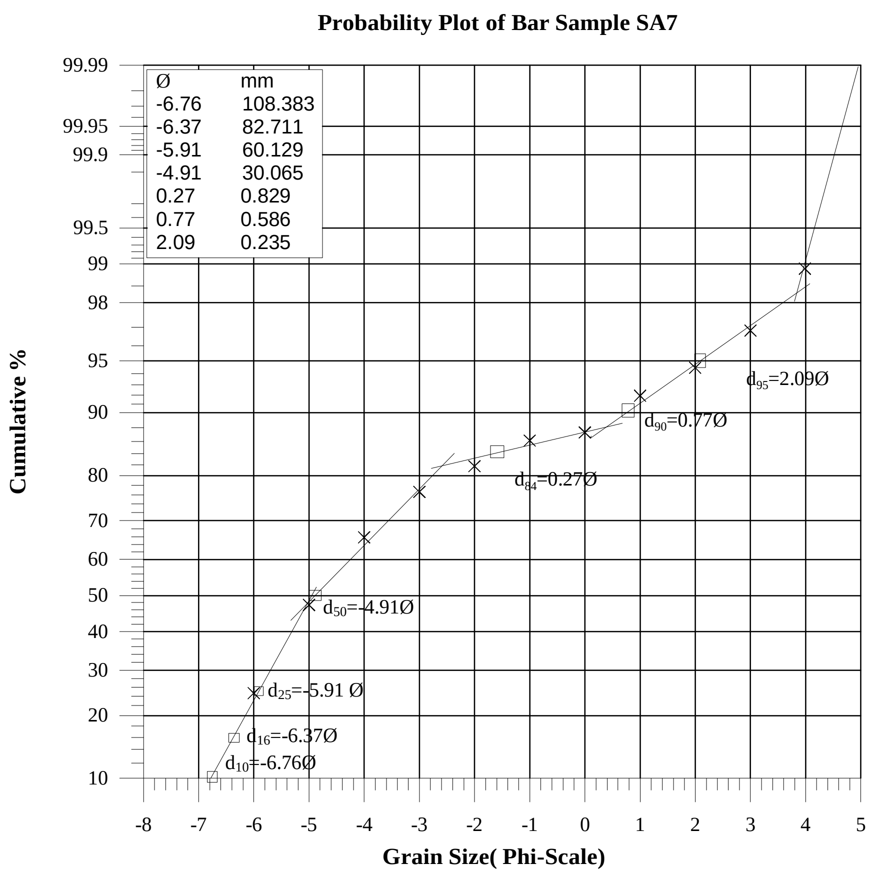
Annex III-6: Result of sieve analysis of bar sample of SA6

Sieve size (mm)	phi (ϕ) scale	Weight Retained (Kg)	F%	CF%	Composition	%
64	-6	48.500	18.531	18.531		
32	-5	30.000	11.463	29.994		
16	-4	40.800	15.589	45.583	Gravel	68.508
8	-3	43.500	16.621	62.203		
4	-2	16.500	6.304	68.508		
2	-1	10.371	3.963	72.471		
1	0	10.405	3.976	76.446		
0.5	1	29.241	11.173	87.619		
0.25	2	14.307	5.467	93.085	Sand	29.509
0.125	3	8.015	3.062	96.148		
0.063	3.99	4.892	1.869	98.017		
Pan	>4	5.190	1.983	100.000	Silt	1.983



Annex III-7: Result of sieve analysis of bar sample of SA7

Sieve size (mm)	phi (ϕ) scale	Weight retained (Kg)	F%	CF%	Composition	%
64	-6	62.000	24.665	24.665	Gravel	76.582
32	-5	57.000	22.676	47.342		
16	-4	46.500	18.499	65.841		
8	-3	27.000	10.741	76.582		
4	-2	13.000	5.172	81.754	Sand	20.256
2	-1	11.000	4.376	86.130		
1	0	3.088	1.228	87.358		
0.5	1	11.501	4.575	91.934		
0.25	2	6.381	2.539	94.472		
0.125	3	5.946	2.366	96.838		
0.063	3.99	5.187	2.063	98.901		
>4		2.762	1.099	100.000	Silt	2.063

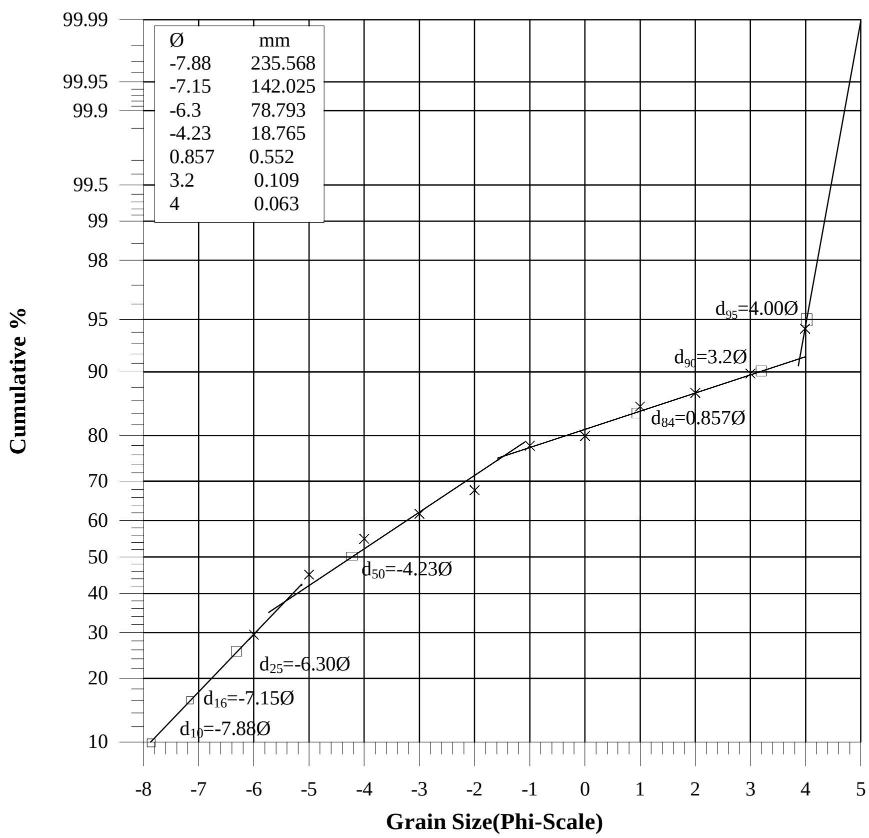


Probability plot for the bar sample SA7

AnnexIII-8: Result of sieve analysis of bar sample of SA8

Sieve size (mm)	phi (ϕ) scale	Weight Retained (Kg)	F %	CF %	Composition	%
64	-6	48.000	29.487	29.487		
32	-5	25.500	15.665	45.152		
16	-4	16.000	9.829	54.980	Gravel	67.819
8	-3	11.000	6.757	61.738		
4	-2	9.900	6.082	67.819		
2	-1	16.500	10.136	77.955		
1	0	3.178	1.952	79.908		
0.5	1	8.495	5.218	85.126	Sand	26.470
0.25	2	3.331	2.046	87.172		
0.125	3	4.274	2.626	89.798		
0.063	3.9885	7.312	4.492	94.290		
pan	>4	9.295	5.710	99.990	Silt	5.710

Probability Plot of Bar Sample SA8



Annex xix

Values for the computation of roughness coefficient (Chow, 1986)

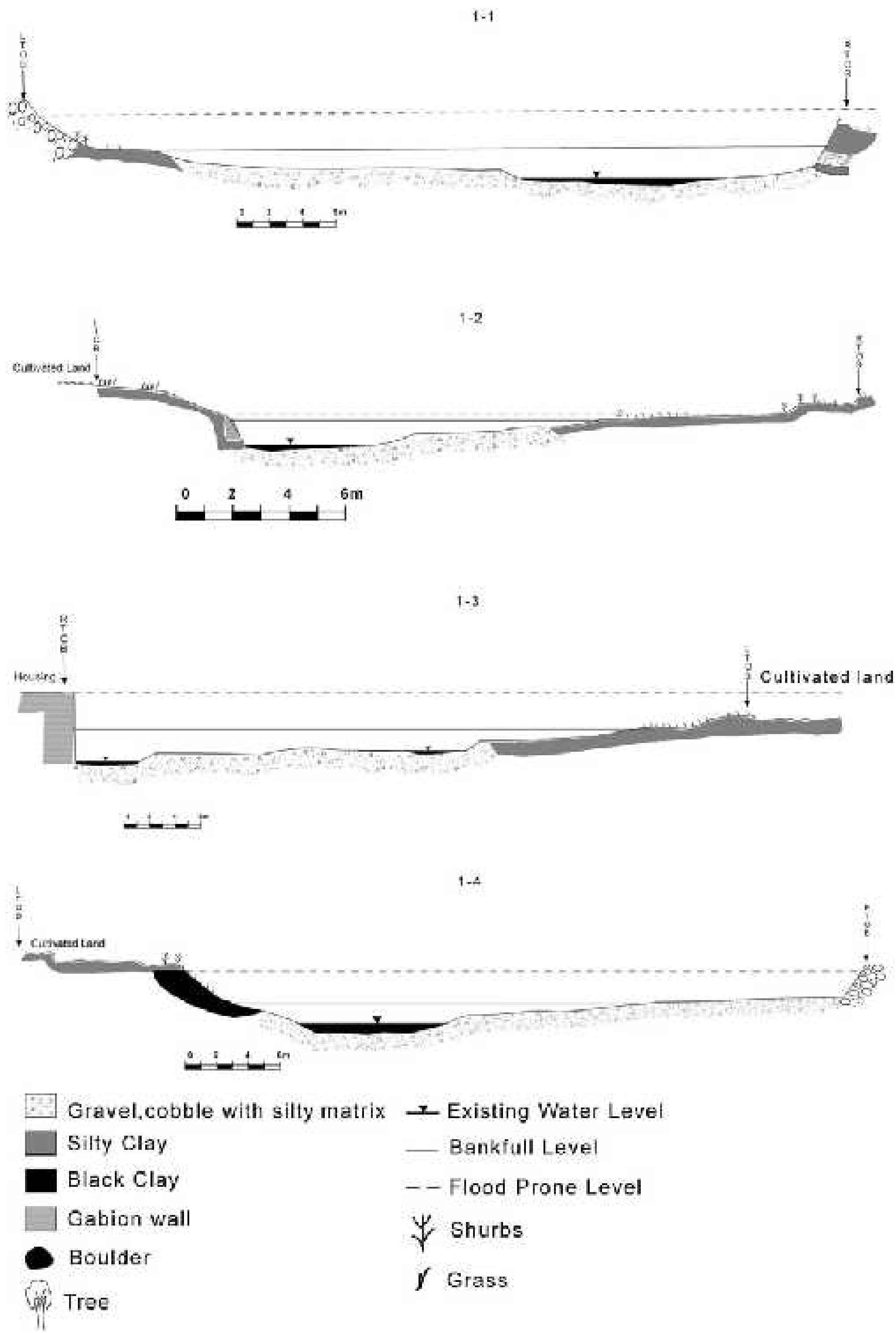
Channel condition		Value	
Material involved	Earth	n_b	0.020
	Rock cut		0.025
	Fine gravel		0.024
	Course gravel		0.028
Degree of irregularity	Smooth	n_1	0.000
	Miner		0.005
	Moderate		0.010
	Severe		0.020
Variation of channel cross-section		n_2	0.000
	Alternating occasionally		0.005
	Alternating frequently		0.010-0.015
Relative effect of obstruction	Negligible	n_3	0.000
	Minor		0.010-0.015
	Appreciable		0.020-0.030
	Severe		0.040-0.060
Vegetation	Low	n_4	0.005-0.010
	Medium		0.010-0.025
	High		0.025-0.050
	Very high		0.050-0.01
Degree of meandering	Minor	m	1.000
	Appreciable		1.150
	Severe		1.300

Annex

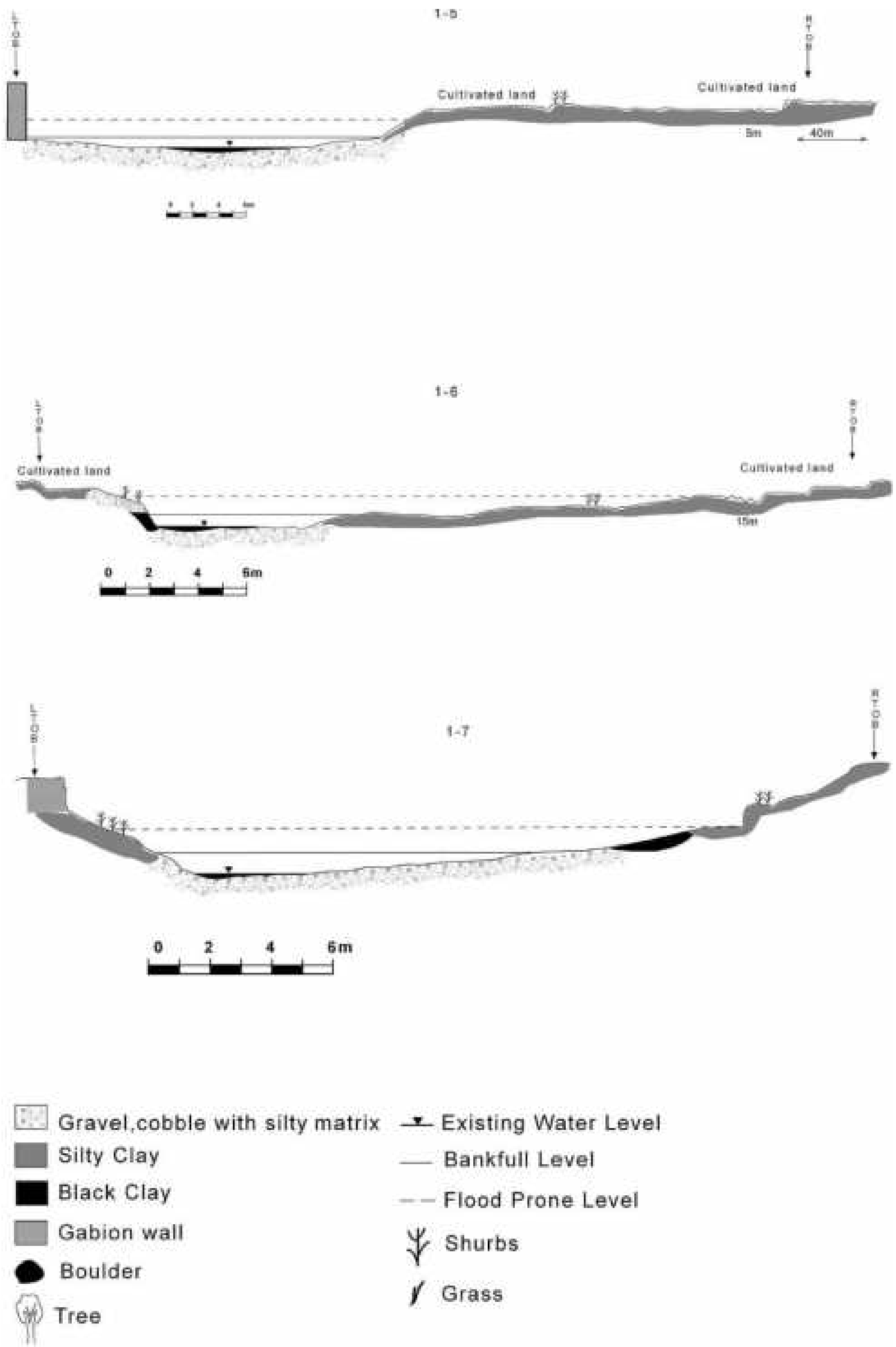
Annex V-1: Summary of delineate criteria for broad-level classification

Stream Type	General description	ER	W/D ratio	S	Slope	Landform/soils/features
Aa+	Very steep, deeply entrenched, debris transport streams.	<1.4	<1.2	1.0 to1.1	>0.1	Very high relief, erosional, bedrock or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps width/deep pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel.	<1.4	<12	1.0 to1.2	0.04to 0.10	High relief. Erosional of depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step-pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks	1.4 to 2.2	>12	<1.2	0.02 to 0.039	Moderate relief, colluvial deposition and W/D ratio. Narrow, gently sloping valleys. Rapids predominate with occasional pools.
C	Low gradient, meandering, point bar, riffle/pool, alluvial channels with broad, well defined floodplains.	>2.2	>12	>1.4	<0.02	Broad valleys with terraces, in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channel .Riffle-pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<0.04	Broad valleys with alluvial and colluvial fans. Glacial debris and depositional features. Active lateral adjustment, with abundance of sediment supply.
DA	Anastomosing (multiple channels) narrow and deep with expansive well vegetated floodplain and associated wetlands. Very gentle relief with highly variable sinuosities. Stable streambanks.	>4.0	<40	Variable	<0.005	Broad, low-gradient valleys with fine alluvium and /or lacustrine soils. Anastomosed(multiple channels) geologic control creating fine deposition with well-vegetated bars that are laterally stable with broad wetland floodplains.
E	Low gradient, meandering riffle/pool stream with low width/depth ration and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<0.02	Broad valley/meadows. Alluvial materials with floodplain. Highly sinuous with stable, well vegetated banks. Riffle-pool morphology with very low width/depth ratio.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	<1.4	>12	>1.4	<0.02	Entrenched in highly weathered material. Gentle gradients,with a high W/D ratio. Meanduring,laterally unstable with high bank-erosion rates. Riffle-pool morphology.
G	Entrenched "gully" step/pool and low width/depth ratio on moderate gradients.	<1.4	<12	>1.2	0.02 to0.039	Gully, step-pool morphology with moderate slopes and low W/D ratio. Narrow valleys, or deeply incised in alluvial or colluvial material; i.e., fans or deltas. Unstable, with grade control problems and high bank erosion rates.

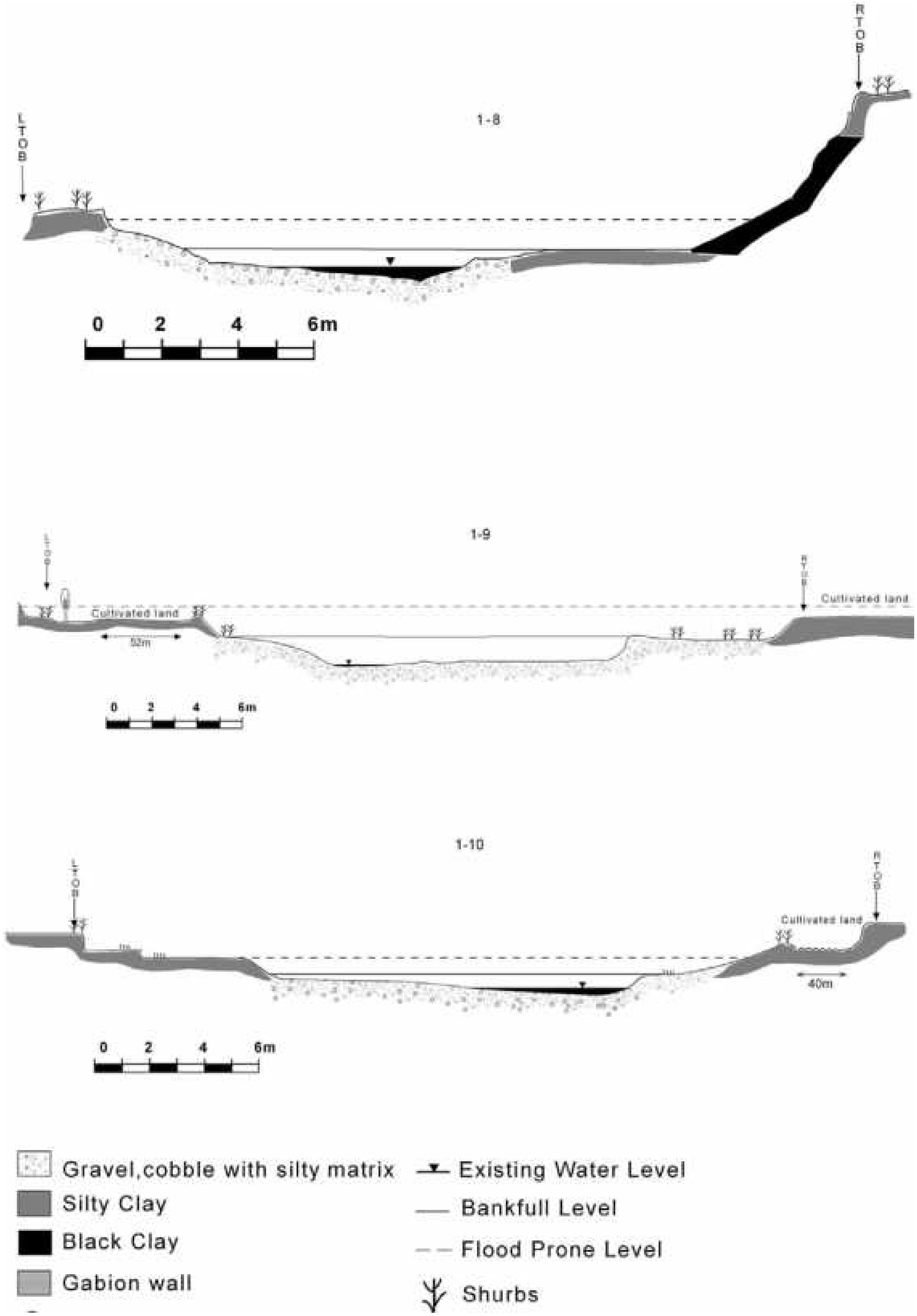
Annex V-2: Crossections of different transects along the Nakhu Khola



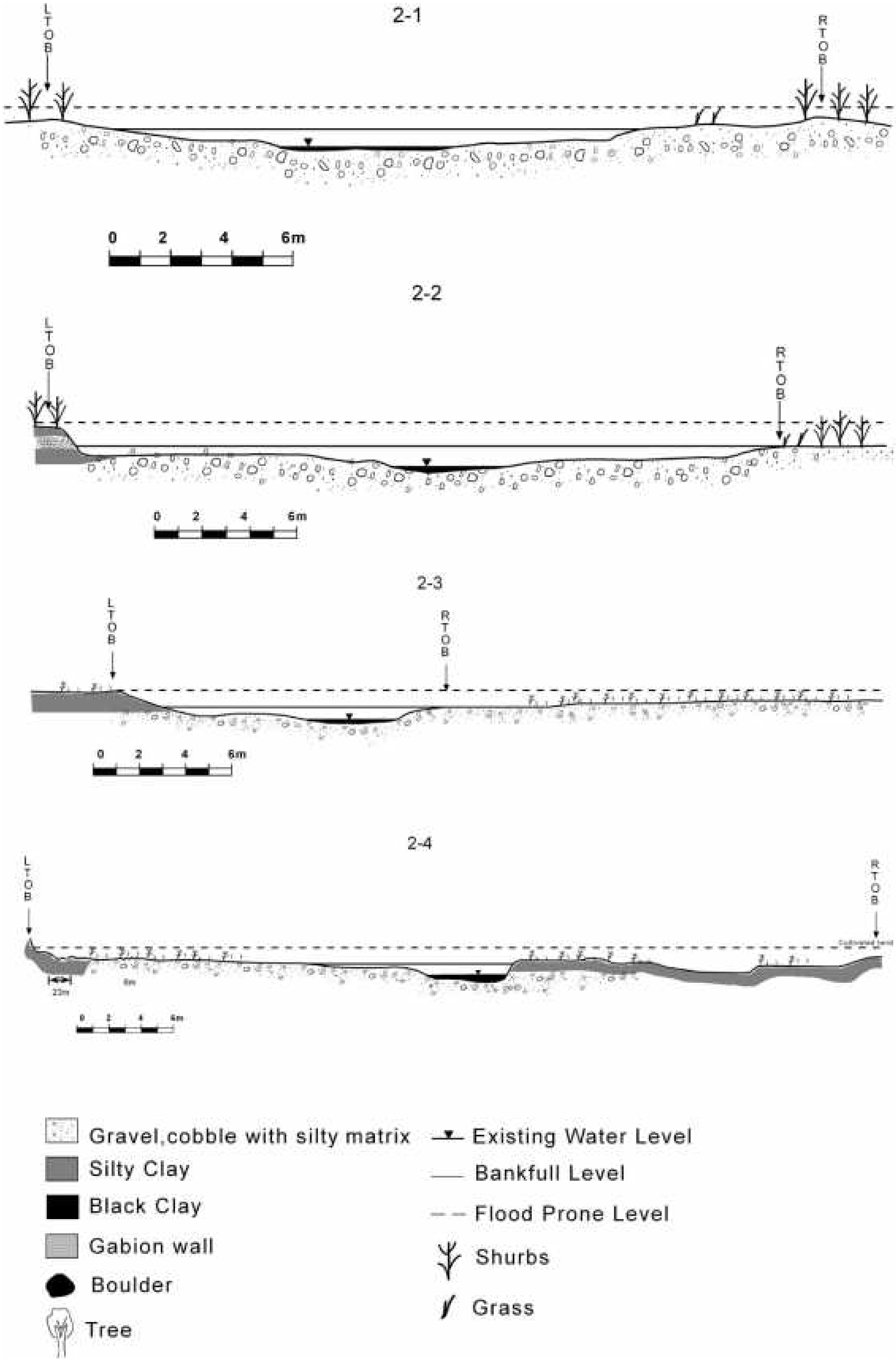
Cross-section of Transects in The NakhuSegment



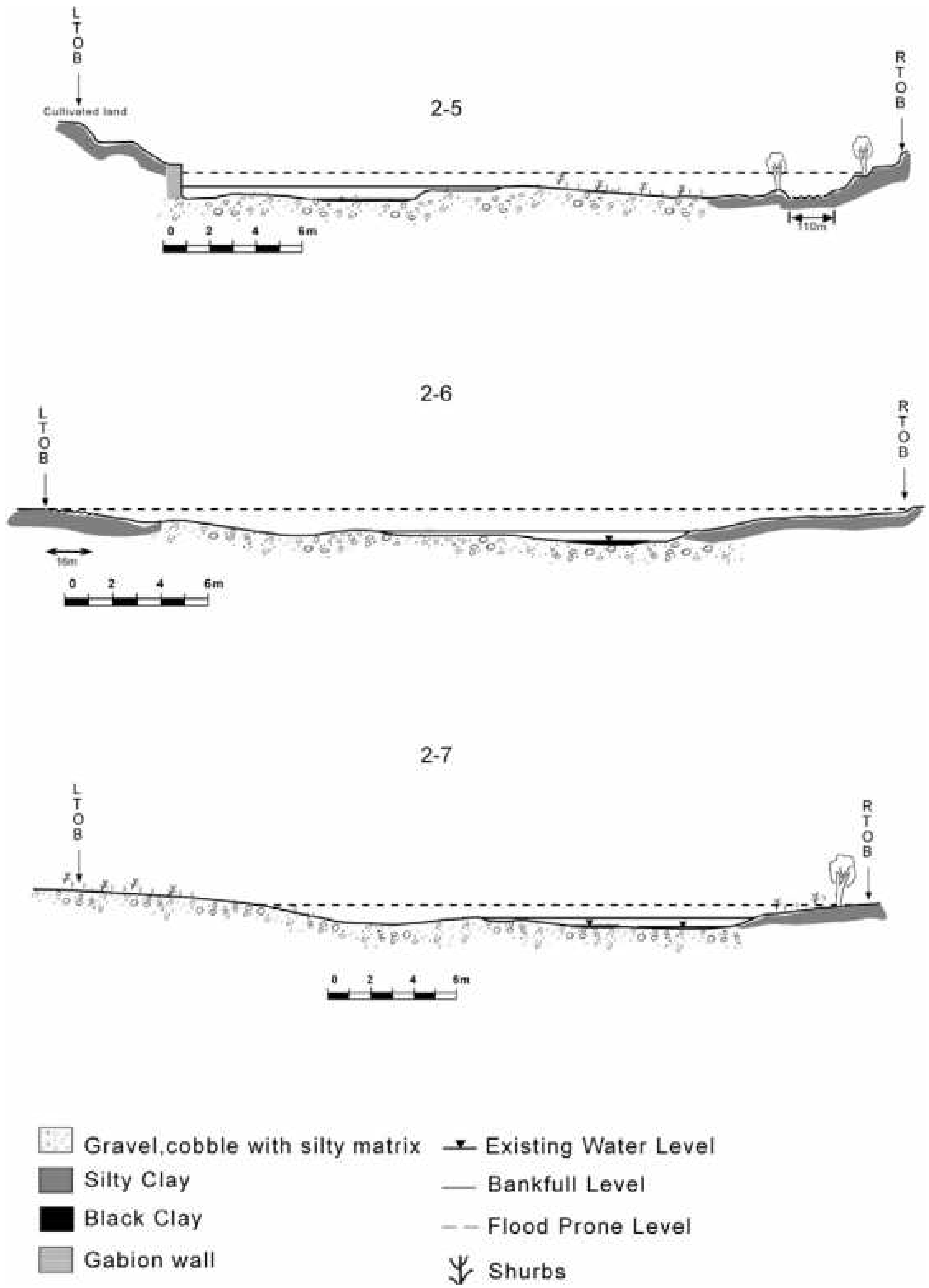
Cross-section of Transects in The NakhuSegment



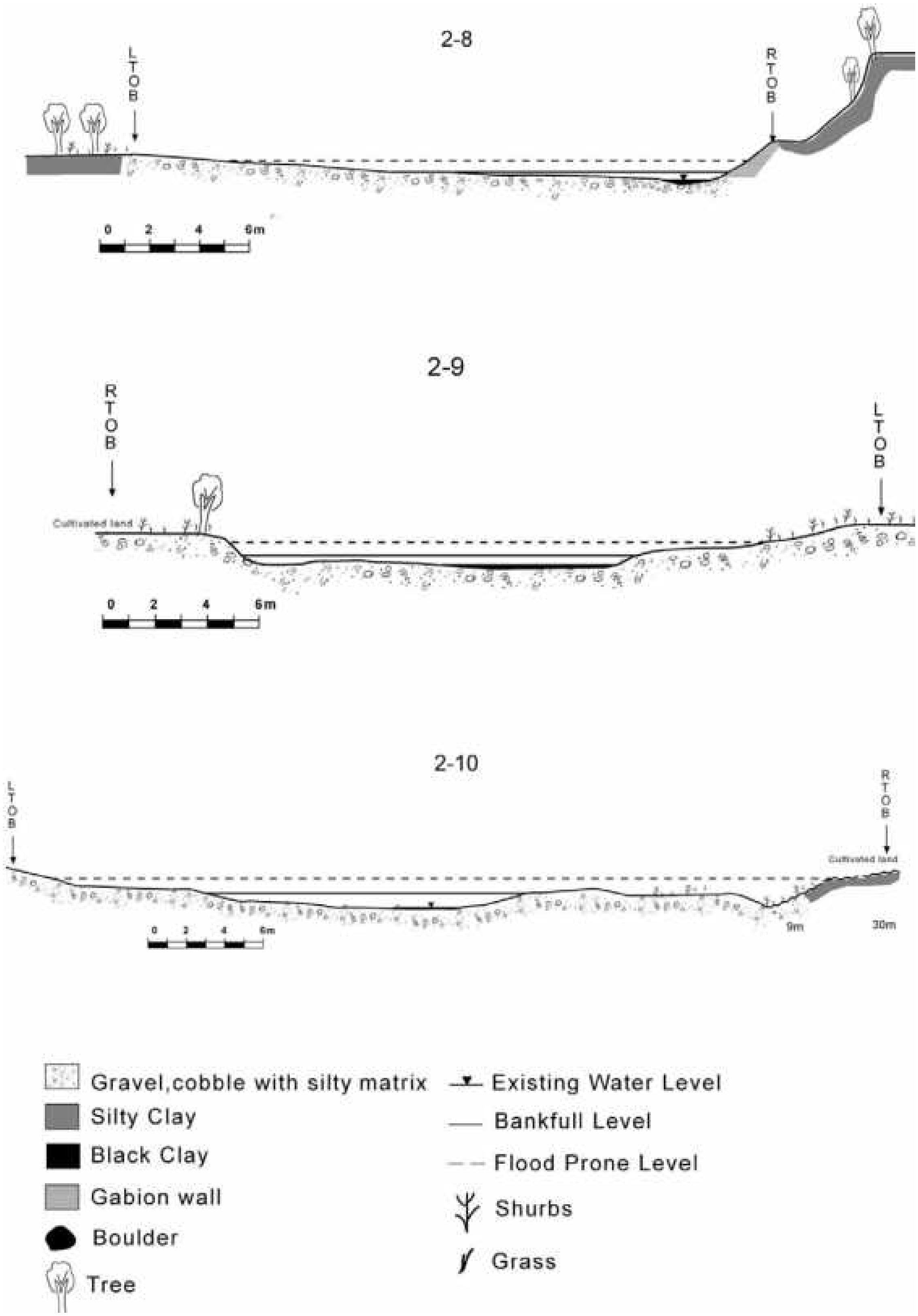
Cross-section of Transects in The NakhuSegment



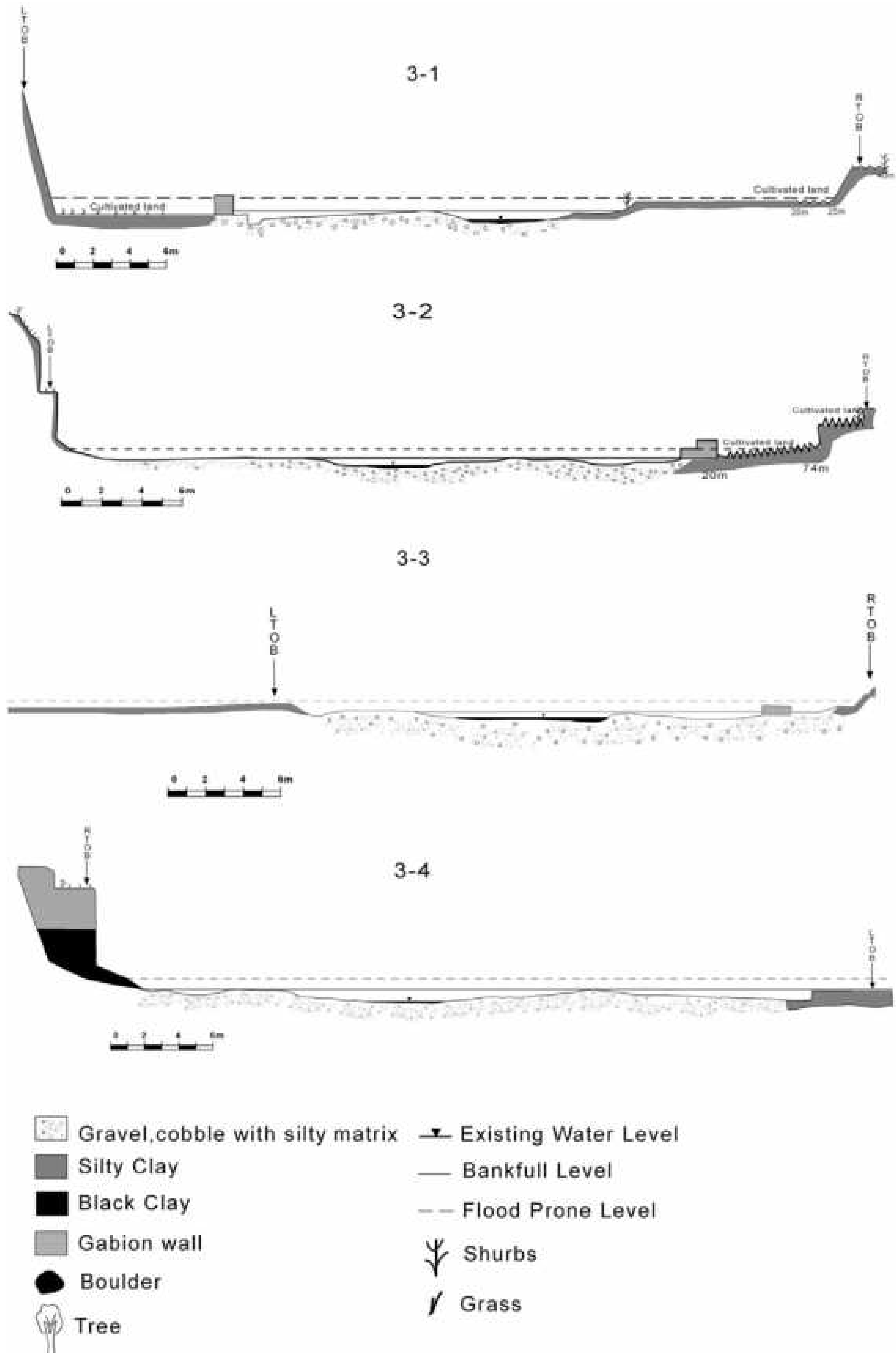
Cross-section of Transects in Bhainsepati Segment



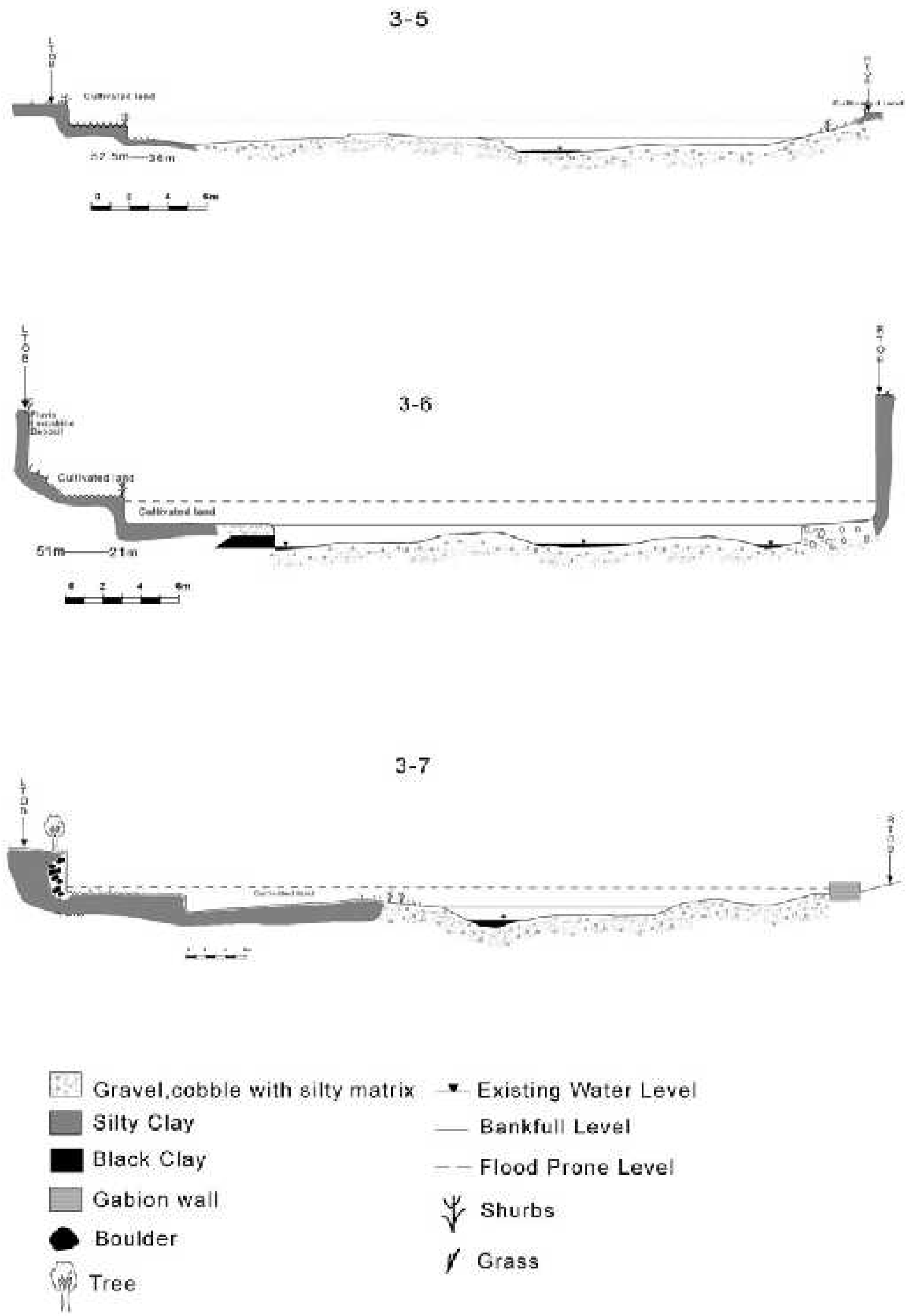
Cross-section of Transects in Bhainsepati Segment



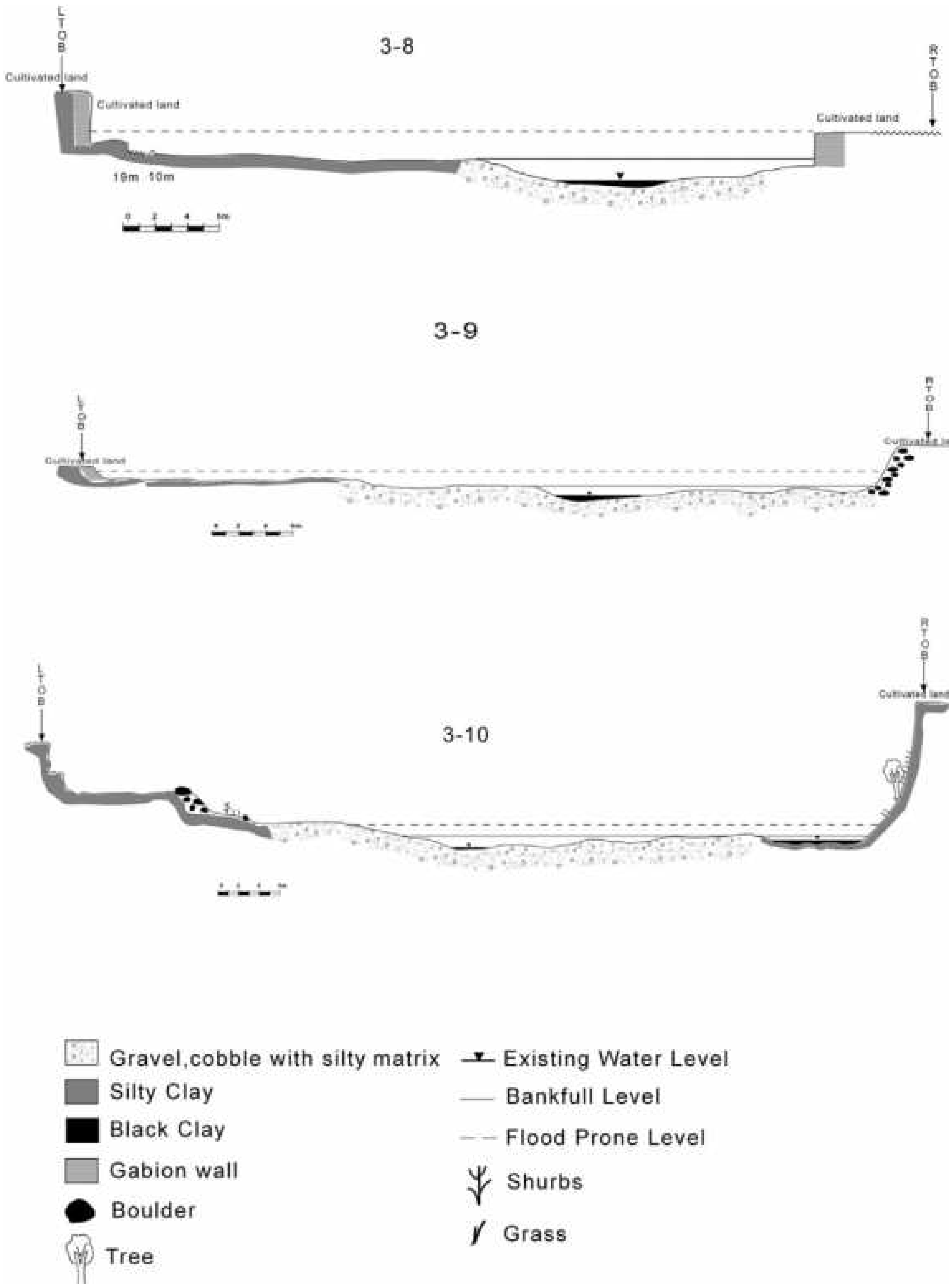
Cross-section of Transects in Bhainsepati Segment



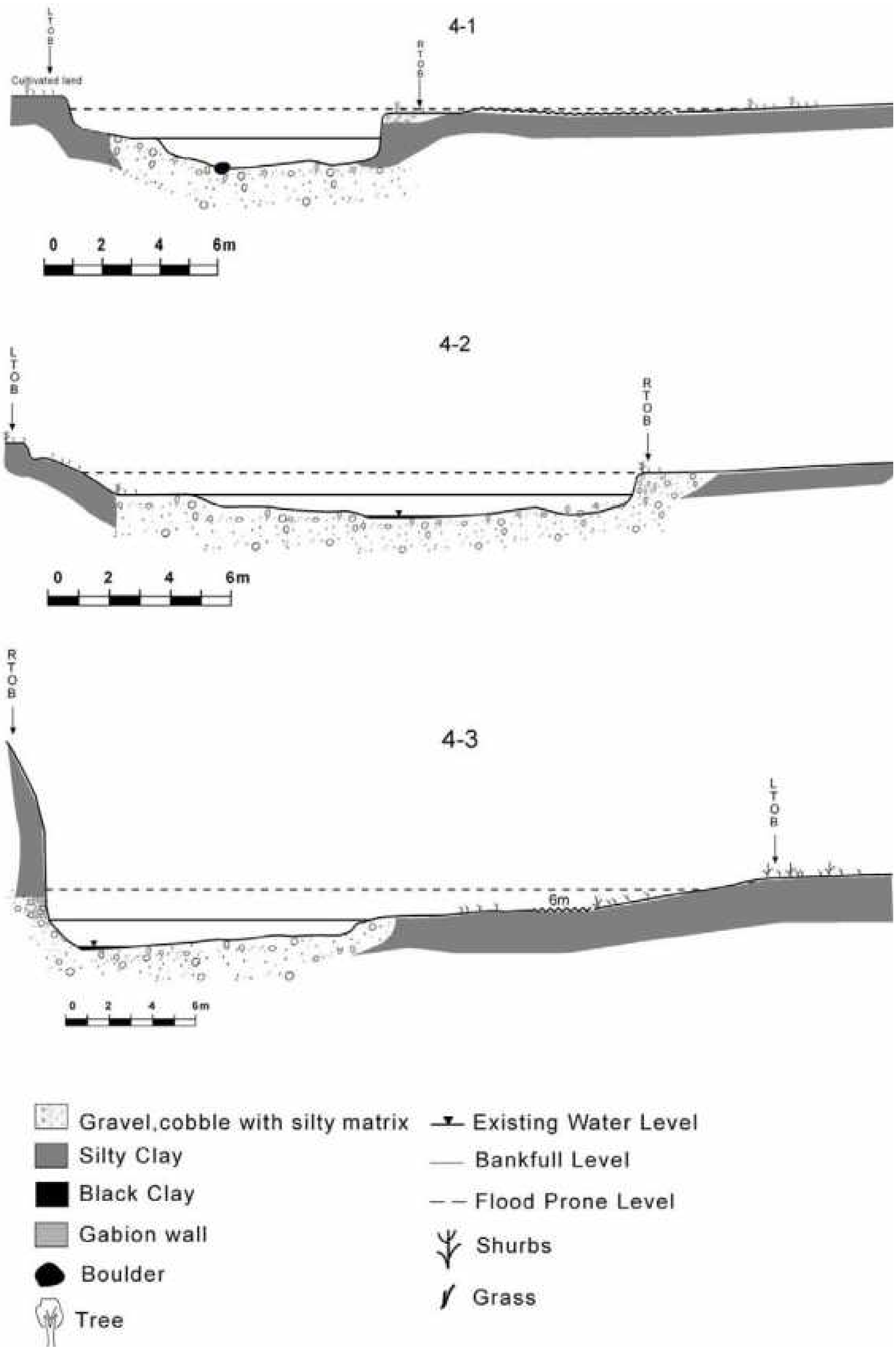
Cross-section of Transects in Chapagaon Segment



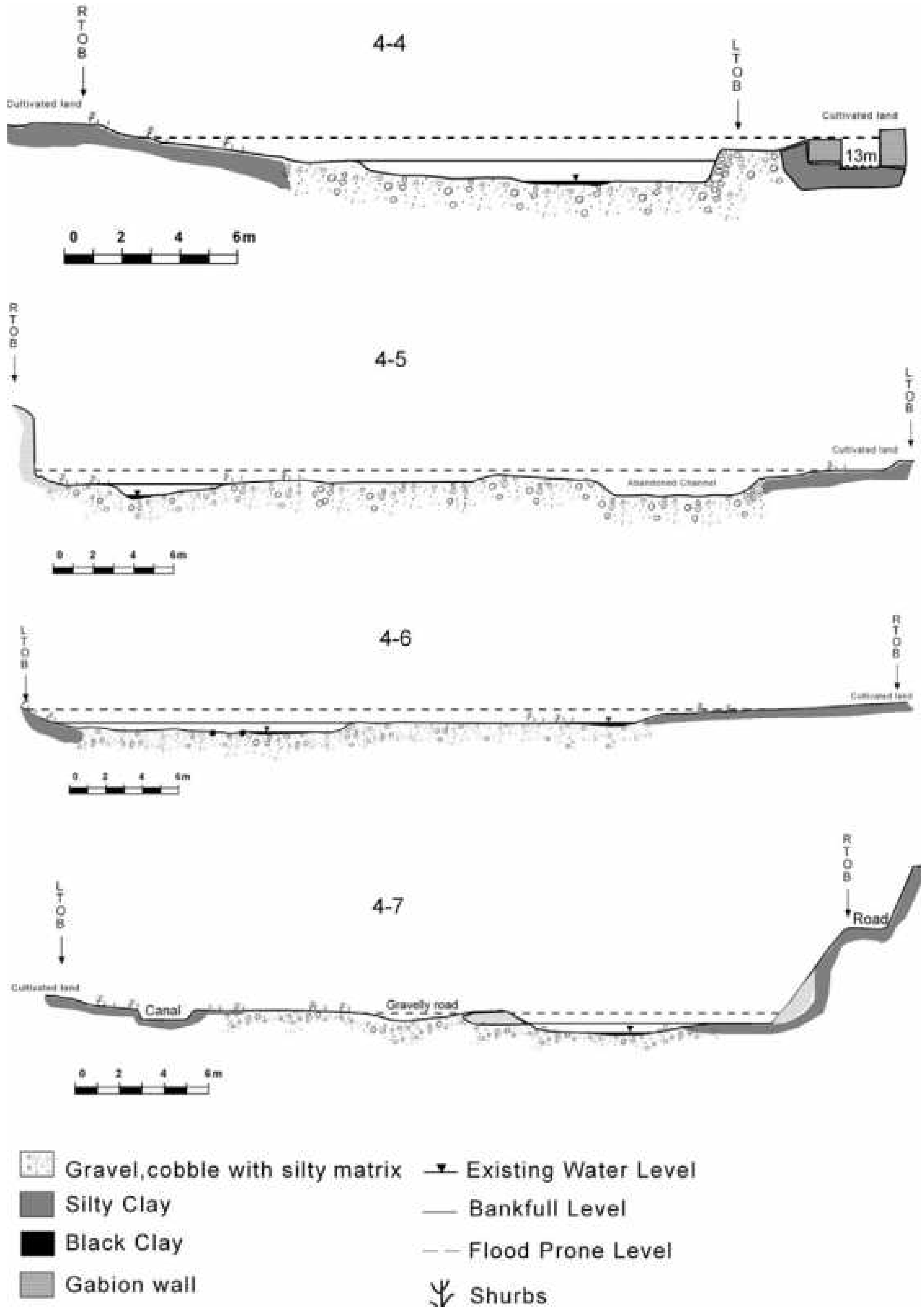
Cross-section of Transects in Chapagaon Segment



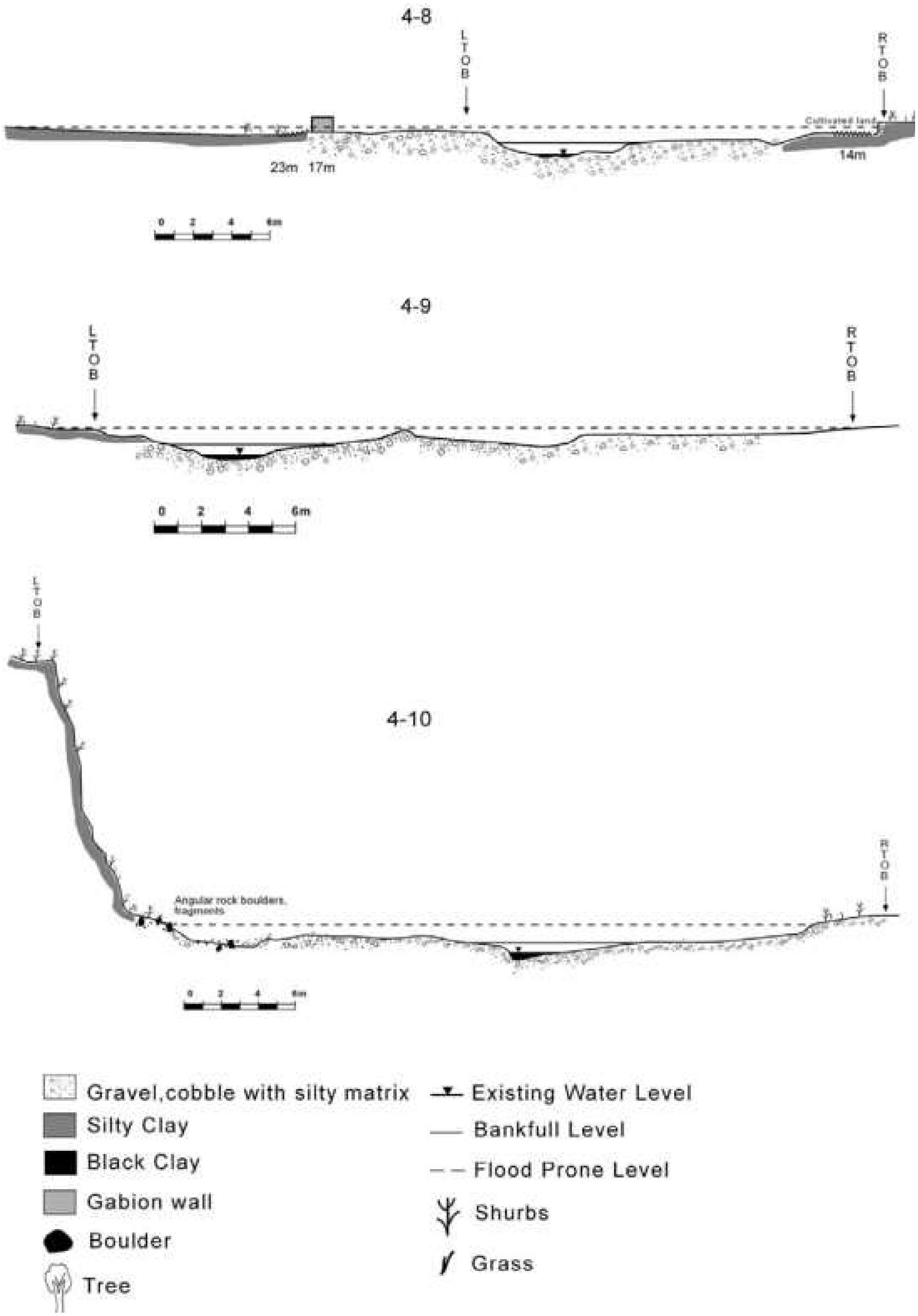
Cross-section of Transects in Chapagaon Segment



Cross-section of Transects in Nallu Segment



Cross-section of Transects in Nallu Segment



Cross-section of Transects in Nallu Segment

Annex VI

Annex VI-1: Conversion of bank height ratio (degree of incision) to adjustive rating of stability

Stability Rating	Bank Height ratio
Stable(low risk of degradation)	1.0-1.05
Moderately unstable	1.06-1.3
Unstable(high risk of degradation)	1.3-1.5
Highly unstable	>1.5

Annex VI-2: Conversion of width depth ratio to adjustive rating of stability from reference condition

Stability rating	Ratio of W/D increase
Very stable	1
Stable	1-1.2
Moderately stable	1.2-1.4
Unstable	>1.4

Annex VII

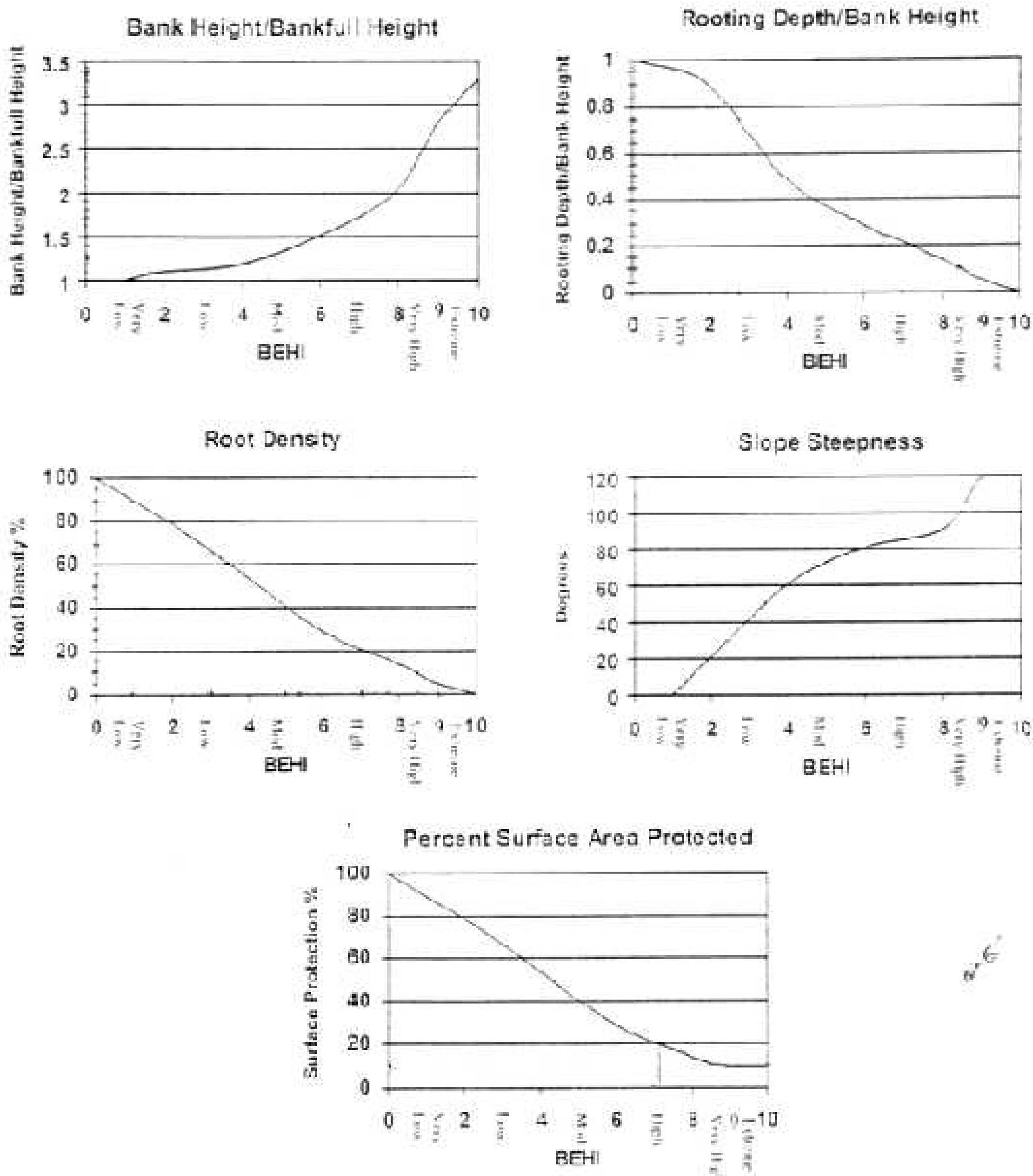


Diagram for finding BEHI for value (after Rosgen 2001)

Annex VIII

Annex VIII-1:Water quality Analysis of the NakhuKhola

Segment No.	Near Confluence	Nakhu		Bhainsepati		Chapagaon		Nallu	
	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9
Temperature(°c)	26.6	26.9	26.8	26.1	26	28	26	25.3	21.6
pH	6.4	6.41	6.22	6.8	7.16	8.06	7.6	8.3	8
NaCl%	0.05	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Conducitivity(Ωm)	8.9	21.6	28.6	29.4	33.4	32.2	32.8	62.9	62
Voltage((mV)	37	39	51	24	14	-99	-49	-72	-55
EC(ms/m)	115.4	46.1	35	33.9	30.1	30	30.7	15.3	15.1
NH4(mg/l)	10	2	0.16	0.16	0.16	0.16	0.4	0.5	0.16
NO3(mgNO3-/l)	0.23	0.46	0.23	0.23	0.23	0.2	1.15	0.23	0.23
COD(mgO/l)	75	50	50	50	20	50	50	20	50