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Morphometric analysis of Arun River Valley, eastern Nepal

Pramod Kumar Thakur
Central Department of Geology, Tribhuvan University, Kirtipur,Kathmandu, Nepal

ABSTRACT

The Arun River shows antecedent characteristics but almost all tributaries show consequent characteristics. The drainage system of the Arun River Valley (ARV) is influenced by local geological structures in number of ways. The sharp bending, sudden high gradient, narrow valleys that suddenly become wide are common. In the ARV, major tributaries are of sixth order, as the order becomes higher, total number of stream segments becomes progressively smaller, but physical dimensions of the streams increase gradually. In some areas, the divides are low and indistinct, while in others they form high mountain systems. Valley deepening is affected by various factors such as- hydraulic action, corrosion/abrasion of the valley base and weathering of the stream bed increased by subsequent removal of weathered materials. Valley deepening is very high between Pisu la and the Barun Dovan; between the Num and Yamchung as well as Leguwaghat and Barachetra. Valley widening process is predominant near Kimathanka, between Tumlingtar and Surtibari and Sattare areas. The Arun River, flowing in the state of channel equilibrium condition partially modified after local recent tectonic events. In the near future there is very low risk of vast channel shifting phenomena in the valley. The paper describes major morphometrical analysis of the Arun River Valley, eastern Nepal.

INTRODUCTION

The Arun (Pumqu) River originates from the Yebokanjiala Glacier on the north of Mt. Xixapangma (8012 masl) in Tibet, China (27°49' - 29°05'N and 85°38' - 88°57'E) and enters into Nepalese territory at Kimathanka Village and extend between 26°55' - 27°50'N and 86°55' - 87°30'E (Thakur and Adhikary 2001).

Total length of the river channel is about 531 km out of which 155 km lies in Nepalese territory and fed by a number of tributaries (Table 1), before it joins with the Sunkoshi from the west and Tamor from the east near Tribeni (Fig. 1).

The Arun Basin has a total 25,307 km^2 catchment area of which 5,028 km^2 lies in Nepal and rest 31,472 km^2 in China; within a span of 120 km the altitude varies from 150 masl to 8,470 masl. There are 39 sub-basins (micro-watersheds) within the ARV.

The sharp bendings, sudden high gradients, narrow valleys which suddenly become wide are common in the ARV. In the ARV, major tributaries are of sixth order, as the order becomes higher, total number of stream segments becomes progressively smaller, but physical dimensions of the streams increase gradually.

Valley deepening is effected by factors such as-hydraulic action, corrosion/ abrasion of the valley base and weathering of the stream bed added with subsequent removal of weathered materials. Valley deepening is very high between Pisu la and the Barun Dovan, between the Num and Yamchung as well as Leguwaghat and Barachetra.

Valley widening process is predominant around Barun-Chamlang area, especially in the lower part of the Barun glacier, near Kimathanka, between Ekua and Simma, between Tumlingtar and Surtibari and Sattare areas (Fig. 1 and 2).

GEOLOGY

The Arun River Valley can be divided into three major litho-tectonic groups such as the Nawakot Nappe, the Kathmandu Nappe and the Khumbu Nappe (Hagen 1969). Similarly, Akiba et al. (1973) divided the region into several structural units namely, the Siwalik Zone, South Marginal Zone, Midland Autochthonous Zone, Midland Allochthonous Zone, Basement Gneiss Zone and Tibetan Zone.

Amatya and Jnawali (1994) mentioned the Kuncha Group (phyllite and quartzite); Nawakot Group (phyllite, quartzite, calcareous sandstone, dolomite, and slate); Higher Himalayan Crystalline and Tibetan Sedimentary Zone (Fig. 3). There are considerable amount glacial, periglacial deposits of Holocene age and the fluvial deposits of Pleistocene age in the study area.

The Arun River Valley can be divided into two geomorphic zones, namely – the Upper Arun Periglacial Valley (UAPV) and Lower Arun Fluvial Valley (LAFV) (Fig. 4 and 5). These geomorphic zones are separated by a distinct lineament of Jaljale Danda, Harale Danda and Sichok Danda (Fig. 3). Each geomorphic zone is further subdivided into various geomorphic provinces with number of geomorphic surfaces (Thakur and Adhikary 2001).

Table 1: Location of major tributaries in the Arun River Valley

Tributary	Location (Latitude / Longitude)	Tributary	Location (Latitude / Longitude)
Barun Khola	27° 49'-27°41/7°05'-87°22'	Chirkhuwa Khola	27° 19'-27°23'/87°01'-87°08'
Sursing Khola	27° 49'-27°44/87°19'-87°21'	Kakuwa Khola	27° 11'-27°12'/87°11'-87°14'
Thung Khola	27° 49'-27°45/87°23'-87°23'	Chyawa Khola	27° 26'-27°23'/87°11'-87°09'
Wakang Khola	27° 51'-27°47'/87°34'-87°27'	Khakuwa Khola	27° 20'-27°19'/87°05'-87°10'
Lhase Khola	27° 50'-27°45'/87°39'-87°27'	Sabhaya Khola	27° 30'-27°12'/87°27'-87°13'
Inkhuwa Khola	27° 44'-27°34'/87°05'-87°15'	Yanguwa Khola	27° 15'-27°16'/87°02'-87°13'
Apsuwa Khola	27° 44'-27°32'/87°03'-87°15'	Mamtang Khola	27° 12'-27°07'/87°07'-87°13'
Sankhuwa Khola	27° 42'-27°26'/87°00'-87°07'	Pikhuwa Khola	27° 04'-27°02/86°57'-87°11'
Chepuwa Khola	27°42'-27°44'/87°27'-87°24'	Leguwa Khola	27° 08'-27°09'/87°23'-87°16'
Leksuwa Khola	27° 41'-27°40'/87°31'-87°21'	Manmaya Khola	27° 05'-27°06'/87°23'-87°15'
Ikhna Khola	27° 38'-27°36'/87°34'-87°23'	Munga Khola	27° 01'-27°00'/87°18'-87°11'
Induwa Khola	27° 31'-27°32'/87°27'-87°18'	Dhanre Khola	26° 57'-26°58'/87°14'-87°10'

BASIN ANALYSIS

Morphometric analysis is the quantitative analyses of the landscape on the basis of different geomorphological parameters; such as nature of slope, area, altitude, drainage, lithology, etc. According to Strahler "Measurement of the shape, or geometry, of any natural form is termed as morphometry" (Strahler 1952, 1957, 1964) but in geomorphology, morphometry should be defined as measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms' (Clark 1966).

Basin analysis includes three broad aspects for the morphometric analysis (Table 2), as described below.

Linear aspect analysis

Linear aspects of the basins are primarily related to the channel patterns of the drainage network. The drainage network consists of all segments of streams of a particular river developed within a watershed. The nature of flow patterns is reflected in flowing channel in terms of sinuosity which plays a vital role in the study of linear aspects of the drainage basins. It comprises stream orders, stream numbers, bifurcation ratio, stream length, sinuosity index, stream junction angles, etc.

Areal aspect analysis

Basin area plays a very decisive role in morphometric analysis of a basin. It is related to the distribution of a number of significant attributes such as drainage density, stream frequency, drainage texture, slope, absolute and relative relief, dissection index, etc. The drainage basin area is to differentiate on the basis of watershed boundary and the areas of all stream segments of each other are measured and calculated.

Relief aspect analysis

The relief aspects of the drainage basins are related to the study of three dimensional features of the basins involving area, volume and altitude of vertical dimension of landforms, where different morphometric methods are used to analyze terrain characteristics, which are the result of basin processes. Thus, this aspects includes the analysis of the relationship between area and altitude (hypsometric

Table 2: Morphometric relation in aspect, basin, drainage network and channel cross-section

Aspect	Basin	Drainage Network	Channel cross-section
Areal	Area, basin shape	Area of stream channel, drainage pattern	Cross-sectional area of channel, channel shape
Linear	Length and perimeter	Drainage density, stream length	Channel length, width, and sinuosity indices
Relief	Basin slope, basin relief	Network relief	Slope, relief, longitudinal profile of river channel

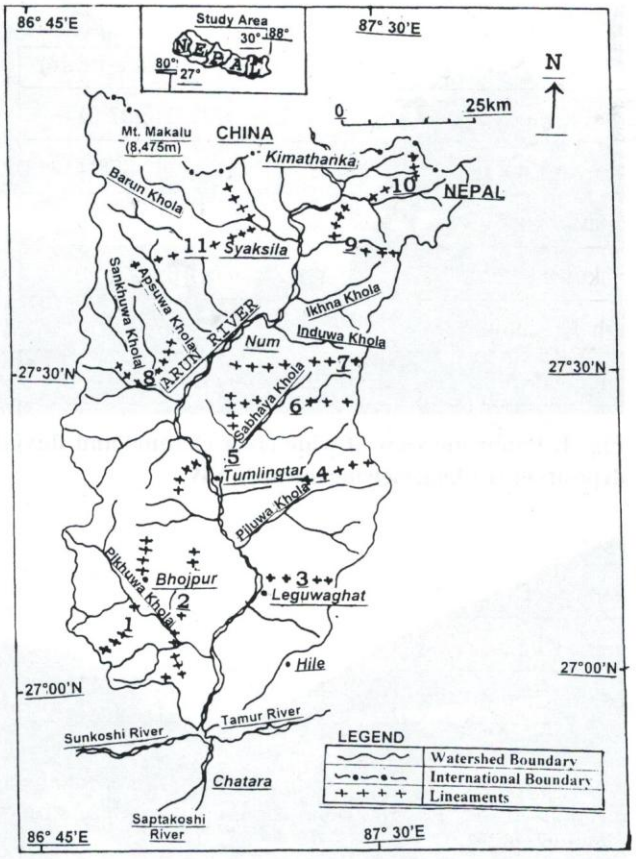

Fig. 1: Major drainage and lineaments in the Arun River Valley. Major Lineaments are: 1. Patlegaon-Salme, 2. Yampang-Tintole, 3. Pubang-Mujure Danda, 4. Piple-Chainpur, 5. Arunthan-Harale Danda, 6. Dandagaon-Chitre, 7. Harale Danda-Gunyang Danda, 8. Shichok Danda-Kulung Danda, 9. Namche-Gyabling Danda, 10. Chepuwa-Dukan, 11. Khumbu-Barun.

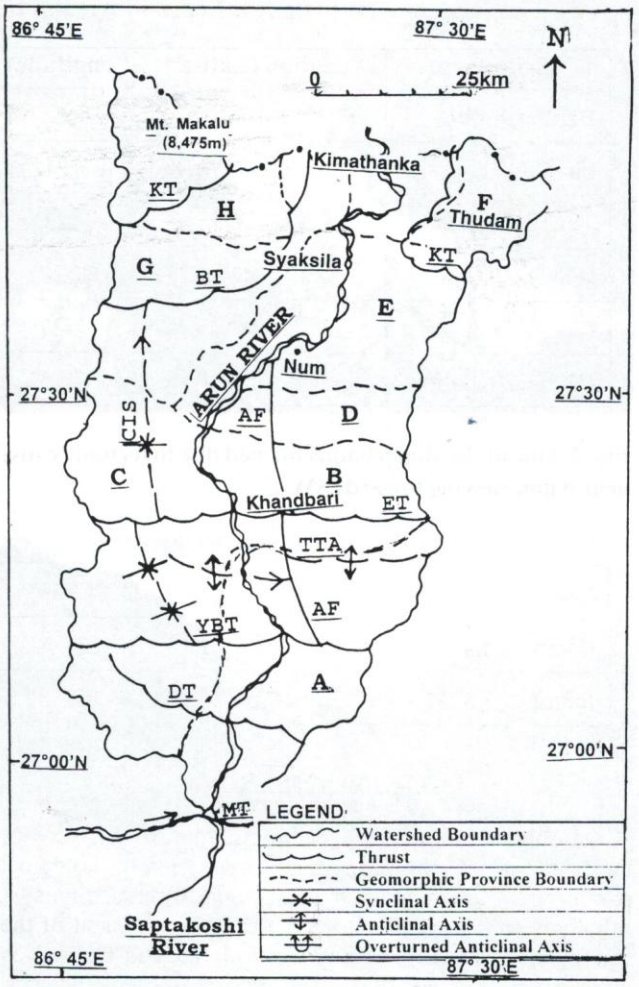

Fig. 2: Major geological structures and geomorphic provinces of the Arun River Valley. MT - Mulghat Thrust, DT- Dhankuta Thrust, YBT- Yaku Bilte Thrust, AF - Arun Fault, TTA – Tumlingtar - Tamur Anticline, CIS – Chamlang-Irkhuwa Synform, BT – Barun Thrust and KT – Khumbu Thrust (after Akiba et al. 1973)
Geomorphic Provinces: A- Chatara-Mangmai Province, B-Tumlingtar-Pangma Province, C-Mempang-Kulung Province, D- Gogane-Bhotebas Province, E- Num-Hatiya Province, F- Kimathanka- Ridak Province, G- Sursing Khola-Popti Bhanjyang Province and H-Barun-Chamlang Province.

analysis), and slope angle (clinographic analysis), average ground slope, relative relief, relief ratio, dissection index, profiles of terrain and the rivers, etc.

MORPHOMETRICAL FINDINGS

In the ARV there are 39 micro- watersheds but few of them are very small which can be analyzed jointly with others. Thus, only 25 are included in tables related to findings. There are 7,594 streams categorized as first order streams; 1,515 as second order streams; 301 as third order streams; 56 as fourth order streams; 18 as fifth order streams; 03 as sixth order streams and trunk river as seventh order stream (Table 3, 4 and 5). Morphometrical analysis and studies of the Arun River Valley show that it is a young fluvial valley influenced by local tectonics and climatic factors.

Analyses of micro watersheds show that most of them are elongated and rest are of sinuous which reflect towards geological as well as hydrological controls such as high angled slope, absolute and relative relief. Generally, the elongation ratio depends on the size of the basin and length of the master stream of the basin as well as basin parameter. Almost all of these factors depend upon absolute relief, slope of the terrain, geological structures, and lithological controls, etc. (Table 6).

Drainage density refers total stream length per unit area i.e., a ratio of total length of all stream segments in a given

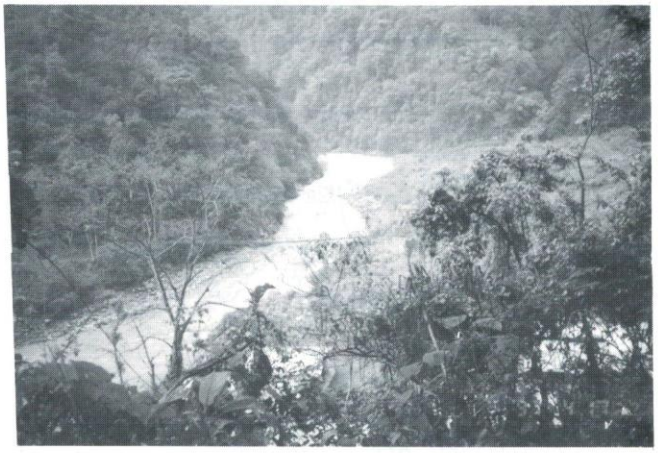

Fig. 3: One of the sharp bands formed due to tectonic cause near Num, viewing towards SW

Fig. 4: Panormic view of wide river channel and fluvial deposits near Ekua, viewing towards NW

Fig. 5: Steep hill slope forming due to hard rock type causing stable channel condition near Sting Danda, viewing towards NE

Fig. 6: Panormic view of comparatively wide valley base showing fluvial terrace near Harale Danda, viewing towards NE

drainage basin to the total area of that basin (Table 5). The range varies from low to high, depends upon nature of lithology, infiltration rate, varying degree of vegetal covers, etc. In the present case minimum value is 0.762 for Dhanre Khola and Maximum value goes up to 3.116 in Sabhaya Khola (Table 7).

Bifurcation ratio shows interrelationship between stream orders and stream length controlled by drainage density, stream junction angles, basin areas, shape of the basin, climatic condition, topography, etc. In present case, the value of bifurcation ratio varies from 3.369 to 7.958 which indicates almost all of the micro-basin, are developed in rolling basins which have flat valley base to hilly, dissected valleys. For example, the Sankhuwa Khola micro-basin starting from lower reach of the UAPV around 17,300 ft and meet the Arun River in the Lesser Himalayan zone. The distance traverse by the Sankhuwa Khola is gradually become flat in lower reaches. The Kakuwa Khola originates at the altitude of 11,400 ft in Lesser Himalayan Zone having low mean value. In other hand, the Chepuwa Khola originates in higher Himalayan zone and hardly touch the Lesser Himalayan zone, has very high and dissected basin with maximum mean value, shows great variations controlled by number of factors as mentioned above.

Sinuosity index is influenced by structure, climate, vegetation, etc. It varies as sinuous as well as meandering and very few as straight (Table 6). Basin shape depends on relief, slope, structure and lithology. Three types of basin shapes have been recognized, such as circular, elongated and indented. The value varies from 0 to 1, where 0 stands for highly elongated shape and 1 for perfect circular shape. In present case majors are categorized as circular basin shapes while few are categorized as elongated basins (Table 6).

Stream frequency refers the number of streams per unit area. It depends upon lithology, slope, vegetation coverings,

Table 3: Stream order and total number of stream in the Arun River Valley

Sub-basin	1st order	2nd order	3rd order	4th order	5th order	6th order	Total
Barun Khola	264	47	07	02	01	-	**321**
Sursing Khola	33	07	03	01	-	-	**44**
Thung Khola	18	05	01	-	-	-	**24**
Wakang Khola	169	35	05	02	01	-	**212**
Lhase Khola	558	111	21	04	01	-	**695**
Inkhuwa Khola	155	31	05	01	-	-	**192**
Apsuwa Khola	330	41	09	01	-	-	**381**
Sankhuwa Khola	623	132	27	06	02	01	**791**
Chepuwa Khola	47	12	01	-	-	-	**60**
Leksuwa Khola	70	15	03	01	-	-	**89**
Ikhna Khola	240	48	14	03	01	-	**304**
Induwa Khola	90	23	10	01	-	-	**124**
Kasuwa Khola	108	24	06	02	01	-	**141**
Chirkhuwa Khola	208	49	12	03	01	-	**273**
Kakuwa Khola	664	158	32	08	02	01	**865**
Chyawa Khola	22	04	01	-	-	-	**27**
Khakuwa Khola	104	20	04	01	-	-	**129**
Sabhaya Khola	1827	355	58	12	04	01	**2257**
Yanguwa Khola	332	63	14	03	01	-	**413**
Mamtang Khola	130	27	7	1	-	-	**165**
Pikhuwa Khola	930	180	35	08	01		**1154**
Leguwa Khola	194	42	07	02	01		**246**
Manmaya Khola	283	66	13	03	01		**366**
Munga Khola	143	28	05	01			**177**
Dhanre Khola	52	10	01				**63**

and climatic zone, etc. In the present case, the value varies from 0.950 to 4.726 for very low category (Table 8).

Drainage texture shows stream distribution pattern per unit area. If the stream distribution is very sparse then texture is called coarse but if the distribution is very dense then it is called fine texture (Table 5).

Relative relief refers the ratio of maximum basin relief to the horizontal distance along the longest dimension of the basin. Greater the value, more will be the sediment loss, i.e., more erosional activities, in a unit area. In present case, the value is minimum for Yanguwa Khola (0.015) and maximum is for Thung Khola (0.491) (Table 9).

CONCLUSIONS

The Arun River Valley is a young glacio-fluvial valley in the Central Himalaya. The valley accommodates number of sub-basins. Especially, the Arun River is a trunk river of seventh order stream. Valleys deepening and widening processes are continued since geologic past.

Valley deepening is effected by various factors such as- hydraulic action, corrosion/ abrasion of the valley base and weathering of the stream bed is increased by subsequent removal of weathered materials. Valley deepening is very high between Pisu la and the Barun Dovan; between the Num and Yamchung as well as Leguwaghat and Barahakshetra.

Table 4: Maximum stream order, total number of channels, area and maximum relief (ft) in the ARV

Streams	Max. Order	Total Channel	Area (km^2)	Max. Relief (ft)
Barun Khola	5	321	254	**22170**
Sursing Khola	4	44	38.5	**14000**
Thung Khola	3	24	25.25	**13700**
Wakang Khola	5	212	92.5	**19209**
Lhase Khola	5	695	220.75	**19000**
Inkhuwa Khola	4	192	98.75	**14000**
Apsuwa Khola	4	381	207.25	**18392**
Sankhuwa Khola	6	791	301.75	**17300**
Chepuwa Khola	3	60	18.75	**11000**
Leksuwa Khola	4	89	75.5	**13750**
Ikhna Khola	5	304	164.25	**17120**
Induwa Khola	4	124	79.5	**15823**
Kasuwa Khola	5	141	106.55	**13498**
Chirkhuwa Khola	5	273	71	**10942**
Kakuwa Khola	6	865	183	**11400**
Chyawa Khola	3	27	12	**4068**
Khakuwa Khola	4	129	39	**6868**
Sabhaya Khola	6	2257	530.75	**9300**
Yanguwa Khola	5	413	119.8	**9000**
Mamtang Khola	4	165	59.75	**5620**
Pikhuwa Khola	5	1154	98.75	**10000**
Leguwa Khola	5	246	63.75	**9500**
Manmaya Khola	5	366	81.75	**8862**
Munga Khola	4	177	72	**6452**
Dhanre Khola	3	63	13.75	**4809**

Table 5: Stream length, average length, drainage density and stream frequency in the ARV

Sub-basin	Stream length (km)	Average length	Drainage density	Stream frequency
Barun Khola	578.95	24.744	2.279	1.264
Sursing Khola	69.8	12.317	1.586	1.142
Thung Khola	37.55	6.243	1.564	0.950
Wakang Khola	190.35	14.796	2.057	2.291
Lhase Khola	544.350	24.583	0.783	3.148
Inkhuwa Khola	212.45	20.84	2.151	1.944
Apsuwa Khola	331.2	33.585	0.869	1.838
Sankhuwa Khola	719.4	27.961	2.384	2.621
Chepuwa Khola	54.05	7.968	0.900	3.200
Leksuwa Khola	112.95	16.752	1.269	1.178
Ikhna Khola	302.85	22.478	1.843	1.850
Induwa Khola	147.15	16.163	1.178	1.559
Kasuwa Khola	147.15	14.421	1.381	1.323
Chirkhuwa Khola	211.45	15.576	2.978	3.845
Kakuwa Khola	662.45	23.381	0.765	4.726
Chyawa Khola	26.15	3.659	0.968	2.25
Khakuwa Khola	102.15	9.129	0.791	3.307
Sabhaya Khola	1654.1	43.555	3.116	4.252
Yanguwa Khola	334.6	17.121	1.456	3.445
Mamtang Khola	149.95	13.08	0.908	2.744
Pikhuwa Khola	1151.90	41.767	1.987	1.989
Leguwa Khola	227.8	12.211	0.926	3.858
Manmaya Khola	296.9	14.631	0.811	4.477
Munga Khola	178.15	12.884	2.474	2.458
Dhanre Khola	48.050	6.218	0.762	4.581

Table 6: Sinuosity index, elongation ratio, stream frequency in the ARV

Sub-basin	Stream frequency	Relief ratio	Elongation ratio	Sinuosity index
Barun Khola	1.264	0.082	0.185	0.961
Sursing Khola	1.142	0.372	0.252	1.043
Thung Khola	0.950	0.491	0.430	0.988
Wakang Khola	2.291	0.374	0.162	1.015
Lhase Khola	3.148	0.214	0.207	1.025
Inkhuwa Khola	1.944	0.147	0.144	1.051
Apsuwa Khola	1.838	0.175	0.159	1.051
Sankhuwa Khola	2.621	0.153	0.099	1.101
Chepuwa Khola	3.200	0.472	0.389	1.056
Leksuwa Khola	1.178	0.269	0.206	1.038
Ikhna Khola	1.850	0.233	0.210	1.017
Induwa Khola	1.559	0.292	0.270	0.963
Kasuwa Khola	1.323	0.248	0.201	1.046
Chirkhuwa Khola	3.845	0.225	0.209	1.216
Kakuwa Khola	4.726	0.150	0.125	1.110
Chyawa Khola	2.25	0.225	0.206	0.963
Khakuwa Khola	3.307	0.210	0.168	0.964
Sabhaya Khola	4.252	0.076	0.068	1.000
Yanguwa Khola	3.445	0.015	0.015	1.014
Mamtang Khola	2.744	0.111	0.089	1.006
Pikhuwa Khola	1.989	0.076	0.078	0.980
Leguwa Khola	3.858	0.182	0.169	1.133
Manmaya Khola	4.477	0.160	0.188	1.038
Munga Khola	2.458	0.151	0.149	0.961
Dhanre Khola	4.581	0.220	0.225	0.872

Valley widening process is predominant near Kimathanka, between Tumlingtar and Surtibari and Sattare areas. The Arun River, flowing in the state of channel equilibrium condition is partially modified after local recent tectonic events. In the near future there is very low risk of vast channel shifting phenomena in the valley.

There are 7,594 streams categorized as first order streams; 1,515 as second order streams; 301 as third order streams; 56 as fourth order streams; 18 as fifth order streams; 03 as sixth order streams and trunk river as seventh order stream.

Analyses of micro watersheds show that most of them are elongated and rest are of sinuous which reflect towards geological as well as hydrological controls such as high angled slope, absolute and relative relief.

The range of drainage density varies from low to high, depends upon nature of lithology, infiltration rate, varying degree of vegetal covers, etc. In the present case minimum value is 0.762 for Dhanre Khola and maximum value goes up to 3.116 in Sabhaya Khola.

In present case, the relative relief ratio value is minimum for Yanguwa Khola (0.015) and is maximum for Thung Khola (0.491).

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Table 7: Drainage density analysis in the Arun River Valley

Interval	Category	Unit area	Main tributaries
≃ - 1	Poor	10	Lhase, Apsuwa, Chepuwa, Kakuwa, Chayawa, Khakuwa, Mamtang, Leguwa, Manmaya, Dhanre
1.1 – 2	Medium	8	Sursing, Thung, Leksuwa, Ikhna, Induwa, Kasuwa, Yanguwa
2.1 - >	High	7	Barun, Wakang, Inkhuwa, Sankhuwa, Chirkhuwa, Sabhaya, Munga

Table 8: Stream frequency analysis in the Arun River Valley

Interval	Category	Unit area	Main tributaries
≃ - 2	Poor	10	Barun, Sursing, Thung, Inkhuwa, Apsuwa, Leksuwa, Ikhna, Induwa, Kasuwa, Pikhuwa
2.1 – 3	Medium	5	Wakang, Sankhuwa, Chyaba, Mamtang, Munga
3.1 - >	High	10	Lhase, Chepuwa, Chirkhuwa, Kakuwa, Khakuwa, Sabhaya, Yanguwa, Leguwa, Mangmaya, Dhanre

Table 9: Relief ratio analysis in the Arun River Valley

Interval	No. of Basin	Main tributaries
0.015 - 0.1	4	Barun, Sabhaya, Yanguwa, Pikhuwa
0.11 – 0.2	8	Inkhuwa, Apsuwa, Sankhuwa, Kakuwa, Mamtang, Leguwa, Mangmaya, Munga
0.21 - 0.3	9	Lhase, Leksuwa, Ikhna, Induwa, Kasuwa, Chirkhuwa, Chyawa, Khakuwa, Dhanre
0.31 – 0.5	4	Sursing, Thung, Wakang, Chepuwa

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