Physio-geographical Characteristics

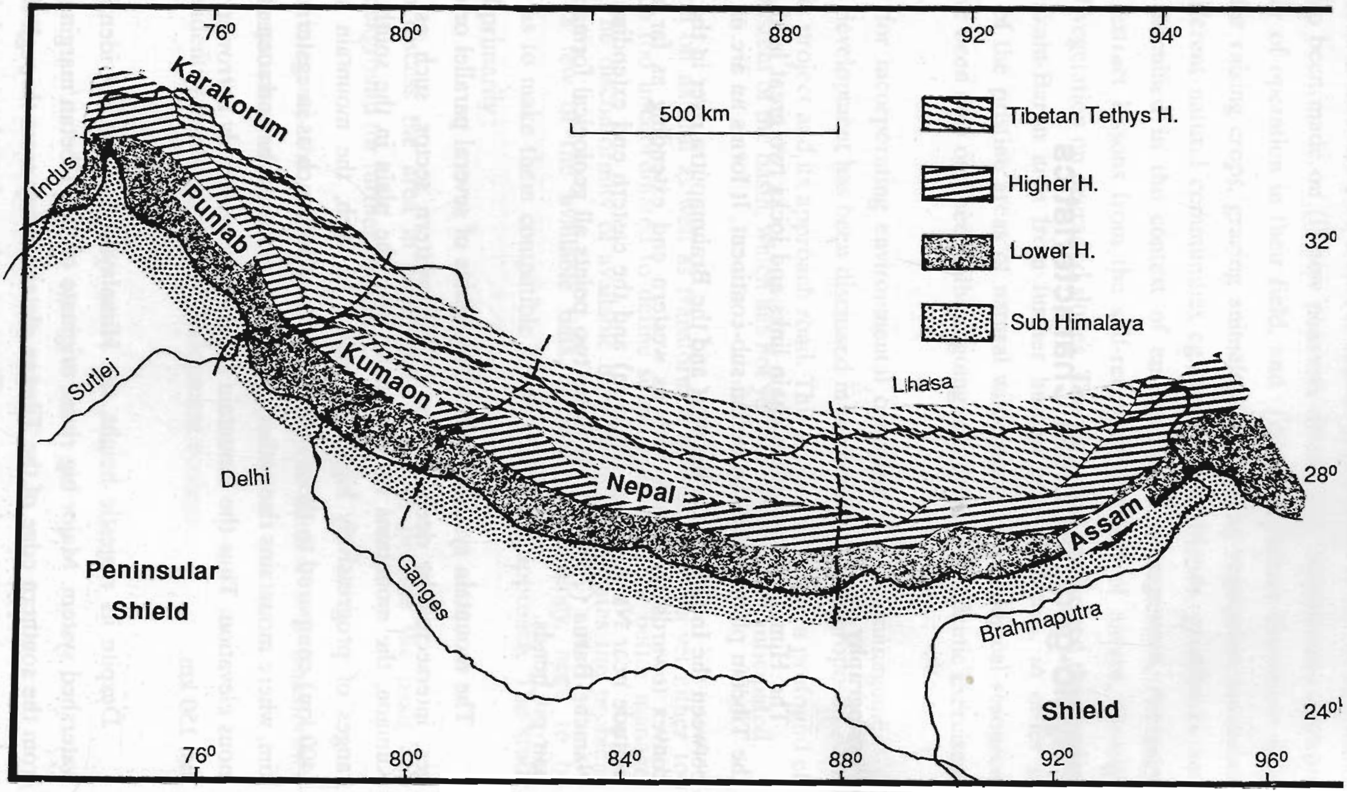
Physiography

The Himalayan mountain chain links and locks two great land masses of Asia, the Tibetan plateau and the Indian sub-continent. It forms an arc of about 2,500 km between the Indus river in the west and the Brahmaputra river in the east. The arc is convex towards the south, with its western end extending as far north as 36^0 N latitude near Nangaparbat (8,126 m) and the eastern end extending to 26^0 N near Namche Barua (7,756 m). At those two points all geological formations take sharp hair-pin bends.

The mountain system constitutes a series of several parallel or converging ranges, intersected by deep valleys. In the western sector, such as in Punjab and Kumaon, the mountains rise gradually from the plain in the south with numerous ranges of progressively higher altitudes. As such, the mountain system is wider (400 km) compared to those in the eastern sector, such as in eastern Nepal and Sikkim, where mountains rise rather abruptly from the plains and soon attain their enormous elevation. Thus the mountain system is considerably narrower with a width of just 150 km.

Despite its majestic height, the Himalayan range is not identified as a main watershed system. Major big rivers originate on the Tibetan marginal range or even from the southern edge of the Tibetan plateau. They cross through the much higher main range in spectacular gorges. There are altogether eleven such large rivers col-

FIG. I THE GENERAL SUBDIVISION IN THE HIMALAYA (Modified after Gansser, 1964)



lecting on the Tibetan Plateau or marginal ranges or northern slopes of the great Himalayan range, and they subsequently cross the Himalayas to the south.

The traverses of such major rivers are conveniently used to delineate various sectors of the Himalayas. Tichy (1968) has made four divisions of the Himalayas as following (Fig. 1):

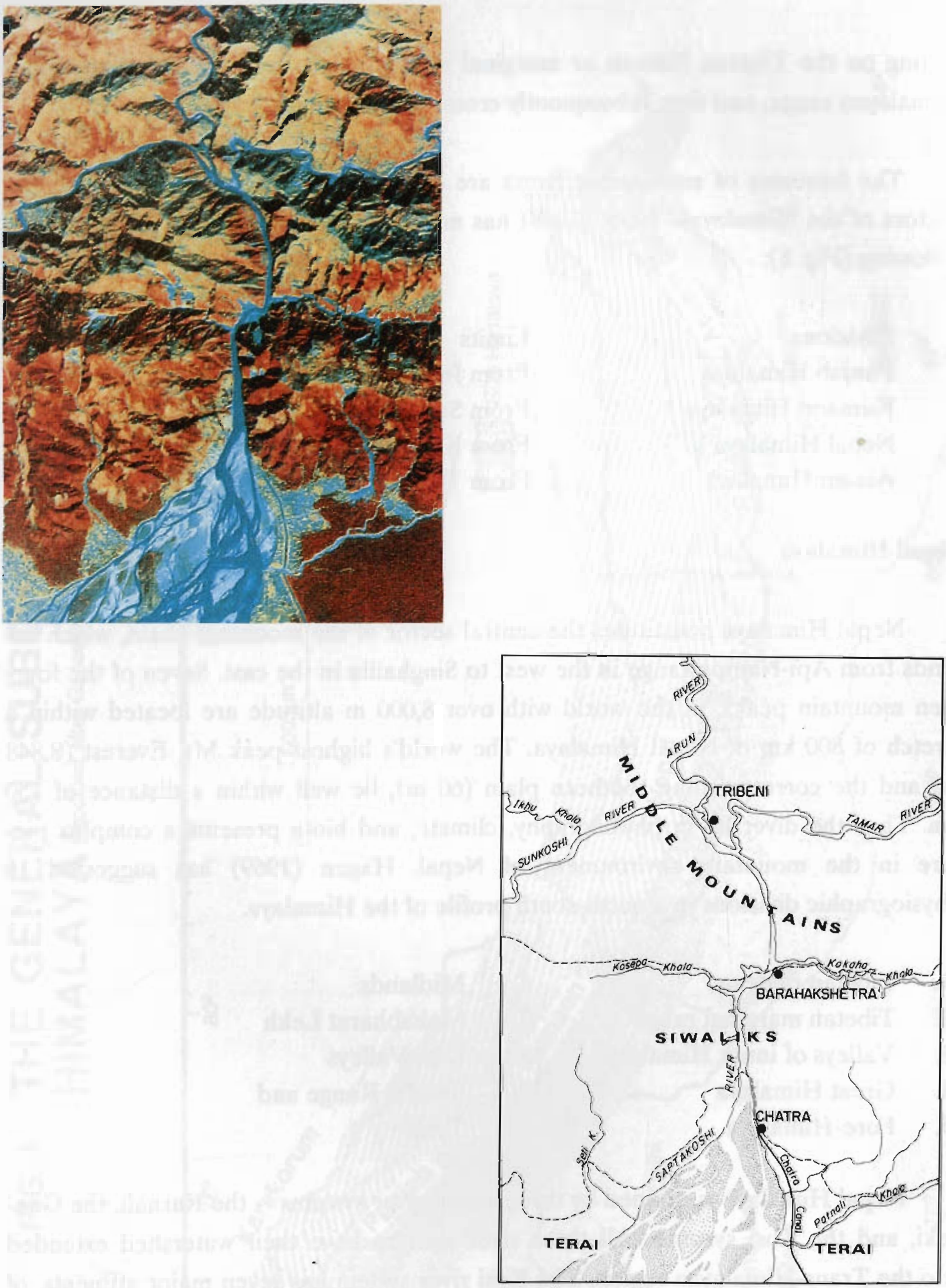
Divisions	Limits	Length (km)
Punjab Himalaya	From Indus to Sutlej	592
Kumaon Himalaya	From Sutlej to Kali	352
Nepal Himalaya	From Kali to Tista	800
Assam Himalaya	From Tista to Brahmaputra	752

Nepal Himalaya

Nepal Himalaya constitutes the central sector of the mountain chain, which extends from Api-Nampa range in the west to Singhalila in the east. Seven of the fourteen mountain peaks, in the world with over 8,000 m altitude are located within a stretch of 800 km of Nepal Himalaya. The world's highest peak Mt. Everest (8,848 m) and the corresponding southern plain (60 m), lie well within a distance of 150 km. Thus the diversity in physiography, climate, and biota presents a complex picture in the mountain environment of Nepal. Hagen (1969) has suggested 10 physiographic divisions in a north-south profile of the Himalaya.

1. Tibetan plateau
2. Tibetan marginal range
3. Valleys of inner Himalaya
4. Great Himalaya
5. Fore-Himalaya
6. Midlands
7. Mahabharat Lekh
8. Dun Valleys
9. Siwalik Range and
10. Terai

Nepal Himalaya is drained by three major river systems -- the Karnali, the Gandaki, and the Kosi systems. All these river systems have their watershed extended into the Trans-Himalayan region. The Kosi river system has seven major affluents, of which three originate in the Tibetan plateau. They are the Sunkosi, the Bhote Kosi and the Arun Kosi. The other four, the Indrawati, the Tamba Kosi, the Dudh Kosi, and the Tamur Kosi, originate in the cis-Himalayan region. These rivers get unified at Tribeni (26^0 54' 55" N 87^0 9' 45"E) and flow down into the Terai plains as the



A remote-sensing imagery showing the confluence of the Arun river with the Tamur and the Sun Kosi to form the Sapt Kosi that traverses the Terai plain of Nepal and goes further South to join the Ganges in India
(Courtesy of V. Galay)

Fig 2A

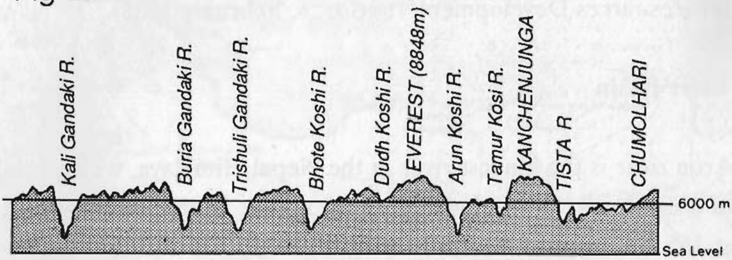
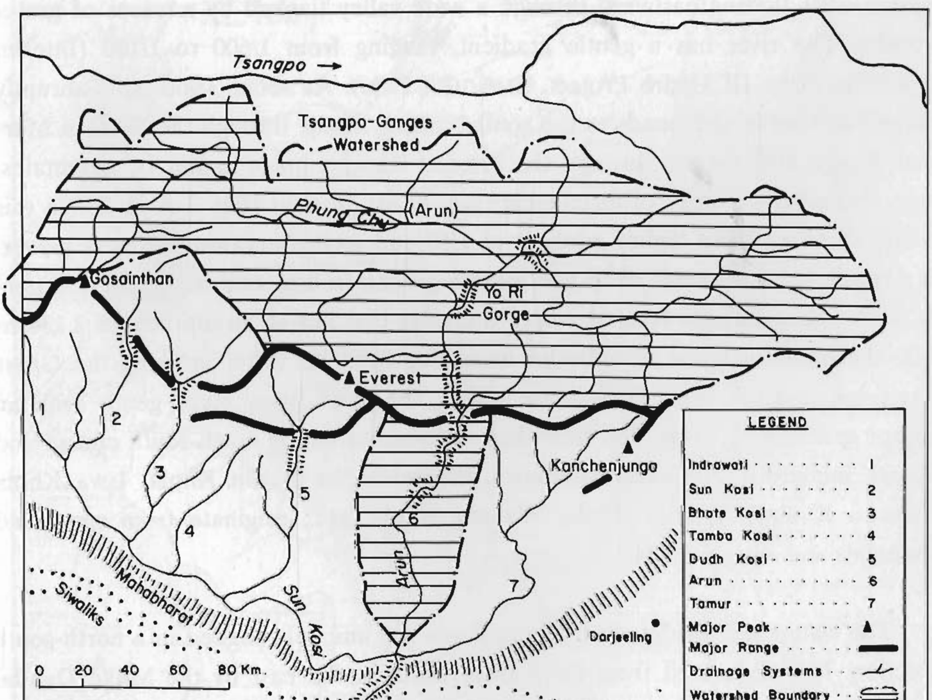


Fig A Section along the Great Himalaya of Nepal, showing the dissection of the Range by rivers. (After E.H. Pascae in Holmes 1972)

Fig. 2B Sketch map of the Arun River Catchment showing the gorges (After Holmes 1972)



Sapt Kosi. The Sapt Kosi has a drainage area of 61,000 sq km, and the Arun has a share of 59 per cent, i.e., 36,000 sq. km. (Source: Master Plan Study on the Kosi River, Water Resources Development, HMG/JICA, February 1985).

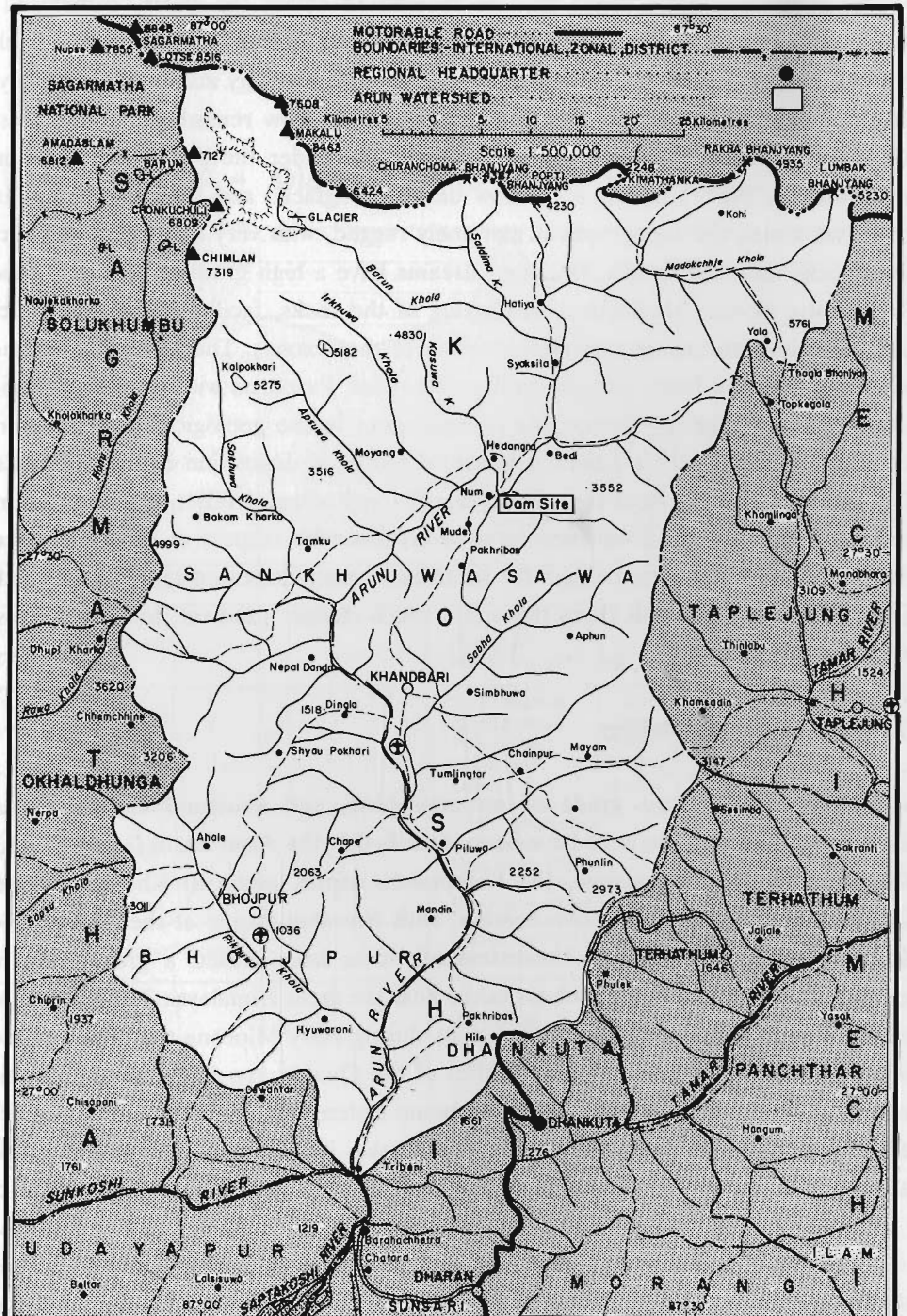
The Arun River Basin

The Arun river is the longest river in the Nepal Himalaya, with a total length of 510 km and a catchment area of about 36,000 sq km. Within Nepalese territory, the river is just 155 km long, with a catchment area of 5,028 sq km, which amounts to 14.17 per cent of the total catchment.

The Arun river starts its journey from the southern edge of the Tibetan Plateau at an elevation of about 6,700 m, and after dropping to about 4,270 m it becomes a braided river flowing eastward through a wide valley flanked by terraces of gravel deposits. The river has a gentle gradient, ranging from 1/600 to 1/100 (Interim Report on Arun III Hydro Project. HMG/JICA 1986). At about 3,960 m, it abruptly changes its course and heads to the south, cutting firstly, through the Tibetan Marginal Range and thence through the Everest-Kanchanjunga group of mountains. Deep and narrow gorges of formidable nature are formed (Fig. 2 A & B). In this section the river has a higher gradient of 1/50 and attains enormous erosive power. As a result, it has formed deep and narrow gorges; in fact, one of the deepest gorges in the Himalayas is formed where the river bed lies at an altitude of 2,136 m while the mountains rise to altitudes exceeding 8,000 m. After crossing the Great Himalayan and the Fore Himalayan ranges, the river flows more gently with an average gradient of 1/360. The river then maintains a nearly north-south course and collects numerous perennial tributaries, of which the Barun Khola, Iswa Khola (Irkhuwa Khola), Apsuwa Khola, Wakang Khola, etc., originate from snow-clad mountains and are glacier fed.

The watershed divides of the Arun Basin are uniquely aligned in a north-south direction. It is separated from the Tamur Basin in the east by the Milke Danda, which continues as Lumbasumba Himal towards the north. The western divide of Chamlang and Mayam Danda separates the Arun Basin from the Dudh Kosi Basin in the west. Thus the Arun Basin in Nepal forms a rectangular watershed. (Fig. 3)

FIG. 3 **MAP OF ARUN BASIN**



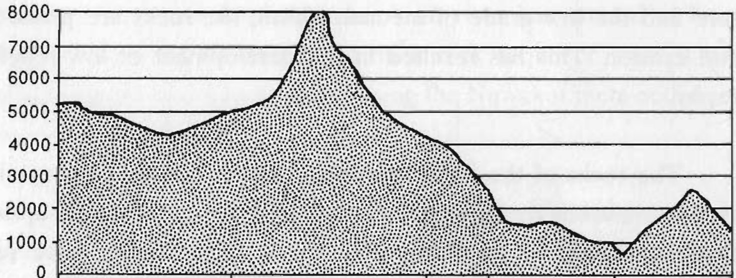
Four physiographic zones may be recognized within the Basin, namely, (1) Great Himalaya, (2) Fore Himalaya, (3) Midlands and (4) Mahabharat Lekh (Fig. 4). Due to variations in elevation, relief, climate, geology and tectonic history, hill-slope characteristics and drainage characteristics show remarkable differences. While the great Himalayan areas are continuously under the action of glaciation processes, the Fore Himalayas are now under peri-glacial and fluvial activities. In these two zones, the topography is extremely rugged, with very high relief and serrated rocky mountain peaks. Drainage streams have a high gradient and thus have high erosive power. Mechanical weathering of the rocks, facilitated by high relief and the cold arctic climate, is characteristic of these zones. The Midlands, on the other hand, have a lower altitude and gentler relief. Favoured with warmer climatic conditions and relatively lower rate of upliftment in the geological past (Quaternary), the Arun river has passed a phase of sediment deposition in the Midlands. The tributary streams have concave (upward) longitudinal profiles, and their riverbeds have reached the local base level of erosion with respect to the main river. However, the Mahabharat Lekh in the south has a much increased relief and ruggedness. The Arun river thus flows through a much steeper gradient, forming narrow valleys in this section.

Geology and Geomorphology

Based on lithology, grade of metamorphism, and structural characteristics, three main litho-tectonic units have been identified in the Arun Basin (Hagen 1969). They are: (i) Nuwakot nappe, (ii) Kathmandu nappe, and (iii) Khumbu nappe. These units are piled one above another, with Nuwakot nappe at the bottom and Khumbu nappe on the top. These tectonic units have moved a great distance towards the south and their "root-zones" lie near the great Himalayas. It is this southward thrust movement of the tectonic units during early Miocene that has resulted in the Himalayan orogeny. Recent studies of the Quaternary deposits, geomorphic features, and geodetic surveys of this mountain system show that the Himalayas are still active. The occurrence of frequent earthquakes in the region also supports this fact.

The Nuwakot nappe rocks are exposed in a tectonic window in the middle part of the Arun valley between Diyale (north of Dhankuta) to Chandanpur, and between Dingla and Chainpur. The Nuwakot nappe rocks are surrounded by the rocks

FIG. 4 Diagrammatic Profile of Arun Basin



	Tibetan Marginal Range	Great Himalaya	Fore Himalaya	Midlands	Mahabharat
ARUN River gradient	1/600 to 1/100	1/50			
Hill Slope angle		Steep(>40°) = 73% Moderate(<40°) = 27%		Steep 41% Moderate 57.25% Gentle 1.75%	
Land use		Cultivated land 2.5% Grazing land 20.0% Forest land 34.5% Shrub land 12.75% Others 30.25%		45.0% 4.5% 41.25% 8.75% 2.0%	
Geology		Gneiss, Migmatite, Calc-gneiss, Mica schist, Granite		Phyllite, Quartzite, Slate, Mica schist, Gneiss	
Climate		Sub-Alpine to Nival		Tropical to Temperature	
Active Geomorphic Process		Glacial, Fluvi-glacial and Mass movements		Fluvial and Mass movements	
Major Mass movement Processes		(i) Rock slide (ii) Rock fall (iii) Talus creep (vi) Solifluction (v) Creep (vi) Debris and debris avalanche		(i) Debris fall and flow (iii) Earthslump (vi) Rock fall (v) Mud flow.	
Population density per Sq. Km.		37.2		145	

of higher tectonic unit, the Kathmandu nappe. In the east, near Chainpur and Phakuwa, the Nuwakot nappe rocks occur between Kathmandu nappe rocks as tectonic scales. The Nuwakot nappe rocks are characterized by low grade metamorphism (epigrade), and the rock types include (1) green-grey and dark grey phyllites, (2) silicious phyllite, (3) calc-phyllite, (4) argillaceous quartzite, and (5) limestone. These rocks are interbedded with each other. Because of their dominantly pelitic nature and the low grade of metamorphism, the rocks are prone to easy weathering and erosion. This has resulted in the development of low relief and gentle topography.

The rocks of the Kathmandu nappe unit, which are tectonically superimposed on the Nuwakot rocks, are more metamorphosed, reaching up to garnet grade and occasionally up to kyanite grade. These rocks, being more recrystallized during metamorphism, are relatively more resistant to weathering and erosion. Such rocks are exposed in the Milke Danda, Dhankuta, Bhojpur and Mayam Danda area. The rock types are (1) Muscovite-Biotite Schist, (2) Garnet-Muscovite-Biotite Schist, (3) Calc-Schist, (4) Quartzite, (5) Augen gneiss, and (6) Porphyroblastic gneiss. At places, pegmatite veins and basic intrusive rocks are seen traversing these rock-types, both along and across the foliation plane. From the economic point of view, this rock unit bears much importance, as numerous deposits of precious and semi-precious stones like aquamarine, beryl, garnet and tourmaline occur in this unit and a number of small-scale mining operations are taking place in the Chainpur-Hyakule area.

The rocks of Khumbu nappe occur in the northern part of the Arun valley. The rocks are hard, resistant, and massive in nature. They include (1) Garnet mica Schist, (2) Kyanite mica Schist, (3) Micaceous quartzite, (4) Migmatites, (5) Augen gneiss, (6) Porphyroblastic gneiss, (7) Calc gneiss, and (8) Crystalline limestone. The Makalu granite, constituting the Makalu group of mountains, is an intrusive leucogranite body of Tertiary age. The intrusive veins of the off-shoot of this granite intrusion are seen in the Jyak Kharka area also.

Major Geologic Structures

The Arun transverse anticline and the Lumbasumba-Milke Danda and Bhojpur transverses syncline are major geological structures that have substantially influenced the physiography, climate, and consequently the biota of the region. The Arun Anticline has dictated the course of the Arun river, as the anticlinal hinge provided an easy path for erosion and excavation by the river. The Arun anticline is believed to be a pre- Himalayan structure (Lombard 1958), that has been reactivated during the Himalayan orogenic movement (Hagen 1969). The down-cutting of the Arun river kept pace with the rise of the Himalayas at most times (Wagner 1937; Hagen 1969). It has been estimated that the Arun river has eroded at least 8,000 m (Hagen 1969) to 15,000 m (Bordet 1961) thick rock sequence since it has formed a tectonic window in the midland zone, exposing the Nuwakot meta-sedimentary rocks of the lowermost tectonic unit.

The thrust planes along which the three tectonic units (Nuwakot nappe, Kathmandu nappe, and Khumbu nappe) travelled to the south have produced effects of shearing in the rocks of its vicinity. As a result, these thrusts provide weak zones, which are susceptible to erosion and instability.

Drainage Characteristics

Drainage is one of the most important sculpturers in the Himalaya. The drainage pattern in the Arun basin may be described as dendritic in form. In the Great Himalayan as well as the Fore Himalayan regions, rivers mostly follow geological structures like foliation and joints. Besides, the relief ratio and the quotient of height to length of the tributaries like Barun Khola, Kasuwa Khola, Apsuwa Khola, etc., are quite high. As a result, the longitudinal profiles of these streams are straight. Active down-cutting becomes inevitable for those rivers, thus rendering the valley slopes a steep angle. Mass wasting is favoured in such a situation. The main valley of Arun is also deep and v-shaped in areas lying north of Num. The river, with its gradient of 1/50, is quite active in down-cutting, while the tectonic upliftment is also quite active in this area. Thus the valley has become v-shaped, with numerous hanging tributaries (water falls), which could not keep pace with the Arun River in its down-cutting activity.

The drainage pattern in the midlands is quite different in character. The river, with its gentler gradient (average 1/360) shows a riffle and pool character. The valley is broader and the slopes are gentle. This is a favourable feature for intensive agriculture. The tributary streams also have a gentle gradient, and the L-profile has its concavity towards the sky.

The Arun has formed a number of flat terraces, composed of alluvial plain deposits of Quaternary time. The Tumlingtar air strip itself is about 180 m above the riverbed, and the river is still cutting down these alluvial plain deposits without reaching the bed rock. The river is reactivated for powerful down-cutting in the Mahabharat region, which could well be attributed to the relative upliftment of the region.

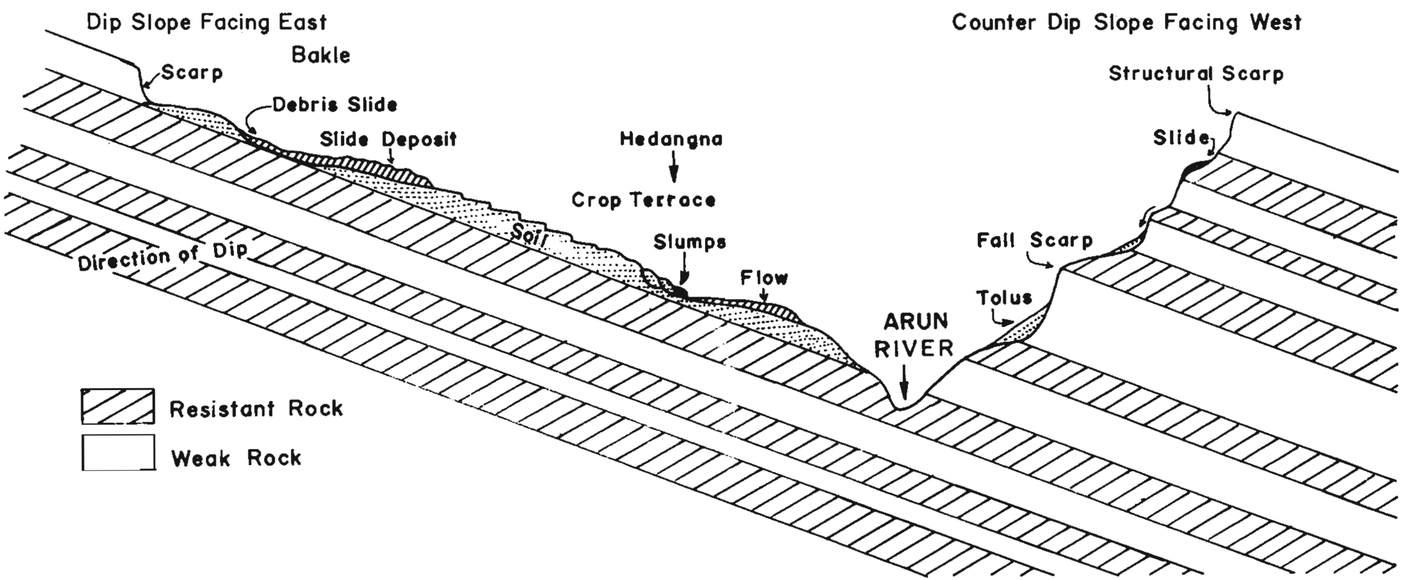
The Arun drainage in Nepal has three distinct zones: (i) northern zone of the Great Himalaya and the Fore Himalaya, where the river is flowing with active down-cutting through steeper gradients and deep gorges; (ii) the midland zone of wide valleys, with depositions of thick alluvial sediments of old age and with tributaries, which form extensive alluvial fans near confluences; and (iii) the Mahabharat zone, with narrow and deep valleys, which are being actively subjected to down-cutting.

Slope Characteristics

Hill slope characteristics are determined by various tectonic movements and other geological processes, such as glacial, fluvial, gravity (mass movements), and the base level of erosion. The effects of climate, vegetation, and human interventions contribute to the dynamics of those slopes. The Arun Basin may be divided into two distinct zones on the basis of slope characteristics - (i) the northern zone of Great Himalaya and Fore Himalaya, and (ii) the southern zone of Midlands and Mahabharat range.

1. **The northern zone:** The northern part of the Arun Basin, lying north of Num, is characterized by high elevation (more than 2,500 m), high relief (3,000 m), cool-temperate to Nival climate, and lower population density (37.2 inhabitants per sq km). Most of this region had been affected by past glaciation, and a variety of glacial, periglacial, and fluvio-glacial landforms can be observed in this area. About 73 per cent of the area is steeply sloping ($>40^0$ slope) and 23 per cent has a moderate slope ($<40^0$ slope) as can be seen on the LRMP maps. Most of the streams are along the geologic lineament structures, i.e., foliation, joint, or fault planes. Because of the extreme relief (height difference between valley bot-

Fig.5 IDEALISED CROSS-SECTION ACROSS UPPER ARUN SHOWING TYPICAL MASS WASTING FORMS ON DIP AND COUNTER-DIP SLOPES



tom and ridge top) and cold climate, mass wasting processes in the form of rock-fall, rock-slides, debris fall and flow, solifluction and soil-creep are to be seen at various places. The relationship between geologic structure, hill slope form, and geomorphic processes may be illustrated in a cross-section diagram designed for Hedangna areas (Fig. 5). The rocks have a NNE-SSW strike with dip amount of 35^0-40^0 due east. They are jointed mainly along three sets; N 30^0 - 50^0W /90^0, N 70^0 W/90, and N 20^0 - 40^0 E/70^0 S - 90^0. The Arun river, particularly from the village of Uwa to Pheksinda, has an almost straight course, flowing from NNE to SSW and follows the strike of the country rock. The east-facing slopes of Bakle-Hedangna villages are situated on the east dipping foliation surface of the gneissic country rock, whereas the west-facing slope on the left of the Arun river is a counter dip slope (Fig. 5). Thus, the interaction of geologic features with geomorphic processes and the climate has given rise to a sequence of landforms from the ridge top above Bakle village to the riverbed, which is quite different from those on the eastern-side slope of the river valley. The rock fall and rock slide, aided by freeze- thaw cycle at suitable elevation produce rock scarp with rock debris, which ultimately slides and gets collected at favourable slopes to form soil cover on the bed rock. Such sites are generally terraced for agriculture. The toe parts of those terraces are susceptible to slumps and flows from excessive moisture content and increased slope angle near the river. On the other hand, the counter dip slopes have only narrow patches of talus deposits available for cultivation. Thus most villages and agricultural fields are located on the western side of the valley, where various processes of mass-movement are operative.

The southern zone: In the southern zone, the Arun river and its tributaries have formed relatively wider valleys, flanked by gentler valley slopes. Chemical weathering has played an important part in shaping the landscape of this zone. The topography is more mature, with thick soil cover and red-clay formations. However, physical denudation is, nevertheless, also an active process, which is manifested by gully and rill erosion on the slopes, and by the active down-cutting of earlier flood plain deposits and bed rock by the streams. In this zone, about 57.25 per cent of the land area constitutes moderate slopes (<40 slope), 1.75 per cent alluvial plains (Tars) and fans and 41 per cent steep slopes (>40 slope).

Terracing a steep slope in the Arun Valley is a futile effort for farmers. The picture shows a steep slope (near the confluence of the Barun) under heavy human pressure and its consequences

Soil Erosion Processes

Soil erosion has been recognized as a major problem confronting mountain development, and lack of reliable data compounds the problem. This is further aggravated by contradictory data on measurements of land resources, soil erosion, sedimentation, forest coverage, and so on.

Soil erosion, in terms of both surface erosion and mass wasting, has been observed in the Arun Basin during the field expedition of August-September 1986. Sufficient attention to surface erosion, which is more damaging to the rural communities in their agriculture, forestry and livestock, has not yet been paid. Erosion is especially severe in the tropical and sub-tropical area, which is dominated by red soils. Streams flowing through red-soil hill-slopes and river terraces (Tars) virtually 'bleed' during rains. Slopes without adequate terracing and without dense coverage of trees and shrubs are turning into bad lands through sheet erosion. Even forested areas with Pine, Sal, and Schima have bare forest floor with exposed tangles of tree roots, as observed near Legua Ghat. Altitudinally, such areas lie below the range of '*Eupatorium*' coverage and no equivalent weed cover is available. Some farmers use *Jatropa* shrub as a contour hedge. This plant seems to be very effective in protecting contour bunds.

Slopes lying between 1,000 m and 3,000 m are rather heavily terraced, and abandoned areas also are luxuriantly covered with *Eupatorium adenophorum*. The detrimental effects of slash-and-burn are also curtailed by the invasion of *Eupatorium*. Thus the soil loss of 8 mm estimated for slash-and-burn areas (Carson 1985) would not be true for the Arun Basin. Surface erosion above 3,000 m does not seem to contribute a lot to the general loss of top soil in the Arun Basin. It has been observed that even heavily grazed areas are rapidly colonized by unpalatable plants. Vast stretches of colourful meadows with *Primula, Potentilla, Ranunculus*, and other beautiful herbs can be attributed to over-grazing by sheep and yaks.

Loss of shrublands from the sub-alpine zone due to mountaineering expeditions, however, contributes to various processes of erosion, ranging from rock fall to landslides. Surface erosion in the Arun Basin has yet to be studied or measured systematically in order to build up reliable data. The data from Chatra Research Centre (vide Ramsay 1986) show that the annual erosion rate has been in the order of 7.8 to 36.8 t/ha, but the period of measurement and number of plots are unknown. Other data, compiled by Ramsay (1986), show that the denudation rate in the Arun catchment is lower, i.e., 1.9 mm/yr than in the adjoining Tamur catchment where the denudation rate is from 2.56 to 5.15 mm/yr. This seems to correlate with the higher percentage of landslide area (13.85 per cent) in Tamur compared to 1.16 per cent in the Arun catchment (HMG/JICA 1985). Similarly, sedimentation load in the Arun ($970 m^3/yr/km^2$) is much less compared to that of the Tamur ($5,000\ m^3/yr/km^2$) (Table 2).

Table 2. SEDIMENTATION AND LANDSLIDE IN KOSI CATCHMENT

	Catchment area (km^2)	%	Total sedimentation load (m^3/yr)	annual sedimentation ($m^3/yr/km^2$)	landslide area (km^2)	% to total catchment
Sunkosi	19,000	31.1	$54x10^6$	2,840	642	3.38
Arun	36,000	59.0	$35x10^6$	970	419	1.16
Tamur	6,000	9.8	$30x10^6$	5,000	813	13.85
Saptkosi	61,000	100.0	$119x10^6$	1,950	1,801	2.95

Source : Master Plan Study on the Kosi River Water Resource Development HMG/JICA, February 1985.

Surface erosion has a detrimental effect on agriculture, horticulture, forestry, and livestock. Mass-wasting processes, on the other hand, cause more dramatic damage to the lands and lives of people. Although there are limited things that man can do to control those natural processes, there is a lot of scope for men to escape from disastrous effects of floods and landslides. It needs knowledge to do so. Studies and research generate such knowledge, which is transferred from people to people through training.

In the Arun Basin, mass movement may be categorized inot two zones:

(i) Southern zone (South of Num)

Type of Mass Movement	Type of Land Forms	Examples observed
1. Rock fall	Structural scarp	Along embankments of major streams and tributaries e.g.,Leguwa khola
2. Debris fall	Colluvial deposits and alluvial deposits	Near Diale, along Arun banks
3. Earth slump	Gentle to moderate slopes	Dandakharka
4. Debris slide	Moderate to steep hill slopes	Arun river banks
5. Debris flow	Alluvial plains and tars	Tumlingtar

(ii) Northern zone (North of Num)

Type of Mass Movement	Type of Land Forms	Examples Observed
1. Rock fall	Structural scarps	Upper Barun valley, Bakle, Ala, Uling
2. Debris fall	Talus, scree deposits, morainic deposits	Upper Barun valley, lower valley slopes of Arun
3. Rock slump and rock slide	Rocky terrain with steep slopes and highly fractured rocks	Kikila pass, Jark kharka, eastern slopes at Num
4. Soil creep	Gentle to moderately sloping mountain slopes	Near Tashigaon and other places in Kasuwa valley
5. Solifluction	Talus and scree aprons, gently to moderately sloping mountain slopes, slopes with soil and saprolite cover	Upper Arun valley, Barun valley

Climatic Features

Physical factors of the mountain environment, particularly latitude, altitude, and position in relation to seas and land-masses, determine or limit not only the dis-

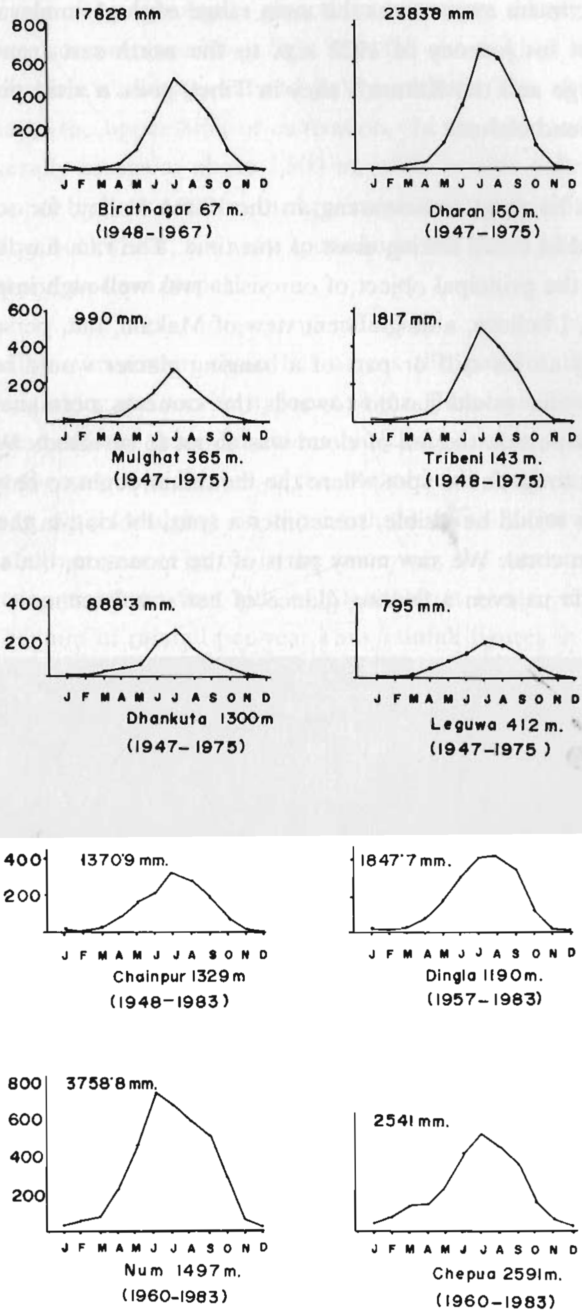
Down-cutting is very active along the Barun river. Slopes are unstable and erosion is a natural phenomenon

Leaning trees in an aldar forest (*Alnus nepalensis*) indicate soil-creep on the slopes of the Kasuwa Valley, a tributary of the Arun tribution of plants, animals, and natural resources but also the activities of human beings. Many of the most important physical factors of land environment are understood in terms of climate. The climate of an area is generally expressed in various meteorological parameters, considering the whole range of weather conditions, temperature, rainfall, evaporation, sunlight, wind, and so on. Unfortunately, the terrain and topography of mountains, coupled with the lack of material resources and educational base among the people, have resulted in a serious paucity of meteorological data in the Hindu Kush-Himalayan region. The Arun Basin has less than 20 meteorological stations along its river course of 510 km, and most of them record rainfall only. Pakhribas Agricultural Centre is the only place to have initiated systematic records on meteorology in the whole of the Arun basin.

The Arun Basin falls in the eastern Himalayan regime, where the monsoon starts early and lasts longer. The premonsoon rainfall during April and May is also much more pronounced. It is often accompanied with hailstorms and thunderstorms. The premonsoon rain gradually passes into the full force of the monsoon by the first ten days of June. The premonsoon precipitation plays a significant role in initiating the growth and spread of protective vegetal cover of weeds and grasses on land surfaces, before they are subjected to the heavy downpour of monsoon rains. Besides, the spring rain is indispensable to hill agriculture for planting maize, millet, and potato. Stainton (1972) found the Arun and the Tamur Valleys to be far wetter than he had experienced in other parts of Nepal during April and May. Winter rain, which is rather conspicuous in the weather system of western Himalaya, plays a much diminished role in the Arun Basin.

The annual rainfall amount in the Arun Basin suggests that midland regions, as exemplified by Bhojpur (1,200 mm/yr), Chainpur (1,370 mm/yr), and Dingla (1,850 mm/yr), have a medium range of rainfall comparable to other midland regions such as Okhaldhunga (1,800 mm/yr), Kathmandu (1,324 mm/yr), and Dailekh (1,300 mm/yr) (Fig. 6). Areas lying closer to the main range of the Himalaya show much wetter conditions. Num, for example, has an average annual rainfall exceeding 3,400 mm/yr. At times, the record goes as high as 6,300 mm/yr. Thus a pocket of heavy rainfall is to be identified in the upper Arun. The occurrence of tropical monsoon forests, with tree ferns at lower altitudes and big leaved species of *Rhododendron* at higher elevations shows a close resemblance between the upper Arun and northern Pokhara Valley, which has been known to be a pocket

Fig.6. Rainfall records of various stations located in Arun Basin



of heavy rainfall in Nepal (Dhar and Mandal 1986). Unlike the Pokhara pocket, the Arun Valley allows the monsoon rain to penetrate far towards the north, creating a corridor of humid climate even across the main range of the Himalaya. Colonel C.J. Morris's account of his journey of 1922 A.D. to the north-east frontier of Nepal, along the Arun gorge and the Karma Valley in Tibet, gives a vivid picture of a wet season towards the end of June:

"We had been in camp at Sakyateng, in the Kama Valley, for some days, and had been enveloped in cloud during most of this time. The rain hardly ever ceased, and photography - the principal object of our visit - was well-nigh impossible. From Sakyateng, there is, I believe, a magnificent view of Makalu, but, personally, I never saw it. Occasionally an ice cliff or part of a hanging glacier would be visible for a few moments, and one would hasten towards the cameras permanently set up in readiness - in the hope that the fall of cloud was about to be lifted. We spent hours in this way, looking towards the spot where the mountain ought to have been visible; sometimes the base would be visible, sometimes a spur, looking in the evening glow as though carved in coral. We saw many parts of the mountain, but she was always too shy to vouchsafe us even a fleeting glance of her stately summit" (Northey and Morris 1928).

The glacial valley of Yangle (upper Barun), unlike other inner valleys of Nepal, is extremely wet. It is used as a summer pasture for yak and sheep

The months of August and September were similarly wet and snowy during the 1986 scientific expedition of the present author. The shower of rain at the subtropical and temperate zones gradually passed into a misty drizzle in the sub-alpine region, which was soon replaced by a light snowfall above 4,000 m altitude. Thus the kind of precipitation is directly related to the altitude.The altitude at which the cloud hangs marks the upper limit of cultivation. In the main valley of upper Arun, cultivation generally ceases at about 1,800 m, while in side valleys local conditions allow cultivation as high as 4,000 m in rare instances. High altitude crops, such as naked barley and buckwheat, are very sporadic in the Arun basin, as compared to those in central and western Nepal.

The Himalayan mountain chain lies across the path of the monsoon, which flows east to west along the southern slopes of the Himalaya. Thus mountain ranges that run east-west enforce drier conditions on leeward areas. For example, Dharan Bazaar lying at the southern foothill of the Mahabharat Lekh receives 2,380 mm of rainfall per year, while Mulghat on the northern foothill (leeward) receives only 990 mm of rainfall per year (Fig. 6). In the same way, the southern edge of the Arun basin lying on the northern foot-hills of Mahabharat range, such as Leguwaghat, receives only 790 mm of rainfall per year.Thus rainfall figures in the Arun Basin increase progressively from south to north until the Himalayan crest screens off the Tibetan plateau from the monsoon rains.

Altitudinal gradient is the most apparent and conceivable of all the parameters in describing mountain environments. Changes in climate with change in altitude are always noticed by a mountain traveller. On an average, the air temperature falls by $0.6^{0}C$ per 100 m. Based on the correlation between altitudinal distribution of vegetation zones and air temperature, various authors have classified Himalayan mountains into various bioclimatic zones. It should be noted here that although temperature in general falls with increase in altitude, other environmental conditions do not mirror precisely all along the Himalayas. This is well illustrated by the differing flora and vegetation along the Himalayas. The effect of latitude, for example, is readily observed in the distribution of vegetation patterns on various slopes. In the western Himalaya, south-facing slopes and north-facing slopes have totally different types of vegetation. In the eastern Himalaya, this aspect is rather diminished. In the Arun Valley, forest vegetation on southern slopes, hardly differs from those on northern slopes, especially at tropical and sub-tropical levels.

There are many features of mountain climate that are not understood even today. Our knowledge of these features will improve only when we acquire more data and better monitoring facilities. With remote sensing technology at hand, better information on the climate of Himalaya would build up more rapidly. However, more data from field stations will have to be generated to supplement data from remote sensing in order to understand the functioning of ecosystems in the Himalaya.

Water Resources

The Himalayas shoulder vast seas of snow and ice, which are renewed annually by monsoon clouds. A large quantity of water, in the order of 200 billion cubic metres, goes back to the sea as surface runoff (B.K. Pradhan *et al.* 1983) through innumerable rivers which drop thousands of metres before reaching the plains. It is estimated that Nepal has 6,000 rivers distributed into three river basins -- the Karnali, the Gandaki, and the Kosi basin. Government estimates place the theoretical hydroelectric development potential in Nepal at 83,000 megawatts; economically feasible schemes amount to 25,000 MW only. However, the existing power- generating capacity in Nepal, as of 1985, is approximately 128 MW (Master Plan Study on Kosi River HMG/JICA 1985).

In the Kosi basin, 52 sites have been identified with an installed capacity of 10,909 MW. The Arun basin has six sites for installed capacity of 1,185 MW. Among them, Arun III has been regarded as the most attractive scheme in the Kosi basin. The feasibility study on Arun III Hydro-electric Power Development Project (Nov. 1986) has worked out a scheme with 400 MW capacity. This scheme is the run-of-river type hydropower project, and the construction cost is originally estimated to be U.S. dollars 472.6 million. The cost includes an access road of about 170 km, transmission lines and sub-stations.

The project site is located 40 km south of the Nepal-China border, and three village panchayats, Num, Pathibhara, and Diding in Sankhuwasabha district of Kosi Zone, come into direct contact with this site. The catchment area at the dam site has been estimated to be 29,310 sq km., of which 90 per cent lies in the Tibetan region. The area under heavy monsoon rainfall amounts to some 10 per cent of the catchment, and the monsoon flood does not seem to be so severe. Numerous glaciers and snow-packed mountains serve as the source of feeding for this river. The annual average discharge is calculated to be 321 m^3 per second at the project site. (H.M.G./JICA 1985.). A large part (almost 68 per cent) of Sapt Kosi River lies above 3,000 m, where the drainage area is covered by perennial snow and glaciers. Thus the larger part of the basin produces an insignificant portion of the runoff, especially flood runoff, resulting in a low specific flood discharge (HMG 1982). In the Tamur basin also, summer runoff due to seasonal snowmelt was found to be insignificant (A.N.. Dhar *et al.* 1986). The run-off fluctuation in the Arun River is small in comparison to the Tamur and the Sunkosi rivers. (Master Plan Study on Kosi River HMG/JICA Feb. 1985). However, heavy siltation and steep topography do not favour a large reservoir type dam on this river, and thus a simple Run-of-River (SRR) type was recommended for hydro-electric developments.

The annual discharge of water from the Arun River constitutes 36 per cent (18,300 million cubic metres) of the Sapt Kosi discharge which is of the order of 50,900 million m^3. Annual average discharge is estimated at 600 m^3/sec. Thus the water resources of the Arun for hydro-electric power has great potential in Nepal. The active process of down-cutting by the river, steep slopes, heavy rainfall, and progressive deforestation in the area make it imperative to make an efficient management of the watershed, consisting of afforestation, soil conservation, slope and landslide protection works, and mitigation of riverbank erosion. The special focus of management should lie in the area traversed by the Arun between Chepuwa and Num.

Water mills, locally known as "Ghatta", are most popular as a power device for grinding maize, millet, wheat, etc., and also for turning prayer wheels and for carving out wooden blocks to make small pots and cups. It has been estimated that over 2,500 water mills are in operation in Nepal (Joshi 1983). The watermill survey team of Toshitaka Chuma and Akihiko Namura (Numata 1983 a) did not report a single one from the Arun Basin. However, the author did find a water mill in Syaksila village where various kinds of wooden pots were skillfully made by the use of water as a motor force. Similar mills designed to produce juniper paste by rubbing against stone was recorded from Thudam. Furer- Haimendorf (1975) mentions that in November 1957, verandahs and homes were full of heaps of powdered pulp and large balls made of juniper. Juniper pulp is an important ingredient of the incense used in Buddhist rituals. The development of such traditional devices for harnessing water resources at the rural level would have far-reaching effects on the local economy as well as ecology.

Irrigation, Drinking Water and Fisheries

The Arun Basin on the whole depends on direct precipitation for irrigation in the hilly regions. Rivers and streams are used in low-lying alluvial plains and river-beds. A number of terrace lands, "Tars", could well be converted into fertile lands if irrigation could be provided for them. Quite a number of villages in Sat Tar and Tumling Tar have to rely on the Arun river for drinking water, which flows 100-200 m below their village level. In most of the other parts, hill streams and natural springs are prime sources for drinking water. Local townships and new settlements lying on the ridges and saddles have to lay pipes for long distances. Such locations are few and far between. In fact the beneficiaries of piped water by the end of Sixth Plan (1980-85) amounted to only 18 per cent in the rural sector (HMG 1986).

Fish resources in the waters of Arun have not yet been studied. It is generally accepted that the Arun has a large number of native fish (84 species) and a number of them (14 species) have commercial potential. The fish fauna will be discussed later in this study.