Ecohydrology of River Basins of Nepal

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Abstract

Nepal presents diverse geoecological conditions due to differences in altitude, geology, and orientation of the mountains. Because of these differences, the climatic and hydrological regimes also vary from one part to another. An understanding of the availability of water, its flow behaviour, and controlling factors is essential not only for the development of water resources but also for better management of other environmental resources, particularly soil and vegetation. The present paper attempts to analyse temporal and spatial variation in surficial water and upstream-downstream linkages and to highlight issues of ecohydrological concern.

The study is primarily based on monthly and annual river discharge data published by the Department of Hydrology and Meteorology (DHM) and Nepal Electricity Authority from 65 hydrological stations. In addition, information on the basin characteristics of 44 watersheds published by the Water and Energy Commission Secretariat (WECS) has been used. The length of observations in these stations ranged from only four to 32 years. Given the limited data, this paper attempts to discuss the hydroecological issues and trends within the country in general terms only.

Biophysical Features

Altitude changes rapidly over short distances along the north-south transects in Nepal. For example, even within the short distance of about 160km, the height of the Nepal Himalayas, including the *Terai,* ranges from 60m in the south to 8,848m in the north, and the mountains belong to several different geological periods. All these mountain chains essentially extend from east to west and in parallel with the 'Greater Himalaya' creating a sequence of wetter and drier areas. This has resulted in significant differences in landscape patterns. Nepal is broadly divided into five physiographic regions, viz., the *Terai,* in the south, Siwaliks, Middle Mountains (hills), High Mountains, and High Himal from south to north (Fig. 1). The *Terai* plain in the south, representing about 14 per cent of the total area of the country, is composed of Quaternary alluvial deposits of altitudes ranging from 60m to 300m. Nearly 70 per cent of the total area in the *Terai* is under agricultural use. The dominant vegetation is sal (*shorea robusta).* The Churia Hills (Siwaliks) are composed of Tertiary sandstones, shales, and conglomerates, its altitude ranging from 200 to 1,500m. The inner *Terai* (Dun valleys) lies within the Churia Hills.

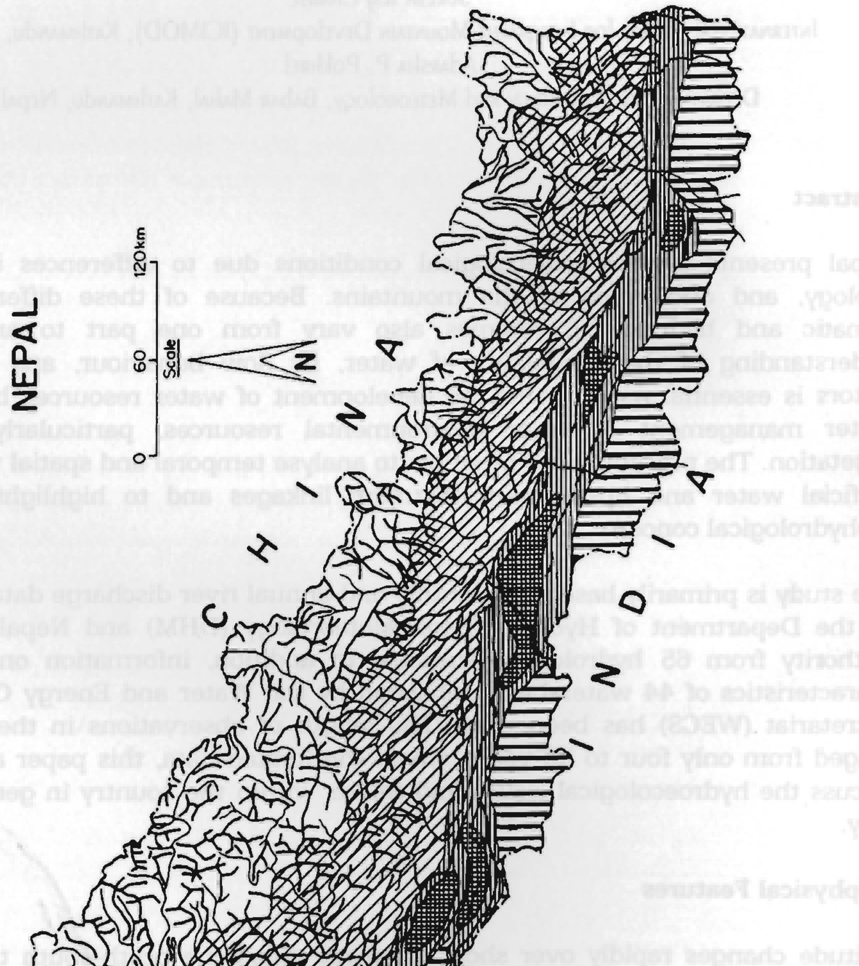

Figure 1: Physiographic Regions, Major Ranges and Rivers

Together they comprise about 12 per cent of the total area. The Middle Mountains, including the Mahabharat *lekh*, are composed of phyllites, quartzites, limestones, and islands of granite and make up 30 per cent of the total area of Nepal. The altitude ranges from 800 to 2,400m. Dominant land-use types in this region are agriculture and forests. The 'Fore-Himalaya' or temperate *lekh* (High Mountains), composed of gneiss, quartzite, and mica schists, represents about 20 per cent of the total area. The altitude ranges from 2,000 to 4,000m and the dominant land-use type is forests. The High Himal in the north is composed of gneiss, schist, limestone, and Tethys sediments. It occupies nearly 24 per cent of the total area. The High Himal presents four distinct physiographic units: the 'Greater Himalaya,' trans-Himalayan valleys (*Bhot*), Tibetan marginal lands, and the Tibetan plateau. The dominant land-use types in this region are rock and ice (67%) and grassland (26%). Three major tectonic discontinuities - the Main Central Thrust (MCT), the Main Boundary Fault (MBF), and the Main Frontal Thrust (MFT) — lie parallel to the entire Himalayan system.

The distribution of temperature is influenced primarily by elevation, although slight variations occur due to position, both in terms of aspect and geographical location. Nearly 99 per cent of the variability of temperature can be explained by elevation, latitude, and longitude, and 90 per cent can be explained by elevation alone (Chalise et al. 1996, Nayava 1980). The observed lapse rate over the Nepal Himalayas is 0.52°C/100m altitude (Dobremez 1976). Except at high elevations, the maximum temperatures are experienced in May or June before the onset of the monsoon and minimum temperatures in January or February. Elevations of the 0°C isotherm of the mean monthly minimum temperature correspond to 2,430masl in January and 5,200masl in July, while those of the same isotherm on the basis of the mean monthly average temperature correspond to 3,460masl and 6,000masl for January and July respectively (Chyurlia 1984).

The average area-weighted annual precipitation for Nepal is about 1,630mm, with half of the country lying within the 1,500 - 2,000mm precipitation zone (Chyurlia 1984). Both temporal and spatial variations in precipitation are pronounced. Nearly 80 per cent of the total precipitation occurs during the monsoon season between June and September, followed by eight per cent during the post-monsoon (October-January), and 12 per cent during the pre-monsoon season (Chalise et al. 1996, Chyurlia 1984). Orographic effects are strong on the spatial variation in precipitation. The recorded average annual precipitation ranges from only 163mm at Lomangtang (Mustang *Bhot*) to 5,244mm at Lumle (near Pokhara). The trans-Himalayan region, which includes Mustang and Manang, receives an annual precipitation of less than 500mm. The Karnali, Langtang valleys (Chilime, Timure) and the Khumbu Valley in the north of the high 'Fore-Himalaya' and river valleys in the north of Mahabharat *lekh*, such as Pachuwarghat, Kuruleghat and Leguwaghat, have an annual precipitation between 500 and 1,000mm. The *Terai*, Churia Hills, and lower valleys in the Middle Hills receive between 1,000 and 2,000mm of precipitation, while the major parts of mountain slopes in the Middle Hills and High Mountains receive between 2,000 and 3,000mm (Fig. 2). Diurnal rainfalls exceeding 300mm, which produce simultaneous disturbances of both slopes and channel equilibrium on a regional scale, occur frequently in the country (Khanal

1995a, 1995b). Diurnal precipitation of 540mm with an intensity of 70mm/hour has also been recorded (Dhital et al. 1993, Chalise et al. 1996).

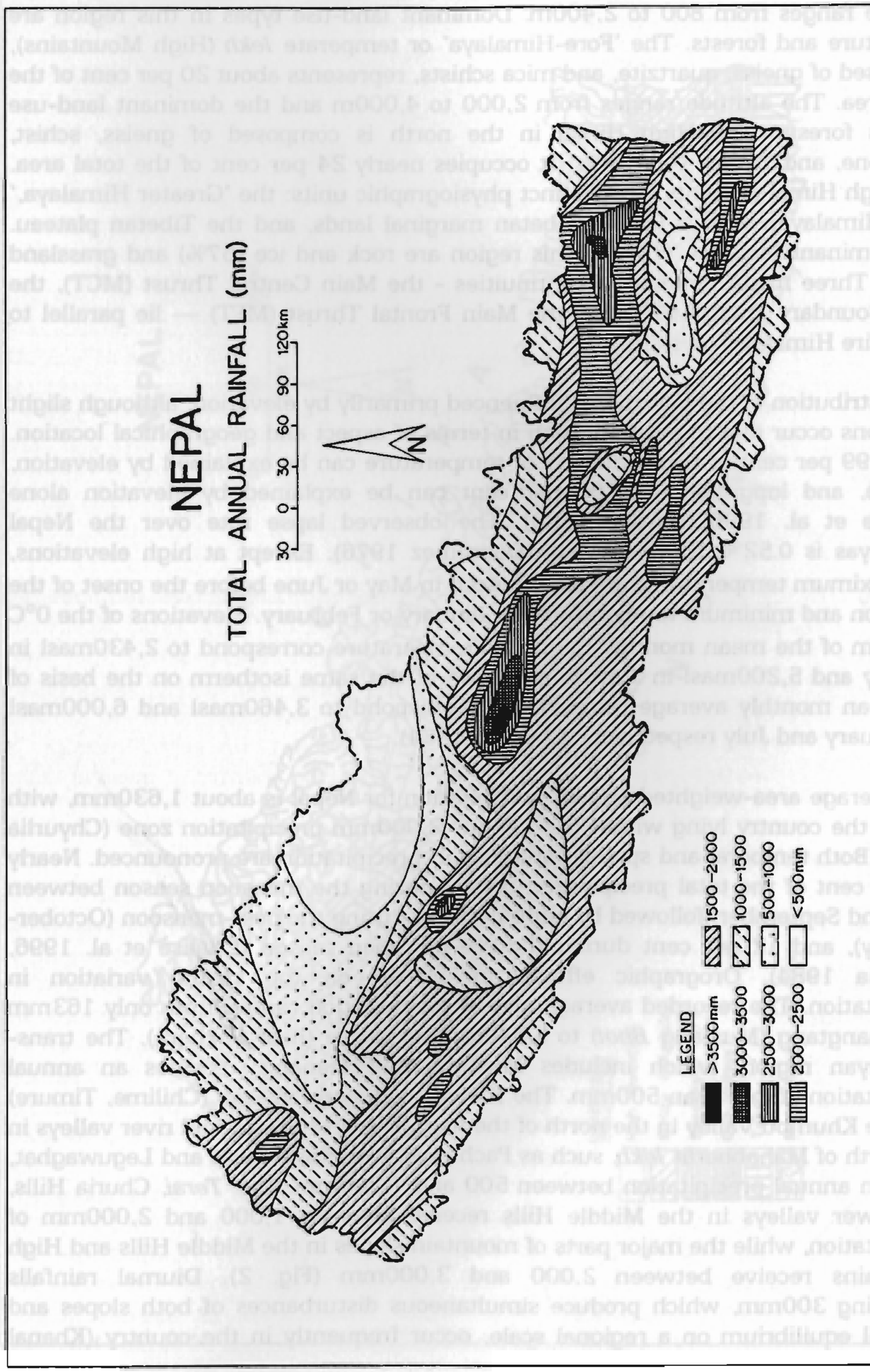

Figure 2 Total Annual Rainfall (mm)

There are some pockets of high precipitation, such as Pokhara (Kaski), Khudi Bazaar (Lamjung), Pansayakhola (Nuwakot), Sermathang (Sindhupalchok), and Kanyam Tea Estate (Illam) with more than 3,000mm of annual rainfall. At present there are only 264 pluviometric stations in the country, with more than five-years of records, whereas a minimum of 600 to 1,500 stations is required for good representation of the country as a whole (Chalise et al. 1996). This limited pluviometric network is a serious weakness when it comes to estimating the total precipitation (input) for the study of hydroecological behaviour in the river basins of the country. The estimated total annual snow accumulation for Nepal is approximately 21.10 million cubic metres of water equivalent (Chyurlia 1984).

Drainage Network

Nepal has more than 6,000 rivers and is considered to be one of the richest countries in terms of water resources. Of these 6,000 rivers, 1,000 are more than 11km long, and about 100 of them are more than 160km (Shankar 1991). The average drainage density (considering rivers greater than 2km in length) is about 0.31km/sq.km., the extremes ranging from 0.29 to 0.37km/sq.km. by watershed (Chalise et al. 1996). A general characteristic of the river system is that the number of first-order streams is comparatively high; they are of very short length and do not exhibit graded profiles, indicating a very high rate of downcutting by them. However, the major antecedent rivers (those originating from the northern part of the main Himalayas) present more or less graded profiles, with neckpoints in quite a few places of geological control (Chyurlia 1984). The width-depth ratio in relation to basin size of the rivers originating from the Churia region is exceptionally high, indicating a very high bed load. Most of these rivers are ephemeral (Gurung and Khanal 1987). The width-depth ratio in the rivers originating from the southern part of the main Himalayas is very high compared to the rivers originating from the northern side. When the rivers from the high mountain areas enter into the *Terai*, the beds become wide, and the rivers themselves exhibit anastomosis. Rivers in the *Terai* and Inner *Terai* are much more unstable. Various forms of channel shift, including avulsion, chute-off, neck-off, and meander shifts, are common in this area. This has many implications for the economic growth and infrastructural development in this region (Khanal 1993).

Temporal and Spatial Variations in River Discharge

Some 70-90 per cent of the total annual surface runoff occurs during the monsoon and post-monsoon period. The mean monthly flow volume of water ranges from less than one per cent to seven per cent of the total annual discharge in the pre-monsoon period between January and May (Table 1).

Interannual discharge variation is also very high. The coefficient of annual variation ranges from as little as seven per cent to more than 41 per cent. The coefficient of variation in the mean annual flow is significantly higher in the rivers originating from the Middle Hills and Churia area than the coefficient of variation of snowfed rivers (Table 2). An analysis of the relationship between river discharge and basin characteristics for 44 river basins indicates a negative relationship between the discharge and monsoon precipitation. As the size of the basin increases, the contributions of monsoon precipitation to runoff decreases because of the inclusion of and increase in drier and hotter lowland areas in the south as well as the trans-Himalayan region in the north.

Table 1: Percentage Ratio of Mean Monthly Flow to Total Annual Flow from Different Watersheds

Month	Minimum	Maximum
January	0.99	4.30
February	0.81	3.82
March	0.81	3.95
April	0.79	4.36
May	0.82	6.66
June	4.32	12.25
July	14.38	28.42
August	18.07	30.25
September	12.85	24.19
October	6.14	12.09
November	2.56	6.23
December	1.42	4.86

The ratio of maximum instantaneous to minimum annual average discharge is more than 500 times in many rivers of the middle and southern parts of the country. Exceptionally high flows were recorded in the upstream stations, such as Rabuwa on the Dudhkosi, Barahbise on the Sunkosi, and Arughat on the Budhigandaki, at the time of glacial lake outbursts and landslide damming flood events, whereas high flows were recorded in downstream areas at the time of high-intensity monsoon precipitation. An attempt has been made to estimate the maximum flow of a 10-, 50-, and 100-year return period using three methods: least square regression, Log Pearson Type III, and Gumbel I procedure. The average value obtained from these three methods was compared with the mean discharge. The ratio of the 50-year maximum value to the mean annual flow shows that the rivers originating in the Middle Hills are prone to frequent and severe flooding (Table 3).

Table 2: Coefficient of Variation in Mean Annual Flow

Coefficient of Variation	Stations/Rivers
> 30 %	Surna Gad, Babai, Myagdi, Badi Gad, Manahari, Lothar, Sundarijal, Kulekhani (8)
25 – 30%	Nayagaon, Tigra, Bishnumati, Tikabhairab, Chobhar, Kulekhani, Khimti (7)
15 – 25%	Rajdwari, Mulghat, Khurkot, Pachuwarghat, Melamchi, Jalbire, Barahbise, Rajaiya, Tadipul, Betrawati (Phalankhu), Khundibazar, Lahachok, Andhikhola, Setibeni, Chisapani, Jamu, Rimna, Bangaseti, Benighat, Sinja (20)
10 – 15%	Tumlingtar, Chatra, Kampughat, Rabuwa, Sangutar, Busti, Narayanghat, Betrawati (Trisuli), Bimalnagar, Shisaghat, Phoolbari, Bangasoti, Asarghat, Chamelia (14)
<10%	Uwagaon, Num, Beni, Simle, Turkeghat, Arughat, Goplingghat, Tila (8)

Table 3: Ratio of the Estimated Flow of a 50-Year Return Period to the Mean Annual Discharge

Ratio	Stations/Rivers
> 100	Mainachuli, Rajdwari, Kulekhani, Tikabhairab, Manahari (5)
50 - 100	Khimti, Panauti, Karmaiya, Pandhara, Kulekhani, Chobhar, Lothar, Rajaiya, Tadipul, Betrawati, Balephi, Jalkundi, Tigra, Babai, Sundarijal (15)
25 - 50	Rabuwa, Khurkot, Jalbire, Barahbise, Garambesi, Shisaghat, Lahachok, Andhikhola, Bangasoti, Surnagad (10)
< 25	The remaining 34 stations

It is clear from the above discussion that the heavily populated Middle Hills, Dun valleys, and *Terai* experience severe shortages in the supply of water during winter when the demand for water for irrigation and hydroelectricity is very high. Similarly, these regions are prone to flooding in summer, causing the loss of lives and property. The rapid growth in population in combination with a subsistence economy and a consequent change in land use in this region may lead to a change of natural hydrological behaviour and aggravate the problem. The big antecedent graded rivers flowing through this region are very deep. Many rivers originating from the High Himal are found to be prone to serious flooding at the time of glacial lake outbursts and landslide damming. The use of water from these rivers for irrigation and electricity generation entails huge cost. It is in this context that more attention should be paid to regulating the discharge of small- and medium-sized rivers in the Middle Hills, Dun valleys and *Terai*.

Spatial Variation in Annual Runoff

The mean annual runoff in the river basins (Fig. 3) ranges from about only 412mm in the upstream area of the Arun to 3,284mm in the Khimti. River basins which lie in a high precipitation zone, such as the Seti, the Madi near Pokhara, and the Phalanku *Khola* near Pansayakhola, have high annual runoffs of more than 2,500mm. Figure 3 clearly indicates that the annual runoff is comparatively higher in the central part than in other parts of the country. The annual runoff ranges from 874mm in the Koshi basin to 1,029mm in the Karnali and 1,624mm in the Gandaki basin. Although total monsoon precipitation in the southern part of the Himalayas in the Koshi basin (eastern Nepal) is comparatively high, a significant portion of the basin lies on the much drier northern side of the main Himalayas, and this results in low annual runoff. Similarly, the Karnali basin in the west, which receives less precipitation than the central and eastern parts of the country, also has less annual runoff than the Gandaki and Koshi basins. The influence of the High Himalayas on the precipitation and consequently on annual runoff is evident from the fact that rivers entering Nepal from the northern side of the main Himalayas, such as the Arun, Trishuli, Budhigandaki, Kaligandaki, Bheri, and the Mugu Karnali, have less annual runoff than rivers originating from the southern side of the Himalayas such as the Tamur, Dudhkosi, Khimti, Likhu, Balephi, Chepe, Madi, and the Seti. Similarly, rivers originating from the Middle Hills have higher annual runoff in the central and eastern parts of the country. Annual runoff for these rivers is found to be positively correlated with monsoon precipitation and channel slopes.

Temporal and Seasonal Variations in Sediment Discharge

Sediment yield data for the rivers in Nepal are very limited. Shankar (1989) has reported the annual sediment load for 15 rivers in Nepal. The sediment yield in these rivers ranged from only 0.173×10^3 tonnes/sq.km. in Kulekhani to 10.25×10^3tonnes/sq.km. in the Tamur (Mulghat). Except for the Tamur, the comparatively high amounts of sediment load are found in high precipitation zones such as Phoolbari and Setibeni (in the Middle Hills) and Narayanghat and Kankai Mai (Churia area).

Some 88-96 per cent of the total sediment is discharged during the four summer months (June-September) in snowfed rivers, while the same figure is 91-97 per cent for rainfed rivers (Shankar 1989). A large amount of sediment is discharged during the short periods of single events. A study in the Khimti basin reveals that the concentration of sediment ranged from only 13ppm in the morning to 8,536ppm in the afternoon on the same day and 61ppm the next morning (Norwegian Hydrotechnical Laboratory 1995). A very weak relationship is observed between discharge and sediment concentration in many rivers in the country (per-

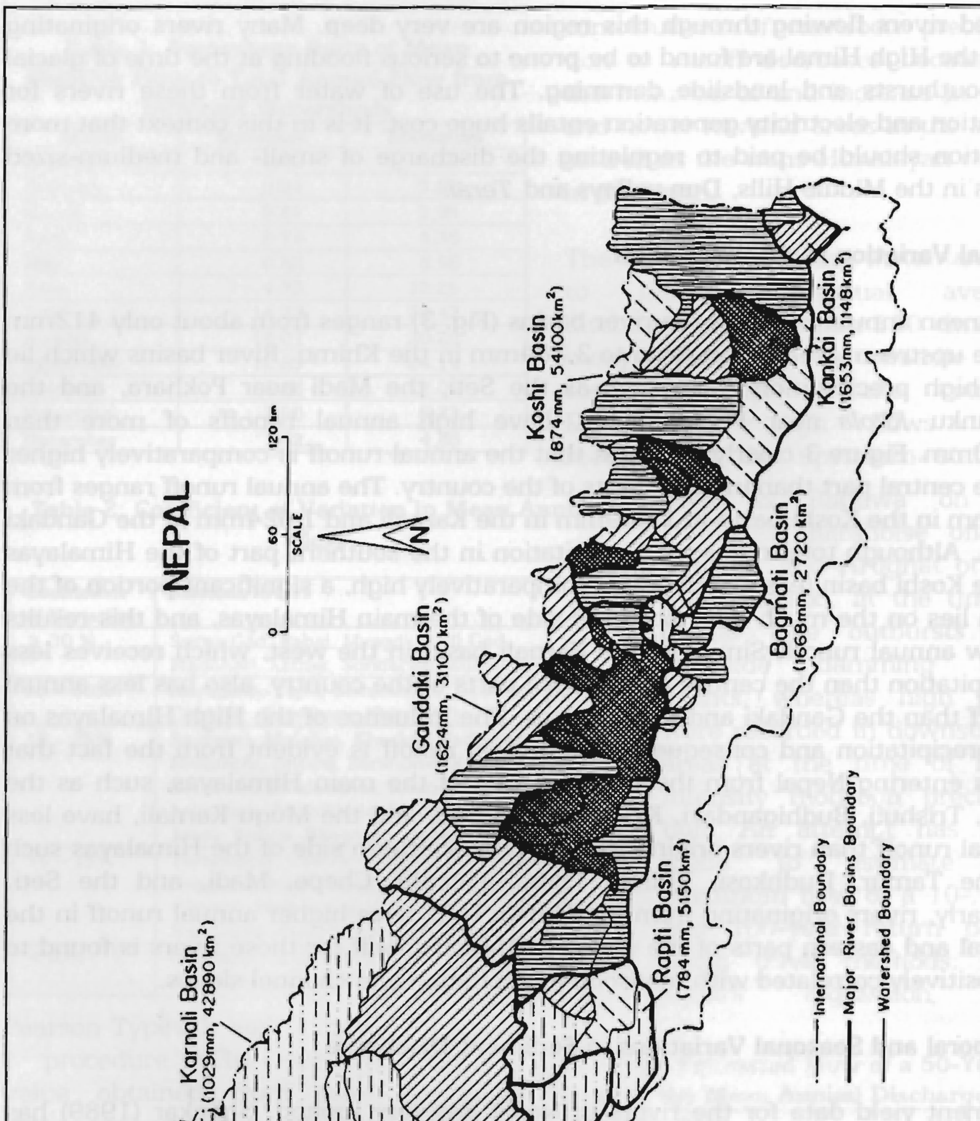

Figure 3: Mean Annual Specific Runoff from Major River Basins

sonal communication with Dr Hariman Shrestha, WECS, and Mr Haakon Kyrkjeeide, Khimti I Hydropower Project). Such high fluctuations of sediment flow within a short period of time have implications for the methods used to collect sediment discharge data and to estimate the total sediment loads in rivers. There is a need for intensive monitoring in order to estimate total sediment yields and draw valid conclusions.

Highland-Lowland Linkages in Discharge

From the available data on the Koshi basin, it is found that, although upstream utilisation and diversion of water are virtually non-existent, the mean absolute volume of water decreases in the downstream section (Fig. 4). The sum of the mean annual discharges recorded in the upstream areas at Kampughat (Sunkosi River), Simle (Arun River), and Mulghat (Tamur) is higher than the mean annual discharge recorded at Chatra downstream from the confluence of these rivers. For example, the mean annual discharge is 24,203 hectometres at Kampughat, 21,445 hectometres at Simle, and 11,098 hectometres at Mulghat, amounting to a total of 56,746 hectometres. But the mean annual discharge recorded at Chatra is only 47,283 hectometres. This means a loss of 9,463 hectometres of water or 17 per cent of the total volume of water recorded at the upstream stations. Such anomalies in discharge were also noticed in other areas. For example, the mean annual volume of water recorded at Kampughat on the Sunkosi is less (24,203 hectometres) than the total of the mean annual discharges recorded at Khurkot, Sangutar, and Rabuwa in upstream stations (25,084 hectometres).

The maximum discharge of water generated either by heavy precipitation, landslide damming, or glacial lake outburst floods in the upstream areas does not have any direct connection with floods in distant downstream areas (Table 4). For example, at the time of the outburst of Dig Tsho Lake, the maximum instantaneous discharge recorded at Rabuwa (Dudhkosi River) was 11,600 cumecs, whereas the maximum instantaneous discharge reported in the same year at Kampughat about 85km downstream, combining the water coming from the Sunkosi, Tamakosi, and Likhu, was less than 5,300 cumecs. In the same year the maximum instantaneous discharge combining water coming from the Arun and Tamur was 9,200 cumecs at Chatra about 125km downstream from Rabuwa. Similarly, on July 10, 1991, the maximum discharge recorded at Barahbise was 3,300 cumecs, whereas it was less than 2,420 cumecs at Pachuwarghat in a downstream area, even though two big rivers, i.e., the Balephi and Indrawati, join the Sunkosi in between Barahbise and Pachuwarghat. In 1974, the maximum discharge recorded at Pachuwarghat was 5,100 cumecs, while it was only 5,000 cumecs at Kampughat about 50km downstream. Though three big rivers, namely the Tamakosi, Likhu, and Dudhkosi, join with the Sunkosi after Pachuwarghat, the maximum discharge was less at Kampughat than at Pachuwarghat. A similar condition was observed along the Kaligandaki River in 1987. The peak instantaneous discharge was estimated to be 8,500 cumecs at Tatopani, whereas it was less than 2,000 cumecs at Setibeni about 73km and 3,590 cumecs at Kotgaon about 120km downstream from Tatopani. The maximum instantaneous discharge recorded at Tigra (West Rapti River) in 1986 was 2,170 cumecs and only 1,610 cumecs at Bangasoti and 2,150 cumecs at Jalkundi. A study on the floods in Bangladesh also shows that the discharge of

Himalayan tributaries is integrated into the base flow of the Ganges in downstream areas over long distances (Hofer and Messerli 1997).

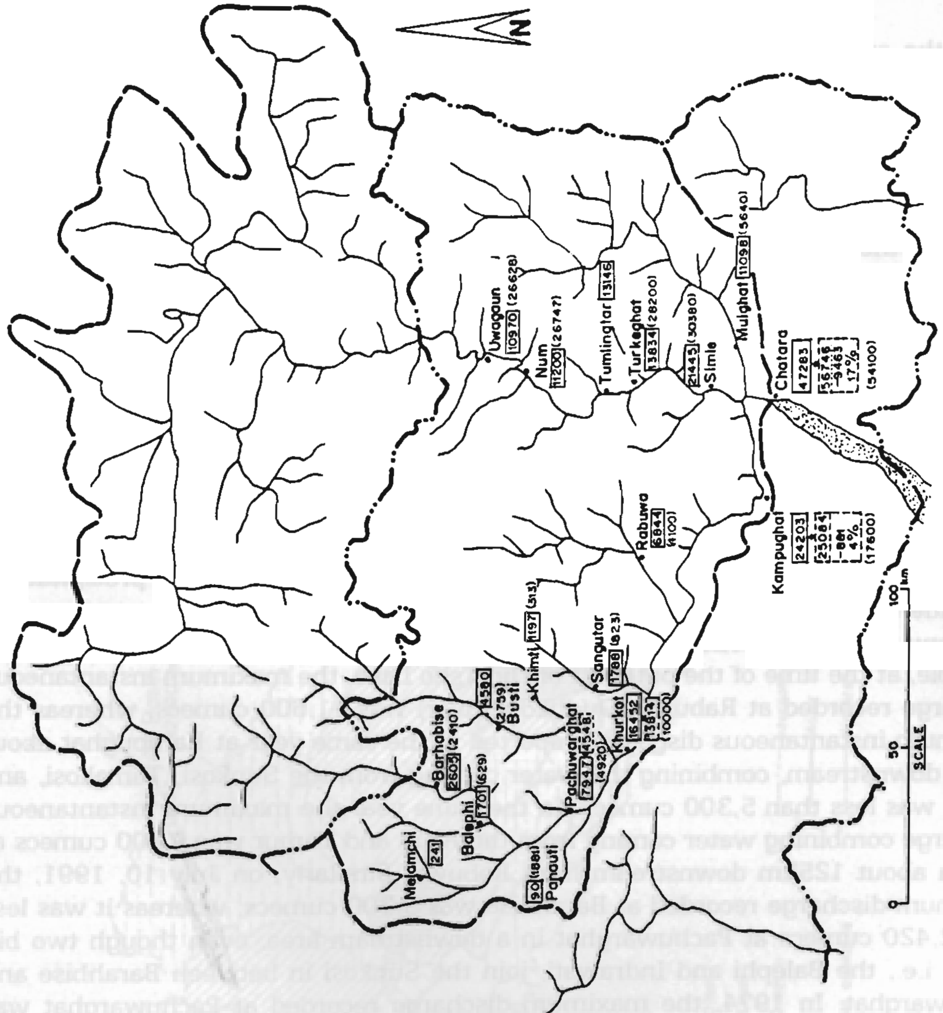

Figure 4: Mean Annual Flow Volume of Water (Hectometre)

The reason for such anomalies in annual discharge could be i) the very high estimation of discharge at Simle and Kampughat due to the backwater effect; ii) low estimation of discharge at Chatra due to a lack of understanding of the stage-velocity relationship; and iii) geohydrological losses of water between Kampughat

Table 4: Maximum Instantaneous Flow of Water Recorded at Different Stations

River Basin	Stations					
	Upstream				**Downstream**	
	Khumbu	**Rabuwa**			**Kampughat**	**Chatara**
A. Dudhkosi (DigTsho Lake outburst)	Water: 5xm^3 10^6 Sediment:3 x 10^6 m^3	11,600 cumecs (Aug 4)			5,300cumecs (Sept 5) [85 km down stream]	9,200cumecs (Sept 5) [125km downstream]
B. Bhote Koshi (July 11, 1981)	**Zhangzang Boja in Tibet**	**Barahbise**	**Pachuwarghat**	**Khurkot**	**Kampughat**	
	16,000cumecs Sediment: 4 x 10^6 m^3	3,300cumecs (July 10)	2,420cumecs (Aug 6)	4,500cumecs (Sept 29)	4,280cumecs (Aug 22)	
1974			5,100cumecs (Aug 5)	5,000cumecs (Aug 5) [50km downstream]	5,460cumecs (Aug 5)	
1971				5,550 cumecs (June 12)	5,500cumecs (June 12) [30km downstream]	
C. Kaligandaki 1987	**Tatopani** 8,500 cumecs	**Setibeni** 1,500-2,000 cumecs [73km down stream]	**Kotgaon** 3,590cumecs (Aug 13) [120km downstream]	**Narayanghat** 17,600 cumecs		
D. Budhi Gandaki Aug. 1968	**Arughat** Rock slide damming for 29 hours 5240 cumecs (Aug. 2)			**Narayanghat** 10,200 (Oct 5)		
E. Rapti west 1986	**Tigra** 2,170cumec (Sept 6)	**Bangasoti** 1610cumecs (Jun 19)	**Jalkundi** 2150cumec (Jun 10)			

and Chatra. A study on the stage-discharge relationship of the Padma River at Goalundo just south of the junction of the Ganges and the Brahamaputra indicates a highly non-linear behaviour between stage and discharge at high stage because of the increase in the velocity of flow from the smoothing out of sediment dunes on the river bottom without any change in water level (Simons 1988). Thus the estimation of discharge on the basis of a limited number of velocity observations could be the reason for the low estimation of discharge at Chatra. The mean annual volume of water starts to decrease where the rivers enter into the much drier, tectonically active, and geologically weak zone of the Siwaliks. This is the zone of extremely rapid groundwater recharge. It has been reported from the *Terai* that the deep aquifer is at least 1,800m below the surface and contains fresh-water at those depths (Jones 1986 cited in Rogers et al. 1989). An analysis of base flow data in the Karnali basin also reveals a three per cent loss of the total input into the Churia area due to deep seepage (Chyurlia 1984). The anomalies in maximum instantaneous discharge at the time of outbursts of glacial lakes, landslide damming, and cloudbursts could be due to the high volume of sediment concentration in water upstream. The estimation of discharge by recording the stage (water level) without considering the contribution of sediment load, particularly bedload, could have caused the overestimation.

These anomalies and uncertainties have created complexities in understanding the hydrology of these rivers. An intensive monitoring and in-depth study of these aspects is called for. Although there are more than 260 pluviometric stations, this number is still below the recommended WMO standard. Similarly, there are only 40 hydrological stations with automatic water-level recording devices in the country. Most of them are located along big rivers. This has created uncertainty in understanding specific process-response systems. The intensive monitoring of river flow in at least some selected basins will be necessary in order to generate a reliable database for the better understanding of ecohydrological processes of river basins in Nepal.

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