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# HYDROCHEMISTRY OF MELTWATERS AT THE BORDER OF TWO ALPINE GLACIERS, LAHUL VALLEY, HIMACHAL PRADESH

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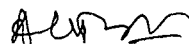
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C E R T I F I C A T E

The research work embodied in this dissertation entitled "Hydrochemistry of meltwaters at the border of two Alpine glaciers, Lahul valley, Himachal Pradesh" has been carried out in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. The work is original and has not been submitted in part or full for any other degree or diploma of any university.



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## CHAPTER - 1

### INTRODUCTION

Present day glaciers are remnants of pleistocene glaciation during which most part of the earth was covered by ice. Studies indicate that the glaciation was not a continuous one but cyclic. Every glacial period is followed by an interglacial period. General recedence of glaciers suggest that present is an interglacial period. Despite this Himalaya, as its very name indicates, contains innumerable big and small valley glaciers in the upper reaches.

Glaciers occupies an important position in the hydrological cycle. 2.7% of total water in the hydrological cycle is stored in glaciers. The ice sheets of Antarctica and Greenland possess 99% of this water, leaving only 1% in the glaciers over the rest of the world. The valley glaciers are important because of their proximity to human inhabitations and their melting contributes to the water in rivers. They also influence the climatic conditions of the region. The significance of Himalayan glaciers has to be fully realised as they influence climatic fluctuations of the

Indian sub-continent and comprising 75% of the fresh water resources of India.

Importance of physical weathering in glacial environment is widely studied in geomorphology. But, the chemical weathering processes which operate in this environment are not given due attention. Some studies on the chemistry of meltwaters coming out of glaciers indicate that chemical weathering is more intense in these regions than in tropics. Evidently the low average temperatures generally associated with an active glacier do not inhibit chemical weathering reactions. Moreover, waters at near freezing temperatures are capable of reacting rapidly with silicate minerals (Reynolds et al., 1972). High dissolution of atmospheric CO<sub>2</sub> in these cold waters supplies H<sup>+</sup> ions needed for acid hydrolysis of minerals during which bicarbonate, cations and dissolved silica will be released to water (Raiswell, 1984).

The concentration of suspended sediments in water depends on the competency and capacity of the stream and the availability of suitable size fractions of sediment which can be carried in suspension. Grinding action of glaciers produces fine fractions of

sediment which can be carried in suspension. The high velocity, turbulent meltwater streams also erodes the morainic material and carries huge quantities of sediment in suspension.

Diurnal variations in discharge, total suspended matter and total dissolved salts are also of considerable interest. It is generally observed that increased discharges causes an increase in the concentration of suspended matter and dilution of dissolved salts.

Keeping in view the importance of weathering processes in glacial environment, the glacierised catchment of Chandra river was selected for the study. The objectives of present work are to study

1. the processes and controls of chemical weathering in the region
2. source of major cations and anions in the water
3. concentration of suspended matter
4. mineralogy of suspended matter and its relation to water chemistry
5. diurnal variations in chemical and sediment load from morning to evening.

## **LITERATURE REVIEW**

Study of chemical weathering in temperate glacial environment has been started in the early sixties. Most of these studies were based on sampling of meltwater and discharge measurements near the snout of glaciers (Rainwater and Guy,1961; Keller and Reesman,1963; Lorrain and Souchez,1972; Collins,1978; Lemmens and Roger,1978; Collins,1979; Collins,1983; Collins,1987; Hasnain et al,1989). Attention has been paid to the study of factors influencing chemical weathering and the processes involved. Diurnal variation in discharge and its effect on dissolved and suspended load of meltwaters was given importance in their work. Raiswell(1984) attempted to evolve chemical models for the study of solute load in meltwaters.

### **1.1 Source of dissolved constituents in meltwaters:**

The negligible presence of biota, in alpine environment, limits the sources of solute in meltwaters to lithogenic and atmospheric(Collins, 1979). As snow is less efficient in removing materials from atmosphere (Gorham, 1961), the constituents of dissolved load in meltwaters are mainly derived from lithogenic sources.

The atmospheric  $\text{CO}_2$  dissolves in water and produces  $\text{H}_2\text{CO}_3$ , which is a source of hydrogen ions in water. Bicarbonate, cations, dissolved silica, and clay minerals will be released when  $\text{H}_2\text{CO}_3$  reacts with minerals (Raiswell, 1984). Increased solubility of  $\text{CO}_2$  in cold waters indicates that, other things being equal, carbonation reactions will proceed more vigorously in colder regions than under more moderate environmental conditions.

#### 1.2 Factors controlling the Chemical weathering in glacial environment:

The factors, which control the water composition were investigated by several workers. Gorham(1961) and Gibbs(1967) described climate, geology, topography, biota, and time as principal environmental factors which interact to determine the concentration and composition of atmospheric precipitation, soil solutions and surface water bodies. Gibbs(1970) proposed three major mechanisms -- atmospheric precipitation, rock dominance, and the evaporation-crystallisation process -- as major factors controlling the composition of dissolved salts of world waters. He plotted calcium and sodium concentrations as end members on X-axis and total dissolved solids on Y-

axis for world major river waters and demarcated the areas where these mechanisms plays dominant role (Fig. 4.6). Relief, vegetation, and composition of material in the basin were described by Gibbs (1970) as second-order factors which play minor role within the zones dominated by the three major factors. Ion exchange and sorption mechanisms as factors in the transport of major cations by water were described by Gorham(1961), Lorrain and Souchez (1972), and Lemmens and Roger (1978). The concentration of hydrogen ions in the water plays an important role in the chemical weathering of primary minerals (Lemmens and Roger, 1978; Raiswell, 1984). In the absence of dissolved organic matter in the glacial environment, three chemical factors -- water composition, water flow rate, and rock mineralogy -- influence the chemical weathering to a greater extent (Raiswell, 1984). Diurnal variations in discharge and dissolved and suspended load were given due attention by almost every author, whoever worked on the meltwater chemistry.

**1.2.1 Geology:** Influence of geology on water composition was studied by Gorham (1961); Gibbs (1967); Collins (1979); and Meybeck (1983). Quoting Clarke (1924), Gorham explained that the local geological

Table 1.1 Influence of rock type on the average composition of world riverwaters (Meybeck, 1981)

Constituent	Average concentration (mg l <sup>-1</sup> )		
	Plutonic and highly metamorphic rocks	Volcanic rocks	Sedimentary rocks
SiO <sub>2</sub>	1.5x	3.5x	x
Ca <sup>2+</sup>	4	8	30
Mg <sup>2+</sup>	1.0	3	8
K <sup>+</sup>	1.0	1.5	1.0
Na <sup>+</sup>	Oceanic influence dominant		
Cl <sup>-</sup>	Oceanic influence dominant		
SO <sub>4</sub> <sup>2-</sup>	2	6	25
HCO <sub>3</sub> <sup>-</sup>	15	45	100

x = Average SiO<sub>2</sub> content of water from rivers draining sedimentary rocks at a given temperature.

variations may greatly affect the character of rivers, especially near their sources. In large rivers, these variations are evened out by the intermixing of tributaries, which tend to produce an average composition, which may be called that of a normal water. Meybeck (1983) presented average values of total dissolved solids and their constituents for waters flowing over different rock types viz., plutonic and highly metamorphosed rocks, volcanic rocks, and sedimentary rocks. However, he attributed dominance of oceanic influence to sodium and chloride ion concentrations (Table 1.1). Dissolved load is also influenced by rock mineralogy, as the minerals weather at different rates. Raiswell (1984), pointed out that the sulfide minerals breakdown at exceedingly rapid rates in oxygenated surface environments and carbonate minerals weather more rapidly than silicates and aluminosilicates. The sulfate ions in water indicate presence of sulphide minerals in the lithological units of the catchment. Low variation in the concentration of potassium and dissolved silica is attributed to the dominance of silicate mineral weathering as a source.

**1.2.2 Relief:** Relief as a controlling factor in influencing the supply of major ions to waters was



investigated by Gorham (1961) and Gibbs (1967). While discussing the environmental factors influencing the water chemistry of Amazon, Gibbs (1967) found that the 12% mountainous area in the Amazon river basin contributes 86% of the total dissolved solids. The turbulent waters in the hilly regions exposes fresh rock surface, thus by promoting chemical weathering in those regions. Water velocity, which depends on relief, was described as major controlling factor by Raiswell (1984). He explained that, as many silicate and aluminosilicates have equilibrium constants of similar magnitude, only a small increase in the concentration of aqueous products (and decrease in  $[H^+]$ ) are needed to approach equilibrium and stabilize solid phases. At high flow rates fresh supply of hydrogen ions and flushing out of dissolved solids prevent the waters reaching equilibrium. So, it is generally assumed that increased flushing rates causes increased rate of mineral dissolution.

**1.2.3 Suspended sediment:** The grinding action of glaciers produces very fine sediment. So, the turbulent meltwaters emerging out of glaciers carry lot of suspended sediment with them (glacial milks). This increases effective contact surface area of sediment

with water and thereby promotes chemical weathering. Partial dissolution of the suspended sediment may substantially contribute sediment to the solute concentration (Collins, 1979).

**1.2.4 Ion exchange and Sorption:** Ion exchange and sorption mechanisms were discussed by some workers as contributing factors to the dissolved load (Gorham, 1961; Lemmens and Roger, 1978). In ion exchange, the hydrogen ions in water will be exchanged with cations in the Guoy layer of suspended and bed sediments. The hydrological conditions in these regions favour ion exchange in two ways -- by an increase in the surface area and in the time of contact between water and morainic material (Lemmens and Roger, 1978). Ion exchange causes rapid increase in the concentration of sodium and potassium in the frontal zone of glaciers (within few meters from the snout). There will be very little variation in their concentration further downstream due to slowing down of diffusion, as a result of diminishing gradient between Guoy layer and concentration of cations in water (Lemmens and Roger, 1978).

Gorham (1961) referred to sorption phenomenon, but his studies were confined to lake bottom muds and nothing was said about suspended sediment in streams. However, sorption mechanism in glacial environment was studied in detail by Lorrain and Souchez (1972). According to them, the sorbed cations are originally the exchangeable cations held on morainic particles. These particles with their sorbed cations are carried away in suspension by superglacial meltwaters. Because of the very dilute character of these meltwaters, before they reach morainic deposits, desorption occurs. The amount of sorbed cations on suspended sediment is more important than that held on bed sediment. This is because of increase in effective contact area of sediment in suspension. Sorption is significant in the chemical transport, especially for calcium and potassium.

**1.1.5 Rate of Melting:** Diurnal variations in discharge and composition of water was investigated by almost all the workers, whoever, studied the character of meltwater streams. Rainwater and Guy (1961), and Collins (1979) proposed two-component subdivision of total flow, waters passing through the subglacial channels having ground environment and meltwaters

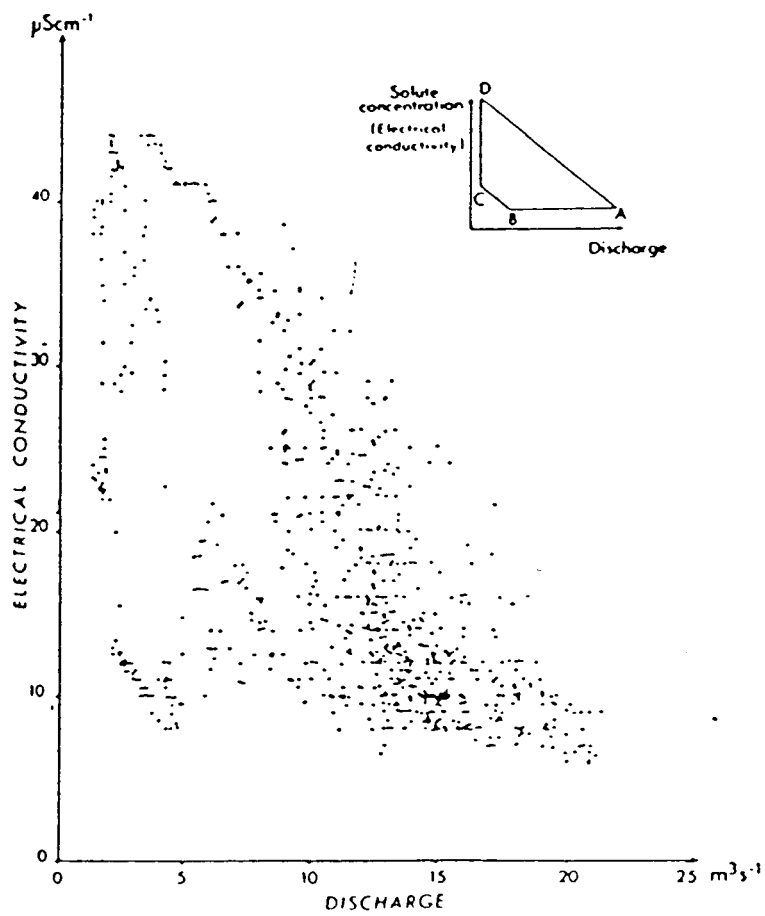


Fig 1.1 Inverse relationship between solute concentration (as electrical conductivity and discharge (After Collins, 1979).

running off rapidly in englacial channels, without undergoing chemical change. Diurnal variation in the concentration of total dissolved solids in meltwaters results from the variable dilution of stable discharge from the ground environment by surface meltwaters. Walling and Web (1986) pointed out the influence of permeability and ground water circulation on water composition. According to Collins (1979), every morning with the starting of ablation, a steep increase in discharge and corresponding decrease in electrical conductivity were observed. Following peak discharge in the late afternoon, conductivity rises as discharge decreases, both at a relatively slow rate.

Collins (1979) plotted electrical conductivity against discharge at Gornera (Fig 1.1). It produced an inverse relationship between the two components. The solute-discharge relationship shows trapezoidal distribution. Side AB represents the lowest observed conductivity which occurs independent of discharge at higher flows, and which is determined by the solute content of ice and snow meltwaters from the glacier surface at times when there is minimal subglacial outflow. Point D is located by the maximum

observed solute concentration which ideally is the concentration which would be measured in interstitial waters of basal moraine. Side CD indicates lowest discharge with varying proportions of surface run-off and basal outflow. When further surface contributions inhibit the basal outflow, solute content is decreased (CB), as discharge rises. The upper limit of the distribution (AD) are located by daily maximum conductivities.

**1.1.6 Distance from the snout:** Chemical composition of meltwaters does not alter much from the frontal part of glaciers to further downstream. Reynolds (1972) compared the waters flowing out of scree cones at the base of Le Conte mountain with the Cascade river water 8.3 mile downstream from the outflow of South Cascade lake. He found that the essential character of waters was fixed by the time they leave the alpine watershed and little further change occurs during miles of transit downstream. The dilute superglacial waters after passing over 30m on morainic material in the frontal zone of glacier, does not alter much (for sodium and potassium) even after one kilometer (Lemmens and Roger, 1978).

Table 1.2 Major water types associated with world riverwaters  
(Meybeck, 1981)

Cations	Anions	Percentage of global sample
$\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$	$\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$	33.1
	$\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$	2.5
	$\text{SO}_4^{2-} > \text{HCO}_3^- > \text{Cl}^-$	1.0
$\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$	$\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$	46.7
	$\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2+}$	15.0
$\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$	$\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$	1.4
	$\text{SO}_4^{2-} > \text{Cl}^- > \text{HCO}_3^-$	0.1
	$\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$	0.1

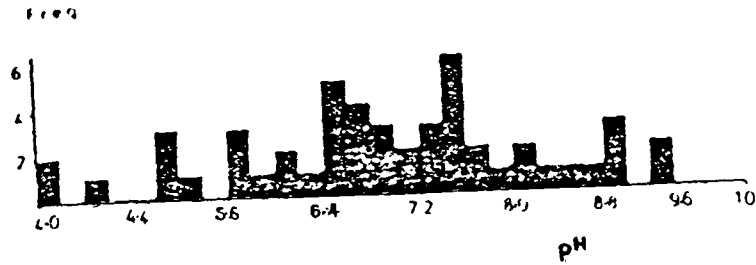


Fig 1.2 Range of pH variations in glacial meltwaters (After Raiswell, 1984)

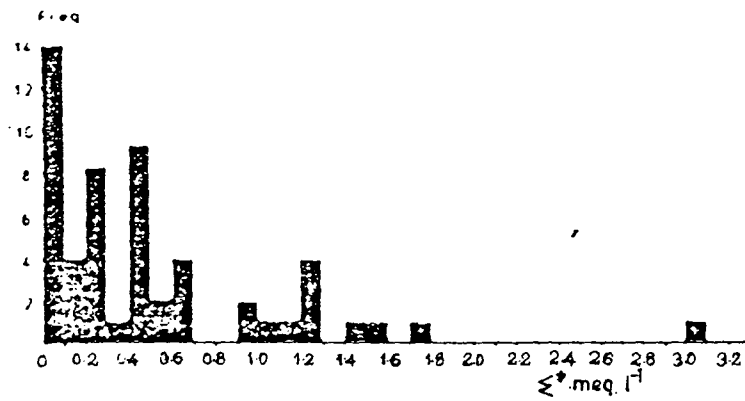


Fig 1.3 Range of solute load variations in glacial meltwaters (After Raiswell, 1984).

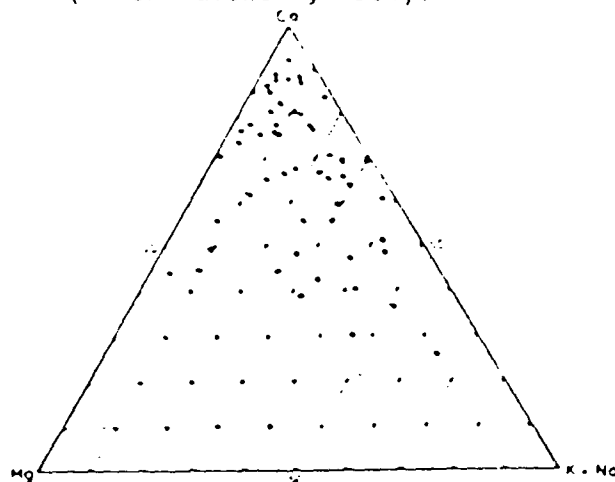


Fig 1.4 Variations in the cation composition of glacial meltwaters (After Raiswell, 1984)



### **1.3 Composition of world fresh waters:**

Calcium and bicarbonate represent the dominant cation and anion in the of the waters. According to Meybeck (1981), more than 97% of world water run-off is of this type (Table 1.2). Calcium and bicarbonate are the dominant ions where rock weathering is the major mechanism controlling solute content and when total ion concentration typically ranged ranged between 50 and 1000 gm l<sup>-1</sup> (Gibbs, 1970). Using nine studies of meltwater composition, covering nearly 40 meltwater streams, Raiswell (1984) has plotted distribution of certain parameters -- pH, sum of cations, cation composition (Fig 1.2,1.3,1.4), and anion composition. Calcium is the dominant cation in approximately 88% of the meltwaters and often comprises more than 70% of the total cation equivalents. Among the anions, bicarbonate and sulfate dominate half the analyses each and Cl<sup>-</sup> is almost invariably low.

### **1.4 Suspended sediment in meltwaters:**

In alpine environment, the streams carries much higher suspended load with them. The competency and capacity of these streams is more because of high relief in those areas. The amount of suspended matter

in glacial meltwaters is controlled by the character of the rock eroded, glacial abrasion and glacial melting (Keller and Reesman, 1963). The fine sediment which is ground by glacial abrasion will be carried away by turbulent meltwater streams. In general, more sediment is removed per sq. km in small basins than in the larger areas (Morisawa, 1986). Sheet flow on the morainic deposits supplies a great part of the suspended load. Because of the particle size this debris is more likely to be quickly removed from the watershed than the coarse bedload eroded from the channel.

## CHAPTER - 2

### AREA OF STUDY

The mighty ranges of Himalaya stretching for about 2,414 km between the Indus valley in the west and Brahmaputra gorge in the east with numerous peaks rising above the snowline is a store house of glacial environment. The glaciation in the Himalaya started during the ice age in the pleistocene period. Four to six Pleistocene glacial advances interrupted by interglacial retreats were traced out in Kashmir region. These glacial cycles are comparable to Penek-Bruckner cycle of Alpine region(Kar, 1971).

Lahul occupies an area of about 4,570 sq.km. in the Lahul & Spiti district, Himachal Pradesh (Latitude  $30^{\circ}08'$  N to  $30^{\circ}59'$  N and Longitudes  $76^{\circ}49'$  to  $77^{\circ}50'$ ). It includes the valleys of Chandra and Bhaga rivers and a part of the territory drained by Indus river. The rivers are fed by numerous glacial streams emerging either from the Great Himalayan or Pir Panjal ranges. The altitude of the Lahul valley varies from 2,750m to 6,400m above m.s.l. with several high rising peaks. The area can be approached from Laddakh through Bara Lacha pass( $16,047'$ ) from Spiti through Kumzum

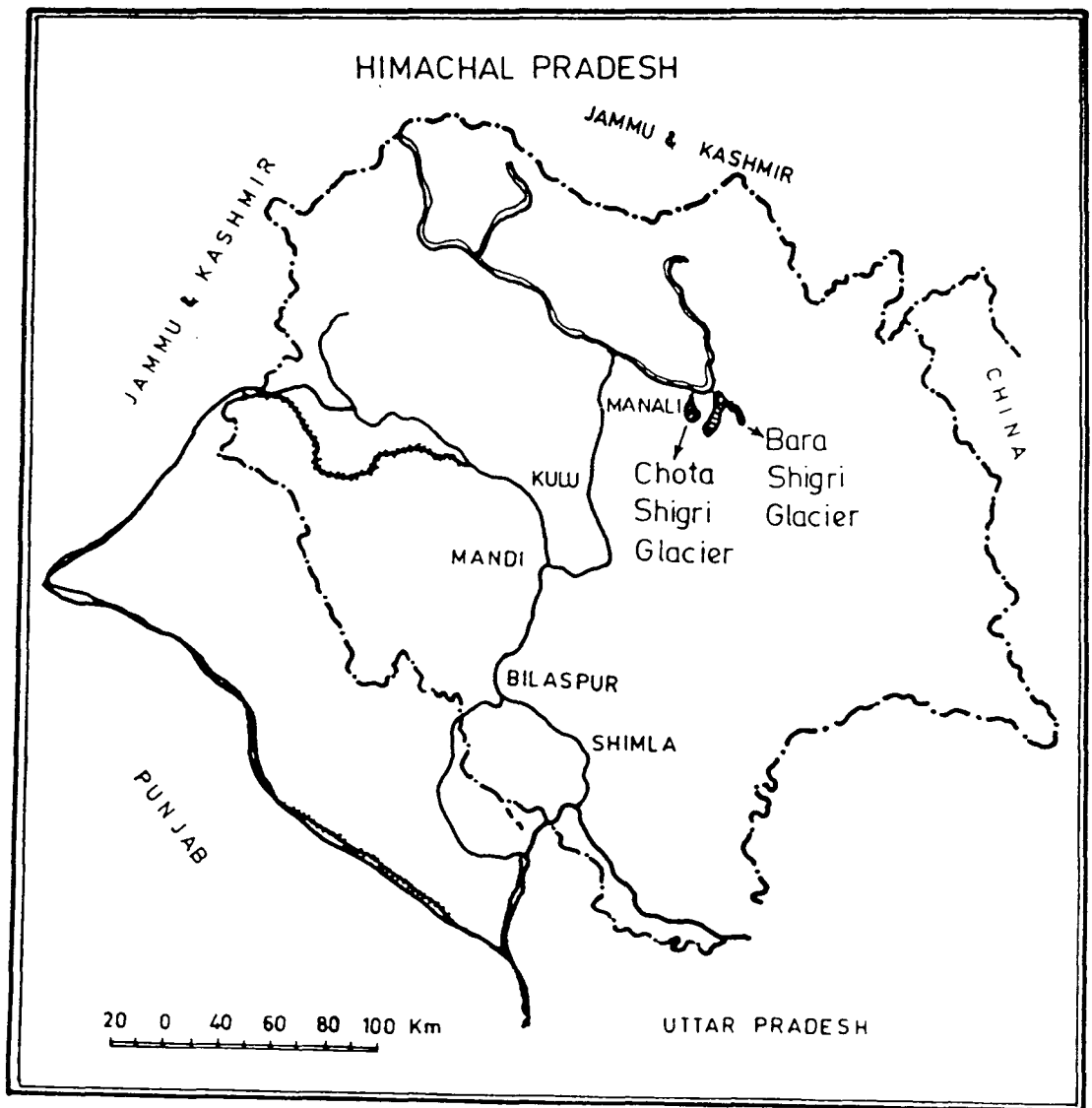


Fig 2.1 Location Map

pass(14,500') and from Manali via Rohathang pass(13050'). However, the approach from Manali side is more convenient.

Chandra river emerges from a huge ice sheet in the vicinity of Bara Lacha pass and flows in the southerly direction for about 50 km and then in westerly and W.N.W. for about 65 km up to Tandi where it meets the river Bhaga. After meeting the river Bhaga, it is known as Chandrabhaga or Chenab, which is a part of Indus system.

Chandra river is fed by several glacial streams. However, the study was confined to the area which lies around the confluences of meltwater streams from Bara Shigri and Chhota Shigri glaciers.

The Bara Shigri glacier( $32^{\circ} 16'$  :  $77^{\circ} 35'$ ) lies in the Great Himalayan ranges of Lahaul. The glacier was first surveyed in 1907 by Walker and Pascoe and by G.N.Dutt in 1956. Srikantia visited the area in 1963. This is a valley glacier characterized by a number of hanging valleys. The main glacier is slightly crescentic in shape with a westerly arching. The source of the glacier is around 12 km south of Shigri. The accumulation and ablation areas are around 20 sq. km.

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and 2 sq. km. respectively. The meltwater stream, which is emerging from an ice cave at the snout, runs almost parallel to the main Chandra river and meets with it at about 4.5 km north-west of the snout. At present the glacier is retreating fast. According to Srikantia et al (1971), Bara Shigri retreated 219 m along the eastern front within seven years(1956-63).

The Chhota Shigri glacier ( $32^{\circ} 12' - 32^{\circ} 17'$  :  $77^{\circ} 30' - 77^{\circ} 32'$ ) is a valley type glacier. It is about nine kilometers long north verging glacier from the Pir Panjal ranges of Himachal Himalaya. The glacier was extensively studied during 1986-88 by a group of scientists in the multidisciplinary glacier expedition to Chhota Shigri sponsored by Department of Science and Technology. This group reported some fluctuations in the position of snout since last two years. The meltwater stream which emerges out of the snout meets Chandra river.

### **2.1 Climate:**

The climate of Lahul valley is characterised by long cold winters extending from October to April. The temperature in the winter season is well below the freezing point where as the maximum temperature in the

summer months goes up to 24°C. Eventhough the accurate snow fall data is not available, it is about 6m per annum in the areas lying between 3,050m and 3,350m. The rainfall is scarce due to the fact that the Pir Panjal ranges obstruct the passage of monsoon clouds further north in to the valley. The average annual rainfall recorded is 15 cm. The perpetual snow line is at about 4,260m. However, to the south of Pir Panjal, in spite of the higher perception of snow, it is nearly 4,250m. In addition to the seasonal climatic changes, the vertical variations also to be taken in to account as even in summers the temperature goes below freezing point at higher altitudes.

## **2.2 Geomorphology:**

The most striking topographic features of the area are the high mountain ranges and deep narrow river valleys. The glacial and fluvial processes and their combination played an important role, as exhibited by the morphological features, in the evolution of geomorphology of the region. The triangular area between the rivers Chandra and Bhaga has numerous corries and cirques, which nourish all the glaciers and finally the river with immense water.

Several U-shaped valleys on both sides of main Chandra valley characterise the glacial erosion whereas the V-shaped Chandra valley typify the fluvial erosion. As a result of more intense erosion by the main glacier than the tributary glaciers, hanging valleys were developed. Steep slopes developed due to downcutting along the valleys. As a consequence, various mass wasting processes, scree and rock fall, mud flow, debris flow etc., became active. High angle scree slopes rest near the natural angle of repose for angular rock debris.

Till is the unsorted and unstratified tabular mass of material deposited by glaciers, which is found along the lower reaches of the valley. Various types of moraines which can be seen in the area includes lateral, medial, englacial, subglacial, and end moraines. Low angle alluvial fans were developed in the lower reaches of the valley. Well developed terraces can be observed on both sides of the Chandra river. The continuity of these terraces was interrupted by the transportation and deposition of glacial rock debris. The intermingling of silt and boulders in the sediment deposited along the river valley indicates the



involvement of both fluvial and glacial processes in their formation.

### 2.3 Geology:

The general sequence of geological formations met with in Lahaul area of which our study area forms a part is given below:

AGE	LITHOUNITS	FORMATION
Pleistocene- Recent	Morainic material	
Carboniferous	Shale, bedded gypsum, limestone, dolomite and quartzite	
Devonian	Grey and white quartzite	Muth quartzite
Silurian- Ordovician(?)	Brown and pale pink quartzite, green and pale purple shale and siltstone	
Cambrian	Green, purple and grey shale, siltstone, slate, sandstone, quartzite and dolomite	Batal formation

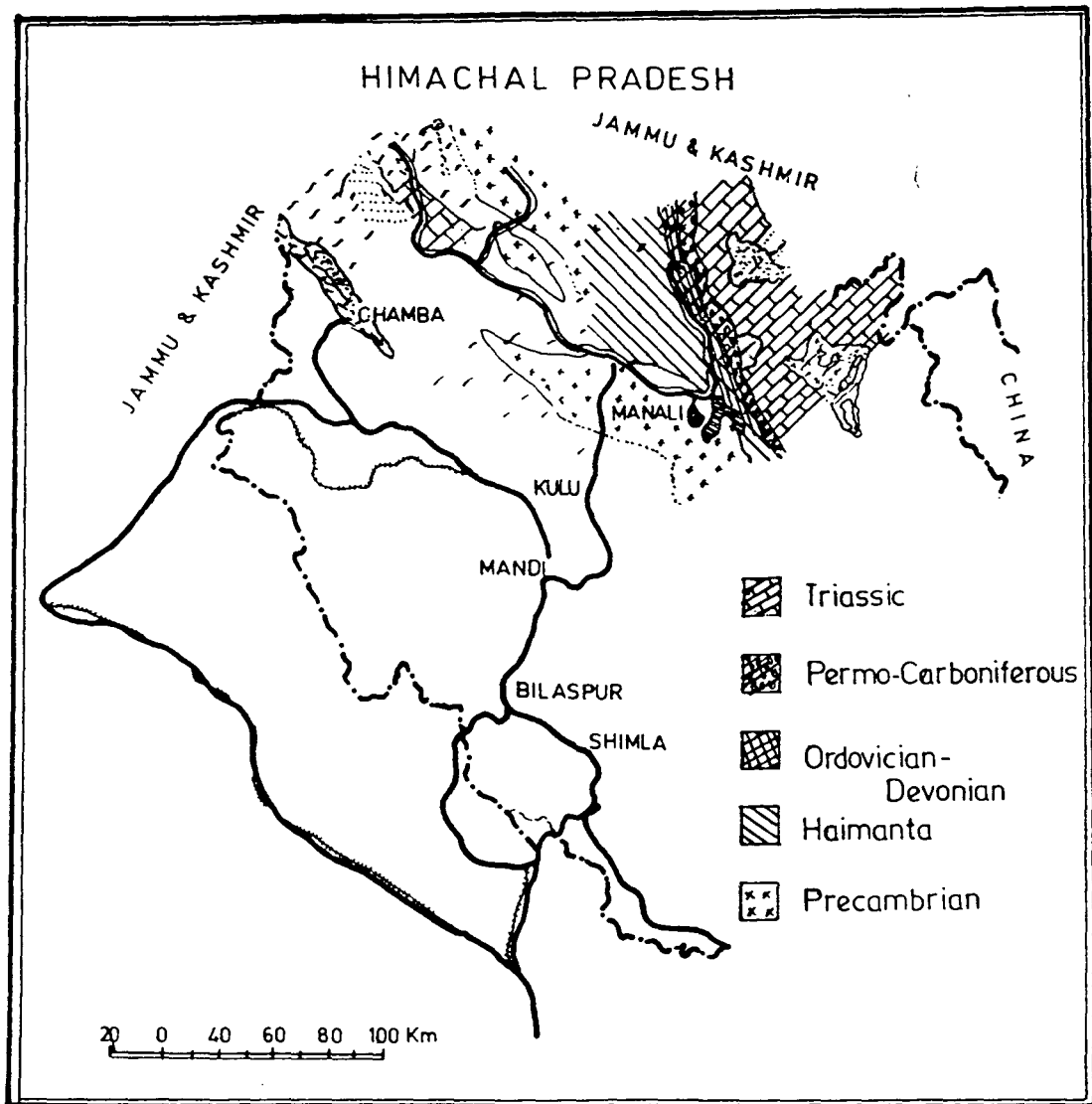


Fig 2.2 Geology of the area (Redrawn from a GSI map)

Pre-cambrian	Slate, phyllite, schist,	Sissu fm.	
	crystalline limestone,		Chandr
	dolomite, quartzite,	Rohtang	Bhaga
	quartz-schist, migmatites	Gneissic	group
	and gneisses	Complex	

\* Compiled from Srikantia (1977) and Rawat and Purohit (1988)

The Chandra-Bhaga group is divided in to two divisions viz., the Rohtang gneissic complex and Sissu formation. The Rohtang Gneissic Complex forms the crystalline basement for a vast file of proterozoic and phanerozoic sediments of Lahaul. These rocks are of batholithic dimension and occupy an area between Bara Shigri and Teling. This zone represents an area of anatexis and migmatisation. According to Rawat and Purohit(1987), the Rohtang Gneissic Complex is widely composed of the mica gneiss, augen gneiss, granitic gneiss, mylonite gneiss, kyanite-schist, porphyritic granite and amphibolites. At places the rocks are associated with pegmatite and aplite veins.

The Rohtang Gneissic Complex is gradually succeeded by Sissu formation which in turn is overlain by the Haimantas along a tectonic contact. The major

rock types in Sissu formation are - garnet-biotite schist, quartz-sericite schist, schistose quartzite and leucogranites. Srikantia and Bhargava reported Rattilaman granite as an intrusive with in these metasediments (Rawat and Purohit, 1987).

The Haimantas are succeeded by sediments of supposedly Ordovician-Silurian age, which in turn are succeeded by Muth quartzite of Devonian age. Limestones, quartzites and shales of Carboniferous are the youngest rocks found in the area (Srikantia,1977).

#### **2.4 Mineral Deposits:**

The occurrence of Stibnite (Antimony Sulfide) near the Bara Shigri glacier is known since the middle of the 19 th century. This deposit was first referred in a letter in 1854 by Capt. W.E.Hay, then the Asst. Commissioner of Kullu (Srikantia,1977). Mining operations were undertaken in 1905 by Col. Rennick, who succeeded in shipping about 15 tons of ore to England (Chatterjee,1963). However, the mining was stopped due to the inaccessibility of the for most part of the year and the operational costs involved.

The deposit is of cavity filling type and confined to the fractures in the peripheral zone of a granitic intrusion which is a part of the Central Himalayan Crystallines. The maximum width of a vein is about 10 cm. Stibnite occurs in two types of veins, viz., monometallic and multimetallic (associated with lead, zinc, pyrite and chalcopyrite) (Srikantia, 1977). Stibnite marks the culmination of the Hydrothermal activity and formed after lead and zinc with the falling of temperature.

#### **2.5 Vegetation and Human interference:**

The study area do not possess any permanent vegetation since it is covered with snow for most part of the year. However, after seasonal snow cover melts away in the summer, grass and small flowering plants grow along the lower reaches of the valley and the river terraces. After Gramphu, the upstream side of the valley is free from human settlements. In summers, after the clearing of Rohtang pass, some sheperds moves in to the valley to feed their sheep. The area is free from any sort of industrial pollution, since there are no industries in the near vicinity.

## CHAPTER - 3

### MATERIALS AND METHODS

In order to find out the hydrochemistry of Chandra river and influence of Bara and Chhota Shigri glacial meltwater streams on it, water samples were collected during the summer ablation period of 1988, at four stations along Chandra river (Fig 3.1, A,B,C and D are the sampling sites), before and after it meets with the glacial streams. pH and electrical conductivity were measured immediately after collection. Temperature correction was applied to conductivity (1.4 at 5<sup>0</sup>C). Suspended sediment was removed from the samples by using 0.45u millipore membrane filters. The filtered samples were analysed for major anions and cations by following standard methods. The details of analytical methods adopted were discussed below.

#### 3.1 WATER ANALYSIS:

**3.1.1 pH and Electrical Conductivity (EC):** pH and electrical conductivity of samples were measured by Consort C-425 pH-conductivity meter. The instrument was set for standard pH 6.87 buffer at the water temperature and pH of the samples were taken. For EC

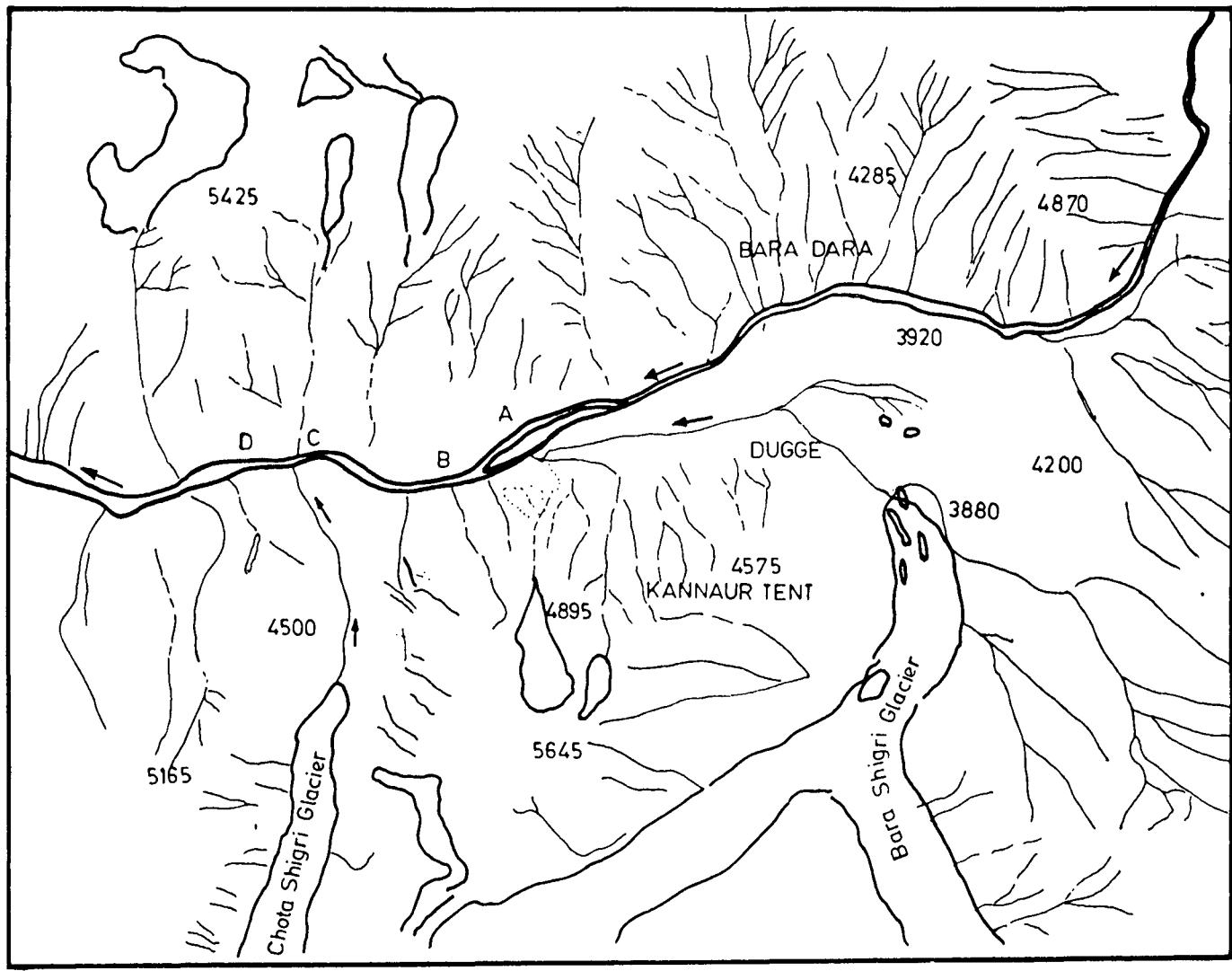


Fig 3.1 Sampling locations

measurements, the instrument was calibrated and set for 0.01 KCl standard. Then conductivity was measured in  $\text{US cm}^{-1}$  for water samples.

**3.1.2 Bicarbonate:** The bicarbonate was determined in the laboratory by following the potentiometric titration method. In this method no indicator was used, instead, the pH of the samples as well as that of standard solutions were maintained at 4.5 to signify the end points, by adding HCl (0.005 N). A graph was plotted for standards against the amount of HCl consumed and from the graph the amount of bicarbonate in the samples was calculated.

**3.1.3 Chloride:** Chloride was determined in the laboratory by following potentiometric titration method. Standards were prepared for concentrations ranging from 1 ppm to 10 ppm. 25ml of each standard and sample were titrated against 0.003N silver nitrate solution. Potassium chromate was used as indicator. The colour change is from yellow to pink. Concentration of chloride in samples was determined from the graph plotted for standards against amount of silver nitrate consumed.



**3.1.4 Sulphate:** The sulphate concentration was determined by titration method. Before titration, the samples were passed through a cation-exchange resin to remove interfering cations and the titration was carried out in 80% ethanol, to keep the barium sulphate in solution. In order to activate the resin, 30% HCl was passed through the column. After that it was rinsed with 100 ml distilled water. Then approximately ml of unacidified standard and sample was passed through the column. The first 40 ml of the sample was discarded and the rest was collected for the analyses.

Sulphate standards of various concentrations were prepared by using sodium sulphate. 10 ml of each standard and sample were taken, 40 ml of ethanol, was added to it. This was titrated against 0.005 M barium perchlorate in 80% ethanol (prepared by taking 2 gm barium perchlorate in 200 ml distilled water and 800 ml of ethanol). Thorin was used as indicator. The colour change at the end point being pink.

**3.1.5 Phosphate:** Phosphate was determined by the ascorbic acid method. Phosphate standard solutions of different concentrations ranging from 0.01 ppm to 1 ppm were prepared from potassium dihydrogen phosphate

( $\text{KH}_2\text{PO}_4$ ). 40 ml of each standard solution and water samples were pipetted out in to a 50ml volumetric flask and 5 ml of molybdate antimony solution and 2 ml of ascorbic acid solution was added and mixed well. The mixture was diluted to 50 ml and optical density was measured at 640 nm using Spectronic 1001. Molybdate solution was prepared by dissolving 4.8 gm of Ammonium molybdate and 0.1 gm of sodium antimony tartrate in 400 ml of 4N -  $\text{H}_2\text{SO}_4$  and making the total volume up to 500 ml with same acid. Ascorbic acid (0.1M) was prepared by dissolving 2 gm of ascorbic acid in 100 ml of water.

**3.1.6 Dissolved Silica:** The dissolved silica content was determined by the molybdo-silicate method. Standard solutions of different concentrations ranging from 0.1 ppm to 5 ppm were prepared by dissolving  $\text{NaSiO}_3$ . 20 ml of each standard and water samples were pipetted out in to a 50 ml volumetric flask and 10 ml of Ammonium molybdate solution and 15 ml of reducing reagent were added and mixed well. Ammonium molybdate solution was prepared by dissolving 2 gm of Ammonium molybdate in 10 ml of distilled water and adding 6 ml of concentrated HCl and the total volume was made upto 100 ml by

further diluting it with distilled water. Reducing reagent was prepared by mixing 100 ml of metol sulphite solution, 60 ml of 10% oxalic acid and 120 ml of 25% sulphuric acid and making the total volume 300 ml by adding distilled water. Metol sulphite solution was prepared by dissolving 5 gm of metol in 210 ml of distilled water and 3 gm of sodium sulphite was added and the volume was made upto 250 ml by adding distilled water. The samples were stirred properly and kept for 3 hours to complete reaction. The optical density was measured for standard and water samples at 650 nm using Spectronic 1001.

**3.1.7 Calcium, Magnesium, Sodium and Potassium:** For the analysis of cations GBC 902 Atomic Absorption Spectrophotometer was used. Calcium and Magnesium were analysed in absorption mode, and Sodium and Potassium were analysed in emission mode. The instrument was calibrated using different chemical standards.

### **3.2 Mineralogy:**

The bulk mineralogy of suspended sediment was studied by using X-ray diffractogram technique. The slides were prepared by drop on slide technique (Gibbs,

1967). The samples were glycolated and run on Philips X-ray diffractometer using Cu, K radiation source and Ni filter. The chart drive 1 cm/minute, goniometer  $1^{\circ}$ /minute and intensity  $2 \times 10^2$  were maintained. Carroll (1970), methods were used in identifying the minerals.

## CHAPTER - 4

### RESULTS AND DISCUSSION

Chemical analysis of water samples was done in the laboratory by using standard methods described in the previous chapter. The results are tabulated for samples collected from Chandra river at four places, before and after Bara Shigri and Chhota Shigri glacial meltwater streams meets with it, in tables 4.1, 4.2, 4.3 and 4.4. Table 4.5 shows range of different parameters observed at the four sampling sites. Based on these results, the discussion on the character of meltwaters in Chandra river and the affect of Bara and Chhota Shigri glacial meltwater streams is described below.

#### 4.1 pH and Electrical Conductivity:

The pH of Chandra river water at all the four sampling sites is alkaline with an average of 7.97 and standard deviation of 0.27. The minimum pH observed is 7.5 and maximum is 8.58. The alkalinity of Chandra river water is in contrast to the almost neutral pH (Hasnain et al., 1988) of Chhota Shigri glacier meltwaters. To the upstream side of Shigri, most part

Table 4.1 Chemistry of Chandra river before Bara Shigri stream meets with it. (Concentrations are given in mg l<sup>-1</sup>)

Sample No.	Date (Aug, 1989)	Time	pH	EC uS cm <sup>-1</sup>	Na <sup>+</sup>	K <sup>+</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>-3</sup>	SO <sub>4</sub> <sup>-2</sup>	Silica	TSM	TDS/ TSM
1	14	15	8.16	154.60	1.33	0.92	5.35	16.67	2.12	75.00	0.08	2.00	1.05	966.4	9.2
3	14	17	8.27	150.00	0.70	0.70	3.13	15.49	2.24	70.00	0.06	2.55	0.93	1138.3	11.9
5	15	9	7.84	180.80	1.01	0.79	5.63	18.79	2.63	91.00	0.07	1.40	1.31	628.8	5.0
7	15	12	8.09	166.10	1.36	0.95	5.87	17.01	2.56	78.50	0.07	1.65	1.42	605.2	5.5
9	15	15	7.68	164.20	1.02	0.81	3.85	17.00	1.48	68.00	0.11	1.80	1.24	726.0	7.6
21	17	9	7.72	148.10	0.94	0.54	6.41	16.17	2.56	59.00	0.08		1.10	324.4	3.7
23	17	12	7.90	136.30	0.78	0.35	6.05	14.69	0.92	49.50	0.08		1.33	288.4	3.8
25	17	15	7.62	137.80	1.72	0.75	4.94	15.46	1.60	51.00	0.07		1.24	566.8	7.2
27	17	17	7.99	145.80	0.93	0.59	5.73	15.09	0.80	53.00	0.08		1.54	843.6	10.6

Table 4.2 Chemistry of Chandra river after Bara Shigri stream meets with it. (Concentrations are given

in mg l<sup>-1</sup>)

Sample No.	Date (Aug, 1989)	Time	pH	EC uS cm <sup>-1</sup>	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>-3</sup>	SO <sub>4</sub> <sup>-3</sup>	Silica	TSM	TDS/ TSM
2	14	15	8.17	165.20	0.73	0.92	16.45	4.67	2.00	70.00	0.07	2.00	1.91	1101.2	11.2
4	14	17	8.31	156.50	0.72	0.69	16.64	5.09	2.08	66.00	0.07	1.80	1.54	1164.0	12.3
6	15	9	7.86	175.40	0.70	0.76	18.91	5.96	1.84	93.00	0.07	1.50	1.89	622.4	5.0
8	15	12	7.95	155.60	0.67	0.60	15.92	3.08	1.60	80.50	0.07	1.75	1.42	566.0	5.4
10	15	15	7.88	162.90	0.77	0.79	16.63	3.22	1.20	77.00	0.07	1.50	1.21	707.0	6.9
22	17	9	8.31	142.20	0.96	0.54	14.99	5.65	1.92	48.50	0.09		1.24	374.2	4.9
24	17	12	8.09	134.00	0.75	0.45	14.76	5.97	1.12	47.00	0.07		0.96	305.6	4.2
26	17	15	7.53	133.00	1.09	0.72	14.17	5.59	0.76	50.00	0.07		1.33	643.6	8.5
28	17	17	8.31	131.70	0.59	0.54	14.33	5.48	1.68	41.50	0.08		1.73	835.2	12.2

Table 4.3 Chemistry of Chandra river before Chota Shigri stream meets with it. (Concentrations are given in mg l<sup>-1</sup>)

Sample No.	Date (Aug, 1988)	Time	pH	EC uS cm <sup>-1</sup>	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>-3</sup>	SO <sub>4</sub> <sup>-2</sup>	Silica	TSM	TDS/ TSM
11	16	7	7.65	142.60	0.83	1.00	15.52	5.69	2.20	57.50	0.08	2.00	1.87	568.0	6.2
13	16	9	8.09	127.80	1.19	1.13	14.38	5.63	1.12	56.50	0.08		1.26	585.6	8.0
15	16	11	8.19	115.70	0.70	1.03	12.99	5.27	1.20	43.50	0.07	1.90	1.56	603.6	8.8
17	16	15	7.50	119.60	1.32	1.32	13.24	5.33	1.76	46.00	0.08		2.52	684.4	9.3
19	16	18	7.70	135.20	1.28	1.30	15.66	4.87	2.80	57.50	0.09		1.52	795.6	9.1
29	18	7	7.65	128.70	1.40	0.98	15.41	3.53	1.04	50.00	0.09		1.59	484.0	6.4



Table 4.4 Chemistry of Chandra river after Chota Shigri stream meets with it. (Concentrations are given in  $\text{mg l}^{-1}$ )

Sample No.	Date (Aug, 1989)	Time	pH	EC $\text{uS cm}^{-1}$	$\text{Na}^+$	$\text{K}^+$	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	$\text{Cl}^-$	$\text{HCO}_3^-$	$\text{PO}_4^{-3}$	$\text{SO}_4^{-2}$	Silica	TSM	TSM/TDS
12	16	7	8.08	127.60	0.72	0.84	13.59	2.88	1.20	55.50	0.08		1.63	535.2	6.8
14	16	9	7.83	122.20	0.97	1.03	13.88	3.99	0.80	54.00	0.08	1.30	1.80	470.4	5.9
16	16	12	7.76	114.30	0.75	1.11	13.01	4.96	2.64	43.50	0.07	1.80	2.12	615.2	8.8
18	16	15	8.31	101.00	0.73	0.87	11.29	4.28	1.36	35.50	0.11		1.56	753.2	13.1
20	16	18	8.58	116.00	0.77	0.84	12.52	2.49	1.20	39.50	0.07		1.42	784.8	12.9
30	18		8.11	116.40	0.83	0.73	13.90	3.30	0.56	43.50	0.11		1.12	462.4	7.0

Table 4.5 Range of various chemical parameters at different sampling locations.

(concentrations are given in  $\text{mg l}^{-1}$ )

	A	B	C	D	* Chhota Shigri
pH	7.62-8.27	7.53-8.31	7.50-8.58	7.76-8.58	
EC ( $\mu\text{S cm}^{-1}$ )	136.30-180.80	131.70-175.40	115.70-142.60	101.00-127.60	23.2-29.0
$\text{Na}^+$	0.70-1.72	0.59-1.09	0.70-1.40	0.72-0.97	0.7-0.8
$\text{K}^+$	0.35-0.95	0.45-0.92	0.98-1.32	0.73-1.11	0.4-1.4
$\text{Ca}^{2+}$	14.69-18.79	14.17-18.91	12.99-15.66	11.29-13.90	0.9-9.9
$\text{Mg}^{2+}$	3.13-6.41	3.08-5.97	3.53-5.69	2.49-4.96	0.35-0.5
$\text{Cl}^-$	0.80-2.63	0.76-2.08	1.04-2.80	0.56-2.64	
$\text{HCO}_3^-$	49.50-91.00	41.50-93.00	43.50-57.50	35.50-55.50	
Silica	0.93-1.54	0.96-1.91	1.26-2.52	1.12-2.12	
TSM	288.4-1138.3	305.6-1164.0	484.0-795.6	462.4-784.8	
TSM/TDS	3.7-11.9	4.2-12.3	6.2-9.3	5.9-13.1	

\* From Hasnain et al., 1989.

of the Chandra river catchment is underlain by sedimentary rocks whereas the Chhota Shigri glacier is flowing over Rohtang Gneissic Complex. The dissolved load in waters flowing over sedimentary rocks will be more than those waters flowing over igneous and metamorphosed rocks (Meybeck, 1981). During the acid hydrolysis of water the  $H^+$  ions will be consumed. So, the higher dissolution rates in sedimentary environment turns the water to alkaline. Thus, the Geology plays an important role in determining the pH.

Electrical conductivity is a measure of total dissolved solids. During the observation period the minimum conductivity is  $101 \text{ uS cm}^{-1}$  and the maximum is  $180.8 \text{ uS cm}^{-1}$  with a standard deviation of 20. Electrical conductivity depends on ionic strength of the solution. Increase in concentration of dissolved solids increases the ionic strength of the solution ( $1/2 \sum m_i z_i^2$ , where  $m_i$  = concentration of  $i$ th ion in moles per liter and  $z_i$  is the valency of  $i$ th ion). This means an increase in dissolved solids causes a proportional increase in electrical conductivity. The ratio of total dissolved solids (in ppm) to electrical conductivity is generally accepted as 0.7 (Davies and

GATEWAY

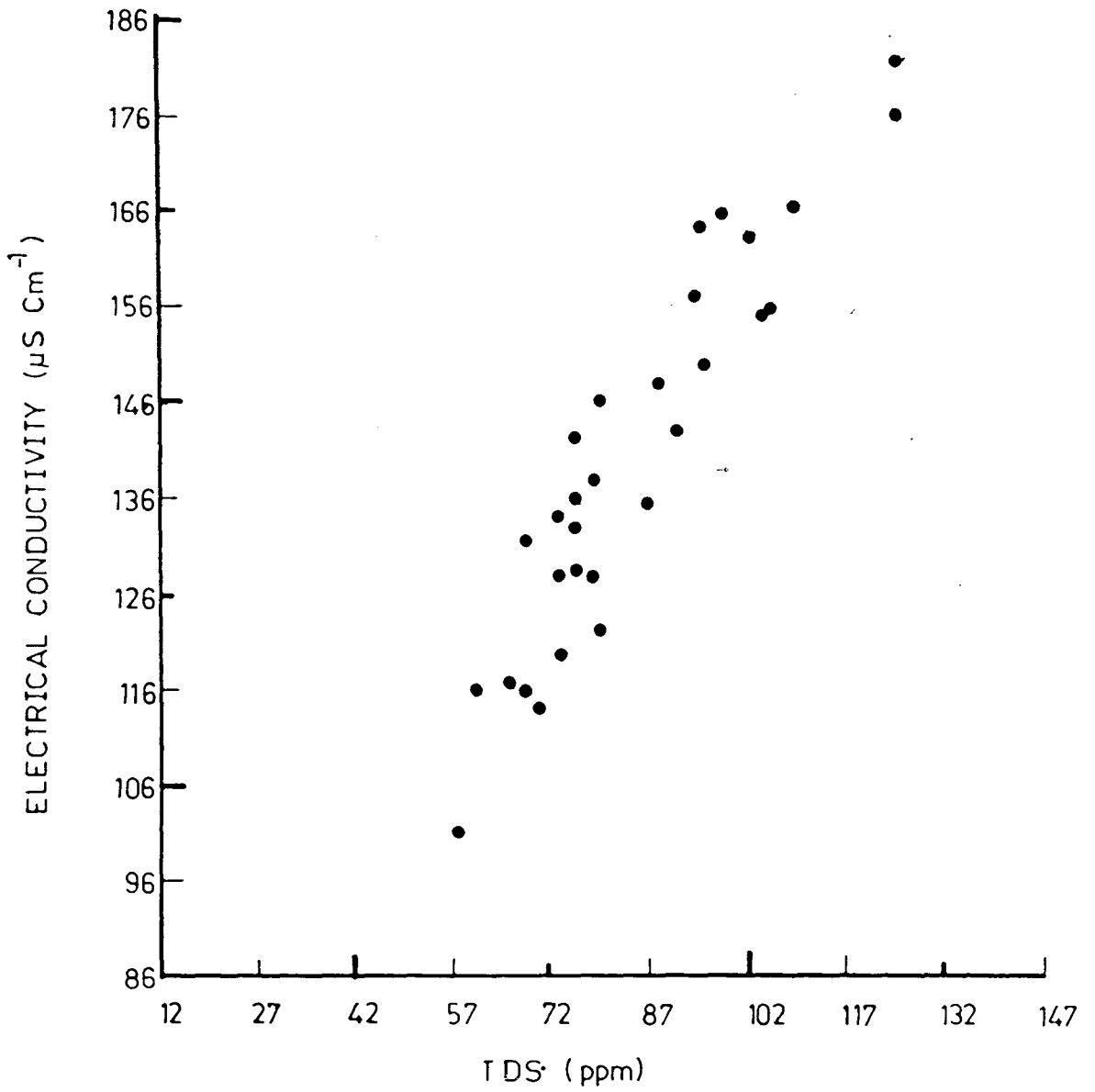


Fig 4.1 Electrical Conductivity vs. TDS

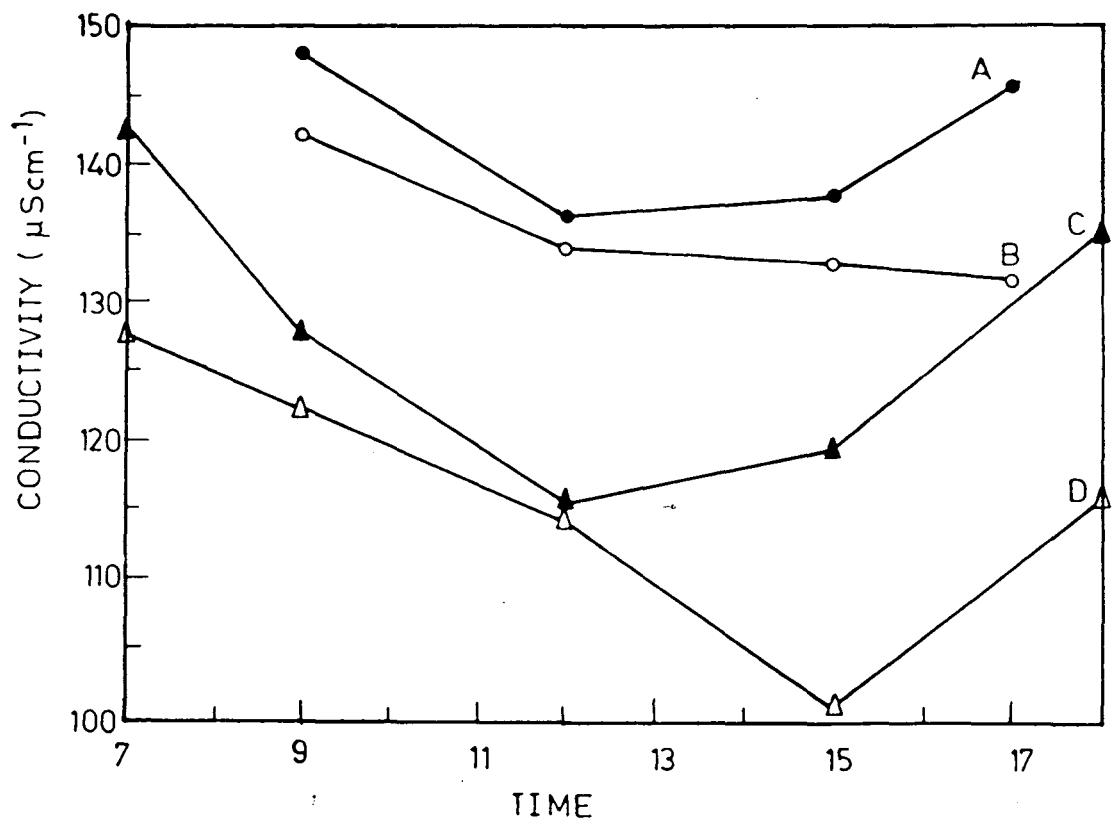


Fig 4.2 Diurnal variations in Electrical Conductivity (Samples were collected at A and B on 17th and at C and D on 16th August, 1988).

Deweist, 1962). For Chandra river, however, the ratio is coming around 0.61 (Fig 4.1).

Most of the meltwaters shows an electrical conductivity of less than  $50 \text{ uS cm}^{-1}$ , except for Lewis river, Baffin Island, where Church (1974) reported a maximum of  $205 \text{ uS cm}^{-1}$  (Collins, 1979). The Chhota Shigri glacier meltwater shows an average electrical conductivity of 23.2 to  $29.0 \text{ uS cm}^{-1}$  (Hasnain et al., 1989). All these catchments underlie igneous and metamorphic rocks. However, for Chandra river most of the catchment area is underlain by sedimentary rocks. As indicated by Meybeck (1981), the waters flowing on sedimentary rocks carries more dissolved load than the others (Table 1.1). So the high values of electrical conductivity observed for Chandra river are influenced by lithology.

Repeating periodic diurnal variations in electrical conductivity were observed throughout the sampling period. Fig 4.2 shows diurnal variations in conductivity at the four sampling sites (A,B,C and D). A two component subdivision of total flow was put forward by Rainwater and Guy (1961), and Collins (1979) to explain diurnal variations in glacierised catchments. Variable dilution of water coming from the

ground environment, which undergoes chemical change while slowly passing through ice-sediment-rock interface and basal sediments, by water running off rapidly through englacial channels without undergoing much chemical change. In the morning, with the supply of solar energy, ablation starts and produces more englacial water which causes an increase in discharge and decrease in electrical conductivity due to dilution (Fig 4.2). Slowing down of ablation in the late afternoon causes an increase in the electrical conductivity.

In the forenoon, the rates of decrease in electrical conductivity are higher at the sites A and C as compared to those at B and D. The difference in rates of change of electrical conductivity at the four sampling sites also highlights the importance of lithology and the contribution of water from the ground environment to the total flow. As shown in Fig 4.2, the higher rates of decline of electrical conductivity at A and C in the forenoon, as compared to those at B and D, are due to decrease in the contribution of water from the ground environment to the total flow in the upstream side of the catchment, where the underlaining rock types are mainly sedimentary. Eventhough the

contribution of subglacial flow to the total flow decreases for Bara Shigri and Chhota Shigri meltwater streams, after they meet with Chandra river, the electrical conductivity changes at slower rates as compared to those of upstream side due to the fact that these two glaciers are underlain by high grade metamorphic rocks. So the meltwaters coming out of these two glaciers will be low in solute content and the variation as compared to the main Chandra river will also be less. Thus the mixing of these waters with Chandra river causes comparatively slow rate of variation of electrical conductivity. The higher rates of increase at A and C compared to those at B and D in the late afternoon can also be explained in the same way.

#### **4.2 Dissolved Load:**

**4.2.1 Total Cations:** Average chemical composition of Chandra river water shows 70% calcium out of total cations, followed by magnesium (22%), sodium (4.3%) and potassium (3.8%). The water is of  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$  type of Meybeck (1981). 63% of world river waters are of this type. The range of percentages of cations tabulated by Collins (1979) from different sources



suggests that  $\text{Ca}^{2+}$  is the dominant cation in meltwaters, except those at Baffin Island, where the dominant cation,  $\text{Na}^+$  is preferentially supplied from the underlying bed rock. Calcium is the dominant cation in approximately 88% of the meltwaters and often comprises more than 70% of the total cation equivalents (Raiswell, 1984). Thus, the cationic composition of Chandra river is similar to the majority of world's fresh waters.

**4.2.2 Total Anions:** Bicarbonate constitutes 94.74% of total anions followed by chloride and sulphate in almost equal proportions (2.6 and 2.53 percent respectively). The concentration of phosphate ions in the Chandra river water is negligible (0.13%). Available data on meltwater chemistry compiled by Raiswell (1984) shows that half of the meltwaters are bicarbonate dominant whereas the other half dominated by sulphate. According to him, chloride is invariably less and below detection limits in most of the cases. 98.7% of the world's major river waters are dominated by bicarbonate (Meybeck, 1981).

**4.2.3 Bicarbonate, Calcium and Magnesium:** Bicarbonate constitutes an average concentration of  $58.37 \text{ mg l}^{-1}$  with 15.25 standard deviation. The range of bicarbonate

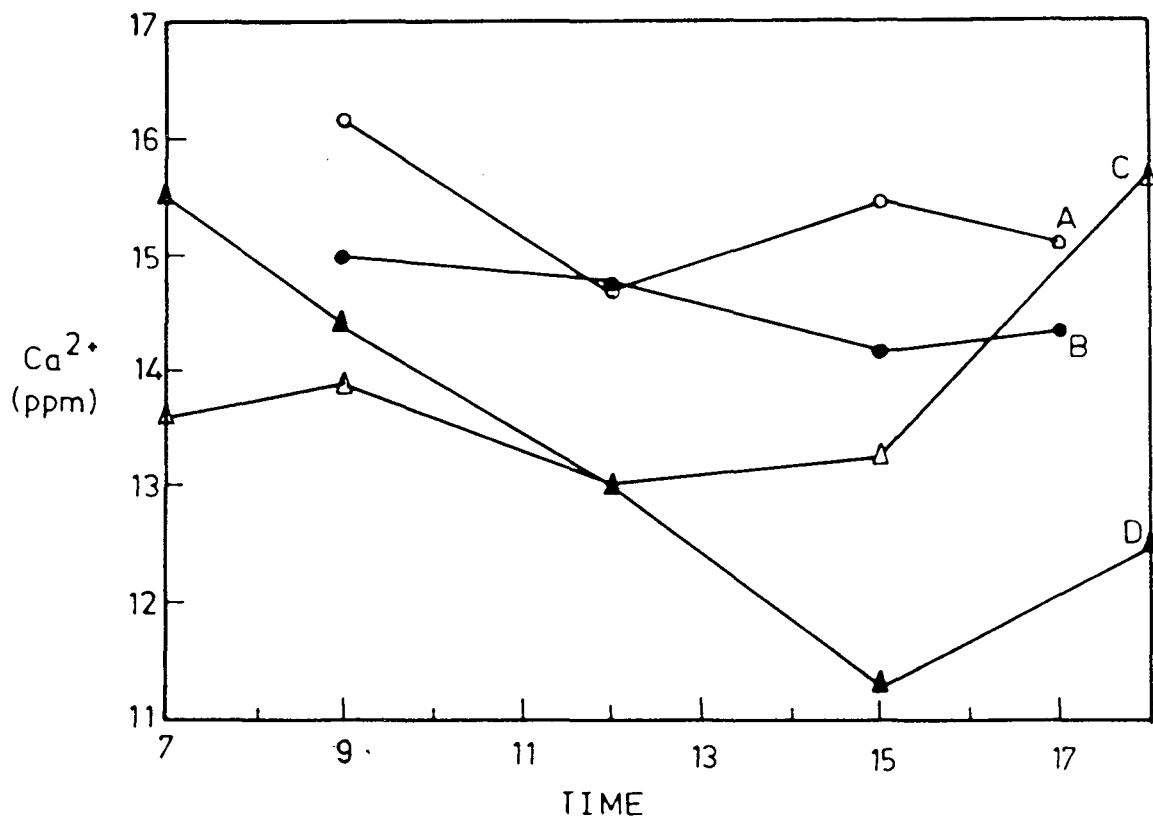


Fig 4.3 Diurnal variations in Ca<sup>2+</sup> concentration (Samples were collected at A and B on 17th and at C and D on 16th August, 1988).

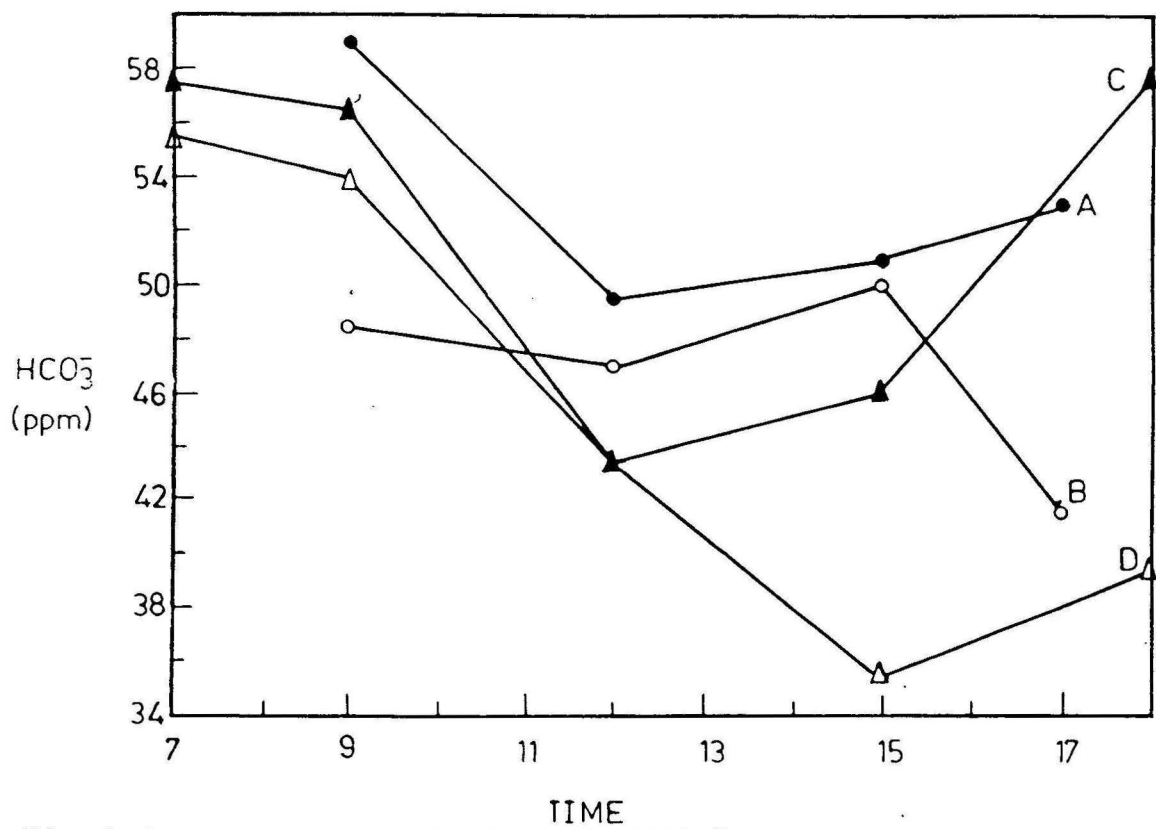


Fig 4.4 Diurnal variations in  $\text{HCO}_3^-$  concentration (Samples were collected at A and B on 17th and at C and D on 16th August, 1988).

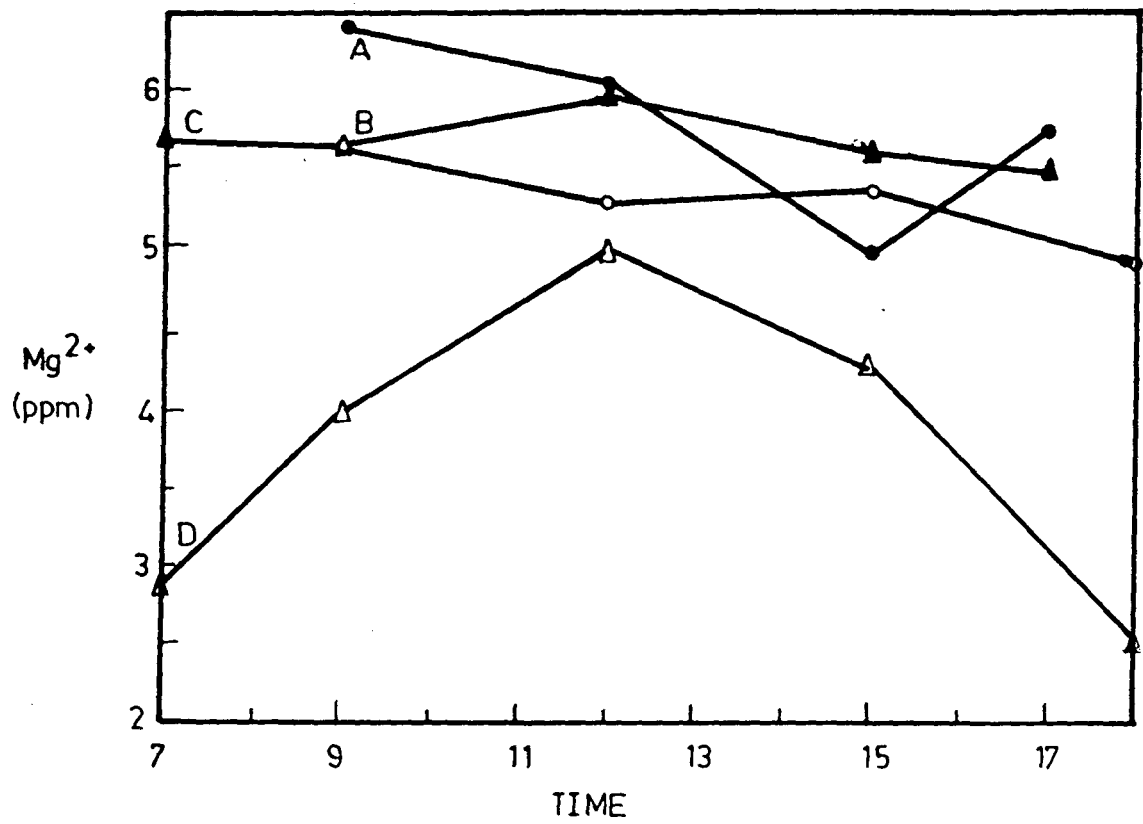


Fig 4.5 Diurnal variations in Mg<sup>2+</sup> concentration  
 (Samples were collected at A and B on 17th and  
 at C and D on 16th August, 1988).

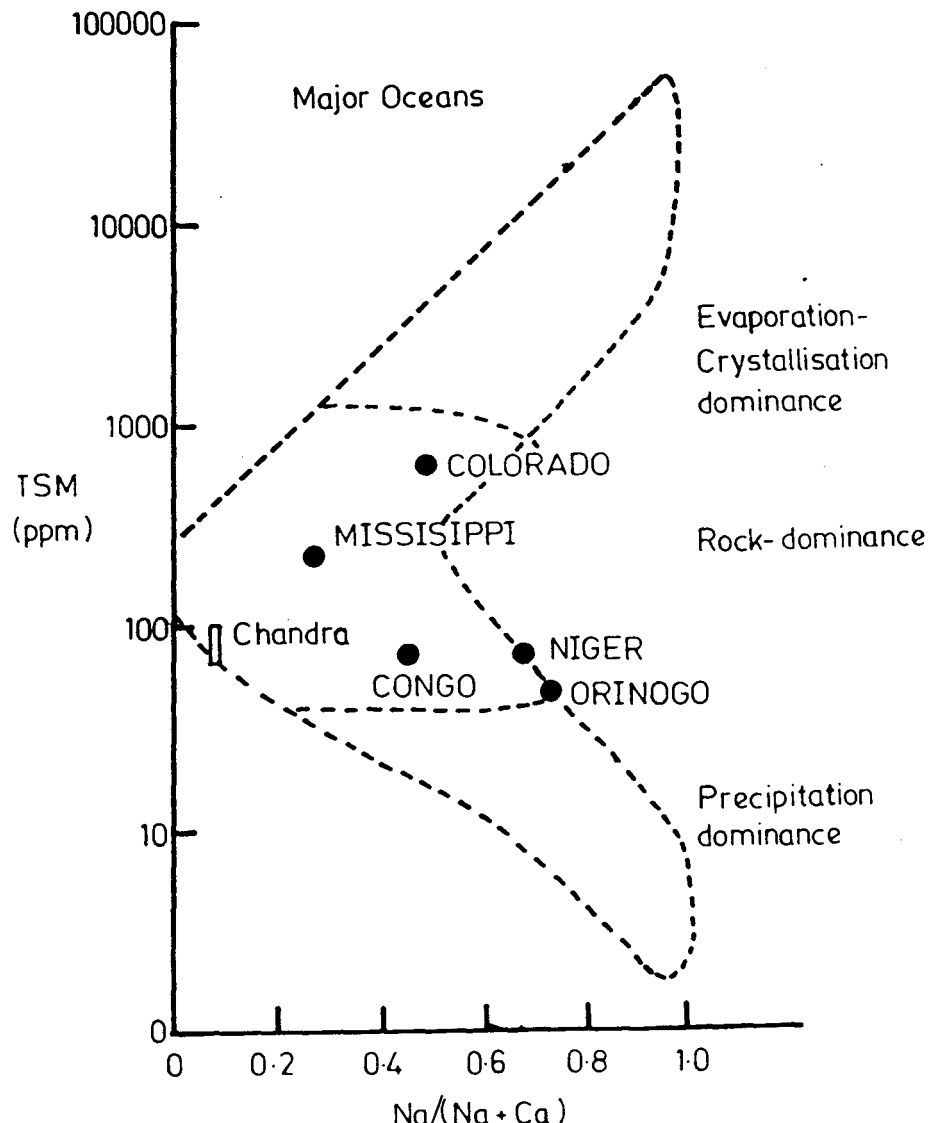


Fig 4.6  $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$  vs. TDS  
 (Redrawn after Gibbs, 1970)

is from 35.5 to 93 mg l<sup>-1</sup> during the sampling period. Calcium and magnesium ions constitute 92% of the total cations. The minimum and maximum concentrations observed for calcium are 11.29 and 18.91 mg l<sup>-1</sup> and for magnesium 2.49 and 6.41 mg l<sup>-1</sup> with standard deviations 1.74 and 1.13 respectively. The range of these ions observed at all the four sites are given in table 4.5. Diurnal and spatial variations are observed for these ions throughout the sampling period. A definite trend in the variations could be traced for calcium and bicarbonate, but no specific relation is found in case of magnesium (Fig 4.3, 4.4, 4.5). Concentrations of calcium and bicarbonate decreases in the forenoon as discharge rises with the starting of ablation. The concentration rises in the late afternoon as the discharge starts declining.

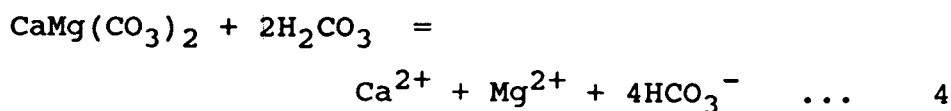
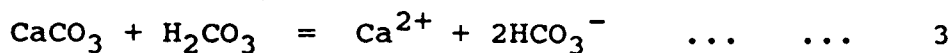
Plotting of  $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^+)$  against total dissolved solids (Fig 4.6, after Gibbs, 1970) suggests the dominance of rock weathering in contributing solute to the water. The single most important process in the chemical weathering of rocks is acid hydrolysis. The source of bicarbonate in waters is dissolution of CO<sub>2</sub>. The organic matter in the soil zone of the glacierised catchments is negligible to contribute CO<sub>2</sub> to water. So

the main source of dissolved CO<sub>2</sub> in water is from the atmosphere. The dissolved CO<sub>2</sub> produces bicarbonate in two steps and releases hydrogen ions to water required for the acid hydrolysis.



In the first step dissolved CO<sub>2</sub> reacts with water and produces carbonic acid (1). This weak carbonic acid dissociates itself to produce hydrogen and bicarbonate ions(2). The bicarbonate may again split into hydrogen and carbonate ions at pH values higher than 10.3 (Raymahashay,1986). This reaction is not important as the pH observed is much less.

In general, total bicarbonate in river water has two fractions namely, (1) bicarbonate derived from primary carbonates as well as calcareous cements and (2) bicarbonate derived from silicates (Raymahashay, 1986).



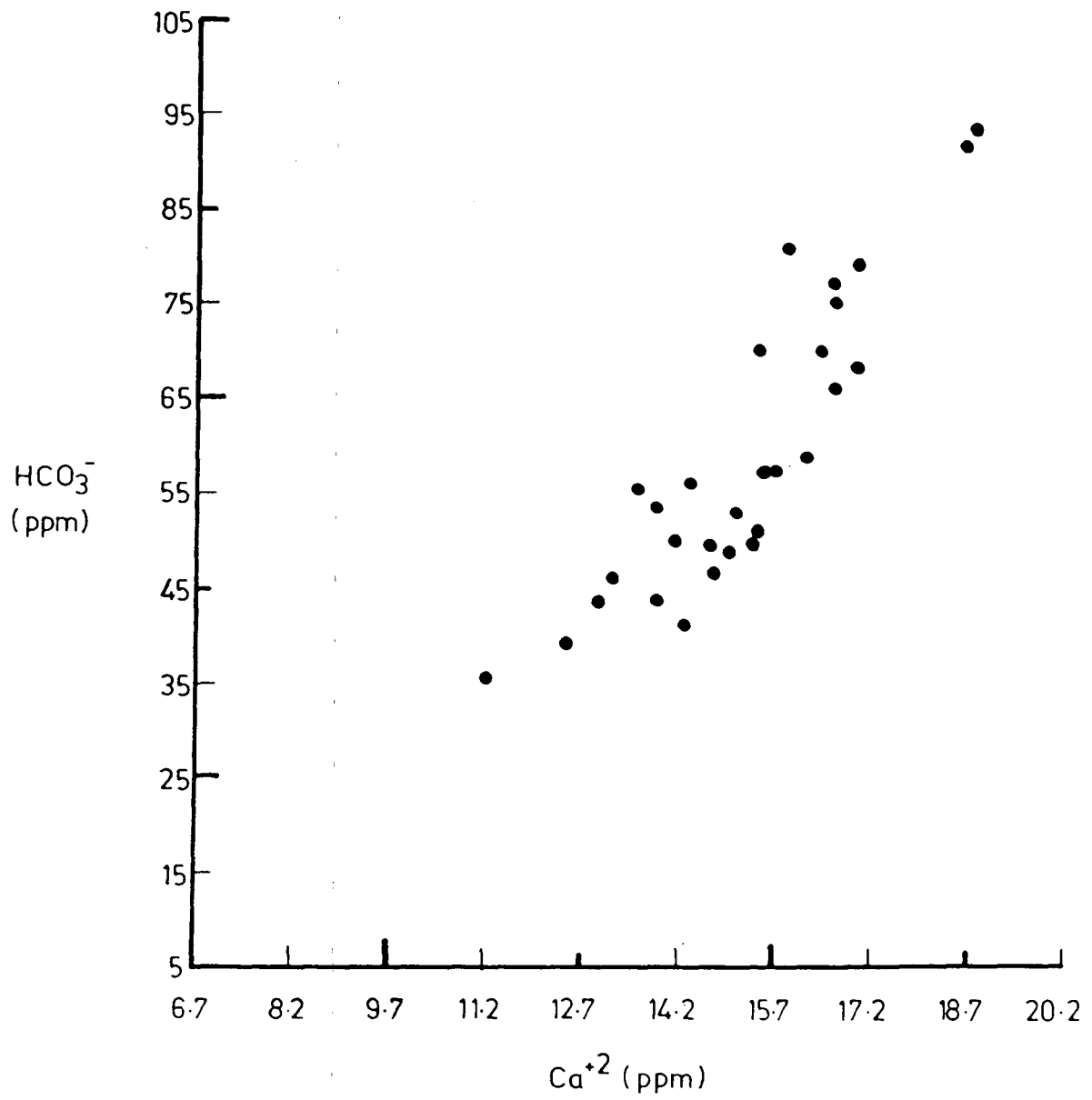
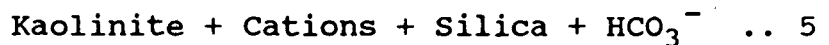


Fig 4.7 Calcium vs. bicarbonate.



Carbonates react with dissolved  $\text{CO}_2$  and releases bicarbonate and cations to water. If the carbonate involved in reaction is calcite, then according to reaction(3),  $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$  will be released in 1 : 2 proportion. If dolomite is involved, then calcium, magnesium and bicarbonate will be released in 1 : 1 : 2 proportions (equation 5).

The carbonic acid produced by dissolved  $\text{CO}_2$  in water reacts with primary silicate minerals and produces cations, clay minerals, bicarbonate and silica  
 Feldspar +  $\text{H}_2\text{CO}_3$  =



The cations released to water in these reactions depends upon the composition of original minerals.

In reactions (3), (4), and (5), the bicarbonate and cations are derived from the same source. Similar trends followed by concentrations of calcium and bicarbonate ions in the diurnal and spatial variations (Fig 4.3, 4.4), and a very good positive correlation of 0.89 between these two ions (Fig 4.7) indicates a common source for both these ions. The

concentration of bicarbonate in moles per liter is nearly double to the total of calcium and magnesium, indicating the dissolution of carbonates as major source of these ions in water. Very low concentrations of these ions in meltwaters from Chhota Shigri glacier when compared with Chandra river waters are because of nonavailability of carbonates in Rohtang gneiss over which the glaciers are flowing.

Some important observations can be made with the rates of variation in the concentration of these ions. At sites A and C, before Chandra river meets with Bara Shigri and Chhota Shigri glacial streams, the rates of variation for bicarbonate and calcium are more when compared to those at B and D (Chandra river after meeting with both the glacial meltwater streams). This pattern of changes are observed with electrical conductivity also as explained earlier. As explained earlier in case of electrical conductivity, the diurnal variations in concentrations of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$  can also be related to the contribution of englacial stream water to the total flow. The dilution effect in Chandra river, after Bara Shigri and Chhota Shigri glacial meltwaters meets with it and comparatively lower variations at B and D can be explained on the

basis of geology of the area and contribution from subglacial flow to the total flow.

**4.2.4 Sodium and Potassium:** Sodium and Potassium together contributes only around 8% of the total cations. The Chandra river shows  $\text{Na}^+$ , and  $\text{K}^+$  concentrations ranging from 0.59 to 1.72  $\text{mg l}^{-1}$  and 0.35 to 1.32  $\text{mg l}^{-1}$  with standard deviations 0.28 and 0.24 respectively. Limited diurnal variations are observed but no definite trend could be found.

Low concentration of  $\text{K}^+$  is because of its less mobility. The average  $\text{K}^+$  concentration observed in the area ( $0.82 \text{ mg l}^{-1}$ ) is slightly less than the average for world river waters. This is due to the fact that most of the  $\text{K}^+$  in river waters is derived from the chemical weathering of rocks and atmospheric input is less significant. When sodium is derived from the atmosphere, its concentrations will not be affected by dilution (Meybeck, 1983). So the dilution in concentrations observed after glacial streams meets with the river (Fig 4.8) indicates the lithogenic source of  $\text{Na}^+$  in water. High latitude, their position far away from the seas and low concentration of sodium in meltwater when compared with the average world

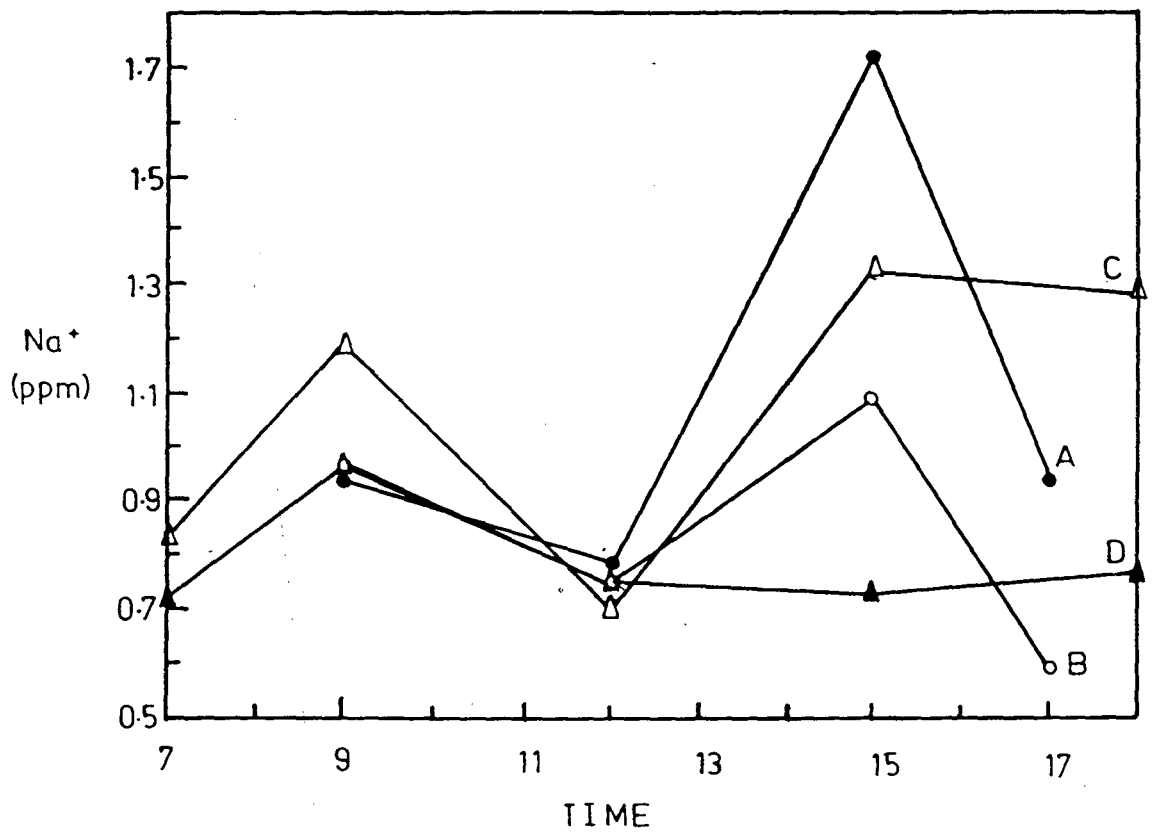


Fig 4.8 Diurnal variations in  $\text{Na}^+$  concentration  
 (Samples were collected at A and B on 17th and  
 at C and D on 16th August, 1988).

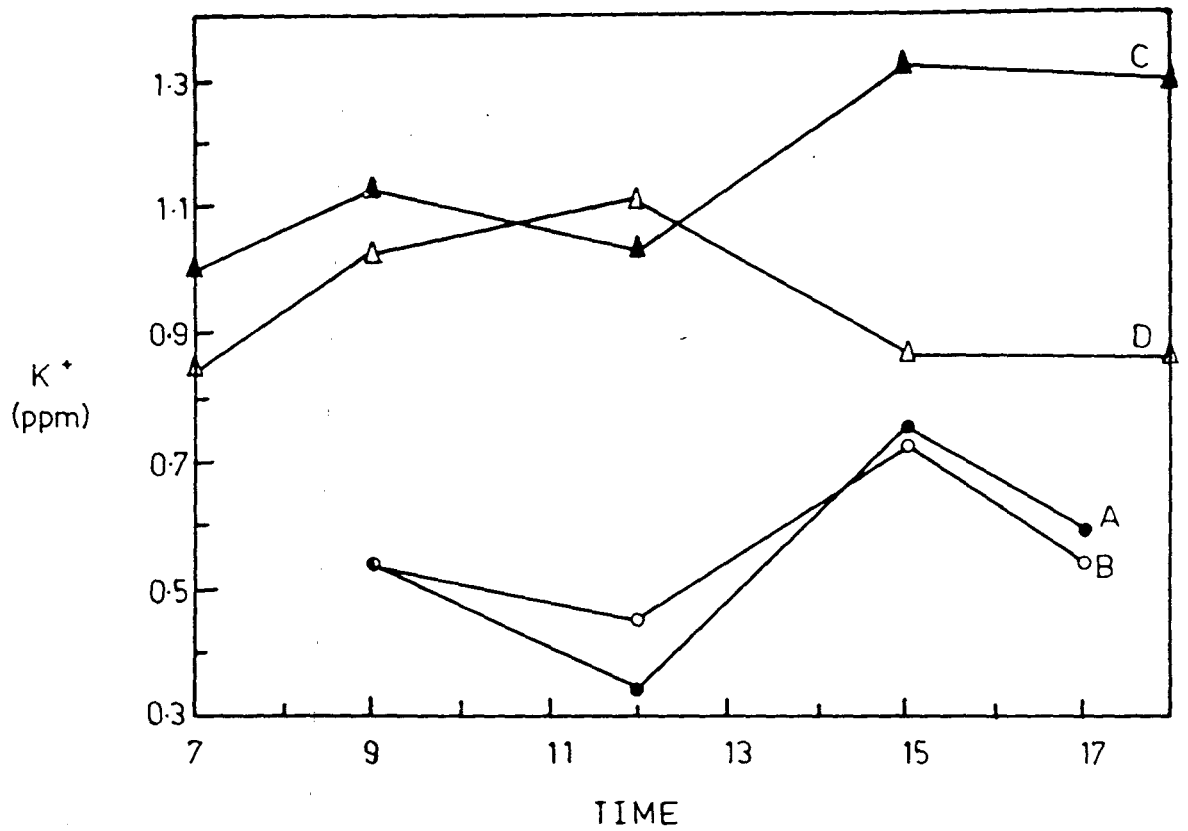


Fig 4.9 Diurnal variations in K<sup>+</sup> concentration  
 (Samples were collected at A and B on 17th and  
 at C and D on 16th August, 1988).

river waters points out the least significance of atmospheric input in these regions.

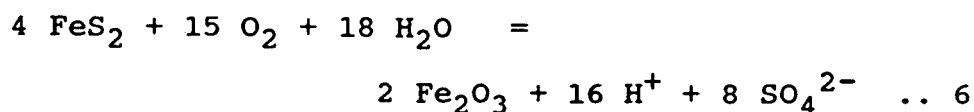
Negligible contribution from the atmosphere, suggests the origin of these alkalies to the evolution of clay minerals. When K-feldspar reacts with the carbonic acid, ion exchange takes place in the initial stage. Cations will be released to the water and hydrogen ions with feldspar forms H-feldspar. This H-feldspar is not stable and produces bicarbonate, kaolinite and dissolved silica after some time (Wollast, 1967; quoted by Berner, 1971). Excess concentrations observed for sodium and potassium than the proportional dissolved silica concentrations suggests ion exchange as major process in determining the composition of these alkalies. Sudden rise in concentration of sodium and potassium near the frontal zone of glaciers indicates that ion exchange is an essential mechanism in the release of cations from minerals (Lemmens and Roger, 1978).

The diurnal variations in  $\text{Na}^+$  and  $\text{K}^+$  concentrations shows the same trend (Fig 4.8 and 4.9). But no definite relation could be found out with other major ions. This indicates that the processes involved

in the formation of sodium and potassium are different from the processes responsible for the release of calcium and magnesium.

**4.2.5 Sulphate, Chloride and Phosphate:** All these anions are minor in our study area. Altogether they constitute only 5.3% of total anions. The minimum and maximum concentrations observed for sulfate are 1.3 and 2.56 mg l<sup>-1</sup> with a standard deviation of 0.68. The range of chloride concentrations in Chandra river waters from 0.56 to 2.8 mg l<sup>-1</sup>. Standard deviation for chloride values is 0.64. Phosphate is almost in negligible amounts having concentrations ranging from 0.06 to 0.11 mg l<sup>-1</sup>.

The presence of sulfate in the water indicates existence of sulphide minerals in the bedrock. Raiswell (1984), pointed that in an oxygenated environment these sulphide minerals breakdown rapidly to produce sulfate ions.



The hydrogen ions released in this reaction helps in the chemical weathering of rockforming minerals. So the anionic composition of meltwaters

helps in the identification of source of acid potential of the water. Sulfide mineral deposits found in the area may be contributing sulfate to some extent.

Chloride in the water is mainly derived from oceanic source. The atmospheric fallout contributes most of the chloride in fresh waters. Walling and Web (1986) discussed about the influence of certain factors, such as altitude and proximity to the sea, on chloride concentration. The himalayan glaciers are found on high altitudes and located far from the seas. The less efficiency of snow in recovering materials from the atmosphere can also be cited as a reason in explaining extremely low concentrations of chloride in meltwaters.

**4.2.6 Dissolved Silica:** Dissolved silica concentration is ranging from 0.93 to 2.52 mg l<sup>-1</sup> with a mean concentration of 1.48 mg l<sup>-1</sup>. Concentration of dissolved silica in moles per liter is much less than those of Na<sup>+</sup> and K<sup>+</sup>. Ion exchange as a reason was already explained while discussing Na<sup>+</sup> and K<sup>+</sup>.

#### **4.3 Suspended Load:**

The amount of suspended matter in water depends on the hydraulic condition of the streams and



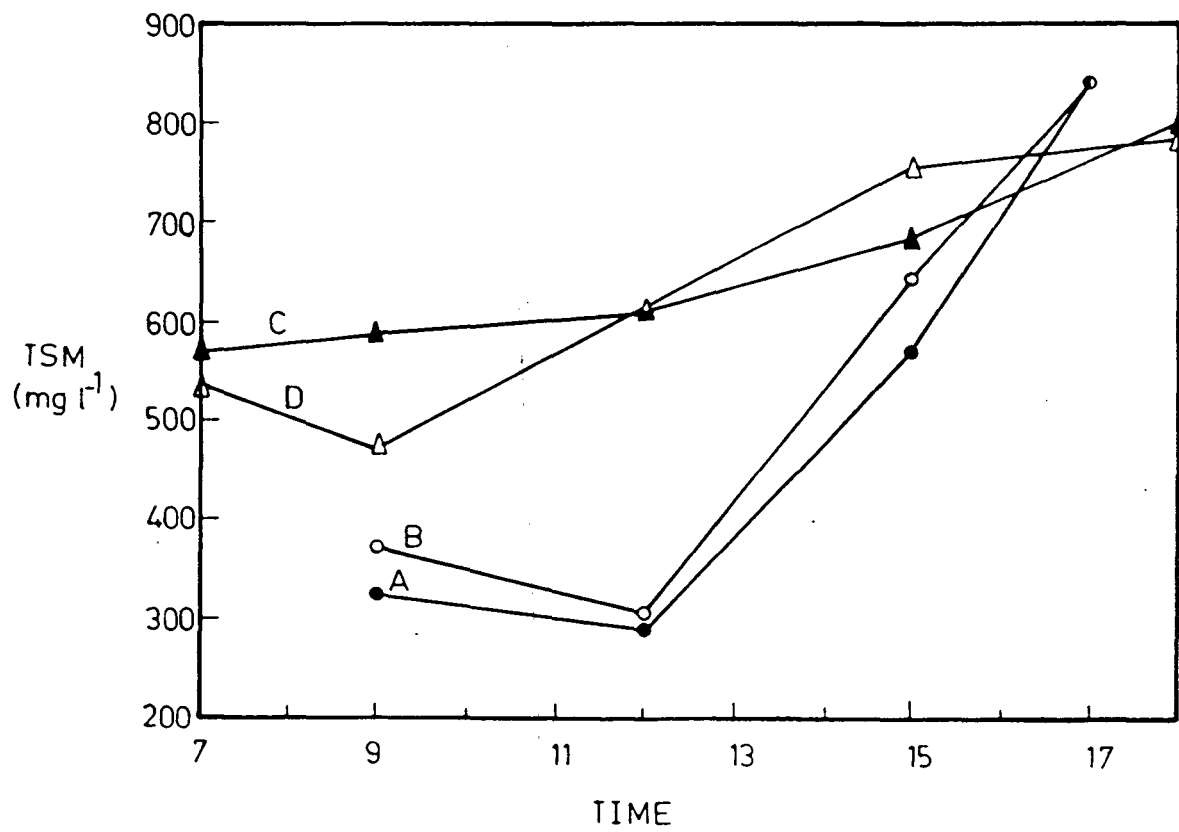


Fig 4.10 Diurnal variations in TSM concentration  
 (Samples were collected at A and B on 17th and  
 at C and D on 16th August, 1988).

availability of suitable size fractions of sediment. Wide variations are observed in total suspended matter. The range of suspended sediment concentrations found during the sampling period is from 288.4 mg l<sup>-1</sup> to 1164 mg l<sup>-1</sup>. Very high deviation from the mean value (standard deviation = 228) is observed. Repeated continuous diurnal variations are observed during the sampling period.

The grinding action of glaciers produces very fine sediment which contributes substantial amount of suspended sediment. Gibbs (1967) found that 82 percent of suspended sediment is derived from 12% mountainous area in the Amazon river catchment. The higher competency and capacity of these streams, provides more sediment to be carried away in suspension. The sediment concentration is increasing from morning to evening because of increase in discharge due to melting of snow and ice. Chandra river carries more suspended load per liter after Bara Shigri glacial stream meets with it, than before, because of increase in velocity and possibility of more concentration of suspended sediment in the glacial stream (Fig 4.10).

The samples collected on 14th August shows high values for both suspended and chemical load when

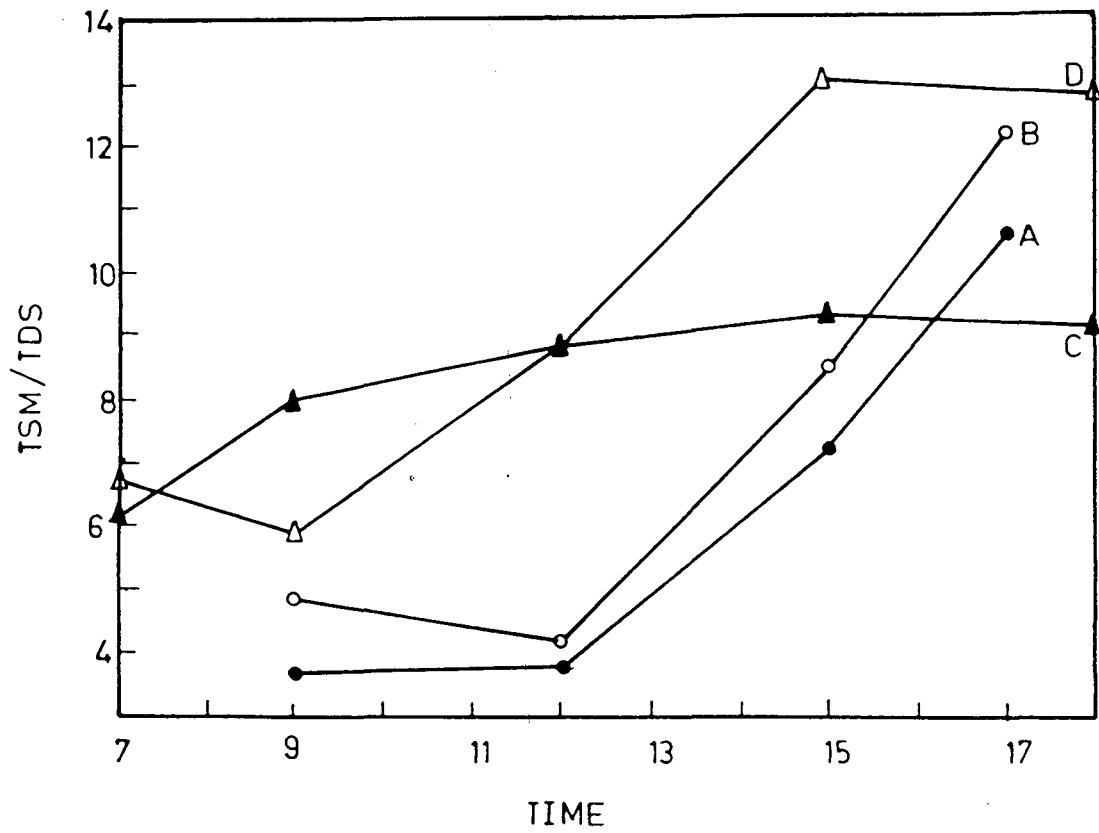


Fig 4.11 Diurnal variations in TSM/TDS ratio  
 (Samples were collected at A and B on 17th and at C and D on 16th August, 1988).

compared to those samples which were collected on 17th August. This may be due to spread of waters on morainic material on 14th. This provides more material to be taken in suspension and high dissolution because of increased contact area of sediment with water. On 17th the waters might have been confined to channels. Comparatively less availability of sediment and less contact area of sediment in channels caused decrease in both chemical and sediment load.

#### **4.4 TSM/TDS:**

The ratio of sediment load to chemical load gives an idea about the importance of physical and chemical weathering processes in the area. In the present study this ratio shows importance of diurnal variations in physical and chemical weathering (Fig 4.11 ). The sediment load is increasing accompanied by decrease of chemical load in the afternoon.

With the addition of more and more water from the englacial channels, the dissolved load in water gets diluted. In the same time the increased discharge causes more supply of sediment by erosion. This ratio is comparatively more at B and D, after the river meets with meltwater streams. This is because of dilution of

Table 4.6 Mineralogy of suspended sediment in percent.

Sample No	Quartz	Feldspar	Muscovite	Dolomite	Kaolinite	Illite	Chlorite
9	42.07	16.39	2.59	1.26	26.12	8.34	3.23
10	43.08	11.59	1.53	0.37	31.20	8.97	3.93
12	42.36	19.30	3.24	1.21	19.05	12.74	2.00
17	34.73	21.86	3.63	2.25	24.79	11.01	1.73
18	33.17	22.08	5.00	3.79	19.63	14.14	2.19

chemical load and increase in suspended sediment concentration of Chandra river after it is met by Bara Shigri and Chhota Shigri meltwater streams.

#### **4.5 Mineralogy:**

Mineralogy of suspended sediment was determined for some samples with the help of X - Ray diffractogram. Table 4. shows the percentage of various minerals found in suspended sediment. Among the primary minerals quartz is major one followed by feldspar (Table 4.6). Dolomite and muscovite constitute very small amounts. Kaolinite is the dominant clay mineral and considerable amount of illite is present. Minor amounts of chlorite is also found.

Depending on the rate of weathering of common igneous minerals Goldich (1938) has proposed weatherability series which is similar to that of Bowen's reaction series in Igneous petrology. Among the primary minerals observed in the sediment, feldspar, muscovite and dolomite are rapidly weatherable where as quartz is more resistant to weathering. The weathering of feldspar and muscovite produces clay minerals. With the intensity of weathering, the quartz component increases among the primary minerals and the weathering

Table 4.7 Correlation between minerals in suspended sediment.

Mineral	Feldspar	Muscovite	Dolomite	Kaolinite	Illite	Chlorit
Quartz	-0.81	-0.86	-0.93	0.44	-0.62	0.65
Feldspar		0.92	0.84	-0.81	0.75	-0.95
Muscovite			0.96	-0.82	0.85	-0.78
Dolomite				-0.64	0.75	-0.64
Kaolinite					-0.87	0.80
Illite						-0.74

of other minerals results in the increase of clay content. This relationship among the quartz and other minerals can be confirmed from the correlation coefficients between different constituent minerals (Table 4.7).

Relief plays an important role in the type of clay mineral formation. Our study area is having high relief, and it is well drained, favouring the formation of kaolinite. Under conditions of limited weathering and decomposition, muscovite, k-feldspar and plagioclase may provide the alumina and silica necessary for forming kaolinite (Berner, 1971). Negative correlation coefficients for kaolinite with feldspar, muscovite and illite (-0.81, -0.82, -0.87 respectively) indicates that the weathering of these minerals leads to the formation of kaolinite in suspended sediment.



## CHAPTER - 5

### SUMMARY

Based on the discussion in previous chapter, the present work can be summarised as follows -

1. The Chandra river water is alkaline because of high dissolved load it carries. The major source of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  is the dissolution of carbonates whereas  $\text{Na}^+$  and  $\text{K}^+$  concentration is related to clay mineral formation and ion exchange.
2. Quartz, feldspar, kaolinite and illite are the major mineral species found in suspended sediment. Formation of kaolinite from the weathering of feldspar is the source of alkalies in water.
3. Diurnal variations in suspended sediment, dissolved load are because of discharge variations. The suspended sediment concentration is increasing from morning to evening whereas the dissolved load shows an opposite trend. This indicates the dominance of physical weathering with increased discharge.

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