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Preliminary Studies on the Environmental Geochemistry of the Brahmaputra River Basin

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CERTIFICATE

This is to certify that the Dissertation entitled **"Preliminary studies on the Environmental Geochemistry of the Brahmaputra River Basin"** submitted to the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, for partial fulfilment of the M.Phil. degree is original and has not been submitted in part or in full for the award of any degree or diploma of any University.

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THE RIVER

"I donot know much about gods ; but I think that the river
Is a strong brown god - sullen, untamed and intractable,
Patient to some degree, at first recognized as a frontier;
Useful , untrustworthy , as a conveyor of commerce;
Then only a problem confronting the builder of bridges.
The problem once solved, the brown god is almost forgotten
By the dwellers in cities - ever , however implacable,
Keeping his seasons and rages , destroyer , reminder
of what men chose to forget. Unhonoured, unpropitiated
By worshippers of the machine, but waiting,watching and
Waiting."

T.S.Eliot
"The Dry Salvages"

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ABSTRACT

Twenty six samples of water collected over two seasons (Jan'81 and June-July'89) and thirteen bed sediments and suspended sediment samples collected during monsoon (June-July'89) from different locations of about a 800 Km stretch of the Brahmaputra river have been analysed. Downstream and seasonal variations in the water chemistry were studied. The Brahmaputra river shows a higher bi-carbonate content, reflecting that significant chemical weathering takes place in the basin along with physical weathering. From the water chemistry, the aluminosilicates and carbonate minerals expected to be in equilibrium with Brahmaputra river water were determined. From the X-ray diffraction studies, these minerals were also observed in the suspended sediments. Suspended and bed sediments were analysed for their elemental chemistry and the distribution of different elements over the basin is evaluated. The suspended sediments size distribution were studied and varions stastistical parameters of these sediments have been determined. The mineralogy of bulk suspended sediments were investigated and percentage of detritals, Carbonates and clay minerals derived. Average sediment composition of the Brahmaputra river were calculated taking 90% of suspended and 10% of bed sediment composition. Based on availabile

sediment load data, individual fluxes of elements at an extreme downstream location of Pandu. have also been calculated. Geoaccumulation indices for the heavy metals in suspended sediments of Brahmaputra reveal overall no enrichment of these metals in the river indicating absence of pollution.

INTRODUCTION

Rivers are amongst the major natural forces changing the face of the earth. A river basin is the most active component of the hydrological cycle involving continuous mobility of water as well as erosion, transportation and deposition of dissolved, suspended and tractively carried materials. Considering the fact that more than 90% of the continental weathering products are transported to the ocean by the rivers, knowledge of river water chemistry and elemental flux through them is imperative for a comprehensive understanding of exogenic cycles of elements.Environmental geochemistry of rivers represents complex interactions in the rock-water-air-life system giving rise to a wide range of chemical characteristics in the surface environment which consequently is of dominant importance to man.

The circulation of water through the hydrological cycle provides a mechanism for geochemical changes through weathering and transport of dissolved and solid materials. River processes form a major link in this geochemical cycle.With an estimated annual discharge of 37,000 km^3 of water, 13.5 billion tonnes of sediments (Milliman and Meade, 1983) and 3.25 billion tonnes of dissolved load

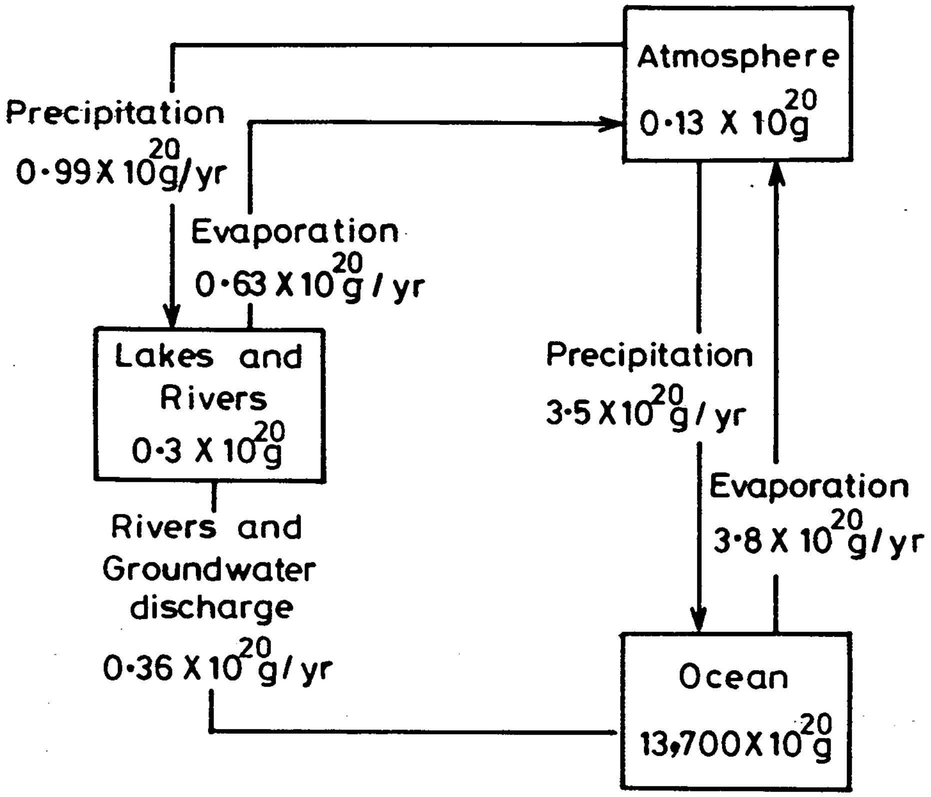


Fig.1·1 Hydrologic cycle; Drever, 1982

weathering, and on the response of the uplifted materials to the chemistry of the atmosphere (Garrels and Mackenzie, 1971). Subramanian (1979) estimated that at the present rate of erosion, with no compensating uplifting mechanism, river basins in India would achieve their base levels of erosion in 5 million years.

Several attempts have recently been made to understand river transport of materials. The pioneering works include that of Gibbs (1977), Martin and Meybeck (1979), Milliman and Meade (1983). Milliman and Meade (1983), estimated that nearly 30 per cent of transport of sediments by world rivers take place in the Indian sub-continent. To understand the geochemical mass balance between land and ocean, the estimation of mass transfer from continent to ocean, is very important. Since rivers are by far the most important supplier of materials to the ocean system, several attempts have been made to understand river trasport of materials. The important among these are by Gibbs (1977), Meybeck (1976), Milliman and Meade (1983), Martrin and Meybeck (1979). In the Indian sub-continent, mass transfer studiies have been initiated by Jha and Subramanian (1986), Biksham and Subramanian (1985), ,Ramesh and Subramanian (1985), Raymahasay (1970),Subramanian (1978, 1979) and others.

Textural, mineralogical and chemical studies on riverine sediments offer an insight into river basin

(Meybeck,1976), they are the leading transporting agents from the continents to the oceans.World rivers with 1.2 thousand cubic km. of water account for an almost insignificant (0.0001 %) of the total water in the hydrosphere (Lvovich,1973); but taking account of the rapid circulation of this water, the world rivers annually discharge about 38,000 cubic km. of water into the oceans.

The two fundamental processes of weathering - mechanical and chemical, result in the suspended and dissolved loads of rivers and they represent quantitatively, the most important input to the oceans (Holland,1978). The components which are very mobile, such as silica, aluminium, iron, titanium and potassium are mainly exported by mechanical erosion processes, whereas calcium, magnesium, sodium and carbonates are removed from the basin primarily by chemical erosion (Probst, 1986). The river and stream borne soluble and suspended loads get affected in estuaries where there is continuous mixing between fresh water and sea water (Evans et al., 1977, Fukai et al., 1973, Krishnaswamy, 1976, Sholkovitz, 1976, Turekian, 1971, 1977) by processes such as flocculation, adsorption-desorption, recycling through biological processes etc. The chemical composition of the eroded matter depends on the mean composition of the minerals lifted above the sea level, on the relative effectiveness of chemical weathering compared to physical provenance and the effect of transport on the original relationship in the geological formations. The clay minerals of river suspensions reflect in general the geological setting of the respective drainage areas. Large rivers with a heterogenious geology in their catchment basins show a great variability in the clay mineral composition of their suspended load.

There is an enormous effect of human activity on weathering and erosion processes as a result of ploughing agricultural fields, deforestation, acid rain and all types of engineering works on the earth's surface. Now there is a strong growing realisation that understanding of our environmental surroundings is of vital importance for the repair of prior degradation and development of future strategies (Pagenkopf, 1976). This awareness has led to a rapid increase in the number of studies involving the various aspects of natural water chemistry.

CHAPTER 1

LITERATURE REVIEW

1.1 General

Geochemical studies of surface waters have always constituted an integral part of the efforts for finding solutions to general problem in geochemistry. This is so because surface water is the most obvious medium to assess, monitor and control pollution as the data are then directly related to their possibl adverse effects. However, river waters having strong fluctuations in elemental concentrations due to many variables, their study has been a more challenging and difficult task.

Dissolved and suspended matters of continental waters have been investigated to find the nature and composition of these matters transported by rivers to the ocean (Berth, 1961; Gibbs, 1972; Subramanian, 1979), to estimate erosion rates and to determine geochemical balance as a whole. Studies on chemical quality and of dissolved transport by rivers have received greater attention only recently.The transport of solid was generally considered initially to be the major process of material supply to the ocean and some studies on denudation rates took only mechanical erosion into account. The first well documented review on river transport is made by Livingstone (1963) which is concerned mainly with the major dissolved elements.Since then, a substantial amount of work have been attempted on the world's largest rivers; for example Amazon (Gibbs, 1967; Stallard & Edmond,1981; 1983), Parana (Depetris and Griffin, 1968), Mekong (Meybeck and Carbonnel,1975), Chinese rivers (Hu-Ming-Hui et al, 1982).

With Meybeck (1976)'s estimated annual global dissolved transport by rivers of 3.25 billion tonnes, the total suspended load carried annually by the rivers to the ocean (13.5 billion tonnes according to Milliman and Meade, 1983) is four times more than the dissolved transport.However a large amount of additional data for rivers in Asia and Africa only will give a clear picture about the continental input into the world oceans.

Gibbs (1970) discussing the mechanisms controlling the world water chemistry, suggested three such main mechanisms: atmospheric precipitation, rock dominance and evaporation-crystallisation processes as the major factors influencing the composition of dissolved solids in the world rivers. Holl(1955) and Lindroth (1957) suggested to add to these, the abiogenic and biogenic contributions of dissolved atmospheric gases to broadly define the overall origins of the chemical load of rivers under natural conditions. The major ion chemistry of the Amazon river basin had been studied in detail to know the influence of geology and

Table 1.1

Average suspended sediment discharge by continents.

Continents	Suspended sediments $(t\ km^{-2}/yr)$	discharge (10 T/yr)
Africa	27	0.55
Asia	600	16.16
Australia	45	0.23
Europe	35	0.33
North America	96	1.99
South America	63	1.22

Gregory and Walling (1973)

Table 1.2 Major rivers that flow to the sea, listed in order of discharge.

River	Location	Annual Discharge water (km^3/yr)	 diss. solids $(10^6/yr)$	 sus.solids $(10^6/yr)$	diss./sus.	Drainage area $(10^6 km^2)$
Amazon	S.America	6300	223	900	0.25	6.15
Zaire	Africa	1250	36	43	0.84	3.82
Orinoco	S.America	1100	39	210	0.19	0.99
Yangtze	Asia	900	226	478	0.47	1.94
Brahmaputra	Asia	603	61			0.58
Mississippi	N.America	580	125	210	0.60	3.27
Yenisie	Asia	560	65	13	5.0	2.8
Lena	Asia	514	70	12	5.8	2.50
Mekong	Asia	470	70	160	0.44	0.79
La Plata	S.America	470	16	92	0.17	2.83
Ganges	Asia	450	75			0.97
Irrawady	Asia	428	92	265	0.35	0.43
St.Lawrence	N.America	447	59	4	14.8	1.03
Mackenzie	N.America	306	64	100	0.64	1.81
Columbia	N.America	251	35	8	4.4	0.67
Indus	Asia	238	41	100	0.41	0.97

Berner and Berner,1987.

weathering conditions on dissolved load by Stallard and Edmond (1983). The relationship between solid concentration and water chemistry of western Australian rivers has been studied by Imeson and Verstreten(1981).

The river water chemistry and chemical transport studies on Indian rivers had been very limited till recent past. The chemical analyses of Indian river waters that have been used in calculations by Livingstone(1963), Meybeck (1976), Raymahasay (1970) and others are quite old and may not have always been based on systematic sampling and study. The Central Water and Power Commission had carried out partial analyses of waters of the major Indian rivers over a period of years (e.g. Deb and Chadha, 1964), but their studies were more oriented towards determination of river water quality for irrigation purpose. Handa (1972) studied the chemical composition of the Ganga river water. During more recent times, however, preliminary as well as detailed investigations have been periodically reported by Borole, Raymahasay, Sarin and Krishnaswamy, Somayajulu, Subramanian and others. The observations out of these studies can be summarised as :

Indian rivers are alkaline in nature and they carry a greater annual solute load than the Amazon. However, they have a smaller annual solute flux than similar Chinese river systems. Compared to other river systems in the world,

Table 1.3 Erosion rates for the continents

Continent	Load (10^6 /yr)			Rate (t/km^2/yr)		
	chemical	sediment	total	chemical	sediment	total
Asia	1490	14500	15990	32	302	334
Africa	710	490	1200	24	16	40
Europe	460	250	710	42	23	65
Australia	20	210	230	2	21	23
N.America	700	1780	2480	32	85	117
S.America	550	1100	1650	28	56	84
Continental earth	3930	18300	22230	23	108	131

Garrels and Mackenzie,1971.

Table 1.4 Hydrological characteristics of river basins of India

River	Mean annual discharge ($10^9 m^3$/yr)	Drainage area ($10^3 km^2$)	Mean basin elevation (m)	TDS (ppm)	TSM (ppm)
Ganges	493	970	3000	178	1631
Brahmaputra*	510	690	5000	148	1170
Indus	207	1165	2500	124	450
Godavari	92	313	400	181	1845
Krishna	30	251	420	360	1158
Mahanadi	67	132	500	155	31
Narmada	41	90	760	322	130
Cauvery	21	87	630	172	30
Tapti	18	62	740	322	333
Minor rivers	104	240	-	-	-

Subramanian,1987. * as studied earlier

Indian rivers transport a higher amount of Na & Cl which may be attributed to the influence of the monsoon on continental run off (Subramanian,1983).

The Himalayan drainage system, consisting of the Ganges-Brahmaputra and Indus together contribute an enormous amount of water to the Bay of Bengal and the Arabian sea. The total annual flow in all the river systems of India is broadly assessed at 1,645 thousand million cubic metres (Rao,1975). Of this, only the Brahmaputra itself contributes about 625 thousand million cubic metres (Goswami, 1985). However, no serious attempt has been made so far to study the geochemistry of the Brahmaputra river system except a few efforts by Sarin and Krishnaswamy (1984, 1989) and Subramanian (1983) to comment on the major ion chemistry of the Ganga-Brahmaputra river system taken as a whole.

The mass of river transported sediments entering the ocean are estimated by two methods: by considering the mass itself that is being carried oceanward by rivers (e.g. Holeman, 1968; Milliman and Meade,1983) or by the average mechanical denudation rate of the continents (e.g. Fournier, 1960; Schumm, 1963). The second method gives a significantly greater estimate e.g. 18.4 billion tonnes/yr. by world rivers to the oceans (Holeman, 1968), since they also take into account a large amount of eroded material which never reaches the ocean.

Table 1.5 Average chemical composition of Indian rivers (in mg/l).

River	HCO_3	Cl	SO_4	SiO_2	Ca	Mg	Na	K
Krishna	178.0	38.0	49.0	24.0	29.0	8.1	30.0	2.4
Cauvery	53.3	18.0	39.0	8.4	15.4	16.0	30.0	2.6
Godavari	105.0	17.0	9.0	10.0	22.0	5.0	12.0	3.0
Ganges	100.0	5.6	9.4	3.1	40.5	6.0	8.7	3.9
Brahmaputra	37.5	15.0	9.5	6.7	29.0	7.4	12.0	2.5
Indus	64.0	9.2	15.0	5.3	26.8	0.7	1.3	2.1
Narmada	225.0	20.0	5.0	9.0	14.0	20.0	27.0	2.0
Tapti	150.0	65.0	0.6	16.0	19.0	22.0	47.5	3.0

Subramanian, 1987.

Table 1.6 Erosion rates of some important rivers of India

River	Load (million tonnes/yr)			Rate ($t/km^2/yr$)			Sed/Chem.
	Chem.	Sed.	Total	Chem.	Sed.	Total	
Krishna	10.4	4.00	14.40	41	16.0	57.0	0.39
Godavari	17.0	170.00	187.00	55	555.0	610.0	10.00
Cauvery	3.5	0.04	3.54	40	0.5	40.5	0.01
Brahmaputra	51.0	597.00	648.00	88	865.0	953.0	9.80
Ganges	84.0	329.00	413.00	111	438.0	549.0	3.90

Subramanian, 1987

Milliman and Meade (1983) have observed that rivers with large sediment loads (annual discharge greater than 15 million tonnes) contribute about 7 million tonnes of suspended sediment to the ocean yearly. By extrapolating available drainage basin data, they suggested that the total suspended sediment delivered by all rivers to the oceans is about 13.5 billion tonnes annually, bedload and floods accounting for another 1-2 billion tonnes.An important observation made from the world wide compilations of Lopatin (1950), Holeman (1968) and Milliman and Meade (1983) is that the Asian rivers are the main contributors of the continental mass transfer. Thus the asian rivers are the determining factors of world sediment load. About 70% of total world sediment load is derived from southern Asia and the big islands from Indian and Pacific oceans.

The average sediment yield of Asian rivers (543 tonnes km^2yr^{-1}) assumed by Holeman appears to be more acceptable considering many recent studies of non-Himalayan rivers (e.g. Subramanian, 1979; Bikshamiah & Subramanian, 1980). Moreover, the recent estimates of sediment yield of Himalayan rivers (Abbas and Subramanian, 1984) are much higher than the observation made by Milliman and Meade (1983).

The sediment transport of Indian subcontinent is estimated as 1.21 billion tonnes (Subramanian, 1979) which is nearly 10% of the global sediment load estimated by Milliman and Meade (1983).The rate of physical denudation of the Indian Sub-continent (327 tonnes km^{-2}.yr^{-1}) is more than two times the world rate(150 tonnes km^{-2}.yr^{-1}) estimated by Milliman and Meade (1983).

1.2 Relationship Between Dissolved and Sediment Load in Rivers

Varied relationships between dissolved and solid transport rates have been described by many authors (e.g. Judson and Ritter, 1964; Alekin and Brazbuicora, 1962; Corbol, 1964; Gibbs, 1967; Meybeck, 1976). The principal assumptions can be summarised as:

(1) The dissolved transport is inversely related to solid transport (Judson and Ritter, 1964). This assumption has been quoted many times in American literature (Strahler, 1971).

(2) The dissolved transport is directly related to solid transport (Alekin and Brazhnikova, 1962). This is mainly the view of the Soviet authors (Strakhov, 1967). Klhile Corbel (1964) found no relationship between these two forms of transport.

(3) The ratio of solid transport to dissolved transport increases when solid transport increases (Alkin and Brazhnikova, 1962) and when specific discharge decreases (Leopold et.al., 1964).

(4) The sediment to solute ratio is highly variable according to climate and relief (Meybeck, 1976).

The importance of relief has been demonstrated by Gibbs (1967) in Amazon river basin. Though the imporatnce of climatic and topographic factors in sediment/solute balance cannot be denied, the effect of human activities must not be forgotten. Man increase the sediment load by agricultural practices and deforeststion and at the same time decreases the load by building dams which trap the sedimwnts. solutes are also effected, for example, by industrial effuluents and by dissolved fertilizers in surface run off. Consequently, the measured load of a river sytem may in many cases be a reflection of human interfernce rather than of natural erosion processes.

1.3 Sediment Chemistry

The sediments that are carried by rivers are responsible for flooding the rivers, need for maintanance of in-channel structures, navigation system etc ; but the most important of all is that the sediment particles absorb many contaminants such as pesticides, radionuclides and toxic metals, that are transported , deposited and stored as part of the sedimentary component of the river system (Milliman and Parker, 1985). The association of heavy metals with sediments can range from weak van der walls bonds to strong covalent bonding, co-precipitation with Fe-Mn oxides and incorporation within crystal lattices (Jonassen, 1970; Gibbs, 1973).

Sediment analysis plays an important role within the framework of environmental forensic investigations (Meiggs, 1980) in those areas in which a short term or past pollution event is not or only insufficiently traceable from water analysis. In addition to their significance as an indicator medium, sediments are depending on environmental conditions a sink or source for trace metals in the surface waters. Metals are not necessarily fixed permanently by sediment, but may be recycled via biological and chemical agents, both within the sedimentary compartment and back into the water column (James, 1978). From economic point of veiw, sediments are also a medium in which certain substances can be concentrated from solution and threby represent profitable sources of raw materials.

The elememtal concentrations of the suspended sediments are of considerable importance in giving greater insight into crustal weathering processess on a global scale and in determining the elemental fluxes between land and ocean, to compare the river-borne materials with the oceanic suspended matters and deposited elements (Strakhov, 1967 and Mekenzie, 1971).

In general, the chemical composition of the river particulate material has received less attention, despite some recent studies (e.g., Martin et al., 1973; Gibbs, 1977; Martin and Meybeck 1979). Martin and Meybeck (1979) published data for the major rivers of the world. They have estimated the average river particulate matter composition based on the analysis of more than 40 elements in the Amazon, Congo, Ganges, Magdalena, Mekong, Parana and Orinoco rivers and compilation of published data on 13 major world rivers. These 20 major rivers represent 25 per cent of the world drainage area and 15 per cent of the world rivers sediment discharge.

The geochemistry of the sediments of the eastern continental shelf and slope of India has been studied by several workers (Subbarao, 1958; Naidu et al., 1967; Rao and Murty 1968; Seetharamaswamy 1968; Veankatarathanam and Tilak 1968; Rao and Rao 1969; 1973; Sarin et.al., 1979; Kalesha et.al., 1980; Mascarrnhas et.al., 1985). Partial analysis of sediments from some of the Indian rivers, at their month, has been reported earlier by Sarin et.al., (1979) and Borole et.al., (1982).

The sediment chemistry of Indian rivers also has not received due attention. Subramanian et al., (1985) have made a comprehensive study on chemistry of river sediments from the Indian sub-continent. This study is based on the chemical analysis of 120 samples collected from diferent major rivers such as Ganges, Brahmaputra, Godavari, Krishna, Narmada, Tapti and Cauvery. Based on the data they have calculated the average sediment discharge weighted chemical composition for the rivers draining the Indian sub-continant. It has been observed in this study that in spite of the very diverse geology of the individual drainage basins, the chemical composition of individual river basins differ only in those elements such as Ca, Fe, Mg, etc., which are active in water-sedimemt system.

Paul and Pillai (1983) studied the trace metal distribution in Periyar river. This study indicates that Zn and Cd which are industrial pollutants increased by a factor of 10 both in sediment and water.

1.4 Mineralogy

Scant attention has been directed at processes acting in river drainage basin as a source of variability in riverine sediments (Weava 1967; Johnson and Kelley 1984). The cause of variation in sediment mineralogy at river mouths has been the subject of of many studies (Powers 1957; Griffin and Parrot 1954; Porrenga 1966; Edzwald and O'Melia 1975; Gibbs 1977).

In India, investigations on the clay minerals in the Bay of Bengal sediments have been carried out by many workers (Siddique 1967; Rao and Rao 1977). Naidu (1985) studied the bed sediments in the delta region of Godavari river. Mallick (1976) studied the mineralogy of the sediments in the Ganges cone of the Bay of Bengal. But only limited attention has been paid on mineralogy of the sediments of other Indian river basins (Kumar and Singh 1978; Subramanian 1980; Biksham 1985).

1.5 Objectives of the present work

The present work has been planned and executed with the objective of examining the following:

1. The average chemical compositions of Brahmaputra river water,suspended sediment and bed sediment.
2. Variation in the major ion chemistry with space and time.
3. Factors controlling the nature of the water (chemistry) and sediments (Physical and chemical) of Brahmaputra .
4. The theoretically expected stable minerals in carbonate and silicate system in the water of the Brahmaputra river .
5. Wheather the theoretically predicted mineral assemblages from water chemistry agree with that of the suspended sediments.
6. Chemical and sediment erosion in the Brahmaputra river basin, calculation of fluxes of individual elements.
7. Grain size distribution of suspended sediments and their relation to sediment transportation.
8. Mineralogy of the suspended sediments.
9. Enviromental impact asseessments. The overall anthropogenic effect on the geochemical processes and the environment of the Brahmaputra river basin.

CHAPTER 2

THE BRAHMAPUTRA RIVER BASIN

2.1 General

Rich in history and encompassing outstanding beauty the river Brahmaputra embodies an entire range of ecology from the clear mountain headwaters 5300 metres above sea level, through the hilly terrains of Arunachal and the fertile plains of Assam with increasingly brackish water, finally discharging into the Bay of Bengal after a distance of more than 2800 km.The Brahmaputra is one of the major rivers of the world with a vast catchment area encompassing an area of more than 924,000 sq. kms spread over three countries: Tibet, India and Bangladesh.The drainage area falling in India is around 258,000 sq.kms which is about 7.8% of the total area of the country.The Brahmaputra yields as much as 33.7% of India's total water resource(Rao,1975).

The Brahmaputra basin lies approximately between latitudes $24^{\circ}13'$ and $31^{\circ}30'$ North and longitudes 82° and $96^{\circ}4'$ East.The whole basin is bounded by an almost continuous chain of mountains and plateaus on the north, south and east.The part of the basin lying in Assam is a tectonosedimentary province with an average width of 80-90 kms and elevations ranging from 120 m at Kobo in the extreme east through 50.5 m at Guwahati to 28.45 m at Dhubri in the

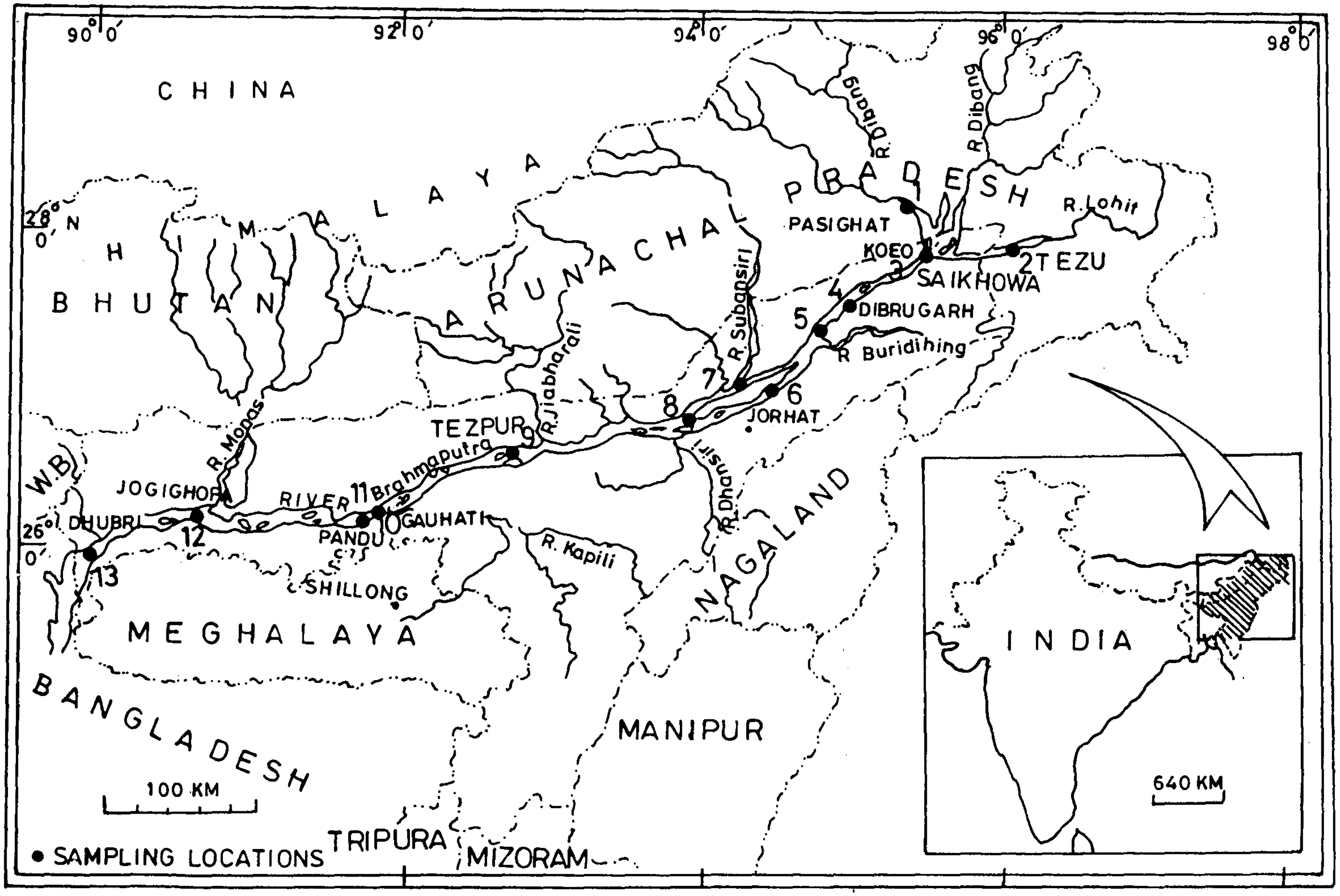


FIG. 2·1 MAP OF THE STUDY AREA WITH SAMPLING LOCATIONS extreme west(Goswami,1985).The bed slope of the Brahmaputra in its upper reaches is quite steep for a river of its size.The river plunges down from an altitude of 3,650 metres at Pe in Tibet to less than 150 metres at Pasighat in Arunachal where it enters the plains.It does so in a series of cascades through gorges but without a single fall of more than 50 metres.Between Kobo and Dibrugarh the bedslope is 25 cm/km; between Dibrugarh and Noamati 14 cm/km; between Noamati and Guwahati 11cm/km and between Guwahati and Dhubri 8 cm/km.

2.2 The river system

The river Brahmaputra is a principal arm of the Ganga-Brahmaputra-Meghna system. Figure 2.2 shows the river course of Brahmaputra along with its tributaries. It originates as Tsan-Po, meaning the great river of Tibet, which pours its waters through Dihang(also called Siang) into the river known then on as Brahmaputra. The source of the Tsan-Po is in $31^{O}30'$N and 82^{O}E in Tibet,near the upper waters of the Indus and the Sutlez and a little to the east of the Mansarovar lake. Rising in a great glacier mass, this mighty river having a total length of about 2900 kms (and an enormous catchment area of around 9,24,000 square kms) flows for almost half of its length in a trough, north of the Himalayas running parallel to the main Himalayan range.

Then it swings north-east , runs through many gorges in a series of cascades and rapids, makes a hairpin bend at a few kms, east of Namcha-Burwa. The bending is well marked near the Longitude 94 near Pemkai Sung, ten miles below Gyala Singdon. It then turns south and southwest taking the name Dihang. After being joined by two major tributaries the Dibang and the Lohit at a place called Kobo, the united stream from this point assumes the name Brahmaputra and flows for about 720 kms, down the Assam valley in a vast sheet of water dotted with numerous islands, the chief among them being the Majuli and the Umananda. In its course through Assam, it is further joined by 42 (major) tributaries, 27 in the north bank and 15 on the south bank.

2.3 General features of the River Basin

The Brahmaputra with its chief tributaries the Subansiri, Bharali, Barnadi, and Manas in the north bank and the Disang, Dikhou, Janji and Dhansiri in the south, traverses an alluvial plain about 724 kms in length with an average width of 30 km. It receives the drainage of the Himalayas in the north and the Assam range in the south and confirming its course round the western spurs of the Garohills for about 290 kms, joins the Ganga at Goalunda from where the river flows under the name of Padma, and reaches the Bay of Bengal by the broad estuary of the Meghna.

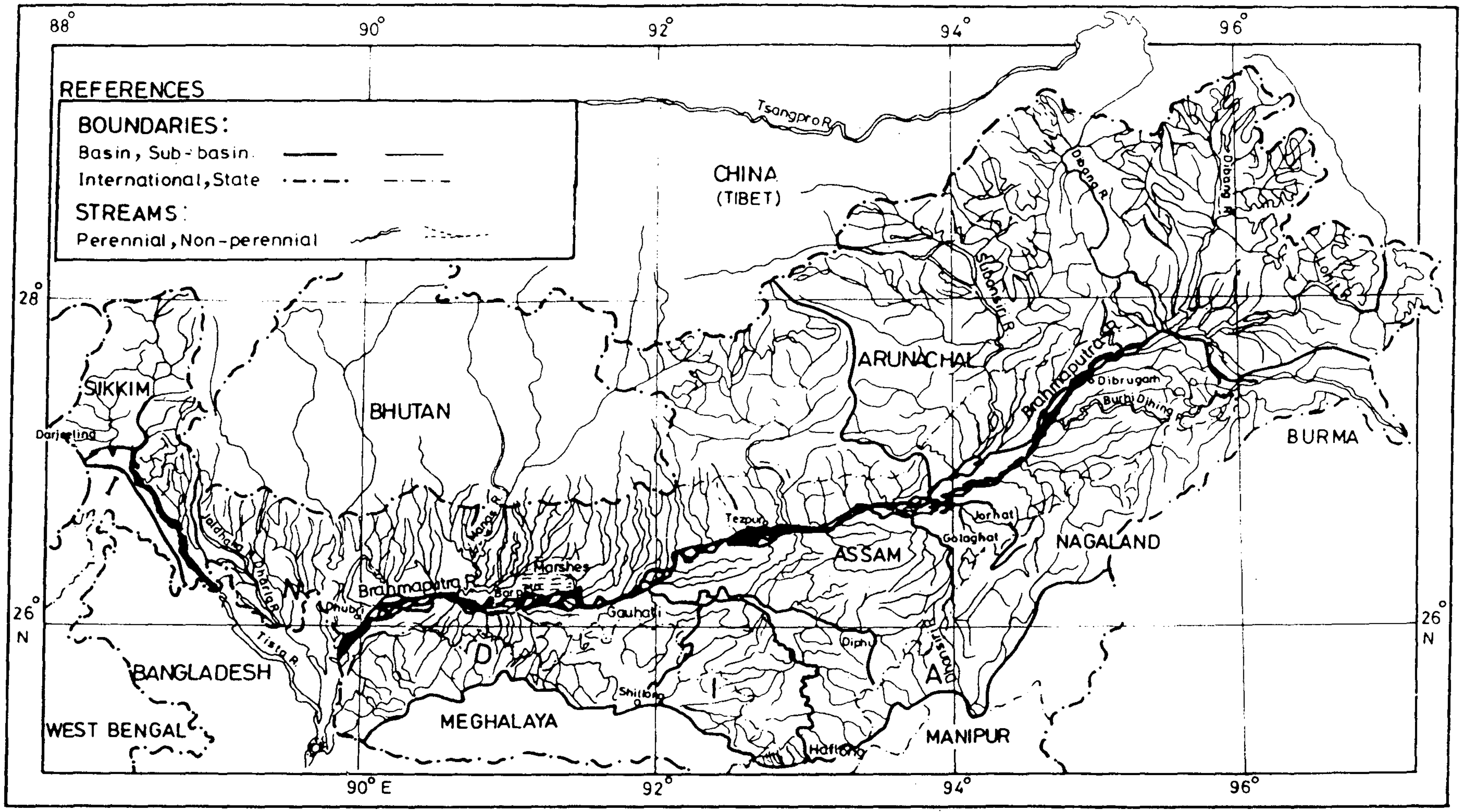


FIG. 2·2 BRAHMAPUTRA BASIN WITH ITS TRIBUTARIES.

The mass of silts brought down from the Himalayas is sufficient to form sandbanks and even islands in the lower valley, wherever it is blocked by any impediment in the current of the river, which thus alters its channel amidst an intricate network of waterways. Broad streams diverge from the main river and rejoin it after a long separate existence of uncontrollable meandering.

Throughout the greater part of its course in Assam, the Brahmaputra is bounded on either sides by stretches of marshy land covered with thick grassy jungle relieved occassionally by patches of cultivated land. Further behind, however, where the elevation is higher, the plain is covered with rice fields, dotted with lumps of bamboo, palm and fruit trees.

The tributaries of the Brahmaputra for most of their length drain the steep slopes of the Himalayas to the south where rainfall is heavy. Consequently, they not only carry heavy run off, particularly where slopes are denuded of foresets, but also a very large volume of detritus, the result of excessive soil erosion.

A great amount of the materials contribute, without doubt, to raising the land surface in the plains by bank spill, but the major portion of the heavily silt ladden flood carried to the Brahmaputra not only aggravates its flood congestion, but also adds to the silt discharge of the flood. The plain area of the valley has since been built up and is being raised gradually by comparatively coarse material carried down from the hill slope. The soil is very friable, resulting not only in considerable tortuosity of the streams , but also frequent shifting of inner courses which in fact is necessary to a certain extent in the economy of the nature as it is only by such shifting that the alluvial plain can be raised uniformly.

The Brahamputra valley within Assam is 80 to 90 km. wide, out of which the river itself occupies 6 to 10 km. and there are places where the river width extends to even 15 to 20 km. The Brahmaputra valley suffers from severe flood problems which sometimes create rather grave situation in the valley. Due to building up of the bed the flood height also have been showing increasing tendency from year to year.Besides flood and drainage congestion, there is a serious erosion problem along the main river and some tributaries which has become a matter of great concern.

2.4 The Tributaries

The characteristics of the north and south bank tributaries are quite conspicuously different from one another. Most of the northern bank tributaries of the Brahmaputra are very much larger than those of the south bank. The northern bank tributaries have bigger catchments, are with steeper slopes, shallow braided channels for a considerable distance from the foothills and in some cases, right upto the outfall. They have coarse sandy bed and heavy silt discharge. They are also generally prone to having flash floods. On the other hand the south bank tributaries have comparatively flatter gradients, deep meandering channels almost from the foothills, the banks and the beds of non-alluvial soil and a comparatively low silt discharge. The principal north bank tributaries are the Jiadhansiri, the Subansiri, the Rangandai, the Dikrong, fthe Burai, the Bargang, the Jia-Bharali, the Dhansiri, the Puthimari, the Pagladia, the Manas, the Aie, the Champamati and the Sankosh. The principal south bank tributaries are the Noa-Dihing, the Dhansiri, the Kapili, the Buri-Dihing, the Disang, the Dikhon, the Janji, the Dudhnai, the Krishnai, the Jinari and the Jinjiram.

A few principal tributaries are briefly described below:

2.4.1 The Manas

The Manas is the largest Himalayan tributary of the Brahmaputra. Its contributive net, spread over Tibet, Bhutan and Arunachal Pradesh, collects into a single channel in the Sub-Himalaya and splits into a distributive net after debouchment into the Assam plains at Mathanguri. The drainage basin of the Manas spans an area of 36,910 sq. km. (approximately) of which 14,830 sq. km. is in Tibet, 17,540 sq. km.in Bhutan and Arunachal Pradesh and 4,540 sq. km. in the alluvial valley of Assam.

2.4.2 The Jiabharali

The Jiabharali debouches from the Himalaya through a dissected piedmont plain and is restricted within a narrow valley wall. The drainage basin spans an area of 12,361 sq. km. and the total perimeter length of the drainage divide is 543 km. The catchment covers the Outer hills, Lesser and Greater Himalaya.

2.4.3 The Subansiri

The Subansiri with a basin covering an area of about 2,700 sq. km. of alluvial plain of Assam and Arunachal Pradesh, rises in the Central Himalaya at an average height of 5182 m. The total drainage area of the Subansiri in the Himalayan terrain, from about 5486 m in the Central Himalaya and Tibet to 152 m in the foot-hills is about 30,000 sq. km. The broadly crescent shaped drainage basin of the Subansiri is a composite basin with two major sub-basins viz. the Ranga sub-basin and the Dikrang sub-basin.

2.4.4 The Pagladiya

The Pagladiya river system, although drains a comparatively small area of the Bhutan Himalaya, has a tendency of propagating its high discharge through flash floods. The whole of the Pagladiya catchment lies in the

Sub-Himalaya. The basin perimeter with a total length of about 96 km. and covering an area of about 480 sq. km., is bound by ranges varying in height from 1,830 m to about 3,048 metres. The catchment lies in the wet belt and is long, linear andwith higher bifurcation ratio.

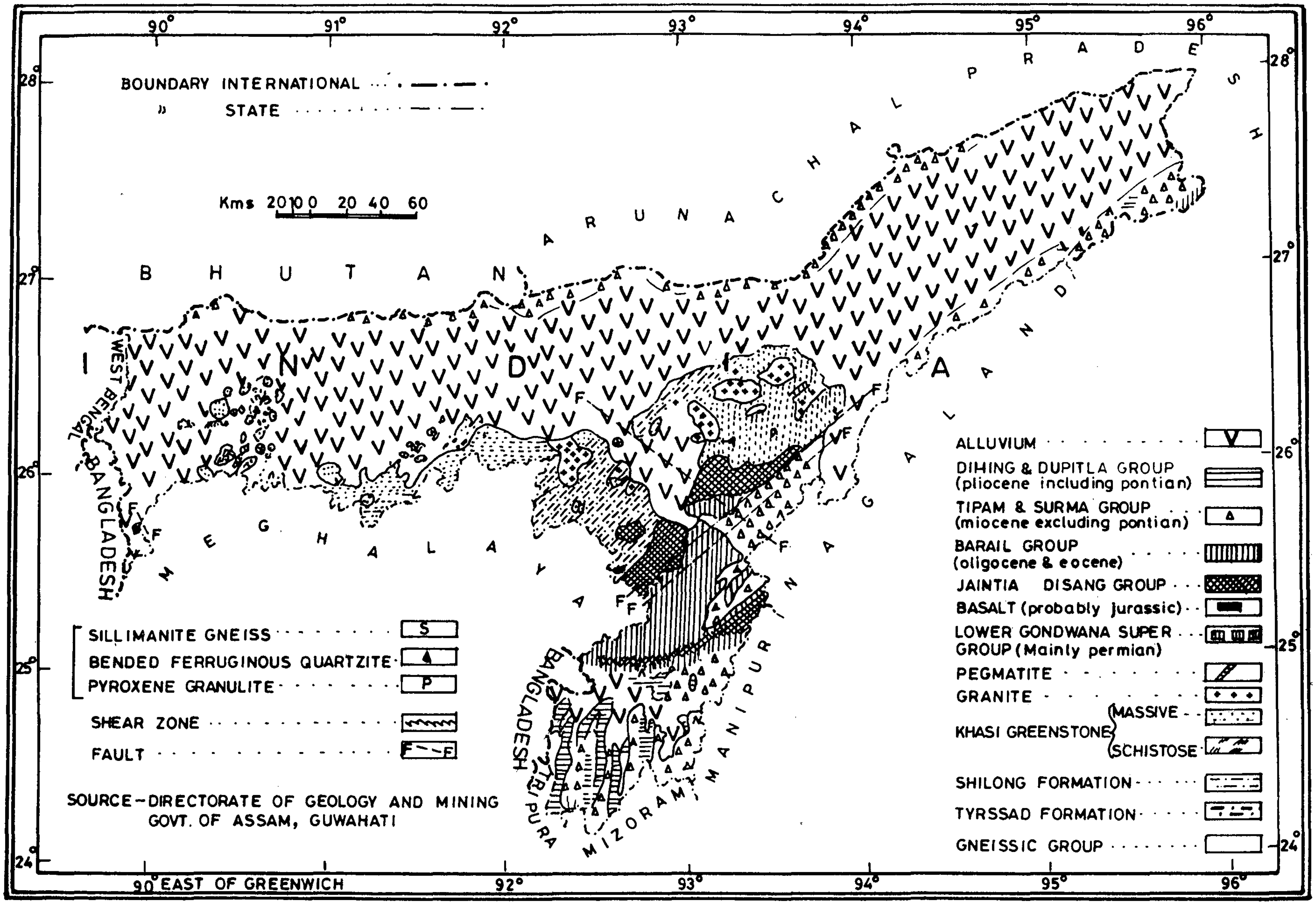
2.5 The Channel of the Brahmaputra

The Brahmaputra is a braided channel throughout its length in Assam, distributed in a number of subchannels and cross-channels between its hilly banks. There is constant silt movements resulting in shifting of these channels and sandy shoals. The transient nature of most of the channel bars are attributed to their submergence during summer high flows which drastically change their geometry and location.

2.6 Geological evolution of the Brahmaputra Basin

The Brahmaputra basin is presently confined by the Eastern Himalayas on the north and east, Naga hills and Patkai range on the southeast and Mikir hills and Shillong plateau on the southwestern side. The present master slope of the basin finds a gap between the Shillong plateau and the Eastern Himalayas to open up in Bangladesh.

The geological successions on the Shillong plateau and those in the Naga-Patkai ranges are at variance with those seen in the Himalayan catchment (Balasundaram et. al.,19).The oldest formations are seen in E-W Shillong plateau and



SOURCE – DIRECTORATE OF GEOLOGY AND MINING
GOVT. OF ASSAM, GUWAHATI

FIG. 2·3 GEOLOGICAL MAP OF A PART OF THE BRAHMAPUTRA BASIN INCLUDING THE STUDY AREA

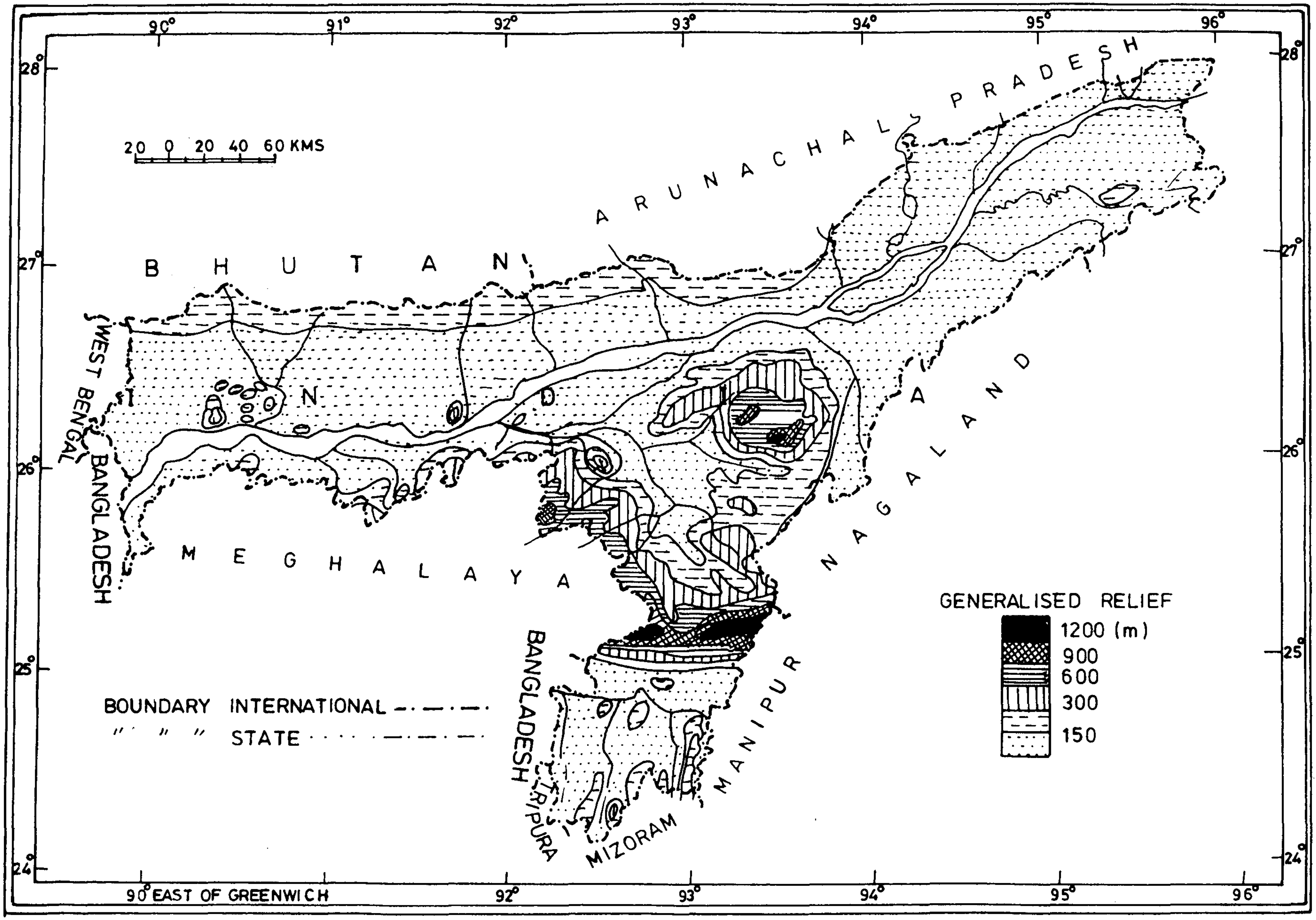


FIG. 2·5. RELIEF AND DRAINAGE MAP OF THE STUDY AREA IN THE BRAHMAPUTRA BASIN

Mikir hills, the projections of which are seen as inselbergs within the basin approximately as far east as longitude 94° in Numaligarh area. East of Numaligarh the total absence of the basement exposures and the gradual thickening pile of the Eocene-Recent sediments clearly indicate the regional slope of the basement towards the eastern side. High grade metamorphites, gneisses and granites etc. of the Shillong plateau constitute the basement and these are over lain by the low grade metasediments of the Shillong plateau

On the northern side of the Brahmaputra valley the inselberg zone gradually gives way to alluvial plain abutting against the Siwalik ridges of the Himalayan front running ENE-WSW. A highly tectonised zone of Palaeozoic sediments follow the Siwaliks on which the gneisses and schists are overthrust.This latter group of metamorphites may be correlated with the Pre-Cambrians of the Shillong Plateau.On the extreme east of the Brahmaputra basin,the alluvial deposits directly abutt against the metasediments. However, it may be assumed that the basement of the entire Brahmaputra basin is made up of the Shillong Plateau-Mikir hills type of metamorphites.

The fluvial or continental Gondwana sedimentation provides the Palaeozoic history of the Brahmaputra basin. Continental sequence of Gondwana is best developed in Kameng district of Arunachal Pradesh. The Palaeozoic environment of the Brahmaputra basin and its catchment was represented by an arcuate NE-SW to NW-SE(eastwards) sedimentologic and volcanic environment

The Mesozoic record within the Brahmaputra basin is hardly noteworthy while Tertiary sedimentation in this basin is the most important part of its geologic history. Essentially the Upper Assam plains behaved as a platform with a foredeep on its southern margin, giving way to the Upper Cretaceous-Palaeocene-Oligocene geosyncline now transformed into the Naga-Patkai ranges.During the Plio-Pleistocene times the Disang thrust and the Naga thrust along with accelerated tectonic activity in the Lohit Himalaya, the combined Lohit-Siang system took the westerly course through the top of the Dihings and its platform facies. It was perhaps because of this intense southwesterly directed force from Lohit Himalaya during Pleistocene times that the present westerly flow of the Brahmaputra was founded. Faulting and fracturing in the inselbergs must have further accentuated this change in drainage pattern.

2.7 General Geology

Figure 2.2 shows the geology of the brahmaputra river basin, also shown are the releif map of the Brahmaputra basin(Fig.2.3) .The sub-Himalayas, the Middle Himalayas, the Greater Himalayas and the Trans Himalayas -these four topographic units rising progressively to the north form the

Himalayan watershed of the Brahmaputra. The sub-Himalayas are mainly composed of Tertiary sandstones and the Middle Himalayas are underlain by Palaeozoic deposits comprising of shales, slates and phyllites and overlain by basaltic rocks. While the Greater Himalayas dominantly consist of granites and gneisses, the Tibetan Trans Himalayas are predominant of Palaeozoic to Eocene sedimentary formations (Wadia, 1968). The average elevations of these four physiographic units are 1000 m, 4000 m, 6000 m and 4500 m respectively.

The Shillong Plateau and the Mikir hills with elevation ranging from 600 to 1800 m to the south of the valley, are primarily made up of gneisses and schists of Precambrian age. The Tertiary beds include a similar assemblage of rocks such as hard sandstone, soft and loose sand, conglomerates, coal seams, shale and sandy clay. The lowest Tertiary beds in some parts include limestone.Brahmaputra valley is underlain by 200-300 m thick recent alluvium consisting of clay, silt, sand and pebbles (GSI,1974). Many authors (Holmes, 1964; Evans,1964; Mittal and Srivastava, 1959; Tapponier and Molnar, 1977) have suggested a tectonic origin of the Brahmaputra valley.

The rock formations prevalent in the Brahmaputra basin belong to the following stratigraphical divisions:

Recent	Alluvial, river gravels
Pleistocene	Older alluvium, gravels
Pliocene and upper miocene	Dihing series
Middle miocene and lower miocene	Tipam series, Surama series
Oligocene	Barail series (in parts)
Ecocene	Barail series, Jaintia series, Disang series cherra sandstone
Upper cretaceous	Disang series
Upper carboniferous	Subansiri beds
Pre-Cambrian and Archaean	Shailong series, gneisses

2.8 Soils

Soil map of Brahmaputra river basin are given in Figure 2.4. Approximate traditional nomenclature given in the figures are :

Aquafs - High base status soils(Hydromorphic)

Aquepts - Brown soils (Hydromorphic)

Ustalfs - High base status-red lamy,sandy and alluvial silts

Ochrepts - Shallow black,brown and aluvial soils of northern region

Udalfs - High base status soils of humid regions

Aquents -Recently formed hydromorphic alluvial soils

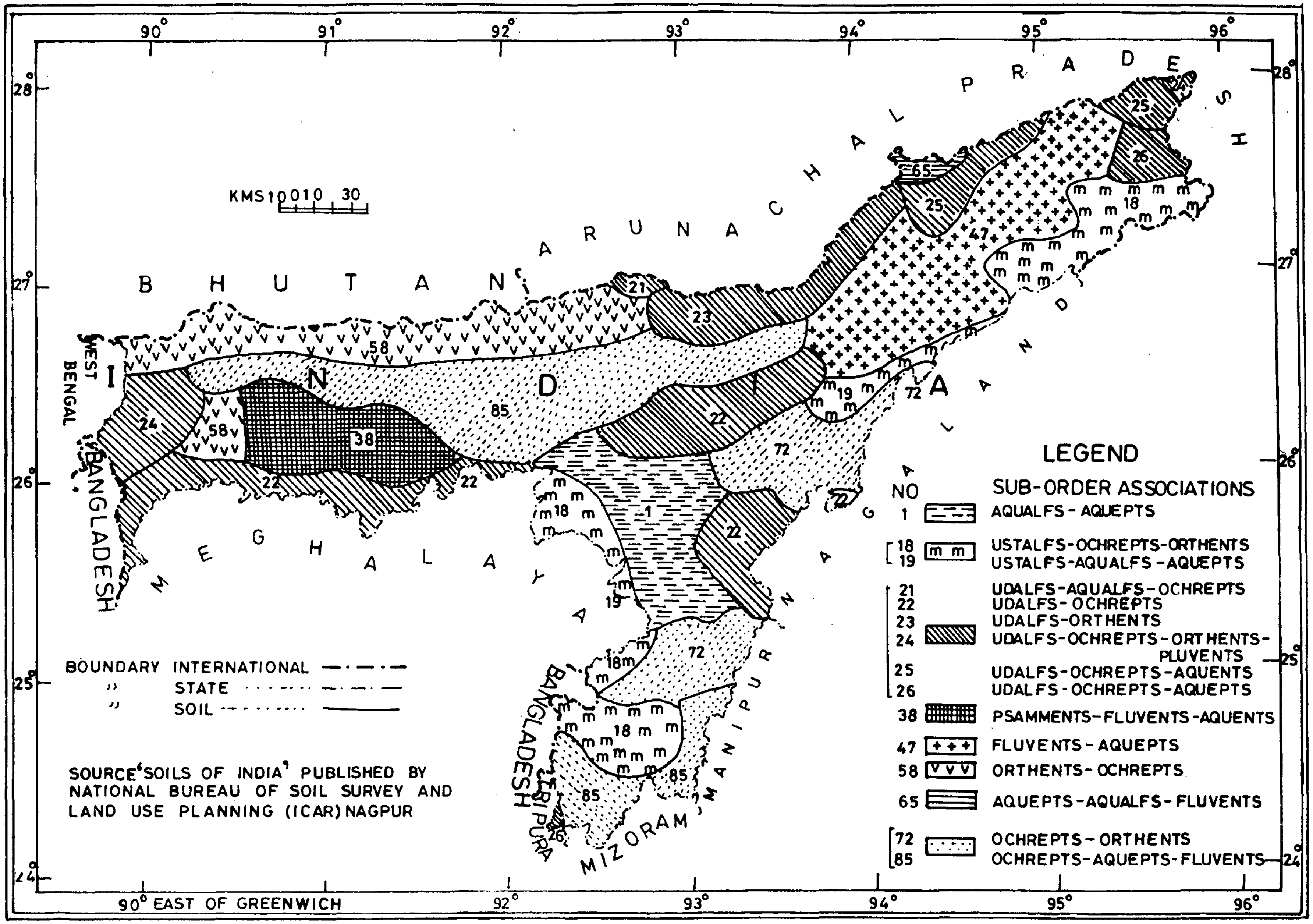


FIG. 2·4 SOIL MAP OF THE BRAHMAPUTRA RIVER BASIN IN ASSAM INCLUDING THE STUDY AREA

Psamments- sandy soils (recent)

Fluvents - Alluvial soils(recent alluvium)

Soils of Assam have been formed from two major types of parent materials, namely (1) residual and (2) transported. The former are dirived in situ from the rocks of Archaeans age which consists mainly of gneisses, schists and granites and latter are brought in by flowing river water from Assam Himalaya and Assam Plateau. Soil in sub-Himalayan region developed on the Tertiary sandstones are shallow and consist primarily of sands with admixture of cobbles and boulders. Alluvial soils, formed recent river deposites, occur in the Brahmaputra valley. A few isolated pockets of deeply weathered older alluvium occur in unland areas within the valley and in piedmont region. Borings in the quaternary sediments of the Bramhaputra valley extending down to more than 100 m (Geological survey of India, 1977) show repeated sequence of clay, fine sand, coarse sand with cobbles, pebbles, and boulders.

2.9 Land Use

Cultivation is the most important use of land in the Bramhaputra valley. Geographical factors play an important role in the agriculture of this valley. Specially, rainfall - its timely arrival, adequacy, consistancy and regularity is the greatest single important factor infuencing agriculture in the Brahmaputra valley. The geographical influence displays an interesting relationship in the agriculture practices in the area and determines many trends which are emerging today. The method of cultivation in the plain areas of the basin is more or less similar to the all India pattern, more particularly to the system prevailing in the Bengal delta. Most of the hill tribes practise a system of cultivation known as Jhuming. The clear the jungle in the slopes with axes, daos and hoes and burn the cuttings. The most striking feature of the agriculture in of Bramhaputra valley is its high productivity. It is mainly due to uniquw fertility of the Bramhaputra valley which is in fact the granery of Assam. Rice and jute are main crops. Tea, rape, pulses, mustard, sugarcane, tobbaco and maize are the other popular crops in this region.

2.10 Climate:

The climate of Assam is quite distinct from that of the rest areas of the country. The pioneer climatologist, Dr. Wladimir Koppen, has recognised the climate of the Ganga-Bramhaputra region as "humid meso-thermal-Gangatic type" (Cwg). The climate of the state is controlled by five dominante factors such as (a) the orography, (b) alternating pressure cells of north-west India and the bay of the Bengal; their perodic western oscillations, (c) their predominance of maritime tropical air mass (mt), (d) the roving periodic western disturbances and (e) the local mountain and valley winds. Besides these five important factors, the latitudinal position, its extensive water bodies and the local storms play a remarkable role in creating variable weather conditions in the Bramhaputra valley. The seasons of Bramhaputra valley can easily be distinguished from the nature of distribution of temperature, rainfall, rainy days and fog. These four elements of weather vaty quite conspicuously from season to season and from place to place. On this basis, the year may be divided into four distinct seasons, (a) winter, (b) premonsoon or summer, (c) monsoon and (d) post monsoon.

The average annual rainfall is about 2841.0 mm. and is distributed as follow:

Winter (December to January)	60 mm
Summer (March to May)	637 mm
Monsoon (June to September)	1633 mm
Post monsoon (October to November)	151 mm

The highest average rainfall amounting to 3357.8 mm has been observed in the hill regions of Assam followed by Surama valley (3256.9 mm) and Brahmaputra valley (2202.7 mm). The mean annual maximum temperature in different districts of Assam lies between 26.7^{o} C and 37.9^{o} C, while the minimum temperature ranges from 3.4^{o} C to 11.0^{o} C. The annual average humidity varies from 74.0 to 87.0 per cent. The maximum evaporation occurs during the month of May and the minimum occurs during the month of January.

2.11 Mineral and Forest Resources

Bramhaputra valley is rich in mineral resources. The known minerals in this basin are petroleum, coal and limestone which has been exploited on a commercial scale. Makum, Jaipur and Nazira are important coal fields in this basin. Oil-bearing strata in the basin are concentrated in Dibrugarh and Sibsagar districts. It is found in sedimntry rocks. Deposits of limestone are concentrated specially in Karbi Anglong districts.

The Brahmaputra basin is also one of the richest regions in the country in forest resources. The distribution of forest is based primarily on three important factors - temperature, rainfall and soils. There are five types of forests in the basin: (1) Tropical evergreen forests which spreads over Sibsagar and Lakhimpur districts (undivided), (2) 'Sal' forests spread over Kamrup and Gopalpara districts, (3) Mixed deciduous forest occur in lower basin as a belt between highland savannah forest and 'Sal' forest in the plains, (4) Riverine forests are found in foothills of Bhutan all along the main river banks from the Sankosh river in the west through Goalpara and Kamrup to the eastern boundary of Darrang, (5) Savannah type forests occur in well drained high land especially in areas adjoining villages. Besides timber, the basin forests are also rich in minor forest produce.

2.12 Industry

Industrially the Bramhaputra valley is not developed. The industrial development is mainly handicapped by its isolation from the rest of India, not so satisfactory transport system, a very small local market and lack of sufficient capital and labour. As a result, this valley has very few industries of significance, other than the production of tea and refining of oil. There are a bright future in agro-based and forest resources-based industries in the Bramhaputra valley. Industrially, Kamrup and Dibrugarh are most daveloped districts. Guwahati by virtue of its central location has been able to attract various industries such as light engineering industries, food processing plants, etc. Some of the traditional and old industries such as handloom weaving, sericulture and bell metal industries are still in existance in the Bramhaputra valley.

2.13 Population

The density of population for the state of Assam which occupies most part of the basin is 186 persons per km^2 against 177 for India in the 1971 census. As the density of population is influenced by various factors such as productivity of soils, climate, topography, industrial develo[pment, urbanisation, irrigational facilities and other factors of the economic development of the area, density is strikingly uneven in the basin. District Nagaon whch falls under central Bramhaputra valley, has the highest density of population (302 persons per km^2) which is agricultrally rich in rice and jute cultivation.Some parts of the state of Assam such as Karbi Anglong and North Cachar Hills districts have very low density of population (37 and 16 persons per km^2 respectively). Among the other districts, the density of population was 215 in Goalpara, 289 in Kamrup, 198 in Darrang, 204 in Sibsagar, 201 in Dibrugarh, 246 in Cachar and 126 in Lakhimpur districts.

2.14 Environmental Hazards

The Bramhaputra valley is subjected to a number of environmental hazards. Flooding of extensive areas is in annual monsoonal feature located in an acotive tectonic zones, the area experiences frequent earthquake tremors with neotectonism causing major geomorphic changes and consequent aggravation of environmental hazards. Faulty landuse practices add to soil erosion, aggradation of drainage channels and flood proliferation. Flood control measure have been hardly effective.

The total north bank sediment load is estimated by the Bramhaputra flood control commission to be 8 to 9 times that of south bank. Between 1942 and 1973, wirth of Bramhaputra increased from 2.5 km. to 10 km. causing serious bank erosion in 44 km. strech from Pasighat to Dihingmukh.

Southward migration of Brahmaputra and a 3 metre rise in the river bed at Dibrugarh were noticed after 1950, with more than 2500 acres of valuable tea estate land lost; navigability was also affected. Discharge records at Dibrugarh from 1913 to 1977 indicated a sudden change in the flood regime after the 1950 earthquake.

As a result of the population explosoin from 1951 to 1961, the flood plains are being encroached for cultivation and temporary settlements; deforestation is also occuring for accommodating settelments and tea plantations; "Jhum" (shifting) cultivation on the hill slopes is causing soil erosion, aggradation of drainage channels and proliferation of floods. Contruction of flood embankments has also caused water logging and inland drainage congestion. Consequently, landscape instability due to stream migration and annual flooding cum waterlogging have been the most distressing environmental problems of the Brahmaputra basin.

CHAPTER 3

METHODOLOGY

3.1 General

Systematic sampling had been carried out in a part of the Brahmaputra river basin between pasighat and Dhubiri during June-July,1989 and samples of water, suspended and bed sediments were collected along a stretch of about 900 kms from Pasighat in Arunachal Pradesh to Dhubri in Assam. The sampling locations of water, bed and suspended sediments are shown in figure and the name of these locations are also given in the following page. The sampling locations were choosen carefully in order to infer the natural, anthropogenic and tributary influences over the region of the river basin studied.

3.2 Field Methods

One litre each of water samples were collected in polythene bottles The samples collected in June -July'89 reprsents monsoon season and samples collected in January'81 have been taken to be representing non-monsoon season. During June-July'89 five litres of water samples were also collected for quantitative studies of suspended sediments. A total of 13 water samples along with 13 bed and 13 suspended sediment samples were collected in the river. pH and alkalinity were measured for water samples in the field itself using Consort C425 pH and Conductivity meter and by micro-titration method.

Bed sediments were collected using a stainless-steel pipe dredge by scooping along the river. In every location bed sediments were collected both in the bank and in the midstream.

3.3 Laboratory Methods

3.3.1 Water Analysis

pH and Electrical Conductivity (EC)

pH and EC of water samples were measured by pH-Conductvity meter model CONSORT C425. EC was measured in microsimens per centimetre (us/cm.). The instrument was first calibrated and set for 0.01M KCL standard (1287 um/cm. at 25° c). Three readings of each sample was taken.

Bicarbonate :

The bicarbonate was determined following the Potentiometric titration method. Standards of bicarbonates (ranging from 5 ppm to 300 ppm) were prepared. 25 ml of each standard and samples were titrated against 0.006 N HCL. The end point of the reaction is attained when the solution comes to a pH of 4.5. A graph was plotted for standard concentration vs. volume consumed. Then the concentration of the samples were determined from the graph plotted.

Chloride : Chloride, in the form of chloride ion (Cl^-) is one of the major inorganic anions in water. It was estimated by Mohr's titration method. Standard solutions of chloride of various concentrations were prepared. 25 ml. of each water and standard solutions were titrated against 0.06 N Silver nitrate solution. Potassium chromate was used as an indicator. The color change is from pink to yellow. Knowing the value of silver nitrate consumed by each sample, the concentration of chloride in each sample was ascertained from the graph of standard solution of chloride vs.volume of silver nitrate consumed.

Fluoride : Fluoride concentration was determined using pH/Ion meter- 135. 25 ml. of each solution is taken, equal volume of Total Ionic Strength Adjustment Buffer (TISAB : 1 molar sodium chloride + 0.25 molar acetic acid + 0.75 molar sodium acetate +0.001 molar sodium citrate) is added, to equalise the ionic strength of the solution and also to suppres the interference of other ions, so that the electrode functions directly as a concentration probe. The instrument was calibrated for the standard fluoride before reading the concentration of the samples.

Sulphate : The sulphate concentration was determined by titration method after Fritz and Yamamura (1955) and Haartz et al. (1979). 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 is passed through the column. After that it was rinsed with 100 ml. distilled water. Then approximately 70 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 in200 ml. deionised water and 800 ml. of ethanol) . Thorin was used as indicator. The color change at the end point being pink .

Phosphate : Phosphate was determined by the ascorbic acid method. Phosphate standards of concentrations ranging from 0.01 ppm to 0.1 ppm were prepared from KH_2PO_4. 40 ml. of each standard solution and sample is taken, 5 ml. of molybdate antimony solution and 2 ml. of ascorbic acid solution was added (strictly in that order). The mixture was diluted to 50 ml. and the optical density was measured at 650 nm. using CECIL SPECTROPHOTOMETER MODEL 594. Molybdate solution was prepared by dissolving antimony tartarate in 400 ml. of 4N- H_2SO_4 and making the total volume upto 500 ml. with the same acid. Ascorbic acid (0.1 M) was prepared by dissolving 2 gm. of ascorbic acid in 100 ml. of distilled water.

<u>Silica</u> : The dissolved sillica concentration was determined by the molybdo-sillicate method. Standard solutions of different concentrations ranging from 0.1 ppm. to 5 ppm. were prepared by dissolving Na_2SiO_3. 20 ml. of each standard and water samples were taken, 10 ml. of ammonium molybdate solution and 15 ml. of reducing reagent was added. Ammonium molybdate solution was prepared by dissolving 2 gm. of ammonium molybdate in 10 ml. distilled water and 6 ml. conc. HCL and the total volume was made upto 100 ml. by diluting it with distilled water. Reducing reagent was prepared by mixing 100 ml. metol sulphite solution, 60 ml. of 100 % oxalic acid and 120 ml. of 25 % sulphuric acid and the total volume was made upto 300 ml. using 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 total volume was made upto 250 ml. using distilled water.

The samples were stirred and kept for 3 hours to complete the reaction. The optical density was measured for standard and water samples at 650 nm. using Cecil spectrophotometer No.CE 594.

Ca,Mg,Na,K : Ca, Mg were analysed in the absorption mode and Na, K were analysed in the emission mode by GBC 902, double beam ATOMIC ABSORPTION SPECTROPHOTOMETER using different concentrations of standards of corresponding elements. To avoid chemical interferences, suppresants were used.

Removal of Organic Matter

The organic material was removed from the bed and suspended sediments by treatments with 35% hydrogen peroxide after the material had been wetted with buffered sodium acetate (pH 4.8) (Jackson, 1973). The organic matter free sediments were used for studying mineralogy and chemistry.

3.4 Grain size analysis

The size distribution of the suspended sediments was determined using "FRITSCH Laser Particle Sizer" based on Fraunhofer diffraction and Mie's theory (Analysette 22 model) which is used for rapid, automatic particle size analysis of solids over the range of 0.3 um to 1100 um. The particle size distribution was calculated from the characteristics of the diffraction pattern at inifinity of a coherent beam passed through a sample.

3.5 Mineralogy

The mineralogy of suspended sediments were studied by X-ray diffraction 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/min., goniometer 1^o/min. and intensity 2 X 10^2 were maintained.Mineral identifications were done as following the mehod of Biscaye (1965).

Identification of minerals from XRD chart

Montmorillonite : It is identified by its 001 peak at 17 A^o in the Mg-saturated and glycolated sample. Sometimes the broad nature of this peak is due to variations in expansion after glycolation and variations in crystallinity. Montmorillonite has its 001 peak at 12.4 A^o in the k-satured sample.

Illite : The main basal peak of the illite is at 10 A^o with other peaks at 5 A^o and 3.3 A^o. The peaks remain unaffected upon glycolation and heat treatment.

Kaolinite and Chlorite : These two minerals give peaks almost at the same spacing and hence their identification becomes difficult. Biscaye (1964), pointed out that kaolinite in addition to two strong peaks at 7.16 A^o and 3.58 A^o, gives always a very small peak at 2.38 A^o. Similarly, chlorite in addition to 7.05 and 3.54 A^o peaks, shows a relatively smaller peak at 4.7 A^o. Therefore, whenever the chlorite peak at 4.7 A^o is present, the peak at 7 A^o and 3.5 A^o is considered as kaolinite peak.

Quartz : Quartz gives a strong peak at 3.34 A^o and another smaller peak at 4.26 A^o.

Alkali Feldspar : It shows a characteristic peak at 3.25 A^o.

Plagioclase Feldspar : The peak at 3.20 A^o is considered for the identificationof plagioclase feldspar.

Calcite : shows a prominent peak at 3.04 A^o.

Dolomite : The peak at 2.89 A^o is identified as dolomite.

Amphibolite : shows peak at 2.82 A^o.

3.6 Determination of Metals and non-Metals in Suspended and Bed Sediments

The sediments were analysed for SiO_2, Al_2O_3 and PO_4 by preparing soln.A, following the procedures of Shapiro and Burnock (1962). Rest of the major elements and minor elements were determined in solution.

Three parts of homogenized USGS rock standards (MAG-1, SCO-1, SDC-1 and G-2) were also likewise analysed along with the bed and suspended sediments to check the precision and accuracy of the measurments. Major elements and heavy metals in solution form were analysed using GBC-902 Atomic Absorption Spectrophotometer. Trace elements were determined by the Graphite generation system attached to the AAS.

Silicon, Aluminium and Phosphate

Solution A : 0.1 gm of fine sediment powder was taken in a 50 ml nickel crucible and 10 to 20 pellets of NaOH was added to the crucible. The crucible was gently heated on a burner for 5 minutes and then it was heated on a burner for 30 minutes. Then the crucible was allowed to cool down to room temperature and 30 ml of water was added and kept over night. Then the solution was transfered to a 1000 ml beaker with the help of policeman. 20 ml of 1:1 HCl and 100 ml of water were added. he solution was boiled till it was clear and the total volume was made to 1000 ml by adding distilled water.

Determination of silica

8 ml of the solution A, reagent blank, rock standard solution and the sample were transfered to 250 ml Volumetric flasks. 50 ml of distilled water was added to all the flasks. 2 ml of Ammonium molybdate solution (prepared by dissolving 7.5 gm of ammonium molybdate in 75 ml of distilled water and 25 ml of 1:4 H_2SO_4) was added and kept for ten minutes. $ ml of Tartaric acid solution (prepared by dissolving 25 gm of the reagent in 250 ml of distilled water) was added by swirling the flask. 1 ml of the reducing agent (Prepared by dissolving 0.7 gm of sodium sulfite in 10 ml of water and then 0.15 gm of 1 amino-2 napthol-4 sulphonic acid was added and stirred well until

dissolved. 9 gm of sodium bisulfite was dissolved in 90 ml of water and this was mixed with the forst solution) was added and the volume was made upto 250 ml by adding distilled water. The samples were stirred properly aand kept for 30 minutes. the concentration was measured as samples at 650 nm in Cecil spectrophotometer.

Determination of Alumina

15 gm of Soln.A(sample,standard,blank) were transferrd to 100 ml volumetric flasks. 2 ml of Calcium chloride solution (prepared by dissolving 7 gms of $CaCO_3$, and adding 100 ml of water and 15 ml of concentrated HCl and diluted to 500 ml) was added. 1 ml of hydroxylamine hydrochloride (Prepared by dissolving 5 gm of hydroxylamine hydrochloride in 50 ml) was added by swirlling the flask. 1 ml of potassium ferricyanide (0.75%) was added to each flask and mixed. 2 ml of thioglycolic acid solution (4 %) was addded and kept for five minutes. 10 ml of buffer solution (prepared by dissolving 100 gm of sodium acetate in water and adding 30 ml of glacial acetic acid and diluted to 500 ml) was added and kept for 10 minutes. 10 ml of Alizarian red-S solution (0.05%) was added to each flask and the volume was diluted to 100 ml by adding distilled water. The samples were stirred properly and kept for 50 minutes. The concentration was measured for standard and samples at 470 um using Cecil Spectrophotometer.

Determination of phosphorous : Phosphate was determined by the ascorbic acid method and the details of the procedures are given in water analysis section. 40 ml of Soln.A sample and sediment standards were used instead of water samples.

Bomb Digestion : 0.1 gm of the sediment sample was transferred into the teflon crucible and 0.5 ml HNO_3, 1.5 ml HCl, and 5 ml HF wereadded and kept in the oven for one to one and half hours at 100°C. Distilled water was added to the crucible after the bomb is cooled and was kept again in the oven for one hour and then cooled and diluted to 100 ml using plastic jar. The digested samples were analysed for heavy metals and major elements by AAS.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Major Ion Chemistry

The major cation and anion concentrations of water samples collected at different locations of the Brahmaputra were determined in the laboratory following various methods described in the procceding chapter. The ionic balance calculations indicate that the results are within a precision of 90-94%. The results of the water analysis are given in Table 4.1(A) alongwith Table 4.1(B) which gives the results of analysis of water samples collected from more or less same locations during January 1981. The results are also plotted in Fig. 4.1(A) & (B) and 4.2(A) & (B) to show the downstream trends of EC, TDS, pH and concentration of major dissolved ions.

4.1.1 pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS):

Average pH value of 7.5 for Brahmaputra river water with a range from 7.2 to 8.4 indicates its alkaline nature for both monsoon and non-monsoon, like other Indian rivers. No specific trend in pH values is noticed either along downstream or with season. Subramanian (1979) reported that for most Indian rivers alkalinity increases downstream irrespective of basin characteristics ; but such a trend is not reflected by the pH observations in the Brahmaputra.

Table 4.1 Chemical composition of water of Brahmaputra (June-July '89)

(Units: mg.l^{-1},except pH and cond.;Conductivity in uS.cm^{-1})

Sample No.	pH	EC	Cl^{-1}	HCO_3^-	SO_4^{2-}	PO_4^{3-}	F^-	H_4SiO_4	Na^+	K^+	Ca^{2+}	Mg^{2+}	TDS
1	7.6	124	3.8	54	2.3	0.09	0.16	7.5	2.0	1.1	12.2	2.3	85
2	7.7	144	4.4	65	1.5	0.05	0.13	11.2	1.6	1.8	14.4	2.3	108
3	7.7	125	5.8	55	1.7	0.05	0.10	10.1	1.5	1.7	11.7	2.3	90
4	7.3	162	4.6	64	2.3	0.06	0.13	8.7	2.5	1.6	15.9	3.3	103
5	7.3	88	4.1	34	1.8	0.04	0.13	9.4	2.1	1.0	7.4	1.8	63
6	7.8	135	4.8	62	2.4	0.07	0.15	11.8	3.7	2.8	13.2	4.5	106
7	7.3	133	5.1	56	1.8	0.07	0.13	10.6	2.4	2.1	12.2	2.4	93
8	7.5	139	4.2	59	2.6	0.07	0.14	7.4	1.9	1.5	15.4	2.9	85
9	7.3	126	4.6	57	1.6	0.12	0.24	9.8	2.0	2.4	11.6	3.1	93
10	7.5	124	4.8	62	2.0	0.10	0.16	8.3	2.1	2.6	14.4	2.6	99
11	7.5	169	4.9	61	2.1	0.14	0.15	9.1	4.8	2.7	16.9	3.1	105
12	7.4	134	5.0	56	1.9	0.16	0.17	10.7	2.4	2.5	11.7	2.4	93
13	7.7	147	5.6	62	2.0	0.18	0.18	10.6	2.3	2.8	13.5	3.3	102

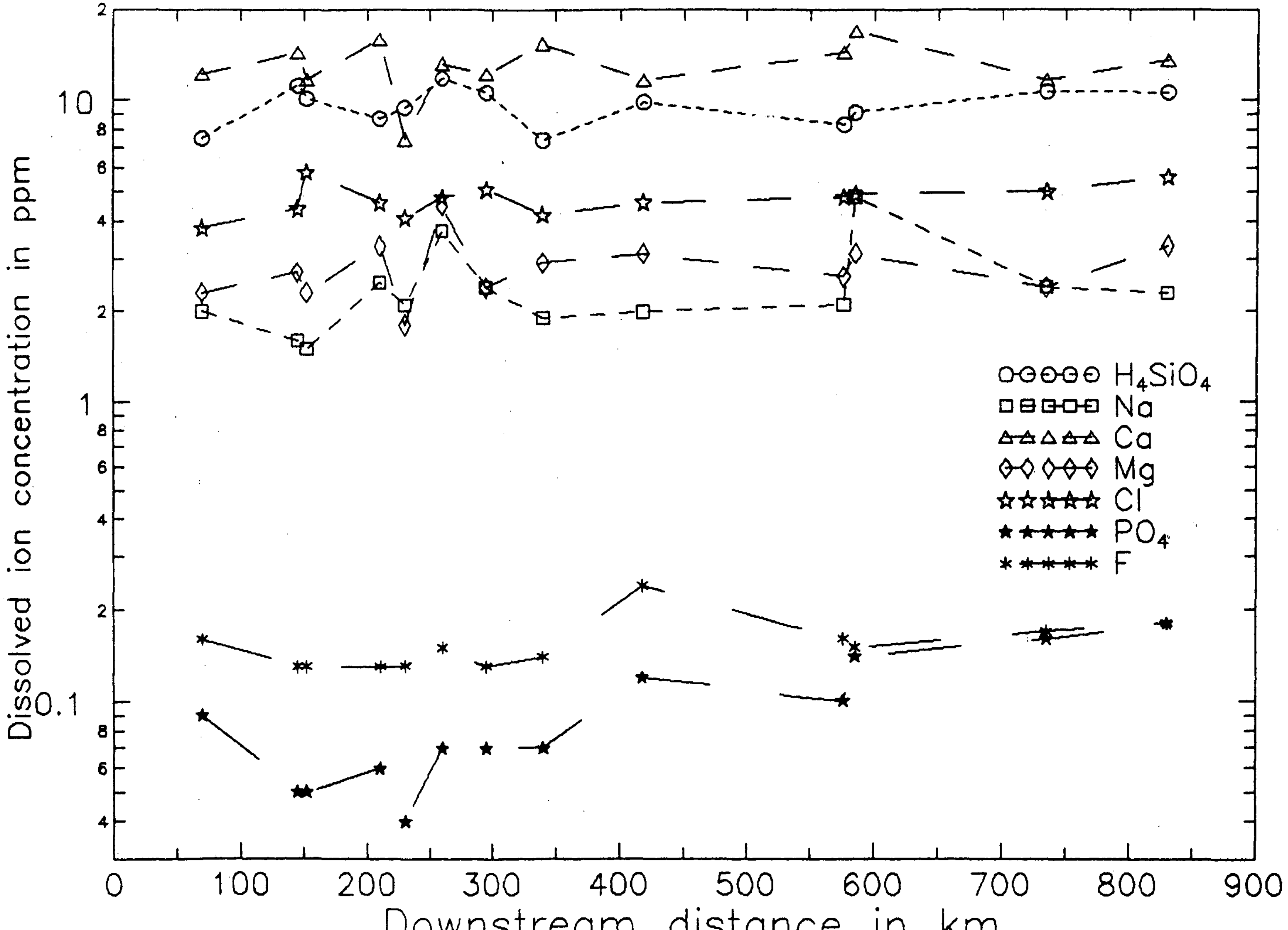


Fig.4.1.(A) Downstream variation in major dissolved ion concentration of Brahmaputra water(Monsoon'89)

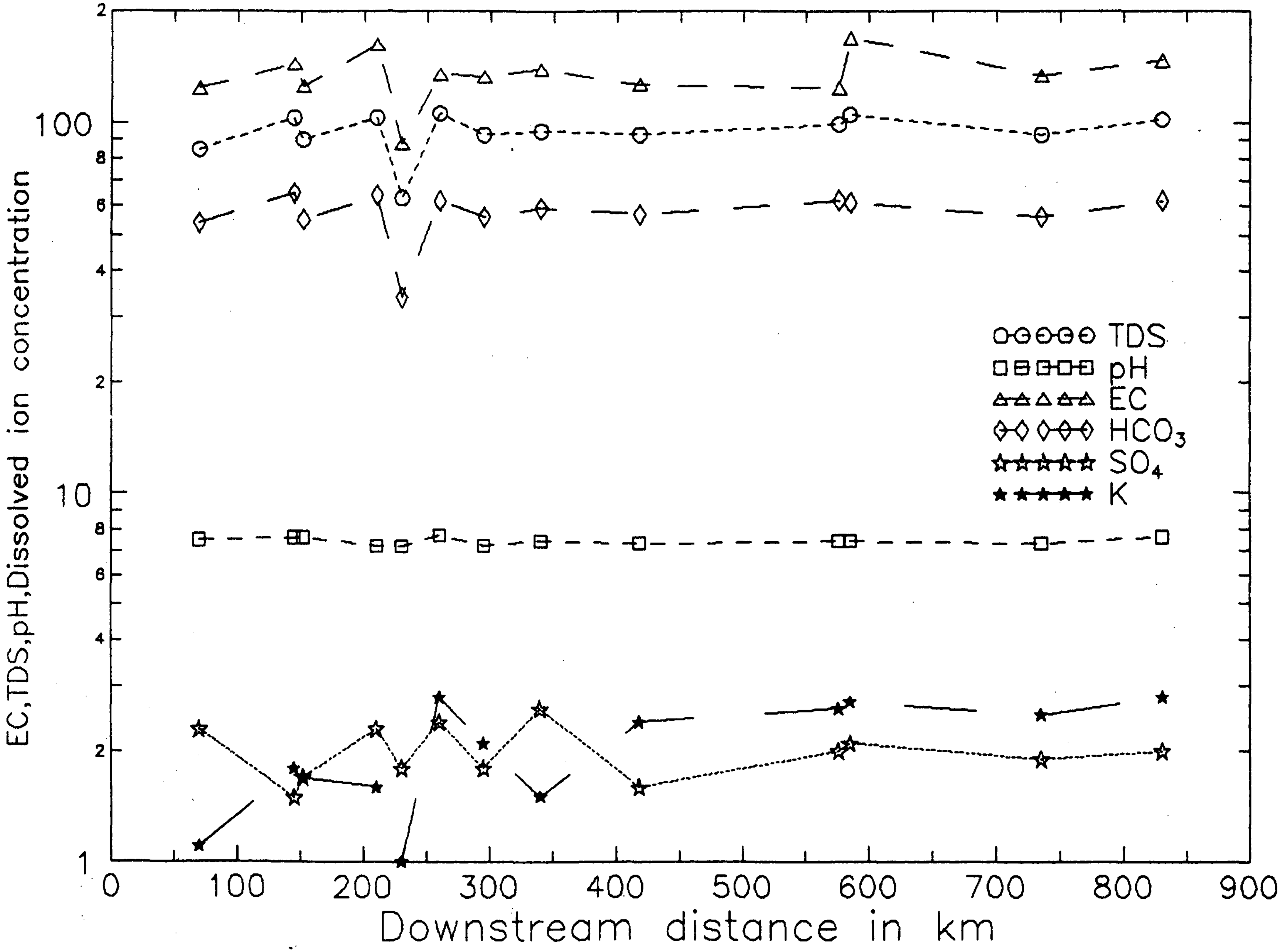


Fig.4.1.(B) Downstream variation in pH,EC,TDS and dissolved ion concentration of Brahmaputra water(Monsoon'89);Units:EC–uS/cm,TDS & diss. ion–ppn

Table 4.2 Chemical composition of water of Brahmaputra (January '81)

(Units: mg.l^{-1},except pH and cond.;Conductivity in uS.cm^{-1})

Sample No	pH	EC	Cl^{-1}	HCO$_3^{-1}$	SO$_4^{2-}$	PO$_4^{3-}$	F$^-$	H$_4$SiO$_4$	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	TDS	TSM	E-	E+
1	7.2	101	13.0	25.0	3.6	0.07	0.1	4.4	7.5	1.5	18.5	2.2	75.9	5	0.857	0.915
2	7.6	145	18.5	25.0	3.9	0.06	0.1	5.3	6.5	2.5	24.5	4.0	90.4	60	1.019	1.123
3	7.5	151	18.9	25.3	3.7	0.08	0.1	6.3	8.0	3.0	26.5	4.4	96.3	31	1.016	1.267
4	7.8	158	22.5	37.2	3.4	0.04	0.1	4.9	8.1	2.9	25.8	7.5	112.4	35	1.325	1.378
5	7.6	167	18.6	37.3	4.9	0.04	0.1	5.5	9.5	3.0	29.3	5.6	113.8	6	1.245	1.451
6	7.8	163	18.3	37.5	4.8	0.05	0.1	5.7	11.5	2.0	29.1	7.2	116.3	19	1.224	1.591
7	7.3	187	16.6	37.5	5.2	0.05	0.1	6.0	14.0	3.5	29.3	5.6	117.9	19	1.197	1.660
8	7.4	191	11.0	37.4	5.3	0.06	0.1	5.9	14.5	3.4	30.3	3.6	111.6	21	1.040	1.624
9	7.4	198	13.0	37.1	7.0	0.06	0.1	6.3	14.0	3.5	31.3	5.9	119.8	10	1.128	1.570
10	7.4	207	12.7	40.3	7.5	0.07	0.1	6.0	14.3	3.6	29.4	6.9	120.9	23	1.181	1.737
11	8.0	212	15.3	41.5	5.2	0.06	0.1	7.9	10.5	2.1	28.5	11.1	122.3	18	1.226	1.678
12	7.8	203	14.9	37.7	5.4	0.07	0.1	8.1	10.6	2.0	27.4	6.8	113.1	19	1.158	1.477
13	7.9	211	15.2	37.4	9.0	0.07	0.1	6.8	12.0	2.5	29.3	7.4	119.8	21	1.234	1.448

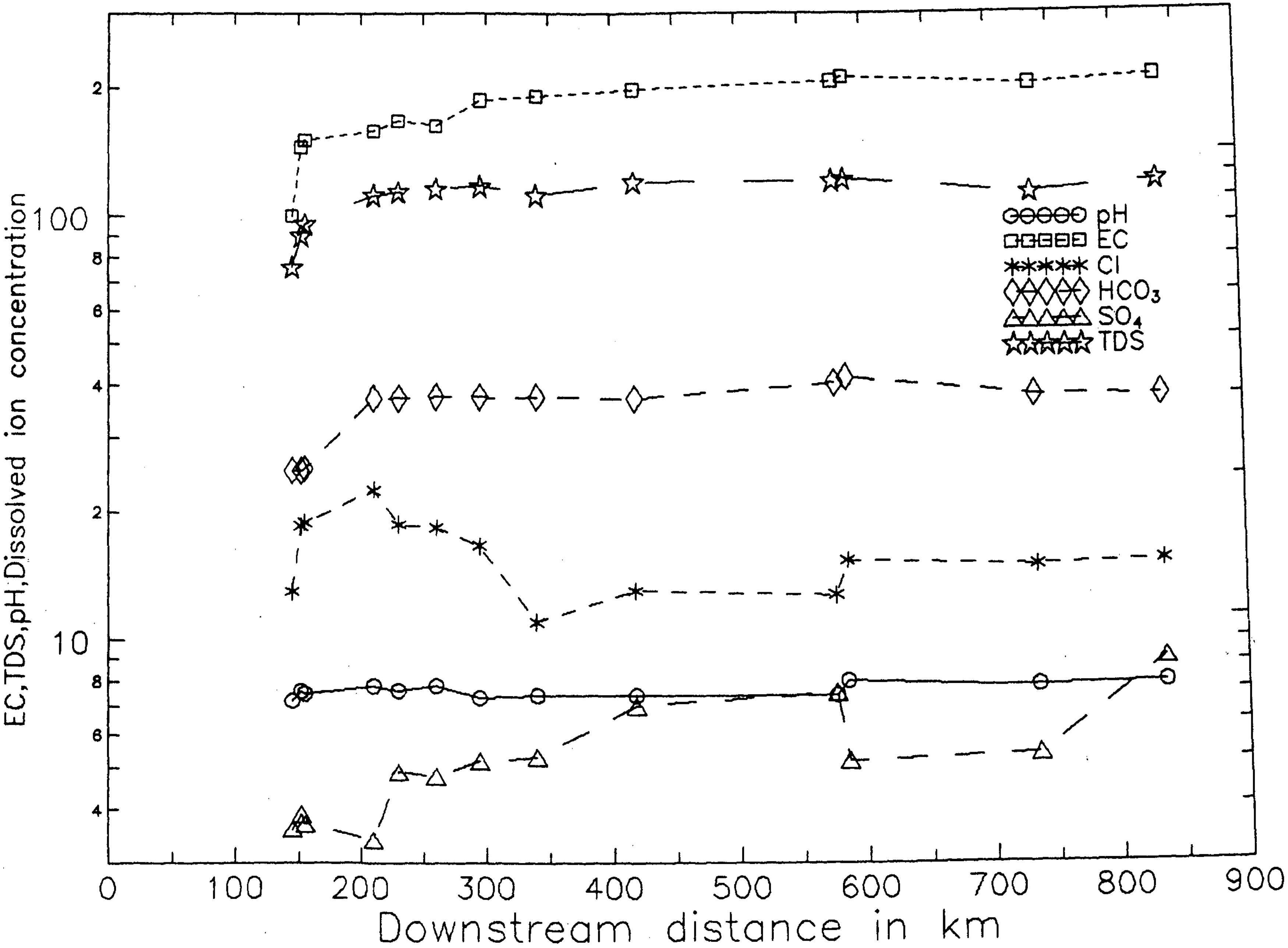


Fig.4.2.(A) Downstream variation in pH,EC,TDS and dissolved ion concentration of Brahmaputra water(Non-monsoon'81);Units: EC–uS/cm,TDS & Diss.ion–ppm

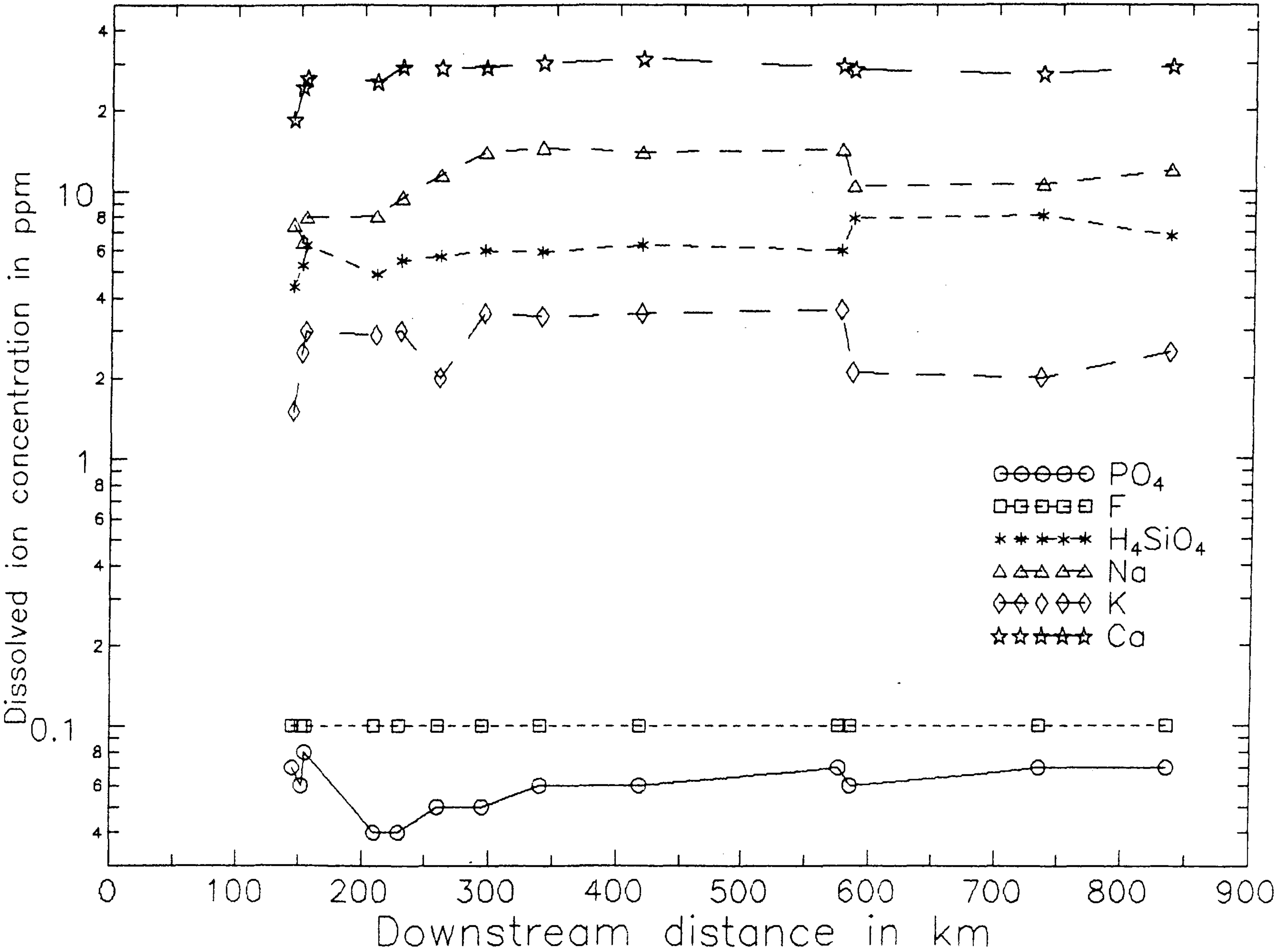


Fig.4.2.(B) Downstream variation in major dissolved ion concentration of Brahmaputra water (Non-monsoon'81)

The pH in most natural waters plays a significant role in all chemical reactions associated with the formation, alteration and dissolution of minerals (Stumm and Morgan,1981). Subramanian (1979) observed that additional pH-buffering mechanism operates in the Indian river systems, since the HCO_3 concentrations are uniformly high and the observed pH is higher than the theoretical values based on alkalinity. The pH of the Brahmaputra water also shows little seasonal variation with average value of 7.5 and 7.6 for monsoon and non-monsoon respectively. This slight depletion in pH during the monsoon may be attributed to dilution effect my rain water.

The EC however shows considerable seasonal variation as well as a changing trend downstream. While the minimum and maximum values of EC in the moonson are 88 and 169 us/cm respectively, those in the non-monsoon are 100 and 211 us/cm. An Ec value of 126 us/cm has been observed at an intermediate location of Bhomoraguri during monsoon 1989 whereas the EC at the same location during non-monsoon had been found to be as high as 198 us/cm. An increase in the EC suggests an increase in the ionic strength of the solution which invariably indicates an increased concentration of major ions. Correspondingly, the ionic strength ($I = 1/2\ Em_i z_i^2$, where m_i is the molality and Z_i is the charge of the ith ion of the solution, the

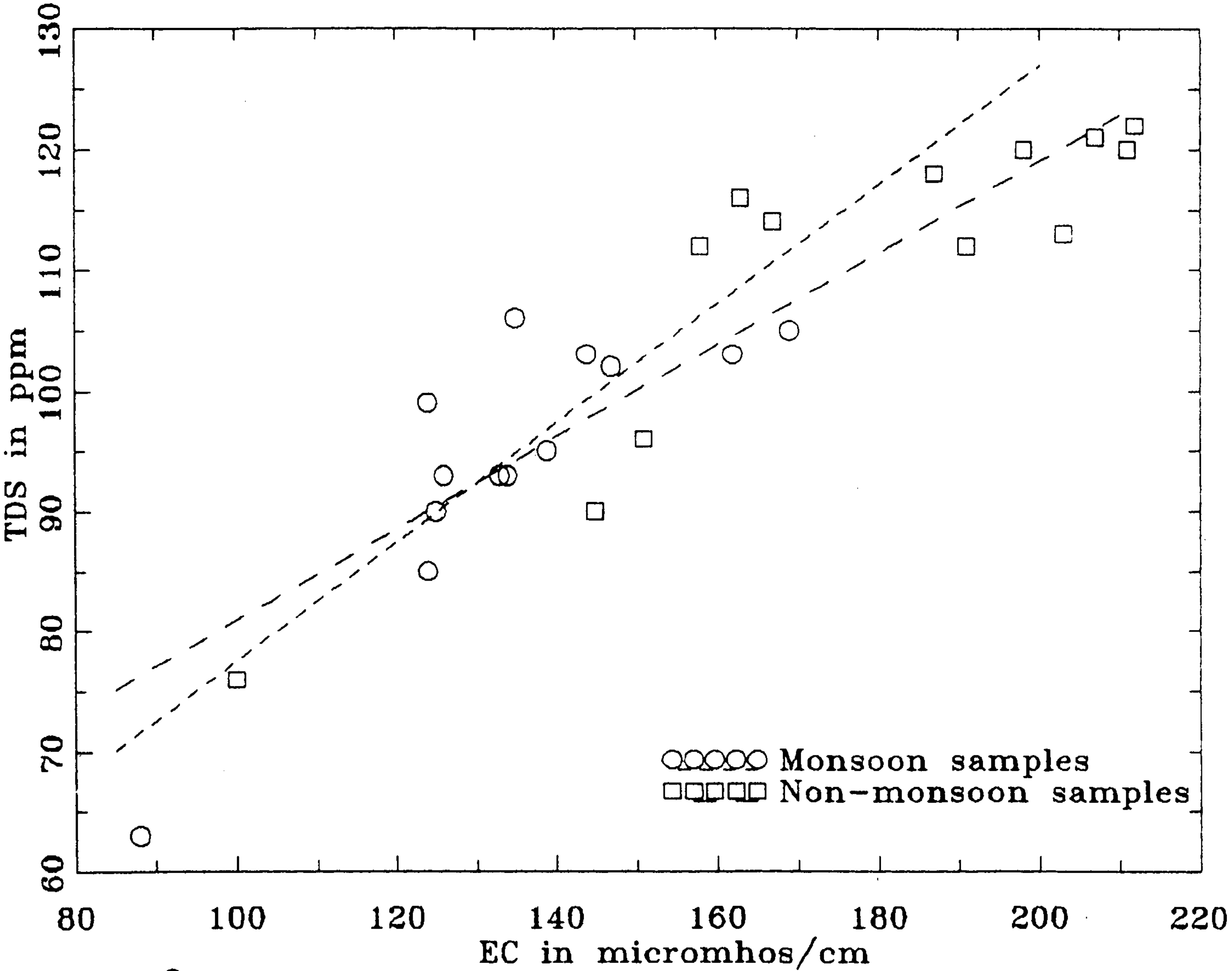


Fig.4.3 Relationship between Total Dissolved Solids (TDS) and Electrical Conductivity (EC) in the water of the Brahmaputra during monsoon and non-monsoon seasons

assumption being taken over all ions, positive and negative; (Garrels and Christ, 1965) of Brahmaputra varies from around .002 in monsoon to .003 in non-monson period. Approximate TDS values computed from the measured EC values by converting it with the commonly accepted factor of 0.7 for fresh water (Davies and Deweist, 1962) does not show a close agreement with the observed TDS values. The correlation co-efficient between EC and observed TDS values are 0.83 for monsoon and 0.68 for non-monsoon respectively. The graph obtained by plotting Total Dissolved Solids against Electrical Conductivity is shown in Fig.4.3.

Downstream and seasonal variation in the chemistry of river waters have been reported for a number of other rivers (e.g. Gibbs, 1967; Grover, 1972; Subramanian, 1974; 1983). In general, minima and maxima in the downstream profile are related to the diluting and concentrating effects of tributary inflows, with high and low TDS content respectively. Besides the effect of the tributaries, human activities such as agriculture and other landuse, construction of dam etc., are prime factors causing erratic changes in the TDS.

4.1.2 Major Anions:

The major anions making up about 70% of the total ions in the river water of Brahmaputra are Cl^-, HCO_3^- and SO_4^{--}.

The main source of chloride in river water is atmospheric precipitation. Except areas where heavy industrial pollution input dominates, chloride concentration by evaporation should not exceed 20 ppm in rivers with rainfall more than 20 cm per year (Holland, 1979). A substantial amount of non-atmospheric chloride in the rivers is derived from sedimentary rocks, released possibly by the reaction with sub-surface connate brines. The average chloride concentration in the Brahmaputra is 10 ppm which is more or less with other Indian rivers: Ganges 5.6 ppm; Yamuna 5.4 ppm; Godavari 17.0 ppm; Cauvery 18.0 ppm (Subramanian, 1987). The much lower average value of Cl^- in Brahmaputra during monsoon seems to be quite acceptable considering the landlocked nature of the basin with rainfall and groundwater discharge as the major sources. However, the increase in chloride ion concentration with an average value of 16 ppm during the non-monsoon period compared to 5 ppm of monsoon is slightly difficult to explain in the light of marine recycling which is otherwise assumed to be major source of Cl in surface waters. In the absence of the high precipitation of the rainy season, the dilution factor is reduced significantly which may lead to the increase in concentration of Cl^-, but however not to the extent as seen in this case. Garrels and Mackenzie (1971) estimated that 55% of Cl in the river is derived from rocks and 45% from recycling through atmosphere. Also taking into consideration the substantial increase in Na ion concentration during non-monsoon, the higher Cl^- content of Brahmaputra water during non-monsoon can be the contribution from the evaporite deposits of Halite reported by Hu Ming Hui et al.,(1982) located in the upper reaches of the Brahmaputra in Tibet.

Sulphate in rivers may be from a variety of sources. Weathering of sulphide and sulphate minerals and sulphates derived from the sea are the major sources of primary sulphate. Anthropogenic sulphate is mostly produced during fossil fuel burning. As indicated by Garrels and Mackenzie (1975), anthropogenic contribution of the total river sulphate can be as high as 45%. The average sulphate content of Brahmaputra is 3.8 ppm which is far less than the Indian average of 13.0 ppm (Subramanian, 1987).

Sulphate concentration in Brahmaputra during non-monsoon is more than that during the monsoon. This may be particularly due to high dilution factor brought about by the enormous amount of water discharge in the monsoon season. Significant increase in the sulphate concentration is observed downstream [Fig.4.2(A)] during the non-monsoon which can be explained in terms of increased population density and consequently enhanced anthropogenic activities gradually towards the lower part of the basin,with more urbanization and industrialisation. SO_4^{--} shows a correlation coefficient of 0.6 with calcium which indicates gypsum or anhydrite to be a major source of sulphate ions in the Brahmaputra. Reported evaporite deposits in the upper reaches of the basin in Tibet (Hu Ming Hui et al., 1982) strongly supports this possibility. Gannser (1964) reported presence of pyritic sediments in the Brahmaputra basin; oxidation of these sediments is also expected to contribute significant amount of SO_4 in the water.

Bicarbonate content determine the alkalinity of fresh water. The possible sources of HCO_3^- to the river water are atmospheric CO_2, dissolution of limestone and dolomites, weathering of primary and secondary silicate minerals and organic activities (Garrels and Mackenzie, 1971). The HCO_3^- is the most abundant ion in all the samples of Brahmaputra river water which indicates siginificant chemical weathering taking place throughout the basin.

The carbonic acid formed by the solution of carbon-dioxide and rain water may dissociate to give rise to Bi-carbonate ions in the water.

$H_2O + CO_2$ .... H_2CO_3 (1)
H_2CO_3 .... $HCO_3^- + H$ (2)

The carbonic acid after reacting with carbonates and silicates releases HCO_3^-.

$CaCO_3 + H_2CO_3$ ..... $Ca^{++} + 2HCO_3^-$ (3)
(Calcite)
$CaMg(CO_3)_2 + 2H_2CO_3$ ... $Ca^{++} + Mg^{++} + 4HCO3^-$ (4)
(Dolomite)

The aluminosilicates after reacting with carbonic acid form clay minerals and release various cations including silica and bicarbonate to the river water. For example, Albite may breakdown to form kaolinite and release sodium, bicarbonate and silica in solution:-

$2NaAlSi_3O_8 + 2H_2CO_3 + 9H_2O$ .... $Al_2Si_2O_5(OH)_4$
(Albite) (Kaolinite)
$+ 4H_4SiO_4 + 2HCO_3^-$ (5)

Chemical weathering of pure calcite releases Ca^{++} and HCO_3^- in the molar ratio of 1:2 (reaction 3) and dissolution of pure dolomite releases Ca^{++}, Mg^+ and HCO_4^- in the ratio of 1:1:4 (reaction 4) (Garrels and Mackenzie, 1971). The water resulting from the reaction (5) would contain HCO_3^-, Na^+ and H_4SiO_4 in the ratio of 1:1:2. Thus, each molecule of CO_2 produces one HCO_3^- ion from silicates and two HCO_3^- ions from carbonates.

The validity of the above reactons to the present discussion is evident from the observation that all the samples from Brahmaputra show high values of HCO_3^- and are alkaline in character. This high percentage of HCO_3^- in the river water is consistent with their drainage lithology, since the upper reaches of Brahamputra is composed of siwalik sediments and limestone, dolomites and calcareous shales (Gannser, 1964). During monsoon season, the HCO_3^- content is higher (average 58 ppm) compared to non-monsoon (average .38 ppm). Ramesh (1985) reported an increased bi-carbonate content for Krishna river during the monsoon compared to other seasons. This has been attributed to the fact that during monsoon period, atmospherically regulated PCO_2 water reactions may further enhance the bicarbonate alkalinity (Subramanian, 1983). A plot of HCO_3^- vs Ca^{++} (correlation co-efficient 0.80) is shown in Fig. 4.4.

Raymahasay (1986) has shown that the variation in bicarbonate in Indian rivers are primarily controlled by varying silicate fractions resulting from kaolinisation reactions. Based on Raymahasay's method (1986), Jha (1986) calculated for Yamuna river that carbonate minerals contribute 57-90% of bicarbonate and the rest comes from silicate minerals. Following the same method, it has been found that for Brahmaputra an average of 37% bicarbonate comes from the carbonate minerals and the rest from the silicates. Based on the HCO_3 content and pH, the P_{CO} of Brahmaputra was calculated. The values lie between 10^{-2} to $10^{-3.5}$ atm. This is a global trend indicating that rivers are commonly out of equilibrium with the atmosphere.

4.1.3 Dissolved Silica (H_4SiO_4)

Siever (1971) has demonstrated that the dissolved

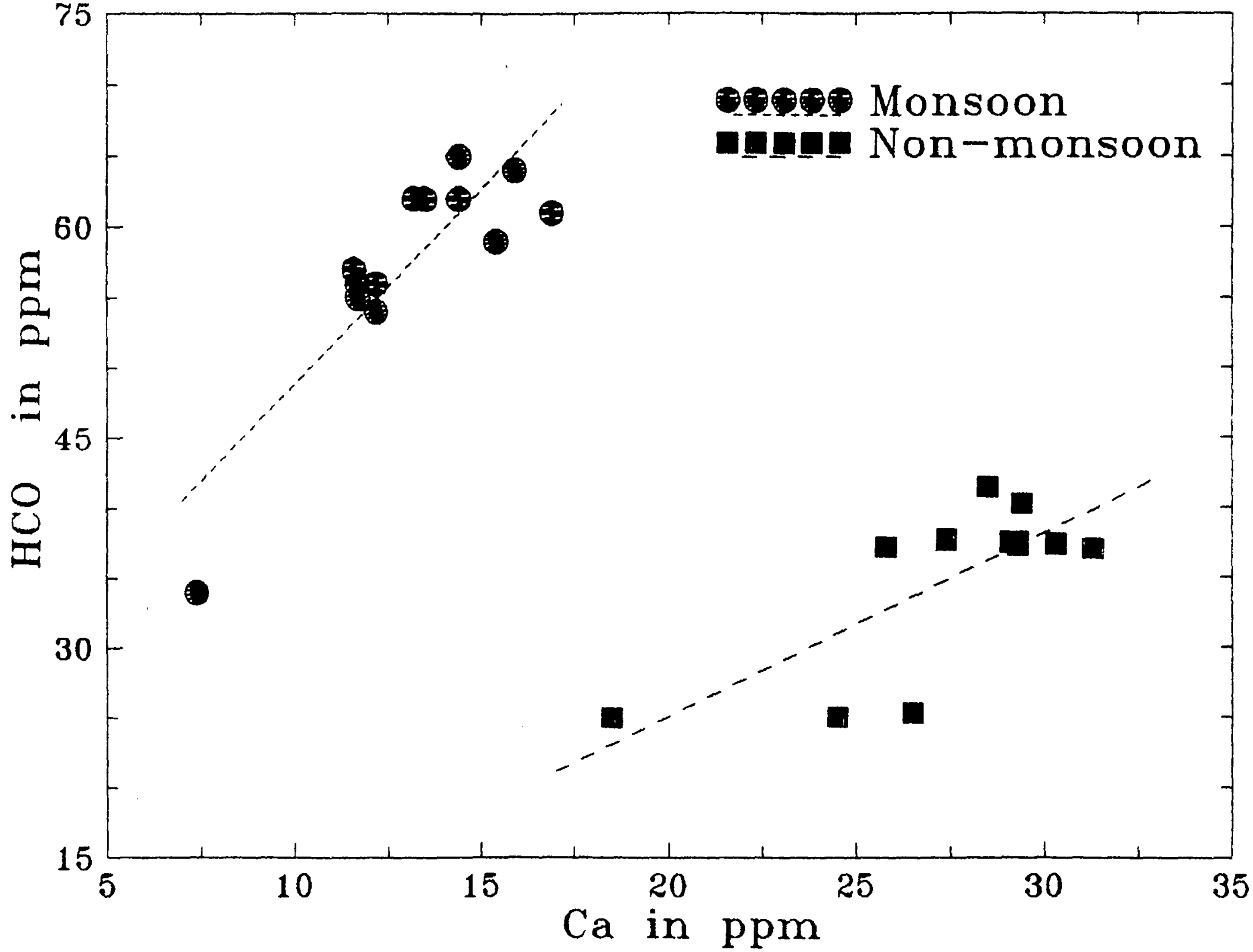


Fig.4.4 Dissolved Calcium vs. Bicarbonate in the water of Brahmaputra

silica will be present as monomeric silicic acid (H_4SiO_4) in the water of pH less than 9. In silicate reactons, pH is an important variable (Garrels and Christ, 1975) and based on solubility acidic waters should be deficient in silica. At pH values above 9, H_4SiO_4 dissociates to $H_3SiO_4^-$ and $H_2SiO_4^{--}$. Major source of silica in river water is the weathering of the silicate minerals.

Dissolved silica concentrations are higher in the monsoon for Brahmaputra. The values of H_4SiO_4 range between 7.4 and 11.8 ppm in monsoon and between 4.4 and 8.1 ppm during non-monsoon. Ramesh (1985), Jha (1986) reported higher values of silica during winter and pre-monson for Krishna and Yamuna rivers respectively. The average dissolved silica concentration for Brahmaputra is 8 ppm which is only slightly higher than the Indian average (7 ppm, Subramanian, 1987) and a little less than the world average (10.4 ppm, Meybeck, 1979). The possible source of the dissolved silica in the Brahamaputra appears to be kaolinisation and chloritisation of silicates such as feldspars, and mica in the gneissic and schistose rocks around the basin.

4.1.4 Major Cations

Ca^{++}, Mg^{++}, Na^+ and K^+ are the four major cations which were studied. They make up more than 32% of the total ionic concentration.

Na^+ is not only derived from the weathering processes but also from recycling of seawater; however as already mentioned while discussing Cl^- ion concentrations,a significant amount of Na input in Brahmaputra comes from the evaporite halite deposits upstream reported by Hu Ming Hui et al., (1982). K-feldspar being a chemically inert mineral under the conditions of weathering, little dissolved material is derived from the alteration of K-feldspars and most of the K^+ comes from the dark silicate minerals like biotite or hornblende. It may be mentioned here that only 15% of the river transported K^+ is in dissolved load while the rest is in particulate form (Berner and Berner, 1987). The relative low concentration of K^+ in Brahmaputra water compared to Na^+ may be due to its uptake by clay minerals, especially Illite.

4.1.5. Phosphate (PO^4) and Fluoride (F):

Subramanian (1984) studied the dissolved phosphat levels in a number of Indian rivers and suggested that all river waters are saturated with respect to all economic phosphate minerals. Based on P and F levels in various samples, he has concluded that they are cogenetic and F is a good indicator of pathways of P. The present study indicates that average dissolved phosphate in Brahmaputra river is about 0.08 ppm. The values are slightly higher in the monson and in both monsoon and non-monsoon PO^{4-3} shows

Calcium in river water is derived largely from the weathering of carbonates, sulphates and silicates. Calcite, aragonite and dolomite are the important carbonates and gypsum and anhydrite are the important sulphates contributing Ca^{++} ion into the river water. Calcium and Magnesium are considered to be two ions with similar behaviours and this is true in many phenomena of the hydrosphere. Ca^{++} in Brahmaputra varies from 12% to 24% of the TDS whereas Mg^{++} varies from 3% to 9%. The Brahmaputra river water probably derives Ca^{++} from dissolution of calcium carbonates, plagioclase feldspars and evaporite deposits of gypsum and anhydrites. Mg^{++} may be released from the hydrolysis of olivine bearing rocks in the source area. During chemical weathering Mg^{++} is released as $MgCl_2$, $MgSO_4$ and partly as magnesium bearing clay minerals which are derived.

Na^+ and K^+ together make up 7-9% of the TDS in Brahmaputra. Millot (1970) from his studies on hydrosphere concluded that in the course of chemical weathering Na^+ turns out to be much more mobile than K^+ and dominates the latter in natural solutions. Incase of Brahmaputra while Na^+ varies from minimum 2% in monsoon to 14% of the TDS in non-monsoon, K^+ shows a very narrow range of variation between 1% to 3% of the TDS. K^+ does not also show pronounced seasonal changes like Na^+.

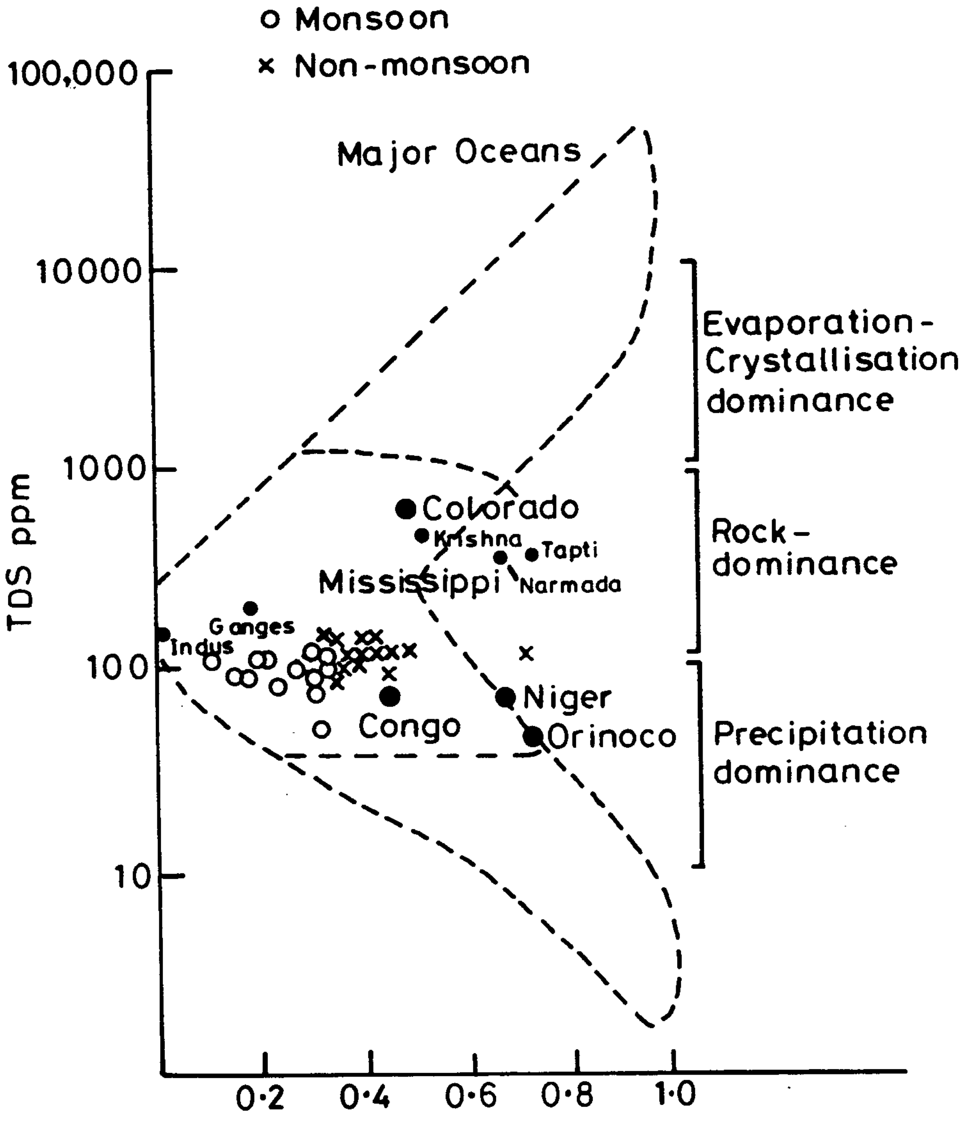


Fig. 4.5. Variation of the weight ratio Na / (Na + Ca) as a function of Total Dissolved solids.

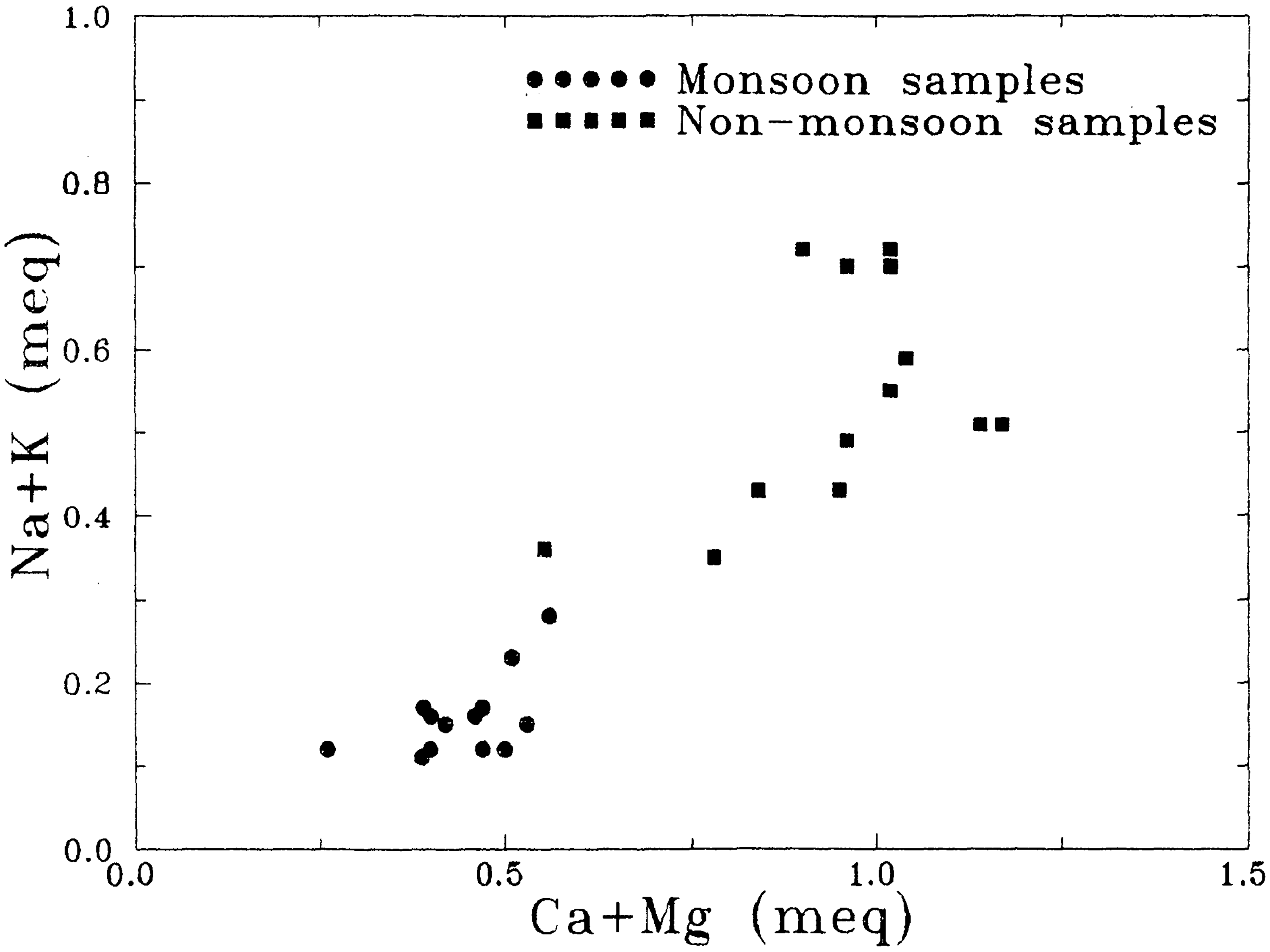


Fig.4.6 (Ca+Mg) vs. (Na+K) in Brahmaputra. The line separates the monsoon samples from the non–monsoon ones.

an increase downstream. According to solubility of various phosphate minerals such as fluorapatite, the dissolved levels of phosphate should not exceed 0.05 ppm. The reported higher values, especially during monsoon, are mostly observed at locations closed to the major urban settlements by the river which reflects the addition of PO^4 from anthropogenic sources. considering the maximum land use for agriculture, agricultural waste, both manures and pesticides are important non-point sources of P.

Solubility of Fluoride mineral (CaF^2) is higher than that of phosphate minerals (apatite). Trace quantities of F are present in minerals like biotite and amphibole; bulk of F in any water is derived either from phosphate or fluorite minerals. The F concentration in Brahmaputra varies from 0.10 to 0.24 ppm. The general acceptable limit of fluoride in drinking water has been fixed by WHO at 0.5 ppm. Desmukh (1974) studied the fluoride content in rivers of Peninsular India and reported that rivers flowing over alluvium contains 0.12 to 0.35 ppm and rivers flowing over granitic terrain recorded upto 3.5 ppm of fluoride.

4.2 Water-Mineral Equilibria in Carbonate and Silicate Systems

The mineral stability in water can be predicted by the application of thermodynamic concepts to chemical equilibria of the water (Kramer, 1967). The principle behind such an application is: that water derives its composition from the parent rock in the weathering region and the suspended sediments owe their mineralogical composition partly to the parent rock and partly to the chemical reaction and water, when such reactions reach chemical equilibrium, certain mineral assemblages, principally clay minerals, will coexist in the sediment phase provided the chemistry of water does not change. For example, the weathering of albite can be written as

$$2H_2CO_3 + 9H_2O + \underset{\text{(Albite)}}{2NaALSi_3O_8} \quad \underset{\text{(Kaolinite)}}{Al_2Si_2O_5(OH)_4} + \underset{\text{(aq)}}{4H_4SiO_4} + 2Na^+ + \underset{\text{(aq)}}{2HCO_3^-}$$

At constant values of CO_2, Na^+ and HCO_3^-, the Albite-Kaolinite assemblage can be considered in stable equilibrium with the water. So a stable mineral assemblage can be theoretically predicted from the water chemistry. In sedimentary processes, pressure and temperature do not vary significantly for surface sediments so all reactions were assumed to take place at constant temperature (25^0C) and pressure (1 atm.). Garrels and Christ (1967); Berner (1971); Garrels and Mackenzie (1971); Jack (1973), Subramanian and d'Anglejan (1976); Ramesh (1983, 1985); Ramesh and Subramanian (1984, 1987); Chakrapani and Subramanian (1990) and several others have predicted the presence of theoretical mineral assemblages using different natural water bodies, expected in equilibriating sediments.

An attempt has been made in this study to apply similar concepts to the Brahmaputra river water. From the dissolved ion chemistry of Brahmaputra water, molality, ionic strength, activity co-efficients, activity and negative logarithm of ion activities for silicate and carbonate systems have been calculated.

4.2.1 Carbonate system

Carpenter (1962) has developed a diagram that shows metastable and stable equilibria among the calcium and magnesium carbonates (Fig.4.7). In the original stability diagram, the negative log of the P^{CO} and log of (Ca^{++}/Mg^{++}) were plotted as variables. The metastable phases involved are aragonite and huntite. The early mineral compatibilities are those that would be deduced from the metastable (dashed lines) diagram and these early minerals apparently eventually equilibrate to give the phase relations demonstrated by the slid lines. The phase diagram for Brahmaputra shows Dolomite (aragonite) to be a stable assemblage irrespective of the season. Subramanian (1979) reported that dolomite is the theoretically expected mineral in the river waters of India. The X-ray diffraction studies of the suspended sediments discussed in the later section of this chapter shows considerable amount of dolomite and calcite in most of the samples.

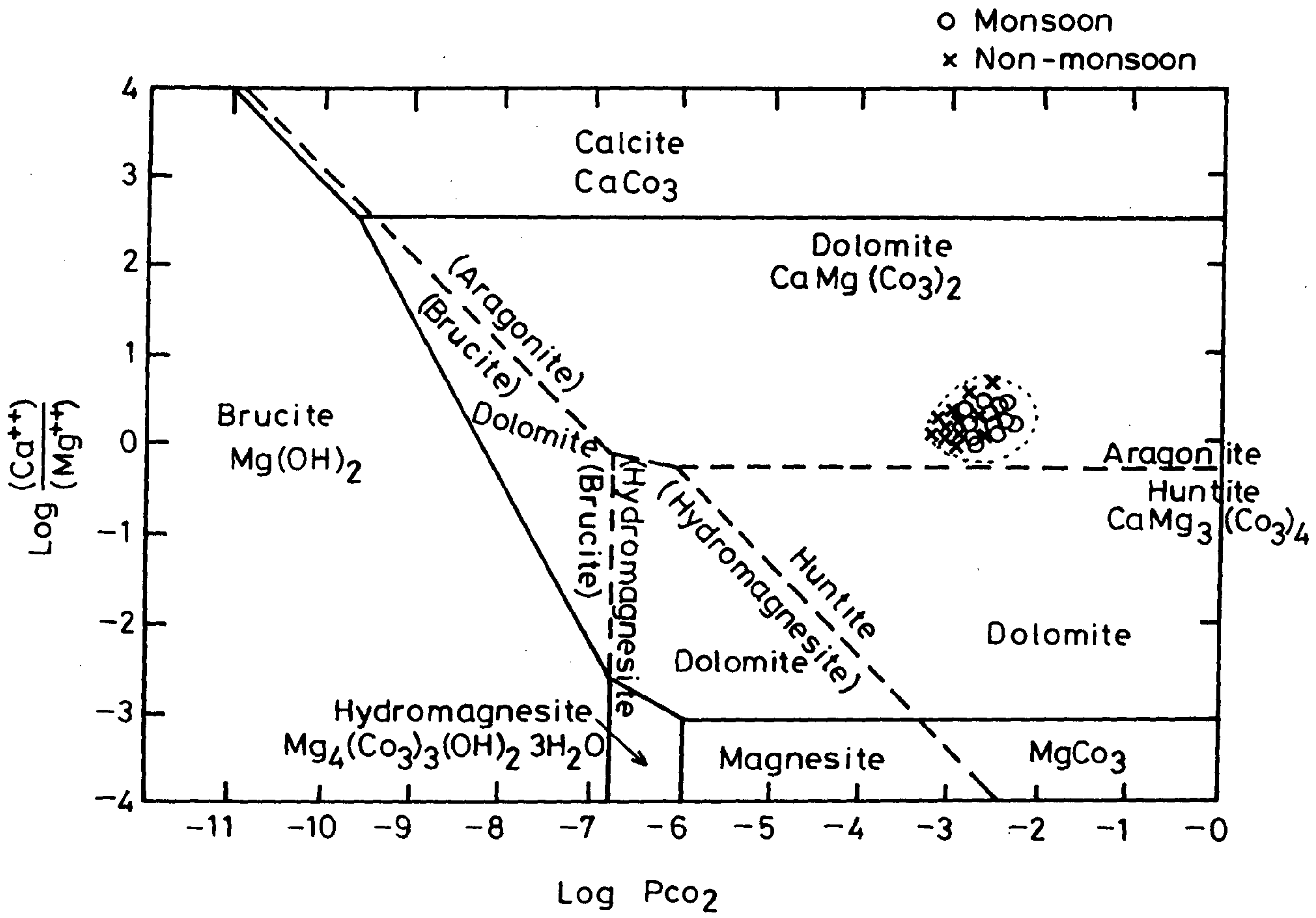


Fig. 4.7. Equilibrium diagram in carbonate system for the Brahmaputra river water.

Dolomite formation does not result from the combination of Ca^{++}, Mg^{++} and CO_3^{t--} ions; it is formed due to combination of calcite ($CaCO_3$) with Mg^{++}.

4.2.2 Silicate System

The chemistry of river water can be represented in a phase diagram consisting of K_2O-Na_2O-MgO-CaO-Al_2O_3 - SiO_2-H_2O as seven components. The composition of Brahmaputra river water has been plotted in the mineral stability diagram in Fig. 4.8 (A, B, C, D, E). The majority of the data points fall in different regions in different silicate eqilibrium diagram. Albite,Kaolinite-chlorite and Ca-feldspar seem to be the stable minerals in Brahmaputra. In the Mg-alumino silicate system chlorite seems to have a stable mineral phase (Fig.4.8.C). Similarly, while K-allumino silicate diagram suggests kaolinite to be a stable mineral (Fig.4.8.B) in Brahmaputra, in Na and Ca - allumino silicate systems Na-felspar (albite) and Ca-feldspar appear to have a dominant stable phase. Subramanian (1979) reported that independent of cations considered, kaolinite is the theoretically expected minerals in rivers of India. Garrels and Mackenzie (1971) have shown that the plot of river water generally falls in K-mica region for K-alumino-silicate system; but Brahmaputra seems to be an exception to this. X-ray mineralogical studies of

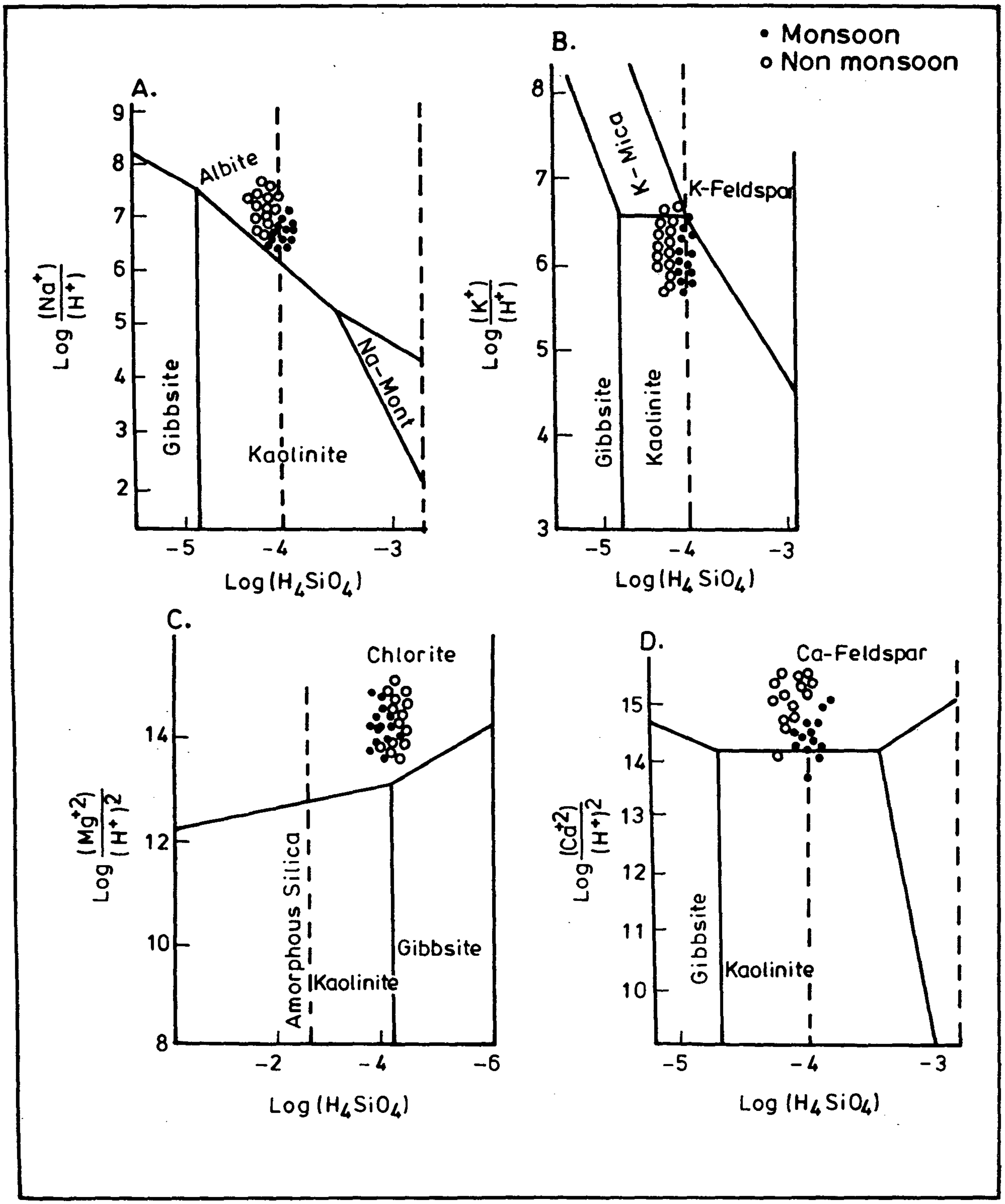


Fig. 4·8. (A,B,C,D). Equilibrium diagrams for silicate system in the Brahmaputra river.

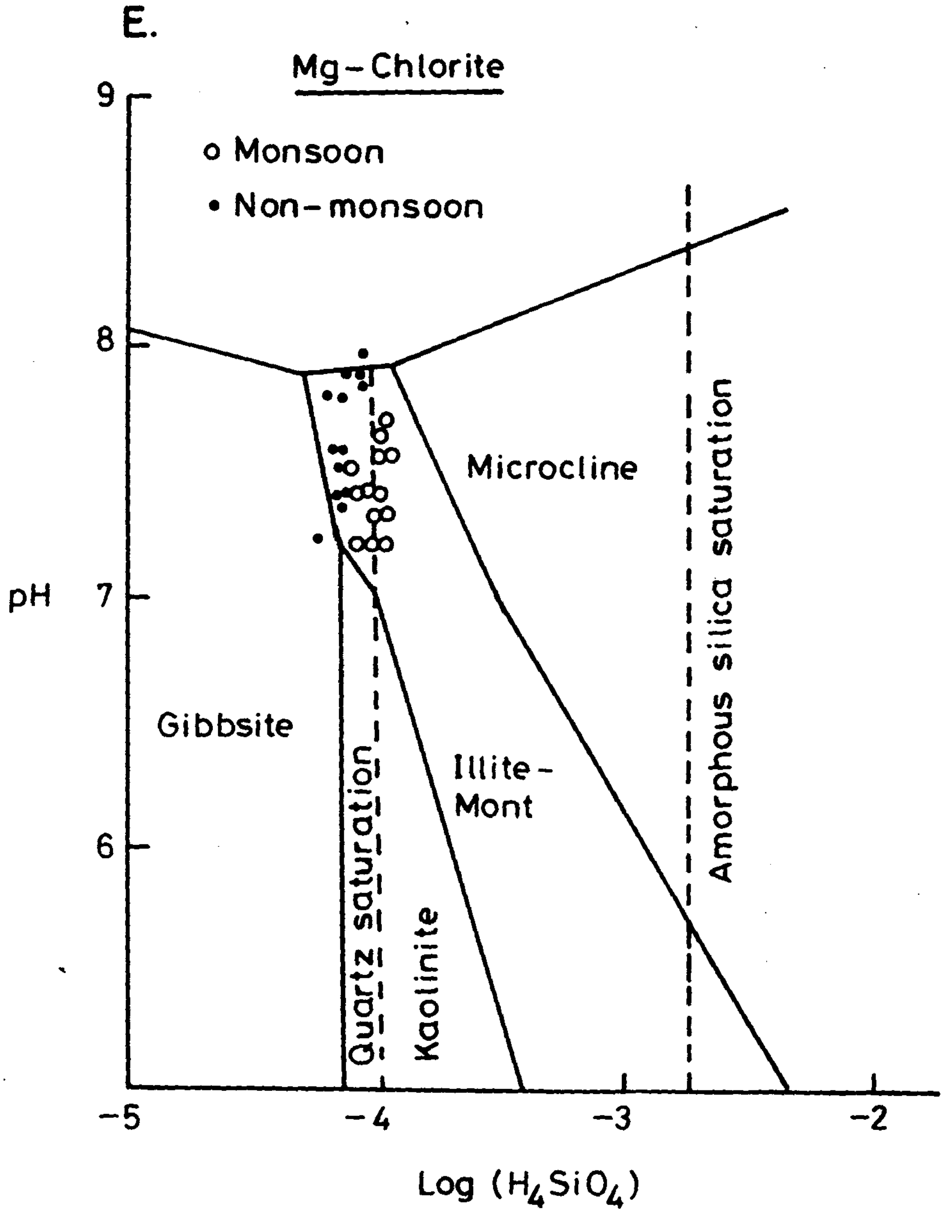


Fig. 4·8 (E). Illite-Montmorillonite are amongst the stable silicates in the Brahmaputra.

the suspended sediment in Brahmaputra river show the presence of the above predicted minerals.

4.3 The Elemental Chemistry of Sediments in the Brahmaputra River Basin

Thirteen samples of freshly deposited bed sediments and seven samples of suspended sediments collected from different parts of the basin have been analysed for major and minor elements. Fig. 2.1 shows these sampling stations. Detailed field and laboratory techniques are described in the methodology chapter.

To check the accuracy and precision of the measurements, various USGS rock standards were also analysed several times during the course of the investigation. Repeated measurements for elemental abundances in SDC-1, MAG-1, SCO-1, AVG-1, QLO-1 and G-2 show satisfactory agreement with the reported values (Flanagan, 1976). Chemical composition of the Brahmaputra river bed and suspended sediments are given in Table 4.3 and 4.4. Also shown are the average published data of other Indian and world rivers in Table 4.5. Table 4.6 and Table 4.7 show correlation co-efficient of bed and suspended sediments.

Since the chemcial data on the source rocks is not available the sediment chemistry is compared with the average composition of surficial rock exposed to weathering.

Table 4.3 : Chemical composition of the Brahmaputra river bed sediments (June-July '89)

All values in $ug.gm^{-1}$

Loc.No	Si	Al	Fe	Ca	Mg	Na	K	P	Cu	Pb	Zn	Cr	Mn	Cd
1	350000	67000	35360	8651	2420	14370	6877	875	49	6	82	25	37	143
2	376000	71000	31700	7470	3140	16130	8624	890	45	8	79	28	32	152
3	394000	69000	35430	6450	4180	12220	7022	520	35	6	78	36	26	132
4	355000	75000	23400	7370	4960	17880	11160	460	32	12	72	13	24	94
5	350000	67000	35360	8430	7580	16580	10495	925	43	24	84	25	34	169
6	402000	83000	29190	6734	3520	13650	7826	750	30	11	77	45	28	135
7	340000	64000	43530	8180	8580	15920	6540	925	34	7	81	14	26	139
8	336000	55000	35880	8620	6520	19010	6647	870	35	22	87	100	27	74
9	365000	68000	28980	7490	8340	14930	8132	350	39	16	93	18	31	113
10	334000	62000	44660	7710	9720	15620	9340	940	44	20	78	11	27	78
11	340000	76000	52230	8260	9810	16130	8397	730	47	17	81	6	25	83
12	360000	65000	37510	8075	6140	16270	8096	800	44	16	84	13	23	79
13	365000	68000	32940	8190	6190	16460	8132	770	34	19	82	31	25	89

Table 4.4 Chemical composition of the Brahmaputra river suspended sediments (June-July '89)

All values in $ug.gm^{-1}$

Loc.No	Si	Al	Fe	Ca	Mg	Na	K	P	Cu	Pb	Zn	Cr	Mn	Cd
1	309000	62000	48430	5324	1970	15480	9941	1020	82	31	121	23	49	169
2	310000	68000	53810	842	2130	10730	15320	980	67	29	98	39	41	162
3	316000	68000	37980	1509	2050	13610	11354	960	49	18	79	56	31	94
4	312000	63000	46160	808	2710	10870	14940	1110	58	38	88	28	38	102
5	310000	43000	36330	1564	2340	14350	9476	1030	57	11	90	13	36	147
6	313000	66000	56830	1500	1980	14660	8473	1200	58	20	94	29	39	83
7	310000	67000	49000	1353	2620	12370	13670	1140	70	18	95	30	42	38

The elemental abundance and their relative mobility in the Brahmaputra basin are as follows.

Bed sediments:

Si>Al>Fe>Na>Ca>K>Mg>P>Zn>Cr>Mn>Cu>Pb>Cd

Suspended sediments:

Si>Al>Fe>Na>K>Ca>Mg>P>Zn>Mn>Pb>Cr>Cd

4.3.1 Variation in major elements :

Si and Al are the most abundant elements in the Brahmaputra river sediments. In the bed sediments Si and Al average to about 35.9% and 61.8% respectively whereas in suspended sediments the average value are 31.1% for Si and 6.7% for Al. They together constitute 85% of the total elemental concentration in bed sediments. In the bed sediment both Si & Al are higher in the upstream and show a decreasing trend downstream (Fig.4.9 and 4.10). This clearly indicates that due to high discharge, physical weathering is more dominant in the upstream and consequently the crystalline rocks after being weathered release more quartz and feldspar load, in the downstream due to attrition and the fine nature of the suspended load, (discussed in detail in the mineralogy chapter), fine alluminium silicates (clay) dominate over the detrital products. However, even than the Si and Al are far in excess than any other element. In the suspended sediment there is no significant variation downstream, their concentration(Table 4.4 and Fig 4.11)

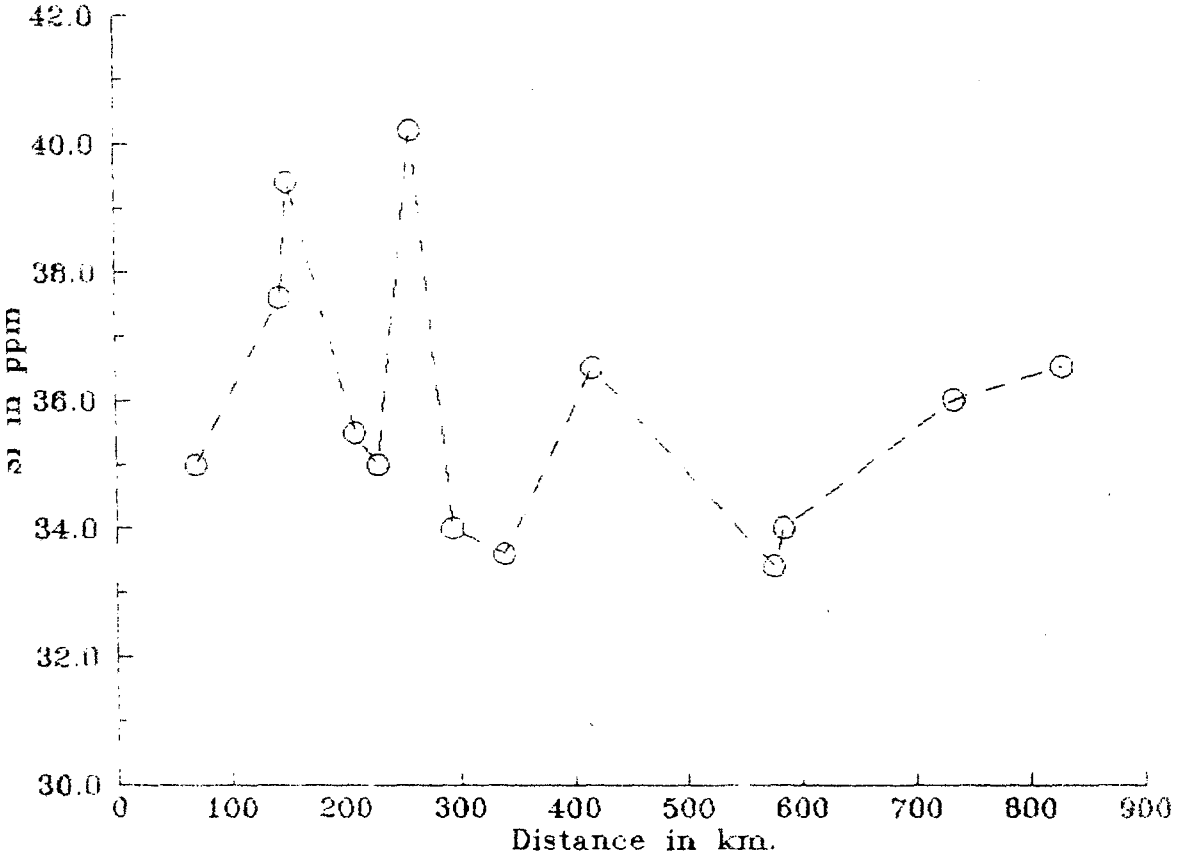


Fig.4.9 Downstream variation of Si in bed sediments of the Brahmaputra river (July '89)

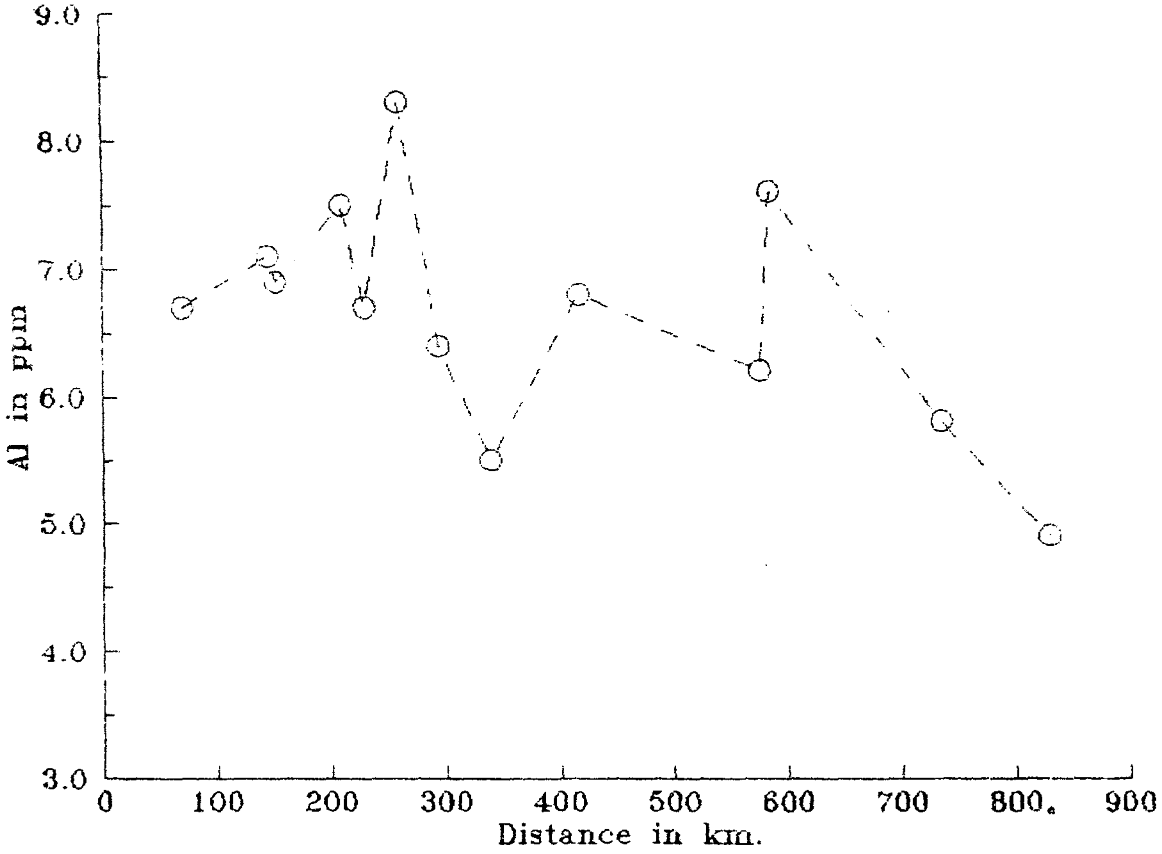


Fig4.10 Downstream variation of Al in bed sediments of the Brahmaputra river (July '89)

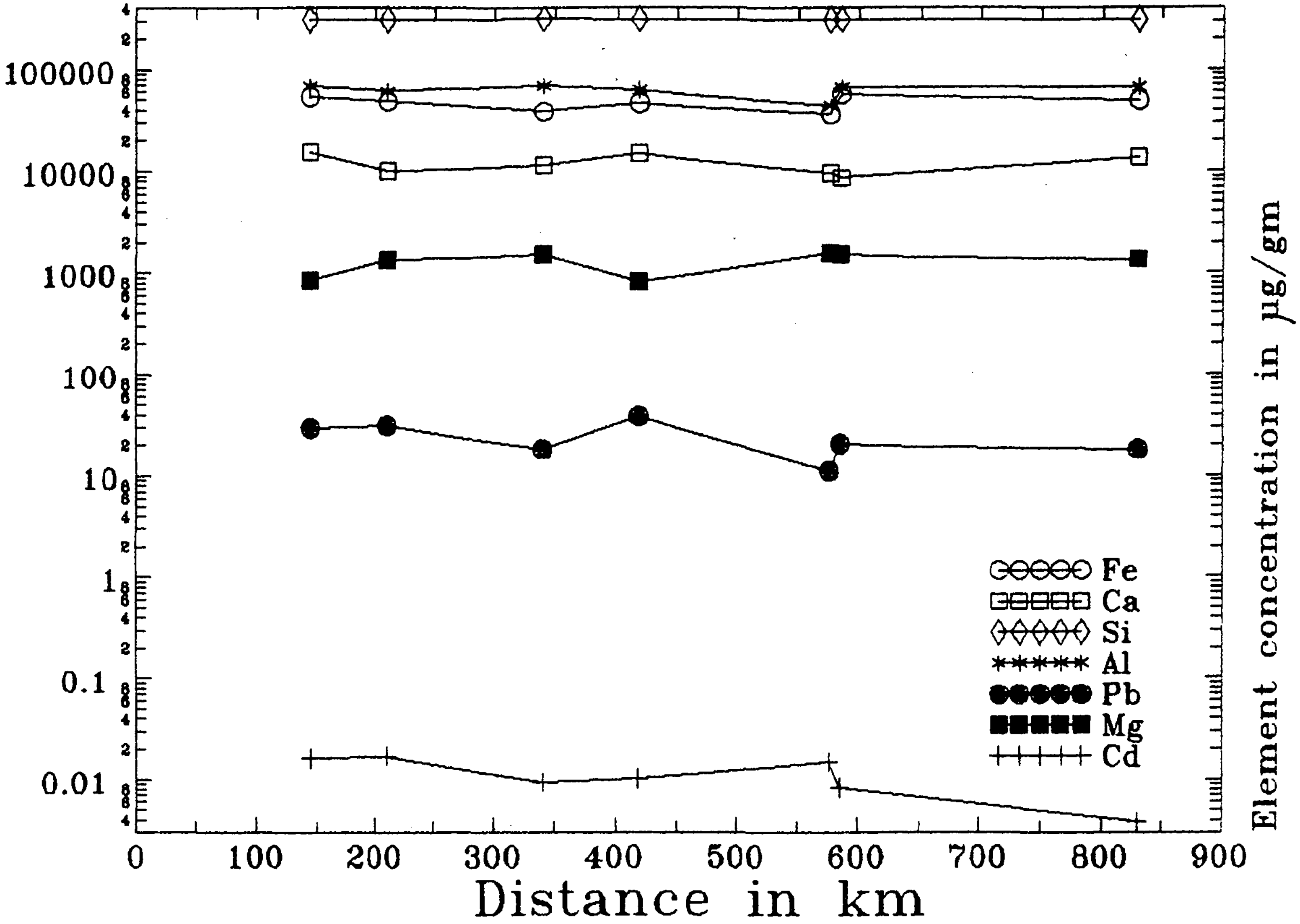


Fig.4.11 Downstream variation in major element concentration in the ~~bed~~ susp. sediments of the Brahmaputra river

being almost consistent throughout the basin. The consistency of Si and Al in the suspended sediments can be explained by the uniform distribution of fine silt and clay all throughout the basin.

Ca, Mg, Na and K together contribute 7% of the total elements in the bed sediments out of which Na is more dominant followed by the other three. This is due to the higher chemical mobility of Na in the basin. In the suspended sediment too, a similar trend of enrichment is observed while Na is uniformly high throughout the basin, K shows an increasing trend downstream indicating enrichment of clay minerals (illite) downstream (Fig.4.12). Poor correlation (Table 4.6) between Na and K also suggests difference in mobility. Distribution of Ca is erratic in the basin but Mg shows a distinct increasing trend downstream (Fig.4.13 & 4.14). Increase of Mg is indicative of enrichment of Mg-chlorite downstream in the bed sediments compared to Ca. So the correlation is poor between Mg and Ca (Table 4.6). In the suspended sediments Ca and Mg shows good correlation (+0.6, Table 4.7). So their mobility and source in particular should be similar compared to the bed sediments. Na and K in suspended sediments show strong negative correlation indicating the selective absorption of K_+ in the clay minerals.

Table 4.6 Correlation matrix for the bed sediments of the Brahmaputra river basin

Element	Si	Fe	Al	Ca	Mg	Na	K	Cu	Pb	Zn	Cr	Mn	Cd	P
Si	--													
Fe	-.54	--												
Al	.61	-.25	--											
Ca	-.80	.40	-.55	--										
Mg	-.64	.63	-.31	.32	--									
Na	-.66	-.01	-.41	.62	.31	--								
K	-.10	-.28	.30	-.10	.16	.32	--							
Cu	-.40	.49	-.18	.47	.13	-.02	.07	--						
Pb	-.46	.17	-.35	.44	.60	.58	.40	.08	--					
Zn	-.22	.08	-.49	.42	.33	.12	-.36	.23	.40	--				
Cr	.07	-.20	-.36	.11	-.31	.28	-.41	-.37	.20	.20	--			
Mn	.02	-.18	-.04	.23	-.33	-.22	-.03	.47	-.13	.30	.04	--		
Cd	.38	-.24	-.27	-.17	-.42	-.43	-.01	.07	-.44	-.06	-.10	.71	--	
P	-.55	.60	-.31	.60	.67	.10	-.11	.38	.50	.50	-.27	-.09	-.17	

Table 4.7 Correlation matrix for the suspended sediments of the Brahmaputra river basin

Element	Si	Fe	Al	Ca	Mg	Na	K	Cu	Zn	Pb	Cr	Mn	Cd
Si	--												
Fe	-.24	--											
Al	.35	.59	--										
Ca	-.03	-.18	-.45	--									
Mg	.10	.15	-.32	.59	--								
Na	.02	-.18	-.35	.86	.25	--							
K	-.13	.15	.42	-.88	-.49	-.95	--						
Cu	-.81	.43	.11	-.01	-.39	.16	.07	--					
Zn	-.70	.40	.01	.24	-.17	.46	-.27	.92	--				
Pb	-.17	.41	.42	-.79	-.72	-.45	.54	.37	.18	--			
Cr	.73	-.02	.73	-.34	-.21	-.29	.31	-.40	-.40	.05	--		
Mn	-.79	.55	.11	.01	-.33	.18	.31	.98	.91	.50	-.47	--	
Cd	-.42	-.10	-.38	-.17	-.16	.15	-.10	.32	.48	.27	.25	.31	--

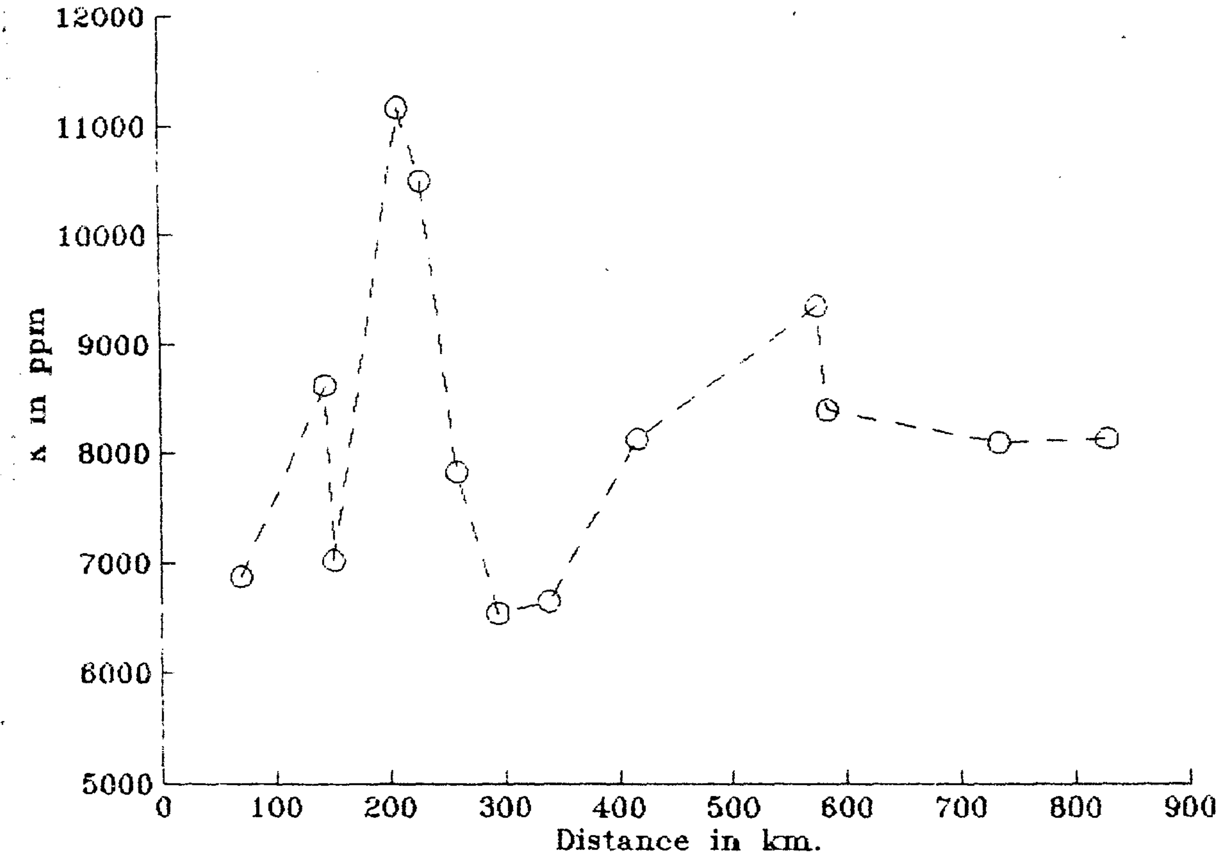


Fig.4.12 Downstream variation of K in bed sediments of the Brahmaputra river (July '89)

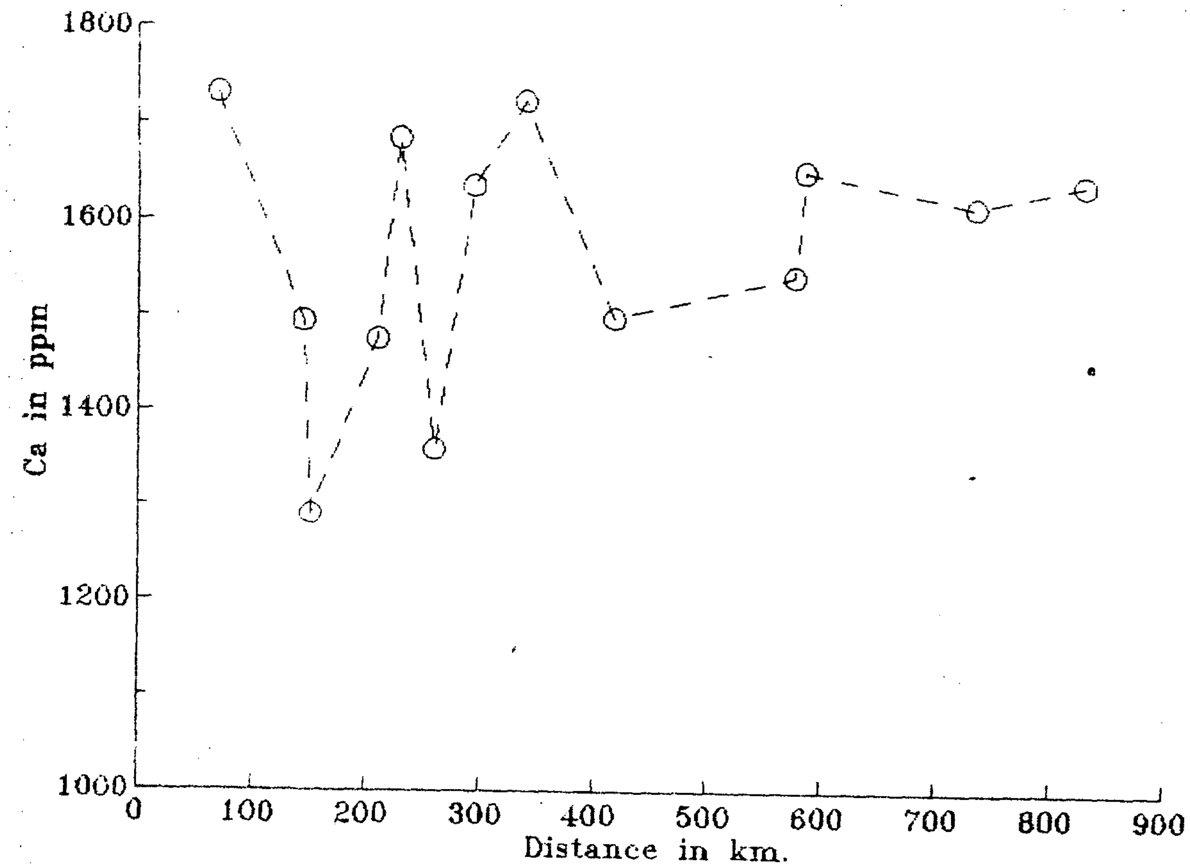


Fig.4.13 Downstream variation of Ca in bed sediments of the Brahmaputra river (July '89)

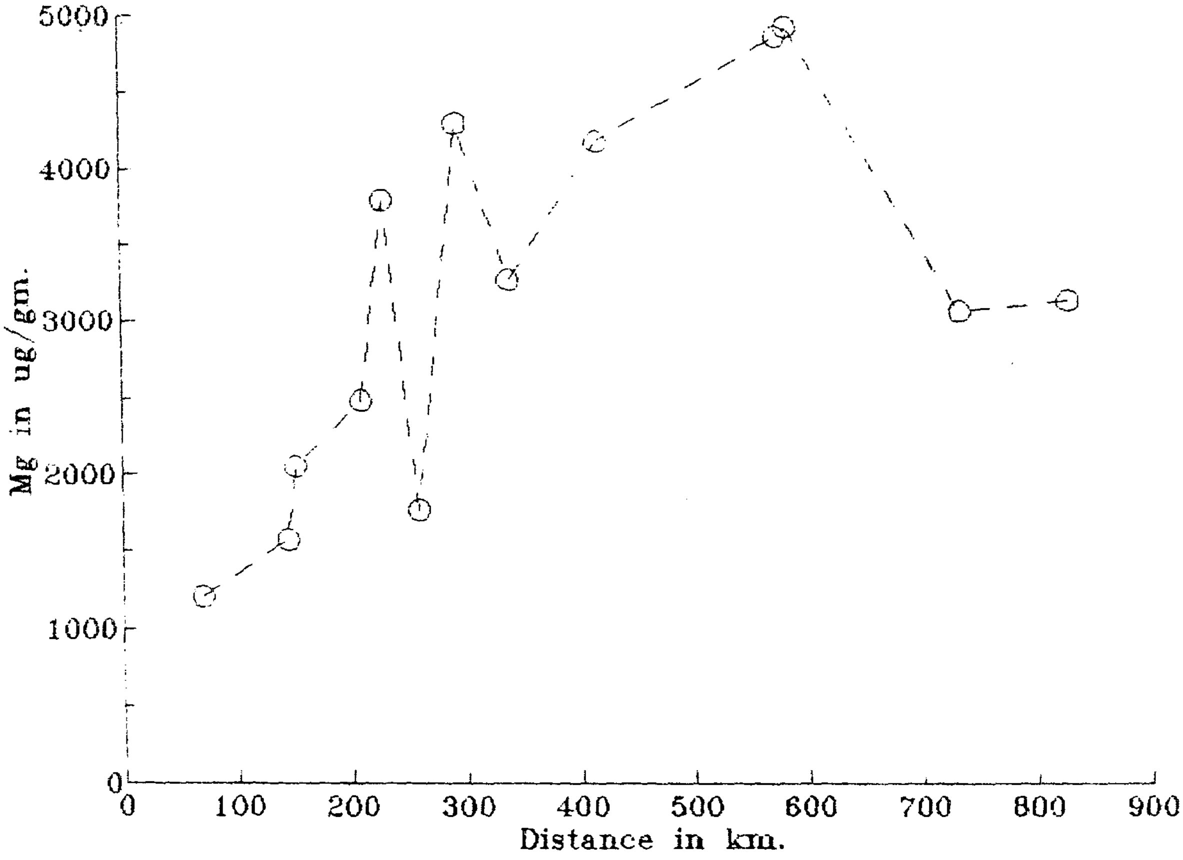


Fig. 4.14 Downstream variation of Mg in bed sediments of the Brahmaputra river (July '89)

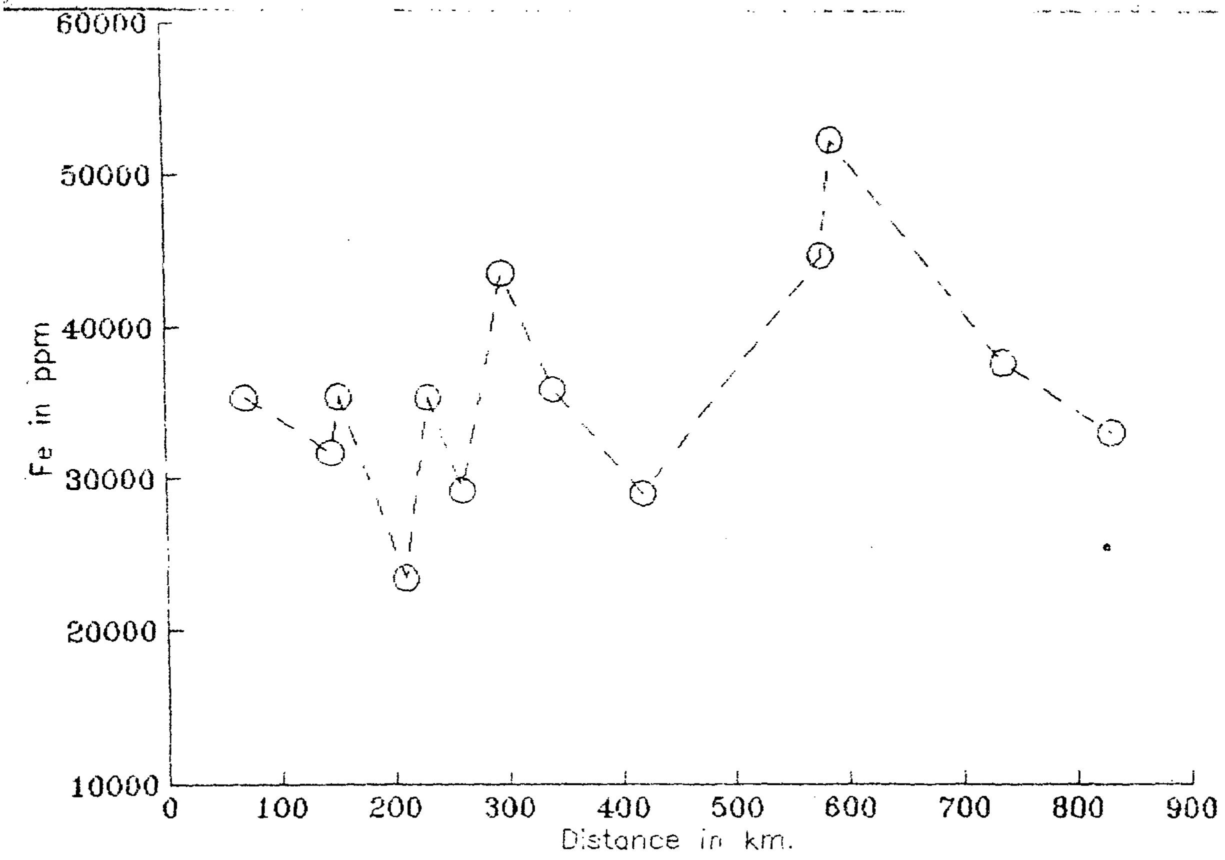


Fig. 4.15 Downstream variation of Fe in bed sediments of the Brahmaputra river (July '89).

Table 4.5 Brahmaputra river sediment chemistry (Si to Mg in %,others in ug/gm)-comparision with other Indian rivers.

Elem-ents	Gan. (N=35)	Bra. (N=20)	Goda. (N=23)	Kri. (N=19)	Cau. (N=21)	Maha. (N=19)	Nar. (N=3)	Tap. (N=3)	Indian average	Bay of Bengal
Si	31.2	31.6	27.0	26.3	34.6	11.9	30.2	32.5	24.5	--
Al	4.66	6.30	4.78	3.38	4.87	6.22	2.89	4.44	5.0	7.60
Fe	2.16	4.60	6.03	4.23	1.76	5.64	3.14	1.09	2.90	3.90
Ca	2.34	1.20	3.81	5.34	1.50	1.36	2.01	8.16	2.46	1.98
Mg	1.32	0.60	1.15	1.30	1.10	0.93	1.02	1.15	1.47	1.43
Cu	21.0	60.60	73.00	49.0	12.0	57.0	56.0	126.0	28.0	26.0
Mn	400.0	382.6	1060.0	1040.0	319.0	2020.0	514.0	1300.0	605.0	529.0
Zn	46.0	93.6	53.0	31.0	26.0	125.0	50.0	118.0	16.0	--
Pb	25.0	23.0	13.0	9.0	10.0	60.0	5.0	5.0	--	--
Cr	52.0	30.7	126.0	68.0	129.0	15.0	--	---	87.0	84.0

--.data not available ; Gan.- Ganges ; Brah.-Brahmaputra; Goda.-Godavari ; Kri.-Krishna ;Cau.- Cauvery; Maha. - Mahanadi river, Nar.-Narmada; Tap.- Tapti . Data- Mahanadai(Chakrapani and Subramanian, 1990), Krishna(Ramesh and Subramanian, 1988), Godavari(Biksham and Subramanian,1988), Brahmaputra-Present work, Remaining from Subramanian et al., 1985.

The particulate P represents 95% of P naturally carried by rivers of which 40% is in organic form (Meybeck, 1982). Total particulate P in the sediments is very widely studied. Subramaian (1984) reported that in Indian river sediments 'P' ranges from 700 to 1200 ug/gm. In Brahmaputra the average value of 'P' in bed sediment is 754 ug/ml, and in suspended particles it is 1063 ug/gm. Due to their fine grain nature relatively more organic contents, suspended sediments are more enriched in 'P' (Vaithyanathan et al., 1989). It shows good correlation with Ca and Fe (Table 4.7) indicating its derivation from minerals like apatite and its affinity with Fe-P phase.

Heavy metals: Suspended sediments are more enriched in heavy metals compared to bed sediments(Table 4.3 & 4.4). The enrichment factor (suspended/bed) varies as follows:

Fe - 1.31,Cu -1.62,Pb -2, Zn -1.17, Cr -1.11, Mn -1.41,
Cd -1.008.

The reason that suspended sediments are more enriched in such metals is their fine nature, higher clay content (see texture and mineralogy chapter) organic content and Fe-Mn coating (Subramanian et al., 1987).

Among the heavy metals, Fe and Mn are more abundant than others in the Brahmaputra sediments. Distribution of Fe is almost consistent throughout the basin (Fig.4.15 and Table 4.3 & 4.4); but in bed sediments it shows a general increase towards downstream. Mn on the other hand shows a depleting trend (Fig. 4.16). While Cu and Cr also have a decreasing tendency downstream, Zn, Cd and Pb are observed to attain higher concentration in bed sediments downstream (Fig.4.17-4.21 and Table 4.8). This clearly reflects the detrital origin of Fe, Cu, and Cr whereas concentration of Zn, Cd and Pb appear to have been influenced by factors other than the source rock weathering which may include significant anthropogenic activities. However, contribution from anthropogenic sources may be there for other elements too. The sudden rise in concentration of certain elements like Fe, Cu, Zn and Al after crossing the city of Guwahati (Fig. 4.15-4.19 & Table 4.10), between 585 km to 600 km) can be explained in terms of anthropogenic input from the urban community. Sampling were done at a point where Brahmaputra enters the urban area and at Pandu where the river leaves the city. At the same time, however, metals like Mn, Cr, Pb show a drop in concentration after crossing the urban settlements.

Correlation co-efficient for heavy metals are fairly good in the suspended sediments but in bed sediments it is poor(Table 4.6 & 4.7). This is mainly because of the more homogeneous nature of the suspendeds than the bed. So size control is less in the suspended sediments. This can be confirmed only after a detailed study of size density in both bed and suspended sediments.

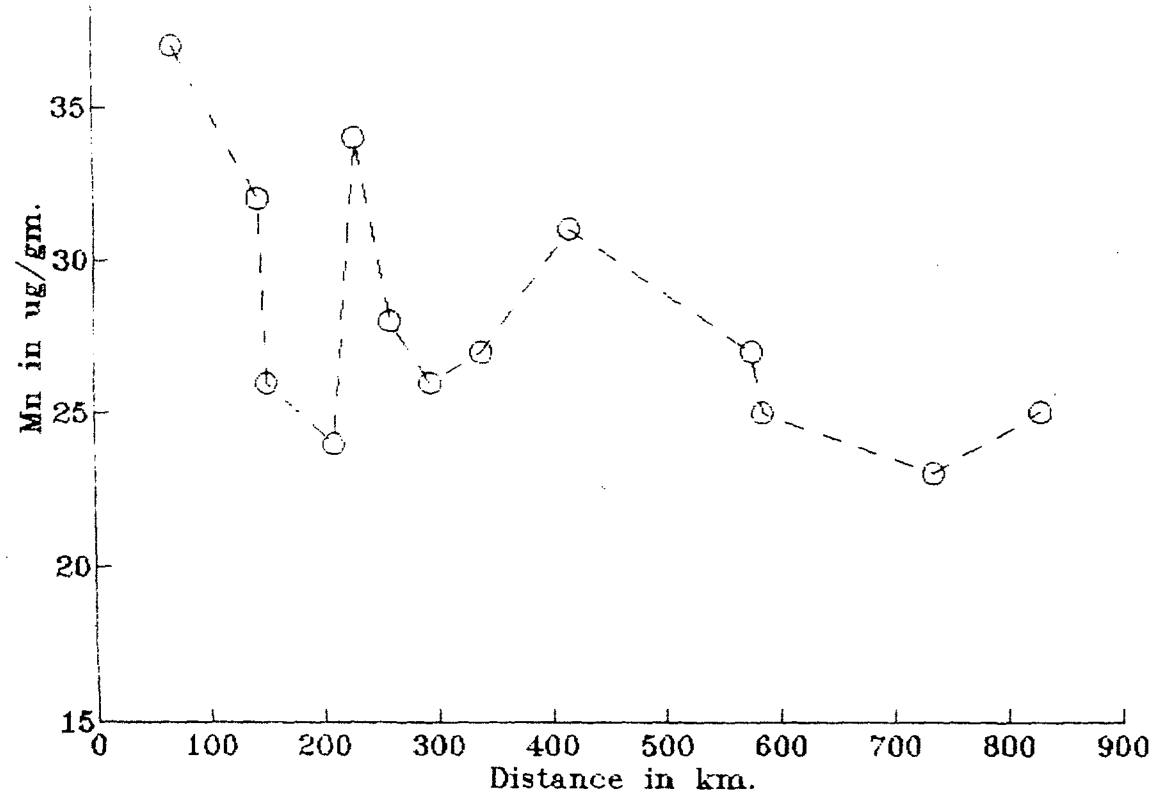


Fig.4.16 Downstream variation of Mn in bed sediments of the Brahmaputra river (July '89)

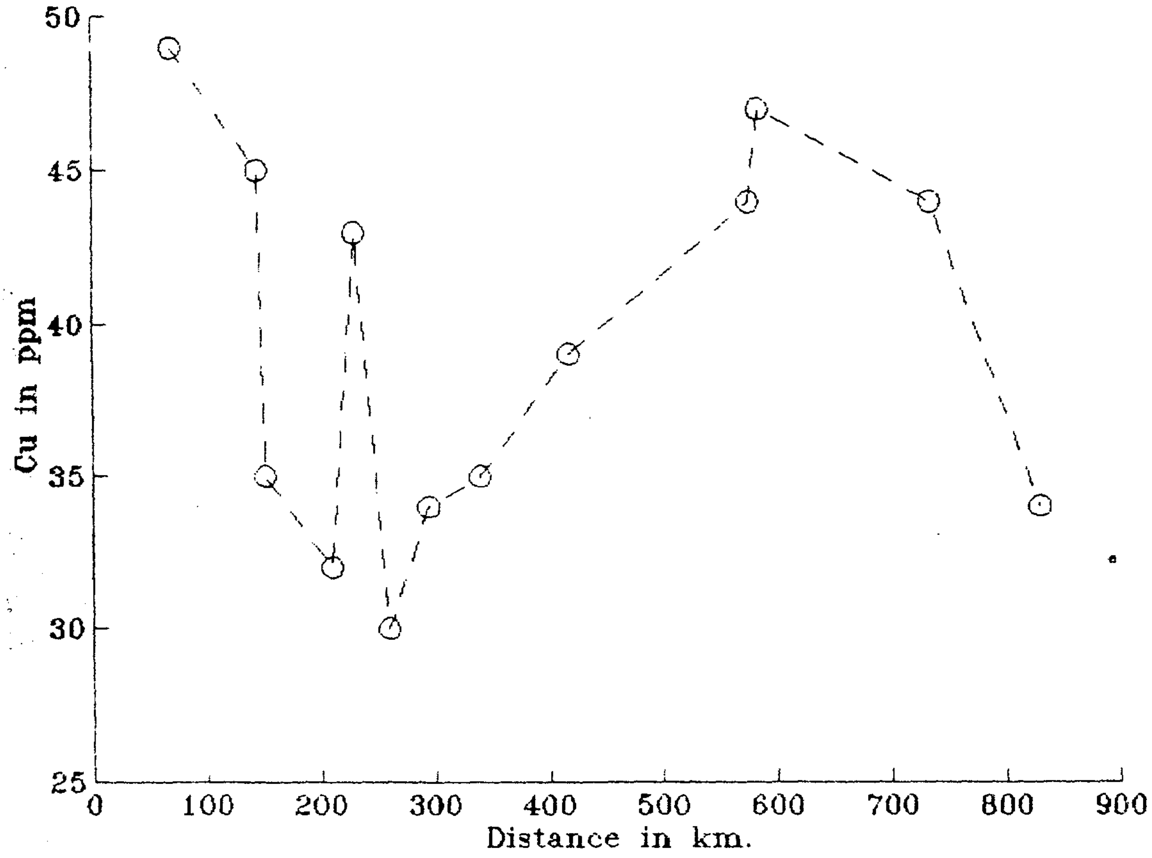


Fig4.17 Downstream variation of Cu in bed sediments of the Brahmaputra river (July '89)

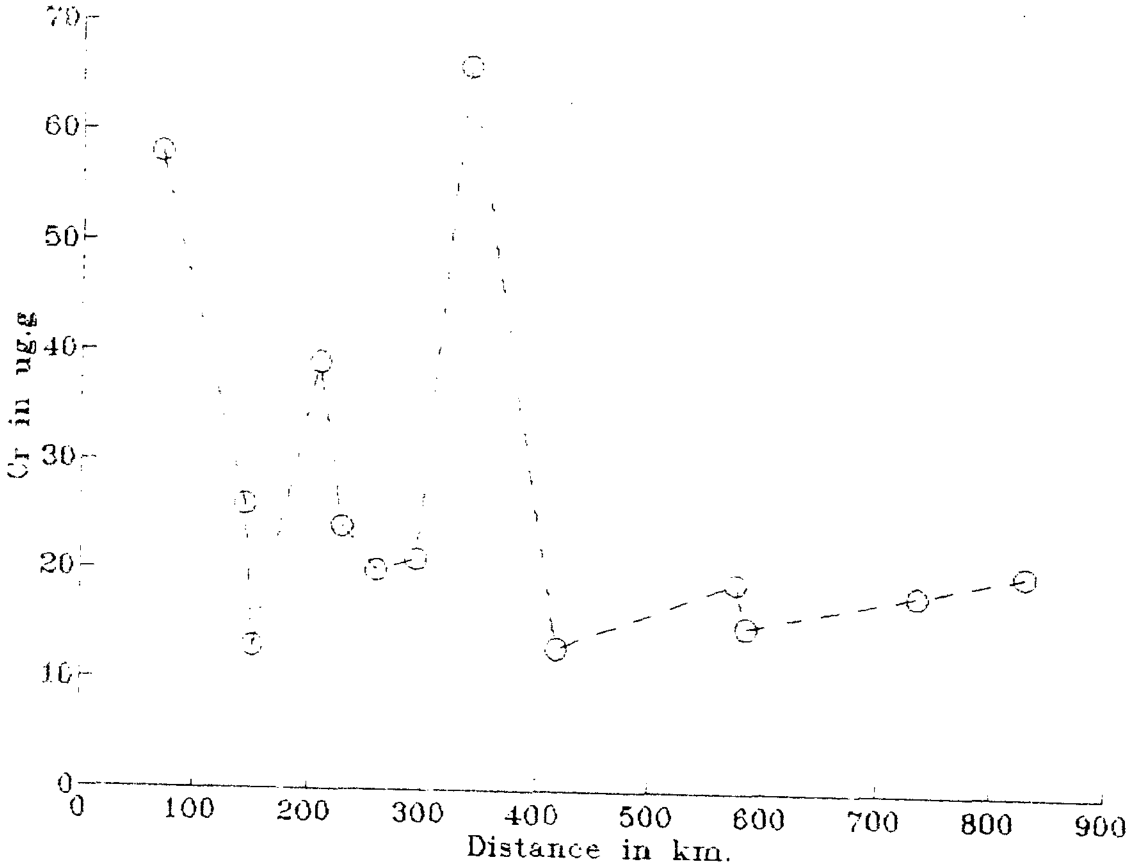


Fig.4.18 Downstream variation of Cr in bed sediments of the Brahmaputra river (July '89)

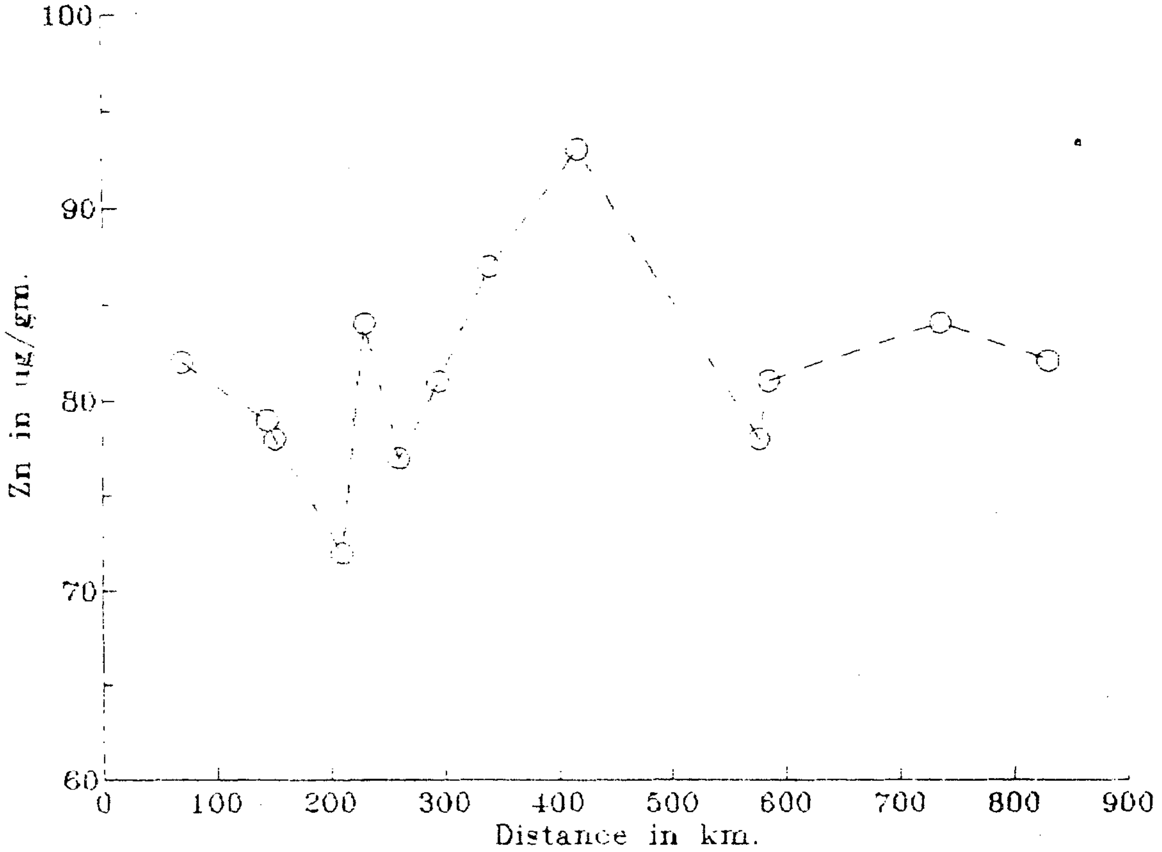


Fig. 4.19 Downstream variation of Zn in bed sediments of the Brahmaputra river (July '89)

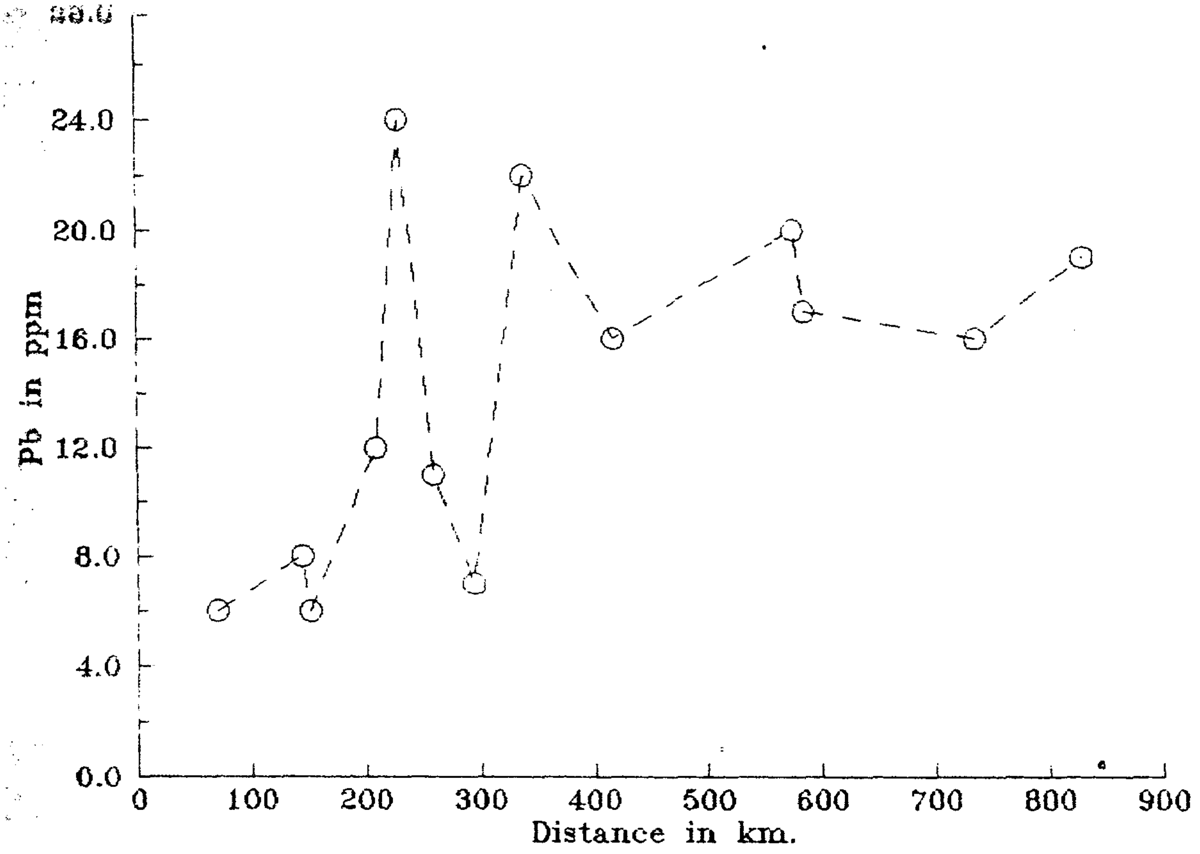


Fig4.20 Downstream variation of Pb in bed sediments of the Brahmaputra river (July '89)

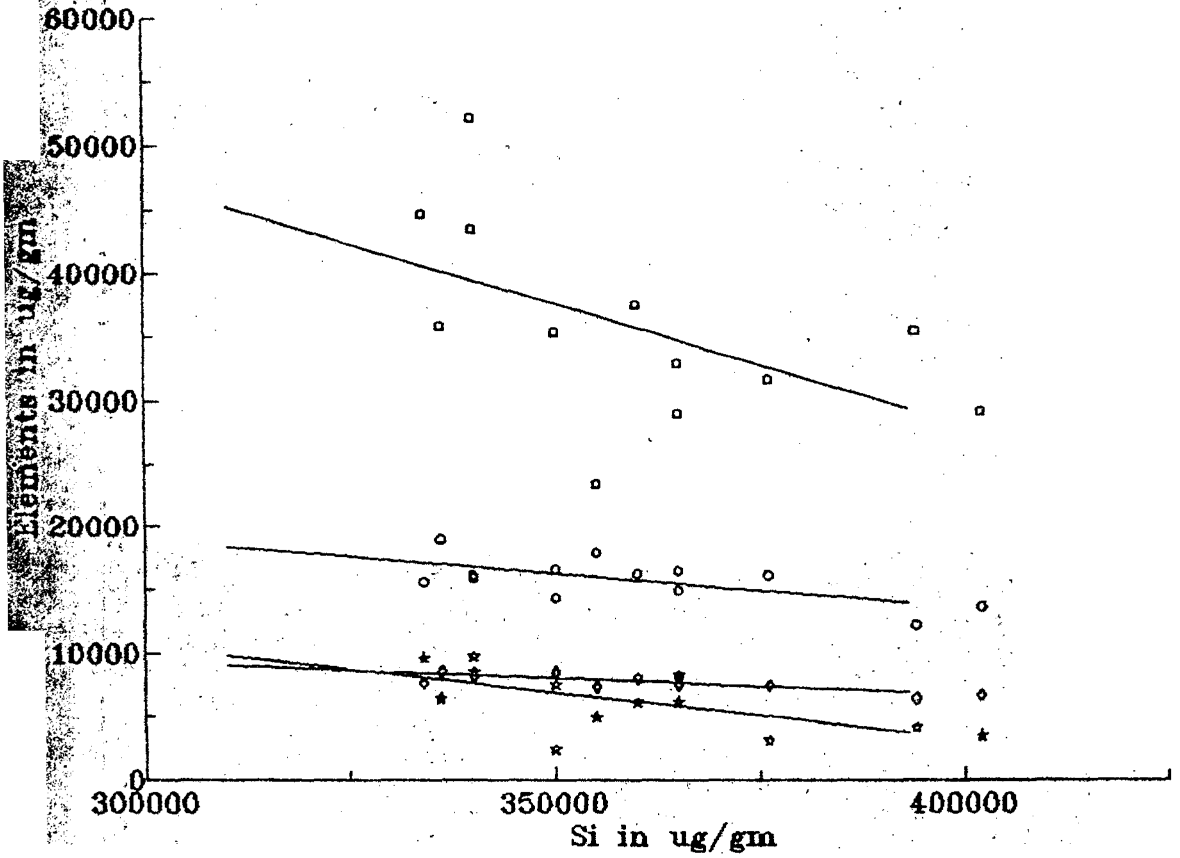


Fig.4.21 Plot of Si vs. Fe,Mg,Ca,Na for sediments of the Brahmaputra (July

Table 4.7 and Fig. 4.22 show negative correlation trend between Si and Fe, Mg Ca and Na indicting the enrichment of fine silt and clay by these elements over the detritals in the river sands. Hence the detrital contribution is restricted to Si and Mn.

Table 4.8 and Fig. 4.23 A & B show the downstream variation in element/Al ratio which expres the relative mobility of the elements. Si/Al and Fe/Al are almost consistent throughout the basin whereas (Cu,Pb,Zn,Mn)/Al ratios show an increasing variation downstream. Once again, it indicates more enrichment of fine silts and clay fraction by these metals which suggest control of size distribution of the suspended particles over the concentration of heavy metals. Moreover, these four metals in particular use to have significant contribution from anthropogenic sources (Forstner and Wittman, 1973; Subramanian et al., 1987).

Based on individual elemental concentrations in bed and suspended sediment, the average composition ofBrahmaputra sediments is calculated, taking 90% of the suspension and 10% of the bed sediment composition. These results alongwith the average composition of sediments in rivers flowing into the Bay of Bengal are presented in Table 4.5.

Table 4.8 Metal/Aluminium ratio of the bed sediments

	Cu/Al	Si/Al	Pb/Al	Fe/Al	Cr/Al	Mn/Al	Zn/Al
1	0.00073	5.22	0.00009	0.53	0.00037	0.00055	0.0011
2	0.00063	5.30	0.00011	0.44	0.00039	0.00045	0.0011
3	0.00051	5.71	0.00009	0.51	0.00052	0.00038	0.0010
4	0.00043	4.73	0.00016	0.31	0.00017	0.00032	0.0013
5	0.00064	5.22	0.00036	0.53	0.00037	0.00050	0.0009
6	0.00036	4.84	0.00013	0.35	0.00054	0.00034	0.0013
7	0.00053	5.31	0.00011	0.68	0.00021	0.00041	0.0016
8	0.00064	6.11	0.00040	0.65	0.00156	0.00049	0.0014
9	0.00057	5.37	0.00024	0.43	0.00012	0.00046	0.0013
10	0.00071	5.39	0.00032	0.72	0.00018	0.00044	0.0013
11	0.00062	4.47	0.00022	0.69	0.00008	0.00033	0.0011
12	0.00067	5.54	0.00025	0.58	0.00020	0.00035	0.0013
13	0.00050	5.37	0.00028	0.48	0.00046	0.00037	0.0012

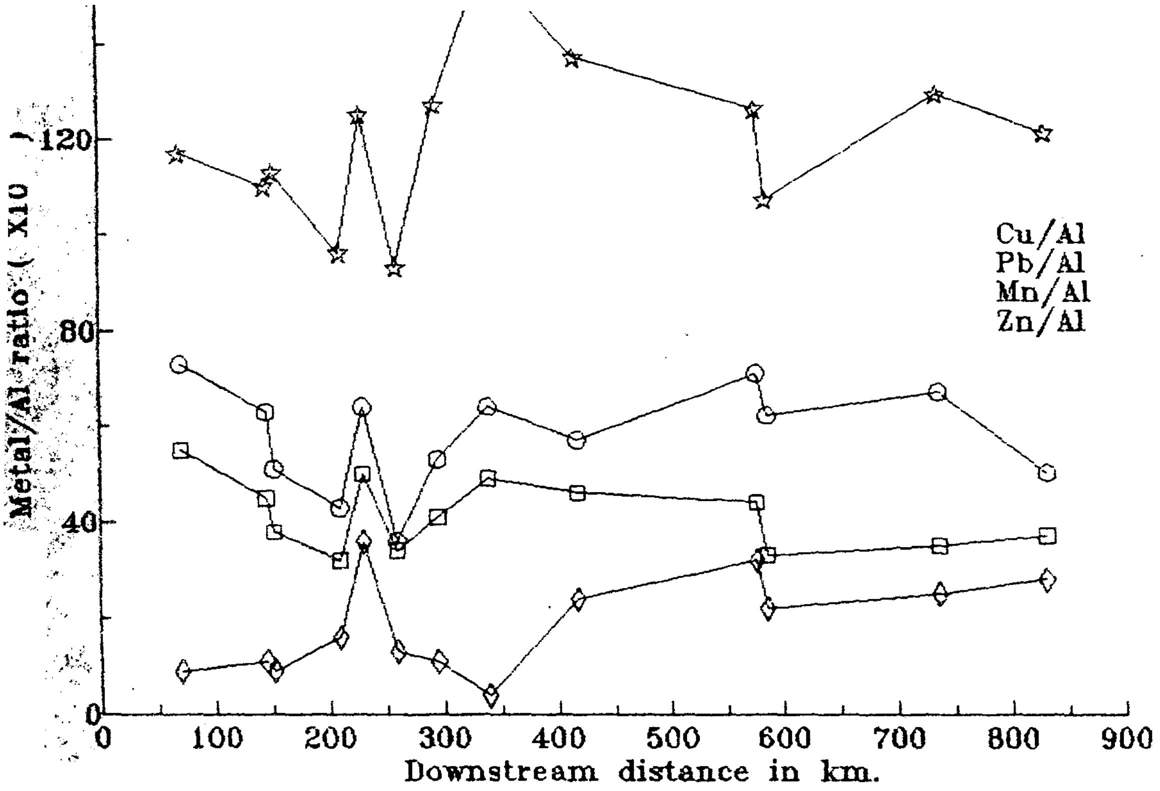


Fig.4.22 Downstream variation of metal/Al ratios of bed sediments in the Brahmaputra river basin

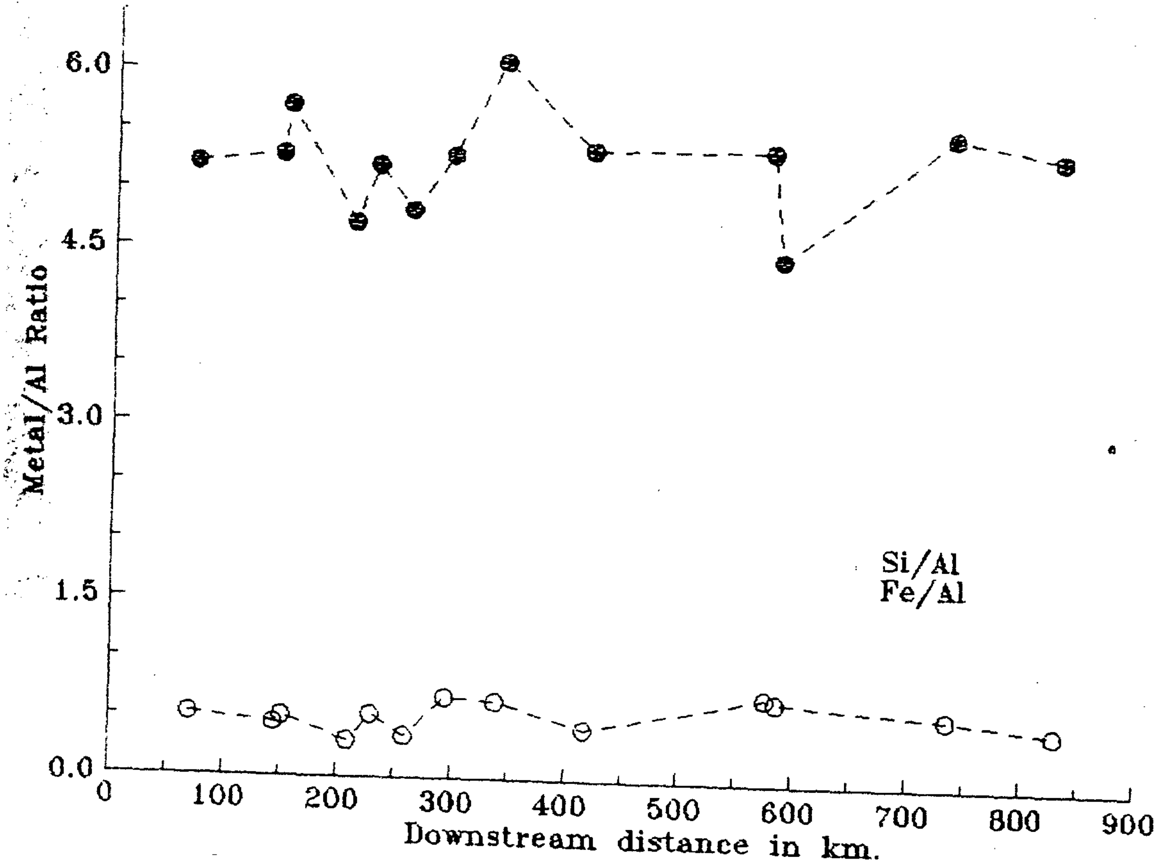


Fig.4.22B Downstream variation of metal/Al ratios of bed sediments in Brahmaputra river basin

4.4 Physical and Mineralogical Characteristics of Suspended Sediments

4.4.1 Grain size distribution:

Grain size study is a fundamental descriptive measure of sediments and the sedimentary rocks. Its major importance lies in understanding the mechanisms operative during transportation and deposition as well as to have an idea of the distance for which transportation takes place. Several approaches have been adopted to interpret depositional environment from grain size distribution, such as plotting skewness versus sorting (Friedman, 1961); comparing coarsest fraction to the medium size (Passegya, 1964); and analysing cumulative curve shape (Visher, 1069); Middleton (1976) and Sagoe and Vishner (1977), examined the relationship between grain-size distribution and hydraulics.

In the present work, the characteristics of the grain-size distribution of the suspended sediments in the Brahmaputra river have been studied and their different statistical parameters were determined by the method of moments. The formulae and the verbal scales are after Folk and Ward (1957). Table 4.9 give the size distribution of suspended sedimetns in percentage for 11 locations and in tabel 4.10 , the statistical parameters for these suspended sediments are given.

TABLE 4.9 GRAIN SIZE DISTRIBUTION OF SUSPENDED SEDIMENTS (IN PERCENT)

Sizeclass(micron)			Freq.(%)										
Low	Average	High	Pasighat	Saikhowa	Tezu	Dibru garh	Badati ghat	Nimati ghat	Tezpur	Gauhati	Pandu	Goal para	Dhubri
0.35	0.41	0.44	0.5	0.0	0.0	0.0	0.4	0.0	2.8	0.9	1.5	3.2	2.9
0.44	0.47	0.50	0.2	0.2	0.2	0.3	0.3	0.6	0.3	0.3	0.3	0.4	0.4
0.50	0.54	0.57	0.2	0.5	0.2	0.3	0.3	0.5	0.3	0.4	0.4	0.5	0.4
0.57	0.61	0.66	0.2	0.3	0.1	0.2	0.3	0.4	0.5	0.4	0.4	0.6	0.4
0.66	0.70	0.75	0.4	0.6	0.4	0.6	0.6	0.8	1.2	0.7	0.8	1.3	1.0
0.75	0.81	0.87	0.5	0.6	0.3	0.5	0.7	0.8	1.4	0.8	0.9	1.7	1.3
0.87	0.92	0.99	0.3	0.4	0.2	0.3	0.4	0.5	0.9	0.6	0.6	1.2	0.9
0.99	1.06	1.14	0.2	0.3	0.1	0.2	0.2	0.4	0.7	0.4	0.5	0.9	0.7
1.14	1.21	1.30	0.3	0.4	0.2	0.3	0.4	0.6	1.2	0.6	0.7	1.4	1.1
1.30	1.39	1.49	0.7	0.9	0.5	0.8	0.9	1.2	2.7	1.4	1.6	3.2	2.5
1.49	1.60	1.71	1.4	1.9	1.1	1.9	1.9	2.5	5.4	2.9	3.3	6.1	5.1
1.71	1.83	1.96	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
1.96	2.10	2.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.25	2.40	2.58	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
2.58	2.76	2.96	1.8	2.7	1.2	2.4	2.6	3.6	7.2	3.8	4.1	8.2	6.4
2.96	3.16	3.39	1.6	2.4	1.3	2.4	2.5	3.2	5.9	3.4	3.4	6.6	5.8
3.39	3.62	3.88	1.5	2.2	1.5	2.3	2.1	2.8	4.8	3.0	3.0	5.2	4.6
3.88	4.15	4.45	0.8	1.6	0.7	1.5	1.4	1.9	4.0	2.1	2.3	4.7	3.4
4.45	4.75	5.10	0.9	1.9	0.7	1.8	1.8	2.2	4.4	2.2	2.5	5.6	3.7
5.10	5.44	5.83	1.6	2.1	1.1	2.5	2.6	3.4	5.4	3.0	3.1	5.8	5.1
5.83	6.22	6.68	1.1	1.5	0.8	2.0	2.7	3.9	6.2	3.4	3.3	5.5	6.4
6.68	7.14	7.67	2.2	3.0	2.8	3.2	4.1	4.3	5.7	4.1	3.8	5.1	5.6
7.67	8.20	8.82	0.7	1.9	0.6	2.2	2.7	2.5	5.9	2.8	2.9	5.9	4.9
8.82	9.45	10.20	0.2	0.7	0.1	0.8	1.4	1.5	6.8	1.7	2.2	7.2	4.9
10.20	10.95	11.89	0.7	2.0	0.3	1.8	2.8	3.6	8.8	3.5	4.3	8.0	7.2
11.89	12.82	13.96	13.6	10.4	9.5	13.4	17.4	17.9	16.6	14.0	14.5	11.0	19.5
13.96	15.11	16.63	0.1	0.0	0.0	0.1	0.5	0.4	0.7	0.2	0.3	0.3	0.9
16.63	18.15	20.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.18	22.22	25.33	0.3	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.1
25.33	28.44	33.86	68.1	61.2	75.9	57.9	49.0	40.2	0.0	42.9	39.2	0.1	4.7
33.86	39.28	50.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.10 Statistical parameters of suspended sediments

(units in phi)

Sample No	Mean	Stand. Dev.	Skewness	Kurtosis
1.	5.91	1.10	0.74	1.47
2.	6.33	1.31	0.85	2.44
3.	5.83	0.83	0.73	4.37
4.	6.20	1.19	0.75	0.94
7.	6.63	1.28	0.17	0.98
8.	6.67	1.38	0.26	0.84
9.	7.70	1.10	0.32	0.68
10.	6.73	1.43	0.26	0.80
11.	6.77	1.41	0.25	0.75
12.	7.93	1.21	0.20	0.80
13.	7.77	1.27	0.30	0.82

4.4.1.1. Mean size (Mz):

The suspended sediments range from coarse silt to fine clay size particles (0.3 to 34 microns). Average mean size of the sediments is 9 micron i.e. medium silt. The gradual decrease in grain size downstream is obvious especially with the coarser silt fraction in the 25 to 34 micron range(Table 4.9).

4.4.1.2 Standard Deviation:

Standard deviation measures the sorting or the uniformity of the particle size distribution. This reflects the consistency in the energy level of the depositing medium. The suspended sediments of Brahmaputra are moderately to poorly sorted (phi = 0.83 to 1.43). This suggests that the suspended sediments are not very uniform in size distribution.

4.4.1.3 Skewness:

Skewness is a measure of the asymmetry of distribution. If there is more material in the coarse tail (coarse skewed), the skewness is referred to as being negative. If there is more material in the fine tail (fine skewed), it is positive. Skewness is useful in identifying sedimentary environments where primary sedimentary structures are lacking. A number of authors (e.g. Awasthi, 1970; Cronan, 1972; Folk and Ward, 1957; Friedman, 1967; Martin, 1965, Sahu, 1964; Valia and Cameroon, 1977) have emphasised the importance of skewness as an indicator of Palaeo-environment. The average skewness of the suspended sediments of the Brahmaputra varies from positively skewed to very positively skewed, i.e. very fine skewed (0 = 0.17 to 0.85). This indicates the presence of more finer materials in the distribution.

4.4.1.4 Kurtosis (K^G)

Kurtosis measures the ratio between the sorting in the "tail" of the distribution and sorting in the central part of the distribution. If the central part is better sorted than the tails, the distribution is said to be excessively peaked or Leptokurtic. If the tails are better sorted than the central portion, the distribution is said to be flat peaked on platykurtic. The suspended sediments of Brahmaputra range from extremely leptokurtic to platykurtic. While in the upstream at locations like Pasighat and Tezu it is very leptokurtic to extremely leptokurtic, as the suspended sediments are carried down to the basin the sediments become mesokurtic to platykurtic.

4.4.2 Mineralogy

There is practically no information on the distribution of clay and non-clay minerals in suspended sediments of the Brahmaputra river basin. In the present study, an attempt has been made to examine qualitatively and quantitatively the mineralogy of these sediments to have an understanding of the nature of sediment transport in the river and to ascertain whether the theoretically predicted mineral assemblages agree with the actually identified clay minerals or not. Table 4.11 gives the mineralogical composition of the suspended sediments of Brahmaputra. The semi-quantitative method (Biscaye, 1965; Carrol, 1970) was used to calculate the percentage of each mineral. Percentages of clay minerals have been given in Table 4.12.

The suspended sediments are dominated by detritals (quartz and feldspar) and clays (chlorite, kaolinite, illite). In all the samples illite is the common dominant clay mineral followed by chlorite. Ramesh (1985) reported chlorite to be the dominant clay mineral in the suspended sediments of Krishna river, Jha (1986) found illite to be the major clay mineral in Yamuna and Chakrapani's (1988) investigation of Mahanadi suspended sediments revealed illite-montmorillonite to be the mostly occuring clay mineral. The Himalayan rivers - Ganges, Gandak and Yamuna are characterised by the presence of large amounts of illite, equal quantities of kaolinite ($7A_o$) and chlorite (measured at 4.2 A_o), Biscaye (1965) and little or no mixed-layer clays and montmorillonite (Subramanian, 1980). Clay minerals are reliable indicator of the climate and soil

Table 4.11 Mineralogy of the suspended sediments(in%)

Sample No.	Quartz	Feldspar	Calcite	Dolomite	Chlorite	Kaolinite	Montmorillionite	Illite	Mica
1	41	39	--	4	--	2	--	14	--
2	43	29	--	--	--	8	--	5	7
3	42	27	8	1	6	8	--	9	--
4	53	37	tr	tr	--	1	--	8	1
5	63	14	1	3	--	2	2	15	--
6	53	13	1	tr	8	6	--	25	4
7	61	10	24	5	7	5	--	6	2
8	36	10	3	1	16	11	tr	17	7
9	44	19	3	2	9	6	--	10	--
10	33	15	1	2	15	15	--	11	2
11	42	18	1	tr	18	12	--	10	--
12	45	14	5	3	13	8	tr	8	5
13	32	10	3	2	20	13	tr	17	5

Table 4.12 Percentage of clay minerals in the supended sediments

Sample No.	Chlorite	Illite	Kaolinite	Montmorillionite
1	--	91	9	--
2	36	25	39	--
3	25	37	38	--
4	--	89	11	--
5	--	81	10	9
6	20	64	16	--
7	39	34	27	--
8	36	38	25	1
9	35	40	25	--
10	36	27	37	--
11	44	26	30	--
12	46	27	27	1
13	40	34	26	1

genesis processes. Chlorite and illite are inherited minerals, formed by the degradation of chlorite and mica of the source rock. Manickam et al., (1985) have shown for Loiré river, France that while kaolinite and illite show a positive correlation with discharge. Chlorite and montmorillonite have a weak negative relationship with river discharge.

There is considerable decrease of carbonates in the suspended sediments. Detrital contribution on the form of Quartz and Feldspar make up more than 80% of the suspended sediments upstream and than it shows a gradual decrease towards downstream. While at location 4 (Dibrugarh), Quartz and Feldspar together form about 88% of the minerals in the suspended sediments, the amount is reduced to as low as 42% at the utmost downstream location Dhubri. On the other hand, clay minerals show a downstream increasing trend ranging from 16% at Pasighat and 10% at Dibrugarh to about 53% at Dhubri. Chlorite and illite alongwith kaolinite form more than 95% of the clay minerals with almost equal contributions from all three. However, dominance of illite is more obvious in the upstream as can be seen from 89%, 81% and 64% illite content in the clay mineral composition of suspended sediments in Dibrugarh, Subansirimukh and Badatighat respectively.

Naidu et al., (1985) reported the presence of expandable clay minerals, illite and kaolinite in equal proportions for Mahanadi. This was attributed to the pre-dominance of Pre-Cambrian rocks in the drainage basin and weathering in a tropical humid climate. The bed loads of the Ganga and its tributaries are dominated by illite with smaller proportions of chlorite. The Narmada, Cauvery, Tapti, Krishna and Godavari bed loads are reported to be pre-dominated by expandable clay minerals with relatively minor amounts of illite, kaolinite and chlorite (Naidu et al., 1985). Raymahasay (1987) has studied the clay minerals as means of controlling pollution. He observed that montmorillonite is capable of removing larger amounts of cationic pollutants compared to kaolinite.

Pre-dominance of detrital minerals in Brahmaputra suspended sediments suggests the leading role played by physical weathering over chemcial weathering. The downstream decreasing trend in the amount of detritals (Quartz + Feldspar), and increase in clay mineral fraction is in close agreement with the grain size distribution (Table 4.9) which shows a fall in the amount of silt size grains and a rise in the clay size particles towards downstream. Kaolinite which is the immediate product of chemical weathering of silicate minerals is not dominant which also indicate relatively lesser input from chemical weathering. Chloride and illite must have been derived from the source rock as a direct product since it does not appear to be possible to form as a secondary altered product of kaolinite in a later stage of weathering. Near absence of montomorillonite in the suspended sediment also indicates lack of intense chemical weathering in the Brahmaputra basin.

The predicted mineral stability in the water-mineral equilibria diagrams in carbonate and silicate systems (Figs. 4 .8 A,B,C,D) totally agree with the suspended sediment mineralogy. Albite (Na. felspar) Ca-feldspar, chlorite, kaolinite are the predicted minerals which can be explained by the dominance of feldspars and clay minerals in the suspended sediments.

4.5. Chemical and Physical Erosion in the Brahmaputra

The Brahmaputra is the fifth large river in the world in terms of average discharge at mouth, with an annual flow of 6,25,350 cubic metre (Goswami, 1985). It is also one of the most sediment carrying rivers in the world next only to the Yellow river in China and Magdalena river of Colombia. At Pandu an average annual suspended load of 402 million tonnes has been reported dring the period 1955-1979.

The water discharge and especially the sediment transport by a Himalayan river like Brahmaputra is of very high magnitude compared to the peninsular rivers. Ganges and Brahmaputra together account for nearly 90% of the total sediment transfer from the Indian subcontinent. The basin area of the Himalayan system (60% area lying in the mountains) is less than that of Amazon (12% area lies in mountains), but their sediment contribution is nearly same as that of the Amazon. This speaks of the control of relief in dictating the environment in the drainage basin.

The annual average water discharge and sediment load data of the Brahmaputra and its major tributaries at different locations have been shown in Fig. 4.24. Monthly water discharge of the Brahmaputra at Pandu for the years from 1982 to 1988 and daily water discharge at the same location for the period of June-July 1989 is also presented in Fig. 4.25 and Fig. 4.26 respectively. As can be seen from Fig. 4.24, the sediment loads for both Brahmaputra and its tributaries are very closely related to the discharge. However, according to Goswami (1985) the peak of the sediment load precedes the discharge peak by one to several days which is generally attributable to the high concentration of relatively fine sediments. The total elemental fluxes in the sediments, carried by Brahmaputra have been calculated and compared with other major Indian rivers falling at the Bay of Bengal in Table 4.13.

Subramanian (1978) calculated that the Brahmaputra river basin is reducing at a rate of 45.1 mm/yr. Of the

Table 4.13 Elemental fluxes (in tonnes) by the Brahmaputra to the Bay of Bengal

	Bessamara	Bhurbandha	Pandu
1.Si	108070000	67392000	172670000
2.Al	23256000	13608000	23951000
3.Fe	12989160	9970560	20235810
4.Ca	5160780	1745280	8711480
5.Mg	7010100	585360	1303380
6.Na	4654620	2347920	7992950
7.K	3883668	3227040	5278132
8.Cu	16758	12528	31749
9.Pb	6156	8208	6127
10.Zn	27018	19008	50130
11.Cr	19152	6048	7241
12.Mn	106020	82080	200520
13.P	328320	239760	573710
Sediment transport ($10^6 t.yr^{-1}$)	342	216	557
Discharge ($10^{11} m^3.yr^{-1}$)	2.76	3.59	4.93

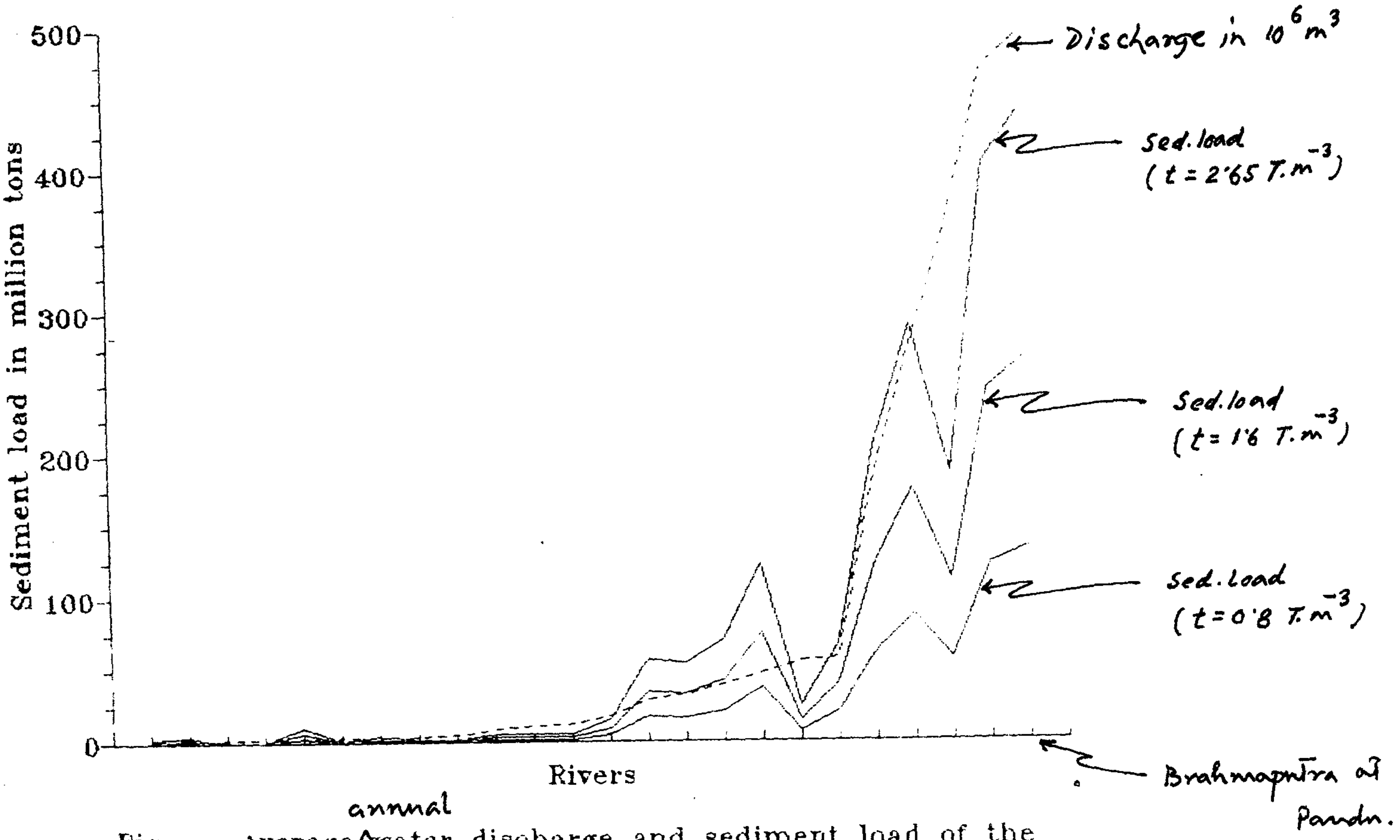


Fig. Average annual water discharge and sediment load of the Brahmaputra river and its major tributaries

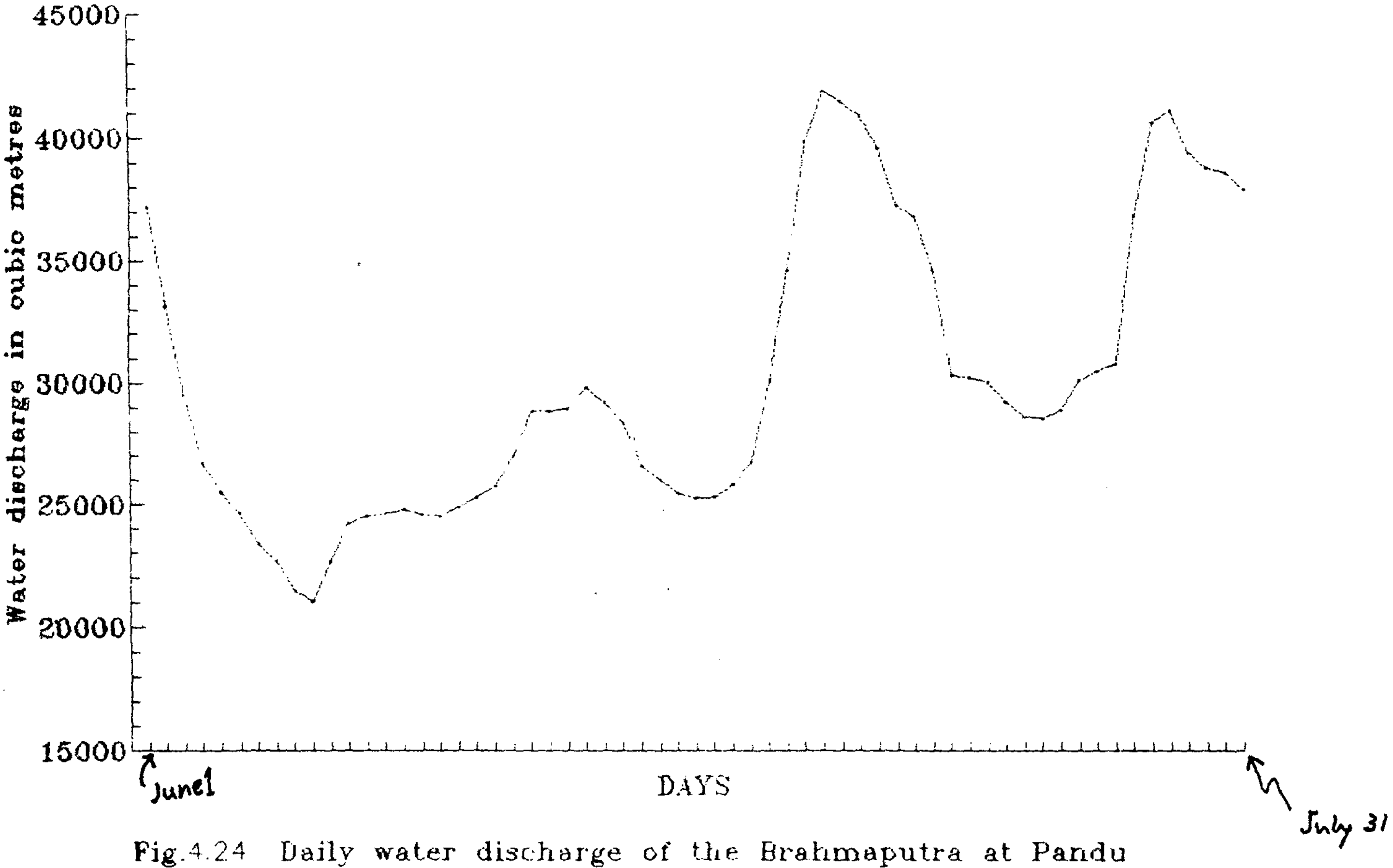


Fig.4.24 Daily water discharge of the Brahmaputra at Pandu for the period of June–July

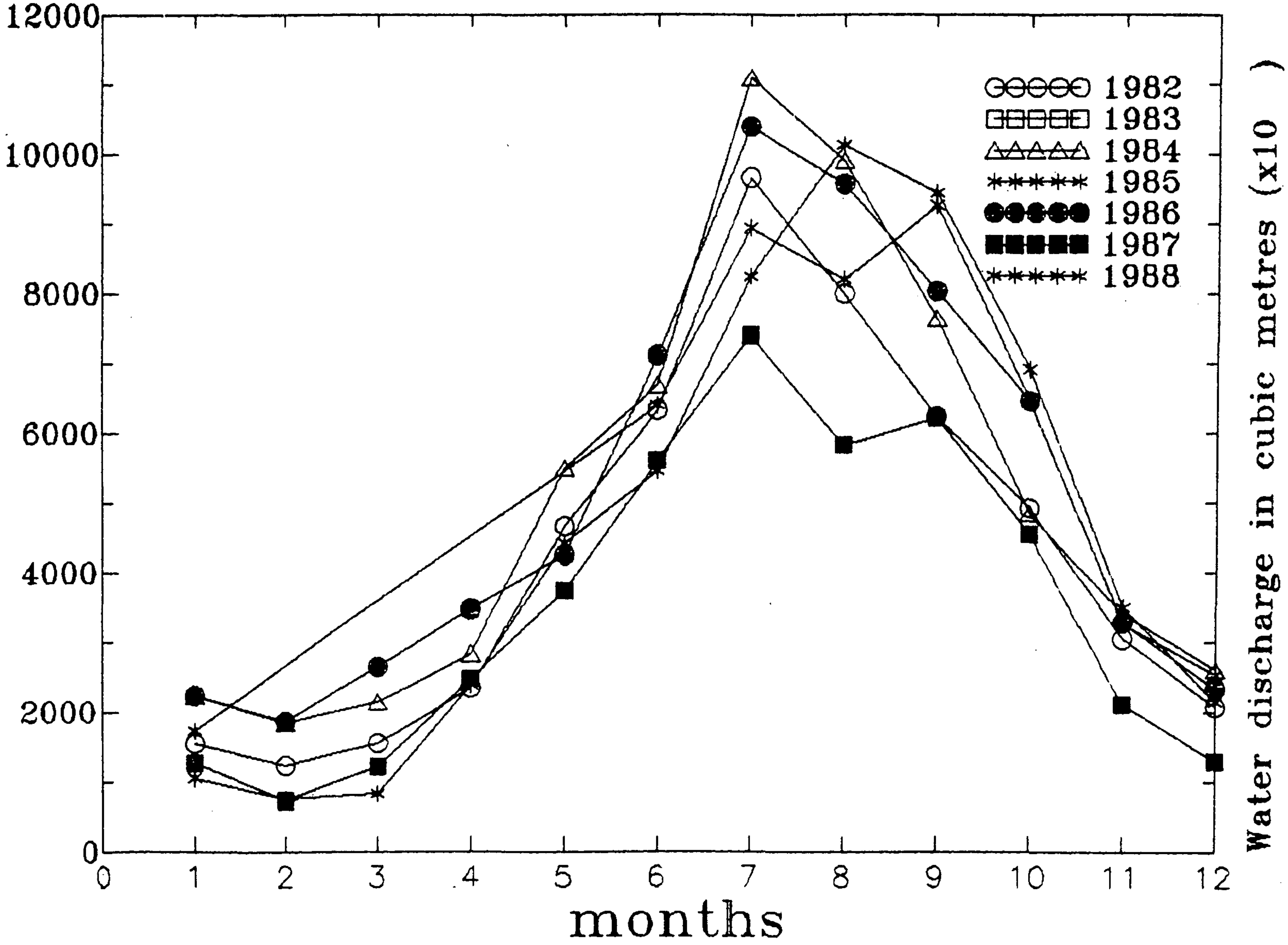


Fig.4.25 Monthly water discharge of Brahmaputra at Pandu for the years 1982–88

four reaches of the Brahmaputra in Assam over a total length of 607 km, two reaches (250 km) have experienced an average aggradation of about 55 cm and the other two reaches (349 km) had suffered a degradation of about 11 cm during 1971-1979. Taken as a whole, the Assam section of the river is estimated to have experienced an aggradation of about 16 cm (Goswami, 1985). However, this aggradation computes at 27 cm if one uses the more realistic bulk density of 1.6 T/m_3.

4.6 Environmental Impact Assessment

A river with a natural flow regimen is a rare phenomenon in this age of intensive resource development. But Brahmaputra to a great extent is still so. But with growing concern for the quality of life on this earth, time has come to focus greater attention on the effects of human activities on the environment of the river basins of the world. Man's influence on the load of sediment carried by rivers is well known and documented. Wohlman (1964) has shown that impact of urban construction in eastern United States water sheds might have increased sediment yield 100 times. Similar results can occur from man's mere interference with vegetative cover and land stability.

Direct effects of water pollution on river water chemistry are obvious. Concerns also are the indirect effects of man's alteration of water sheds upon the resultant water chemistry. The nitrogen cycle and its upset through the activities of man account for some of the indirect effects of man upon river water chemistry. Sulphate enters the watershed from both sea salt sources and from industrial pollution. It has been found that after deforestation, of water sheds, local streams may show five fold increase in hydrogen ion concentration, and change from a sulphuric to nitric acid dominance. However, almost nothing is known about the effects of single imbalancing activities upon the chemistry of otherwise undisturbed river waters.

Extensive flooding and bank erosion accompanied by enormous amount of sediment load are the major environmental problems of the Brahmaputra river basin. The immediate problem of this region is to tame the most bank rivers that came down from the Bhutan Himalayas causing enormous devastation to life and property and crops every year. The total north bank sediment load is 8 to 9 times of that of the south bank as determined by the state flood control departments.

Geochemically, the level of pollution in the Brahmaputra is still very low, as is found by the calculation of geoaccumulation indices. This is a quantitative measure of the extent of pollution in river sediments following the

Table 4.14 : Geoaccumulation indices for heavy metals in the Brahmaputra

Cu	-0.09
Pb	-0.32
Zn	-0.52
Cd	-4.80
Fe	-0.59
Cr	-2.12

method developed by Muller (1979 - as quoted in Salomons and Forstner, 1984) which is given by

$$I^{geo} = \log_2 \frac{Cn}{Bn}$$

where Cn is the measured concentration of the heavy metal "n" in the pelitic fraction of the sediment and Bn is the geochemical background in fossil argillaceous sediments. The index of geoaccumulation consists of seven grades (0-6) where the highest grade (6) reflects 100-fold enrichment above background level.

The index values for the Brahmaputra river sediments are given in Table 4.14. Fe, Cu, Pb, Zn, Cr and Cd - all show negative values indicating that there is no pollution with respect to these metals in Brahmaputra river.

For the analysis of a river system like Brahmaputra, it would be imperative and extremely beneficial to develop a comprehensive data-storage and retrieval system for data management, analysis and design. This system should be formulated to accomodate present and long range requirements and should include at least climatic, hydrological, hydraulic, water quality, soils, geology, controls and channel and water shed geometry data.

CHAPTER 5

SUMMARY AND CONCLUSION

The Brahmaputra river water is alkaline in nature. The Electrical conductivity changes with season indicating the seasonal variation in dissolved ion chemistry. Cl^-, HCO_3^- and SO_4^{--} make up about 70% of the total ions. The average chloride content is in consistency with other Indian rivers but during non-monsoon it is much attributed to possible contribution from evaporite deposits reported in the upper reaches of Brahmaputra, Bicarbonate is higher in Brahmaputra and both carbonate dissolution and primary and secondary mineral weathering are the possible sources of HCO_3^-. Sulphate concentration is lower than the average for Indian rivers. Oxidation of pyrite sediments and Gypsum or Anhydrite appears to have major contribution. Dissolved silica concentration is higher in the monsoon for Brahmaputra. Weathering of carbonates, Sulphates and silicates release most of the Ca in Brahmaputra. It may have common source with Mg in ~~contain~~ certain cases. Na shows greater mobility and more pronounced seasonal variation than K. The (Ca + Mg)/ (Na + K) ratio shows carbonate source rock influence on the water chemistry of the Brahmaputra.

Mineral assemblages expected to be in equilibrium with the chemical composition of Brahmaputra river water are dolomite in carbonate system, and Albite, Chlorite, Ca-felspar and Kaolinite in silicate system, irrespective of seasonal variation.

The theoretically predicated mineral assemblage closely agree with the observed suspended sediment mineralogy.

The sediment chemistry reveals the abundance of Si, Al, Fe, Na, Ca, K and Mg in that order. Among the metals, Zn is most dominant closely followed by Cr, Mn, Pb, and Cd. While average Si content is higher in bed sediments than suspended sediments, Al concentration is almost equal. Consitancy of Si and Al can be attributed to uniform distribution of fine silt and clay all throughout the basin. Fairly good correlation amongst the heavy metals in the suspended sediments suggests their common source and identical mobility.

The suspended sediments range in size from medium silt to clay. The coarser population show downstream fall in amounts. Suspended sediments are moderate to poorly sorted, positively skewed(i.e. more finer materials in the distribution) and from Leptokurtic in the upstream to platykurtic in the lower reaches.

Quartz, Feldspar and clay minerals consitutes more than 90% of the suspended sediment mineralogy. Detrital fractions (Quartz + Feldspar + Muscovite) show a distinct decre~~r~~asing trend with corresponding increase in the clay minerals preparticularly in downstream. Illite, Chlorite and Kaolinite are the dominant clay minerals with almost equal contribution from each.

Geoaccumulation indices show absence of pollution due to heavy metal enrichment in the Brahmaputra.

BIBLIOGRAPHY

ABBAS, N.1985. Geochemistry of the Ganges river basin. Ph.D. Thesis. Jawaharlal Nehru University. 184pp.

ABBAS, N., and V.SUBRAMANIAN.1984. Erosion and Sediment Transport in the Ganges river basin, India. Jour. of Hydrology 69:173-182.

AWASTHI, A.K.1970. Skewness as an environmental indicator in the Solani river system, Roorkee, India. Sed. Geol.4:177-183.

BASKARAN, M., M.M.SARIN, and B.L.K. SOMAYAJULU. 1984. Composition of mineral fractions of the Narbada and Tapti estuarine particles and the adjacent Arabian sea sediments off western India. Chem. Geol.45:33-51.

BATHURST., R.G.C.1976. Development in Sedimentology, Elsevier Scientific Publications Company.633 pp.

BERNER, R.A.1971. Principles of Chemical Sedimentology, McGraw Hills Publ., New York 240 pp.

BERNER, E.K., and R.A.BERNER.1987. The Global Water Cycle : Geochemistry and Environment, Prentice Hall Inc. 397 pp.

BISCAYE, P.E.1964. Distinction between Kaolinite and Chlorite in recent sediments by x-ray diffraction. The American Mineralogist 49:1281-1289.

BISCAYE, P.E.1965. Mineralogy and Sedimentation of recent deep sea clay in the Atlantic Ocean and adjacent seas and oceans. Geol. Soc. Am. Bull.76:803-832.

BOROLE, D.V., M.M.SARIN, and B.L.K.SOMAYAJULU.1982. Composition of Narbada and Tapti estuarine particles and adjacent Arabian Sea sediments. Inian Jour. of Mar. Sci.11:51-62.

BOYLE, E., R.COLLER, A.T.DENGLER, J.M.EDMOND, A.C.NG and F.Stallard. 1974. On the chemical mass-balance in estuaries. Geochemica et Cosmochimica Acta 38:1719-1728.

CARBONEL, J.P., and M.MEYBECK.1975. Quality variations of the Mekong river at Phnom Penh, Cambodia and chemical transport in the Mekong basin. Jour. of Hydrology 27:249-265.

CARROL, D.1970. Clay minerals-a guide to their identification. The Geol. Soc. Ame., special paper 126, 80 pp.

CRONAN, D.S.1972. Skewness and Kurtosis in polymodal sediments from the Irish Sea. Jour. of Sed. Petrology 42:102-106.

D'ANGLEJAN, B.E., and E.C. SMITH.1973.Distribution, transportation and composition of suspended matter in the St.Lawrence DAVIS, S.N., and R.J.M.DEWEIST.1962.Hydrogeology, New York, Wiley Intersci. 463 pp.

DEB, B., and S.P.CHADHA.1964. A study on the quality of Indian river waters. Central Water and Power Res. Stn. Tech. Mem.1:1-51.

DEPETRIS, P.J., and J.J.GRIFFIN.1968. Suspended load in the Riode plata drainage basin. Sedimentology 11:53- 60.

DREVER, J.I., 1982.The Geochemistry of Natural waters. Prentice- Hall Inc. Englewood cliffs.N.J.382 pp.

DUNNE, T..1978. Rates of chemical denudation of sillicate rocks in tropical catchments. Nature 274:244-246.

FOLK, R.L.1968. Petrology of Sedimentary rocks.Austin (Memphill's), 170 pp.

FOLK, R.C., and W.C.WARD.1957.Brazos river bar :A study in significance of grain size parameters.Jour. of Sed. Petrology 27:3-26.

FORSTNER, U., and G.T.W. WITTMAN. 1981.2nd ed. Metal Pollution in the aquatic environment. Springer- Verlag Berlin Heidelberg New York. 486 pp.

FRIEDMAN, G.M.1967. Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. Jour. Sed.Petrology 37:327-354.

FUKAI, R., C.N.MURRAY, and 1.HUYNH-NGOC.1975. Variations of soluble zinc in the Var river and its estuary. Estuarine coastal Mar. Sci.3:177-188.

GARRELS, R.M., and C.L.CHRIST.1965. Solutions, Minerals and Equilibria, Harper and Row, New York. 450 pp.

GARRELS, R.M., and F.T.MACKENZIE.1966.Chemical mass-balance between rivers and oceans, American Jour. of Science 264:507-525.

GARRELS, R.M., and F.T.MACKENZIE.1971. Evolution of sedimentary rocks. Norton and Co.Inc. New York 397 pp.

GARRELS, R.M., F.T.MACKENZIE, and C.HUNT.1975. Chemical cycles and the global environment, William Kaufmann Inc.206 pp.

GIBBS, R.J., 1967. The Geochemistry of the Amazon river system. part I :The factors that control the salinity and the composition and concentration of the suspended solids. Geol.Soc. of America Bulletin 78:1203-1232.

GIBBS, R.J., 1970. Mechanismc controlling world water chemistry, Science 17:1088-1090.

GIBBS, R.J.1972. Water chemistry of Amazon river, Geochim Cosmochim. Acta 36:1061-1066

GOLDBERG, E.D., and J.J.GRIFFIN.1970.The sediments of Northern Indian Ocean, Deep Sea Res. 17:513-537.

GOSWAMI, D.C., 1985. Brahmaputra river, Assam, India: Physiography, basin denudation, and channel aggradation. Water Resour. Res., V 21, No. 7, 959- 978.

GREGORY, B.J., and D.E.WALLING. 1973. Drainage basin form and processes- A Geomorphological approach. Arnold London.

GRIFFITHS, G.A., and G.P.GLASBY.1985.Input of river derived sediment to the New Zealand continental shelf. Estuarine, Coastal and Shelf Science 21:723-787.

GRIM, R.E.1968. Clay Mineralogy, 2nd ed. McGraw Hill, New York 596pp

HANDA, B.K.1972. Geochemistry of the Ganga river water, Indian Geohydrology VIII(2):71-78.

HOLEMAN, J.N.1968. Sediment yield of major rivers of the world, Water Resources Res.4:737-747.

HOLLAND, H.D.1978. The Chemistry of the Atmosphere and Oceans. Willey-Interscience, New York 351 pp.

HU MING-HUI, R.F.STALLARD, and J.M. EDMOND.1982. Major ion chemistry of large Chinese river, Nature 298(5874):550-553.

IMESON, A.C., and J.M. VERSTRATEN.1981. Suspended solids concentrations and river water chemistry. Earth surface processes and landforms 6:251-263.

JACKS, G..1973. Chemistry of groundwater in a district in southern India. Jour. of Hydrology 18:185-200.

JHA, P.K.1986.Nature of chemical and sediment load in the Yamuna river basin.Ph.D.Thesis. Jawaharlal Nehru University. 207 pp.

JOLLY, J.P.1982. A proposed method for accurately calculating sediment yields from reservoir deposition volumes. IAHS publication 137:153-161.

JONES, B.F., H.P.EUGSTER, and S.L.RETTING.1977. Hydrogeochemistry of the Lake Magadi basin, Kenya. Geochimica et Comochimica Acta 41:53-72.

JUDSON, S., and D.F. RITTER.1964. Rates of regional denudation in the United States. Jour. Geophys. Res.69(16):3395-3401

KATTAN, Z., J.Y. GAC andJ.L. PROBST.1987. Suspended sediment load and mechanical erosion in the Senegal basin. Jour. of Hydrology 92:59-76.

KRAMER, J.R.1967. Equilibrium models and composition of the Great Lakes. Amer.Chem.Soc. special pub.67:243- 251.

KRISHNASWAMY, S., D.LAL, J.M.MARTIN, and M.MEYBECK. 1971. Geochronology of Lake sediments. Earth Planet Sci. Letters 11:407-414.

KUMAR, R.1986. Fundamentals of Historical Geology and Stratigraphy of India.Wiley Easter Ltd. India 254 pp.

LEEDER, M.R.1980. Sedimentology- process and product, George Allen and Unwin publication. 339 pp.

LINDHOLM, R.C. 1987. A practical approach to Sedimentology, Allen publication. 276 pp.

LIVINGSTONE, D.A. 1963.Chemical composition of rivers and lakes data on geochemistry (chapter G). U.S.Geol.Survey 440G:GI-G64.

LVOICH, M.I.1973. The world's water. Mir Publishers. Moscow.212 pp.

MAHANADI MASTER PLAN -water balance studies.1981. National Water Development Agency.150 pp.

MACKENZIE, F.T., and R.M.GARRELS.1965. Sillicates: reactivity with sea-water. Science 150:157.

MALLICK, T.K.1976. Shelf sediments of the Ganges delta with a special emphasis on the mineralogy of the western part, Bay of Bengal, Indian Ocean. Mar. Geol.22:1-32.

MANICKAM, S., L.BARBAROUX, and F.OTTMANN.1985. Composition and mineralogy of suspended sediment in the fluvio-estuarine zone of the Loire river, France. Sedimentology 32:721-741.

MARTIN, J.M., and M.MEYBECK, 1978. The content of major elements in the dissolved and particulate load of rivers. In Biogeochemistry of estuarine sediments. Proc. of UNESCO/SCOR workshop, Melreax.

MARTIN, J.M., and M.MEYBECK.1979. Elemental mass-balance of material carried by major world rivers. Marine Chemistry 7:173-206.

MARTINS, L.R.1965. Significance of skewness and kurtosis in the environmental interpretation.Jour.Sed. Petrology 35:768-770.

MASON, B.1966. Principles of Geochemistry. John Wiley and Sons Inc. New York. 328 pp.

MEYBECK, M.1976. Total mineral dissolved transport by world major rivers. Hydro.Sci.Bull.21(2):265-284.

MEYBECK, M.1982 Carbon, nitrogen and phosphorous transport by world rivers. American Jour. of Sci.282:401-450.

MEYBECK, M.1983.Atmospheric inputs and river transport of dissolved substances. Proceedings of the Hamburg Symposium.

MEYBECK, M., and J.P.CARBONNEL.1975.Chemical transport by Mekong river. Nature 255:134-136.

MILLIMAN, J.D., and R.H.MEADE.1983. World-wide delivery of river sediment to the oceans. Jour.of Geol. 91:1- 21.

MILLOT, G.1970.Geology of clays. Springer-Verlag, Paris 305 pp.

MOIOLA, R.J., and D.WEISER. 1968.Textural parameters : An evaluation. Jour. of Sed. Petrology 38:45-53.

MURTHY, M.R., and P.C.SRIVASTAVA. 1979. Clay mineralogy of shelf sediments of north-west Bay of Bengal. Mar.Geol.31:M21-M32.

NAIDU, A.S., and T.C.MOWATT.1983. Sources and dispersal patterns of clay minerals in surface sediments from the continental shelf areas off Alaska. Geol. Soc. Am. Bull.94:841-854.

NAIDU, A.S.1966. Lithological and chemical facies changes in the recent deltaic sediments of the Godavari river, India. In M.L.Shirley(ed), Deltas in their geological frame work. Houston Geol.Soc. 125-157 pp.

NAIR.R.R., N.H.HASHIMI AND V.PURNACHANDRA RAO.1982. Distribution and dispersal of clay minerals on the Western continental shelf of India.Mar.Geol.50:M1- M9.

ONGLEY, E.D.1982. Influence of season, source and distance on physical and chemical properties of suspended sediment.IAHS publ.137:371-383.

PAGENKOPF, G.K.1978.Introduction to natural water chemistry.Marcel Dekker Inc.New York.272 pp.

PARKER, J.G.1982. Grain size characterstics of recent sediments in Belfast Lough.Mar.Geol.50:143-154.

PAUL, A.C., AND K.C.PILLAI.1978.Pollution profile of a river. water, air and soil pollution.10:133-146.

PAUL, A.C., AND K.C.PILLAI.1983.Trace metals in a tropical river environment-distribution.Water, air and soil pollution.19:63-73.

PROBST, J.L.1985.Nitrogen and phosphorous exportation in the Garrone Basin, France.Jour.Hydrology 76:281-305.

PROBST, J.L.1986. Dissolved and suspended matter transported by the Girou river, Hydrological Sciences.31.

PROBST, J.L., and Y.TARDY.1987.Long range stream flow and world continental run-off fluctuations since the beginning of this century. Jour.of Hydrology 94:289-311.

RAMESH, R.1985. Geochemistry of the Krishna river basin.Ph.D. Thesis.Jawaharlal Nehru University.228 pp.

RAO, K.L.1975. India's water wealth. Orient Longman, Delhi. 255 pp.

RATEEV, M.A., Z.N.GORBUNOVA, A.P.LISITZIN et al. 1969. The distribution of clay minerals in the ocean. Sedimentology 13:21-43.

RAY, S.B., M.MOHANTI, and B.L.K.SOMAYAJULU.1984. Suspended matter, major cations and dissolved silicon in the estuarine waters of the Mahanadi river, India.Jour. of Hydrology 69:183-196.

RAYMAHASAY, B.C.1970. Characteristics of stream erosion in the Himalayan region of India.In proc.symp. on Hydrogeochemistry and Biogeochemistry 1:82-89.

RAYMAHASAY, B.C.1987. A comparative study of clay minerals for pollution control.Jour.Geol.Soc.Ind.30:408- 413.

ROOSEBOOM, A., and F.J.MULKE.1982. Erosion initiation.IAHS 137:59-67.

SAGOE, K.O., and G.S.VISHER.1977. Population breaks in grain size distribution of sand, a theoretical model.Jour.Sed.Petr.47:85-310.

SAHU, B.K.1964. Depositional mechanism from the size analysis of clastic sediments.Jour.Sed.Petr.34:73-87.

SARIN, M.M., D.V.BOROLE, and S.KRISHNASWAMY.1979. Geochemistry and geochronology of sediments from the Bay of Bengal and the equitorial Indian Ocean. Proc. of Indian Academy of Sci.88A:131-154.

SARIN, M.M., and S.KRISHNASWAMY.1984. Major ion chemistry of the Ganga-Brahmaputra river systems. India. Nature312(5994):538-541.

SCHMITT, H.H.1962. (ed.) Equilibrium diagrams for minerals. 200 pp.

SERALATHAN, P. and A.SEETARAMASWAMY.1982. Clay minerals in the modern deltaic sediments of the Cauvery river. Indian Jour. Mar. Sci. 11:167-169.

SHEPARD, F.P.1954. Nomenclature based on sand-silt-clay ratios. Jour. of Sed. Pet. 24:151-158.

SHOLKOVITZ, E.R.1976. Flocculation of dissolved organic and inorganic matter during the mixing of river water and sea water. Geochim. Cosmochim. Acta.40:831-846.

SIDDIQUIE, H.N.1967.Recen sediments of the Bay of Bengal. Mar. Geol.5:249-291.

SIEVER, R., and N.WOODFORD.1973. Sorption of sillica by clay minerals.Geochim et Cosmochim. Acta 37:1851-1880.

SIEVER, R., and R.H.SCOTT.1963. Organic Geochemistry. Pergamon Press, Oxford 579 pp.

SILLEN, L.G.1961. The physical chemistry of sea water. Oceanography, ed. M.Sears.Amer. asso. for the advancement of Sci., Washington, D.C. 549-581.

SRIVASTAVA, N.K. 1970. Clay minerals from the Gulf of Kutch and Cambay.Proc. Ind. Acad.Sci.72.

STALLARD, R.T., and J.M.EDMOND.1983.Geochemistry of the Amazon river.The influence of Geology and weathering environment on the dissolved load. Jour.Geophy.Res.88:9671-9688.

STUMM, W, and J.J.MORGAN.1981. Aquatic chemistry.2nd.ed. Wiley Intersci.New York.780 pp.

SUBRAMANIAN, V.1974 Water chemistry of the St.Lawerence river. Maritime Sediments 10(3):97-105.

SUBRAMANIAN, V.1978. Input by Indian rivers into the World Ocean.Proc.Indian Acad. Sci.87A CE and P. Sciences 7:77-88.

SUBRAMANIAN, V.1979. Chemical and suspended sediment characteristics of rivers of India.Jour. Hydr.44:37-55.

SUBRAMANIAN, V.1980.Mineralogical input of suspended matter by Indian rivers into the adjacent areas of the Indian Ocean.Mar. Geol. 36:M29-M34.

SUBRAMANIAN, V.1982.Erosion and sediment yield in the Krishna river basin, India.INS proceedings of the Ext.Sys. IAHS 137:193-198.

SUBRAMANIAN, V.1983 Factors controlling the chemical composition of river waters of India.Proc. of the Hamburg Symposium 141:145-151.

SUBRAMANIAN, V., G.BIKSHAM, and R.RAMESH. 1987. Environmental Geology of Peninsular river basins of India. Jour.Geol.Soc.Ind. 30:393-401.

SUBRAMANIAN, V.and K.SAXENA.1983. Hydrogeochemistry of groundwater in the Delhi region of India.IAHS 146:307-316.

SUBRAMANIAN, V. and R.A.DALAVI.1978. Some aspects of stream erosion in the Himalaya. Himalayan Geology 8(II):882-834.

SUBRAMANIAN, V. R.SITASAWAD, N.ABBAS and P.K.JHA.1987. Environmental Geology of the Ganga river basin. Jour. Geol.Soc.Ind. 30:335-355.

SUBRAMANIAN, V., VAN'T DACK, and VAN GRIEKEN. 1985. Preliminary studies on the geochemistry of the Cauvery river basin.Proc.Ind.Acad.Sci. 94(2):1-12.

SUBRAMANIAN, V., VAN'T DACK, andVAN GRIEKEN.1985.Chemical composition of river sediments from the Indian subcontinent.Chemical Geology 48:271-279.

SWAMY, A.S.R., N.V.N.D.PRASADA RAO, and M.P.RAO.1973. Clay minerals in modern deltaic sediments of the Krishna river.East Coast of India.Jour. Mar.Biol.Asso.India 15:625-631.

THRIVIKRAMAJI, K.P. 1985.River metamorphosis due to human intervencence in the Neyyar basin, technical report submitted to DOE.95p.

THRIVIKRAMAJI, K.P. 1989. River geochemistry, report submitted to State science, technology and environment.50p.

TOTH, S.J., and A.N.OTT.1970. Characterisation of bottom sediments: Cation exchange capacity and exchangeable cation status. Env. Sci.and Tech. 4:935-939.

TUREKIAN, K. 1972. Chemistry of the earth.Wiley Inter.Sci.New York.

VENKATARATHNAM, K. and P.E. BISCAYE.1973.Clay mineralogy and sedimentation in the eastern Indian Ocean. Deep Sea Res. 20:727-738.

VISHER, G.S. 1969.Grain size distribution and depositional processes. Jour.Sed. Pet. 39:1074-1106.

WEAVER, C.E. 1967.Variability of a river clay suite. Jour.Sed. Pet.37:971-974.