Chapter I

Introduction and Review of Literature
INTRODUCTION

A river basin represents the most active component in the hydrological cycle. In material transport, the river plays a very important role. More than 90% of continental weathering products are transported to the oceans. Therefore, the chemistry of river waters and the flux of elements transported by them to the oceans are central to our understanding of exogenic cycles of elements. In natural system, material so transported are recycled through geological time at very slow rates. For example, it is estimated that sediments are completely recycled every 250 million years. Individual elements, such as Na, K, Mg, Fe, etc. are recycled at different rates due to different composition of sediments and varying ability of elements to complex with organic matter which bind the sediments. In our present day conditions, man has considerably altered the natural rate of processes due to increasing erosion and resources consumption. In a river basin, diverse factors influence the hydrological activities - weathering of drainage basin rocks, erosion of weathered products, fractionation of individual metals between water, sediments and biota etc., vary within a basin from the catchment to the river mouth areas. There are thus temporal and spatial variations in these geochemical parameters.
River geochemistry studies have been greatly extended since the last three decades in two major research directions. On the one hand geochemical processes have been studied in detail on individual river basins (for example Gibbs 1967; Stallard and Edmond 1981; 1983; Subramanian et.al., 1985; Biksham 1985) and on the other hand the overall balance of dissolved and sediment load carried to the oceans has been computed on the basis of big river studies (for example Holeman 1968; Meybeck 1976; Martin & Meybeck 1979; Milliman and Meade 1983).

The world rivers with 1.2 thousand cubic Kilometers of water account for only 0.0001 percent of total volume of water in the hydrosphere (Lvovich 1973). These rivers discharge about 38,000 cubic kilometers of water annually into the world oceans. Recent estimates show that 3.25 billion tonnes of dissolved load (Meybeck 1976) and 13.5 billion tonnes of suspended sediments (Milliman and Meade 1983) are delivered by all rivers to the world oceans.

The studies on major ion chemistry dissolved and sediment transport, sediment chemistry, sediment accumulation rates and mineralogy of world and Indian rivers have been reviewed in this chapter. The chief objective of this review is to emphasise the direction in which the studies are being carried out world over and the limitations in understanding the global geochemical process.
Literature Review

a) Major Ion Chemistry:

Geochemical studies in surface waters have been important as an aid in solving general problems in geochemistry. Dissolved and suspended matter of continental waters have been investigated to find the nature and composition of the matter transported by rivers to the ocean (Barth 1961; Gibbs 1972; Subramanian 1979), to estimate erosion rates and to determine geochemical balances as a whole. The studies on chemical quality and dissolved transport by rivers have received wide attention only recently. The solid transport was generally considered as the major process of material supply to the ocean and therefore some studies of denudation rates only took mechanical erosion into account. The first well documented review on river transport is made by Livingstone (1963) and it is mainly concerned with the major dissolved elements. Since then a lot of important works have been attempted on the world's biggest rivers; for example Amazon (Gibbs 1967; Stallard & Edmond 1981; 1983) Parana (Depetris and Griffin 1968), Mekong (Meybeck and Carbonnel 1975), Chinese rivers and Brahmaputra (Hu Ming - Hui et al 1982).

Meybeck (1976) estimated the annual global dissolved transport of rivers as 3.25 billion tonnes on the basis of 40 world major rivers. If chemical transport is a major
process on the earth's surface, the solid material carried by the rivers to the ocean as a whole (13.5 billion tonnes according to Milliman and Meade 1983) is four times more than the dissolved transport. A large amount of additional data is needed for rivers in Asia and Africa before meaningful interpretation can be made about the continental input into the world oceans. Recently Hu Ming-Hui et al (1982) reported that Chiang Jiang river transports $226 \times 10^6$ tonnes annually as dissolved load. This places it equal to the Amazon at $223 \times 10^6$ tonnes year$^{-1}$. This additional data has increased the world's dissolved load from $3.25 \times 10^9$ tonnes year$^{-1}$ to $3.6 \times 10^9$ tonnes year$^{-1}$.

Carbonnel and Meybeck (1975) concluded after their study that chemical quality of the Mekong river is highly variable with a total ionic content ranging from 60 to 190 ppm. They estimated that Mekong river has an average dissolved transport of $75 \times 10^2$ tonnes km$^{-2}$ year$^{-1}$. If this value is taken as an average for southeast Asia $(10 \times 10^6$ km$^2$) this region could contribute up to 30% of the world dissolved input to the ocean.

Gibbs (1970) discussed the mechanisms that control the world water chemistry. He cites three main mechanisms - atmospheric precipitation, rock dominance and evaporation crystallisation processes as the major factors influencing the composition of dissolved solids of world water.
The major ion chemistry of the Amazon river basin has been studied in detail to know the influence of geology and weathering conditions on dissolved load by Stallard and Edmond (1983). The relationship between solid concentration and river water chemistry has been studied on western Australian rivers by Imeson and Verstreten (1981). Moreira-Nordemann (1984) determined the chemical weathering rate of rocks in the Salgado river basin, Brazil, through the use of Uranium as natural tracer.

The river water chemistry and chemical transport studies on Indian rivers have rather limited in the past. The chemical analysis of Indian river waters, as used in calculations of Livingstone (1963), Meybeck (1976) and Raymahasay (1970) and others are very old and are not based on systematic sampling and study. The Indian rivers together discharge approximately $16 \times 10^3 \text{ m}^3 \text{ year}^{-1}$, which is about $5\%$ of global runoff to world oceans (Rao 1975). Although the Indian rivers discharge ($1700 \times 10^3 \text{ m}^3 \text{ year}^{-1}$) together only about onethird of the runoff from the river Amazon ($5500 \times 10^3 \text{ m}^3 \text{ year}^{-1}$), they are important on global scale because of their extensive drainage areas and their intensive utilization by man.

The Central Water and Power Commission has carried out partial analysis of waters of the major Indian rivers over a period of years (for example Deb and Chadha 1964), but their
studies were oriented towards determination of the quality of the river waters for irrigation use. Handa (1972) studied the chemical composition of the Ganga river water. Preliminary and broad investigations of Indian rivers have been periodically reported by Subramanian (1979, 1983); Bikshamia and Subramanium (1980); Abbas and Subramanian (1984); Subramanian et.al (1985). Recently a similar study has been reported for Ganges and Brahmaputra river systems (Sarin and Krishnaswami 1984). The chemical transport of entire Indian subcontinent is estimated as 270 million \(-1\) tonnes year \(^{-1}\) (Subramnaian 1983) with the rate of 69 tonnes \(-2\) \(-1\) \(\text{Km} \text{ yr}\) (Subramanian 1979).

The chemical transport of individual river basins has been studied by several workers for example, Godavari (Bikshamia and Subramanian 1980; Biksham 1985), Cauvery (Subramanian 1985) and Ganges (Abbas and Subramanian 1984; Sarin and Krishnaswami 1984). Sarin and Krishnaswami (1984) reported that the Ganges and the Brahmaputra together supply \(-1\) 118 million tonnes year \(^{-1}\) of dissolved solids to the Bay of Bengal. This accounts for 30\% of the global supply of dissolved salts to the oceans, which is nearly the same as their contribution to the global water discharge. It is well known that physical weathering is dominant in Asian rivers (Gibbs 1981) but it should also be noted that the solute yield (69 tonnes \(\text{Km} \text{ year} \)) of the Indian subcontinent is
twice that of global average \((35 \text{ tonnes Km}^{-2} \text{ year}^{-1})\), (Subramanian 1983).

The dissolved elemental fluxes of certain major elements such as Na, K, Mg, Ca and dissolved Si in the waters of the Mahanadi estuary have been studied by Ray, et. al, (1984). It has been estimated that 11% dissolved Si has been removed from water phase in the estuaries by biological activity.

The study on water quality of the desert river Luni (Rajasthan) has indicated a wide range of TDS from 161 to 12,495 ppm (Choudari and Sharma 1984). Such studies on extreme climatological and different geological conditions are useful in understanding the chemical weathering conditions and the impact of aerosol particles on river chemistry.

b) Sediment Transport:

Rivers are the major carriers of sediments from land to Sea. Two distinct methods have been used to estimate the mass of river transported sediment entering the oceans: One estimates the mass being carried oceanward by rivers (e.g., Holeman 1968; Milliman and Meade 1983), while the other method estimates denudation of the continents (e.g., Fournier 1960; Schumm 1963). Sediment loads based on this later method are significantly greater than those based on the former because they include a large amount of eroded
sediment that never reaches the ocean. Hence, the first method is being accepted as more accurate for estimating the continental transport by rivers to the oceans.

Recently Milliman and Meade (1983) studied the sediment yield of major world rivers and updated the earlier published data of (Holeman 1968). They observed that rivers with large sediment loads (annual discharges greater than 15 million tonnes) contribute about 7 billion tonnes of the suspended sediment to the ocean yearly. They also observed by extrapolating available data for all drainage basins, the total suspended sediment delivered by all rivers to the oceans is about 13.5 billion tonnes annually; bed load and flood discharges may account for an additional 1-2 billion tonnes. Based on their study Millman and Meade (1983) concluded that about 70% of this total is derived from Southern Asia and the larger islands in the Pacific and Indian oceans, where sediment yields are much greater than for other drainage basins. (Table 1). The world wide compilations of sediment budget (Table 1) also reveals that the Asian rivers are the main contributors to the continental mass transfer.

Compared to the estimates made by other workers, Milliman and Meade (1983) estimate of 13.5 billion tonnes of riverine sediment entering the Ocean annually seems to be small. Holeman's often quoted review (1968), for example,
Table 1: Comparison of world sediment budget

<table>
<thead>
<tr>
<th>Area</th>
<th>Drainage area (10 km²)</th>
<th>Sediment load (10 t yr⁻¹)</th>
<th>Sediment rate (t km² yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Holeman &amp; Meade 1968</td>
<td>Holeman &amp; Meade 1983</td>
<td>Lopotin 1950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Holeman &amp; Meade 1968</td>
<td>Holeman &amp; Meade 1983</td>
</tr>
<tr>
<td>Asia</td>
<td>26.6</td>
<td>16.88</td>
<td>14480</td>
</tr>
<tr>
<td>Africa</td>
<td>19.7</td>
<td>15.34</td>
<td>490</td>
</tr>
<tr>
<td>Europe</td>
<td>9.2</td>
<td>4.61</td>
<td>290</td>
</tr>
<tr>
<td>Eurasian Arctic</td>
<td>–</td>
<td>11.17</td>
<td>–</td>
</tr>
<tr>
<td>Australia</td>
<td>5.1</td>
<td>2.20</td>
<td>210</td>
</tr>
<tr>
<td>N &amp; Central America</td>
<td>20.48</td>
<td>17.50</td>
<td>1780</td>
</tr>
<tr>
<td>S. America</td>
<td>19.20</td>
<td>17.90</td>
<td>1090</td>
</tr>
<tr>
<td>Large Pacific Islands</td>
<td>–</td>
<td>3.00</td>
<td>–</td>
</tr>
<tr>
<td>World Total</td>
<td>100.08</td>
<td>88.60</td>
<td>18300</td>
</tr>
</tbody>
</table>
shows a world figure of 15.3 billion tonnes (Table 1). Similarly, Holeman has estimated that about 14.5 billion tonnes of riverine sediment were contributed by the Asian rivers, whereas the recent estimate of Milliman and Meade shows only 6.3 billion tonnes. Millman and Meade have given two main sources for the disagreement.

1. The sediment discharges shown in his paper are generally smaller than those of earlier compilers, because more recent measurements and estimates usually give lower values (Particularly for Asian rivers) or because dams and land conservation - practices have decreased river sediment loads - the colorado, Mississippi, Nile and indus rivers being obvious examples.

2. The other explanation for the discrepancy is that Holeman (1968) has overestimated the contribution of the Asian rivers by considering the Himalayan rivers sediment yield as mean to the entire region.

But the average sediment yield of Asian rivers \( \left( \frac{543}{2^{1}} \text{ tonnes km yr}^{-1} \right) \) assumed by Holeman appears to be more valid considering many recent studies of non-Himalayan rivers (e.g. Subramnaian 1979; Bikshamiah & Subramanian 1980). Moreover, the recent estimates on sediment yield of Himalayan rivers (Abbas and Subramanian 1984) are much higher than the Milliman and Meade (1983) observations. Hence, the
contribution by Asian rivers estimated by Holeman (1968) appears to be more realistic than Milliman and Meade (1983).

Accepting even low value of annual sediment transport of 13.5 billion tonnes, the world ocean would have been filled with sediments long back. The movement of sediments, based on remote sensing revealed that major portion of sediments discharged by world rivers are being deposited in estuaries and on continental shelves before reaching the deep sea floor (Gibbs 1981). The time required to fill shelves and estuaries ranges from 2600 to 3400 years for the Ganges - Brahmaputra to 1 to 1.2 million years for the Yenisei-Ob. For most of the river systems the sea level will change before the shelves are completely filled in. This study has answered certain questions pertaining to the rate of sedimentation on the ocean floor. However, such assumptions are to be confirmed by correlating the sediment transports with the rates of sedimentation at the river mouths and continental shelves.

The study on sediment movement of Huangho river of China (Long Xiong 1981) shows that only 24% of the total sediments mobilised by the river are reaching the ocean. The remaining sediments are deposited in delta region (43%) and alluvial plains (33%). Similarly, studies on Atlantic drainage basins of United States (Meade 1982) and Narmada and Tapti rivers of India (Baskeranet.al, 1984) have
indicated that only less than 5% of sediments transported by the rivers are being deposited on the floor of the continental shelf or the deep sea.

The sediment transport of Indian Subcontinent is estimated as 1.21 billion tonnes (Subramanian 1979) which is nearly 10% of global sediment load 13.5 billion tonnes estimated by Milliman and Meade (1983). Of this amount, nearly 8% goes into Bay of Bengal. Remaining material is carried mainly by the Ganges and Brahmaputra. The rates of physical denudation of Indian subcontinent ($327 \text{ tonnes/km}^2/\text{yr}$) is more than two times the world rate ($150 \text{ tonnes Km}^{-2} \text{ yr}^{-1}$) estimated by Milliman and Meade (1983). The sediment transportation of certain important river basins such as Ganges (Abbas and Subramaian 1984), Cauvery (Subramanian et al. 1985) and Godavari (Biksham and Subramanian 1980) were studied in detail. These studies have provided information on stream erosion characteristics in different Geological, Geographical and Climatological regions. For example the rate of sediment transport of Ganga basin at Farakka ($1235 \text{ tonnes Km}^{-2} \text{ yr}^{-1}$; Abbas and Subramanian 1984) is around 150 times greater than the Cauvery rate ($8.1 \text{ tonnes Km}^{-2} \text{ yr}^{-1}$; Subramanian 1979). Based on the study of preliminary data Subramaian (1982), Ramesh and Subramanian (1985) indicated that the quantity of sediment discharged into the Bay of Bengal does not truly
reflect the actual sediment load because of the influence of upstream dams.

The discharge and sediment load of Indian rivers are measured routinely at various discharge gauging stations setup by the State and Central government agencies over a period of years. This data is primarily generated for civil engineering and irrigation purposes. It can be effectively utilised by individual researchers for the study of continental erosion characteristics.

c) The balance between Dissolved and Sediment load in River:

Average world erosion figures show rates of erosion of about $150 \text{ tonnes km}^{-2} \text{ yr}^{-1}$ (Milliman and Meade 1983) and $32 \text{ tonnes km}^{-2} \text{ yr}^{-1}$ (Meybeck 1976) due to sediment and solute loss respectively. Continent-wise mass transfers are presented in Table-2. The figures vary according to methods of calculation, but on an average solutes comprise about 28% and sediments 72% of the total world rivers. However, the balance is far from constant, from one river to another.

In general, Asian rivers have higher sediment concentrations when compared to world rivers. This is partly a reflection of its size, but even when this is taken into account, sediment loss per unit area of land in Asia is four times greater than the world average.

Many relationships between dissolved and solid transport rates have been described by different authors.
Table 2: *Erosion rates for the continental earth*

<table>
<thead>
<tr>
<th>Continents</th>
<th>6 Load (10 t year⁻¹)</th>
<th>Chemical load</th>
<th>Sediment load</th>
<th>Total load</th>
<th>8 Rate (t km⁻² yr⁻¹)</th>
<th>Chemical rate</th>
<th>Sediment rate</th>
<th>Total rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>1490</td>
<td>14500</td>
<td>15990</td>
<td></td>
<td>32</td>
<td>302</td>
<td>334</td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>710</td>
<td>490</td>
<td>1200</td>
<td></td>
<td>24</td>
<td>16</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>460</td>
<td>250</td>
<td>710</td>
<td></td>
<td>42</td>
<td>23</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>20</td>
<td>210</td>
<td>230</td>
<td></td>
<td>2</td>
<td>21</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>N.America</td>
<td>700</td>
<td>1780</td>
<td>2480</td>
<td></td>
<td>32</td>
<td>85</td>
<td>118</td>
<td></td>
</tr>
<tr>
<td>S.America</td>
<td>550</td>
<td>1100</td>
<td>1650</td>
<td></td>
<td>28</td>
<td>56</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Continental Earth</td>
<td>3930 (3250)</td>
<td>18300 (13505)</td>
<td>22230 (16755)</td>
<td></td>
<td>23</td>
<td>108</td>
<td>131</td>
<td></td>
</tr>
</tbody>
</table>

Data from Garrels & Meckenzie (1971). Values in parenthesis shows the recent estimates by Meybeck (1976) and Milliman & Meade (1983).
(for e.g., Judson and Ritter 1964; Alekin and Brazhnikova 1962; Corbol 1964; Gibbs 1967; Meybeck 1976).

The principal assumptions can be summarised as:

1. 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. Dissolved transport is directly related to solid transport (Alekin and Brazhnikova 1962). This is mainly the view of 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 importance of climatic and topographic factors in the sediment/solute balance cannot be denied, the effect of human activities must not be forgotten. Man increases the sediment load by agricultural practices and deforestation and at the same time decreases the load by building dams which trap the sediment. Solutes are also effected, for example, by industrial effluents and by
dissolved fertilizers in surface run off. Consequently, the measured load of a river system may in many cases be a reflection of human interference rather than of natural erosion processes.

d) Sediment Chemistry:

An understanding of the geochemistry of the basin requires good knowledge about the bed and suspended sediments composition. The elemental concentrations of the suspended sediments are of considerable importance in giving greater insight into crustal weathering processes on a global scale and in determining the elemental fluxes between land and ocean, and to compare the river-borne material with the oceanic suspended matter and deposited elements. (Strakhov, 1967; Carrels and Makenzie, 1971).

In general, the chemical composition of 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 in the world. They have estimated the average river particulate matter composition based on analysis of more than 40 elements in the Amazon, Congo, Ganges, Magdalena, Mekong, Parana and Orinoco rivers and compilation of published data on 13 other major world rivers. These 20 major rivers represent 25% of the world drainage area and 15% 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 Murthy 1968; Seetharamaswamy 1968; Venkatarathnam and Tilak 1968; Rao and Rao 1969; 1973; Sarin et al., 1979; Kalesha et al., 1980; Mascarenhas 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 has received less attention. Subramanian et al., (1985) have made a comprehensive study on chemistry of river sediment from the Indian sub-continent. This study is based on the chemical analysis of 120 samples collected from different 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-continent. It has been observed in this study that in spite of the very diverse Geology of 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 the water-sediment system.

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

e) Sedimentation Rates:

Systematic studies of sedimentation rate variations are fundamental to interpretation of a variety of river - sediment interaction processes. In recent years, radiometric methods have been used to determine sedimentation rates in aquatic environments.

Robbins and Edington (1972, 1975) have shown that measurements of $^{137}$Cs and $^{210}$Pb provide independent methods of establishing a time scale within the sediment column. $^{137}$Cs in sediments has originated from the testing of nuclear devices in the atmosphere since the 1950s. Thus a sedimentation rate calculated from a $^{137}$Cs profile is based on the occurrence of a horizon and is an estimate of the average rate of accumulation of material over the past 30 years. Geochronology with $^{210}$Pb is based on a different principle. This naturally occurring member of the U series is a decay product of radon present in the atmosphere and is added to sediments at a practically constant rate. The determination of a sedimentation rate in this case does not involve the identification of a horizon, but is based on the continuing decay of the isotope. ($t_{1/2} = 22.3$ yr.) after burial (Robbins, 1978). This method in principle is able to reveal much more detail about the sedimentation
process than methods involving discreet time markers. The 

$^{210}$Pb method has been employed primarily in Lakes (e.g., Robbins and Edington 1975; Robbins et al., 1977) oceans (e.g., Joshi and Ku 1979; Sarin et al., 1979; Borole et al., 1982) and more recently in rivers (e.g., Subramanian et al., 1985).

The major source of $^{210}$Pb in surface water is rainfall. Pb can also be introduced into rivers through weathering of soil and effluent discharge from ground water.

Quantitative data on different sources of $^{210}$Pb in rivers are not available; however, it can be inferred from the behaviour of $^{210}$Pb in fresh water system that the amount of $^{210}$Pb contributed to streams by the weathering and ground water discharge should be small.

The first study of $^{210}$Pb in rivers was reported by Rama et al., (1961) who measured Pb concentrations in three locations along the Colorado river, which is contaminated by waste liquids from Uranium mining operations. They observed that the Pb concentrations decreased dramatically, from 1.4 dpm/liter at the source to 0.3 dpm/liter within short distances downstream. Based on this variations, Goldberg (1963) estimated the removal of dissolved $^{210}$Pb in Colorado and Sacramento rivers to be of the order of weeks. Benninger et al., (1975) have
carried out extensive studies of the fate of Pb in the Susquehanna River System. Based on material balance calculations, they have estimated that most of the atmospheric Pb (99%) is trapped in the soil layers, and only (0.8%) leaves the terrain as attached to stream-borne particles.

f) **Mineralogy:**

Scant attention has been directed at processes acting in river drainage basins 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 many studies (Powers 1957; Griffin and Parrot 1954; Porrenna 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; Goldberg & Griffin 1970; Venkataratnam and Biscaye 1973; Rao & Rao 1977). Naidu (1966) 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 the mineralogy of the sediments of Indian river basins. (kumar and Singh 1978; Subramanian 1980; Biksham 1985).
**Objective of the Present Work:**

The above review highlights the different geochemical studies in world and Indian river basins. The literature review also indicates that the Indian rivers particularly peninsular rivers are not well documented. Meybeck (1976) also pointed out that middle size homogenous basins are ideal for the mass transfer studies since in these basins several environmental factors can be well defined. In India, except for the Ganges and Brahmaputra, all other important basins, namely, Krishna, Godavari, Cauvery, Mahanadi, Narmada and Tapti are middle size of the order of \((1-3) \times 10^2\) km² basin area and together they add up to half the basin size of Ganges and Brahmaputra. Hence in the present work, the geochemistry of Krishna river, which is one of the major and intensively used river basins in South India is investigated.

The main purpose of this study is to examine the following questions:

1. How does the major ion chemistry vary with seasons and what is the average composition of Krishna river water?
2. What are the factors controlling the river water chemistry?
(3) What are all the theoretically expected stable minerals in carbonate and silicate system in Krishna river water? Is predicted mineral equilibria from the water chemistry agrees with that of actual observed mineralogical studies of the suspended matter?

(4) What is the load and rate of chemical and sediment transport carried by Krishna river and how does it compare with other Indian and world rivers?

(5) What is the flux of individual elements? How does it vary within the basin and in the river mouth?

(6) What are the elemental abundances in bed and suspended sediments? How does the sediment chemistry vary with depth?

(7) What is the rate of sedimentation and deposition of major and minor elements? Is there any relation between sedimentation and erosion rates?

(8) What is the grain size distribution in suspended and bed sediments? Is it possible to relate these properties with the sediment transportation?

(9) What is the mineralogy of the basin and how is it influenced by the basin characteristics?

(10) What is the overall effect of man on geochemical processes in the Krishna River Basin?