MINERAL LOAD AND TRANSPORT IN UPPER GANGA BASIN

A THESIS

Submitted in fulfilment of the requirements
for the award of the degree
of
DOCTOR OF PHILOSOPHY

By

S. N. KUMAR LAKKAPRAGADA

DEPARTMENT OF BIOSCIENCES AND BIOTECHNOLOGY
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

OCTOBER, 1989

Gratis

DEDICATED

TO

DR. DEBA KUMAR SAIKIA

COWORKER IN THE GANGA PROJECT

WHO

HAS LEFT FOR HIS HEAVENLY ABODE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"MINERAL LOAD AND TRANSPORT IN UPPER GANGA BASIN"** in fulfilment of the requirement for the award of Doctor of Philosophy, submitted in the Department of Bioscience & Biotechnology is an authentic record of my own work carried out during a period from July 1985 to September 1989 under the supervision of Dr. R.P.Mathur.

The matter embodied in the thesis has not been submitted by me for the award of any other degree.

(S.N. KUMAR LAKKAPRAGADA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. R.P. MATHUR)
Professor
Department of Civil Engineering
University of Roorkee

Dated: 18th October, 1989

The candidate has passed the viva-voce examination held on 28.7.90 at 11:00. The thesis is recommended for award of the Ph.D. Degree.

Signatures of External Examiners

Signature of Guide.

ABSTRACT

In recent years studies on the effect of geochemistry on the environmental health has become an interesting area for technologists. Any rational study on a riverine system cannot be full fledged without a fairly adequate knowledge of its mineral quality. Mineral quality, commonly known as salinity, is a basin wide problem of a river and critically important to the users of lower reaches. The in-depth study of mineral occurrence, behavior and transport is an extremely important aspect in river pollution studies because minerals are the first to enter the water-body in its virgin state and exist within it till the river joins the ocean.

River alimentation and flow regimes play an important role in the occurrence and transport of minerals in a riverine system. In general, the geology, weathering and erosion of rocks play a key role in the mineral transport in the areas where the human activities are minimum, but in the lower stretches of the river, human activities also contribute alongwith the abovesaid natural processes. Sometimes, the mineral concentrations in a riverine system are helpful in identifying the mineral sources in geochemical prospecting practices.

The riverine system under the present investigations is Ganga river, the mighty and holy river of India, originating from the snow clad peaks of Himalayas. Ganga river travels approximately 2525 km in its long journey passing through U.P., Bihar and West Bengal. In addition to the traditional religious bearings, the waters are being used for irrigation, domestic and industrial purposes.

The present investigation involved an in-depth study of occurrence and transport of minerals in the unexplored and zero pollution region of Ganga river, comprising of 510 km stretch from Badrinath to Rajghat Narora, 'The Upper Ganga Reach'. The investigations included the visualisation of the variation in other physico chemical parameters to identify the mineralized zones, the influence of important tributaries, identification of human activities and their impact on mineral transport and to develop a suitable mineral index which reflects the mineral transport.

The physico chemical parameters, which influence the occurrence and transport of minerals like p^H, ORP, conductivity and total dissolved solids alongwith the important cationic and anionic mineral constituents were chosen for the study.

To identify the zones of importance extensive surveys were

conducted from Dec. 1984 to May 1985 at the primary network sampling stations. The stations were fixed on the basis of reconnaissance surveys. The data collected has been analysed and the spatial variations explored. The observations between Rishikesh and Haridwar revealed the importance of the stretch with respect to mineral loading of Ganga river. In this 22.2 km stretch the withdrawal of Ganga water into a canal at Chilla head works leaves very little water to flow downstream and the Song river, which carries a lot of mineral matter joins Ganga at this point. In this stretch the recharge of ground water during lean flow season was also found to be significant.

Song river drains Doon Valley in its course, which is known for its richness in limestone and phosphorite mineral reserves. To assess the impact of Song river on Ganga river, the stretch of Song river was also chosen and the secondary network sampling stations were fixed.

The data of extensive sampling on Ganga and Song rivers was exposed to checks for its accuracy of the analysis. To represent the chemical composition of river systems Hill-Piper Trilinear diagram was plotted which revealed that the composition of Ganga river is dominated by alkaline earths and weak acids throughout the stretch, except at Satyanarayana. At Satyanarayana, the waters showed a mixed type of quality, which is due to the confluence of Song. Same effect was also observed in the spatial trends of other parameters.

Besides the general profiles of physico chemical parameters, Principal Component Analysis was resorted to classify the Ganga river into mineralized and non-mineralized zones, to find out dominating parameters at different locations, and to evaluate the validity of the sampling network and frequency. The results obtained from PCA are in concordance with the observations.

The flow of Song river is chiefly derived by the effluent ground water springs. The four major tributaries Baldi, Bandal, Tawa and Bangla Rao, are the major sources to add more mineral content to the river. The chemical composition of Song river and its tributaries showed distinct spatial variations. The composition of Song water in the initial stages is constituted by alkaline earths and weak acids. After the confluence of Bandal river the composition of waters change and is governed by the presence of alkaline earths with strong acids. Later the waters exhibit a mixed type of chemical composition in which no single cation or anion pair exceeds 50 percent of the total ions. The temporal variation in mineral parameters clearly indicated the base flow and run-off conditions of the river, whereas, the spatial variations reflect the gradient of mineral deposits in Song river stretch as it passes towards Ganga river through Doon Valley.

To represent the mineral transport and the impact of various tributaries on the mineral profile of Ganga an attempt was also made to calculate mineral indices by using physico chemical parameters. The proposed indices were aimed to provide tangible information about the mineral quality of Ganga river by avoiding huge amounts of data. The formulations of the reported general WQI and statistical approaches were considered. Out of the reported indices the formulations of Horton's and Mc Duffie's RPI were considered because of the parameter flexibility. Among the statistical approaches, Harkins index was selected.

To minimise the subjectivity in the proposed index, opinion poll was conducted for the selection of parameters, rating scale and weightages for the selected parameters. On the basis of responses received, the following parameters p^H, total dissolved solids, bicarbonates, carbonates, chlorides, sulfates, calcium, magnesium, sodium, cadmium, nickel, manganese, total anions and total cations were included in the calculation. To assess the contribution of heavy metals in the mineral index values, indices were calculated separately by including and excluding the heavy metals.

The trends of all the three indices were observed to be similar, but the extent of increase or decrease was different, because of difference in the formulations. In the trends of mineral indices in Ganga river the impact of Song was clearly visible and is supported by the trends of mineral parameters. From the mineral index profiles of Song river, the impacts of Baldi and Bangla Rao were distinct. Comparison of index values in Ganga and Song rivers, with and without heavy metals, clearly indicated the significance of heavy metal contribution in both the rivers.

ACKNOWLEDGEMENT

I take this opportunity of express my deep sense of gratitude to Dr. R.P.Mathur for his valuable guidance and constant encouragement throughout the period of my thesis work with his valuable suggestions, critical comments and constant involvement in the study.

Iam grateful to the present and former Heads of Civil Engineering Department and Department of Bioscience and Biotechnology for providing necessary facilities to complete this work.

I am highly indebted to Sri Tauqeer A. Siddiqui, Smt. Sangita, Sri R.L.Sharma, Sri Sultan Ahmad, Sri Dinanath, Sri Lal Singh and other coleagues of Centre of Environmental Engineering, Civil Engineering Department for their invaluable help throughout the work.

I gratefully acknowledge the help of Sri Himanshu Joshi, B.P.Nauriyal, S.K.Sisodia, Late Dr. D.K.Saikia and Anil of Ganga Project at different stages.

I am also thankful to Dr. J.P.Gupta, Sri.B.U.M.Gaud, Sri. J.Ravi Sankar and Sri. Dejene W. Mariama and other friends for their valuable cooperation extended to me at the verge of submission.

I acknowledge my gratefulness to the Department of Environment, Government of India and Ministry of Human Resource Development for financial assistance.

It is my immense pleasure to extend my deep sense of gratitude to my parents for their encouragement. Lovely thanks to my wife Rajni and son Prashant for their constant encouragement, moral support and patience which has provided necessary inspiration in this long journey. I gratefully acknowledge my sister Dr. Krishna Kumari (RRL, Hyderabad) for giving me inspiration.

Last but not least acknowledgements are to all my friends for their moral boosting whenever I was out of spirits.

(S.N. KUMAR LAKKAPRAGADA)

Dated: 17th October, 1989

ACKNOWLEDGEMENT

I take this opportunity of express my deep sense of gratitude to Dr. R.P.Mathur for his valuable guidance and constant encouragement throughout the period of my thesis work with his valuable suggestions, critical comments and constant involvement in the study.

Iam grateful to the present and former Heads of Civil Engineering Department and Department of Bioscience and Biotechnology for providing necessary facilities to complete this work.

I am highly indebted to Sri Tauqeer A. Siddiqui, Smt. Sangita, Sri R.L.Sharma, Sri Sultan Ahmad, Sri Dinanath, Sri Lal Singh and other coleagues of Centre of Environmental Engineering, Civil Engineering Department for their invaluable help throughout the work.

I gratefully acknowledge the help of Sri Himanshu Joshi, B.P.Nauriyal, S.K.Sisodia, Late Dr. D.K.Saikia and Anil of Ganga Project at different stages.

I am also thankful to Dr. J.P.Gupta, Sri. B.U.M.Gaud, Sri. J.Ravi Sankar and Sri. Dejene W. Mariama and other friends for their valuable cooperation extended to me at the verge of submission.

I acknowledge my gratefulness to the Department of Environment, Government of India and Ministry of Human Resource Development for financial assistance.

It is my immense pleasure to extend my deep sense of gratitude to my parents for their encouragement. Lovely thanks to my wife Rajni and son Prashant for their constant encouragement, moral support and patience which has provided necessary inspiration in this long journey. I gratefully acknowledge my sister Dr. Krishna Kumari (RRL, Hyderabad) for giving me inspiration.

Last but not least acknowledgements are to all my friends for their moral boosting whenever I was out of spirits.

(S.N. KUMAR LAKKAPRAGADA)

Dated: 17th October, 1989

CONTENTS

1.0 INTRODUCTION

1.1 GANGA RIVER

1.2 MINERAL LOAD IN RIVERS

1.3 EFFECTS OF MINERAL POLLUTION

1.4 OCCURRENCE OF MINERALS IN RIVERINE SYSTEM

1.5 STUDIES ON MINERAL POLLUTION IN WORLD RIVERS

1.6 MINERAL STUDIES IN INDIAN RIVERS

1.1 GANGA RIVER

Ganga is not only the life blood of millions of people who inhabit the sprawling plains and beyond, it is the life force that has fashioned and nourished the unique culture and sustains it to this day. The awesome beauty of the mountain fastness as that it sculptures, the rich wide and lust plains that adorn its varigated apron, and the colourful bathing ghats that line its meandering courses along population centres, all lend enchantment to its legendary waters. Mighty, changeful and capricious, but forever at work, forever beautiful, it symbolises the beauty and mystery of life itself, inspiring sages, seers, poets and philosophers through the ages.

The river Ganga travels approximately 2525 km in its long journey from the origin in Himalayas to reach the Bay of Bengal through Uttar Pradesh, Bihar and West Bengal. The Ganga discharges 459,000 million cubic meters of water as annual discharge (Rao, 1975). Ganga is 21st in world waters with regard to the annual discharge and basin area (UNESCO, 1969). The Ganga basin is the home for more than 37% of national population. Ganga basin consists of eight states viz. Uttar Pradesh, Madhya Pradesh, Haryana, Delhi, Rajasthan, Bihar, and West Bengal (Dasgupta, 1984). It confines 242.1 million people and irrigates vast areas to provide food to a large population. In addition to the traditional religious bearings associated and intensive irrigation, the waters are being used for domestic and industrial purposes.

1.2 MINERAL LOAD IN RIVERS

Any study on a riverine system is incomplete without adequate information of its mineral quality. Mineral quality is a complex basinwide problem and critically important to the users. The study of mineral occurrence, behavior and transport is an important aspect in river pollution studies as minerals are the first to enter the water body in its virgin stage and exist within it till the river joins the ocean. Every element which moves in lithosphere, hydrosphere, biosphere, and atmosphere, has an entire spectrum of possible effects on organisms. For a particular element, trace concentrations may be beneficial or necessary for life and higher concentrations may be toxic, and still higher concentrations are lethal. Along the steps of geochemical cycle, natural processes such as weathering and volcanic activity, combined with anthropogenic activities release all types of minerals into the environment. Therefore they are concentrated or dispersed by other natural processes such as leaching, accretion, deposition, and biological accumulation. Human use of natural resources through agriculture, industrial, and mining activities release the minerals into the environment.

1.3 EFFECTS OF MINERAL POLLUTION

Studies on the effect of geochemistry on environmental health has assumed importance for physicians and scientists. Higher death rates have been observed near the East coast twice than those in plains and mountain areas in America due to mineral concentrations. The severity of the disease Schistosomiasis is considered to be related with climatic conditions. But the appearance of the disease in the Amazon river basin was minimum though the climatic conditions were favourable in the area. This was attributed to the insufficient amounts of calcium in some areas and the acidity of water in presence of copper and other heavy metals in other areas to support the snails, the intermediate host (Saucer, 1971). Some physicians have tried to correlate the heart disease with the mineral content in drinking waters and concluded that drinking of hard water results in low incidence of heart diseases. They have predicted that minerals like calcium, magnesium, lithium, strontium, and silicon may protect against cardiovascular mortality. Psychiatrists have observed that more the content of lithium taken, lesser will be the extent of psychic disorders (Marvin Grosswith, 1980). In a similar study the effect of calcium, magnesium, lead and cadmium in drinking water on Arterioclerosis and hypertension in pigeons have been reported (Nathaneil et al, 1982).

Minerals have some adverse effects also. Voluminous literature is available on the toxicity and adverse effects of minerals including trace heavy metals.

Fluorine is fairly abundant in rocks and soils. Fluorine is an important trace element for the formation of calcium fluoride which increases the crystallinity of apatite (calcium phosphate) and prevents tooth decay. The optimum beneficial dose is about 1 mg/l, but on the other hand fluorine levels of above 1.5 mg/l cause mottling of enamel (Maier, 1971). Regardless, fluoride concentrations of 4 to 6 mg/l greatly reduce the prevalence of Osteoporosis, a disease characterized by the reduction of bone mass (Cargo, 1974).

Lack of iodine causes goiter. Furthermore, an iodine deficient pregnant lady may give birth to mentally disordered dwarf (Spencer, 1970).

The toxicity of heavy metals related to pollution control has been reviewed by many authors. The quality criteria for drinking water and also for irrigation water with reference to heavy metals have been decided with certainty (WHO, 1984).

Zinc is an essential trace element for plants, animals and man, and is most abundant. Zinc deficiencies may lead to plant diseases that cause crop loss and poor seed development (Pories, 1971). Zinc deficiencies in early stages of development may cause disorders in bones, joints and skin in animals and man due to decrease in the activity of DNA-polymerase. Though these effects of zinc deficiency on man are known, but it may also be associated with some arterial diseases, and lung cancer (Gilbert, 1947). Excessive amounts of zinc may be toxic to the aquatic biota (Nriagu, 1980). Prasad(1976) has reported three types of reactions of zinc to human beings.

Manganese is the second most abundant metal after iron and its importance was enhanced by the discovery of its involvement in glucose utilization (Forstner et al, 1983). Though it is an essential element for biological activity, if it exceeds 0.15 mg/l it causes damage like stains on the material, undesirable taste in breweries and in combination with iron it may lead to deposition on the distribution system.

Iron is common in many rocks, it is an important component in clay soils. The quantity of iron present in surface water vary with the geology of the catchment area. The dissolved oxygen of water precipitates iron as $Fe(OH)_3$ which is detrimental to bottom dwelling invertebrates, plants or incubating fish eggs. Iron at levels of about 0.3 mg/l stains plumbing fixtures and laundry and causes an undesirable taste to beverages.

Cobalt is abundant element in the earth's crust (crustal abundance is approximately 25 mg/kg). Cobalt is an essential trace metal for human body, because vitamin B12 is a cobalt(II) complex. Co(II) activates the enzyme by occupying the low symmetry sites in enzymes. Besides its importance in enzymatic activation, cobalt has recognized effects on human thyroid, heart and possibly kidney, along with the occupational lung disease observed in the cement carbide industry and allergic manifestations (Smith and Carson, 1984). Though WHO has not suggested any guiding value for drinking water, due to its known adverse effects, cobalt should be included in multielement surveys of environmental media, human diets and human tissues.

Nickel is another trace metal which is abundant in most of the rocks. Nickel salts are soluble and can occur as a leachate from nickel bearing rocks. Nickel is considered to be non-toxic to man, but studies indicate that nickel in water is toxic to plant life at concentrations as low as 500 µg/l (Train, 1979).

Copper is an essential element required in human metabolism, and is generally considered non-toxic for man at the encountered levels in drinking water. All the rocks of the earth's crust contain copper like basic eruptive rock contain 100-200 mg/l, metamorphic rocks contain 30-40 mg/l, and acid eruptive rocks like gratine, rhyolite contain 10-20 mg/l (Aubert and Pinta, 1980). Though copper is non toxic to man, at levels above 5 mg/l it imparts color and an undesirable taste to water. Copper is toxic for fish and aquatic insects at concentrations 0.01 to 1.7 mg/l (Warmick and Bell, 1969).

Cadmium, a biologically non-essential, non-beneficial element, is highly toxic. Once entered, cadmium is transported to all parts of the body through the blood-stream. Cadmium in high concentrations is observed in pancreas and spleen. The most serious effect of cadmium is the damage to kidneys, particularly the renal tubes. Extreme cases of cadmium poisoning associated with softening of bone is caused by disruption of the calcium-phosphorous balance in the renal tube. Cadmium occurs in nature in the areas of zinc and lead ores as sulfide salts. The WHO guideline value for drinking water is 0.005 µg/l.

Lead is a non-essential toxic heavy metal. It enters the human body via inhalation and through ingestion of lead contaminated food and water. Lungs retain lead more efficiently than gastrointestinal track. Once absorbed into the blood stream it is transported to all parts of the body. It is accumulated in liver, kidneys and in bones by replacing calcium. Organic lead in contrast to inorganic lead does not accumulate in bones but concentrates in lipid tissues, including those of central nervous system. The WHO guideline value for drinking water is 0.05 µg/l.

~~1~~.4 OCCURRENCE OF MINERALS IN RIVERINE SYSTEM

River alimentation plays a key role in the occurrence and transport of minerals in a riverine system. A number of factors influence the river run-off, viz. 1) dimensions and configuration of drainage basins, 2) climatic conditions and types of precipitation, 3) the topography, 4) the nature of slopes and their conditions, 5) water permeability of rocks, and 6) human activities. Mixed type of alimentation is common in piedmont and other areas. Such rivers are alimented by both rains and glaciers by receiving greatest amount of water in summer, and in spring, atmospheric precipitation provides some additional alimentation. Some times, depending upon the watershed strength in the basin underground water also contributes the river alimentation, because it is drained by river channels.

In general, the river water derives its composition by a number of ways:

1. Weathering of minerals in the watershed, since the minerals react with carbonated rain water depending upon the original mineral present in rocks.
2. Contribution of ground waters through seepage during low flow regime or through springs in the watershed.
3. The precipitation, if any, in the river basin.
4. Human activities, particularly in downstream region through domestic and industrial effluents.

In other words, it can be stated that the geology of rocks, weathering and erosion play an important role in mineral occurrence in areas where human activities are minimum. However it is a combined function in stretches where human interference is predominant. Human activities like mining enhance mineral occurrence and transport in the riverine system. The average concentrations of some trace metals in rocks are shown in Table 1.1 (James, 1988).

The movement of a trace metal present in a rock during weathering depends on the mineral in which it occurs and on the intensity of chemical weathering. Many trace metals do not substitute readily in feldspars or the common ferro magnesium minerals. They may be present in chemically resistant accessory minerals such as zircon, apatite, or monazite, or sulfides, which weather rapidly in oxygenated water. The resistant minerals generally remain unaltered unless weathering is very intense by gibbsite formation, thus the alterations do not cause high trace metal concentrations in rivers. Sometimes dilution prevents high trace metal concentrations though the weathering is intense. On the otherhand, many metals occur as sulfides eg. copper, molybdenum, silver, mercury and lead, and these sulfides often contain selenium, arsenic and cadmium. Since sulfides weather rapidly, such ore deposits can give rise to local high concentrations of trace metals. Thus, the concentration of trace metals in rivers and streams is used to locate the ore deposits in geochemical prospecting practices. Mining actvities can result in release of trace metals by the exposure of broken impermeable rocks to water and exposure of sulfide bearing rocks to oxygen during mining activity, resulting in rapid alteration and dissolution.

Table 1.1 Average Trace Metal Concentrations Observed in Rocks (mg/kg)

METAL	GRANITE	BASALT	SHALES	SANDSTONE	LIMESTONE
Manganese	450	1500	850	50	1100
Iron	Major	Major	Major	Major	Major
Cobalt	4	48	19	0.3	0.1
Nickel	10	130	68	2	4
Copper	20	87	115	2	4
Zinc	50	105	95	16	20
Cadmium	0.13	0.2	0.3	-	-
Lead	17	6	20	7	9

Heavy metals dispersed in any source rock get concentrated in shales due to the formation of organo-metalic complexes during weathering and erosion of the geochemical rock cycling. Trace metals, regardless of their source, do not persist as the metals are transported through aquatic systems. They may be in speciation with organic complexes like humic substances and inorganic complexes like $-CO_3^{--}$, $-COOH^-$, $-OH^-$ groups of manganese and aluminium.

In general salt-loading and salt-concentrating effects influence the mineral concentration in streams and rivers. The former is associated with the contribution from natural sources such as springs, influent ground water, run off, and discharge of additional salt into stream through municipal, industrial wastes and agricultural return flows. In contrast, the salt concentrating effect occurs as a result of consumptive use of water, like municipal and industrial, evaporation, out of basin diversions, and irrigation.

1.5 STUDIES ON MINERAL POLLUTION IN WORLD RIVERS

The majority of world rivers have been studied from geochemical point of view. The Colorado river basin Water Quality Control Project identified salt-loading and salt-concentrating effects and their contribution to overall mineral quality. The studies revealed that in upper Colorado basin runoff contributed 52%, irrigation 37%, point sources (like springs, wells) 10%, and municipal and industrial about 1% of the salt load (William et al, 1973).

Gibbs (1967,1970,1972) conducted extensive studies on the Amazon river system. Stallard et al (1983) reported that in the Amazon river basin, the substrate lithology and erosion regime holds the control of surface waters within a catchment. They classified the rivers depending upon the total cation charge and geology. The rivers with total cation charge between 0 to 200 μe/l drain the intensely weathered materials and show high levels of Fe, Al, H^+ and exhibit cation ratios similar to those of substrate rocks. Rivers with total cation charge between 200 to 450 μe/l drain siliceous terrains and their main cation load is typically enriched in Na over K and Ca over Mg when compared to the rocks in their catchment. Rivers with 450-3000 μe/l cation charge drain marine sediments and exhibit high level of Ca, Mg, alkalinity, and $SO4^{--}$, similar to the rivers draining reduced shales and minor evaporites. Rivers with total cation charge more than 3000 μe/l drain massive evaporites and are rich in Na and Cl. The study concluded that the third and fourth rivers to have 1:1 ratio of Na:Cl and Ca-Mg:alkalinity-SO4 caused primarily by the weathering of carbonates and evaporates.

The relationship between the geology of the catchment and the chemistry of river water sample of Mackenzie river, Canada was studied in detail by many workers (Hitchan et al, 1969, Hitchan and Krouse, 1972, Peake *et al*, 1972). Reeder *et al* (1972) used factor analysis. Relatively high concentrations of certain species have been related to the catchment geologies in the following associations:

a) Mg, Ca, Sr, HCO_3, and SO_4 with carbonate rocks and gypsum

b) K, B, and Na with illitic bedrock

c) Si with bentonites and hot spring areas

d) Na and Cl with evaporates

e) Fe and B with glauconitic substrates.

Since the term minerals include the heavy metals also, maximum studies emphasized on heavy metal pollution, because of their toxicity and hazardous effect on environment.

Literature is replete with occurrence of heavy metal content in water and sediment of all important rivers of the world.

The heavy metal pollution in United States was reported by Durrum and coworkers (1963, 1971). They studied eighteen elements in rivers, soil and ocean. The contamination of important American rivers by acid mine drainage, brines from oil fields and mill wastes have been studied by Kopp and Kroner (1967). The preponderance of metal elements in sediments and water column of Genesee river of Central New York state have been studied by Reddy (1977, 1978). Williams, Aulenbach and Clerceri

(1974) have discussed the source and distribution of heavy metals in aquatic environment by providing information in Hudson river, Cuyahoga river, St. Mary's river, and Delwara river. White et al (1985) analyzed heavy metal concentration in terms of relative atomic variation (RAV) and reported the distribution of heavy metals in sediments of various south Lousiana streams and waterways.

Abdullah and Royle (1972a, 1972b, 1974) have studied the heavy metal concentrations in rivers and lakes of Wales and in the coastal waters of Great Britain. They have mapped the cadmium concentration in Welsh river. Vivian and Massie (1977) have reported the impact of smelting and mining activities and other industries on river Tawe and South Wales.

The Rhine river is considered to be one of the heavily polluted rivers of the world. About 70% of the pollution load flows into the river from Federal Republic of Germany (Forstner et al, 1983). Inhoff and coworkers (1980) have reported the behaviour and fate of heavy metals in Ruhr river, a tributary of Rhine river. A compilation of the available reports on the heavy metal in Rhine river system has been presented by Forstner and Wittman (1983).

The presence of heavy metals in water column and sediment in Rhine river in Netherlands has been studied by Groot and coworkers (1977).

The main rivers and lakes in Switzerland, with respect to heavy metals have been investigated by Vernat and coworkers (1977).

The metal association with chemical forms and their availability for biological activity in sediments of Mapocho river, Chile have been studied by Garlaschi and coworkers (1985).

Considerable amount of work on heavy metal contamination has been presented by Forstner and Wittman (1983) after the episodes of Minimata and Itai Itai diseases in Japan. Sakai and coworkers (1986) have reported the distribution of heavy metals in water and sediments of Toyohira river, Japan.

The heavy metal load and concentration of copper in major U.S.S.R. rivers has been investigated by Konovalov and Nazrov (1969, 1975). Forstner and Wittman (1983) reviewed the copper contamination of Moscow river for a period of 1968-1970.

1.6 MINERAL STUDIES ON INDIAN RIVERS

The studies on Indian rivers geared up in early seventies. Unlike the larger riverine system of world the Indian rivers have all climatological, geographical, geological, and human factors to influence their quality. Almost all the major Indian rivers have been studied, in a broader sense. The Chinese and Indian rivers are dominated by chemical weathering and hence show higher total dissolved solids (Meybeck, 1976). Indian rivers transport 30% of sediment transported by the world rivers (Milliman <u>et</u>

al,1983). It indicates that both chemical and physical weathering are equally important in Indian riverine systems.

Handa (1972) has reported the water quality of Ganga river and its relation with the geo-chemistry in the Ganga basin. A stretch between Haridwar to Calcutta was chosen for this study. Sarin and Krishnaswamy (1984) compared the chemical composition of Ganga and Brahmaputra river waters.

A recent review by Subramanian (1987a) on the geochemistry of nine major rivers of India, states that Indian rivers do not follow any well defined variations in the major dissolved constituents such as calcium, magnesium, bicarbonate, sulfates, sodium, and phosphates. The water chemistry of Ganga, Brahmaputra, Indus, Godavari, Krishna, Mahanadi, Cauveri, Narmada, Tapti, and some minor rivers was compared in this study. The variation of total dissolved solids in lean flow seasons indicates ground water interaction whereas dilution reduces solids in high flow seasons.

Rate of erosion and the extent of sediment transport was also reported by Abbas and Subramanian (1984). Bikshamiah et al (1980) have reported the mass transfer of chemicals and sediment in Godavari river basin.

The rate of erosion in Ganga was the subject of study by Gibbs (1980), Subramanian (1979a). The occurrence of minerals and their interrelation in Yamuna has also been reported by

Subramanian (1979b) and by Sarin _et al_ (1984) in river sediments.

Subramanian _et al_ (1987b) have reported heavy metal distribution in the Ganga and the Brahmaputra riverine systems. In their studies on Ganga, sampling was done downstream of Haridwar.

A comprehensive study on Ganga pollution in adjoining region of Patna was presented by Sinha (1986), which included physical and chemical parameters and heavy metals like copper, zinc, nickel, and cobalt.

The effect of municipal waste on Ganga river at Patna was studied by Sharma _et al_ (1987) and they ascribed the regenerating capacity of Ganga to be due to the high concentration of short-lived radium.

In a recent report, Subramanian _et al_ (1987c) mentioned the lithology, physiography and the water chemistry of river Ganga from Rishikesh to Calcutta. In their study they compared the average chemical composition of Indian, Chinese and world rivers.

Central Board for Prevention of Water Pollution monitored the Ganga river with the network of 41 sampling stations from Haridwar to Diamond harbour, Calcutta.

The occurrence and transport of some selected heavy metals in Ganga from Badrinath to Narora was studied by Saikia (1987), as a part of Department of Environment, New Delhi sponsored research project "Pollution Modelling of Upper Ganga Basin".

An integrated research project covering the entire Ganga river from source to bay was sponsored by the Department of Environment, Govt. of India. For efficient implementation of the project the entire Ganga basin was divided into three clusters (1) the upper Ganga stretch from source to Narora (2) the middle Ganga stretch from Narora to Ballia (3) the lower Ganga stretch from Ballia to Hoogly. Fourteen universities were endorsed the task viz. Garhwal University, Gurukul Kangri Viswavidyalaya, University of Roorkee (upper reach), Aligarh Muslim University, Feroze Gandhi College – Raibareilly, Banaras Hindu University (middle reach), Patna University, Bhagalpur University, Rajendra Agricultural University – PUSA, Bardwan University, Kalyani University, Bidhan Chandra Krishi Viswavidyalaya, Jadavpur University and Calcutta University (lower reach).

In the upper Ganga basin (Cluster-A), the integrated research project **"Pollution Modelling of upper Ganga basin"** was undertaken by the University of Roorkee to project a clear picture of the state and extent of pollution of river ecosystem. The stretch of the river from Badrinath to Narora was allotted to this project team. **Mineral load and transport in Upper Ganga Basin** has been incorporated as a sub-theme of the project and constitutes the theme of this work.

2.0 SYSTEM UNDER STUDY

2.0 THE SYSTEM UNDER STUDY

The system under study is a 510 km stretch of river Ganga from Badrinath to Narora (Fig.2.1). The first 240 km stretch, from Badrinath to Rishikesh (upper stretch) is mountainous having an average bed slope of 1 in 67. The latter 270 km from Rishikesh to Rajghat Narora (lower stretch) is plains having an average bed slope of 1 in 4100.

The altitude and relief of the origin governs the climatic conditions of the mountainous region. The valleys experience tropical climate in the summer months. Wild winds in narrow valleys, and heavy fog during winter in wide valleys are conspicuous features of the weather of the region. The precipitation at different locations depends on the altitude and location relative to the ridges. The monsoon generally commences towards the end of June and extends upto the middle of September. Winter depressions cause snowfall (in the higher altitudes) from January to March. April and May are marked with thunder and occasional hailstorm. Occasional rain occurs at high elevations before setting of monsoon. The zone of maximum precipitation, both summer and winter, lies between 1200 m and 2100 m. The zone above 2400 m experiences lesser summer rainfall. Winter depressions at high altitudes cause three to five meters of snowfall from November to May.

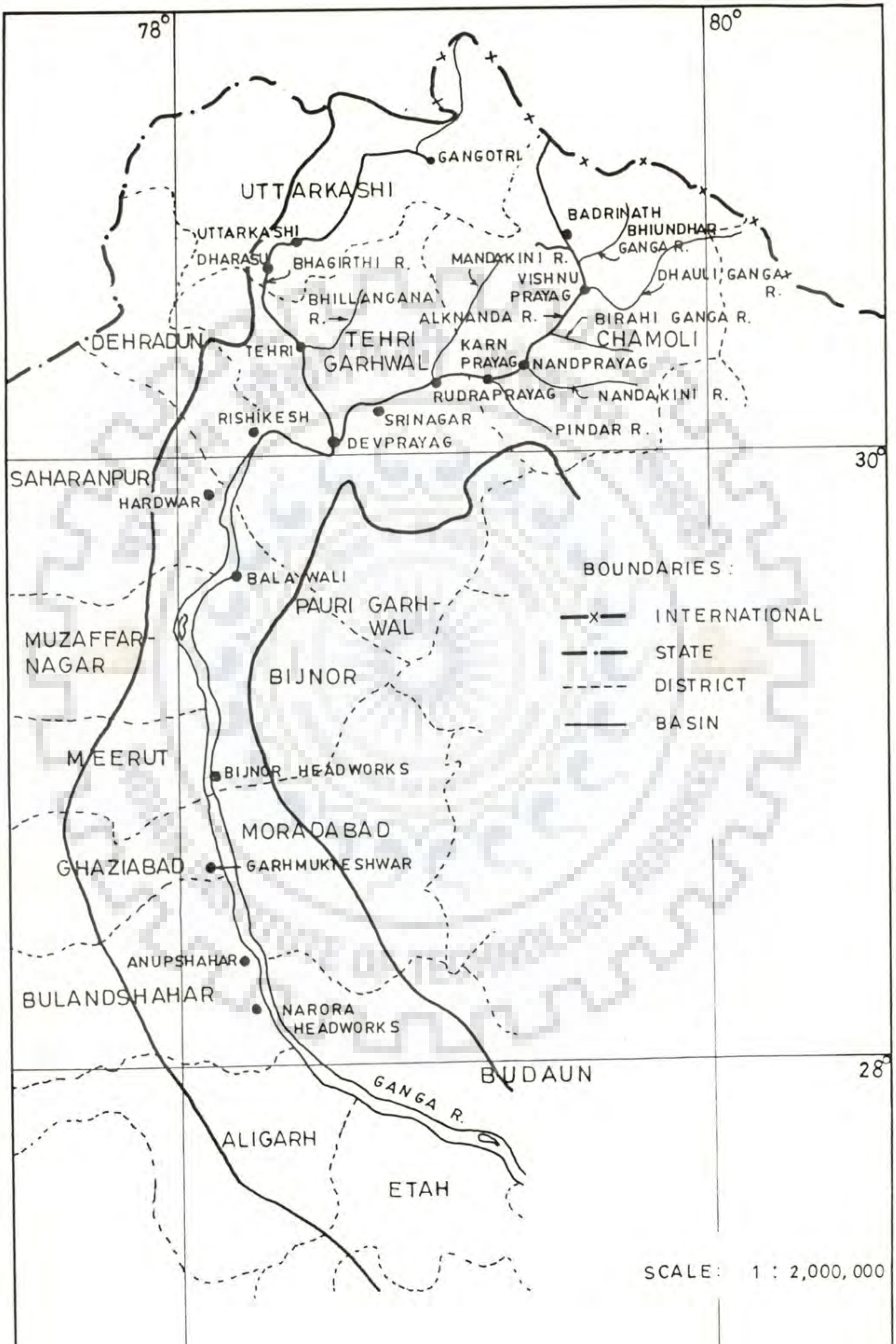


FIG.2·1- UPPER GANGA BASIN

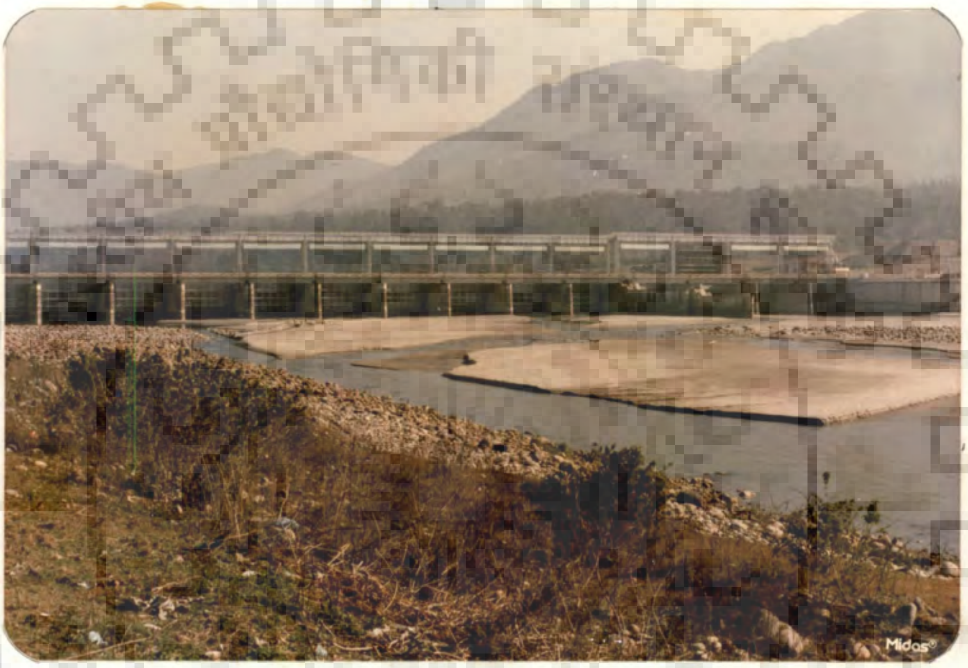
In the lower stretch the air temperature starts rising from March onwards, the hot season covers the period from April to June. The air temperatures drop with the onset of monsoon, June onwards rendering the weather humid. The monsoon sets up by the end of July over the entire region and heavy downpour continues upto September. The winter extends from December to February (Singh, 1987).

The lean flow regime of the river extends from October to March in which the underground water contributes to the river flow. With the starting of summer from April till setting of monsoon the melting of glacier ice from the higher altitudes contributes to the major run-off of the river. In the high flow regime the river flows upto the brim and water with eroded sediment load.

2.1 PHYSIOGRAPHY OF GANGA RIVER

The Ganga proper is formed by two tributaries, Bhagirathi and Alaknanda. Though the Bhagirathi is accepted traditionally as Gangaji, the Alaknanda is the larger river.

The Alaknanda originates from the Saptonath-Kharak group of glaciers and descends at Mana for its downward journey in south-east direction. The river receives the waters of Dhauli at Vishnuprayag at an elevation of 1,517 MSL. The combined river flows south-west to Chamoli district receiving small streams the Rudra, the Garur, the Patal ganga and the Birahi. Thence, in the southerly direction to Nandaprayag, where Nandakini joins from east at an elevation of 897 MSL. Again it turns south-west to Karnaprayag by crossing a mighty gorge across the Central Himalayan range between the peaks of Nandadevi (7,816 m) and Badrinath (7,068 m). At Karnaprayag, the Pindar river, which gathers its waters from Nandadevi and east Trisul (6,803 m) joins the Alaknanda on the left bank (30-15-45 and 79-15-29) at an elevation of 832 MSL. Thence at Rudraprayag it receives Mandakini from north on the right bank (30-17-10 and 79-1-32) at an elevation of 633 MSL. Turning south-west again it flows by Srinagar to Devprayag to join the Bhagirathi, which emerges from Gaumukh glacier, in Tehri district (30-8-45) at an elevation of 625 MSL. The river is now called Ganga river. It passes through north of Mussoorie hills and finally breaks through the Shivalik range near Rishikesh, to enter the plains. 8 km downstream of Rishikesh an off-take channel diverts significant amount of water into a power channel, Chilla head works, leaving practically no water and reducing it to a shimmering thread (Plate-1). Subsequently, however, it gets replenished by many tributaries like the Song at Satyanarayana, the Suswa and the tail waters of Chilla power channel. Again at Bhimgauda head works an irrigation canal, the Upper Ganga Canal, takes the maximum amount of water and leaves very little of water to flow in the river bed. Excess water of Upper Ganga Canal finally meets the river and ground water and some small streams keep the



LEAN FLOW CONDITIONS OF GANGA RIVER DOWNSTREAM CHILLA BARRAGE

PLATE-1

Ganga flow live towards the lower stretch.

The next major headworks is located at Bijnor, about 73 km downstream of Haridwar where the river is intercepted and an appreciable part of flow is diverted to the Madhya Ganga Canal. Further downstream waters from Ramganga feeder meet Ganga river through Baya river at Tigri, about 90 km from Bijnor and provide some relief. The river is once again intercepted at Narora about 82 km from Garhmukteshwar, where the headworks facilitate diversion to Lower Ganga Canal.

The most critical zone in the Upper Ganga stretch is the stretch between Rishikesh and Haridwar. In this 22.2 km stretch the withdrawal of the Ganga river water into a canal influences the salt-loading and salt-concentrating effects. The first diversion at Chilla headwork leaves very little water to flow downstream. Just 5 km downstream of this diversion, the Song river, which carries a lot of mineral matter joins Ganga at Satyanarayana. In between Chilla head-works and Satyanarayana in the lean flow seasons the river run-off is contributed by ground water seepage. About 0.5 km upstream of Song confluence, the treated effluent of IDPL, Virbhadra finds its way to Ganga river along with Rishikesh sewerage.

2.1.1. PHYSIOGRAPHY OF THE MAIN TRIBUTARIES:

Nandakini: Nandakini rises in the glaciers on the western slopes of Trishul in Nandak and paraganah Bodhar of Garhwal district, has its principal sources (30-16-10 and 79-46-15) from the foot hills of Nandadevi temple. Nandakini receives numerous torrents on either side and eventually joins on the left bank of Alaknanda at Nandaprayag.

Pindar: Pindar, a river of Kumaon region, rises from a glacier (30-15-30 and 86-2) in a hallow bounded by snowy peaks (above 6400 m) at an elevation of 3868 MSL and has a course generally south, passing by Kuphini. During its course it receives Sundarbhunga, Konwari, Kaliganga, Goptaragadh and Tousar in addition to numerous small torrents. It joins Alaknanda at Karnaprayag.

Mandakini: Mandakini, a river of Garhwal region, rises near Tehri at south east base of the Kedarnath peak (30-47 and 79-81). It holds a course generally southward (30-38), receiving Sini river, Kali river, Bira river, Sagar, Pabi, Gabini, Byun, Darma and the Lostar torrents. After a course of 72 km from its source it joins the Alaknanda river at Rudraprayag.

Bhagirathi: The Bhagirathi, rises from Gangotri glacier at Gaumukh (30-56:79-41) at an elevation of 3,900 MSL, north of Kedarnath. The Bhagirathi joins Jahnavi, some distance to the north of main Himalayan range and about 11 km below Gangotri temple. The combined river then cuts through the main Himalayan range between Bandarpunch (6,315 m) and Srikanta (6,133 m) through a magnificent gorge in which the river bed is 3,960 m below the peaks on either side. During its course between Dharasu and Devprayag it receives Bhilangna river on its left bank.

Nyar: The Nyar or the Saini, the last tributary to join the Alaknanda in hilly terrain, is formed by the confluence of its eastern and western branches at Bhatkulu in patti Manyarsun. The eastern branch rises on the north west slopes of Dudu-ke-toli range (30-7-30 and 79-10), at an elevation of 2130 m- 2750 m above sea level. It flows southwesterly, then south, then due west to its confluence with the western Nyar. The united stream flows north and west and falls into the Alaknanada at Byas ghati (30-3-40 and 78-38-30), at an elevation of 410 MSL.

The Ganga in the plains receives waters from Song and Suswa tributaries from Doon Valley at Satyanarayana (78-14-50 and 30-2).

2.2 GEOLOGICAL ASPECTS OF THE ALAKNANDA VALLEY

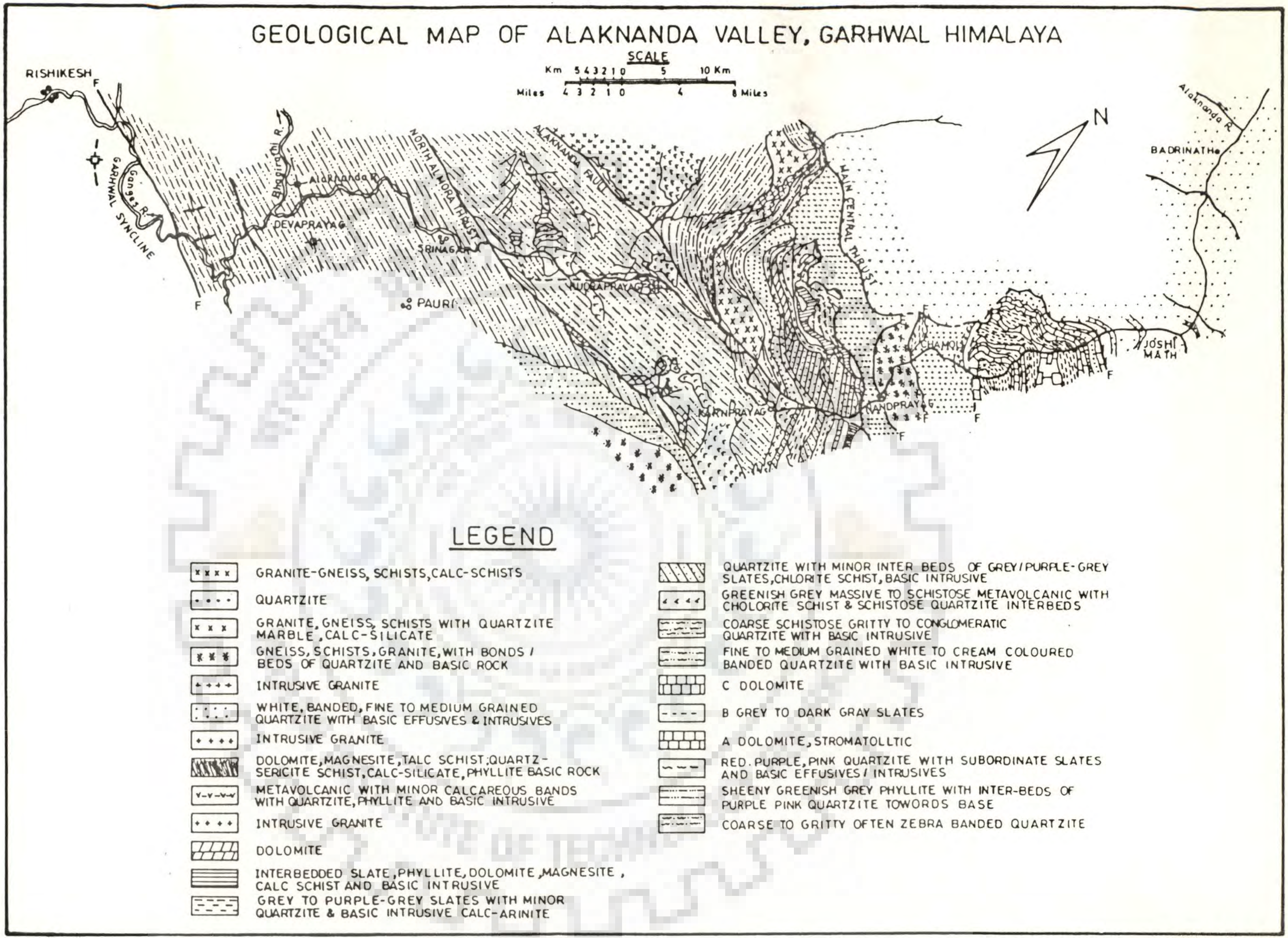
The river in the upper stretch flows over complex geological formations and in the lower stretch on alluvial soils of Indo- Gangetic plain.

Saxena et al (1979) described the drainage pattern in the upper stretch of the river basin. The folded, faulted and fractured terrain of the river is wholly occupied by perennial and intermittent surface and underground torrents, streams and springs. The Alaknanda valley is rich in hidden treasure of waters of underground seepage.

The geology of the mountainous course of the river has been studied by many workers (Kumar et al, 1974,1975, Srivastava et al 1979). The lithological assemblages have been discussed by Robindra and Negi (1979), Kumar (1974). Doval et al (1980) have studied the geology of Alaknanda valley around Srinagar and concluded that the area consists of metapelites, metapsammites and carbonate rocks associated with metabasics. Saklani (1972) has described the litho-stratigraphy of the area between Bhagirathi and Bhilangna rivers. In the lower part of Mandakini stretch and at the Alaknanda confluence the rocks are identified as granite and quartzite (Negi et al, 1980).

The stratigraphic formations of Mandakini valley have been studied by Rao et al (1980). They found the stratigraphic formations at Guptakashi as amphibolite, thin bands of marble, and few intercalations of schist, schistose quartzite. Felspatic quartz schist and quartz mica schist, chlorite schist with thin bands of dolomite and marble are identified at Agasthamuni. At Rudraprayag, ortho quartzite-volcanic associations are observed.

The Alaknanda on its journey from origin to Rishikesh in the Himalayas crosses three major thrusts. They are Main Central Thrust, the Alaknanda Fault and the North Almora Thrust (Fig.2.2).



AFTER A. AHMAD
(1979)

FIG 2·2

The rock types at the origin of the Alaknanda river upto Joshimath are mainly quartzite of central crystalline formation of Precambrian age. Between Pandukeshwar and Joshimath the river encounters a band of intrusive granite of Chamoli crystalline formation of late Precambrian age. Then again downstream to Joshimath it passes through white, bonded, fine to medium grained quartzite with basic efflusives and intrusives of late precambrian age and crosses the main central thrust. Upto and at Pipalkoti the rocks are chiefly quartzite, dolomite, calc-arinic of late Precambrian age. After passing quartzite formation at Chamoli, the river has gneisses, schists, granite with bands or beds of quartzite of Maithana crystalline of precambrian age on its way to Nandaprayag. Then it passes over the rocks dolomite, magnesite, talc schist, calci-silicate, quartz, phyllite basic rocks, granite, dolomite, metavolcanic with minor calcareous bands with quartzite, phyllite and basic intrusive, chlorite schist of Pokhri formation of Precambrian age upto Karnprayag. Between Karnprayag and Rudraprayag the important rocks on the way are conglomeric quartzite with basic intrusive, red, purple, pink quartzite with subordinate slates and basic efflusive or intrusives of Rudraprayag formation of Cambrian to Devonian age. In this stretch the river flows along the Alaknanda Fault in western direction at and near Chamoli crosses it. Then the river crosses the North Almora Thrust and encounters quartzite with minor inter beds of grey or purple-grey slates, chlorite schist, basic intrusives of same age at and around Srinagar and Devprayag. On the way to Rishikesh from Devprayag it encounters mainly conglomerates and clays and doon gravel in Upper Shiwaliks. After Rishikesh, Ganga River enters into the Indo-Gangetic alluvial plains (Srivastava and Ahmad, 1979). Details of various types of rocks occurring in the Alaknanda valley are presented in Table 2.1.

2.3 THE PROBLEM

The problem involves an indepth study of occurrence and transport of minerals in the unexplored and zero pollution region of the river Ganga. The investigations include the following aspects:

1. Visualisation of the variation in the physical characteristics like pH, ORP, conductivity and total dissolved solids; which influence the mineral presence in the riverine system.
2. Identification of mineralised zones in the Ganga stretch.
3. Influence of important tributaries on the behavior of minerals in Ganga river.
4. Identification of probable human activities and extent of their impact on mineral transport in the river.
5. Developing suitable water quality indices which reflect the mineral transport in the river.

TABLE 2.1 DESCRIPTION OF ROCKS OCCURRING IN THE ALAKNANDA VALLEY

Rock Type	Mineral Composition	Mode of Occurrence
Quartz	Quartz (SiO_2)	Metamorphic rocks (formed by the recrystallization of sand stones)
Granite	Quartz (SiO_2) and K-felspar($KAlSiO_3$)	Igneous rock, plutonic and acidic rocks
Dolomite	Dolomite ($CaCO_3$ and $MgCO_3$)	Sedimentary rock with varying chemical composition
Talc-Schist	Schist of Talc [($Mg_3(SiO_{10})(OH)_2$]	Metamorphic
Phyllite	albite ($NaAlSi_3O_8$) Biotite $Mg,Fe)_3(AlSi_3)O_{10}(OH,F)_2]$ Muscovite [$KAl_2(AlSi_3)O_{10}(OH,F)_2$]	Low grade Metamorphic rocks
Canglomerates	Quartz, pebbles	Sedimentary rocks and rudaceous
Basic Intrusives	Plagio clase felspar, hornblende [$(Ca,Na,Mg,Fe,Al)_{7-8}$ $(AlSi)_8$ $O_{22}(OH)_2$], hypersthene [(Mg,Fe) SiO_3] Diopside [Ca Mg Si_2O_6]	Igenous, plutonic and basic rocks
Amphibolites	Hornblende, albite, hypersthene, diopside	High grade Metamorphic
Marble	Calcite	Metamorphic limestones
Schistose quartzite	Quartzite in schistose structure	Metamorphic
Felspartic quartz schist	Schist of quartz and felspar	Metamorphic
Quartz mica schist	Schist of muscovite and quartz	Metamorphic
Chlorite schist	Schist of chlorite [$(Mg,Fe)_5$ Al $(Al,Si_3O_{10}(OH)_9$] epidote [$Ca_2(Al,Fe)_3$ (SiO_4)] garmet [$(Ca,Mg,Fe,Mn)_3$ $(Fe,Al,Cr)_2(SiO_4)_3$]	Metamorphic

These investigations have been taken up with a view

- to bring to light the actual concentrations of minerals transported to Ganga River through various tributaries in the mountainous stretch and to identify the mineralised zones in the stretch
- to obtain adequate information about the impact of human activities on mineral transport in the region, which is supposed to be rich in mineral reserves
- to develop a single water quality index which can show the mineral behaviour in the stretch

2.3.1 PARAMETERS CONSIDERED:

The physico-chemical parameters, which influence the occurrence and transport of minerals in the Ganga riverine system like pH, oxidation reduction potential, conductivity and total dissolved solids along with the anionic constituents like carbonates, bicarbonates, chlorides, sulfates, nitrates, nitrites, phosphates, and their cationic counter-parts like calcium, magnesium, sodium, potassium and trace metals like iron, manganese, lead, zinc, cadmium, nickel, cobalt, copper have been chosen for this study.

2.3.2 THE APPROACH:

To identify the zones of importance with respect to the concentration of the abovesaid minerals in the stretch between Badrinath to Narora, extensive surveys were conducted from Dec.

'84 to 'May 85. The surveys were conducted at sampling stations of primary network fixed for the D.O.En. sponsored project 'Pollution Modeling of Upper Ganga Basin.' The primary sampling network consisted of the following stations:

Badrinath
Nandprayag
Rudraprayag
Srinagar
Devprayag
Rishikesh
Satyanarayana
Balawali
Bijnor
Garhmukteshwar
Anupshahr
Rajghat (Narora)

Sampling was done on a monthly frequency. The data was analysed thoroughly and the spatial variation in total cations and total anions have been explored. The profile (Fig.2.3) shows a sudden increase at Satyanarayana and a sizeable increase at Balawali and Bijnor. The probable reasons for the increase have been visualised. In contrast to other tributaries of Ganga river, which originate from Himalayas, the Song passes through Doon valley, which is famous for its richness in limestone and

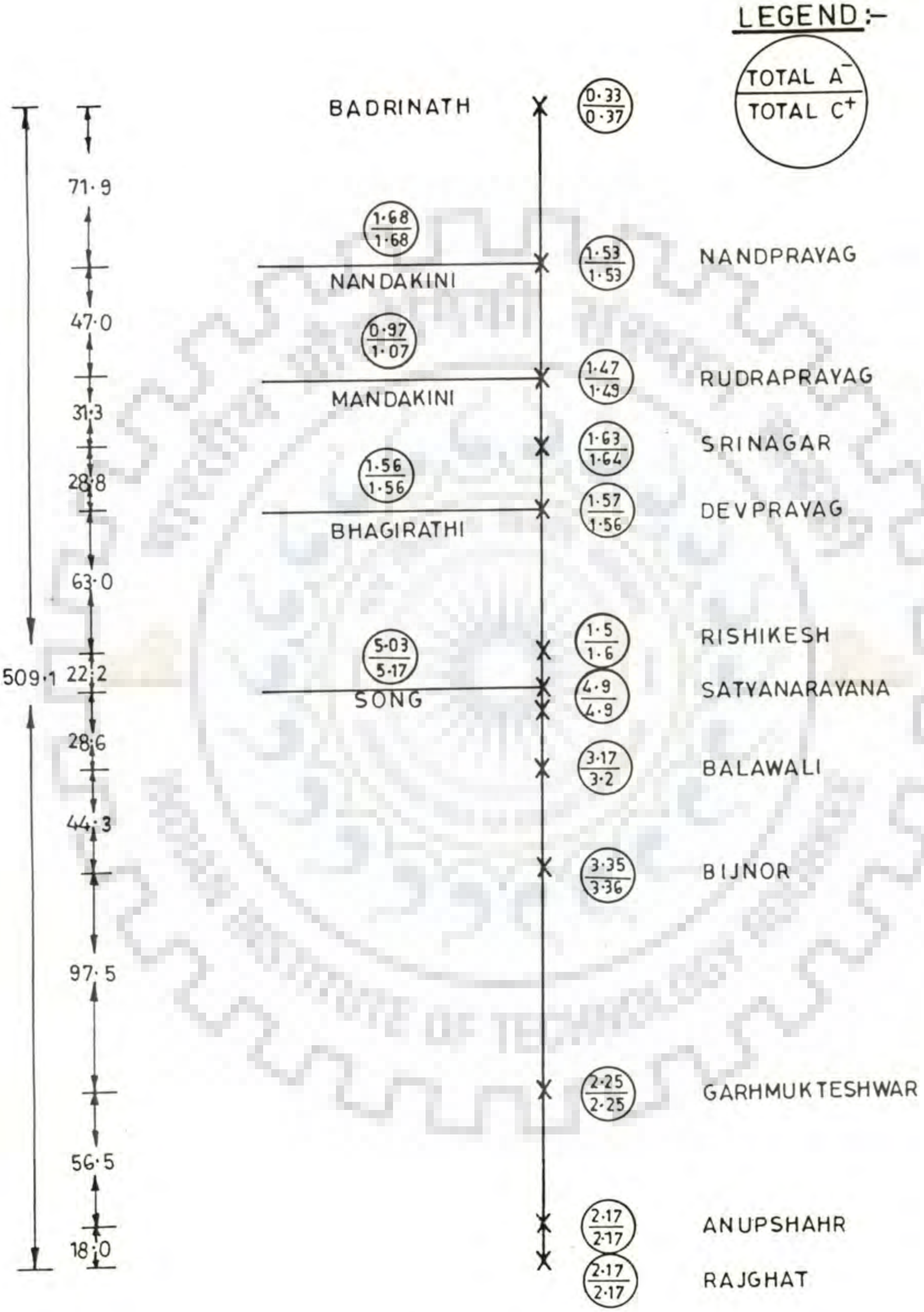


FIG. 2·3—VARIATION IN TOTAL ANIONS AND TOTAL CATIONS (me/l) phosphorite mineral deposits. To assess the impact of Song on Ganga river, the stretch of the former has also been chosen for study in regard to the mineral parameters.

2.4 PHYSIOGRAPHY OF THE TRIBUTARY SONG

Song river gathers its water from the springs and comes into a shape of stream at Unialgaon in Tehri district (78-23-5 and 30-17-40). The course of the river is along the southwestern border of Dehradun district. From Unialgaon it flows southwards for some distance and turns west and northwest to the confluence with Bandal, an important tributary of Song, at Maldevta (78-8 and 30-20-12). It then moves in southwest direction and receives waters from another tributary Baldi on its downward journey (78-22 and 30-20-40) to Doiwala. After Doiwala, Song flows south to the confluence of Suswa and Jakhan Rao and in southeastern direction towards Raiwala. Just under the road bridge on Haridwar-Rishikesh road another tributary Tawa joins Song. Thence the flow is southwards towards Satyanarayana. Finally at Satyanarayana, another stream Bangla Rao adds up to the Song river contribution towards Ganga. (Fig.2.4).

The physiography of the main tributaries is as follows: The first to join Song is Bandal, which arises in Tehri district. From its origin it flows along the border between Dehradun and Tehri in southwest direction to Maldevta. It carries the

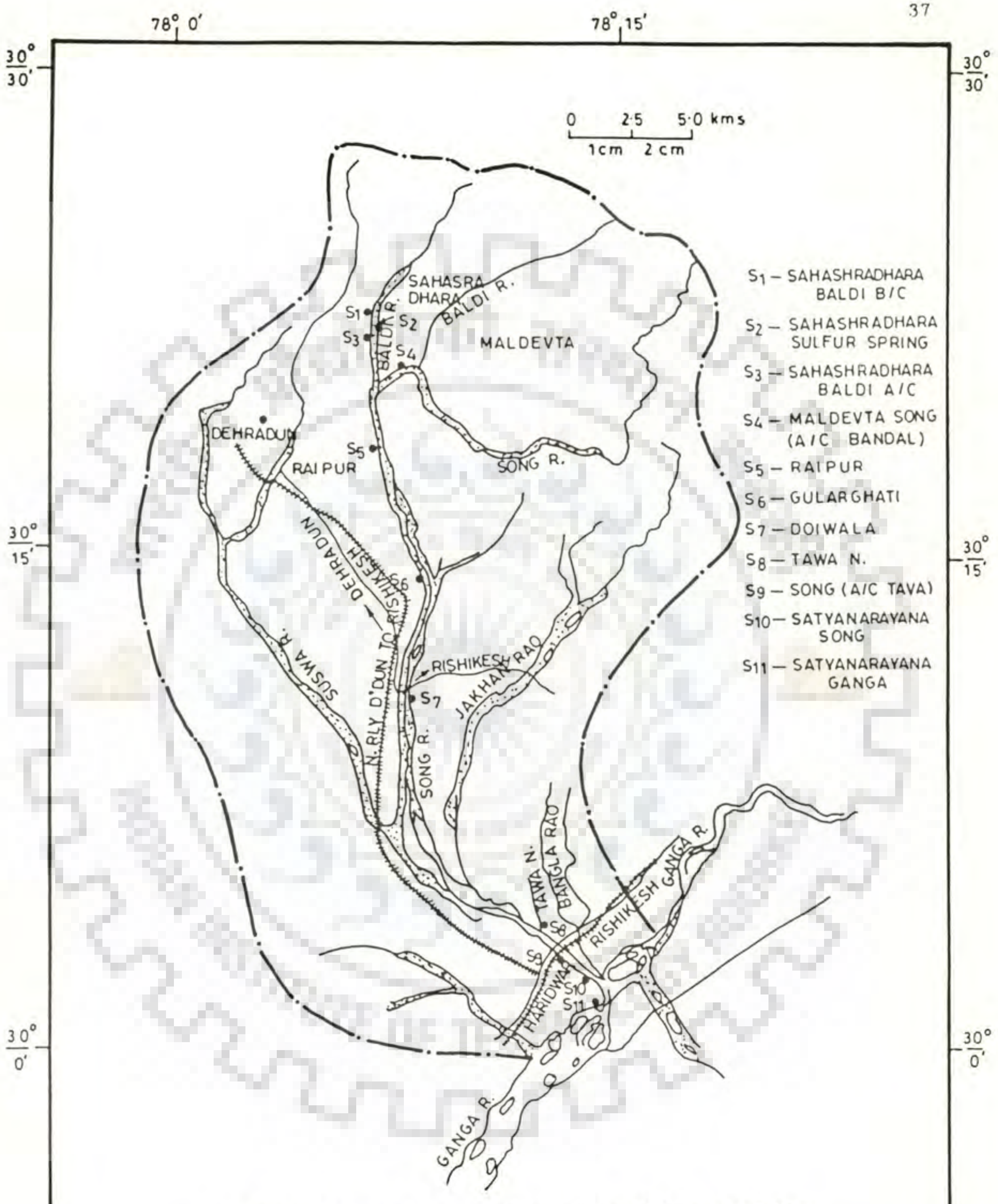


FIG.2·4–LOCATION MAP OF SONG RIVER STRETCH discharge of Maldevta Phosphorite and Pyrite mines.

2.4.1 PHYSIOGRAPHY AND GENERAL FEATURES OF THE SONG RIVER STRETCH:

The Song river and its tributaries are intermittent in their initial stages, where the ground water table is well below the river bed. In the later stages of their flow, they become perennial due to the addition of ground water effluent springs.

Since Doon valley is very significant for faulting, the courses of the rivers flowing through it is unique. Faults are considered as conduit for fluids when it has permeability and potential gradient in the fault plane. Fault plane develops void-channels or channels by separation of walls, applying a little amount of resistance to flow. Fault planes thus give birth to many springs where the intersection of ground surface with watertable is high. Reaches of the river is also intermittent in some areas, where it passes over the outcrop of a porous and permeable formation in which the water-table may, from time to time, lie well below the bed of the river. In such areas the river shows the dying out phenomenon. Thick limestones commonly enhance this process. In the Song river course the geological part and man made activities change the flow from time to time.

Song river in the initial stages is perennial. It is fed by ground water in lean flow months and in monsoon months rain water increases its flow. As soon as it enters Doon valley, the siphons constructed in its course, divert maximum water for irrigation. Similar diversions take place in Baldi and Bandal rivers also all leaving small amount of water to flow in Song river. In the lean flow season ,between Maldevta and Raipur, river becomes intermittent and flow is from recharged waters between Gularghati and Doiwala. From Doiwala onwards the stream Suswa nourishes Song river flow. At Raiwala, the recharged water in the form of Tawa and Bangla Rao joins Song towards its confluence with Ganga.

2.4.2 CLIMATIC CONDITIONS OF THE CATCHMENT AREA:

The climate of the area is subtropical monsoonal. This type of climate implies hot summers and severe winters. The climate shows appreciable spatial variation. The mean summer and winter temperatures are normally 29.1 and 12.1 degrees celsius respectively. The hottest month is June and the coldest is December. The mean annual rain fall is 1585 mm received mostly in the period from July to September. However some winter showers are also common.

2.4.3. CATCHMENT ACTIVITY:

In the upper reach Song river flows through the mixed forest and enters the Doon valley. In the Doon valley, in the initial stages it flows through the area where the limestone mining and phosphate mining is predominant. Downstream Doiwala it has irrigation as the main catchment activity.

2.4.4. DRAINAGE PATTERN IN SONG RIVER CATCHMENT:

The drainage pattern of the Song and its tributaries in the upper reaches is subparallel, while in the lower reaches it tends to become parallel and dendritic. Drainage system is made of braided channels which are not deeply incised. Zones of seepage into river course is common in this area. Thus, the sources of the rivers are mainly the recharged waters and in monsoon the rain water reinforces the flow.

2.5 GEOLOGY OF THE SONG RIVER CATCHMENT AREA

Fig 2.5 shows the catchment area and drainage pattern of Song river. The main geological formations through which the Song river as well as its tributaries pass are the upper Shiwaliks, middle Shiwaliks, the pretertiary rocks and the Doon gravels. The pretertiary rocks are mainly Tal and Krol formations. At Maldevta, the zone betwen Tal and Krol is rich in Phosphates and Pyrites. At Sahashradhara area the main formations are Krol A and Krol B. When compared to pretertiary rocks, the mineral contribution from upper and middle Shiwaliks is minimum. They chiefly consist of sandstone, shale, and claystone.

The mining activity of limestone and phosphorites is significant in the Song river catchment area in contrast to Ganga river catchment area. The important tributaries also flow

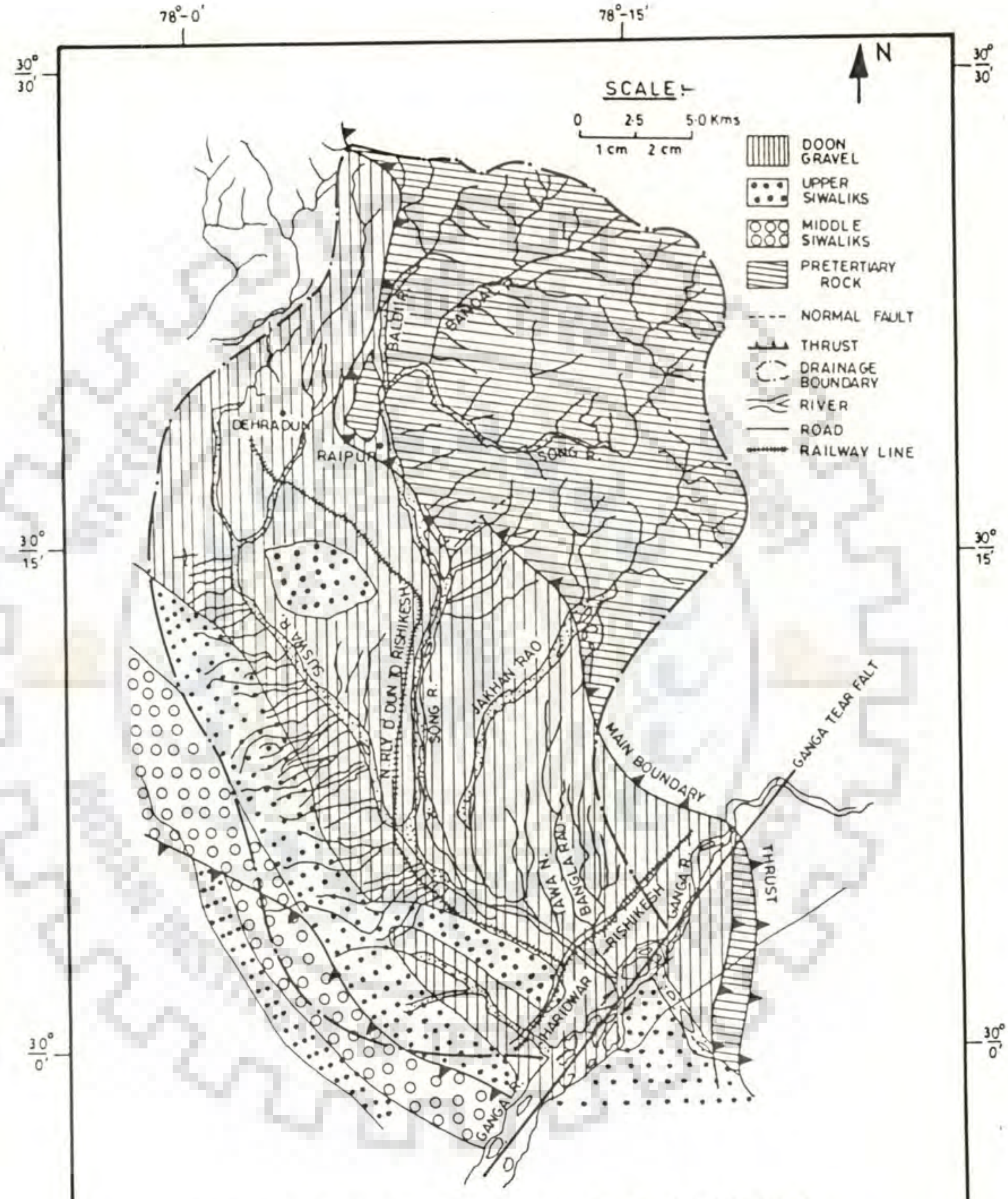


FIG. 2.5- GEOLOGICAL MAP OF THE SONG RIVER CATCHMENT AREA

through these areas. Baldi river flows through the Krol formation consisting of very high grade limestone. In its initial stages, Baldi river has the lower Krol limestone. Then it flows through the upper Krol limestone followed by high grade limestone near Sahashradhara area. Down stream of Sahashradhara the area consists of the Doon gravels. At Sahashradhara, the sulfur spring falls into Baldi river and increases the sulfate concentrations.

Bandal river flows through quartzite of Tal formation in its initial stages, then near Maldevta enters the phosphorite rich lower Tal shales and slates. Phosphorite deposits in Maldevta area are primarily associated with chert, black shales and minor dolomite, belonging to Tal formation of Cambrian age, and more or less conformably overlie a sulfurous craggy dolomite unit of upper Krol formation. These phosphorites are rich in iron-sulphide and inundates the river rich in sulfate ions. Downstream of Maldevta, Bandal flows through upper Krol limestone followed by infra Krol slates. Then it has a band of boulder bed and limestone and slates of upper blaini before its confluence to Song. Then the combined stream flows through Doon gravels of Nagthat quartzite and lower blaini boulder bed. The shales present at the Tal-Krol combination zones are also rich in iron-sulfide and increases the sulfate concentration in the river.

The most critical zone in the Song river is the stretch between Maldevta and Doiwala (Fig 2.4). In this stretch, the salt-loading and salt-concentrating effects influence the transport of minerals caused by extensive mineral reserves, leaching and weathering processes and man-made diversions of waters. The siphons divert significant amounts of water into the channels leaving very small amount for irrigation and drinking purposes. Due to this the Song river remains dry between Maldevta and Gularghati from December to June which may extend from October-June. Thus, the flow regime of Song river can be divided as:

(1) The Flow Regime-I, the period during which the Song river flows from Maldevta to Satyanarayana.

(2) The Flow Regime-II, the period in which Song river remains dry in the upper reaches, upstream Doiwala.

The area around Maldevta and Sahashradhara alongwith its structural features has geological importance being rich in mineral reserves which enriches both surface and ground waters with minerals.

3.0 MATERIALS AND METHODS

3.1 SAMPLING STATIONS
  3.1.1 PRIMARY SAMPLING NETWORK
  3.1.2 SECONDARY SAMPLING NETWORK
3.2 SAMPLING FREQUENCY
3.3 SAMPLE COLLECTION AND HANDLING
3.4 PROCEDURES OF ANALYSIS
  3.4.1 CORRECTNESS OF THE ANALYSIS

3.0 MATERIALS AND METHODS

The study presented herein deals with the upper stretch of Ganga with Alaknanda as the main tributary.

3.1 SAMPLING STATIONS

The primary and secondary sampling stations were fixed after an extensive reconnaissance on the basis:

- that the station represent, the state of the aquatic system including inputs, withdrawals and related features.
- that it should be accessible in all seasons.
- that it should have uniformity of concentration of pollutants across the river section implying well-mixed conditions.

3.1.1 PRIMARY SAMPLING NETWORK:

The primary network was represented by the following stations (Fig.3.1 & 3.2). The relevant details are presented in Table 3.1.

1. Badrinath:It is the first sampling station situated 8 km down of Mana at an elevation of 3123 MSL adjacent to the source of the river Alaknanda. In winter it remains covered with snow. Only from May to 1st part of November it is accessible and attracts a large number of pilgrims. There are hot springs known as 'Tapta Kunda', where the devotees bathe (Plate-2). The effluents from 'Tapta Kunda' finally meet the river downstream.

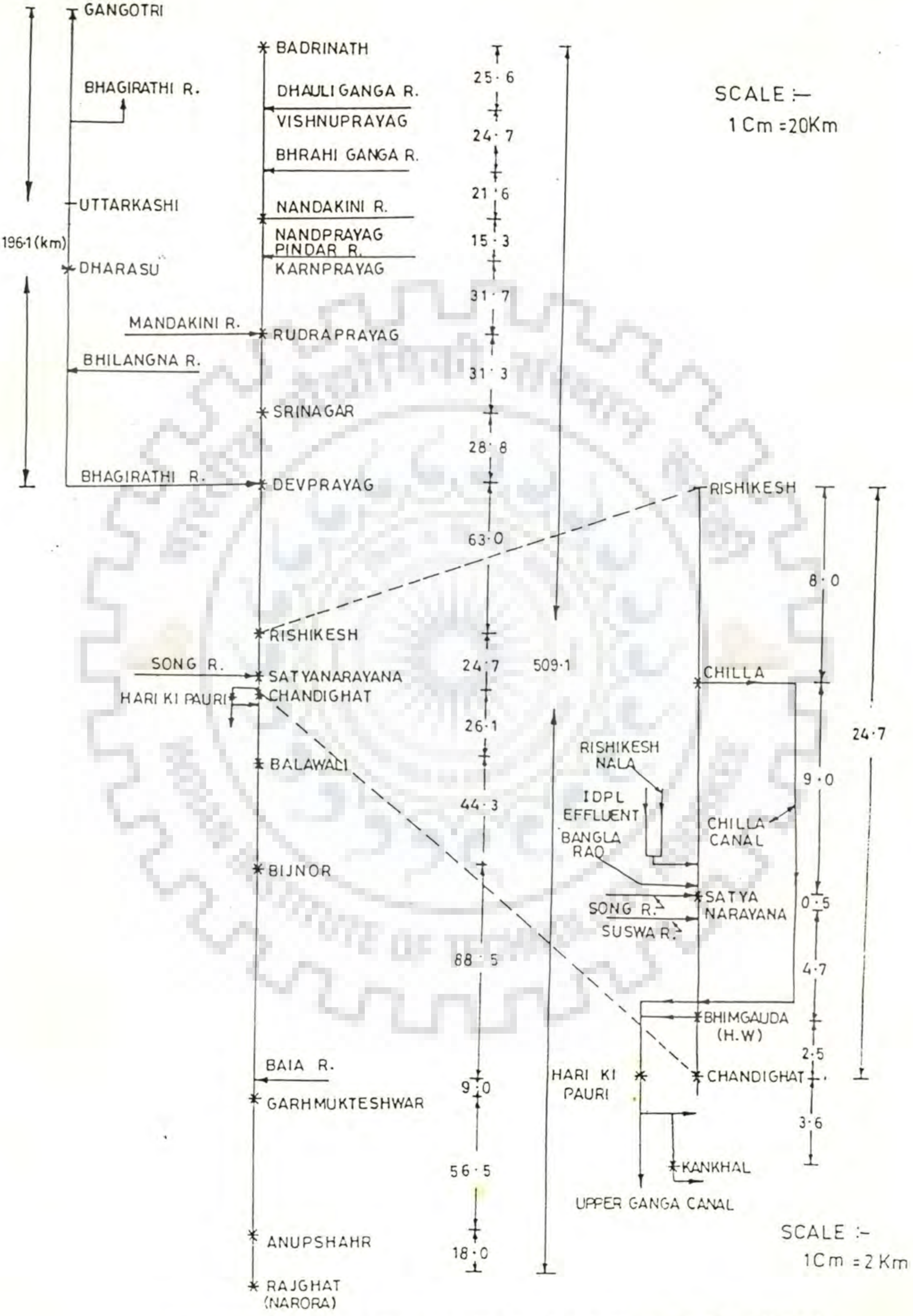


FIG. 3·1 — SCHEMATIC DIAGRAM OF GANGA RIVER SYSTEM

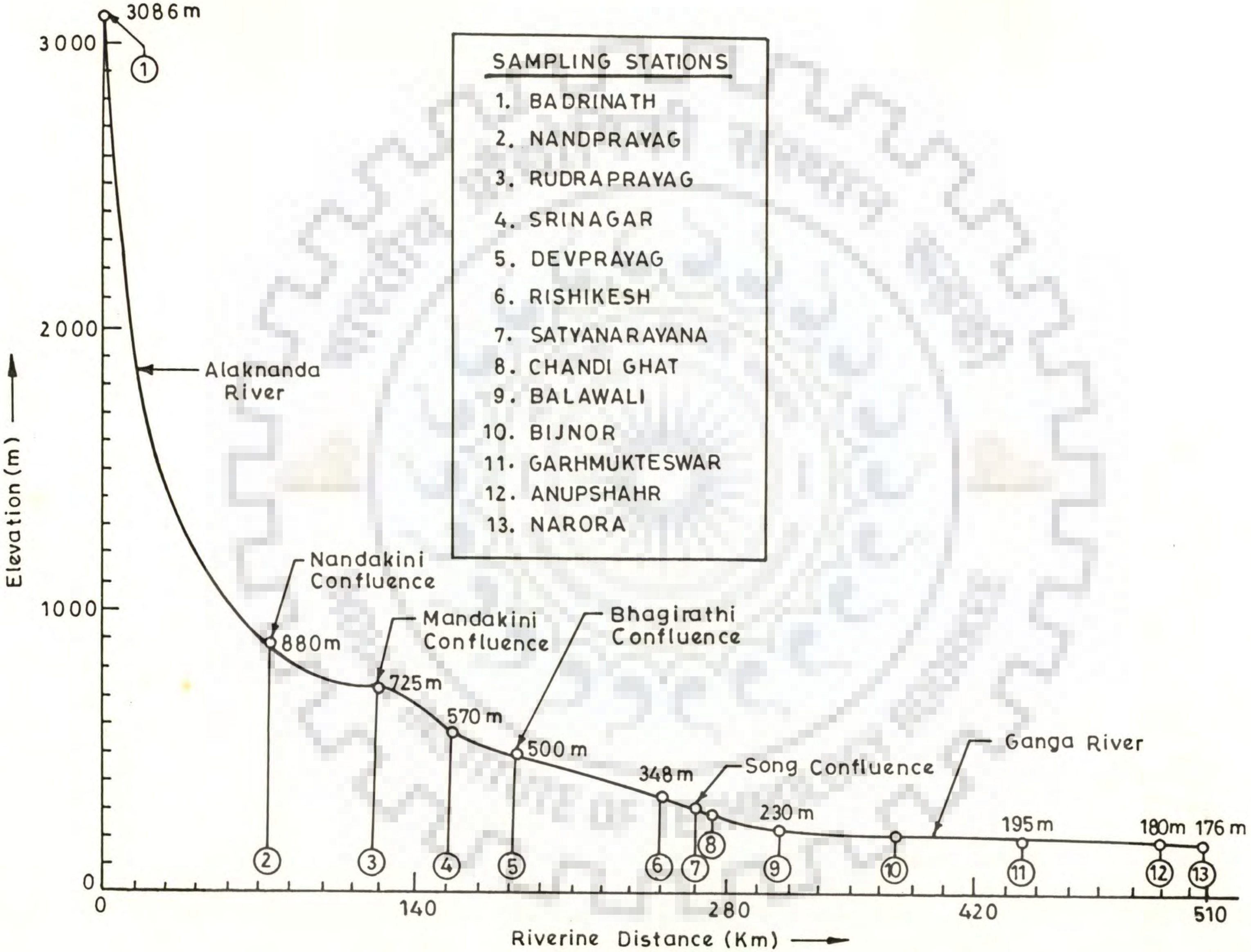


FIG. 3·2 — L-SECTION OF GANGA RIVER
(Badrinath to Narora)

TABLE 3.1 LIST OF PRIMARY SAMPLING STATIONS ALONGWITH RELEVENT DETAILS

Stn. No.	Sampling Stations	Distance from Badrinath	Elevation (m)	Latitude	Longitude	Activities of concern at and around station
0	Badrinath	0	3086	30°-44'-29"	79°-29"-41"	CB,DM
1	Nandprayag	71.9	880	30°-19"-53"	79°-19'-08"	DM,AG
2	Rudraprayag	118.9	715	20°-17'-09"	78°-59'-04"	DM,AG
3	Srinagar	150.2	570	30°-13'-16"	78°-47'-26"	CB,CR,DM & AG
4	Devprayag	179.0	500	30°-08'-54"	78°-36'-59"	CB,DM,AG
5	Rishikesh	242.0	348	30°-07'-21"	78°-19'-10"	CB,CR,DM
6	Satyanarayana	259.0	-	29°-57'-38"	78°-14'-32"	DM,ID,AG
7	Balawali	292.5	230	29°-37'-55"	78°-06'-24"	CR,AG
8	Bijnor	337.1	-	29°-22'-55"	78°-04'-35"	CR,AG,WR
9	Garhmukteshwar	434.6	195	28°-45'-40"	78°-08'-41"	CB,CR,DM & AG
10	Anupshahr	491.1	180	28°-21'-27"	78°-16'-58"	CB,CR,DM & AG
11	Rajghat Narora	509.1	176	28°-14'-32"	78°-21-51"	CB,CR,DM & AG

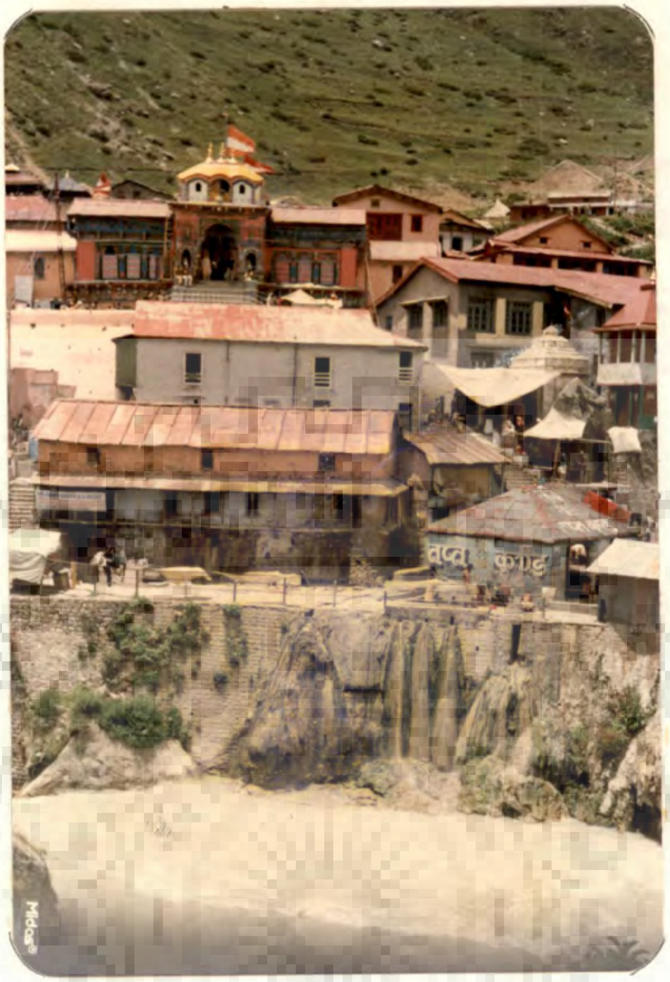
CB = Community Bathing, DM = Point/Nonpoint Domestic Efflents
CR = Cremation and Post Cremation Activity (eg.Disposing of Ash etc.)
ID = Point/Nonpoint Industrial Effluents
WR = Water Regulation, AG = Agrucultural Runoff

2. **Nandprayag:** It is situated 71.9 km downstream of Badrinath at an elevation of 880 meters. The tributary Nandakini meets the river Alaknanda at Nandaprayag. Nandaprayag is small town having few educational institutions, dispensary, tourist lodge and rest houses. Bathing activities and domestic discharges are not significant.

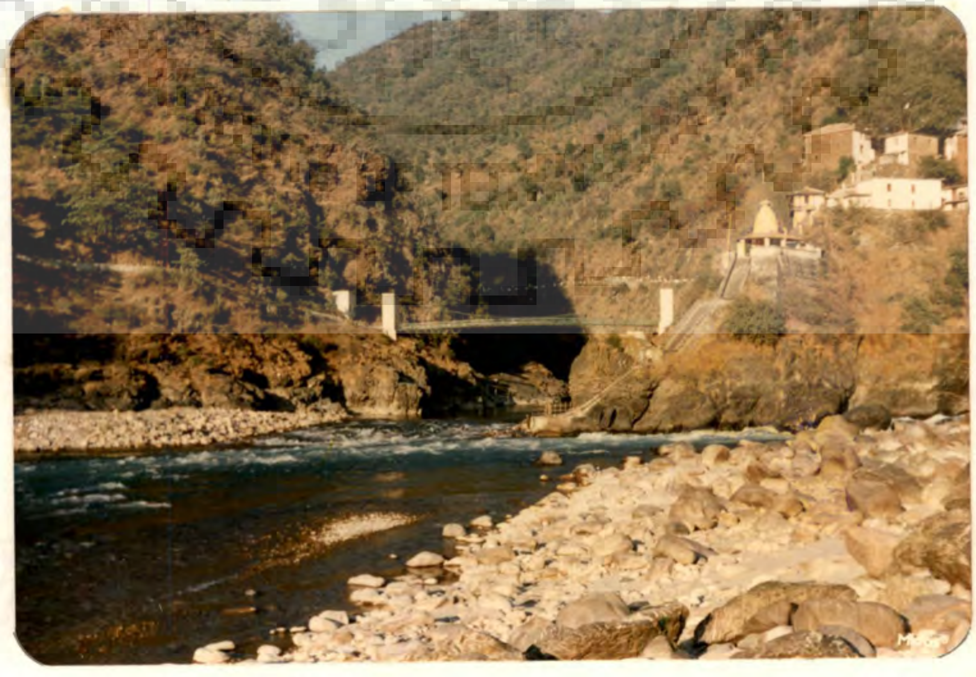
3. **Rudraprayag:** The station is located 47 kms downstream of Nandaprayag on the confluence of tributary Mandakini (Plate-2) with Alaknanda at an elevation of 725 MSL. This small township on the banks of river remains crowded with tourists and pilgrims on way to Badrinath and Kedarnath. The town accommodates a small population with small domestic discharges.

4. **Srinagar:** Srinagar is an important hill town of Garhwal Himalayan region situated 31.3 km downstream of Nandaprayag at an elevation of 570 MSL. The population of the township is about 8000 (1977) and supports educational institutions, health centre, and business centre. There is a sizable floating population preferring overnight stay during their journey to Badrinath and Kedarnath. Pollution due to domestic effluents and soil heaps dumped on the river bank is significant.

5. **Devprayag:** This station is located at the confluence where Bhagirathi meets Alaknanda, 28.8 km downstream of Srinagar at an elevation of 500 MSL. The river here after is called as Ganges (Plate-3). The population of the township is small and bathing



TAPT KUND EFFLUENT AT BADRINATH



CONFLUENCE OF MANDAKINI AT RUDRAPRAYAG

PLATE-2

activity is not very prominent.

6. **Rishikesh:** The Ganges, after completing the mountainous course, enters the plains at Rishikesh and has an elevation of 348 m. It is an important religious and tourist place. Intense bathing activity is observed throughout the year. (Plate-3).

7. **Satyanarayana:** The station is about 15 km downstream of Rishikesh. The tributary Song joins the river around this point. The treated effluents of the antibiotic plant of Indian Drugs and Pharmaceutical Ltd. are also discharged into the river a few hundred metres upstream of this station. (Plate-4).

8. **Chandighat:** This station is located 6 km downstream of Bhimgauda headworks. Cremation and bathing are common upstream activities. During lean flow months much of the water is released in the canal and the flow is depleted.

8. **Balawali:** Balawali is a small township located 22.5 km downstream of Haridwar. Cremation is prominent at this spot. (Plate-5).

9. **Bijnor:** It is situated 44.3 km downstream of Balawali. Madhya Ganga Canal takes off from Bijnor headworks. Cremation activities at the burning ghat downstream of the Bijnor barrage are significant.

10. **Garhmukteshwar:** It is 47.4 km downstream of Bijnor and is a spot of religious importance. Intense bathing activity is observed throughout the year. Baya river which carries mainly

GANGA AT DEVPRAYAG

GANGA ENTERING PLAINS AT RISHIKESH

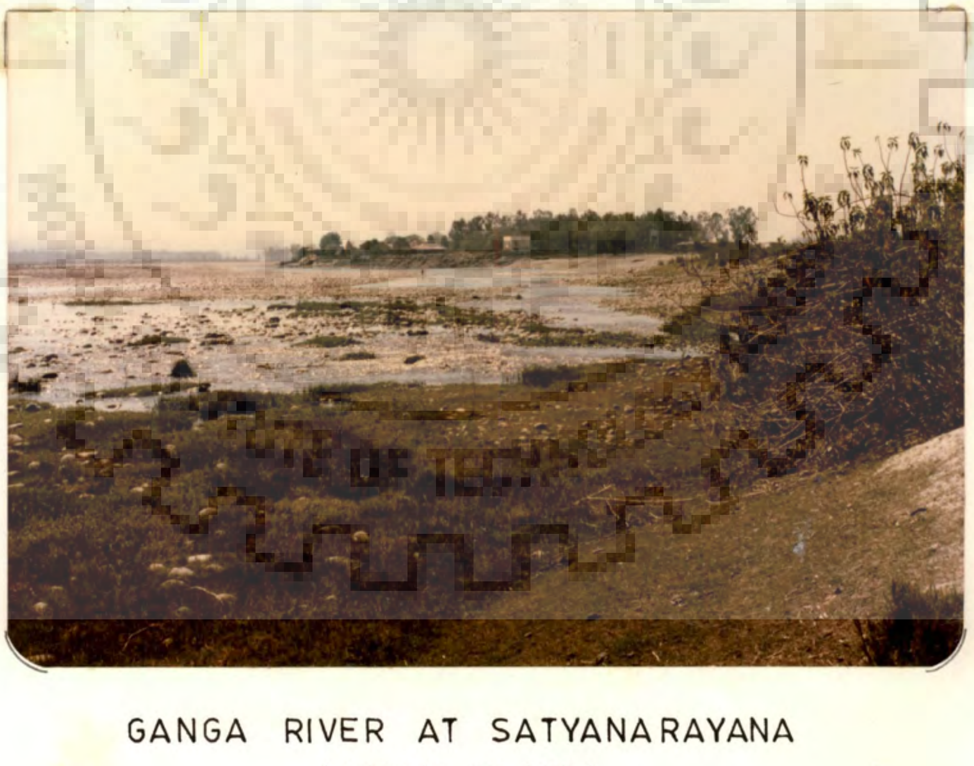
PLATE-3

IDPL EFFLUENT AT SATYANARAYANA

GANGA RIVER AT SATYANARAYANA
(LEAN FLOW)

PLATE - 4

IDPL EFFLUENT AT SATYANARAYANA



GANGA RIVER AT SATYANARAYANA
(LEAN FLOW)

PLATE - 4

LEAN FLOW CONDITIONS AT BALAWALI

GANGA AT BRIGHAT, GARHMUKTESHWAR
(LEAN FLOW CONDITION)

PLATE – 5

the waters of Ram Ganga feeder, an irrigation canal, joins Ganga about 8 km upstream of this station. (Plate-5).

11. Anupshahr: Anupshahr is 71.3 km downstream of Garhmukteshwar and is a small town. Bank erosion is very prominent at this station. (Plate-6).

12. Rajghat Narora: Narora is 18.3 km downstream of Anupshahr. Cremation by burning and bathing are common at this station. (Plate-6).

3.1.2 SECONDARY SAMPLING NETWORK:

Secondary sampling network stations were identified to investigate the Song river stretch, its mineral load and impact on the riverine system. A 56.2 km Song river stretch from Maldevta to its confluence with Ganga has been selected for the secondary sampling network (Fig 2.4 & 3.3).

1. Maldevta Upstream: This is the first sampling station and has gained importance due to underground mining of phosphate rocks by P.P.C.L., Dehradun. Just above the sampling point, the Song river is joined by Bandal River, which carries the mine water from the PPCL plant and waters of Timli Nala (from lime deposits).

2. Sahashradhara: It is important sampling station due to extensive mining of limestone. Sahashradhara is also known for its sulfur. The Baldi river carries these water to Song river.

EFFLUENT DISCHARGE AT ANUPSHAHR

EFFLUENT MOVING TOWARDS GANGA AT RAJGHAT NARORA

PLATE-6

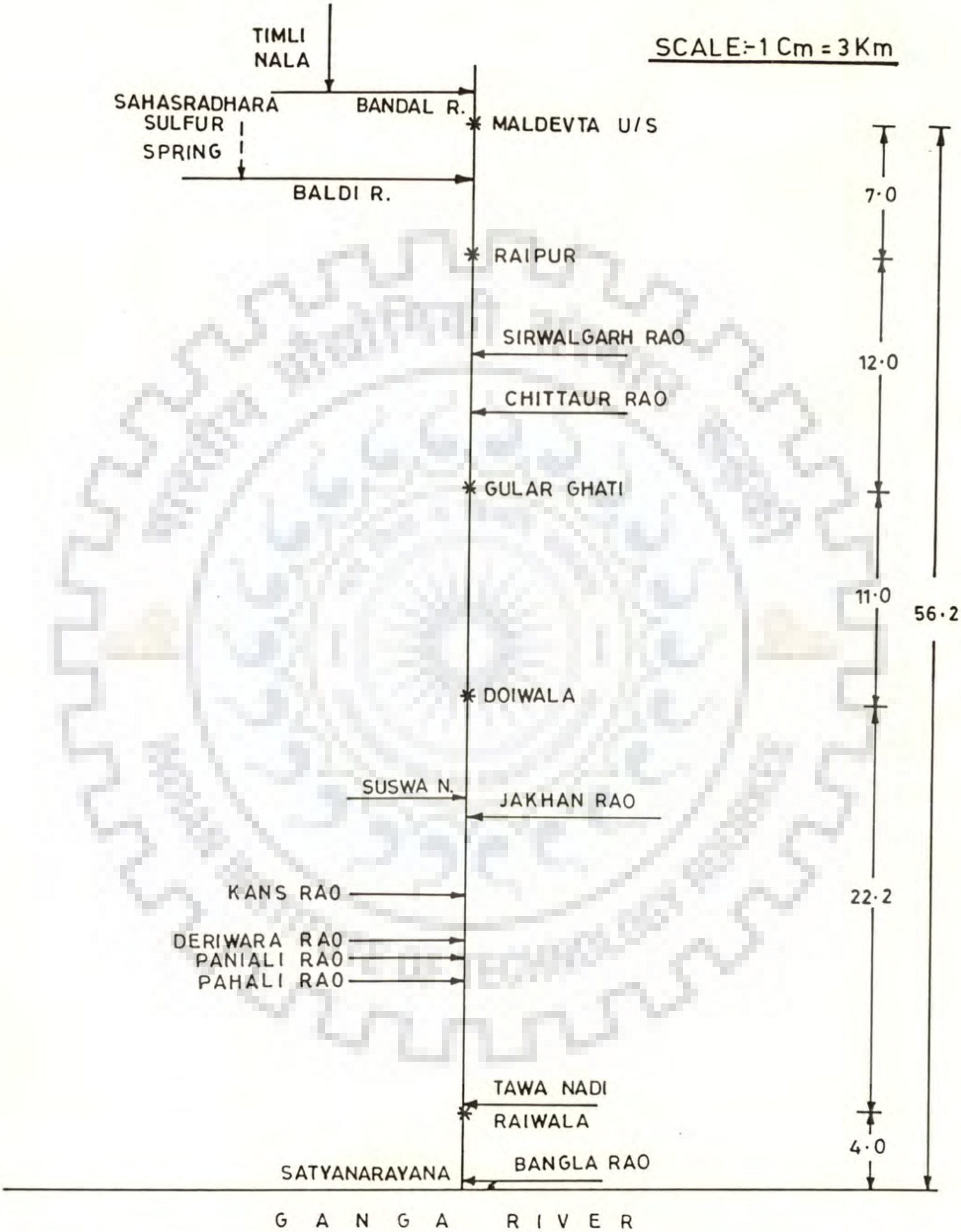


FIG: 3·3 —SCHEMATIC DIAGRAM OF SONG RIVER SYSTEM

(RIVER DISTANCE : Km)

3. **Raipur:** Raipur is situated 7 km downstream of Maldevta and 2.5 km down of Baldi confluence. The impact of Baldi can be visualized at this station.

4. **Gularghati:** Gularghati is located 12 km downstream of Raipur on the right bank of Song river. A small village is situated in the vicinity of the sampling spot. Between Raipur and this point the river remains dry in lean flow season.

5. **Doiwala:** Doiwala is 11 km downstream of Gularghati and is on the Dehradun-Haridwar road. (Plate-7).

6. **Raiwala Road Bridge:** It is 22.2 km downstream of Doiwala and is important with respect to the number of inputs to Song river. 6 km upstream the Suswa and Jakhan Rao tributaries join the Song river. At Raiwala bridge Tawa river joins Song river. (Plate-7).

7. **Satyanarayana:** Satyanarayana is 4 km downstream of Raiwala. It is the place at which Song river after completing its journey through Doon Valley joins Ganga river. Just before the confluence, tributary Bangla Rao joins Song river.

3.2 SAMPLING FREQUENCY

Sampling frequency is related to the purpose of the network, relative importance of the station, the variability of data, the accessibility and available resources. Initially between Dec.1984 to July 1985 the surveys were conducted at monthly intervals to gain information about the trends in the Ganga

SONG AT DOIWALA (RUN-OFF CONDITIONS)

CONFLUENCE OF TAWA WITH SONG AT RAIWALA (LEAN FLOW)

PLATE-7

stretch. After the identification of zones of importance and visualizing the trends of parameters, the frequency was made bimonthly.

To assess the variations of mineral quality within a day diurnal sampling was also conducted at selected stations viz. Nandprayag, Srinagar, Satyanarayana, Garhmukteshwar and Rajghat Narora. The observations, however, revealed no significant variations.

3.3 SAMPLE COLLECTION AND HANDLING

As the velocities in the upper reach were high, ensuring well mixed conditions, only grab samples were collected in the mountainous stretch from Badrinath to Rishikesh. Rishikesh downstream where the velocities reduce integrated samples were collected across the river section. The samples were collected strictly as per standard procedures with the help of samplers.

Samples of the important tributaries were collected before and after the confluence from both the water bodies with due consideration of mixing and stabilization distance.

Every care was taken in sample handling to minimize any change taking place during storage and transportation. Table 3.2 illustrates the procedures applied.

3.4 PROCEDURES OF ANALYSIS

Procedures given in the Standard Methods (AWWA, WPCF, 1978) have been followed for the analysis of the water samples.

TABLE 3.2 SAMPLE HANDLING AND PRESERVATION

Parameter	Container	Optimum Storage Time	Method Of Preservation
Turbidity	P	Within a week	Refrigerated
Solids	P	Within a week	Refrigerated
Conductivity	P.G	Analysed at site	-
p^H	P,G(B)	Analysed at site	-
Alakalinity	P,G(B)	Analysed on same day	Refrigerated
Acidity	P,G(B)	Analysed on same day	Refrigerated
Total Hardness	P,G(B)	Analysed on same day	Refrigerated
Chlorides	P,G	Within a week	Refrigerated
C.O.D.	P,G	Analysed on same day	Acidified with sulfuric acid
B.O.D.	P,G	Analysed on same day	Refrigerated
Ammonical Nitrogen	P,G	Analysed on same day	Acidified with sulfuric acid
Kjeldahl Nitrogen	P,G	Analysed on same day	Acidified with sulfuric acid
Nitrate Nitrogen	P,G	Analysed on same day	Acidified with sulfuric acid
Nitrite Nitrogen	P,G	Analysed on same day	Acidified with sulfuric acid
Sodium	P	Within a week	Acidified with hydrochloric acid
Sulphates	P,G	Within a week	Acidified with hydrochloric acid
Phosphates	P,G	Analysed on same day	Acidified with sulfuric acid
Trace Heavy Metals	P,G(A)	Within a week	Acidified with nitric acid

P = Plastic G = Glass G(A) = Glass acidified

Summary of the techniques for selected parameters is listed in Table 3.3. The summary of definitions and units are given in Table 3.4.

3.4.1 Correctness of the Analysis:

Every precaution for precision and accuracy of analysis has been taken. The results have been analysed on the cation-anion balance and specific conductance methods.

TABLE 3.3 SUMMARY OF ANALYTICAL METHODS

Parameter	Technique	Principle
Turbidity	Nephlometer or Jackson turbidity meter	Nephlometry or Absorptiometry
Residue		
(a) Total	Gravimetric	Evaporation at 103°-105°C
(b) Dissolved	-do-	Evaporation of residue left on a standard filter disc at 108°C
(c) Volatile	-do-	Ignition of the residue obtained for total solids at 550°C
Electrical Conductivity	Conductivity Measurement	CENTURY Portable Water Analyser
p^H	p^H	-do-
Alakalinity	Volumetric	Acid-base titration titrant-N/50 sulfuric acid, indicator-methyl orange
Acidity	-do-	Acid-base titration titrant-N/50 sodium hydroxide, indicator-phenolphthalein/methyl orange
Total Hardness	-do-	Complexímetric titration, titrant-0.01M EDTA indicator-Erichrome Black-T, using ammonia buffer
Calcium	-do-	Complexímetric titration, titrant-0.01M EDTA indicator-Murexide, using 1N sodium hydroxide as buffer

(CONTINUED)

(TABLE 3.3 CONTINUED)

Magnesium	-do-	Difference between total hardness and calcium hardness
Chlorides	-do-	Argentometric titration, titrant-N/35.5 silver nitrate, indicator-pot.chromate
Dissolved Oxygen	-do-	Wrinkler's method titrant-N/80 sodium thiosulfate, indicator-starch (fresh)
C.O.D.	-do-	Reflux method followed by redox titration titrant-0.1 N ferrous ammonium sulfate, indicator-ferroin
Biochemical Oxygen Demand	-do-	Modified Wrinkler's method, 5 day indubation at 20°C.
Ammonical Nitrogen	Colorimetric	Distillation, followed by Nesslerization
Kjeldahl Nitrogen	-do-	Kjeldahl method-Nesslerization
Nitrate Nitrogen	-do-	Phenol di sulfonic acid method
Nitrite Nitrogen	-do-	Diazotization
Sodium	Flamephotometry	Flamephotometer
Sulfates	Gravimetric	Precipitation by $BaCl_2$ as $BaSO_4$ in acidic medium
Phosphate	Colorimetry	Stannous chloride method
Trace Metals	Atomic Absorption	

TABLE 3.4 SUMMARY OF DEFINITIONS AND UNITS

Classification	Characterisrics	Units	Major Causal Factors
Physical	Turbidity	Turbidity units	Microorganisms;metallic substances,clay;temperature
	Suspended solids	mg/l	Temperature;particle size and density
	Conductivity	µS/cm	Temperature, concentration of dissolved solids
	p^H	-	Temperature,pressure, anions and cations present
Chemical	Alkalinity	mg/l $CaCO_3$	Temperature, concentration of dissolved cations and anions, p^H
	Acidity	-do-	-do-
	Total Hardness	-do-	Calcium and magnesium ions predominately, temperature
	Chlorides	mg/l	Conductivity
	Dissolved Oxygen	mg/l	Temperature, dissolved organic matter
	C.O.D.	mg/l	Temperature, degradable organic matter,refractory organics
	B.O.D.	mg/l	Temperature, biodegradable organic matter
	Ammonical Nitrogen	mg/l	p^H,temperature,organic nitrogenous matter which can be destroyed by microbial activitiy
	Kjeldahl Nitrogen	mg/l	-do-
	Nitrate Nitrogen	mg/l	-do-
	Nitrite Nitrogen	mg/l	-do-
	Sodium	mg/l	Temperature,p^H,conductivity and chlorides
	Phosphates	mg/l	
	Trace Heavy	µg/l	

4.0 PHYSICO CHEMICAL CHARACTERIZATION OF GANGA WATER

4.0 PHYSICO CHEMICAL CHARACTERISTICS OF GANGA WATER

The state of physico chemical environment of water in the Upper Ganga stretch, in general, is governed by the following factors:

- geological formations of the catchment area
- anthropogenic activities including water abstraction and regulation in the catchment area
- network of tributaries
- climatic regime from the point of view of wet months necessitating run-off and dry months necessitating groundwater inflows in the rivers/tributaries.

The geology and human activities of the catchment area have been discussed in earlier chapters. In general, composition of Ganga waters in the study area, impact of the major tributaries and trend of physico chemical parameters including trace metals are, however, discussed in the following paragraphs.

4.1 ACCURACY OF DATA

Before utilising the chemical analysis data for interpretation checks of accuracy in terms of available methods of ionic balance method and electrical conductance method (Standard Methods, AWWA, APHA, 1976), were applied.

4.1.1. Ionic Balance Method:

Theoretically in any water sample the sum of total anions and total cations, expressed in me/l, should be equal. But in practice, the sums are seldom equal because of random variation and errors of measurement. This inequality increases as the ionic concentrations increase. The difference should fall between acceptable limits of

$$\Sigma \text{ anions} - \Sigma \text{ cations} = \pm(0.1065 + 0.0155 \, \Sigma \text{ anions})$$

(Standard Methods)

A control chart to represent the ionic balance of samples as monthly values of

$$[\ (\Sigma \text{ anions} - \Sigma \text{ cations}) \div 0.1065\ ] + [0.0155 \, \Sigma \text{ anions}]$$

are shown plotted in Fig. 4.1. The deviations have been marked with station numbers. The plot reveals that 90 % of the data falls within acceptable standard deviations. Thus the data can be considered to be accurate.

4.1.2 ELECTRIC CONDUCTANCE METHOD:

The ionic balance method may sometimes lead to the compensation of errors and produce good agreement between the sum of anions and cations even though the results may not be so. Thus, additional method of conductivity and total dissolved solids correlation was applied. In most natural waters, conductivity and total dissolved solid ratios range in the order of 0.5 to 0.7 depending upon the chemical composition. For inland waters the values will, however, lie around 0.6 while for saline waters it will be around 0.7. The perusal of the ratio will indicate gross mistakes in the analysis. In the present study, these ratios have been found to lie between 0.5 - 0.7, in 95 % of the samples (Fig.4.2). Thus a good agreement of accuracy of physico chemical analysis was established.

4.2 CHEMICAL COMPOSITION OF GANGA WATER

There are several methods available for the representation of chemical analysis data, viz. Collin's Bar Diagram, Stiff Polygons, Pie Diagrams, Hill Piper Trilinear Diagram, Circular Diagram, Radial Coordinate Diagrams, Bico-ordinate Systems, Water Quality Profiles and Longitudinal Variation Diagrams. However, in the present study, two methods have been used to discuss the physico chemical composition of Ganga Water.

(i) Hill-Piper Trilinear Diagram

(ii) Water Quality Profiles

Water Quality Indices to define the mineral transport have also been worked out.

4.2.1. Hill-piper Trilinear Diagram:

The Piper's Trilinear Diagram is one of the most frequently used method for the representation of chemical composition and classification of water samples. The advantage of this method is that it can incorporate several samples in one figure.

As shown in Fig. 4.3, the Hill-piper Diagram comprises three sub-diagrams as

- one triangular diagram for cations

1. NANDAPRAYAG
2. NANDAPRAYAG NANDAKINI
3. NANDAPRAYAG A/C
4. RUDRAPRAYAG B/C
5. RUDRAPRAYAG MANDAKINI
6. RUDRAPRAYAG A/C
7. SRINAGAR
8. DEVPRAYAG B/C
9. DEVPRAYAG BHAGIRATHI
10. DEVPRAYAG A/C
11. RISHIKESH
12. SATYANARAYANA
13. CHANDIGHAT
14. BALAWALI
15. BIJNOR
16. GARHMUKTESHWAR
17. ANUPSHAHR
18. RAJGHAT NARORA

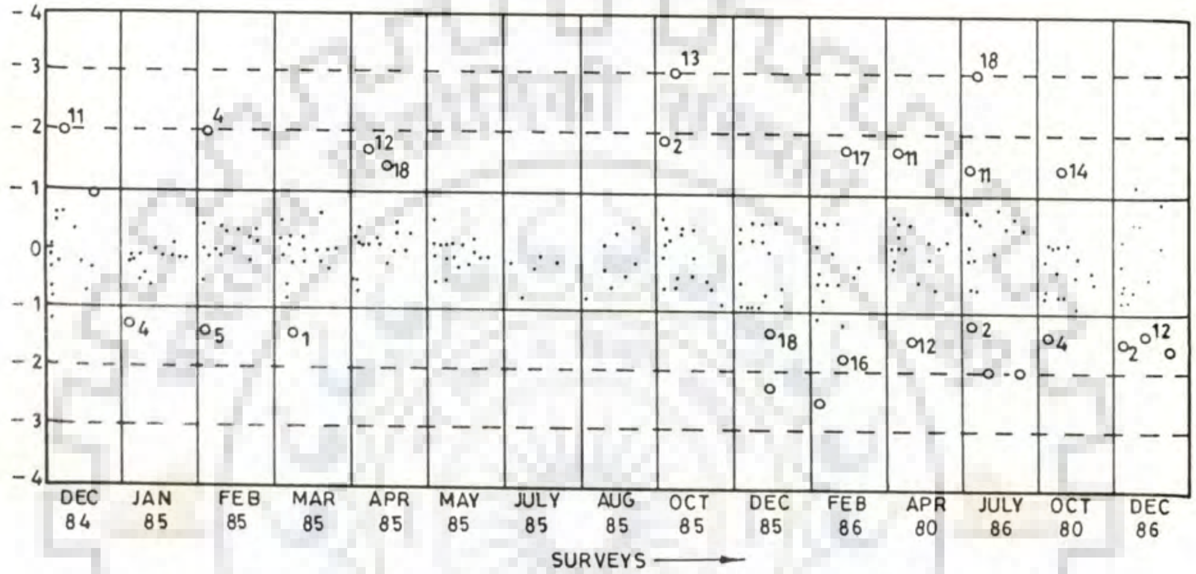


FIG. 4·1 — VARIATIONS IN CATION-ANION BALANCE

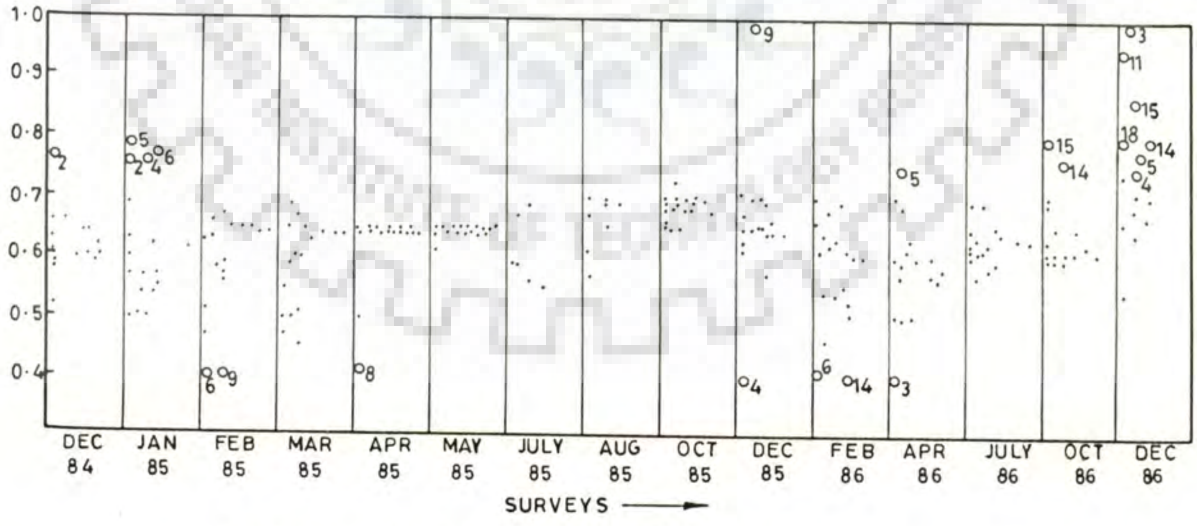


FIG. 4·2 — VARIATIONS IN COND./TDS

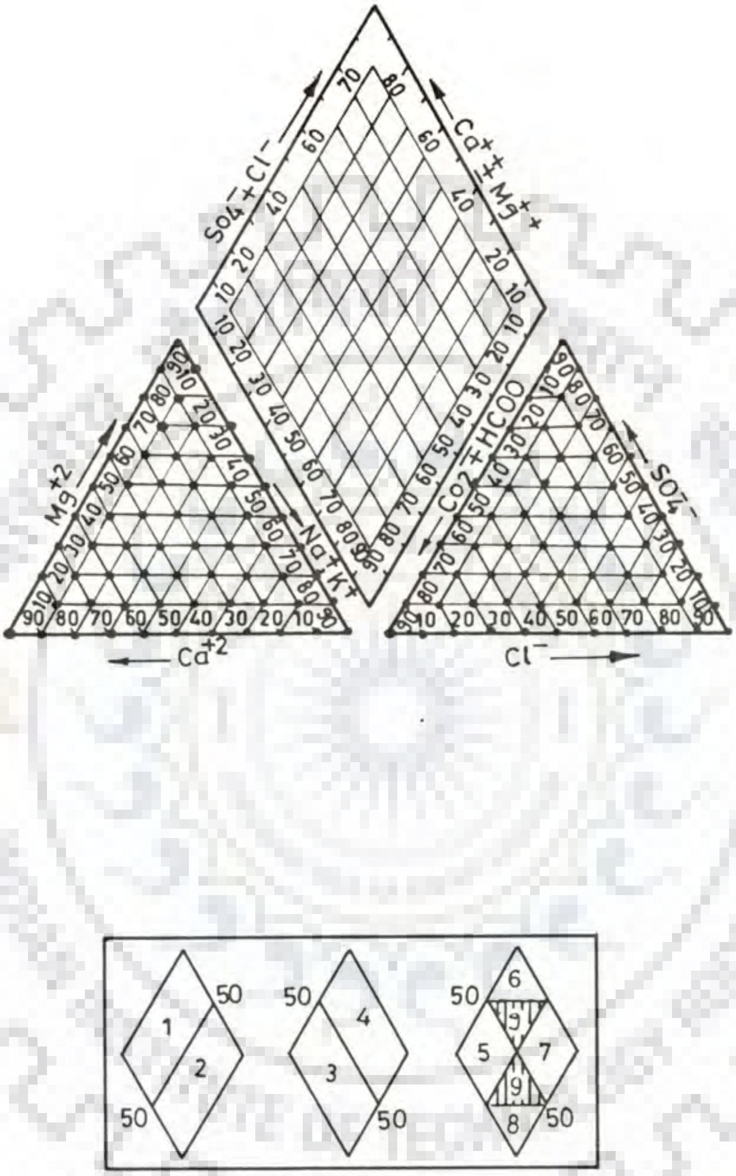


FIG. 4·3—PIPER TRILINEAR DIAGRAM (AFTER PIPER, 1953)

- one triangular diagram for anions
- a centrally located diamond shaped diagram for composite picture of cations and anions.

All the sides of the three diagrams are indicated between 0 to 100 scale.

The diamond shaped field at the centre is divided into different areas which represent 9 groups of water depending upon the major cationic-anionic composition (Fig. 4.3). These nine areas describe the following characteristics of water:

Area 1: Alkaline earth metals (calcium, magnesium) dominate alkalis (sodium and potassium).

Area 2: Alkalis dominates alkaline earths.

Area 3: Weak acids (carbonates and bicarbonates) dominates strong acids (chlorides and sulfates).

Area 4: Strong acids exceeds weak acids

Area 5: Carbonate hardness exceeds 50 percent i.e. the chemical properties of the water are dominated by alkaline earths with weak acids.

Area 6: Non carbonate hardness exceeds 50 percent i.e. the chemical properties are dominated by alkaline earths with strong acids.

Area 7: Non carbonate alkalinity (primary salinity) exceeds 50 percent i.e. the chemical properties are dominated by alkalis and strong acids.

Area 8: Carbonate alkalinity exceeds 50 percent i.e. the chemical properties of water are dominated by alkalis and weak acids.

Area 9: It shows an intermittent category or mixed type of water in which no single cation or anion pair exceeds 50 percent.

To plot the trilinear diagram the percentage me/l of various cations and anions are first calculated. The mean percentage me/l values of calcium, magnesium, sodium and potassium are plotted on the left hand side of triangular diagram as a single point according to conventional trilinear coordinates. The mean percentage me/l values of bicarbonates and carbonates, chlorides, and sulfates are plotted on the right hand side of triangular diagram as a single point. The positions of these two points in the triangular diagram are extended into the diamond shaped field, which gives the overall chemical characteristics of the water sample.

The Piper's Trilinear Diagram plotted for Ganga water samples at different locations in the study area is illustrated in Fig. 4.4. At all locations except no.11, the Ganga water falls in area 5, indicating thereby that the chemical character of water is dominated by alkaline earths and weak acids. In other words, carbonates and bicarbonates with calcium and magnesium are the predominant ionic species at these locations.

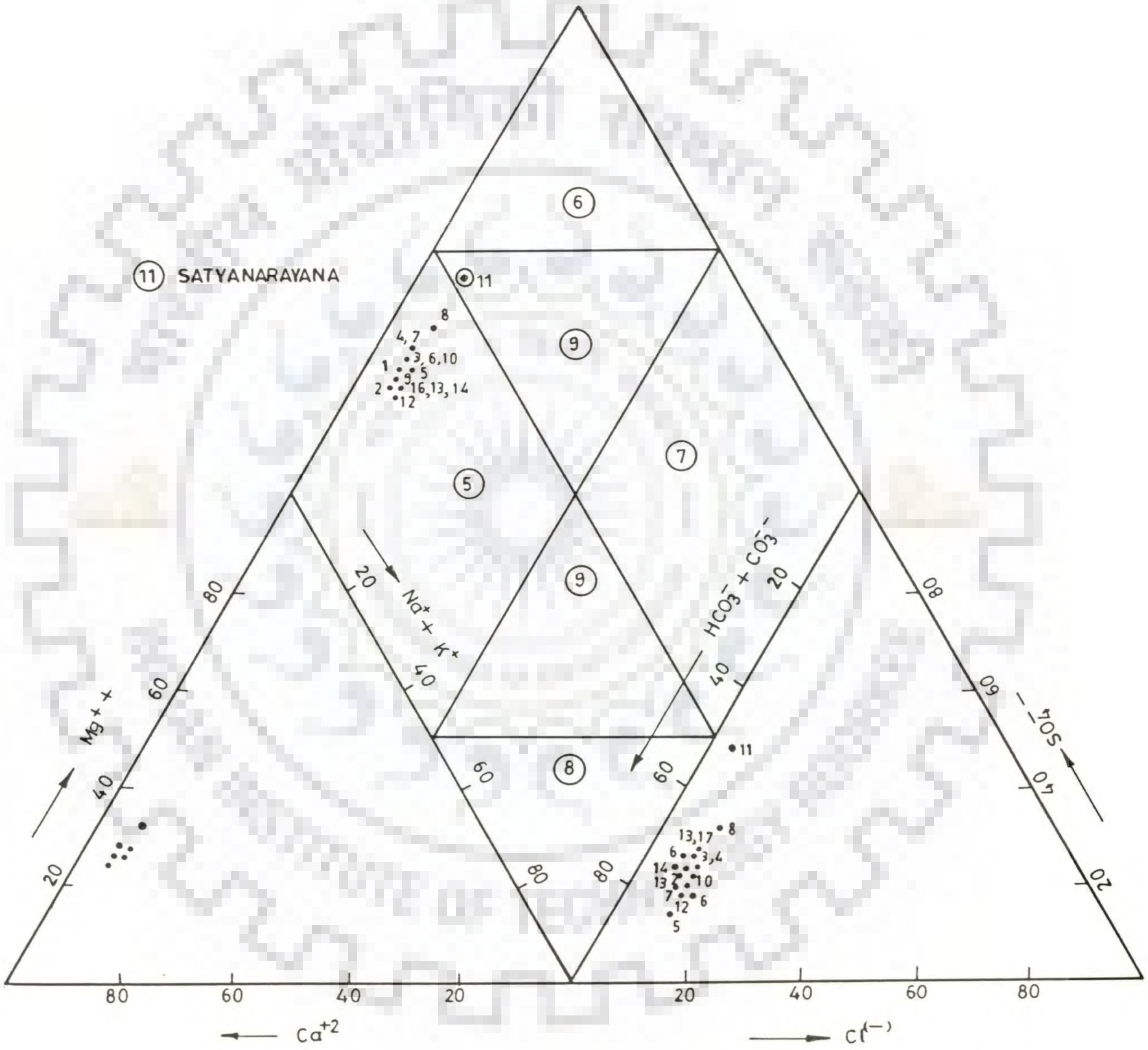


FIG. 4·4 — HILL PIPER TRILINEAR DIAGRAM OF GANGA WATER

Whereas, location no.11, Satyanarayana, shows a mixed character.

4.3 IMPACT OF TRIBUTARIES ON THE PHYSICO-CHEMICAL COMPOSITION OF GANGA WATER

Though the flow of Ganga river in the study area is contributed by numerous small torrents and tributaries; Nandakini, Mandakini, Bhagirathi and Song are the four major ones of the region. All these tributaries have sub-catchment areas with characteristic geology and catchment activity. The respective sources of these tributaries also govern the physico chemical composition of waters. As discussed in earlier chapters, the first three tributaries are glacier based where as, Song is fed through effluent springs. The difference in origin of tributaries is incremental to chemical parameters.

To assess the impact of these four major tributaries, physico chemical parameters have been discussed under four seasons as:

<u>Winter Season</u>, incise the period from November to February, corresponding with lean flow or base flow.

<u>Summer Season</u>, incise the period from March to May, in which river is fed by snow melt.

<u>Monsoon Season</u>, incise the period from June to August with surface run-off from the catchment.

<u>Post-Monsoon Season</u>, incise the period from September to October with reduced flows.

The perusal of Tables 4.1 through 4.4, reveals the seasonal variations as:

Of the three glacier fed tributaries, Nandakini contributes more minerals and Bhagirathi more suspended solids. The temporal variations, however, indicate that Nandakini carries the maximum mineral load in Winter with low chlorides and sulfates, indicating the effluent character of groundwater interaction. This is borne out by the geological formations also.

During Summer season the flows are derived chiefly from snow melt and the tributaries carry more of bicarbonates, carbonates of calcium and magnesium. In Bhagirathi the flows carry more sulfates and chlorides. The p^H values do not show any apparent change, where as ORP values increase in monsoon season. The system althrough remains oxidative with values ranging between +194.8 to +319.0 mV. The reason for increase in ORP values during Monsoon could only be attributed to increase in flow and turbulence.

The mineral matter measured through conductance and total dissolved solids are maximum in summer and winter where as the values are below average in monsoon and post-monsoon. These low values are due to more dilution as compared to summers and winters where the flow contribution is only through snow melt and ground water interaction.

TABLE 4.1 IMPACT OF MAJOR TRIBUTARIES
(Winter Season)

Metal (ppb) [except iron]	NANDAKINI		MANDAKINI		BHAGIRATHI		SONG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
p^H	8.3	0.3	7.9	0.5	8.1	0.5	8.0	0.4
ORP	201.6	58.1	197.7	67.9	194.8	57.0	155.0	56.6
Conductance (µ mohos)	170.2	58.3	135.6	78.3	144.8	54.3	501.1	154.3
T.D.S. mg/l)	103.7	16.4	96.6	56.2	89.9	12.8	341.8	93.6
Bicarbonates (mg/l)	68.4	20.8	42.6	7.1	49.5	12.6	183.4	15.8
Carbonates (mg/l)	1.4	1.0	0.5	0.5	0.9	0.7	2.3	1.9
Chloride (mg/l)	5.2	2.4	3.8	1.2	5.3	1.5	6.3	0.4
Sulfate (mg/l)	14.6	3.8	7.7	4.1	15.0	4.5	172.5	122.9
Calcium (mg/l)	22.6	5.0	14.4	5.7	18.9	3.5	58.7	38.7
Magnesium (mg/l)	5.9	2.0	5.2	2.2	5.7	2.0	27.8	10.4
Sodium (mg/l)	2.0	0.0	2.0	0.0	2.0	0.0	10.0	0.0
Total Anions (me/l)	1.6	0.2	1.0	0.1	1.5	0.2	6.9	2.8
Total Cations (me/l)	1.7	0.2	1.8	0.1	1.5	0.2	7.3	2.8

TABLE 4.2 IMPACT OF MAJOR TRIBUTARIES
(Summer Season)

Metal (ppb) [except iron]	NANDAKINI		MANDAKINI		BHAGIRATHI		SONG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
p^H	8.3	0.2	7.9	0.5	8.1	0.5	8.5	-
ORP	291.0	72.7	264.5	34.8	265.2	25.7	188.0	-
Conductance (µ mohos)	192.3	29.5	131.6	32.5	174.3	27.9	399.4	-
T.D.S. mg/l)	109.5	8.3	82.3	23.1	104.6	16.7	149.5	-
Bicarbonates (mg/l)	72.5	10.4	42.2	3.1	54.6	17.4	145.7	-
Carbonates (mg/l)	1.3	0.5	0.3	0.2	0.6	0.8	4.1	-
Chloride (mg/l)	4.2	1.4	4.9	1.6	6.1	1.4	6.3	-
Sulfate (mg/l)	11.3	6.3	7.5	2.9	17.5	9.6	98.5	-
Calcium (mg/l)	24.8	6.5	17.0	7.3	21.7	6.4	57.4	-
Magnesium (mg/l)	3.2	1.3	2.1	0.6	2.9	0.5	20.6	-
Sodium (mg/l)	2.0	0.0	2.0	0.0	2.0	0.0	10.0	-
Total Anions (me/l)	1.6	0.3	1.0	0.2	1.5	0.3	4.8	-
Total Cations (me/l)	1.6	0.2	1.0	0.2	1.4	0.3	5.0	-

TABLE 4.3 IMPACT OF MAJOR TRIBUTARIES
(Post Monsoon Season)

Metal (ppb) [except iron]	NANDAKINI		MANDAKINI		BHAGIRATHI		SONG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
p^H	8.2	0.4	8.4	0.1	8.5	0.1	8.4	0.2
ORP	229.0	35.5	244.5	37.5	212.5	29.0	240.0	0.0
Conductance (µ mohos)	80.9	58.0	128.0	82.0	75.9	56.7	480.0	21.2
T.D.S. mg/l)	51.5	33.5	85.7	50.3	50.0	35.9	313.3	47.0
Bicarbonates (mg/l)	61.2	14.4	28.4	17.9	47.9	2.5	154.2	49.5
Carbonates (mg/l)	2.5	0.9	0.7	0.1	1.4	0.4	3.7	2.7
Chloride (mg/l)	3.4	2.1	3.7	0.4	3.4	0.2	7.6	0.6
Sulfate (mg/l)	3.5	2.1	10.0	0.0	15.0	7.1	107.5	10.6
Calcium (mg/l)	15.9	1.9	9.3	4.4	15.7	1.7	63.3	9.5
Magnesium (mg/l)	4.5	1.3	3.3	1.1	5.4	1.9	20.5	0.2
Sodium (mg/l)	2.0	0.0	2.0	0.0	2.0	0.0	10.0	0.0
Total Anions (me/l)	1.3	0.1	0.8	0.3	1.2	0.2	5.1	0.7
Total Cations (me/l)	1.2	0.2	0.8	0.3	1.3	0.2	5.1	0.7

TABLE 4.4 IMPACT OF MAJOR TRIBUTARIES
(Monsoon Season)

Metal (ppb) [except iron]	NANDAKINI		MANDAKINI		BHAGIRATHI		SONG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
p^H	7.9	-	7.9	-	7.7	-	8.2	0.3
ORP	319.0	-	290.0	-	291.0	-	231.6	44.5
Conductance (µ mohos)	101.7	-	59.9	-	90.9	-	551.7	72.6
T.D.S. mg/l)	62.6	-	35.7	-	60.1	-	156.8	35.9
Bicarbonates (mg/l)	54.9	-	35.7	-	51.0	-	156.8	33.2
Carbonates (mg/l)	0.5	-	0.3	-	0.2	-	2.4	1.3
Chloride (mg/l)	6.0	-	2.8	-	5.0	-	5.5	0.6
Sulfate (mg/l)	10.0	-	15.0	-	20.0	-	171.5	81.3
Calcium (mg/l)	16.0	-	10.5	-	19.5	-	82.3	26.4
Magnesium (mg/l)	6.8	-	3.7	-	5.3	-	24.4	9.5
Sodium (mg/l)	2.0	-	2.0	-	2.0	-	10.0	0.0
Total Anions (me/l)	1.3	-	1.0	-	1.5	-	6.4	2.0
Total Cations (me/l)	1.4	-	1.0	-	1.5	-	6.6	2.1

The total ionic strength all through the year remains similar with only changes in composition.

The contribution of bicarbonates and or carbonates is dependent on the potential of hydrogen ions and would involve conversion at equilibrium.

On the other hand, the tributary Song contributes a larger mineral load to Ganga river. This is indicated by the high conductance values. The same trend is reflected in total dissolved solids, bicarbonates, sulfates of calcium and magnesium. In general, Song carries more mineral during winter and monsoon as compared to lean flow season i.e. summer.

The following points emerge on the impact of tributaries on the physico chemical characters of Ganga water.

- Maximum mineral load is added by Song river followed by Nandakini and Bhagirathi.
- Bhagirathi emerges out to be the highest contributor of suspended solids. This may be because of many ongoing river regulation projects and human activity on this tributary.

4.4 TRENDS OF PHYSICO CHEMICAL PARAMETERS

Table 4.5 and Figures 4.5 to 4.15 illustrate the trends of physico chemical parameters of Ganga water in the study area from Nandprayag to Rajghat Narora.

TABLE 4.5

S.No	STATIONS	p^H		ORP(mV)		SODIUM(mg/l)	
		MEAN	SD	MEAN	SD	MEAN	SD
1.	NANDPRAYAG B/C	8.00	0.40	238.10	13.00	2.00	0.00
2.	NANDPRAYAG A/C	8.10	0.40	234.00	83.00	2.00	0.00
3.	RUDRAPRAYAG	8.12	0.30	225.60	45.60	2.00	0.00
4.	SRINAGAR	8.20	0.30	207.00	55.00	2.00	0.00
5.	DEVPRAYAG B/C	8.05	0.60	230.00	51.20	2.00	0.00
6.	DEVPRAYAG A/C	8.00	0.50	230.00	51.20	2.00	0.00
7.	RISHIKESH	8.20	0.50	231.50	60.70	2.10	0.50
8.	SATYANARAYANA	8.00	0.50	218.60	63.30	9.50	1.40
9.	BALAWALI	8.10	0.30	214.80	49.30	4.40	1.10
10.	BIJNOR	8.10	0.30	214.80	49.30	4.40	1.10
11.	GARHMUKTESHWAR	8.20	0.40	212.50	57.50	2.80	0.80
12.	ANUPSHAHR	8.15	0.41	212.10	51.00	2.70	0.80
13.	RAJGHAT NARORA	8.20	0.40	192.50	43.20	2.60	0.80

B/C = Before Confluence
A/C = After Confluence

4.4.1 p^H:

p^H is a general physico chemical parameter and indicates the fate of chemical constituents. From the mean values presented in Table 4.5, the p^H was found around 8.0 indicating that the waters were alkaline throughout the stretch. In general, in plains waters tend to be more alkaline as compared to the mountainous reaches. Low p^H values were observed during monsoon season as compared to other seasons, which may be attributed to run-off.

4.4.2 Oxidation Reduction Potential:

ORP is closely related to p^H and reflects the state and migrating conditions of minerals in water. In a riverine system, sometimes it may reflect the geochemical changes that are occurring in the stretch. The values of ORP were in general, on positive scale indicating prevailing oxidative state of the river. The mean ORP values (Table 4.5) in plains were slightly lower than those in the mountainous reaches where the values were more during monsoon season followed by summer, post-monsoon season and winter seasons. Whereas, in plains, though the trends are fluctuating, higher values were observed in summers.

4.4.3 Solids-Total and Suspended:

The amount of total solids and its variation along the course indicate the extent of erosion and weathering in the riverine catchment. In general, where the physical erosion is prominent, the suspended load occupies the main portion of the total solids. In the mountainous stretch the total solid content showed a decreasing trend (Fig. 4.5) between Nandprayag and Devprayag. At Devprayag, Bhagirathi adds large amounts of suspended load as anticipated due to intense construction activities in the catchment. Between Devprayag and Rishikesh the total solid content increased nearly proportional to the increase in dissolved solids.

At Satyanarayana the total solid concentration reached the maximum value. This increase is attributable to dissolved solids added by Song river. Downstream of Satyanarayana the values decreased due to the return of tail waters of Chilla headworks. The variation further down was not very significant though a gradual increase though minimal, was observed.

4.4.4 Conductivity and Total Dissolved Solids:

Fig. 4.6 and 4.7 illustrate the trends of conductivity and total dissolved solids in the study area, reflecting the general changes in the concentration of physico chemical parameters. The similarity in the trends shows the accuracy of the data. In general, the trend shows little variation throughout the stretch except at Satyanarayana. The influence of Song in mineral content is so apparent that the temporal variations got completely masked.

The trends of conductivity and total dissolved solids in

Stations:
1. Nandprayag
2. Rudraprayag
3. Srinagar
4. Devprayag
5. Rishikesh
6. Satyanarayana
7. Balawali
8. Bijnor
9. Garhmukteshwar
10. Anupshahr
11. Rajghat Narora

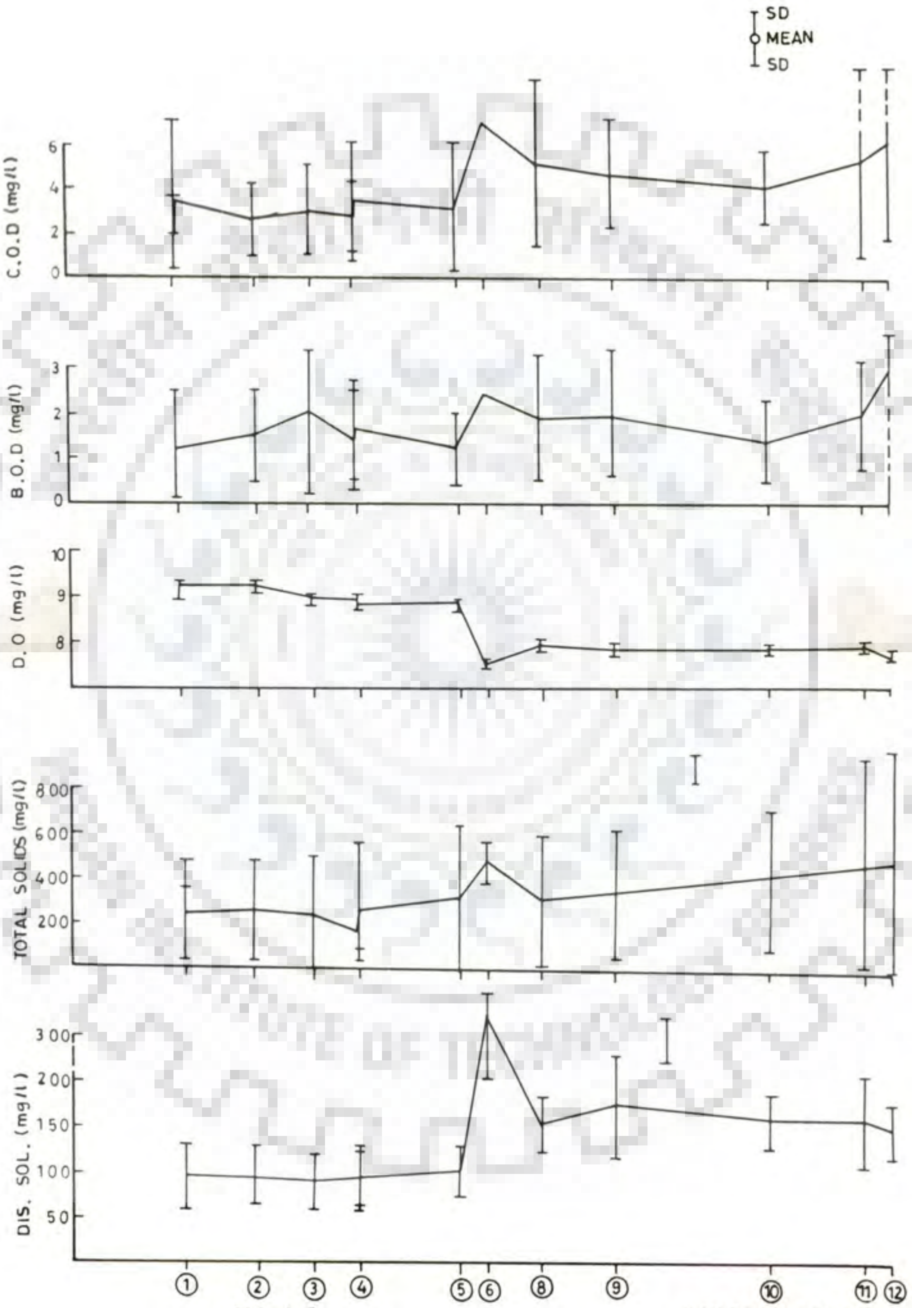


FIG. 4·5

SCALE:-1cm = 28·3 km

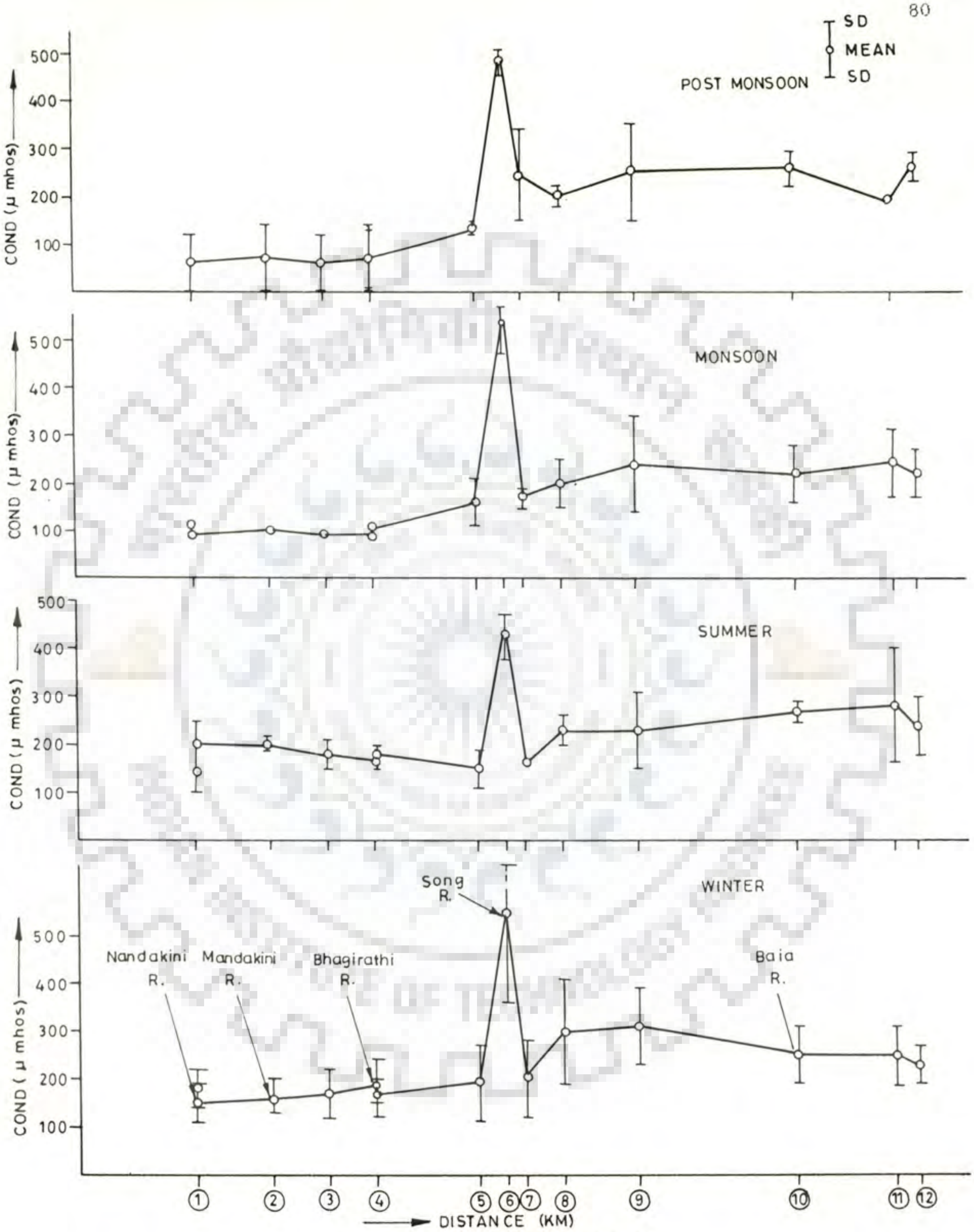


FIG. 4·6 — CONDUCTIVITY

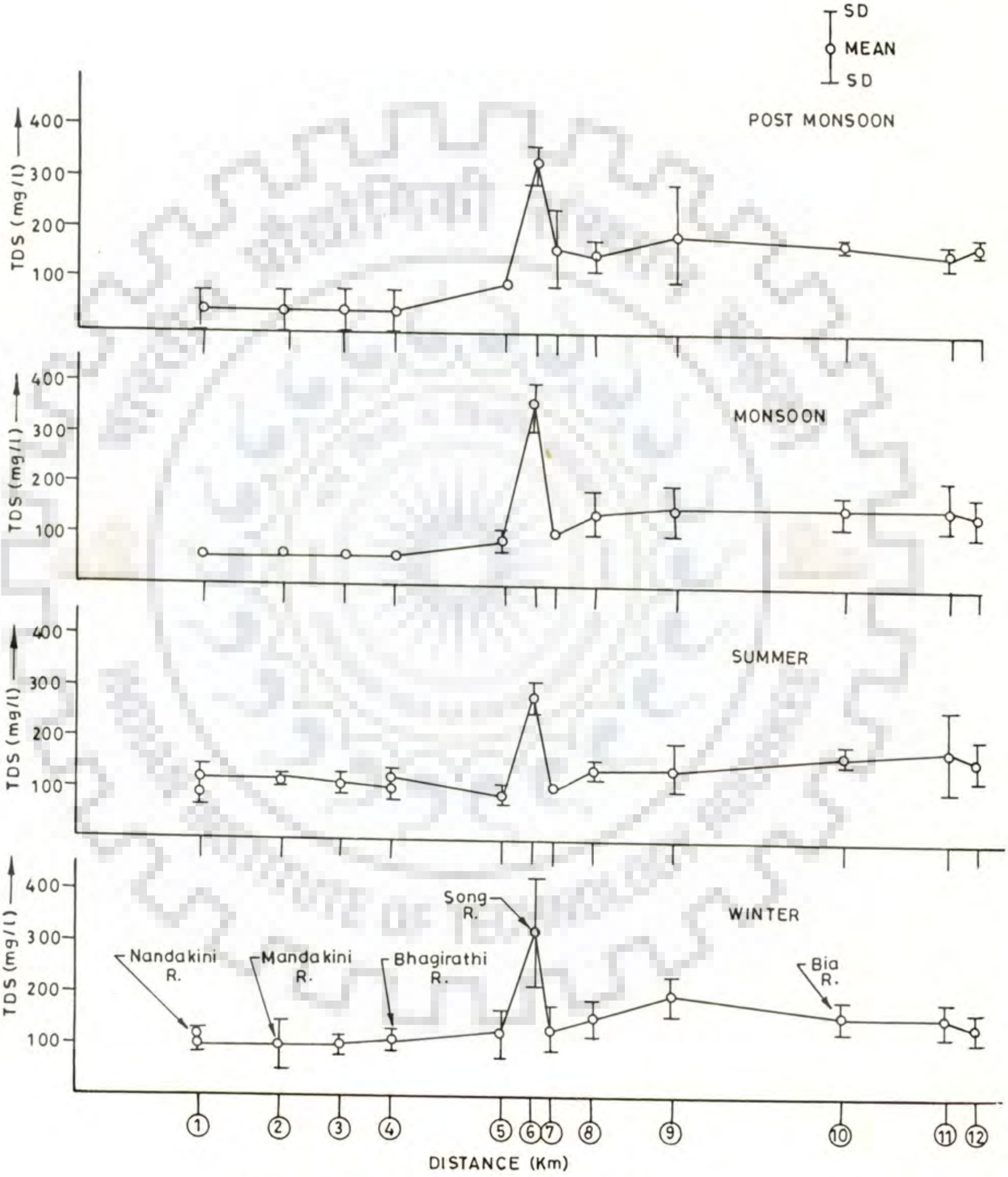


FIG. 4·7—TOTAL DISSOLVED SOLIDS

the upper reach from Nandprayag to Rishikesh reflected the impact of various tributaries and ground water interaction. During Winter season these values exhibited an increasing trend from Nandprayag to Rishikesh by indicating the lean flow conditions of the river. It also indicated that the ground water joining Alaknanda during this period contributes some mineral content. On the otherhand, the trend was decreasing during Summer season indicating the dilution caused by the snow-fed tributaries and lesser interaction of ground water. During monsoon and post-monsoon seasons the values were almost constant between Nandaprayag and Devprayag. Downstream of Rishikesh, the conductivity and total dissolved solids values showed a five fold increase, due to the addition of Song waters. This impact is clearly discernible downstream up to Rajghat Narora.

4.4.5 Bicarbonates and Carbonates:

The variation in the concentration of bicarbonates and carbonates in the hilly terrain up to Rudraprayag was similar during all seasons (Fig. 4.8 and 4.9). The general range of carbonates and bicarbonates was 0.8 mg/l to 5.7 mg/l and 44 to 160 mg/l respectively. Between Rudraprayag and Devprayag the concentration decreased during monsoon season due to dilution from Bhagirathi. In the stretch between Devprayag and Rishikesh the bicarbonate concentration was same in all seasons, except a significant increase during post-monsoon. This could be related

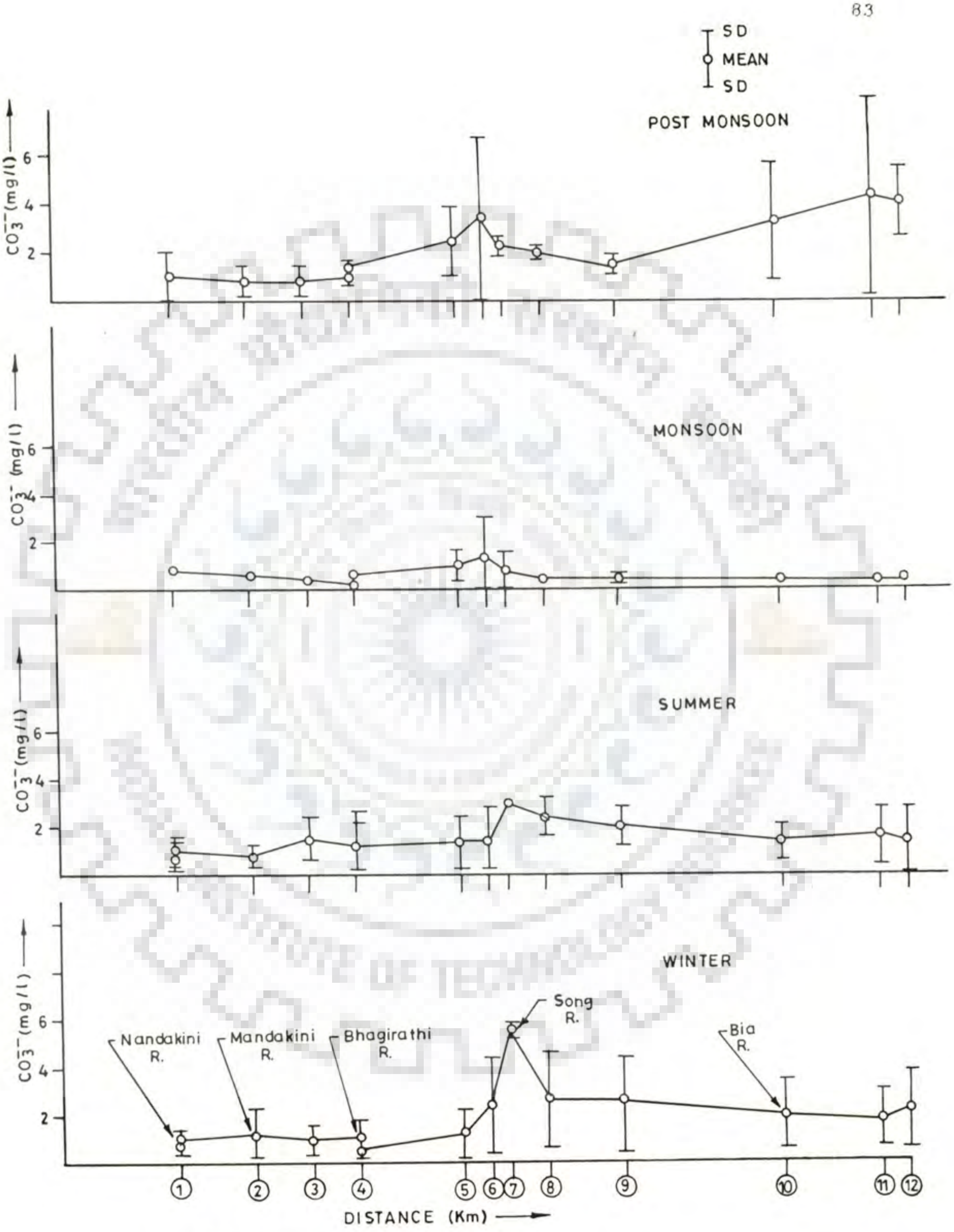


FIG. 4·8— CARBONATES (mg/l)

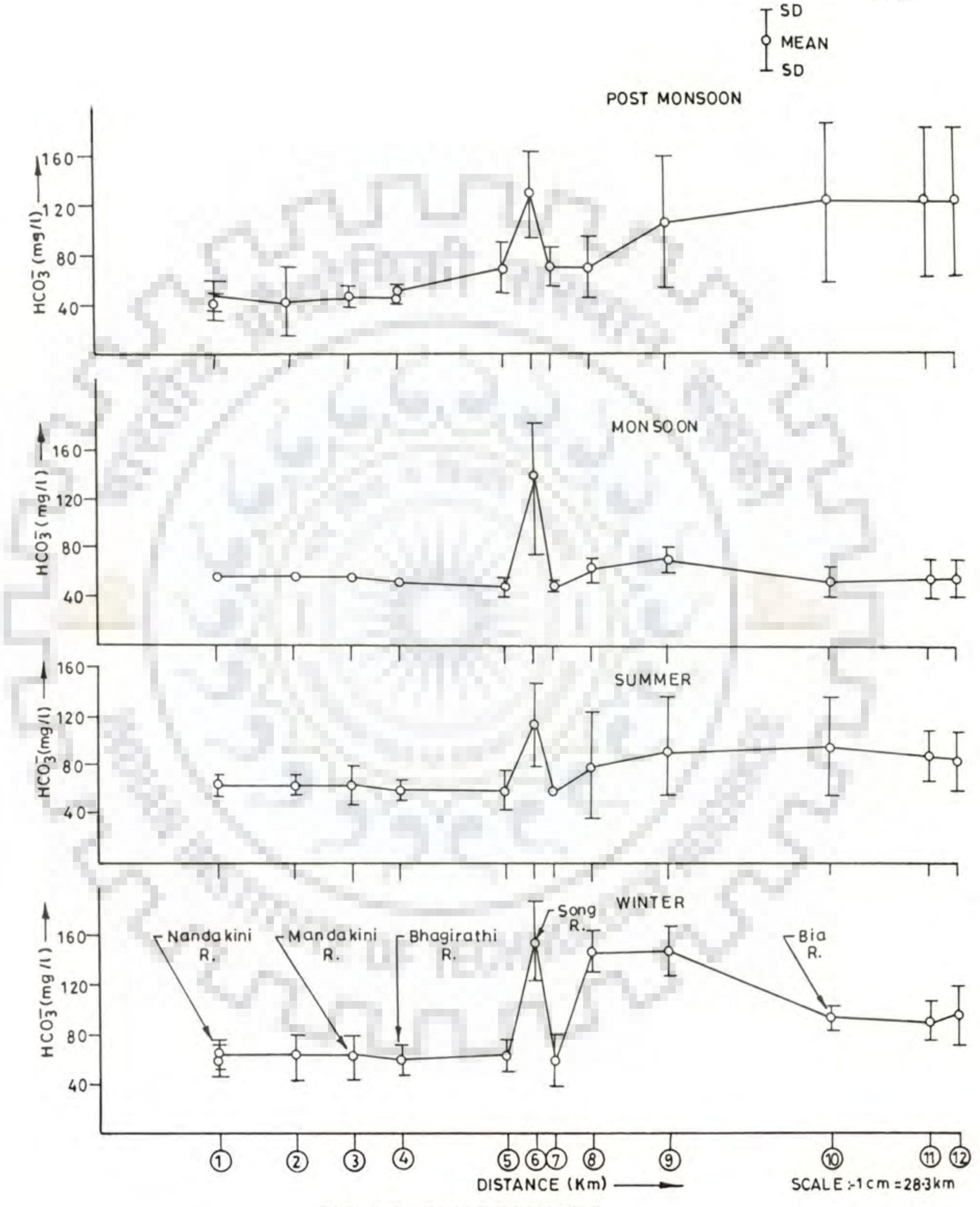


FIG. 4·9–BICARBONATES

to the accessibility of ground water to the carbonaceous shales present in the Shivalik encountered only in this sub-stretch.

In the plains downstream of Rishikesh the influence of Song discharge was notable upto Rajghat Narora.

4.4.6 Chlorides:

Ganga river had low chloride concentration althrough the study area varying between 3.5 mg/l and 8.0 mg/l. The temporal and spatial variations (Fig. 4.10) were minor. Wherever an increase was encountered it was due to prominence of activities like domestic waste discharges, solid waste dumps and cremation. However, there were a few points worth mentioning. The drop in chloride content at Rudraprayag can be attributed to dilution from Mandakini which in fact carried low chlorides. The slight increase observed at Devprayag was due to the discharge of domestic effluents at Srinagar and the increase proportional to flows. The marginal increase at Rishikesh was due to the ground water interaction of Shivalik origin.

The increase at Satyanarayana, in chloride content, was due to the joining of the combined stream of IDPL effluent and Rishikesh nala to Ganga river. In the lower reach the marginal variations due to cremation activities were observed at Chandighat, Garhmukteshwar, Anupshahr and Rajghat Narora.

4.4.7 Calcium and Magnesium:

The concentration and variation of calcium and magnesium in

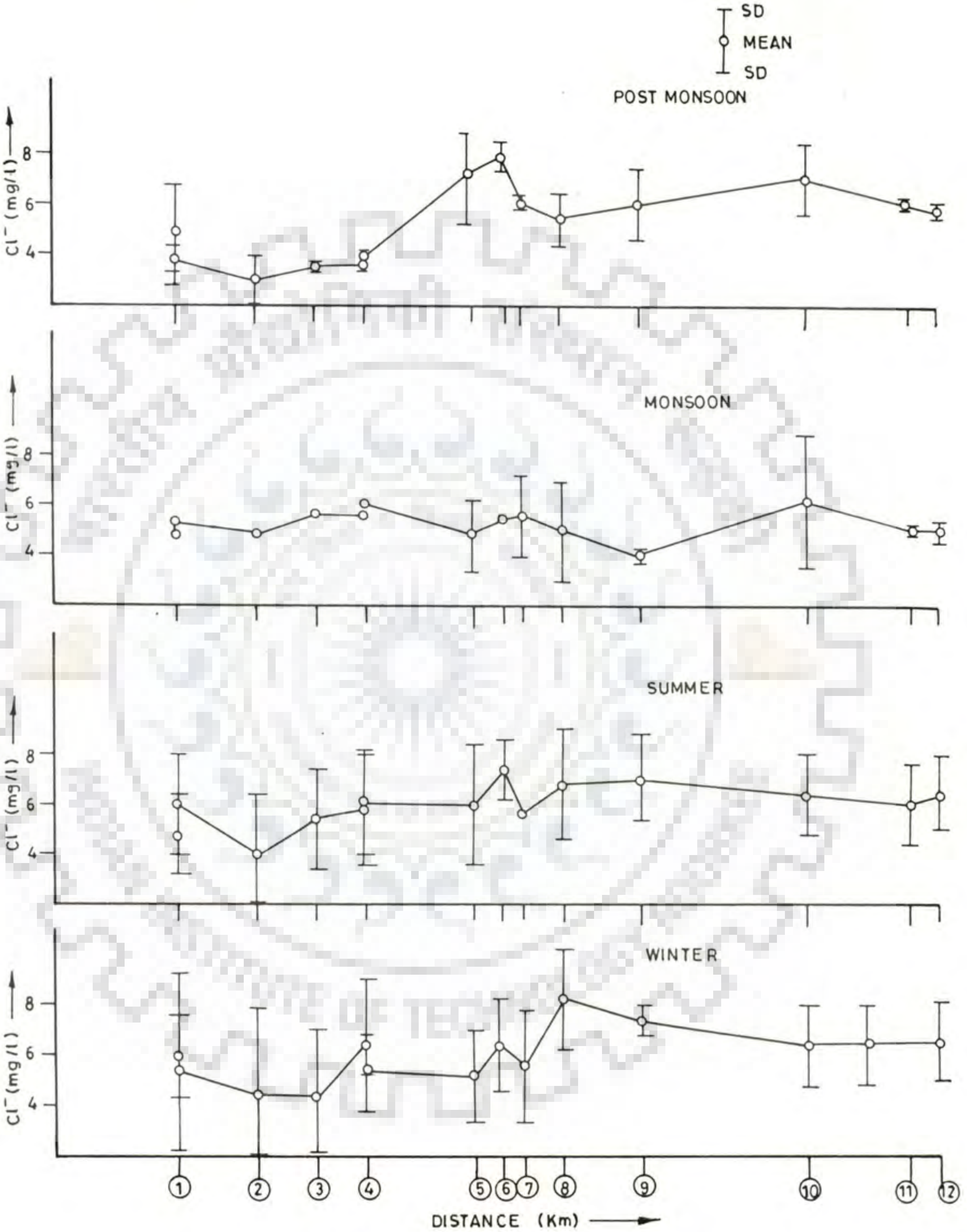


FIG. 4·10— CHLORIDES (mg/l)

mountainous reaches (18 mg/l to 22 mg/l and 4.0 mg/l to 6.5 mg/l) was lesser as compared to the plains (21.0 mg/l to 66 mg/l and 5.0 mg/l to 27.5 mg/l). From Nandprayag to Rudraprayag the calcium content was either constant or decreased in all seasons, whereas magnesium increased (Fig. 4.11 and 4.12). This trend is indicative of the presence of magnesite rocks. Between Rudraprayag and Srinagar, the calcium values increased during winter and summer seasons, and decreased during monsoon and post-monsoon seasons. On the otherhand, magnesium content decreased in all seasons. This depicts that the water joining Alaknanda river and the Alaknanda river itself drains the area in which dolomite rocks are more prominent. Between Srinagar and Devprayag, calcium values show a decreasing and magnesium values an increasing trend during Winter and Summer seasons, which also can be attributed to the presence of magnesites in the stretch.

Downstream of Rishikesh the impact of Song river was visible at Satyanarayana as in the case of other mineral parameters. The trends of calcium and magnesium were comparable with flow conditions of the river. More calcium and magnesium concentrations were observed during lean flow conditions and lesser values during run-off.

4.4.8 Sulfates:

The variations in sulfate concentration was very little in the mountainous stretch (10 mg/l) pertaining to no significant

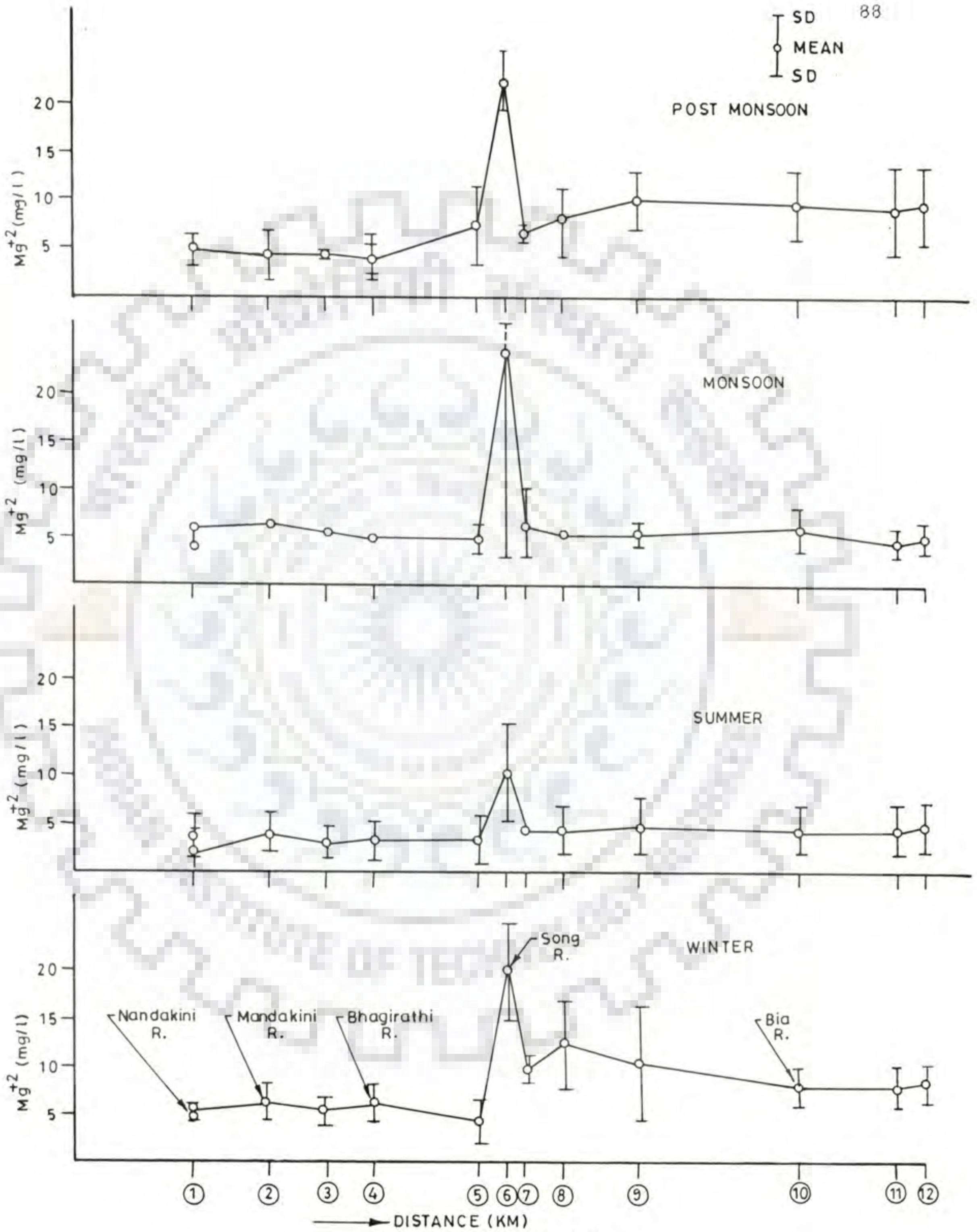


FIG. 4·11 – MAGNESIUM

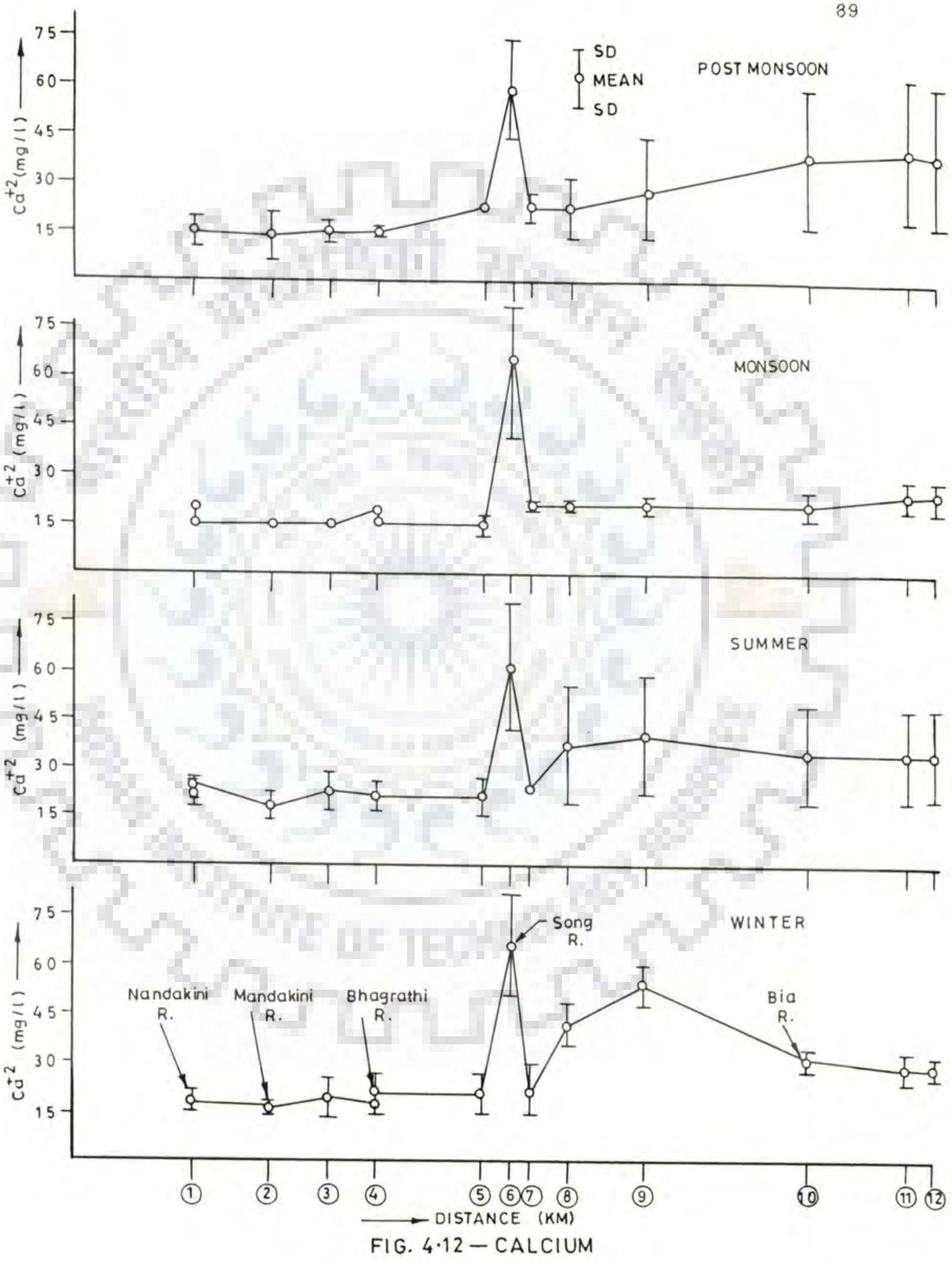


FIG. 4·12 — CALCIUM

contribution from the geology of the catchment area from Nandprayag to Rishikesh. In plains, however, the maximum values were observed at Satyanarayana (Fig. 4.13) due to the addition of Song river which drains the area rich in pyritic and phosphorite deposits. Downstream of Satyanarayana the sulfate concentration decreased due to the dilution caused by Chilla tail waters. Further downstream the sulfate concentration remained nearly constant upto Rajghat Narora.

4.4.9 Sodium:

In the Upper reaches the concentration of sodium was nearly constant (Table 4.5). At Satyanarayana the concentration was maximum because of Song river confluence. Downstream of Satyanarayana high values of sodium alongwith their standard deviations indicate a prominent contribution of groundwater during lean flow months.

4.4.10 Total Anions and Total Cations:

The trend of total anions and cations depicts the changes occurring in the physico chemical quality of water. From the temporal and spatial variations of these (Fig.4.14 and 4.15) one can visualize the areas of important inputs of the mineral parameters in the stretch. The trends were, however similar, indicating good balance. In the mountainous reach the variation was not of much significance, whereas, downstream of Rishikesh projects significant spatial and temporal variations. This is

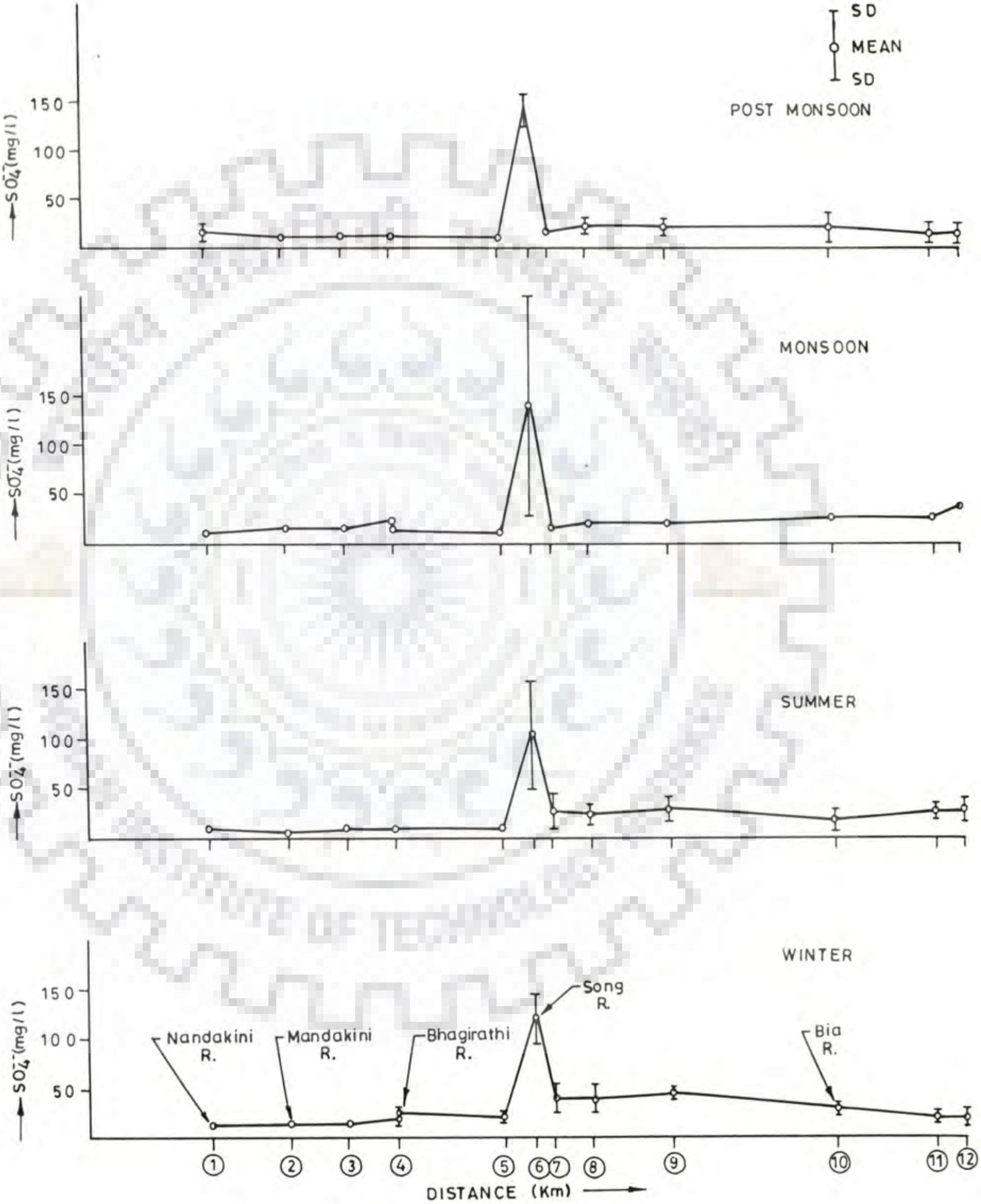


FIG. 4.13 — SULFATE

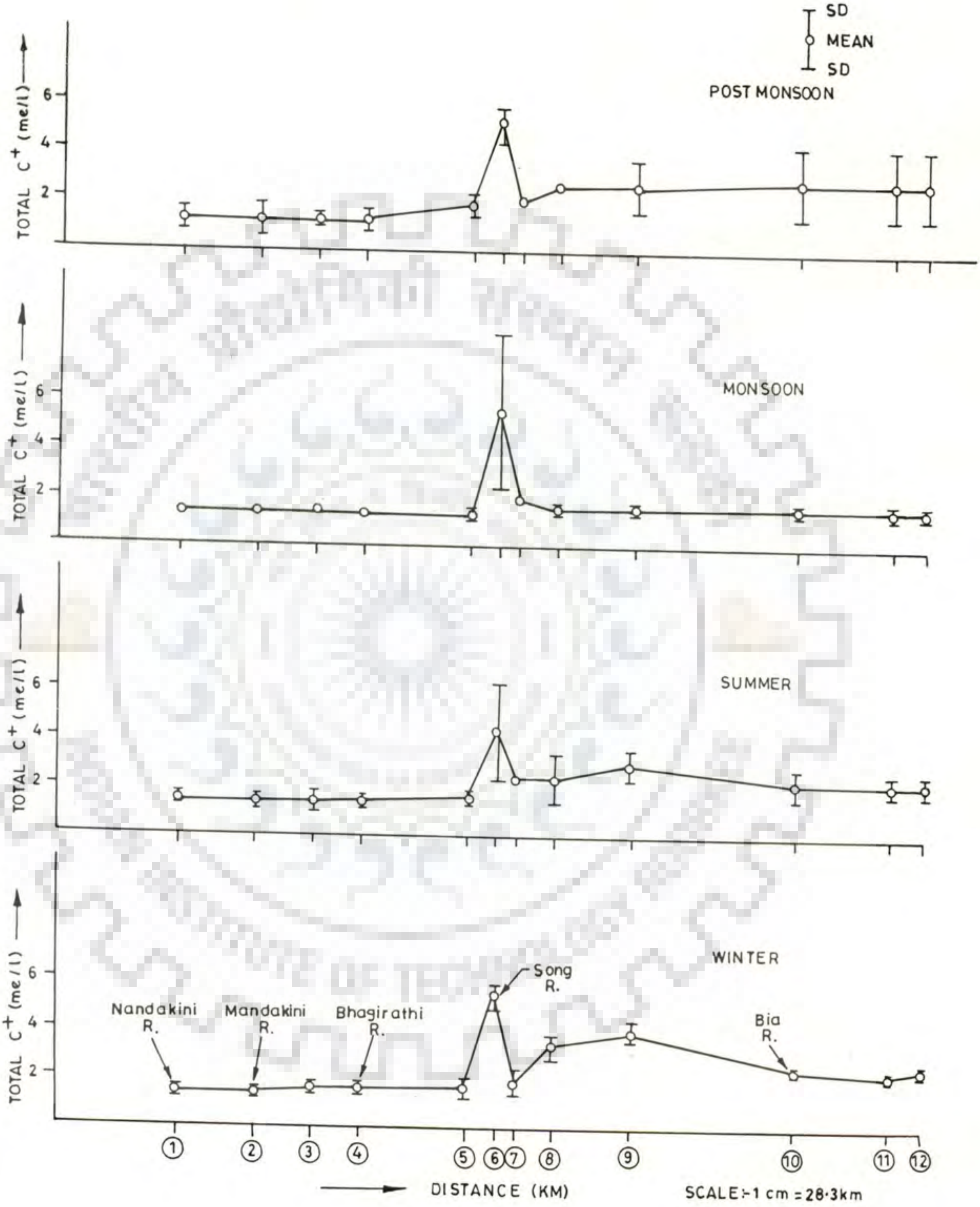


FIG. 4.14—TOTAL CATIONS

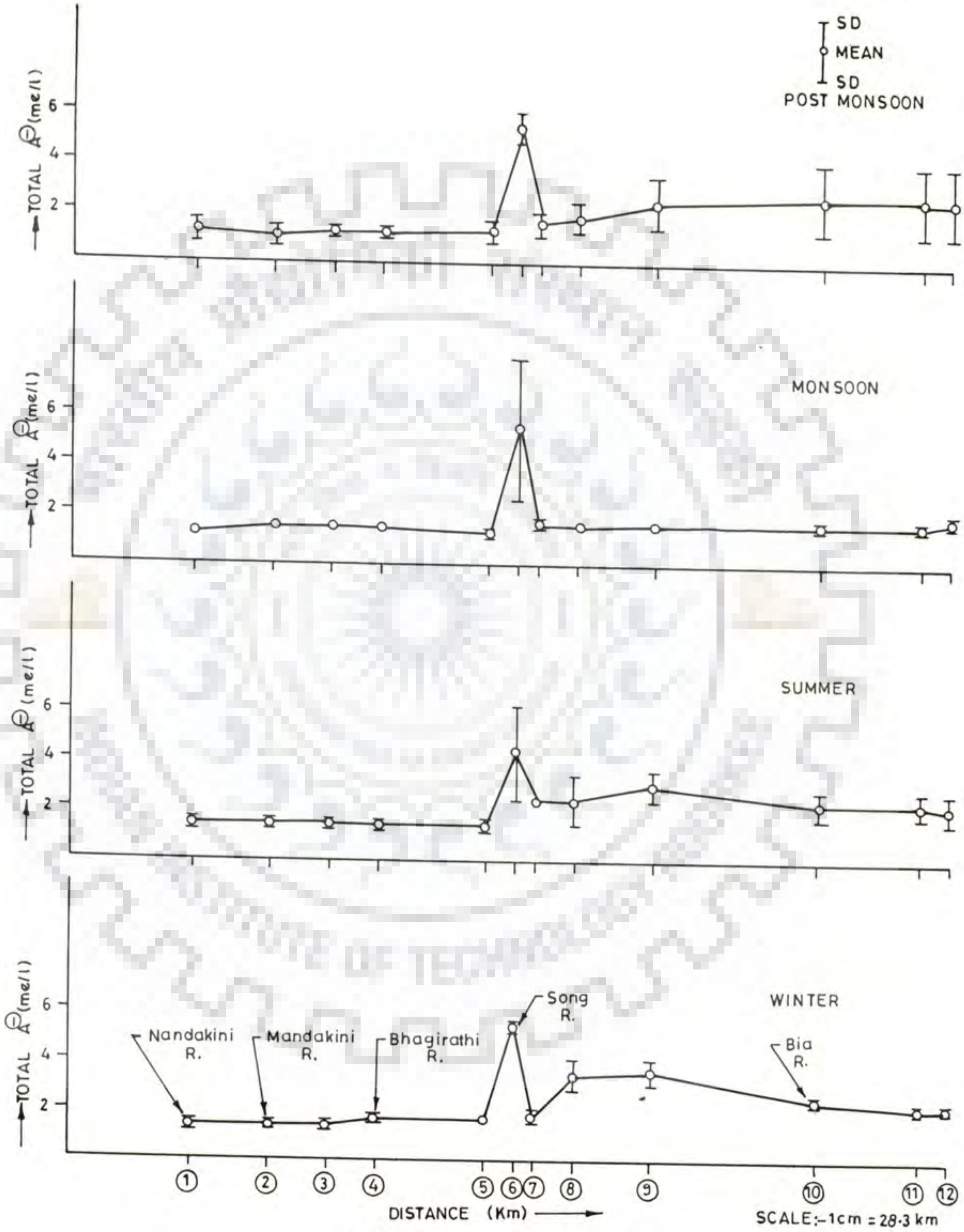


FIG. 4.15—TOTAL ANIONS

more so in the stretch between Satyanarayana and Bijnor. At Satyanarayana the increase in total cationic and anionic strength was due to the input of minerals through Song river. The increase between Balawali and Bijnor could be attributed to the ground water interaction with river and cremation on banks.

4.4.11 D.O.-B.O.D.-C.O.D.:

The organic pollution in the river is of a meagre order as evident by low values of B.O.D./C.O.D. and high D.O. values throughout the stretch. The general trend (Fig. 4.5), however indicates increase in B.O.D. and C.O.D at Srinagar with consequent decrease in D.O. This is because of addition of domestic effluents in the river upstream of sampling location. Next increase in B.O.D/C.O.D was prominent at Satyanarayana where the Song river and Rishikesh sewage alongwith IDPL effluent finds its way to Ganga river. Decrease in D.O. validates this proposition.

Further increase in B.O.D/C.O.D was observed downstream of Garhmukteshwar at Anupshahr and Rajghat Narora, where point and non-point discharges of domestic effluents associated with immense human activity at the river banks contributes to the load.

A general trend of a slow decrease in D.O. also shows the impact of topographical variation along the river stretch resulting in lower velocities and turbulence downstream in addition to the climatic activity factor.

4.5 HEAVY METALS

The study of heavy metal pollution in a riverine system is important not only from hazardous point of view, but also to identify the mineralized reaches and unexplored zones. This is more so for Ganga river. The present study reports the presence/absence of eight heavy metals viz. zinc, copper, iron, cadmium, manganese, lead and nickel, which in other words constitute the mineral load of the upper Ganga reach.

No anthropogenic heavy metal pollution source has been identified in the entire stretch of Upper Ganga. The incidence seems to be only due to the geochemical cycling of rocks and soils. In general, heavy metals in Ganga riverine system have been identified both in dissolved form and in conjugation with sediments. In lean-flow seasons the dissolved form constitutes a larger fraction of the total metal, whereas, in run-off months it is the suspended particulate form which is more significant. This is apparent from the larger standard deviation of annual mean of total metal concentrations (Fig. 4.16 to Fig. 4.18 and Table 4.6 to Table 4.9). In the mountainous stretch, the mineralized zones have been identified as mentioned in earlier chapters. Thus an increase in the dissolved metal concentration of these metals in any particular reach can, in all proximity, be attributed to the presence of unidentified mineralized zones.

TABLE 4.6 HEAVY METAL CONCENTRATION IN GANGA RIVER (Cadmium and Manganese)

S.No.	STATIONS	CADMIUM (µg/l)				MANGANESE (µg/l)			
		Total		Dissolved		Total		Dissolved	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	NANDPRAYAG B/C	121.0	95.0	40.1	21.0	10.7	13.6	1.8	4.0
2.	NANDPRAYAG A/C	105.0	46.0	60.2	60.0	12.7	9.3	5.9	8.1
3.	RUDRAPRAYAG	91.4	30.3	69.3	54.4	6.0	5.9	2.6	5.8
4.	SRINAGAR	128.8	85.8	58.9	28.6	11.3	15.4	7.8	8.8
5.	DEVPRAYAG B/C	103.9	78.6	51.3	30.4	15.6	15.6	3.1	4.3
6.	DEVPRAYAG A/C	110.0	72.1	67.5	27.2	7.4	7.1	4.8	7.6
7.	RISHIKESH	86.5	29.7	58.5	35.4	67.0	12.0	2.8	3.2
8.	SATYANARAYANA	93.2	54.1	82.6	102.0	19.3	15.9	4.6	5.7
9.	BALAWALI	123.9	54.1	100.8	67.6	35.1	44.1	14.1	13.5
10.	BIJNOR	104.0	54.8	60.7	50.0	25.3	16.3	8.1	8.9
11.	GARHMUKTESHWAR	135.0	43.6	92.0	48.3	17.3	22.9	8.1	9.1
12.	ANUPSHAHR	149.7	53.4	101.9	59.8	30.1	48.4	7.9	9.1
13.	RAJGHAT NARORA	113.5	38.7	56.9	35.3	26.1	21.2	6.8	9.0

B/C = Before confluence
A/C = After confluence

TABLE 4.7 HEAVY METAL CONCENTRATION IN GANGA RIVER
(Iron and Copper)

S.No.	STATIONS	IRON				COPPER (µg/l)			
		Total(mg/l)		Diss.(µg/l)		Total		Dissolved	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	NANDPRAYAG B/C	4.40	9.43	15.7	15.7	15.8	10.50	7.7	3.10
2.	NANDPRAYAG A/C	4.00	8.80	270.4	30.6	15.0	9.10	6.2	5.60
3.	RUDRAPRAYAG	1.30	1.63	148.1	106.0	12.8	9.00	5.4	5.00
4.	SRINAGAR	4.30	9.30	85.0	37.4	12.2	8.10	7.4	3.80
5.	DEVPRAYAG B/C	2.30	3.40	81.7	64.8	15.9	13.10	8.8	4.60
6.	DEVPRAYAG A/C	2.00	2.90	63.1	112.3	13.4	14.30	11.2	5.70
7.	RISHIKESH	3.50	4.60	112.3	52.1	13.8	8.40	10.4	8.60
8.	SATYANARAYANA	3.40	5.50	107.0	32.5	13.4	7.10	5.3	6.10
9.	BALAWALI	2.15	2.90	167.3	136.0	14.3	7.90	7.6	8.02
10.	BIJNOR	4.60	6.02	162.6	29.0	16.5	8.01	4.8	0.80
11.	GARHMUKTESHWAR	8.50	13.00	111.8	95.0	19.3	18.70	5.6	1.10
12.	ANUPSHAHR	5.00	6.90	228.3	165.3	19.5	18.50	4.4	3.20
13.	RAJGHAT NARORA	11.00	18.90	132.4	111.2	20.2	11.20	10.3	8.00

B/C = Before confluence
A/C = After confluence

TABLE 4.8 HEAVY METAL CONCENTRATION IN GANGA RIVER (Lead and Nickel)

S.No.	STATIONS	LEAD				NICKEL			
		Total(ppb)		Dis.(ppb)		Total(ppb)		Dis.(ppb)	
1.	NANDPRAYAG B/C	86.0	86.0	24.0	25.0	27.0	31.0	20.0	18.0
2.	NANDPRAYAG A/C	82.0	80.0	24.0	22.0	23.0	34.0	12.0	10.0
3.	RUDRAPRAYAG	82.0	100.0	32.0	30.0	26.0	18.0	14.0	12.0
4.	SRINAGAR	66.0	62.0	14.0	22.0	20.0	17.0	9.0	13.0
5.	DEVPRAYAG B/C	80.0	132.0	28.0	22.0	35.0	23.0	23.0	23.0
6.	DEVPRAYAG A/C	68.0	102.0	34.0	36.0	37.0	21.0	31.0	24.0
7.	RISHIKESH	66.0	44.0	30.0	22.0	26.0	17.0	28.0	50.0
8.	SATYANARAYANA	100.0	72.0	19.0	24.0	19.0	10.0	13.0	12.0
9.	BALAWALI	100.0	135.0	38.0	32.0	21.0	20.0	18.0	27.0
10.	BIJNOR	110.0	70.0	46.0	40.0	16.0	17.0	21.0	5.0
11.	GARHMUKTESHWAR	122.0	166.0	50.0	32.0	22.0	32.0	20.0	15.0
12.	ANUPSHAHR	112.0	100.0	40.0	18.0	18.0	22.0	14.0	10.0
13.	RAJGHAT NARORA	106.0	92.0	38.0	38.0	31.0	26.0	28.0	21.0

B/C = Before confluence
A/C = After confluence

TABLE 4.9 HEAVY METAL CONCENTRATION IN GANGA RIVER (Zinc and Cobalt)

S.No.	STATIONS	ZINC				COBALT			
		Total(ppb)		Dis.(ppb)		Total(ppb)		Dis.(ppb)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	NANDPRAYAG B/C	121.0	95.0	40.1	21.0	10.7	13.6	1.8	4.0
2.	NANDPRAYAG A/C	105.0	46.0	60.2	60.0	12.7	9.3	5.9	8.1
3.	RUDRAPRAYAG	91.4	30.3	69.3	54.4	6.0	5.9	2.6	5.8
4.	SRINAGAR	128.8	85.8	58.9	28.6	11.3	15.4	7.8	8.8
5.	DEVPRAYAG B/C	103.9	78.6	51.3	30.4	15.6	15.6	3.1	4.3
6.	DEVPRAYAG A/C	110.0	72.1	67.5	27.2	7.4	7.1	4.8	7.6
7.	RISHIKESH	86.5	29.7	58.5	35.4	67.0	12.0	2.8	3.2
8.	SATYANARAYANA	93.2	54.1	82.6	102.0	19.3	15.9	4.6	5.7
9.	BALAWALI	123.9	54.1	100.8	67.6	35.1	44.1	14.1	13.5
10.	BIJNOR	104.0	54.8	60.7	50.0	25.3	16.3	8.1	8.9
11.	GARHMUKTESHWAR	135.0	43.6	92.0	48.3	17.3	22.9	8.1	9.1
12.	ANUPSHAHR	149.7	53.4	101.9	59.8	30.1	48.4	7.9	9.1
13.	RAJGHAT NARORA	113.5	38.7	56.9	35.3	26.1	21.2	6.8	9.0

B/C = Before confluence
A/C = After confluence

The highway from Rishikesh to Badrinath runs almost along the course of the river and road construction, development and maintenance continue throughout the year accompanied by blasting, cutting and dumping of rock fragments to the river at many places. This accelerate weathering and entry of heavy metals into the river.

As the hill slopes of Alaknanda valley are significant, during monsoon season, huge amounts of soil from hills and adjoining areas is carried to the river during heavy downpour, adding to the suspended heavy metal load in the river. (Plate-8).

In the lower reach i.e. Rishikesh to Rajghat Narora, the heavy metals seem to have been gained from the geochemical cycling of soil and ground water recharge during the prolonged lean flow season.

4.5.1 Impact of Major Tributaries:

Four major tributaries namely Nandakini, Mandakini, Bhagirathi and Song were also studied for the impact of heavy metal occurrence in Ganga river. The mean concentrations in these tributaries are shown in Table 4.10 and 4.11. Nandakini, Mandakini, Bhagirathi and Alaknanda flow through a catchment of similar geological formations, whereas, Song passes through Doon Valley known for its limestone deposits. The difference in the total and dissolved metal concentration in each is governed by

VISIBLE EROSION IN ALAKNANDA VALLEY

PLATE-8

TABLE 4.10 TOTAL METAL IN TRIBUTARIES BEFORE CONFLUENCE

Metal (ppb) [except iron]	NANDAKINI		MANDAKINI		BHAGIRATHI		SONG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
COPPER	11.5	8.5	11.9	7.6	20.4	34.1	22.8	33.2
IRON (ppm)	0.3	0.3	3.5	6.7	1.1	0.7	1.1	1.9
CADMIUM	8.5	6.3	3.4	4.6	4.0	2.7	13.3	12.2
COBALT	10.4	9.8	18.3	18.7	17.4	17.4	12.8	12.0
LEAD	19.4	120.3	56.3	40.4	78.7	55.5	61.1	56.5
MANGANESE	34.7	42.6	45.9	57.0	38.0	33.6	182.8	102.2
NICKEL	23.8	24.6	35.2	25.4	31.0	26.9	17.2	8.7
ZINC	88.8	39.0	117.6	106.1	107.0	59.1	58.9	32.5

TABLE 4.11 DISSOLVED METAL IN TRIBUTARIES BEFORE CONFLUENCE

Metal (ppb) [except iron]	NANDAKINI		MANDAKINI		BHAGIRATHI		SONG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
COPPER	6.2	5.6	3.8	6.1	7.8	7.6	17.8	29.8
IRON (ppm)	66.0	37.4	108.2	57.8	69.7	38.4	0.9	1.7
CADMIUM	7.4	7.1	2.6	3.6	5.0	1.6	11.3	10.4
COBALT	2.8	5.2	8.9	10.2	0.0	-	10.0	9.7
LEAD	40.4	53.4	31.2	21.6	33.3	25.9	48.4	48.8
MANGANESE	15.9	19.5	14.2	17.6	5.6	4.5	165.2	95.1
NICKEL	7.5	10.4	13.0	13.0	16.0	23.6	13.3	6.6
ZINC	72.1	98.4	46.6	39.0	64.4	55.4	50.0	29.3

the extent of physical erosion and chemical leaching in the stretch respectively. In general, the dissolved fraction and total metal carried by Song clearly indicated that chemical leaching is predominant in Song river catchment.

Nandakini carries lead and cadmium predominantly as compared to other glacier fed tributaries. Mandakini adds iron, cobalt, manganese, nickel and zinc, whereas Bhagirathi carries copper, cobalt, nickel and zinc. Song adds copper, cadmium and manganese to Ganga river. In general, metal in suspended form is added more by Bhagirathi as compared to other tributaries.

4.5.2 Trends of Heavy Metals in the Upper Ganga Reach:

The changes in heavy metal concentrations both in dissolved and total forms are presented in Table 4.6 to Table 4.9 and Fig. 4.16 to Fig.4.18.

In the stretch between Nandprayag and Rudraprayag the dissolved lead values increase slightly with total lead remaining the same implying a reduction in suspended load. The other metals like nickel, manganese, zinc are added in the dissolved form. This implies that the geological formations are rich in nickel, manganese, zinc, cadmium and lead. The decrease in copper, cobalt and iron with the insignificant addition of metals in suspended form indicates lesser extent of physical erosion in the stretch.

The stretch between Rudraprayag and Srinagar projects the

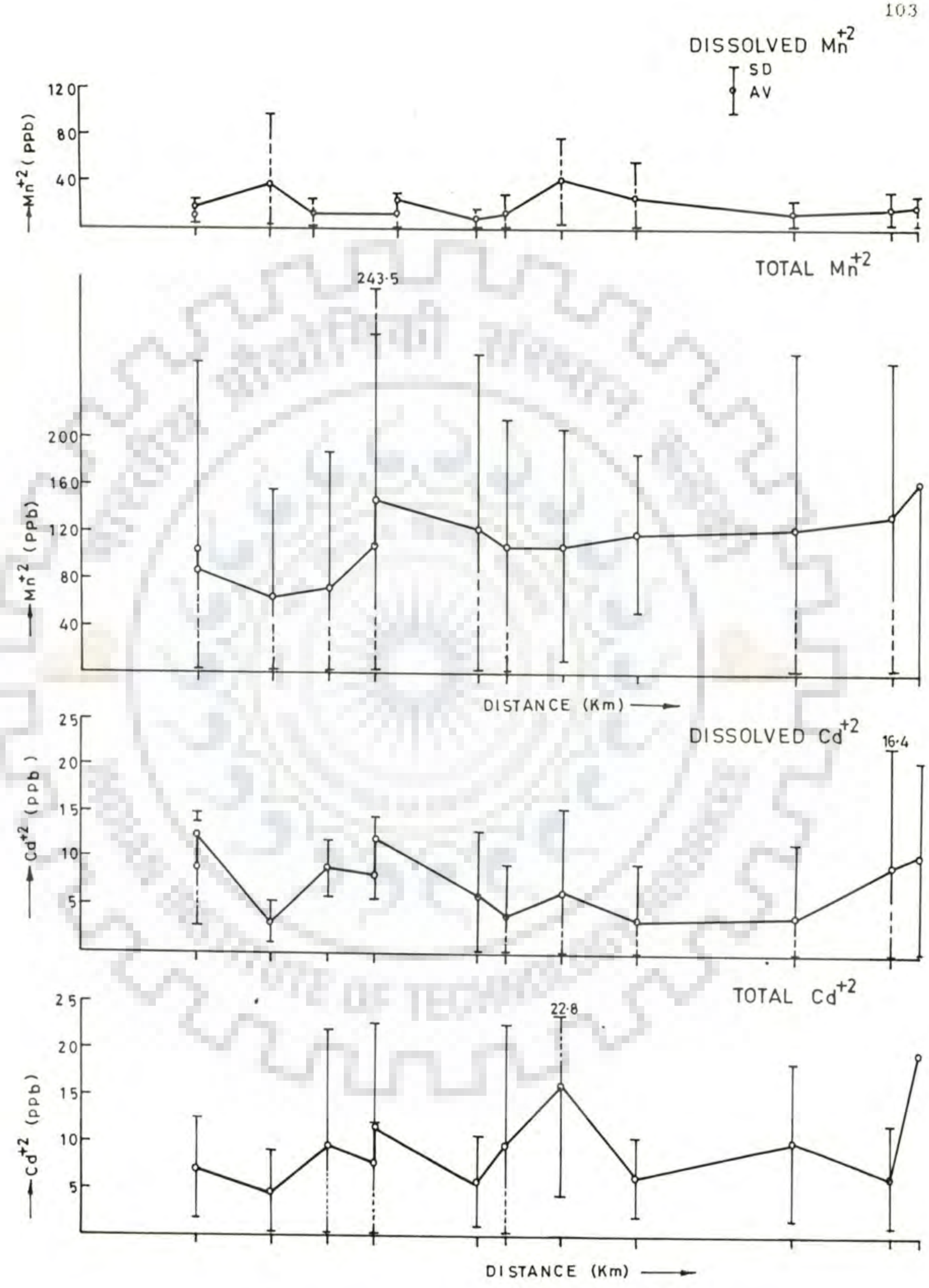

DISSOLVED Mn^{+2}
SD
AV
120
80
40
$\rightarrow Mn^{+2}$ (ppb)
TOTAL Mn^{+2}
243·5
200
160
120
80
40
$\rightarrow Mn^{+2}$ (ppb)
DISTANCE (Km) ⟶
25
20
15
10
5
$\rightarrow Cd^{+2}$ (ppb)
DISSOLVED Cd^{+2}
16·4
25
20
15
10
5
$\rightarrow Cd^{+2}$ (ppb)
TOTAL Cd^{+2}
22·8
DISTANCE (Km) ⟶

FIG 4·16

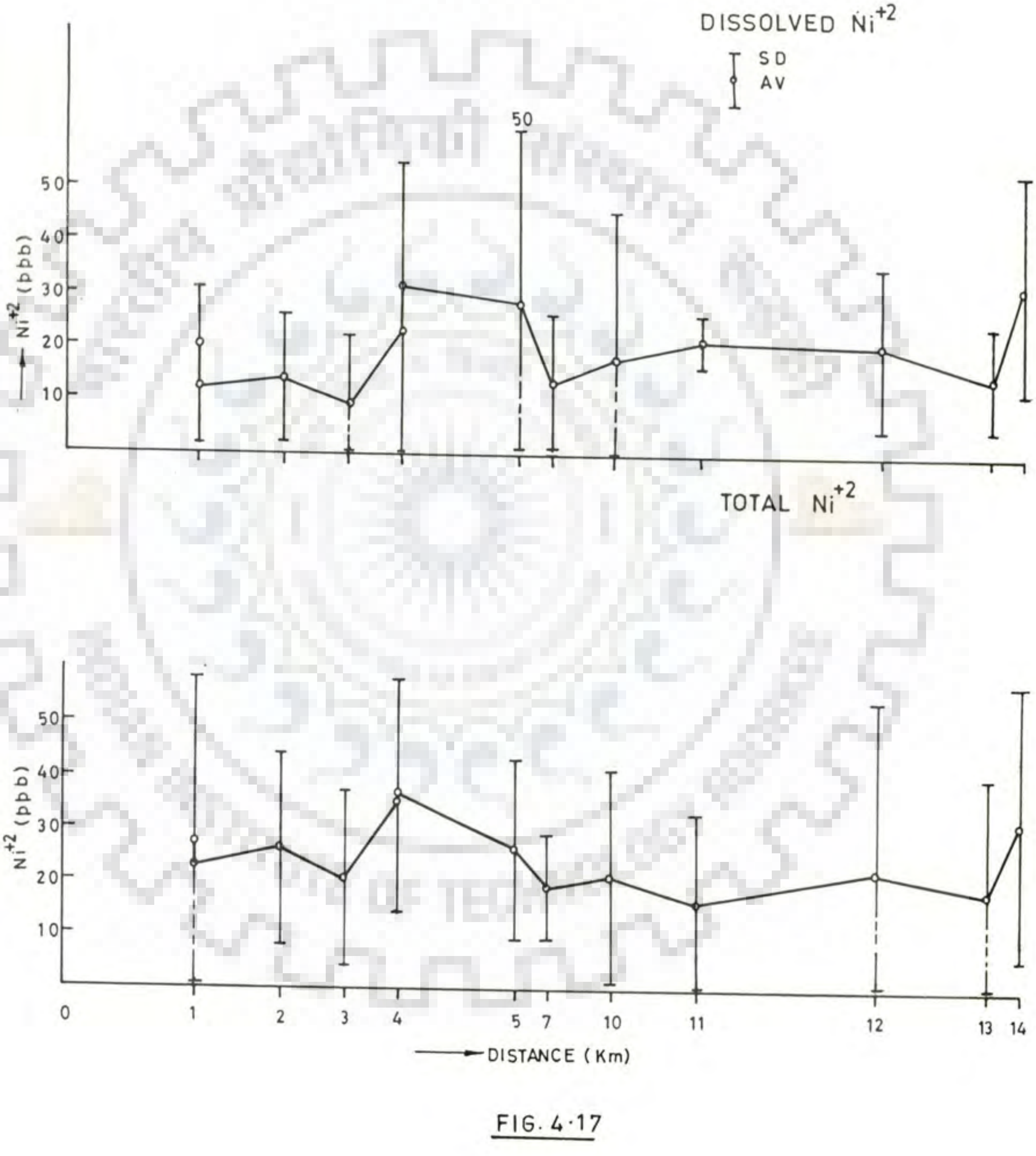

DISSOLVED Ni+2
SD
AV
50
Ni+2 (ppb)
10
20
30
40
50
TOTAL Ni+2
Ni+2 (ppb)
10
20
30
40
50
0
1
2
3
4
5
7
10
11
12
13
14
DISTANCE (Km)

FIG. 4·17

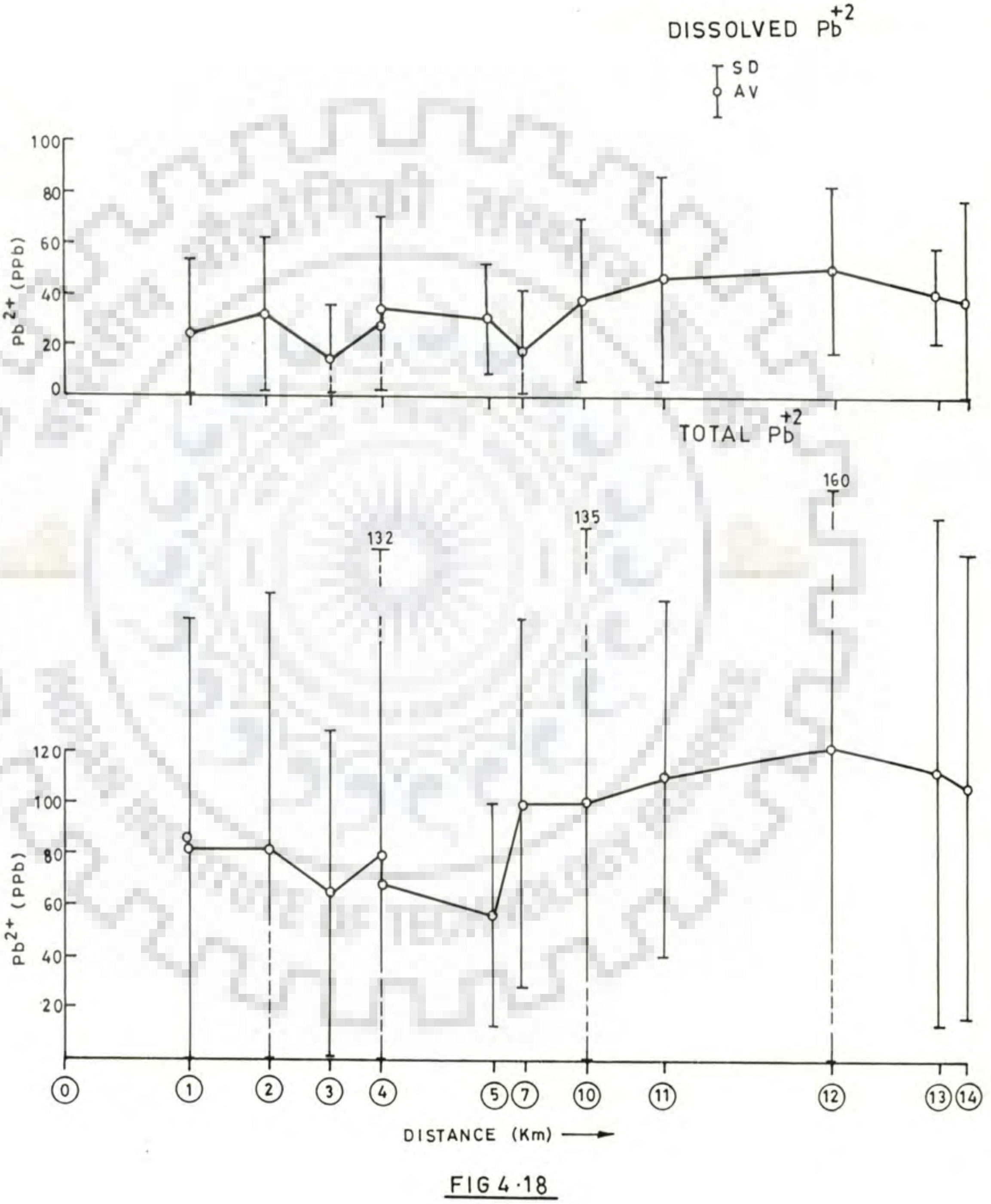

DISSOLVED Pb^{+2}
SD
AV
100
80
60
40
20
0
Pb^{2+} (PPb)
TOTAL Pb^{+2}
160
135
132
120
100
80
60
40
20
Pb^{2+} (PPb)
⓪
①
②
③
④
⑤
⑦
⑩
⑪
⑫
⑬
⑭
DISTANCE (Km)

FIG 4·18

variable behavior of metals. Some metals like iron, cobalt, zinc, lead, nickel, manganese are added in suspended form, whereas, cadmium and copper in dissolved form. This type of variation can be attributed to relatively significant extent of physical erosion taking place and the sulfide mineralization in the stretch. The increase in dissolved cadmium and dissolved cobalt are also indicative of chemical weathering of the region.

In the stretch between Srinagar and Devprayag the prominence of physical erosion is visible. Copper, lead and nickel are added in both forms and cobalt, manganese are added predominantly in the form of suspended particulates.

The stretch between Devprayag and Rishikesh also show an increase in concentrations of copper, cobalt and iron in suspended form. The concentrations of lead, nickel, manganese, zinc and cadmium are less indicating the lesser extent of chemical weathering.

In plains, the stretch between Rishikesh and Balawali is important in view of river flow and types of inputs and withdrawals. A combined effect of Song river and ground water (in lean flow months) is visible in this stretch. Cadmium, nickel, manganese and lead are added in dissolved form and copper, cobalt and zinc in suspended form. Since, iron does not show any variation, there is no significant input in this region. The addition of suspended metal is attributed to the erosion of agricultural soil during monsoon months.

The stretch between Balawali and Bijnor is prominently indicative of ground water interaction with river and agricultural run-off. Due to this, manganese, iron and copper are added in suspended form whereas lead and nickel in dissolved form. Cadmium, cobalt and zinc show similar values with minor variations.

The region between Garhmukteshwar and Rajghat Narora exhibits a decrease in the lead, cobalt and zinc metals, whereas, copper, cadmium, iron, manganese and nickel show an increase, mostly in suspended forms. It is difficult to attribute this behavior to any other activity than to the meeting of non-point agricultural run-off, domestic effluents and contamination of cremation related activities.

4.6 PRINCIPAL COMPONENT ANALYSIS

The purpose of Principal Component Analysis (PCA) in general, is to interpret the structure within the variance-covariance matrix of a multivariate data collection. The technique uses extraction of eigen values and eigen vectors from the matrix of correlations. PCA is commonly regarded as a deep and mysterious methodology of great complexity. Analysts are sharply divided on the topic, both as to the validity and the utility of the technique. Nevertheless, it is one of the most widely used multivariate procedures and extends a beguiling promise to experimenters faced with a welter of complex data and little insight into the structure of the data. Sometimes it confirms the temporal and spatial variations of the parameters, besides providing additional information.

The following terms are used in Principal Component Analysis (PCA):

(i) Mean: Mean is the arithmetic average of sample population and is expressed as

$$X = {}_{i=1}\Sigma^{n} \; X_i/n$$

X_i = Random sample from normal distance whose mean is X^2

(ii) Variance: Variance is defined as the average squared deviation of all possible deviations from the population mean and can be expressed mathematically as,

$$S^2 = {}_{i=1}\Sigma^{n} \; (X_i 1-X)^2/n$$

and the square root of the variation (S^2) is termed as the standard deviation and is expressed as,

$$S = \{{}_{i=1}\Sigma^{n} \; (X_i-X)^2/n\}^{-2}$$

(iii) Covariance: The variables measured on the same observational unit tend to change together in same manner. Because of their dependency, some measure of their mutual interaction is needed. This measure is termed as covariance which, in otherwords, is the joint variances of two variables about their common mean.

(iv) Correlation Coefficient: For determining the degree of interaction between variables, correlation coefficient is used. It is the ratio of the covariance of two variables to the product of their standard deviations and can be expressed as,

$$r_{ij} = \frac{COV_{ij}}{S_i S_j}$$

where r_{ij} is the correlation coefficient of the variable i and j, S_i and S_j are standard deviations of the variables i and j and COV_{ij} is the covariance of these variables.

Correlation coefficient is a unitless number whose values ranges from +1 to -1. The positive sign indicates a direct relation between two variables, whereas, the negative sign indicates that the two variables are inversely correlated.

(v) Eigen Values and Eigen Vectors: PCA mainly consists the finding of the Principal Components which are nothing more than the eigen vectors of a variance-covariance matrix. Eigen values are the length of various axes of the m-dimensional ellipsode and eigen vectors are the orientation of the axes of the ellipsode. PCA is mainly concerned with the finding of these axes and measuring their magnitude. If m variables of data are taken, a m x m matrix of variance-covariance matrix will be computed and m eigen values and m eigen vectors can be computed.

(vi) Principal Components: Principal Components are the eigen vectors of variance-covariance matrix. If a number of variables are measured on a set of samples then a linear transformation of these variables will yield new variables. These new variables are called as Principal Components which are independent of each other and account for as much total variation as possible. This process of computation is called as Principal Component Analysis (PCA).

4.6.1 PCA in the Present Study:

In the present study PCA was resorted to the following objectives by using the physico chemical analysis data.

- to classify the Ganga river into mineralized and non-mineralized zones
- to find out the dominating variables at different locations
- to evaluate the validity of the sampling net work and frequency

Besides the above objectives the PCA is also expected to yield the correlations between the variables, which in other words, helps in identifying the nature of the sources in a broad sense w.r.t. the mineralization at and around a location.

4.6.1.1 Procedures Followed:

The data of 19 variables of 7 observations (months) at 11 locations is organized in 3 matrix types in input files. The first type of matrix contains the data of ith parameter of m observations (7 months) at n locations (11 stations). The input file of total dissolved solids is presented as Appendix-1 as an example. The second type of matrix contains the data of i variables of m observations at nth location. The variables included were p^H, total dissolved solids, conductivity, bicarbonates, carbonates, chlorides, sulfate, calcium, magnesium, sodium, iron, zinc, lead, cadmium, manganese, nickel, cobalt and copper. To illustrate the input file the data at Nandprayag is given as Appendix-2. The third type of matrix contains the data of i variables at n locations during mth observation and input file for the month of Dec.1985 is presented in Appendix-3.

The Principal Components are computed on HP 9000/560 using Davis's (1973) computer program. The flow chart is presented in Fig. 4.19 and the program is given in Appendix-4.

The first line in the input file gives the number of columns (n, the observations) and the number of rows (m, the variables). The second line states the computation procedures viz. standardization.

In the computation of PCA, the standardization plays a key role. The standardization consists of transforming a data set so that it has a mean of zero and variance (or SD) of one, by substracting the mean of the data set from each observation and dividing it by the SD. In this way, the SD of each data set

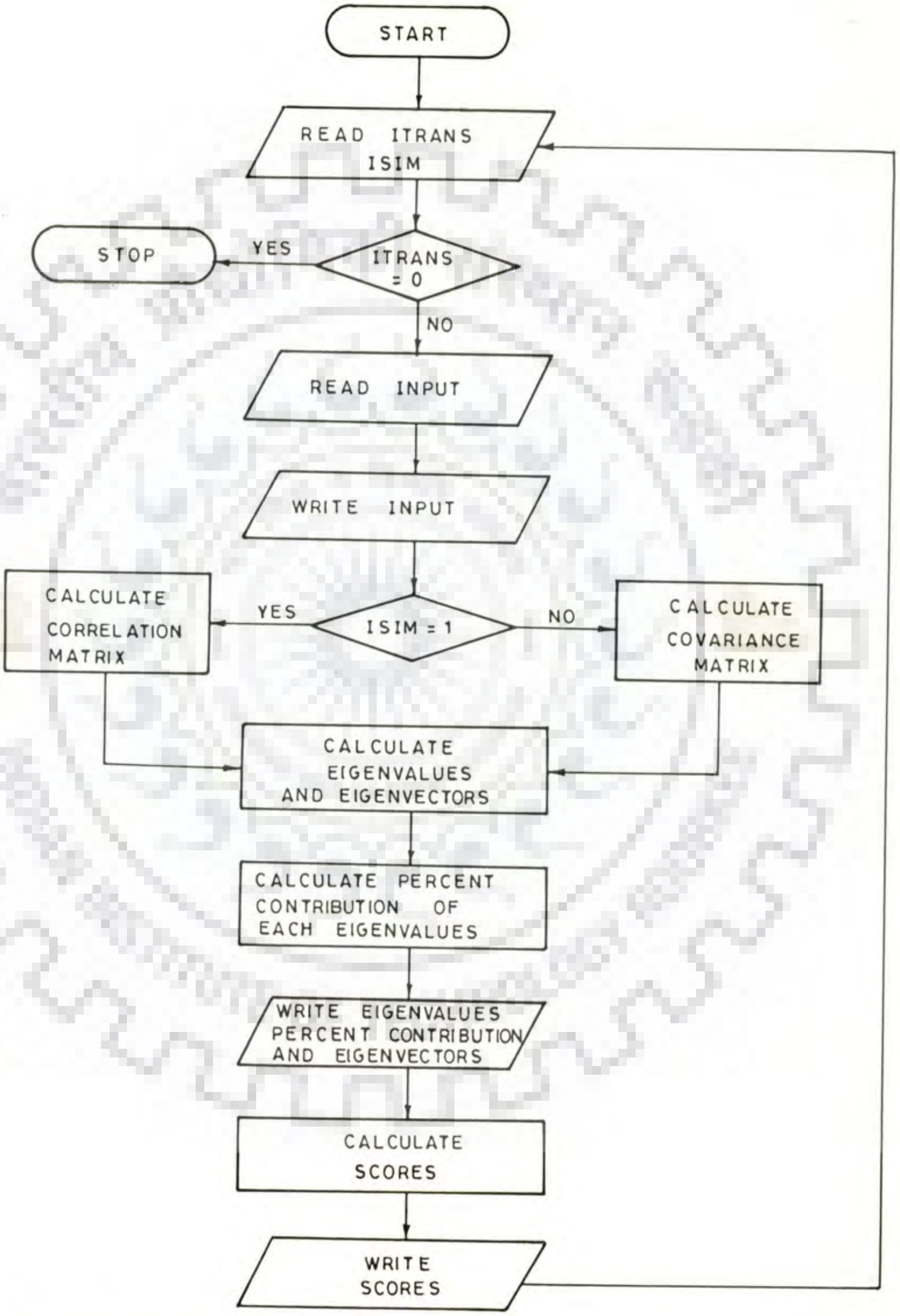


FIG. 4·19 – FLOWCHART OF PRINCIPAL COMPONENT ANALYSIS becomes one as well, and the correlation is equal to the covariance.

The Principal Components contributing upto 95% are considered for further interpretations. In general, the variables that constitute the major Principal Components are identified from the eigen vectors by fixing a cut-off limit and this limit is subjective and as such no clear guidelines are available in literature to decide this limit. In the present study, the cut-off limit for eigen vectors is kept as 0.3 and the variables which are yielding the eigen vectors above 0.3 are only considered.

4.6.2 Interpretations of PCA:

4.6.2.1 Classification of Ganga River in the Study Area:

To classify the Ganga river between Nandprayag and Rajghat Narora into mineralized and un-mineralized zones, PCA is performed on m observations of ith parameter at n locations (Appendix-1). Table 4.12 illustrates the significant sampling locations with respect to 15 parameters which is clearly indicative of the significance of lower stretch locations (Satyanarayana to Rajghat Narora) as compared to the locations in hilly terrain (Nandaprayag to Rishikesh). The percentage contribution of locations upto four Principal Components are presented in Table 4.13 and it can be observed that the locations of lower reach are contributing the first two Principal

Table 4.12 SIGNIFICANT STATIONS FOR PARAMETERS

PARAMETERS	STATIONS										
	1	2	3	4	5	6	7	8	9	10	11
1. Conductivity	*	*				*	*	*	*		
2. Total dissolved solids	*	*			*	*		*	*		
3. Bicarbonates					*	*	*	*		*	*
4. Carbonates					*	*	*	*	*	*	*
5. Chlorides	*	*	*		*		*		*	*	
6. Calcium						*	*	*	*	*	*
7. Magnesium					*	*	*	*		*	
8. Iron			*	*					*	*	*
9. Zinc			*	*		*	*	*	*	*	*
10. Lead	*		*				*		*		*
11. Cadmium			*	*		*	*		*		*
12. Manganese				*				*			*
13. Nickel						*			*		*
14. Cobalt						*	*		*	*	*
15. Copper	*	*		*		*		*	*		*

Stations:
1. Nandprayag
2. Rudraprayag
3. Srinagar
4. Devprayag
5. Rishikesh
6. Satyanarayana
7. Balawali
8. Bijnor
9. Garhmukteshwar
10. Anupshahr
11. Rajghat Narora

Table 4.13 STATIONS CONTRIBUTING UPTO 4 PRINCIPAL COMPONENTS

PARAMETERS	P.C.1	P.C.2	P.C.3	P.C.4
1. Conductivity	7,8 (56.5)	1,2 (23.5)	6,8,9 (10.6)	6,9 (6.4)
2. Total dissolved solids	1,2,8 (51.7)	8 (28.9)	2,9 (12.1)	5,11 5.0)
3. Carbonates	8,9,10, 11 (60.1)	6,7 (23.8)	6,7 (9.4)	5 (3.2)
4. Bicarbonates	6,10,11 (57.9)	8 (18.8)	7,8 (12.1)	5,6 (6.1)
5. Chloride	1,2 (60.6)	2,10 (21.0)	6,5,7 (11.5)	1,3,10 4.6)
6. Calcium	9,10,11 (52.5)	6 (23.7)	7,8 (17.6)	8,9 (4.0)
7. Magnesium	6 (75.4)	7,8 (17.2)	5,8 (3.7)	5,10 (1.6)
8. Iron	6,9 (91.4)	4,10,11 (7.6)	-	-
9. Zinc	3,4 (50.6)	3,7,10 (19.4)	6,8,11 (16.9)	6,9 (8.8)
10. Lead	7,9 (92.0)	6,5 (5.6)	-	-
11. Cadmium	7,11 (59.2)	6,5 (21.9)	3,6 (9.8)	4,9 (5.7)
12. Manganese	4,11 (94.1)	8 (2.6)	-	-
13. Nickel	6 (65.7)	11 (19.1)	2,9 (12.3)	-
14. Cobalt	7,9,10 (72.7)	10,11 (18.6)	6 (4.3)	-
15. Copper	4,11 (59.8)	2,4 (19.5)	6,9 (11.7)	2,3,4,8 (4.7)

P.C. = Principal Component

Stations :		
1. Nandprayag	6. Satyanarayana
2. Rudraprayag	7. Balawali
3. Srinagar	8. Bijnor
4. Devprayag	9. Garhmukteshwar
5. Rishikesh	10. Anupshahr
	11. Rajghat Narora

Components (which is more than 80% of total contribution) for all parameters. This, in otherwords, indicates that all locations are important w.r.t. mineral parameters and the primary net work sampling stations selected in the present study are valid to assess the mineral transport in Ganga river. The significance of lower reach stations clearly classify the Ganga river as mineralized between Satyanarayana and Rajghat Narora and non-mineralized between Nandaprayag and Rishikesh, which was also evident from the profiles of physico chemical parameters.

4.6.2.2 Significant Parameters at Each Location:

PCA was performed among the variables of 7 observations at 11 locations (Appendix-2) to find out the significant parameters at each location. The variables contributing upto 4 Principal Components at different stations are presented in Table 4.14. In all cases it is observed that the first two Principal Components have contributed from 57.0 to 74.0 percent. The variables constituting upto 2nd Principal Component are termed as significant w.r.t. their variation at that location.

In general, p^H, conductivity, carbonates, bicarbonates and calcium are the significant parameters at all locations. Besides these, chlorides are significant at Devprayag and sulfates in the lower reaches. Magnesium is significant at Srinagar, Bijnor and Anupshahr although the spatial and temporal variations of magnesium (Fig. 4.12) are not clear. Among trace metals iron is

Table 4.14 PARAMETERS CONTRIBUTED IN 5 PRINCIPAL COMPONENTS (Stationwise)

STATIONS	FIRST Principal Component	SECOND Principal Component	THIRD Principal Component	FOURTH Principal Component
1. NANDAPRAYAG After confluence	1,5,8,12 (46.7%)	10,11,16 (20.9%)	7,13,14 (12.1%)	4,9,14,17 (11.9%)
2. RUDRAPRAYAG	1,5,11,15 (32.8%)	4,8,12 (27.4%)	2,3,13 (15.8%)	7,14,16 (11.1%)
3. SRINAGAR	1,2,3,5, 13,17,18 (36.7%)	4,8,9,10, 16 (23.6%)	14,15 (18.2%)	6,10,11 (10.7%)
4. DEVPRAYAG After confluence	2,3,11,12 13,15 (48.6%)	1,4,6,10 (19.8%)	4,7,8,16 (14.2%)	14,18 (8.8%)
5. RISHIKESH	4,12,17 (45.6%)	1,3,10,15, 18(29.8%)	2,5,6,7, 10 (8.7%)	2,7,8,13 (7.0%)
6. SATYANARAYANA	1,7,13,15 (37.3%)	2,4,8,12, 16,17 (27.8%)	10,18 (12.9%)	1,6,14,16, 17 (10.0%)
7. BALAWALI	1,5,7,15, 18 (36.0%)	2,4,6,8,16 (33.9%)	10,12 (13.4%)	2,3,5,14 (10.4%)
8. BIJNOR	2,4,5,8,9, 13 (40.7%)	1,7,14,15, 16 (17.1%)	6,11,12, 18 (15.3%)	11,14,16 (11.6%)
9. GARHMUKTESHWAR	1,5,7,15, 18 (45.7%)	10,13,14, 16,17 (20.9%)	4,6,12 (11.7%)	10,12 (10.9%)
10. ANUPSHAHAR	1,2,3,4,5, 8,9,15 (37.2%)	7,13,17,18 (20.8%)	11,12,14, 16 (16.6%)	10,12,13 (14.3%)
11. RAJGHAT NARORA	5 (49.4%)	3,10,14,18 (18.0%)	6,7,11, 12,16 (14.6%)	6,7,9,10 17 (9.4%)

Parameters:

1. p^H
2. Conductance
3. Total dissolved solids
4. Bicarbonates
5. Carbonates
6. Chlorides
7. Sulfates
8. Calcium
9. Magnesium
10. Sodium
11. Iron
12. Zinc
13. Lead
14. Cadmium
15. Manganese
16. Nickel
17. Cobalt
18. Copper

significant at all stations except at Srinagar. Zinc is significant at all stations between Nandprayag and Satyanarayana except at Srinagar. Manganese is one of the significant trace metals at all stations except at Srinagar and Rajghat Narora, however, it showed an increase in suspended form at these stations (Fig. 4.16). Nickel is the significant parameter at Nandaprayag, Srinagar, Satyanarayana, Balawali, Bijnor and Garhmukteshwar. Cobalt and Copper are significant at Srinagar, Rishikesh, Satyanarayana, Balawali, Garhmukteshwar, Anupshahr and Rajghat Narora. Lead is significant at Srinagar, Devprayag, Satyanarayana, Bijnor, Garhmukteshwar and Anupshahr, whereas, cadmium is significant at Bijnor, Garhmukteshwar and Rajghat Narora.

4.6.2.3 Significant Months w.r.t. variation of Mineral Parameters:

Thirdly, PCA was applied to assess the significant months w.r.t. variation of mineral parameters in Ganga river between Nandaprayag and Rajghat Narora. The significant variables falling upto four Principal Components are presented in Table 4.15. From the table one can visualize that all the months are equally significant w.r.t. the mineral parameters. In general, total dissolved solids, bicarbonates, carbonates, calcium, magnesium, iron and manganese are the significant parameters in all months for their variation in the total upper Ganga stretch. Sulfates

Table 4.15 PARAMETERS CONTRIBUTING IN FOUR PRINCIPAL COMPONENTS (monthwise)

MONTH	First Principal Component	Second Principal Component	Third Principal Component	Fourth Principal Component
1. October, 1985	2,3,8,9 (44.1%)	5,11,15 (20.3%)	1,12,16 (14.9%)	15,17 (9.0%)
2. December, 1985	2,3,4,7,8,9,10 (43.6%)	1,5,13 (18.5%)	11,12 (12.1%)	6,12,16,17 (8.0%)
3. February, 1986	3,4,8,9 (46.9%)	7,13,15,17,18 (24.9%)	1,5,15 (10.5%)	11,12,16 (6.3%)
4. April, 1986	2,3,4,7,8,11 (45.5%)	1,5,11,13 (21.9%)	1,11,14,18 (9.0%)	1,16,17 (7.9%)
5. July, 1986	2,3,4,7,8,9,10 (42.7%)	1,11,12,16,17 (19.6%)	1,5,11,16,18 (13.6%)	6,11,14,15,16 (9.6%)
6. October, 1986	2,3,4,8,9,11 (47.5%)	1,12,14,15 (16.9%)	7,14,15,16 (10.8%)	6,12,14,17,18 (8.3%)
7. December, 1986	2,3,4,8,9 (51.8%)	11,12,15,16,17 (18.0%)	1,13,16 (10.6%)	12,13,14,16,17,18 (7.6%)

Parameters:

1. p^H
2. Conductance
3. Total dissolved solids
4. Bicarbonates
5. Carbonates
6. Chlorides
7. Sulfate
8. Calcium
9. Magnesium
10. Sodium
11. Iron
12. Zinc
13. Lead
14. Cadmium
15. Manganese
16. Nickel
17. Cobalt
18. Copper

are found to be significant in all months except October, which is the post-monsoon period. Cadmium is significant in October and December months, whereas, lead is significant in February and April months.

From the above observations it is clear that the significant parameters are common in all months, therefore it can be stated that the bimonthly frequency selected for sampling is valid.

4.6.2.4 Correlation between Parameters:

The correlation matrix obtained in the PCA is helpful to examine the extent of correlation between parameters at different locations. The variation with a correlation factor between ±0.8 to ±1.0 are considered as highly correlated ones. In the present study the correlation factors are not used to establish any relationship between variables, but to findout the common sources of mineralization at a location. The positively correlated parameters at each location are presented in Table 4.16 and a brief explanation is given in the following lines. By observing the correlation factors it can be stated that positively correlated parameters at any location are added from a common source at that location.

In general, p^H is negatively related to all trace metal at all locations except at Rudraprayag. At Rudraprayag p^H is positively related to zinc and nickel confirming that the waters

TABLE 4.16 POSITIVELY CORRELATED VARIABLES AT DIFFERENT LOCATIONS

STATIONS	VARIABLES																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1.NAND-PRAYAG	3,8	3	2	-	1,8	-	-	1,5	-	11,15	10,15	16	-	-	10,11	12	-	-
2.RUDRA-PRAYAG	5,12,16	3	2	8	1	-	-	4	-	-	15	1,16	-	-	11	1,12	-	-
3.SRINA-GAR	5	3,5	2	8	1,2	-	-	4	-	-	13	12	-	17	-	1,15 18	17	
4.DEV-PRAYAG	5	3	2	-	1	-	9	-	7	-	12,13 15	11,13 15	11,15 16,17	-	12,13	13	13	-
5.RISHI-KESH	5	-	-	8,9, 12,17	1	9,13	-	4,17	4,6, 13	-	14,17 18	4,9, 14,17	6,9	11,12 17	-	-	4,8, 11,12 14	11
6.SATYA-NARAYANA	-	16	-	-	14	-	9,13, 15	-	7	-	-	-	7,15	5	6,13	2	-	-
7.BALA-WALI	10	-	-	8,9	9	-	-	4,9	4,5,8	1	16	-	-	-	-	11,17	16	-
8.BIJNOR	5,10	3,5	2	8,9	1,2	-	-	4,9	4,8	1	-	-	-	-	-	-	-	-
9.GARHM-UKTESHWAR	7	3	2	5,8,9	4,7,8 9	-	1,5	4,5,9	4,5,8	-	15,18	-	-	-	12,18	17	16	11,15
10.ANUP-SHAHR	7	3	2	5,8,9	4,8,9	-	1	4,5,9	4,5,8	-	-	-	-	-	-	-	-	-
11.RAJ-GHAT NARORA	-	-	-	5,8,9	4,8,9	-	-	4,5,9	4,5,8	-	-	-	-	-	-	-	-	-

1. p^H
2. Conductivity
3. Total dissolved solids
4. Bicarbonates
5. Carbonates
6. Chloride
7. Sulfate
8. Calcium
10. Sodium
11. Iron
12. Zinc
13. Lead
14. Cadmium
15. Manganese
16. Nickel
17. Cobalt
18. Copper

joining in this area are rich in dissolved zinc and nickel. Total dissolved solids and conductivity, p^H and carbonates, calcium, magnesium with carbonates and bicarbonates are positively related at all stations.

At Nandaprayag sodium is correlated with iron, manganese, and zinc with nickel. It indicates that the waters joining Ganga river in this region drain the geological formations rich in zinc and nickel. The negative correlation of zinc, lead with p^H, bicarbonates, carbonates and calcium indicates that these metals are added predominantly in suspended form.

At Rudraprayag calcium is correlated with bicarbonates indicating the presense of dolomite deposits between Nandaprayag and Rudraprayag. Among the trace metals iron is correlated with manganese, and zinc with nickel.

At Srinagar, bicarbonates are correlated with magnesium, zinc is correlated with lead, cobalt with manganese and copper.

The negative correlation of p^H with iron, zinc, lead and manganese at Devprayag indicates that these metals are added predominantly in suspended form. Magnesium is inversely related to nickel and lead. Among the trace metals, the correlations of iron with lead, zinc, manganese; manganese with cobalt, lead, iron; lead with zinc, iron, manganese, nickel, cobalt; nickel with cobalt and lead indicate the nature of respective sources of trace metals.

At Rishikesh, chlorides are in correlation with magnesium and lead, and the correlation of bicarbonates with cobalt indicates the association of cobalt with dolomite rocks in this region. The correlation of bicarbonates and magnesium with lead indicates that the magnesite rocks of this area contain lead mineralization. Iron is related with cadmium, cobalt, copper; zinc with magnesium, cadmium, cobalt; cadmium with iron zinc, cobalt; cobalt with bicarbonates, calcium, iron, zinc, cadmium; and copper with iron, at this station.

At Satyanarayana, sulfates are correlated with magnesium, lead and manganese indicating the magnesite deposits in Doon Valley contain lead and manganese. On the other hand, the negative correlation of carbonates with cadmium and chloride with manganese indicates that chloride and cadmium are added prominently by IDPL effluent, where as, carbonates and manganese through Song river.

In the lower reaches the correlation among trace metals is not significant. However, it can be stated that iron, nickel, manganese, copper and cobalt are positively correlated, and magnesium and carbonates are negatively correlated with lead.

5.0 PHYSICO CHEMICAL CHARACTERISTICS OF SONG RIVER

5.1 ACCURACY OF DATA

  5.1.1 IONIC BALANCE METHOD

  5.1.2 ELECTRIC CONDUCTANCE METHOD

5.2 CHEMICAL COMPOSITION OF SONG WATER

5.3 IMPACT OF TRIBUTARIES

5.4 TRENDS OF PHYSICO CHEMICAL PARAMETERS IN SONG RIVER

5.5 TRACE METALS

  5.5.1 IMPACT OF TRIBUTARIES

  5.5.2 TRENDS OF TRACE METALS IN SONG RIVER

5.0 PHYSICO CHEMICAL CHARACTERISTICS OF SONG RIVER

The physico chemical composition of Song river water during its course towards Ganga river in Doon Valley, is chiefly governed by the following factors:

(i) Geological formations of the catchment area.

(ii) Human interaction in the catchment area, including water regulation practices and irrigation.

(iii) Flow regimes. Dry months constituting the base flow and wet months necessiating run-off from the catchment area.

The geology and the net work of tributaries is discussed in Chapter-2. In general, the human interaction with the Song river was much more significant as compared to Ganga river. The water regulatory, check dams, constructed in the Maldevta area on Song river and its tributaries Baldi and Bandal, divert maximum flow for irrigation purpose leaving little amount or no flow in the rivers. Thus, Song river and its two major tributaries, namely Baldi and Bandal, have little or no flow during base flow season. During base flow regime, these rivers exhibit dying out behavior. Massive limestone deposits of the area are responsible for this behavior. During early monsoons the ground water gets recharged to contribute to river during post-monsoon and base flow seasons. This results the flow in Song river from Maldevta to Gularghati only in the monsoon and post-monsoon seasons. During the total study period (July 1985 to January 1987) the river was completely dry in the base flow season of 1986-1987.

The general composition of Song waters in the study area (between Maldevta and Satyanarayana), impact of major tributaries and trend of physico chemical parameters, are however, discussed in the following paragraphs.

5.1 ACCURACY OF DATA

As in the case of Ganga river, the chemical analysis of Song river was also exposed to checks for accuracy by ionic balance and electrical conductance methods.

5.1.1 IONIC BALANCE METHOD:

A control chart for Song river data is depicted in Fig. 5.1, which reveals that 85% of the data lies within the acceptable limit of ±1.0. This ensures the accuracy of data for further interpretation.

5.1.2 ELECTRICAL CONDUCTANCE METHOD:

The ratio of total dissolved solids and conductivity is shown in Fig 5.2. 75% of the data falls in 0.65 to 0.7 range indicating that the Song water was more saline as compared to Ganga river. In other words, the Song water contains more minerals than Ganga river water.

5.2 CHEMICAL COMPOSITION OF SONG WATER

To represent the chemical composition of Song river water, Hill-Piper diagram was plotted by conventional trilinear co-ordinates. The diagram (Fig. 5.3) shows a distinct spatial

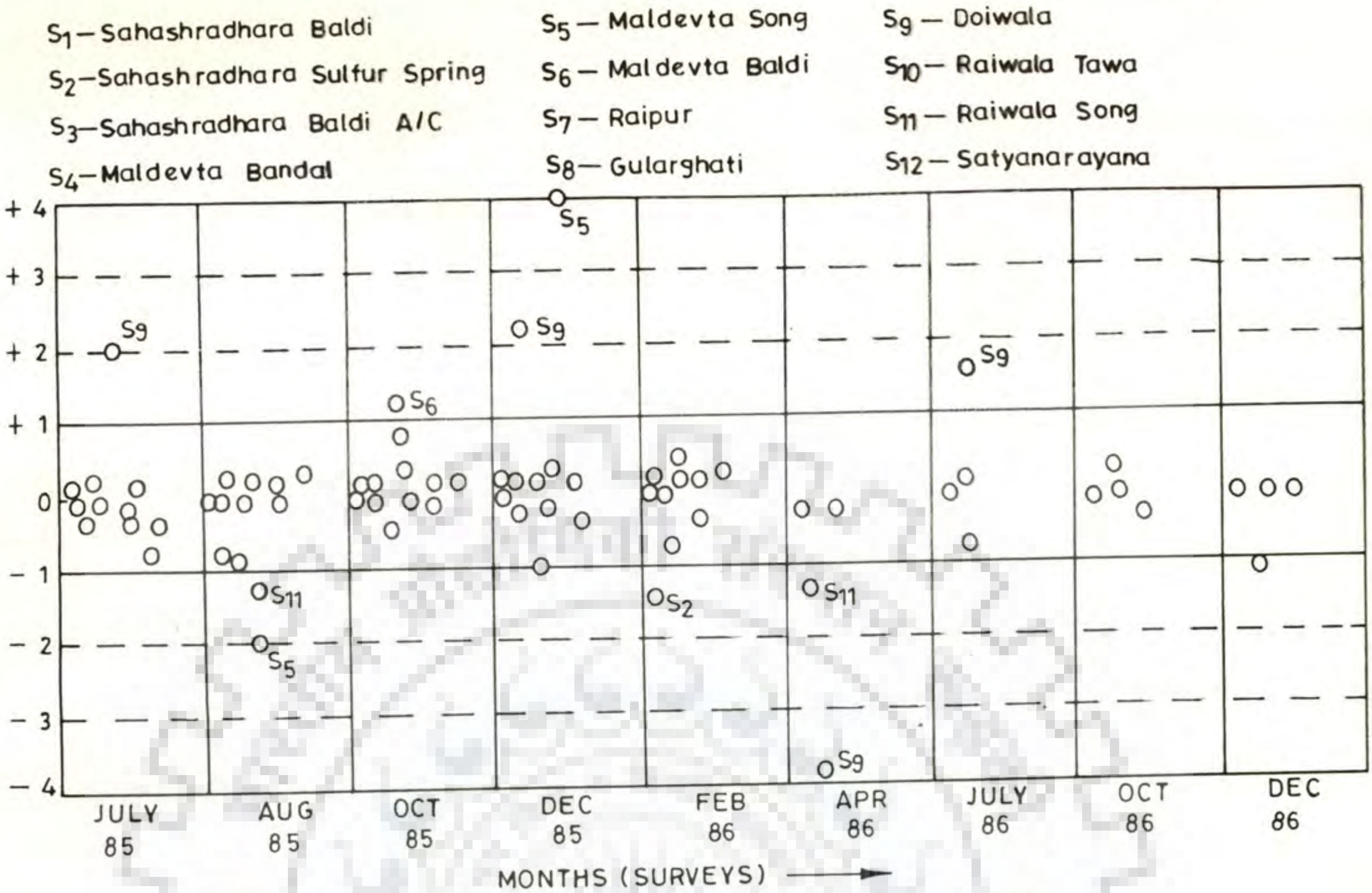


FIG. 5·1—VARIATION IN CATION-ANION BALANCE

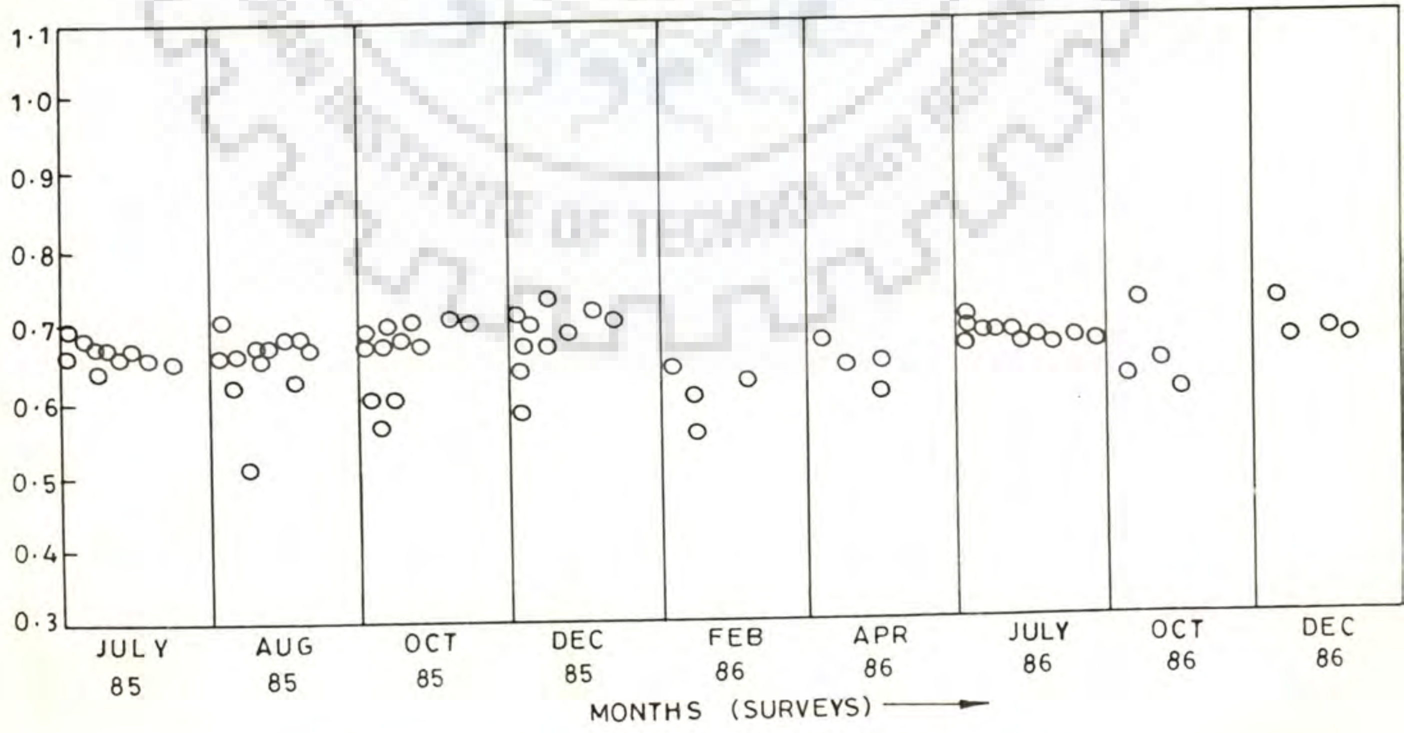


FIG. 5·2—VARIATION IN COND./TDS RATIO

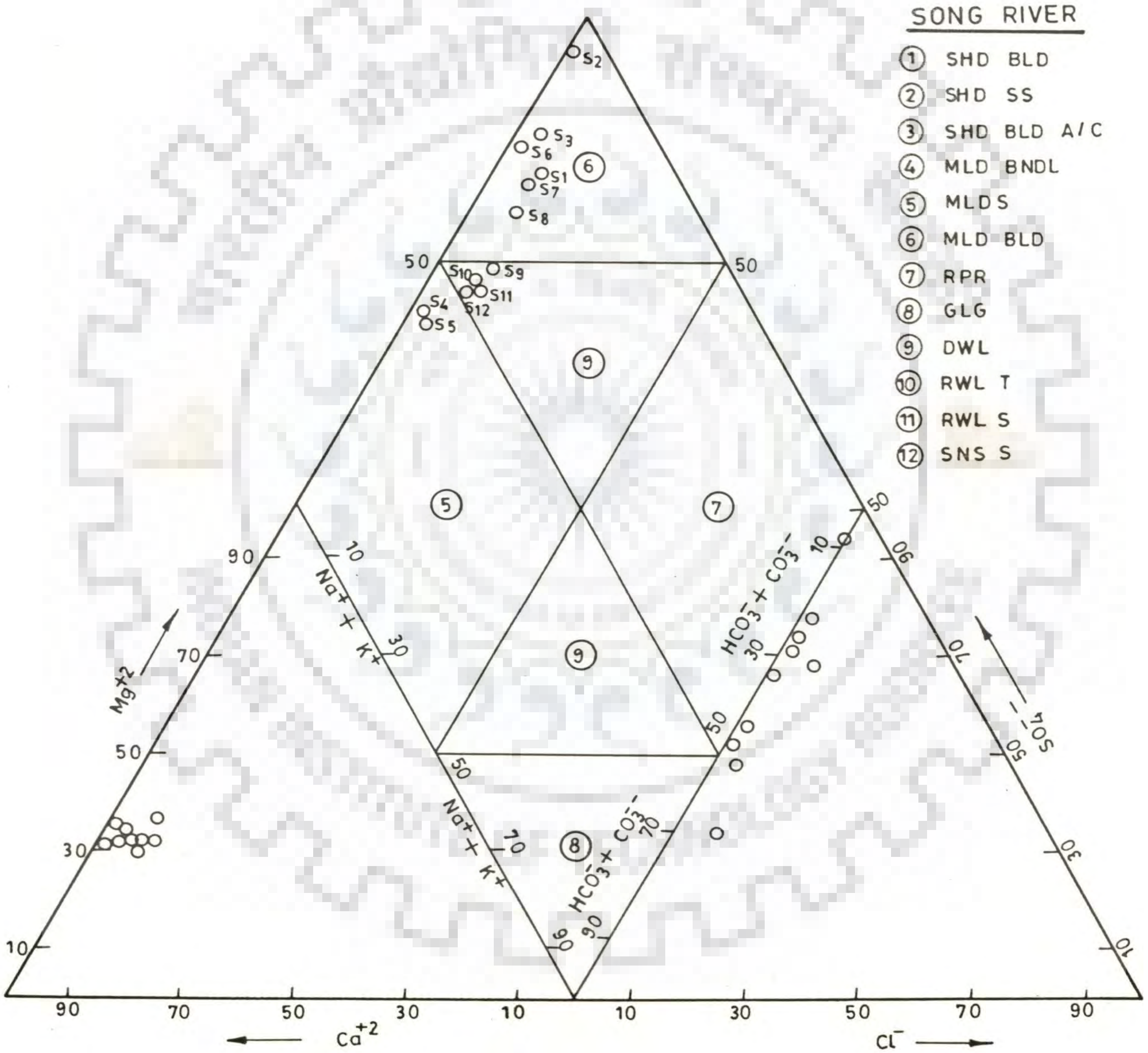


FIG. 5·3 — HILL PIPER TRILINEAR DIAGRAM OF SONG WATER variation in the chemical composition of Song river and its tributaries. The water of the river Song and the tributary Bandal fall in area 5 depicting properties of alkaline earth and weak acids. Where as after the confluence upto Gularghati falls in the area 6 of the diagram. This emphasizes that the waters flowing in this reach are rich in sulfates and the composition is dictated by alkali earths with strong acids. This is in good agreement with the catchment geology and the flow patterns of the rivers. This, in other words, indicates that the water flowing in Maldevta area is rich in carbonates and bicarbonates of calcium and magnesium. The composition of Song water downstream of Gularghati is mixed type in which no single cation or anion pair exceed 50% as the data falls in area 9 of the diagram.

5.3 IMPACT OF TRIBUTARIES

The flow of Song river in the study area is contributed by numerous hilly streams, locally named as 'Raos'. Bandal, Baldi, Tawa and Bangla are the perennial streams of this region. These tributaries have their sub-catchment area with characteristic human activity with nearly common geology. Song river in its initial stages passes through Maldevta area which is known for its pyretic and phosphoritic mining. The tributaries Bandal and Baldi also join the river at Maldevta. Bandal derives its water from Timli area, whereas, Bandal gets it from Sahashradhara. At both these places limestone mining is common. The common feature with Song and other tributaries is that they have effluent ground water springs as the principle source. Tawa and Bangla Rao join Song river between Raiwala and Satyanarayana where Song ends the journey and meets the Ganga river. Bangla Rao passes through villages like Shyampur and Raiwala. Thus it carries more domestic and agricultural wastes of the catchment area.

To assess the impact of these tributaries on Song river water physico chemical characteristics were studied and seasonal patterns recorded

(1) Monsoon season, that incise the period from June to August.

(2) Post-monsoon season, that incise the period from September to November.

(3) Base-flow season, that incise the period from December to May.

The perusal of data given in Table 5.1 illustrates the changes occurring in the water quality of these tributaries. These changes can be elaborated as follows.

In general, the total solids are carried in the form of dissolved solids in all the tributaries, which is evident from the small amounts of suspended solids observed. The suspended solid content was observed to be maximum in monsoon season and minimum both in post-monsoon and base flow seasons. The variation is between 8 mg/l to 45 mg/l. More solids in dissolved

TABLE 5.1 MEAN MINERAL QUALITY OF TRIBUTARIES BEFORE MEETING SONG RIVER

PARAMETER	Sulfur Spring		Baldi		Bandal		Tawa		Bangla Rao	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.p^H	7.3	0.2	8.0	0.3	8.1	0.4	8.3	0.4	7.8	0.3
2.ORP	-202.0	31.9	193.8	35.2	217.5	6.5	200.6	14.4	175.0	20.0
3.Conductance (µ mhos)	2094.1	148.1	652.2	89.4	412.2	82.4	336.4	72.8	600.0	55.0
4.Total dissolved solids (mg/l)	1405.7	110.3	445.6	73.0	277.8	54.2	239.6	63.6	402.5	40.0
5.Suspended solids (mg/l)	25.0	10.0	83.8	26.9	82.5	20.2	96.2	19.9	45.0	15.0
6.Bicarbonates (mg/l)	270.9	22.2	151.5	20.0	120.3	9.3	125.5	53.9	140.5	26.5
7.Carbonates (mg/l)	0.8	0.2	1.7	0.8	1.8	0.6	3.5	2.3	1.6	-
8.Chlorides (mg/l)	6.3	1.2	5.1	0.9	5.6	0.5	6.2	1.8	9.5	1.8
9.Sulfates (mg/l)	3532.2	416.8	376.8	62.9	195.0	36.7	124.2	57.4	140.0	25.0
10.Calcium (mg/l)	1014.2	103.3	134.4	13.7	72.8	11.8	55.3	10.5	68.0	20.0
11.Magnesium (mg/l)	317.4	42.5	39.8	5.6	27.2	3.4	21.5	8.4	20.0	5.0
12.Sodium (mg/l)	10.0	-	10.0	-	10.0	-	8.7	2.3	12.0	0.6
13.Potassium (mg/l)	2.6	1.3	1.5	0.6	1.5	0.6	0.6	0.7	2.0	0.2
14.Total anions (me/l)	78.2	9.1	10.5	1.0	6.2	0.9	4.9	1.2	5.6	-
15.Total cations (me/l)	78.6	8.5	10.4	0.9	6.3	0.8	4.9	1.0	5.6	-
16.Dissolved oxygen (mg/l)	-	-	8.1	0.1	6.1	0.1	7.8	0.2	7.7	0.2
17.Bio chemical oxygen demand (mg/l)	-	-	1.0	0.2	0.9	0.1	1.7	0.4	1.9	0.6
18.Chemical oxygen demand (mg/l)	-	-	0.7	0.1	0.5	0.1	1.2	0.3	2.4	0.8

form are added by Bandal in all seasons. The temporal variations in conductivity values emphasizes that all the tributaries carry more dissolved solids during base flow season followed by post-monsoon and monsoon seasons.

Among the tributaries Bangla Rao adds more chloride of sodium and also carries more organic matter as reflected by slightly high C.O.D./B.O.D. values and low D.O. This is attributable to several non-point and point domestic discharges. Contribution of Baldi is more in the concentration of sulfates of calcium and magnesium than other tributaries due to influence of Sahashradhara.

Closely looking into the data and the variation in the quality of these tributaries, the following conclusions can be drawn:

- The influence of human interaction is more visible in Bangla Rao and Tawa than other tributaries.
- The mineral content is more in base flow season followed by post-monsoon and monsoon seasons indicating the extensive ground water recharge to the rivers.

5.4 TRENDS OF PHYSICO CHEMICAL PARAMETERS IN SONG RIVER

Table 5.2 and Fig.5.4 to Fig.5.14 illustrates the spatial and temporal variation and trends of physico chemical parameters in Song river. The trends are explained in the following paragraphs.

TABLE 5.2

STATIONS	p^H		ORP		SUSPENDED SOLIDS		CARBONATES		SODIUM		POTASIUM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.MALDEVTA U/S	8.1	0.2	198.4	32.2	55.1	32.7	1.5	0.8	10.0	-	1.6	0.5
2.RAIPUR	8.2	0.4	210.6	43.3	56.1	16.6	2.5	2.1	10.0	-	1.6	0.5
3.GULARGHATI	8.1	0.4	223.2	32.9	83.2	27.2	1.8	1.4	10.0	-	1.6	0.5
4.DOIWALA	8.4	0.3	202.8	47.4	81.1	29.9	3.3	2.9	10.0	-	1.8	0.7
5.RAIWALA	8.2	0.3	204.5	23.0	81.3	25.9	3.2	2.5	10.0	-	1.5	0.5
6.SATYANARAYANA	8.2	0.3	197.0	42.7	92.8	28.6	3.3	1.8	10.0	-	1.5	0.5

U/S = Upstream

5.4.1 p^H:

p^H of the river Song varied between 7.9-8.7 (Table 5.2) indicating the alkaline nature of the river water throughout. The low values were observed during monsoon season between Maldevta and Gularghati and high values during post-monsoon and base flow seasons. This trend indicates the dilution during monsoon season, and extensive ground water recharge in the remaining seasons.

5.2.2 ORP:

The ORP values of Song river water varied between +183.0 mV to +258.0 mV (Table 5.2) which were slightly lesser as compared to Ganga river water. The ORP values were more towards positive side during post-monsoon season followed by monsoon season and base flow season. Though the trend of ORP was fluctuating, in general, the maximum values were observed at Gularghati.

5.2.3 SOLIDS TOTAL AND SUSPENDED:

Song river carried more dissolved solids than suspended solids. The little variation observed in suspended solids (Table 5.2) showed that more load was observed during monsoon season followed by post-monsoon and base flow seasons. The suspended solid content was low between Maldevta and Gularghati and increased as the river flowed downstream. This can be attributed to less physical erosion in Doon Valley.

5.2.4 CONDUCTIVITY AND TOTAL DISSOLVED SOLIDS:

Trends of conductivity and total dissolved solids (Fig. 5.4 and Fig. 5.5) were similar and the temporal variations observed were in proportional to the flow conditions. Base flow yields more conductivity and total dissolved solids as compared to monsoon and post-monsoon season. However, significant spatial variations were observed at some locations emphasizing the following:

- Significant increase was observed between Maldevta and Raipur due to the confluence of Baldi river. The impact was also proportional to the flow conditions.
- The decrease between Raipur and Gularghati is attributed to the dilution imposed by Sirwalgarh Rao and Chittaur Rao which carry lesser mineral content as compared to that of Song.
- The increase between Gularghati and Doiwala was due to Suswa which joins Song upstream of Doiwala. Suswa carried Dholani Nadi, which carried the domestic discharges of Gularghati.
- The decrease between Doiwala and Raiwala was due to the dilution caused by epimeral streams and Tawa Nadi.
- Significant increase between Raiwala and Satyanarayana was observed due to the tributary Bangla Rao which carries domestic and agricultural return waters to Song.

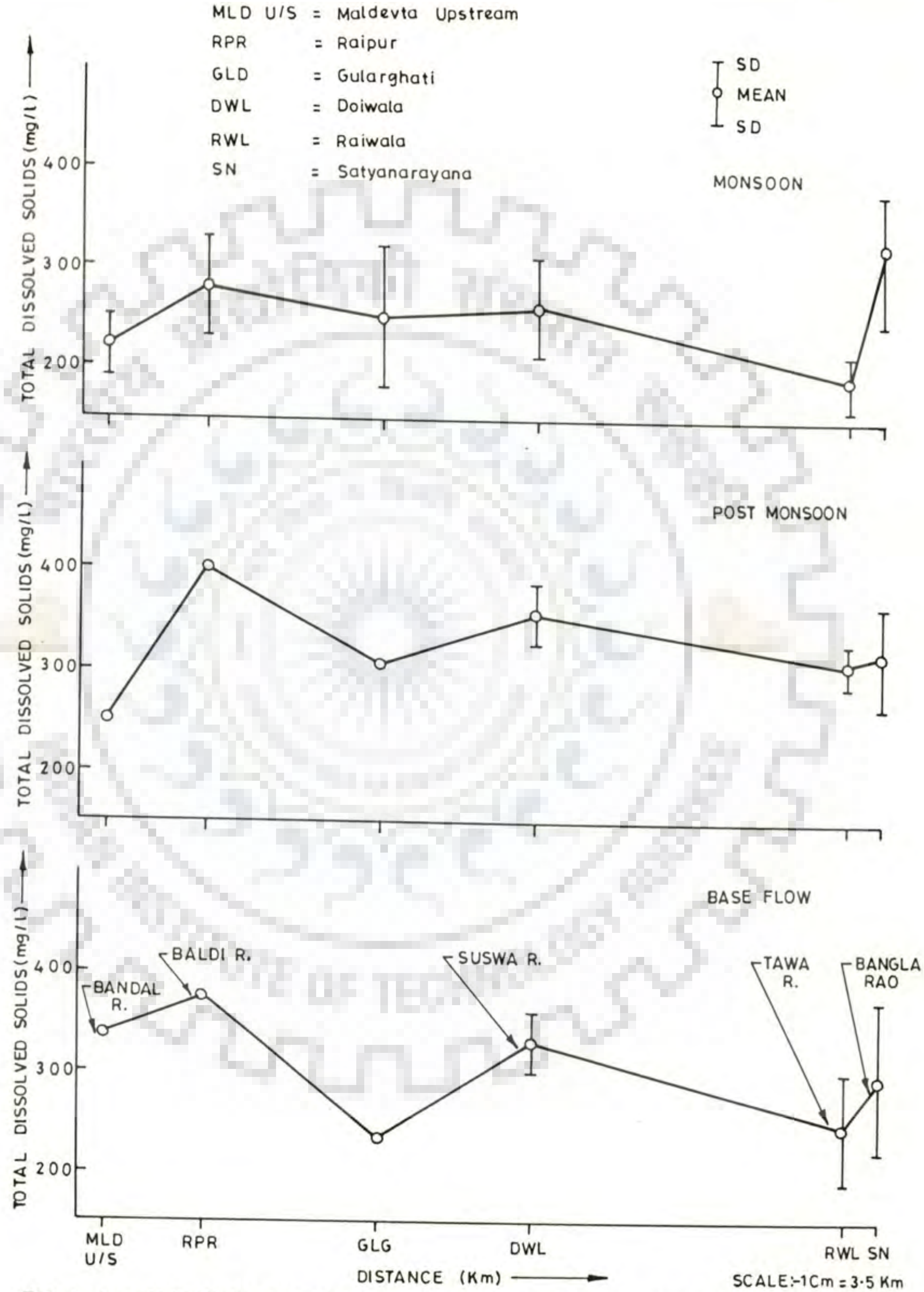


FIG. 5·4 — VARIATION IN TOTAL DISSOLVED SOLIDS (mg/l)

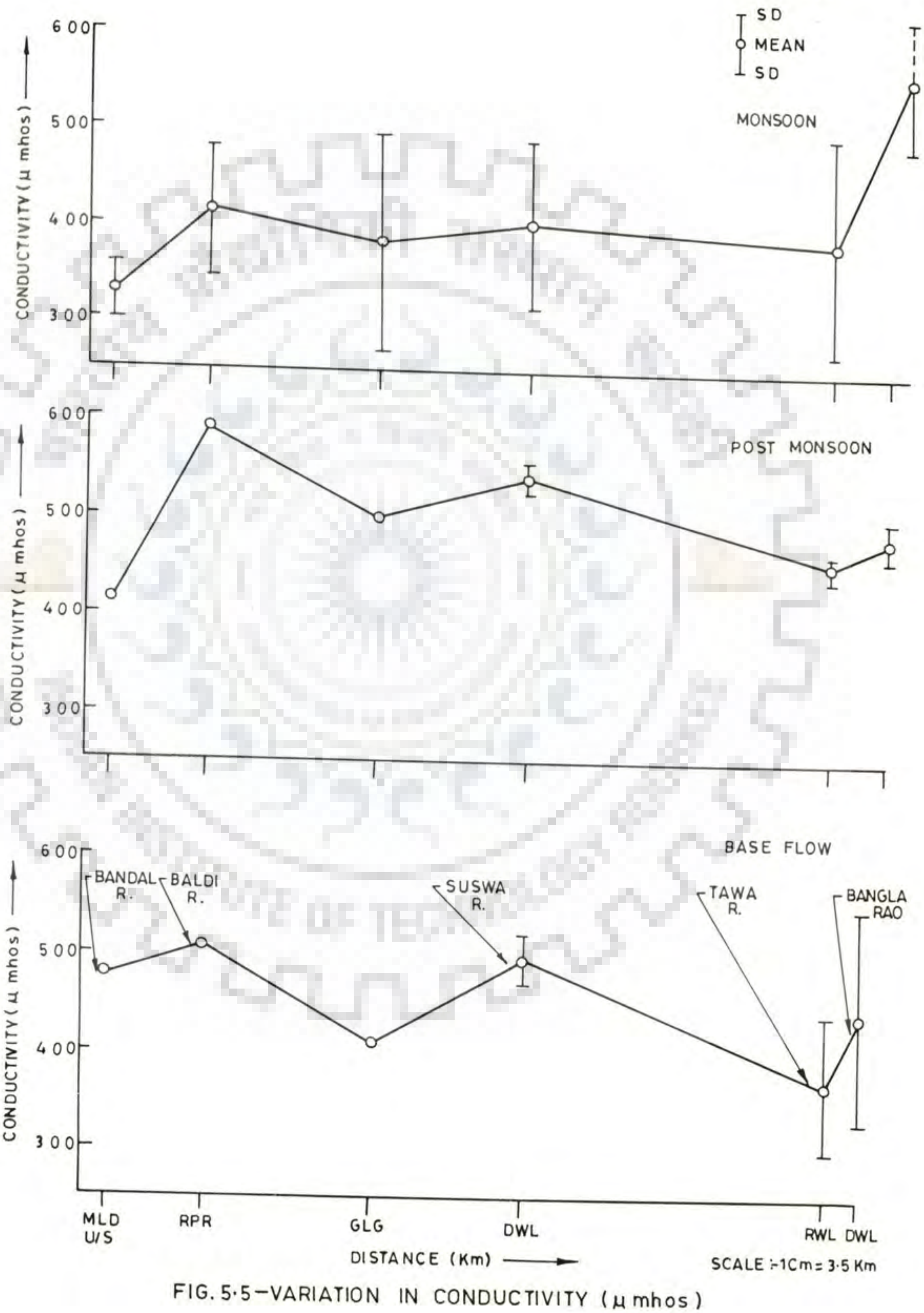


FIG. 5·5—VARIATION IN CONDUCTIVITY (µ mhos)

5.2.5 BICARBONATES AND CARBONATES:

Bicarbonate and carbonate varied between, 80 mg/l to 180 mg/l and 0.9 mg/l to 4.98 mg/l, respectively with distinct temporal variations (Fig.5.6 and Table 5.2). The bicarbonate concentrations were, in general, high during monsoon season followed by base flow and post-monsoon seasons, on the other hand, the variation of carbonates was of a low order i.e. between 0.9-4.9 mg/l. This trend indicates the significance of richness of limestone deposits and the interaction of ground water originating from these deposits.

During monsoon season the bicarbonate concentration increased consistently upto Raiwala and decreased slightly at Satyanarayana. The former increase can be attributed to the joining of perennial and epimeral rivers and the latter to the dilution caused by Bangla Rao.

During post-monsoon season, the bicarbonate concentration showed a consistent decrease upto Gularghati due to decrease in flow in Baldi river. Downstream of Gularghati, the impact of Suswa and Bangla Rao is distinct with resultant increase upto Doiwala and later between Raiwala and Satyanarayana.

The profile during base flow season does not show abrupt change but a gradual pile up.

5.2.6 CHLORIDES:

Chlorides in Song river varied in a narrow band from 4.1

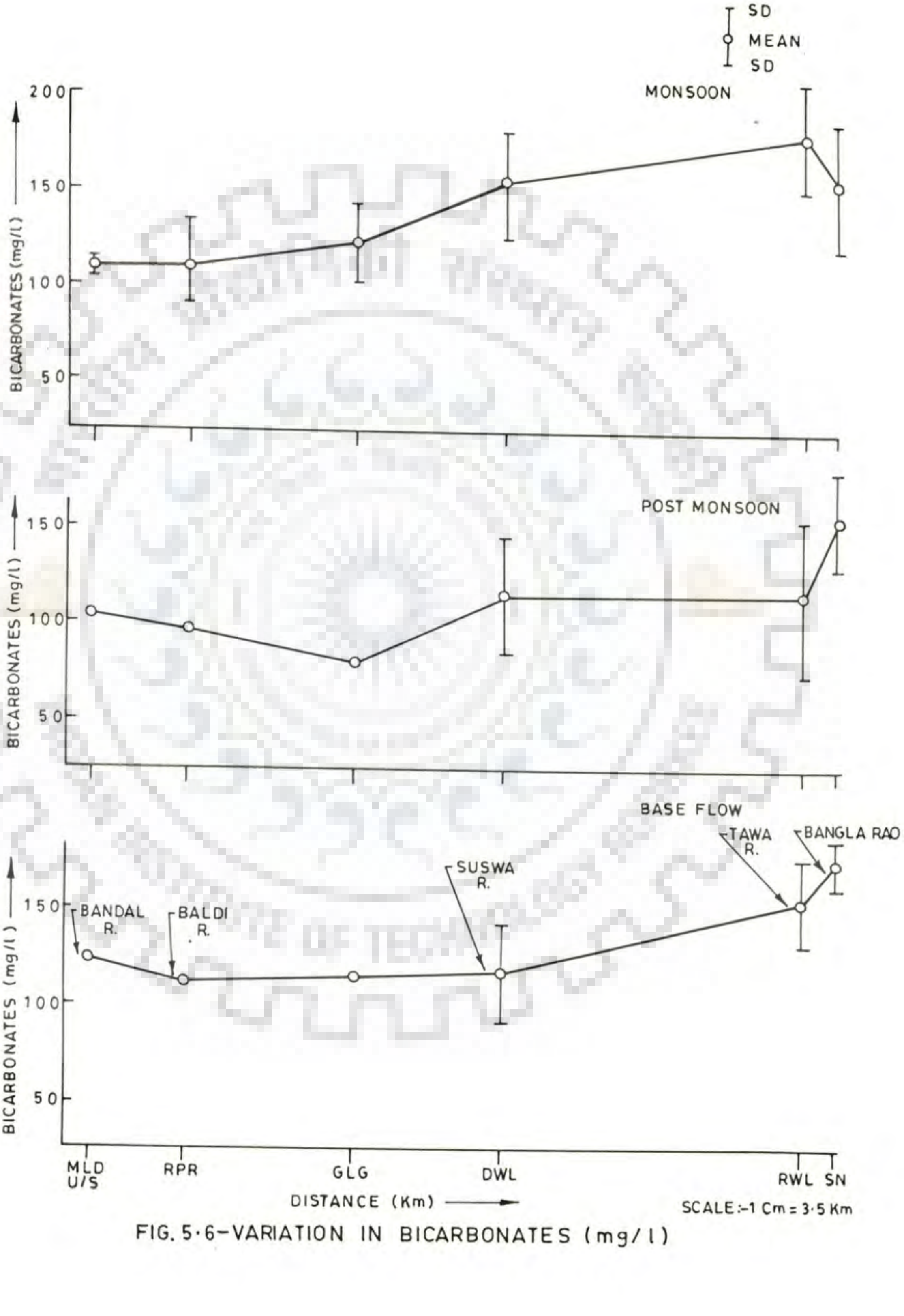


FIG. 5·6–VARIATION IN BICARBONATES (mg/l) mg/l to 7.6 mg/l. Maximum chloride content was observed during base flow season (Fig. 5.7). Though the variations were not much of significance, however, the impact of Suswa was visible at Doiwala. During monsoon and post-monsoon seasons the chloride concentration increased while there was a decrease during base flow regime.

5.2.7 SULFATES:

The concentration of sulfates in Song waters in the study area varied between 150 mg/l and 260 mg/l, indicating the presence of sulfate bearing rocks along with limestone deposits of the Doon Valley. The chief contributor of sulfates was the river Baldi which drained the Sahashradhara including sulfur spring (Fig. 5.8). The concentrations at all stations and at all seasons downstream of Raipur decreased due to dilution. There is no other contribution of sulfate bearing waters.

5.2.8 CALCIUM AND MAGNESIUM:

The trends of calcium and magnesium (Fig.5.9 and Fig.5.10) clearly indicate of the qualitative and quantitative gradient in limestone deposits in the study area. The cations varied from 40 mg/l to 104 mg/l and 20.5 mg/l to 30 mg/l respectively. The trends show that downstream of Raiwala there is no significant addition of waters rich in calcium and magnesium. Some perturbations however are apparent due to flow and dilution.

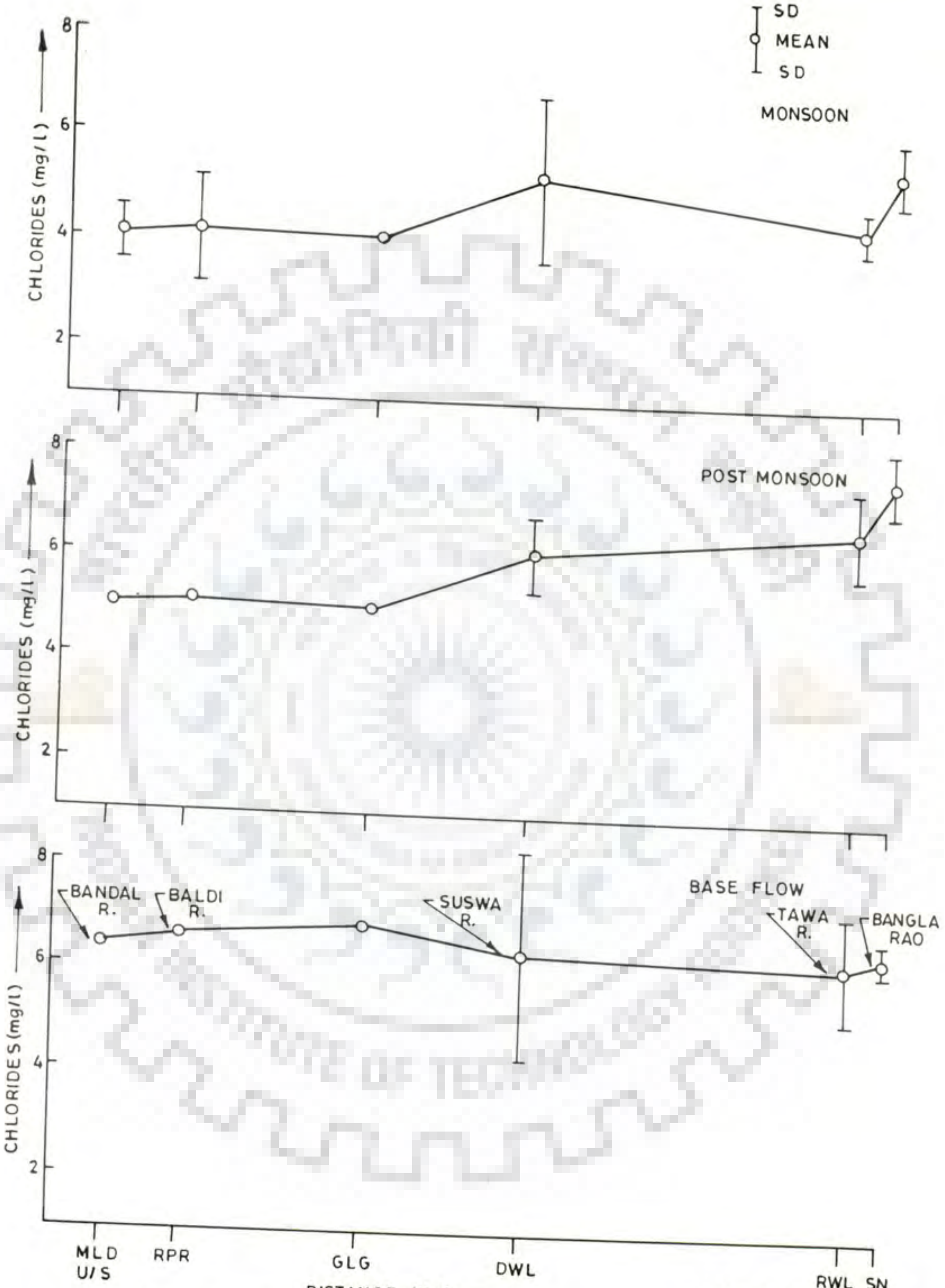


FIG. 5·7—VARIATION IN CHLORIDES (mg/l)

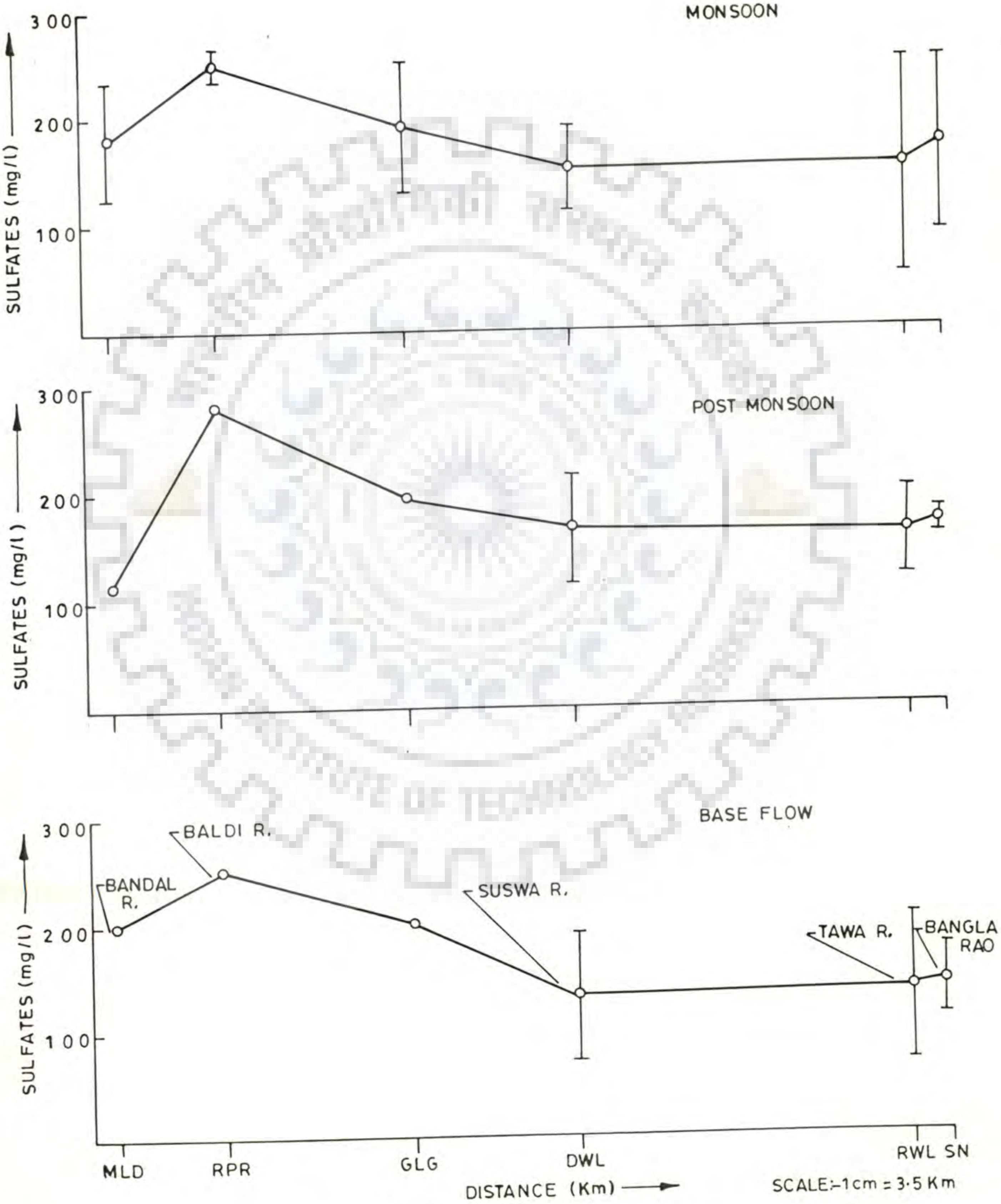


FIG. 5·8 – VARIATION IN SULFATES (mg/l)

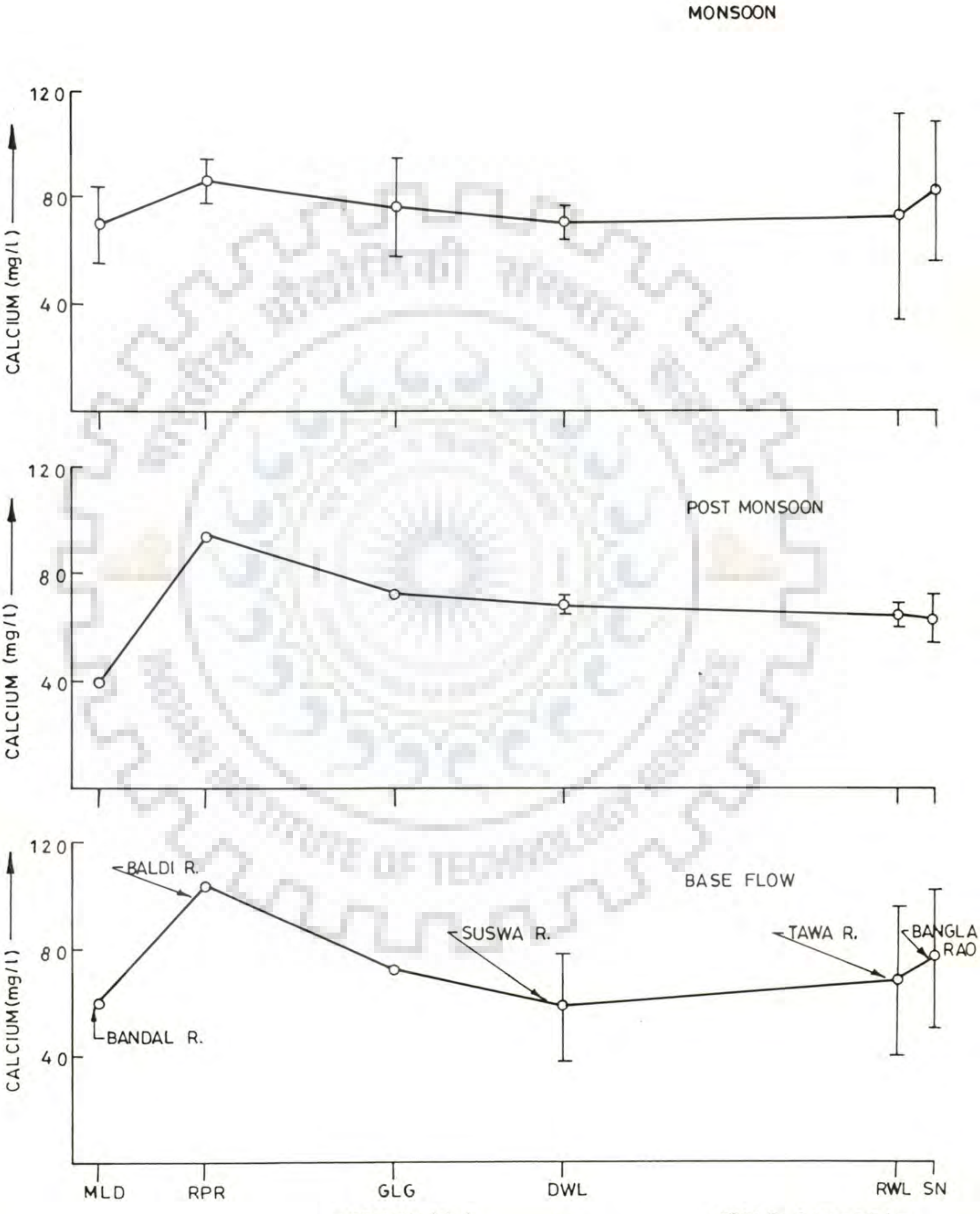


FIG. 5.9—VARIATION IN CALCIUM (mg/l)

5.2.9 SODIUM:

Sodium values were observed around 10 mg/l in the study area all through (Table 5.1) indicating thereby that the waters flowing in Doon Valley are rich in Sodium as compared to Ganga river. This trend, is typical of ground water interaction.

5.2.10 TOTAL ANIONS AND TOTAL CATIONS:

Fig. 5.11 and Fig. 5.12 illustrate the changes occurring in the total ionic strength of Song waters in the study area. The trends of anions (me/l) and cations (me/l) were similar indicating a good ionic balance in Song waters. The profiles clearly indicate the impact of Baldi river at Raipur which adds sulfates and calcium predominantly. The increase at Raipur masks all other variations upto Doiwala, however, slight increase visible between Doiwala and Satyanarayana was due to Tawa and Bangla Rao.

5.2.11 D.O., B.O.D. and C.O.D.:

Fig. 5.13 to Fig. 5.15 illustrate the changes in D.O., B.O.D. and C.O.D. in Song river. The variations observed were, from 7.4 mg/l to 8.5 mg/l, 0.5 mg/l to 1.9 mg/l and 1.0 mg/l to 2.5 mg/l, for D.O., B.O.D. and C.O.D. respectively. In general, more D.O. and less C.O.D., B.O.D values were observed during monsoon season followed by post-monsoon and base flow seasons. Though the spatial variations were not significant it was clear from the profiles that little organic load was introduced in Song

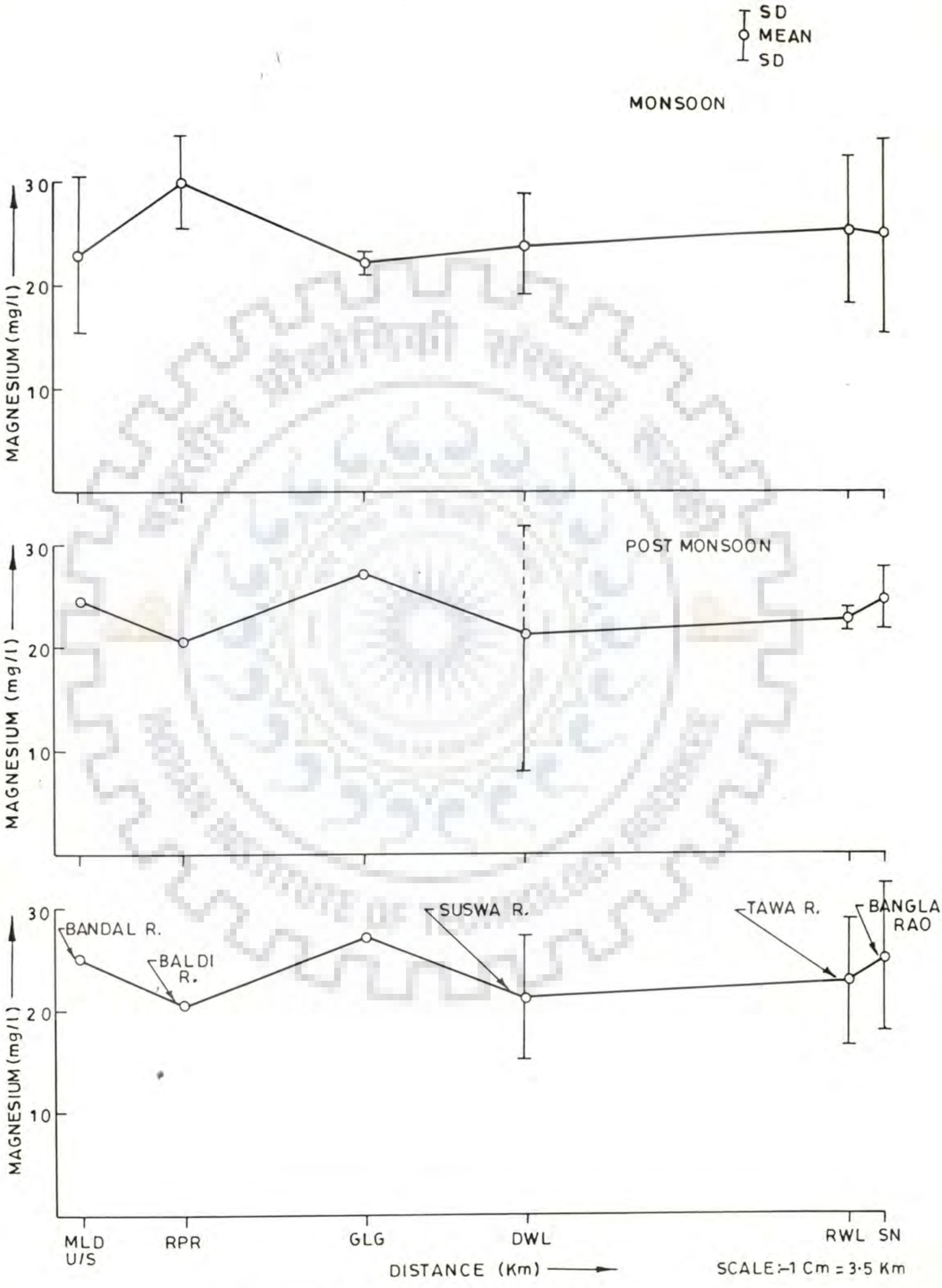


FIG. 5·10–VARIATION IN MAGNESIUM (mg/l)

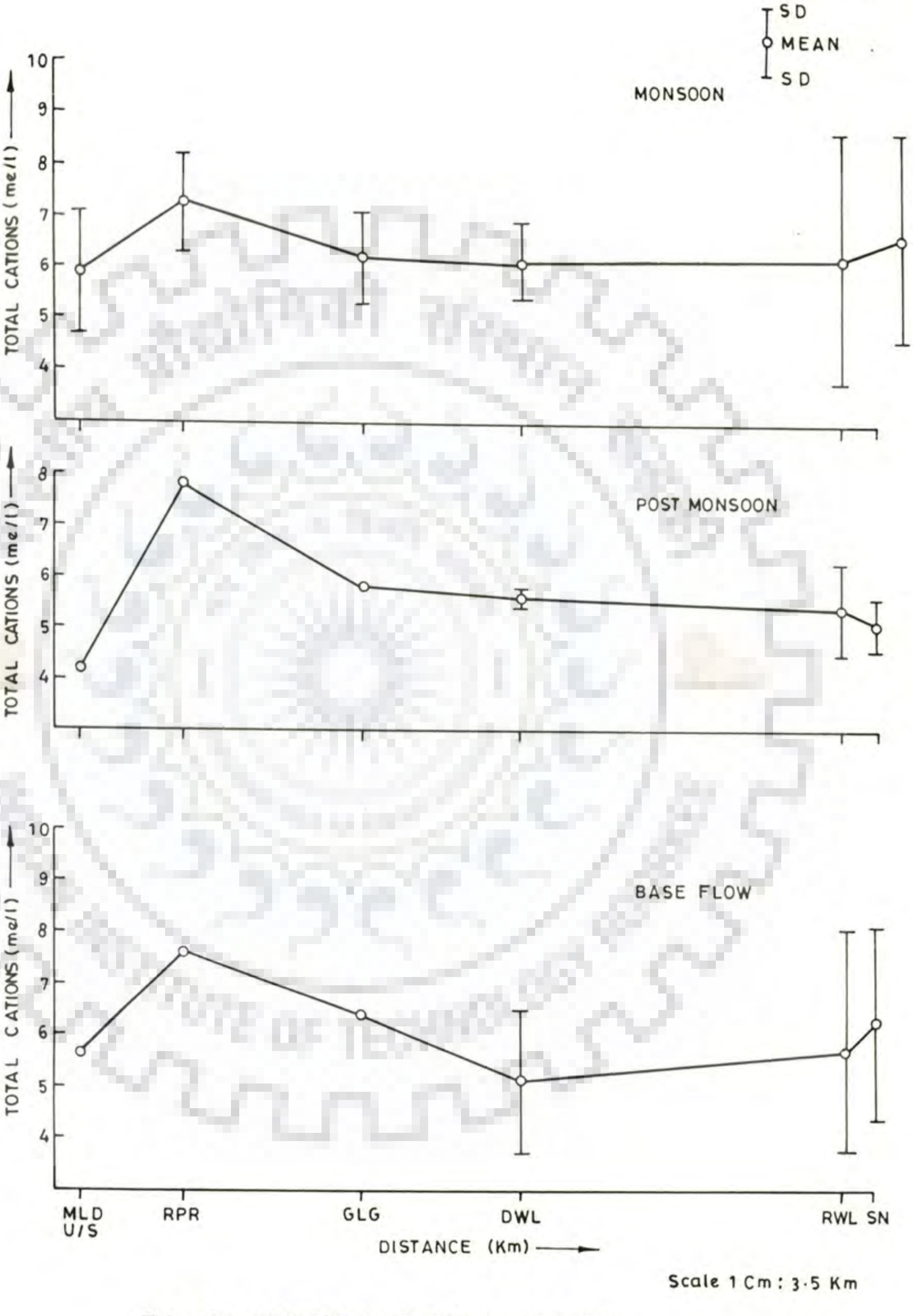


FIG. 5.11—VARIATION IN TOTAL CATIONS

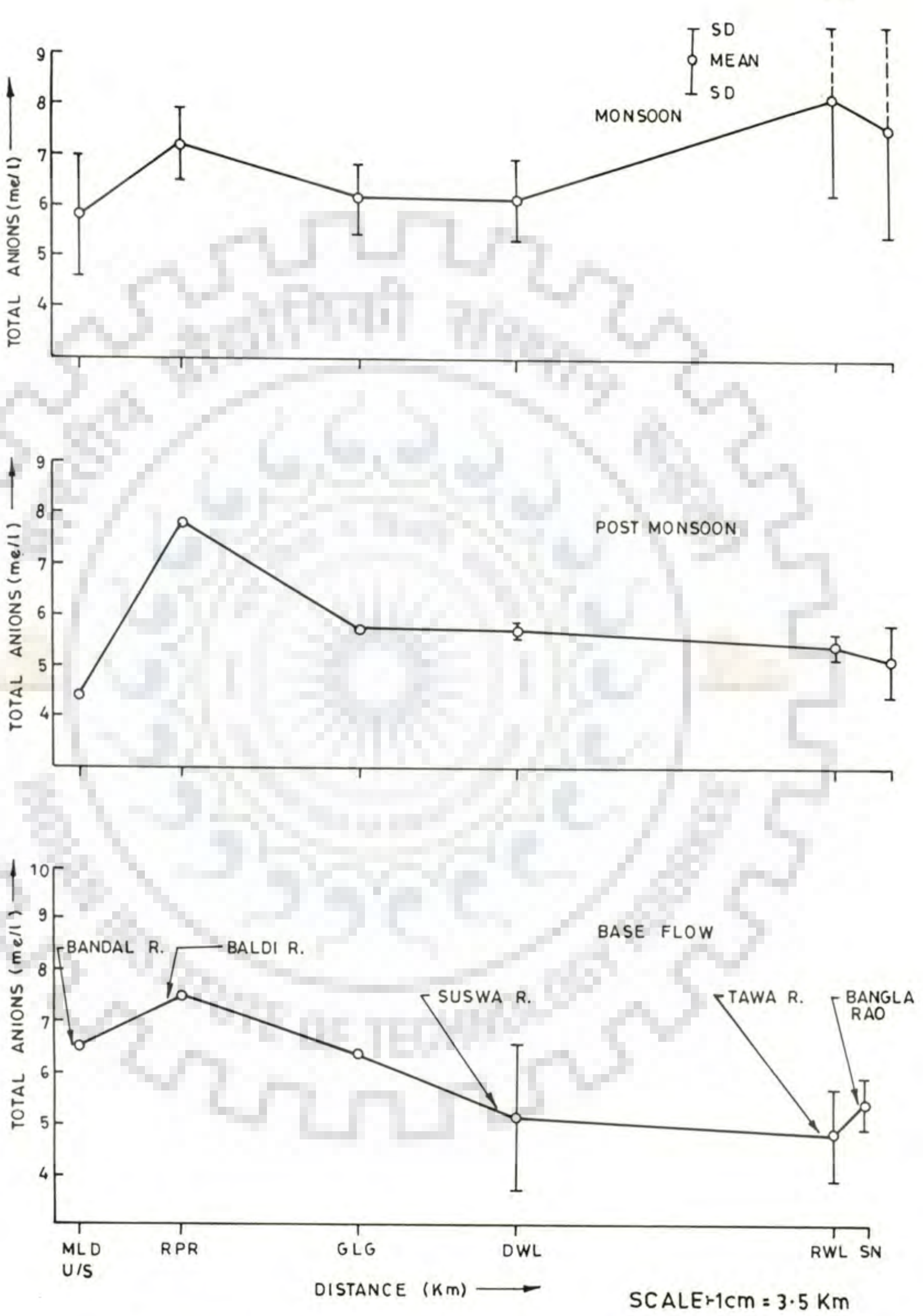


FIG. 5·12—VARIATION IN TOTAL ANIONS

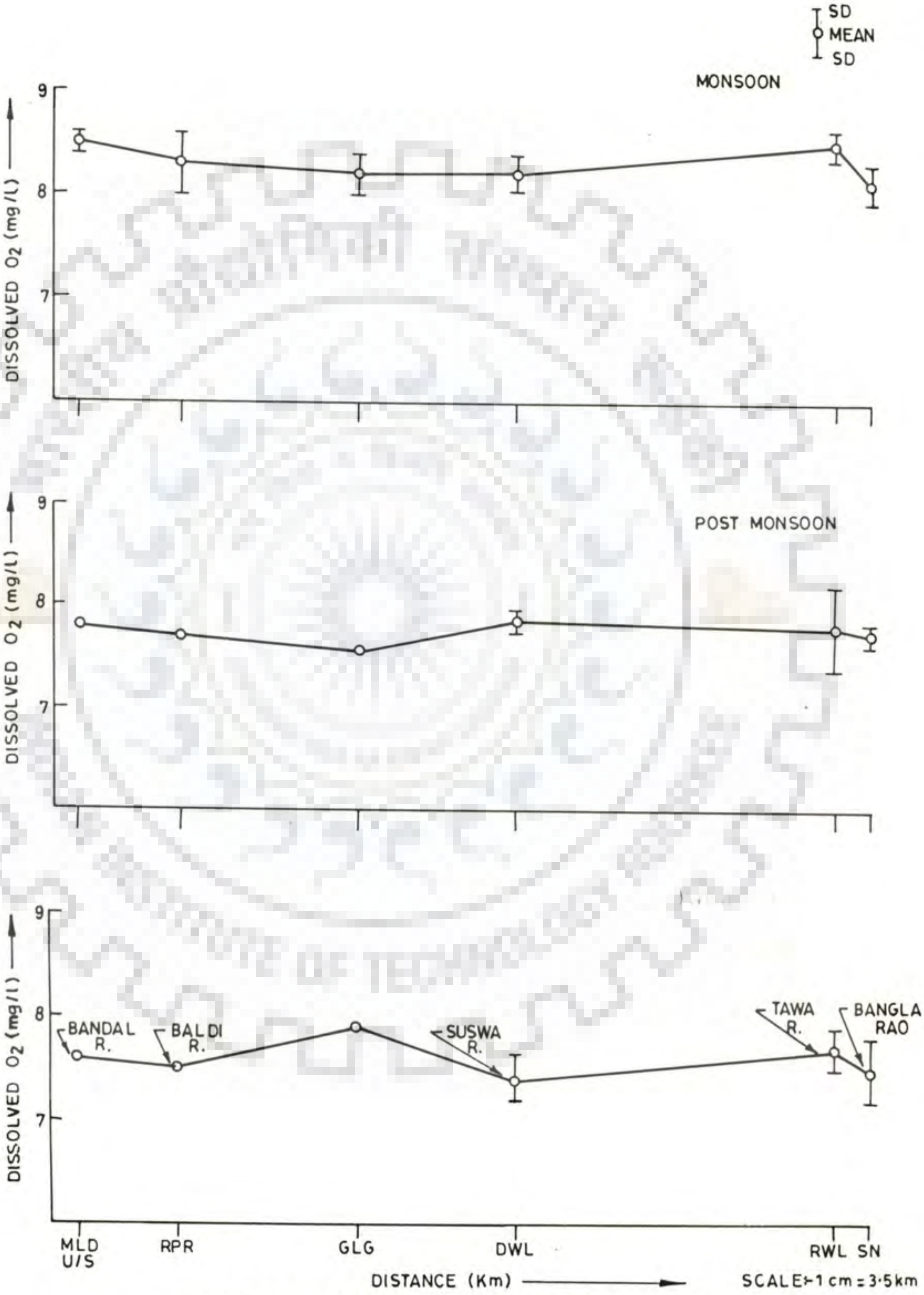


FIG. 5·13—VARIATION IN DISSOLVED OXYGEN (mg/l)

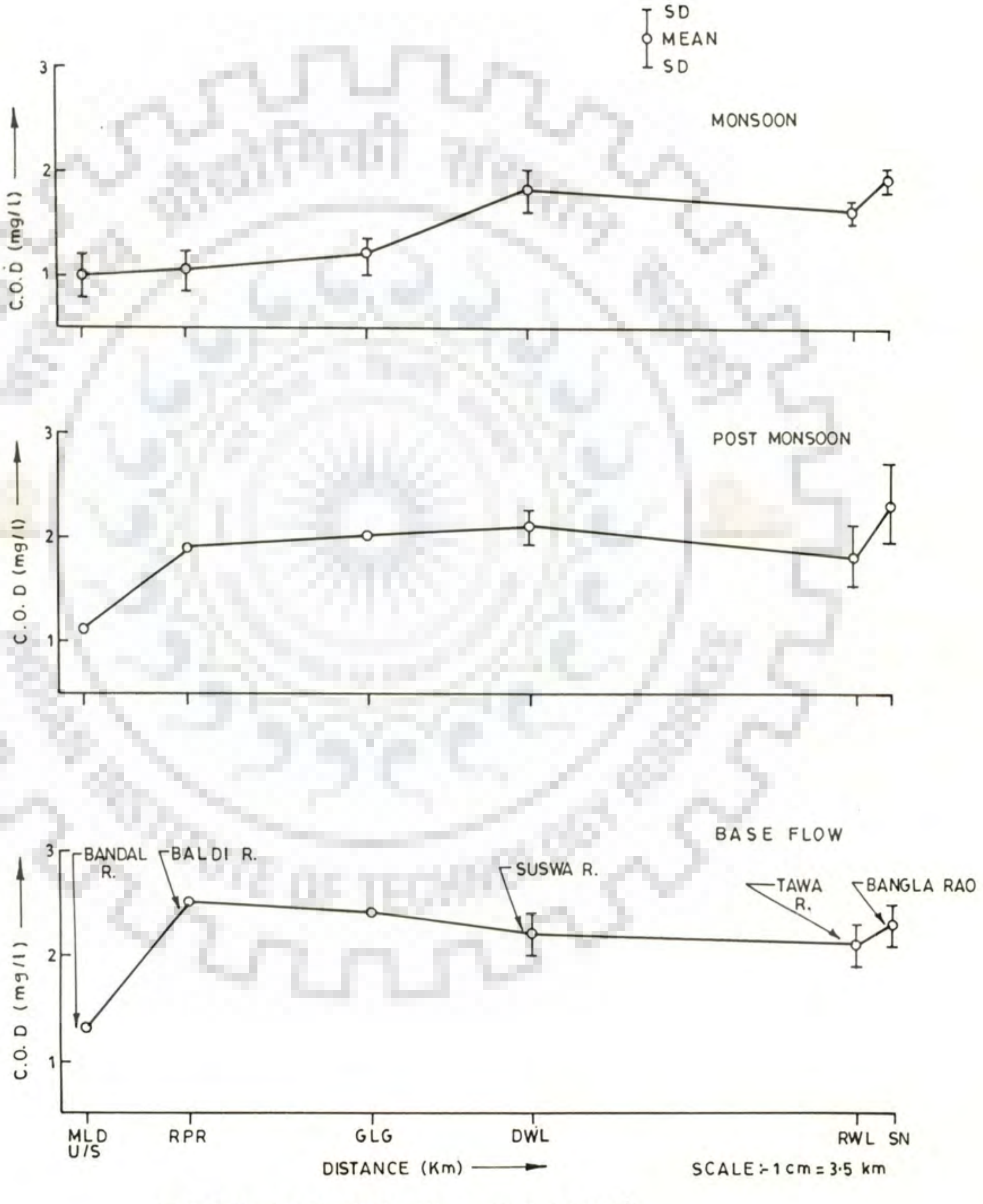


FIG.5·14—VARIATION IN C. O. D (mg/l)

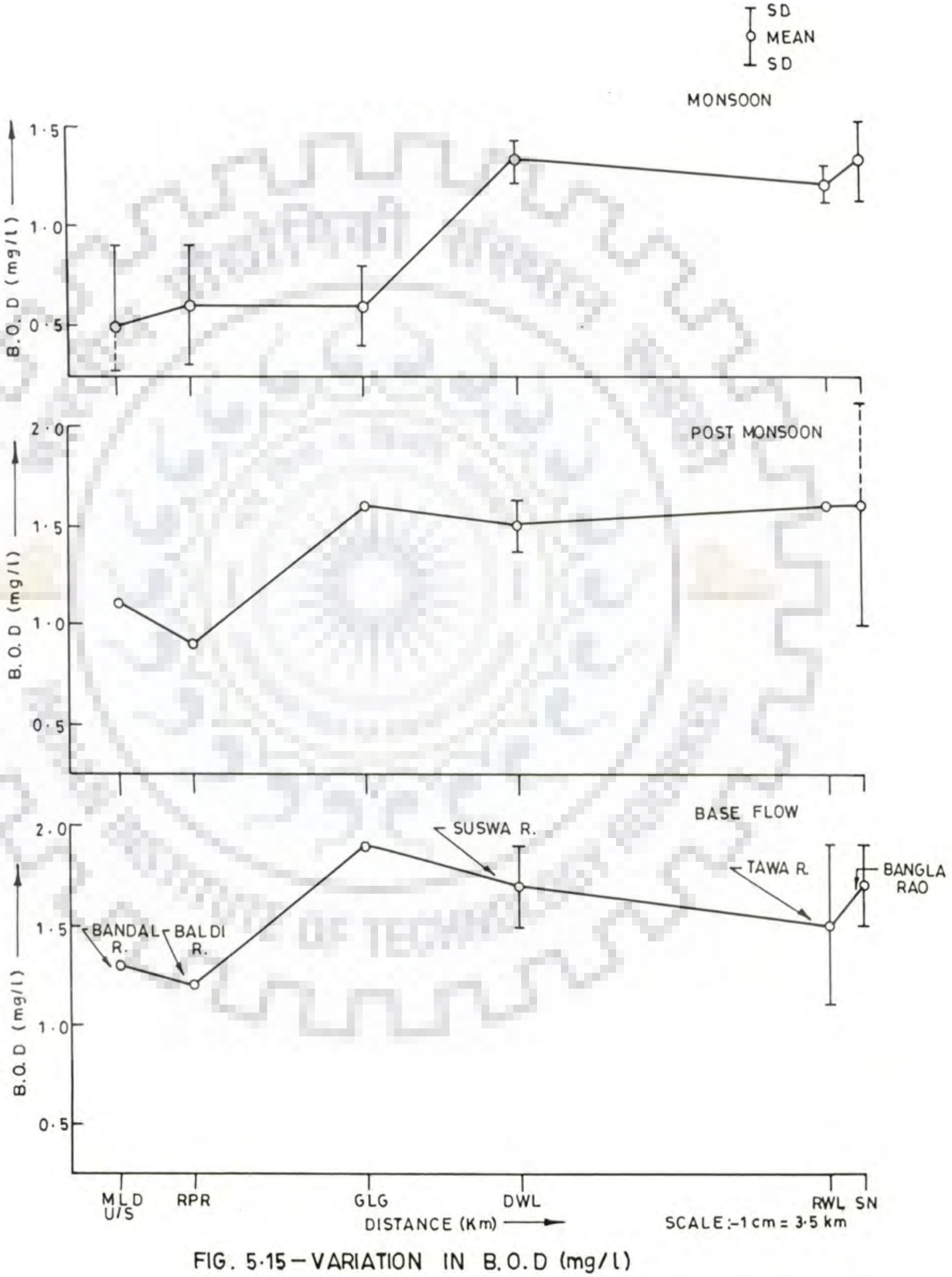


FIG. 5·15 — VARIATION IN B.O.D (mg/l)

river by Bangla Rao as it descends downwards.

5.5 TRACE METALS

The study of heavy metals in Song river was to assess the impact of Doon Valley to the Ganga system. Occurrence and transport of heavy metals viz. iron, lead, zinc, cadmium, manganese, nickel, cobalt and copper were studied. No anthropogenic heavy metal source was identified in the study area and the incidence was only due to the geochemical cycling of rocks. Although heavy metals were identified both in suspended and dissolved forms, the dissolved fraction dominated the suspended counterpart. This was apparent from the standard deviations of the mean total metal ion concentrations. However, the metals in conjugation with suspended particulate matter were carried during heavy downpour. Thus the higher dissolved metal content as compared to suspended can, in all probability, be due to the leaching of these trace metals from the limestone, shales and sandstone. The hill slopes in the Doon Valley were found to be not much significant to yield heavy suspended load during monsoon season.

The heavy metals were added through the tributaries and the recharged ground water. The tributaries Baldi and Bandal have different catchment activities and geology as compared to Tawa and Bangla Rao. The mining activities in these areas accelerate the chemical leaching and more metals are carried in the tributaries. Thus, upper Song river contains more heavy metal concentration as compared to lower reaches.

5.5.1 IMPACT OF TRIBUTARIES:

The mean concentrations of total and dissolved trace metals in four major tributaries are presented in Table 5.3 and Table 5.4. Baldi and Bandal flow through mining areas of Sahashradhara and Maldevta, where as Tawa and Bangla Rao, originate in Doon Valley, have the agricultural land, domestic discharges to contribute to Song river. The overall difference in total and dissolved metal concentration was observed to be minimum, indicating the lesser extent of physical erosion in Doon Valley. The same also is supported by the geology of the catchment area. Distinct spatial variation was observed among the tributaries. The tributaries flowing around Maldevta area were found to contain more metal content as compared to others. The observed variations were elaborated in the following lines.

Among the tributaries, Baldi carries more iron, lead and manganese. The presence of sulfur spring in Sahashradhara and profound limestone deposits also supports these observations. The Bandal which passes through Maldevta pyritic deposits carry zinc, cadmium, cobalt, nickel and copper. The tributary Bangla Rao add more iron, manganese and cobalt to Song as compared to Tawa. The concentrations of other metals were more or less same in both tributaries. The following conclusions emerge after

TABLE 5.3 MEAN TOTAL METAL CONCENTRATION IN THE TRIBUTARIES BEFORE CONFLUENCE OF SONG RIVER

S.No.	METALS	BALDI		BANDAL		TAWA		BANGLA RAO	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	IRON (mg/l)	2.7	3.6	1.0	0.2	0.4	0.2	1.2	0.8
2.	LEAD (µg/l)	294.1	82.4	270.1	35.7	45.6	23.8	50.0	38.5
3.	ZINC (µg/l)	219.0	157.2	262.5	25.0	67.6	44.5	62.5	30.0
4.	CADMIUM (µg/l)	130.0	47.6	172.5	57.2	10.5	10.6	10.0	7.6
5.	MANGANESE (µg/l)	487.5	118.1	372.6	65.6	103.2	67.5	200.0	120.5
6.	NICKEL (µg/l)	117.9	85.6	146.5	11.1	17.6	11.0	12.5	5.5
7.	COBALT (µg/l)	111.3	60.3	138.8	24.9	9.6	10.6	10.0	2.5
8.	COPPER (µg/l)	117.8	19.5	137.5	18.9	14.1	8.1	25.5	6.8

TABLE 5.4 MEAN DISSOLVED METAL CONCENTRATION IN THE TRIBUTARIES BEFORE CONFLUENCE OF SONG RIVER

S.No.	METALS	BALDI		BANDAL		TAWA		BANGLA RAO	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	IRON (mg/l)	1.5	1.8	1.0	0.2	0.4	0.2	1.2	0.8
2.	LEAD (µg/l)	294.1	82.4	270.1	35.7	45.6	23.8	50.0	12.5
3.	ZINC (µg/l)	84.6	10.1	140.0	56.7	52.5	38.4	42.1	15.0
4.	CADMIUM (µg/l)	88.0	32.0	111.3	63.6	7.7	7.6	8.2	9.1
5.	MANGANESE (µg/l)	265.0	167.8	267.1	72.3	80.6	53.2	150.0	90.5
6.	NICKEL (µg/l)	60.7	32.5	73.2	19.0	10.7	7.8	7.5	4.0
7.	COBALT (µg/l)	75.6	46.2	93.9	24.5	7.5	8.9	7.0	2.5
8.	COPPER (µg/l)	89.4	27.1	94.3	15.7	8.6	4.5	10.0	7.8

close observation of data.

- The variations in metal content in these tributaries reflect the gradient of heavy metal enrichment in the limestone deposits.
- The impact of mining activity was not significant in heavy metal enrichment in Song river, as the open cast mining at Sahashradhara has been stopped in 1983 and the treatment of P.P.C.L. mining return waters is being practiced.

5.5.2 TRENDS OF TRACE METALS IN SONG RIVER:

Table 5.5 to Table 5.8 and Fig. 5.16 to Fig. 5.19 illustrate the trend of trace metals in the Song river from Maldevta to Satyanarayana. In general, metals are added both in dissolved form and in conjugation with suspended particulate matter. Trace metals exhibit a typical dilution pattern in the Song river, however, certain spatial and temporal variations worth mentioning, are as follows:

The contribution of metals like copper, cobalt, manganese, cadmium, nickel and lead is predominant in the suspended form in the stretch between Maldevta and Gularghati. This observation alongwith the increased dissolved metal fraction during post-monsoon and base flow seasons indicate that the area between Maldevta and Gularghati is rich in mineral deposits. However, the concentration of these metals decrease in the sub-stretch

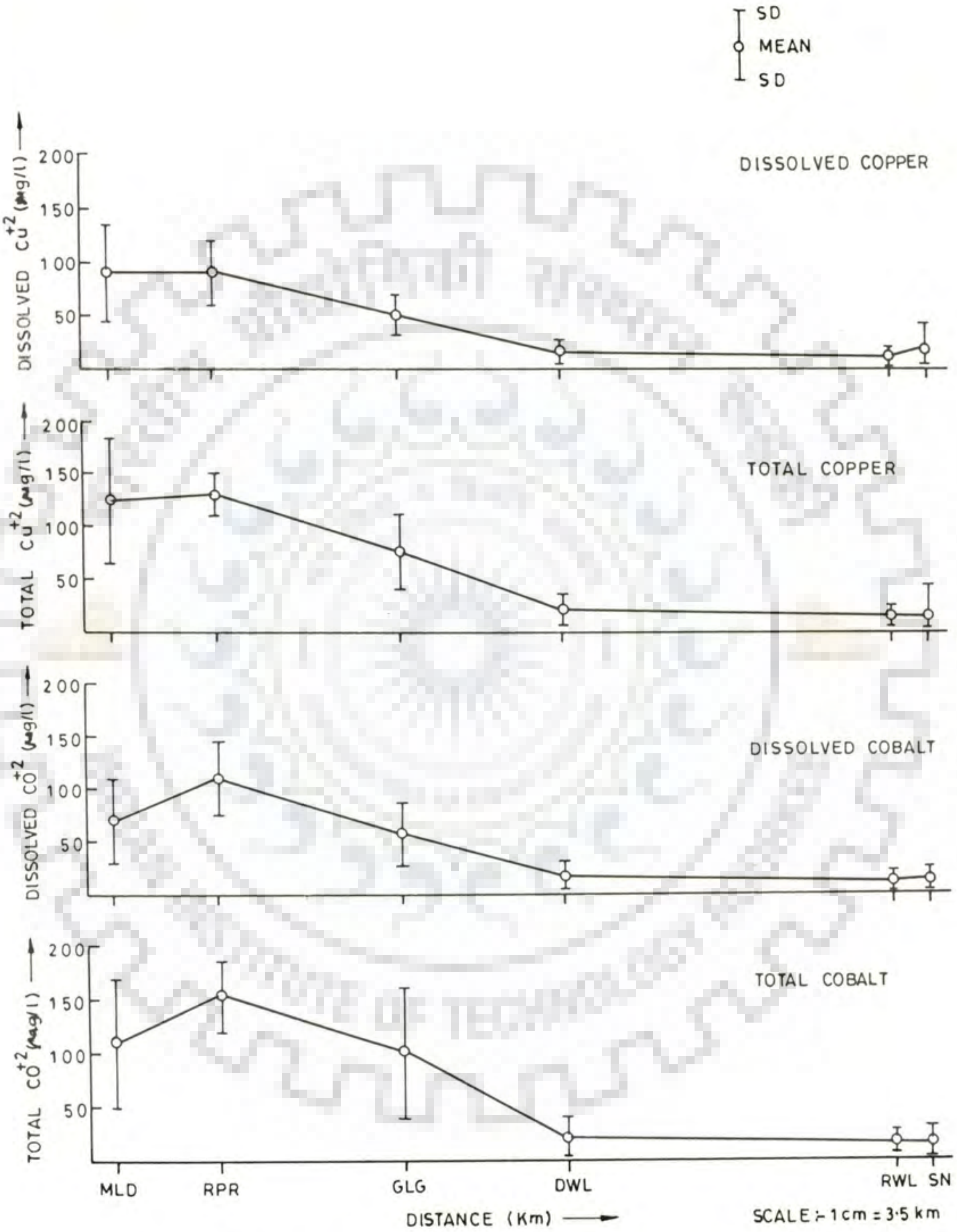


FIG. 5·16 — VARIATION IN TRACEMETALS

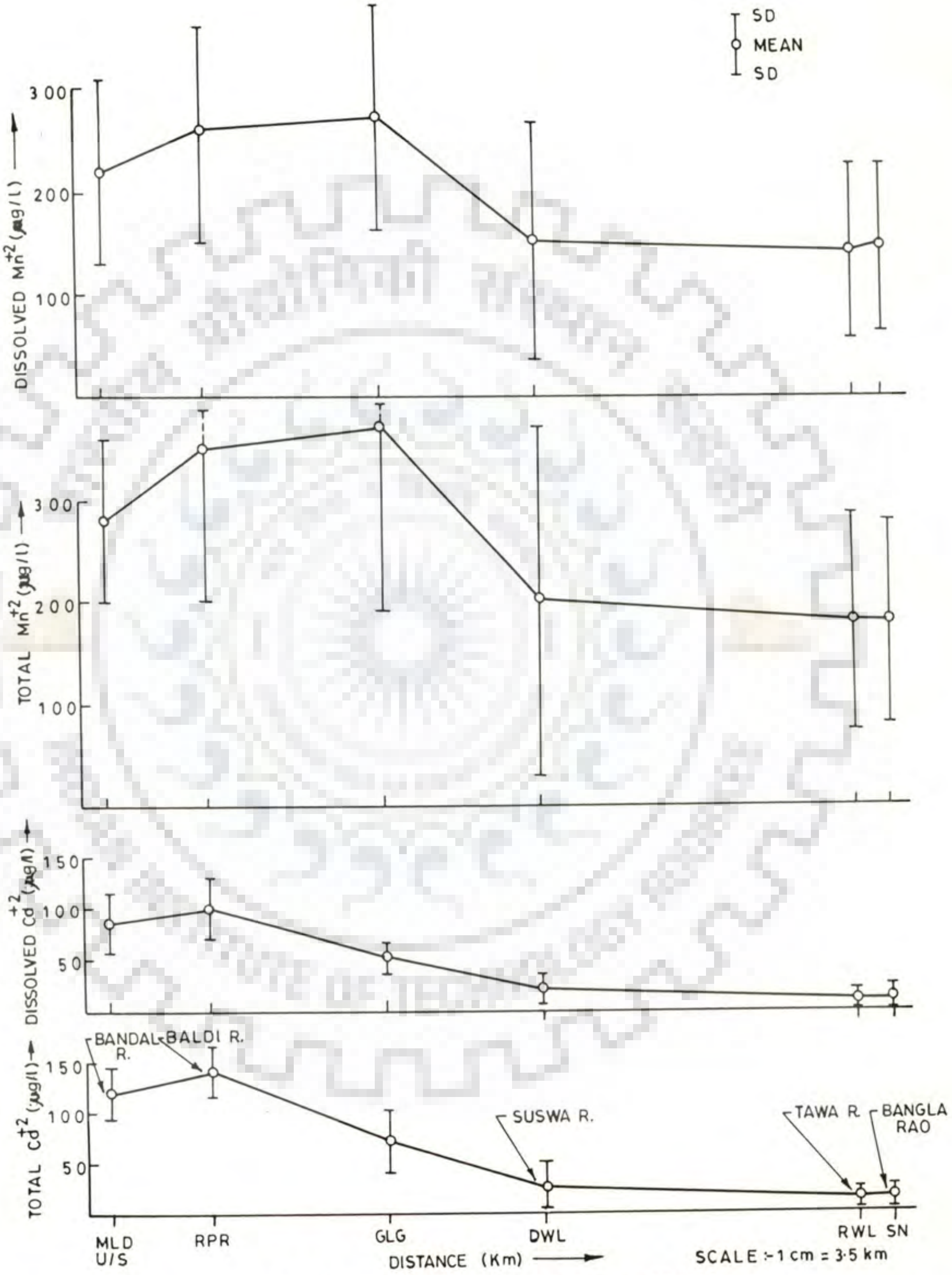


FIG.5·17—VARIATION IN TRACE METALS

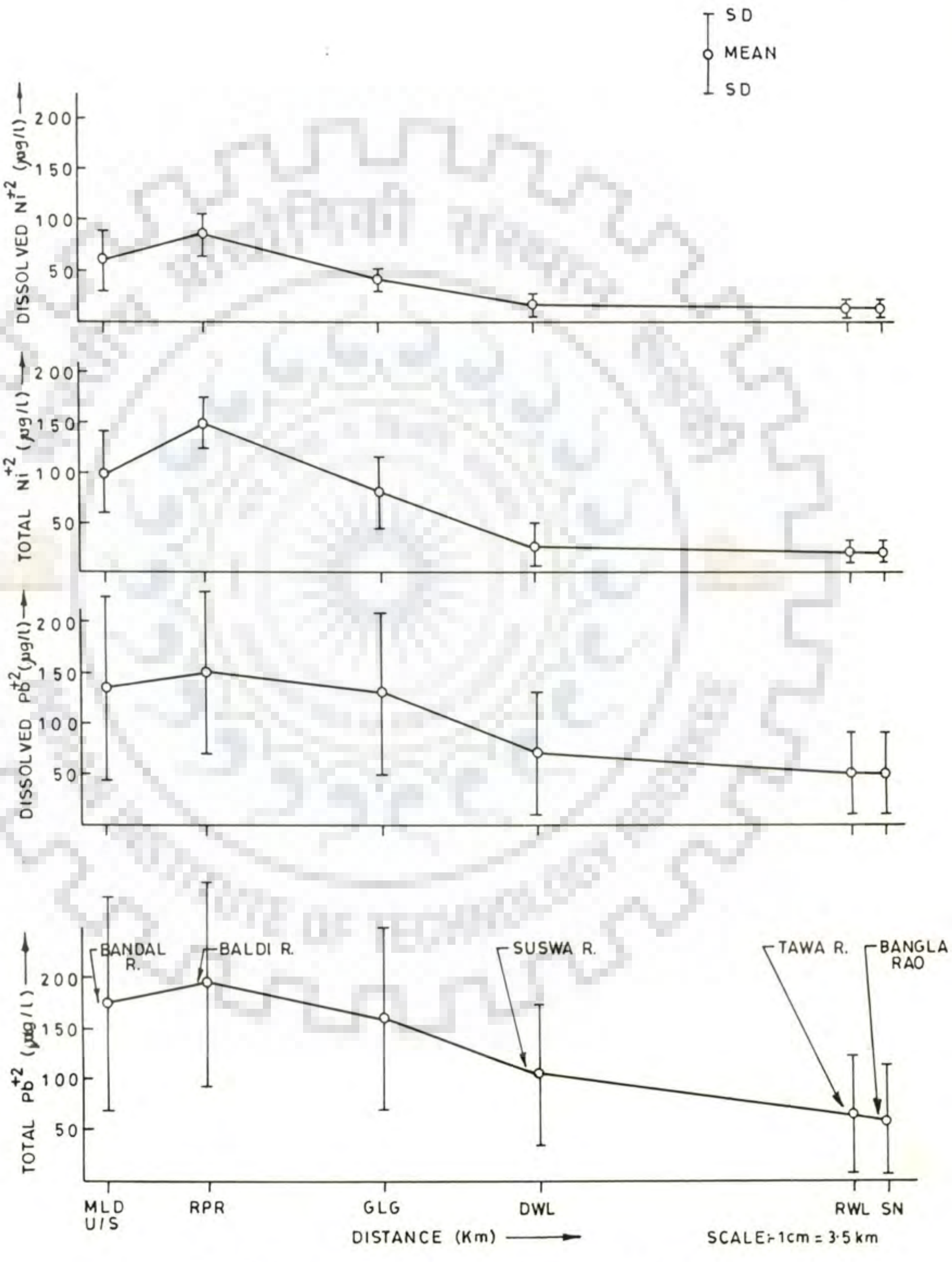


FIG. 5·18—VARIATION IN TRACE METALS

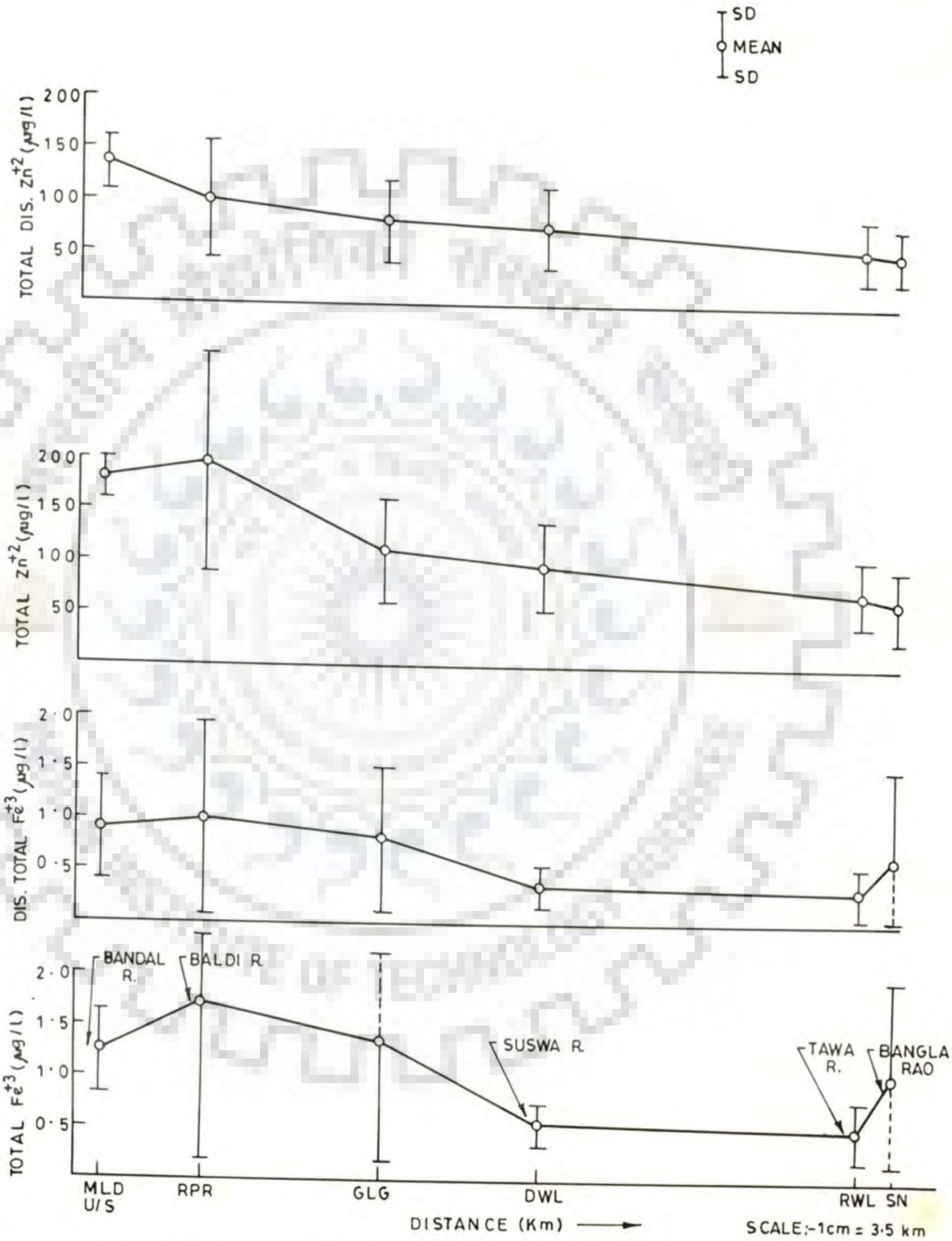


FIG. 5·19—VARIATION IN TRACE METALS

TABLE 5.5 MEAN METAL CONCENTRATIONS IN SONG RIVER

(Iron and Lead)

S.No.	STATIONS	IRON (mg/l)				LEAD (µg/l)			
		Total		Dissolved		Total		Dissolved	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	MALDEVTA Song	1.25	0.40	0.88	0.50	175.1	106.1	136.6	85.9
2.	RAIPUR	1.68	1.90	0.96	0.87	192.3	101.8	148.7	82.2
3.	GULARGHATI	1.44	1.45	0.81	0.70	162.0	94.4	130.0	79.8
4.	DOIWALA	0.55	0.20	0.35	0.20	104.4	71.5	72.6	58.7
5.	RAILWALA	0.46	0.26	0.33	0.25	65.8	58.9	50.9	42.8
6.	SATYANARAYANA	1.06	1.90	0.60	0.90	61.7	56.5	48.2	44.5

TABLE 5.6 MEAN METAL CONCENTRATION IN SONG RIVER

(Zinc and Cadmium)

S.No.	STATIONS	ZINC (µg/l)				CADMIUM (µg/l)			
		Total		Dissolved		Total		Dissolved	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	MALDEVTA Song	180.0	20.9	137.4	24.0	120.2	27.4	87.0	29.1
2.	RAIPUR	195.6	105.4	100.0	54.9	137.7	32.8	102.6	28.6
3.	GULARGHATI	110.0	51.8	82.0	39.1	69.0	28.6	48.0	15.6
4.	DOIWALA	96.7	44.6	78.5	39.0	26.1	24.6	18.2	16.9
5.	RAIWALA	69.4	36.0	55.6	28.5	15.3	13.6	10.9	9.2
6.	SATYANARAYANA	58.9	32.6	47.5	26.8	13.3	12.2	10.1	9.8

TABLE 5.7 MEAN METAL CONCENTRATIONS IN SONG RIVER

(Manganese and Nickel)

S.No.	STATIONS	MANGANESE (µg/l)				NICKEL (µg/l)			
		Total		Dissolved		Total		Dissolved	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	MALDEVTA	280.0	83.7	218.0	92.6	97.0	40.9	58.0	30.5
2.	Song RAIPUR	352.2	154.1	262.3	109.6	152.0	23.6	83.0	21.0
3.	GULARGHATI	372.1	181.8	270.3	111.9	81.1	36.4	39.7	11.3
4.	DOIWALA	201.6	171.4	150.1	117.6	26.0	19.1	14.0	7.9
5.	RAILWALA	179.7	105.9	142.3	86.3	19.0	9.6	11.2	5.1
6.	SATYANARAYANA	182.8	102.2	146.4	79.3	17.2	8.7	9.4	4.3

TABLE 5.8 MEAN METAL CONCENTRATION IN SONG RIVER

(Cobalt and Copper)

S.No.	STATIONS	COBALT (µg/l)				COPPER (µg/l)			
		Total		Dissolved		Total		Dissolved	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.	MALDEVTA	116.1	61.7	73.0	43.1	124.1	60.8	88.8	46.0
2.	Song RAIPUR	155.1	32.8	108.9	34.1	128.1	19.1	92.6	29.1
3.	GULARGHATI	100.0	58.6	53.5	26.6	73.0	36.5	50.3	20.5
4.	DOIWALA	19.1	20.7	13.1	13.2	21.0	14.2	15.0	9.1
5.	RAIWALA	13.1	13.3	9.0	9.1	14.8	7.8	10.3	4.8
6.	SATYANARAYANA	12.8	12.0	9.7	9.2	22.8	33.2	15.7	23.1

between Gularghati and Satyanarayana indicating the dilution caused from various tributaries in monsoon, post-monsoon seasons and recharge ground water during base flow regime.

The metals zinc and iron (Fig. 5.19) were added in suspended and dissolved forms althrough the stretch. More suspended fraction of the metals was added during monsoon season, and metals in dissolved form were added in post-monsoon and base flow seasons.

Among the tributaries, the prominent impact of trace metals on Baldi was visible at Raipur. Baldi adds maximum concentrations of heavy metals and this hinders the spatial and temporal variations in the stretch from Raipur to Doiwala. The total and dissolved fractions of trace metals studied showed an increase at Raipur except a decrease in dissolved zinc concentration. This decrease was due to the lesser amount of zinc in dissolved form carried through Baldi.

The Bangla Rao, the last tributary to join Song, adds more iron in both the forms. The other metals like copper, cadmium and manganese were added prominently in dissolved form.

6.0 MINERAL INDICES

6.1 HISTORY AND DEVELOPMENT OF WATER QUALITY INDICES
  6.1.1 IMPORTANCE OF WATER QUALITY INDICES
  6.1.2 TYPES OF WATER QUALITY INDICES AND SELECTION OF FORMULATIONS
6.2 INDICES SELECTED
  6.2.1 HORTON'S INDEX
  6.2.2 MC DUFFIE'S RIVER POLLUTION INDEX
  6.2.3 STATISTICAL APPROACHES
6.3 COMPARISON OF THE MINERAL INDICES CALCULATED AND THE TRENDS IN THE STUDY AREA
  6.3.1 TRENDS OF MINERAL INDICES IN GANGA RIVER
  6.3.2 TRENDS OF MINERAL INDICES IN SONG RIVER

6.0 MINERAL INDICES

To represent the mineral transport and the impact of tributaries on the mineral profile of Ganga river an attempt has been made herein to indicate the river water quality by using physico chemical indices.

Water quality indices, in general, are formulated as a numerical scale to represent the gradations in water quality levels. An index, in general, is the comparison of a quantity to a scientific or arbitrary standard or to a pre-specified base (Lohani, 1984). Thus, the water quality indices mean, tools used to monitor and quantitatively report the environmental status and trends on the standards.

6.1 HISTORY AND DEVELOPMENT OF WATER QUALITY INDICES

The concept of water quality indices started way back, in 1848 when attempts were made to correlate the levels of water purity with the occurrence of certain biological organisms. Since then, various countries have applied concepts depending on the amount of pollution present and the occurrence of organisms, to classify the waters flowing within their boundaries. These classifications, define waters as one of several pollution classes or levels. In contrast a concept of classification of a water body, based on use of a numerical scale to represent gradations of quality was pioneered by Horton in 1965 (Horton, 1965). The Horton's index provided basis for the development of others in later years.

6.1.1. IMPORTANCE OF WATER QUALITY INDICES:

Water quality indices (WQI) provide tangible information about the percentage of pollution or purity of waters, by avoiding huge amount of data to present the water quality.

Water quality indexing system also facilitates a better system for quality monitoring. For that the monitoring data must be shaped in to easy-to-understand indices for the top management and general public policy development. National Academy of Sciences (NAS, 1978) in a report by its Planning Committee on Environmental Indices, indicated that the environmental indices perform an active role

- in assigning policy information
- in assisting designing programs
- in facilitating communication with concerned people.

After reviewing the literature available on the subject, Ott (1978a) identified six basic uses of WQI as

- resource allocation,
- ranking of the location by comparing the environmental conditions at different locations or geographical areas,
- standard enforcement. Indices can be used to specific locations to determine the extent to which legislature standards and existing criteria are being met or exceeding,
- trend analysis. Indices can also be applied to

environmental data at different locations in time to determine the changes in environmental quality which have occurred over a period,

- public information. Indices can also be used to inform the public about the environmental conditions,
- scientific research. indices may be applied as a means for reducing large quantity of data to a form that gives insight to the research, conducting study of some environmental programs.

In otherwords, indices are the concise and objective tools to analyze the trends of water quality. Graphs of parameters against each other or against time are not concise and do not show the trends clearly because of data overlap and sheer volume.

6.1.2 TYPES OF WATER QUALITY INDICES AND SELECTION OF FORMULATIONS:

The WQI were developed by individuals, agencies or organisations. Ott (1978b) suggested a classification in a generalised way (Table 6.1). This may have some differences of opinion.

(i) General WQI are those based on the assumption that water quality is a general attribute of surface waters, irrespective of the use to which the water is put.

(ii) Specific use WQI are those developed with respect to a specific use of the water body viz. irrigation, outdoor

TABLE 6.1 CLASSIFICATION OF WATER QUALITY INDICES

(Ott, 1978)

Index Name	Reference	Number of Variables	Scale	Range	Index Name	Reference	Number of Variables	Scale	Range
General WQI					Planning WQI				
Water Quality Index	Horton	10	Decreasing	0 to 100	Prevalance Duration Intensity (PDI)	Truett et al	Any number can be included	Increasing	0 to 1
NSE WQI	Brown et al	9	Decreasing	0 to 100	National Planning Priorities Index (NPAI)	•	•	•	•
River Pollution Index	Mc Duffie and Haney	8	Increasing	0 to 1000+	Priority Action Index	•	•	•	•
Implicit Pollution Index	Prati et al	13	Increasing	0 to 15+	Environmental Evolution System(EES)	Dee et al	78	Decreasing	0 to 1000
Social Accounting System	Dinius	11	Decreasing	0 to 100	Canadian National Index	Inhaber	Any number can be included	Increasing	0 to 1
Specific Use WQI									
Fish and Wildlife Index (FAWL)	O'Connor	9	Decreasing	0 to 100	Potential Pollution Index	Zeotman	3	Increasing	0 to 1000+
Public Water Supply Index (PWS)	O'Connor	13	Decreasing	0 to 100	Pollution Index (PI)	Johanson &Johanson	Any number can be included	Increasing	0 to 1000+
Index for Public Water Supply	Deininger &Landwehr	11/13	Decreasing	0 to 100					
					Statistical Method				
Index for Recreation	Walski & Parker	12	Decreasing	0 to 1	Composite Pollution Index	Shoji et al	18	Increasing	-2 to 2
Index for Dual Water Uses	Stoner	31	Decreasing	-100 to 100	Index for Partial Nutrients	Joung et al	5	Decreasing	0 to 100
Index for Three Uses	Nemerow & Sunitorno	14	Increasing	0 to 1+	Index for Total Nutrients	•	5	Decreasing	0 to 100
					Principal Component Analysis	Coughlin et al	Any number can be included	N.A.	N.A.
					Harkin's Index	Harkins	•	Increasing	0 to 100+
					Beta Function Index	Schaeffer &Janardan	•	Increasing	0 to 9

bathing, drinking.

(iii) Planning WQI are those generated for management purpose for decision making. They are basically custom designed to assist the user in making specific decisions and in solving specific problems.

(iv) Statistical approaches are mainly based on either factor analysis or non parametric multivariate transforms.

In addition, some agencies have developed their own indices with variation in parameters, rating, weightages and the form of aggregation of sub-indices (Ott, 1978b). Some of them, however, do not fall exactly under the category of General WQI. These indices include the Trend Monitoring Index (TMI) of Georgia's Department of National Resources (Environmental Pollution Division), Pollution Index (PI) of Illinois Department of Transportation Division of Water Resource Management, and the Water Quality Index developed by Orgenan's Department of Environmental Quality.

In India Bhargava (1983 and 1985) developed two specific use indices for Ganga waters. Wariyar (1986) has calculated a general WQI to show the pollution levels in Ganga river in a 30 km stretch from Rishikesh to Haridwar. In this index the formulations of NSF-WQI with a weighted arithmetic aggregation function was used with modifications in weightages. The rating scale of Horton's index was modified and the formulations were applied to the Hindon river system, U.P. by Singhal et al (1986). The impact of community bathing on Ganga river at Haridwar during Kumbh Mela (1986) was shown by Ganga Project team of Roorkee University, U.P., India. The formulations of Mc Duffie's River Pollution Index and Harkin's index based on statistical approaches were used for the calculation of these indices.

Calculation of a single index which includes important physico-chemical parameters and show the mineral trend with respect to time and space concisely has been planned. The formulations of the reported general WQI and statistical approaches were considered. The variables included are presented in Table 6.2. From the perusal of the information one can visualise that no index among the reported is suitable. Hence, it was planned to calculate a mineral index by taking suitable formulations.

Table 6.3 illustrates the mathematical characteristics of the seven general WQI reported in literature. The principle behind the index calculation, the main formulations and the flexibility to include or exclude any parameter is presented in Table 6.4.

Out of the seven general WQI, the NSF-WQI is the most widely used and accepted index. It was not considered for the present mineral index, because of its limited parametric flexibility. Though the NSF-WQI was considered to have less

TABLE 6.2 VARIABLES USED IN GENERAL WATER QUALITY INDICES

VARIABLES	Horton	NSFWQI	Prati *et al*	Mc Duffie *et al*	Dinius	Dee *et al*
Physical						
p^H	*	*	*		*	*
Temperature	*	*		*	*	*
Conductivity	*			*	*	
Turbidity		*				*
Dissolved Solids						*
Suspended Solids			*			
Total Solids		*				
Color					*	
Other						*
Chemical						
D.O.	*	*	*	*	*	*
C.O.D.			*	*		
B.O.D.5		*	*	*	*	*
Alkalinity	*				*	
Hardness					*	
Chlorides	*		*		*	
Sulfates						
Phosphates		*		*		
Fluorides						
Nitrogen						
Ammonical			*			
Nitrite						
Nitrate		*	*			
Other				*		*
Oil and grease						
Phenol						
ABS			*			
CCE	*		*			
Iron			*			
Manganese			*			
Other			*	*		*
Biological						
Fecal coliform		*			*	*
Total coliform	*			*	*	

TABLE 6.3 MATHEMATICAL CHARACTERISTICS OF GENERAL WQI

INDEX	SUBINDICES	AGGREGATION FUNCTION	COMMENTS
Horton	Segmented Linear	Weighted sum multiplied by two dichotomous terms	Eclipsing Region
NSF WQI	Implicit Nonlinear	Weighted sum	Eclipsing Region
Landwehr *et al*	Implicit Nonlinear	Weighted product	Nonlinear
Mc Duffie and Haney	Linear	Weighted sum	Eclipsing Region
Prati *et al*	Segmented Nonlinear	Weighted sum (Arithmetic mean)	Eclipsing Region
Dinius	Nonlinear (Linear, Power)	Weighted sum	Eclipsing Region
Dee *et al*	Implicit Nonlinear	Weighted sum	Eclipsing Region

TABLE 6.4 FORMULATIONS AND THE PARAMETER FLEXIBILITY IN THE REPORTED GENERAL WATER QUALITY INDICES

INDEX	FORMULATIONS	PRINCIPLE	PARAMETER FLEXIBILITY
Horton's	$QI = \frac{\sum_{i=1}^{n} W_i I_i}{\sum_{i=1}^{n} W_i}$	Rating & Weightages based on author's judgement	Any parameter can be included or excluded
NSF WQI	$WQI_a = \sum_{i=1}^{n} W_i I_i$	Rating & Weightages based on experts opinion poll	Parameters were fixed
Pratis's implicit Index of Pollution	$I = 1/13 \sum_{i=1}^{13} I_i$	Explicit Mathmatical function for sub-index values have been developed on the basis of author's own judgement on severity of pollution	Parameters are fixed
McDuffie's River Pollution Index(RPI)	$I_i = 10[X/XN]_i$ $RPI = \frac{10}{n+1} \sum_{i=1}^{n} I_i$	Sub-indices were calculated by dividing the parameter value with a control value (standard) and multiplying with a factor to put the index value in a scale	Any parameter can be included or excluded
Dinius Social Accounting System	$I = [1/21] \sum_{i=1}^{21} w_i I_i$	Subindex functions and weightages taken were based on the author's evaluation of the importance of each pollutant variable	Any parameter can be included or excluded

subjectivity as compared to other WQI, the number of mineral parameters included were less (Table 6.2). Out of the remaining indices, the formulations of Horton's index and Mc Duffie's RPI were considered because of the extent of parameter flexibility. The statistical approaches were also adopted for calculating the proposed mineral indices.

6.2 INDICES SELECTED

Two general WQI viz. Horton's index, Mc Duffie's RPI were calculated for the Ganga river in the present study. Horton's index based on non-parametric multivariate transforms was also calculated. For these indices the limits were modified. The modifications done in the present study are discussed in the following paragraphs.

6.2.1 HORTON'S INDEX:

Horton proposed the first formal WQI for evaluating abatement programs and to provide public information. According to him the indices based on rating system can offer a means for measuring pollution abatement progress since the condition of the stream at any time can be compared with the condition that is expected or planned for future. Thus the indices are useful for administrative purpose and for public communication. He opined that the stream classifications were misleading as they did not allow for gradations in conditions. The lack of agreement among different agencies as standard setting criteria makes such classification systems unworkable. To avoid these problems of connotation Horton proposed an index based on rating of water quality on comparative basis.

In Horton's index 10 variables were included by following the selection criteria

- the number of variables should be limited to avoid the index becoming bulky
- the variables should be of significance in most parts of the country
- the variables should reflect the availability of the data

The variables with their respective weightage and break points of rating scale of variable of Horton's index for the Ohio River Sanitation Commission's data is presented in Table 6.5 and Table 6.6.

Horton's WQI uses a linear sum aggregation function. It consists of the weighted sum of the sub-indices divided by the sum of the weights and multiplied by two coefficients M_1 and M_2. These coefficients reflect the temperature of the water body and the offensive conditions respectively. The formulation used was

$$W.Q.I. = \frac{{}_{i=1}\Sigma^{n} W_i \; I_i}{{}_{i=1}\Sigma^{n} W_i}$$

The break points of rating scale and the weightages assigned to the variables were based on the author's judgment.

TABLE 6.5 WEIGHTAGES FOR HORTON WATER QUALITY INDEX (Horton, 1965)

PARAMETER	WEIGHTAGES
Dissolved Oxygen	4
Sewage Treatment (per % population served)	4
p^H	4
Coliforms	2
Specific conductance	1
Carbon chloroform extract	1
Alakalinity	1
Chloride	1

TABLE 6.6 BREAKPOINTS FOR HORTON'S WQI (Horton, 1965)

I	D.O. (%)	COLIFORM (MPN/100ml)	CCl_4 EXTRACT (0.001	p^H	SPECIFIC COND. (μ m)	ALAKALINITY (mg/l)	CHLORIDES (mg/l)	SEWAGE TREAT-	COEFFICIENTS
100	>7.0	<1000	0-100	6-8	0-750	20-100	0-100	95-100	If temp > critical value M1=½ otherwise M1=1
80	50-70	1500-5000	100-200	5-6; 8-9	750-1500	5-20; 100-200	100-175	80-95	
60	30-50	5000-10000	200-300	4-5; 9-10	1500-2500	0-5; >200	175-200	70-80	
30	10-30	10000-20000	300-400					60-70	
0	<10	>20,000	>400	<4; >10	>2500	Acid	>250	<50	If obvious pollution is present M2=½ otherwise M2=1

Singhal et al (1986) have modified the rating procedure and the weights with inclusion of few more parameters in their index calculated for Hindon river quality data. They considered total dissolved solids, conductivity, p^H, dissolved oxygen percentage saturation, chemical oxygen demand, biochemical oxygen demand, ammonical nitrogen, nitrate nitrogen, nitrite nitrogen, phosphates, chlorides, sulfates, cadmium, lead and chromium. They fixed the rating scale from 100 to 400, where 100 was the permissible (or allowable) values for a specified parameter for an arbitrary defined use and 400 was the cut off value which corresponds to the highly objectionable concentration of specified parameter. The coefficients of temperature and obvious pollution have been eliminated as they were less sensitive in the study. The formulation used was as follows:

$$WQI_i = \frac{{}_{i=1}\Sigma^{n} \; Q_i W_i}{{}_{i=1}\Sigma^{n} \; W_i}$$

where Q_i = Rating values of the ith parameter

W_i = Assigned weightage of the ith parameter

n = Number of parameters included.

The rating value of the ith parameter was computed as

$$Q_i = 300[(X - X_1)/(X_2 - X_1)] \times 400$$

where X_2 = Concentration of ith parameter corresponding to 400 on rating scale.

X_1 = Concentration of ith parameter corresponding to 100 on rating scale.

X = Observed concentration of ith parameter.

The minimum and maximum and the corresponding weightages were fixed on the basis of available literature, the experience of author and his associates and the maximum observed value of the particular parameter.

Procedures Adopted in the Present Study:

Following procedure was followed in calculation of mineral indices using Ganga river data.

In general, the permissible limits of variable were taken as the minimum and maximum values of the rating scale. For the variables where the limits are not existing, some arbitrary standards on the basis of experience were fixed. The rating scales were so chosen that each parameter was assigned a rating value corresponding to the observed concentration of the parameter. These rating scales for different parameters were also expressed mathematically in terms of measured mineral concentrations and the rating scale was expressed in the range of 100 to 400. The corresponding minimum and maximum value of ith parameter was chosen from the observed data of Ganga and Song rivers. The minimum of the scale 100, was the minimum value of the ith parameter observed in Ganga river. The maximum value of the scale 400, corresponds to the maximum observed value in Ganga and Song rivers. The rating scale was shown graphically in Fig. 6.1.

Weightages to the parameters, in general, were assigned on their relative importance. The weightages were proposed over a range of 1 to 5. The range was in increasing order of relative importance of the parameter.

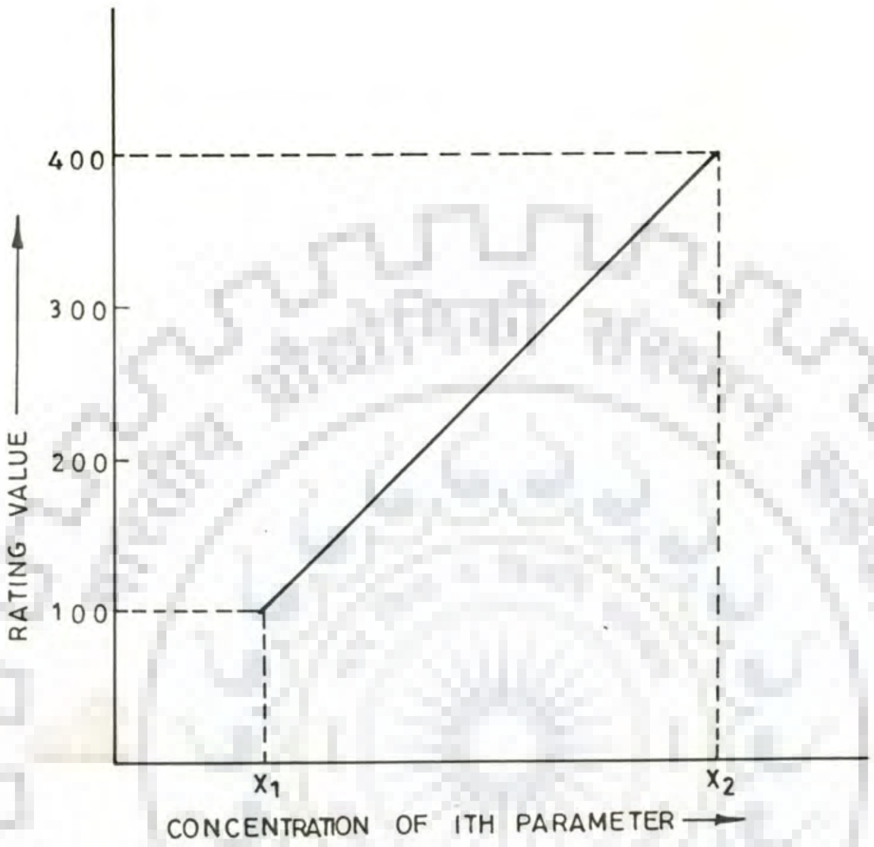
To minimize the subjectivity in the proposed index, opinion poll was conducted to establish the rating scale and weightages.

A questionnaire was sent to the persons working in the field in the country. The objectives of the proposed index and the observed minimum and maximum values of parameters in the present study were enclosed with the questionnaire. The questionnaire is presented as Table 6.7. The experts were asked to give their opinion on:

(a) whether the proposed index, aimed chiefly, to show the mineral transport was feasible or not,

(b) if yes, what parameters were relevant out of the following parameters monitored in the present study

p^H		Sodium	(mg/l)
ORP		Potassium	(mg/l)
Conductivity	(µmhos)	Iron	(µg/l)
Total Dissolved Solids	(mg/l)	Cadmium	(µg/l)
Bicarbonates	(mg/l)	Lead	(µg/l)
Carbonates	(mg/l)	Zinc	(µg/l)



MATHEMATICAL EXPRESSION

Rating Value $Q = 300\left(\frac{x - x_1}{x_2 - x_1}\right) + 100$

x_1 = The minimum concentration limit of ith parameter
x_2 = The maximum concentration limit of ith parameter
x = Observed value of the ith parameter

If $x \leqslant x_1$, $Q = 100$
$x > x_2$, $Q = 400$

FIG. 6.1–GRAPHICAL REPRESENTATION OF RATING EQUATION

TABLE 6.7 QUESTIONNAIRE

S.No.	PARAMETER	RELEVANT	IRRELEVANT	If relevant, what weightage is to be assigned					What value out of minimum values listed to be assigned as 100	What value out of maximum values listed to be assigned as 400
				1	2	3	4	5		
1.	p^H									
2.	Conductance									
3.	Dissolved solids									
4.	Total cations(me/l)									
5.	Bicarbonates									
6.	Carbonates									
7.	Chlorides									
8.	Sulfates									
9.	Phosphate									
10.	Nitrates									
11.	Calcium									
12.	Magnesium									
13.	Sodium									
14.	Potasium									
15.	Iron									
16.	Zinc									
17.	Cadmium									
18.	Copper									
19.	Lead									
20.	Cobalt									
21.	Manganese									
22.	Nickel									

Experts were asked to tick in the relevant and weightage columns and write the values corresponding to 100 and 400 rating values, according to their personal opinion.

Chlorides	(mg/l)	Cobalt	(µg/l)
Sulfates	(mg/l)	Nickel	(µg/l)
Ammonical nitrogen	(mg/l)	Manganese	(µg/l)
Nitrate nitrogen	(mg/l)	Copper	(µg/l)
Nitrite nitrogen	(mg/l)	Total anions	(me/l)
Phosphates	(mg/l)	Total cations	(me/l)
Calcium	(mg/l)		
Magnesium	(mg/l)		

(c) if the parameter was relevant, what values one would suggest as X_1 and X_2 for the rating scale. The observed minimum and maximum values in Ganga and Song rivers were provided for reference,

(d) what weightage over a range of 1 to 5 should to be assigned to the relative parameters in their opinion.

The response received was analysed and the rating scale and weightages of relevant parameters established. The following criteria was followed:

(i) The parameter suggested by more than 50 percent of the experts as relevant were considered.

(ii) The mean X_1 and X_2 values suggested by experts for the rating curve of ith parameter were considered.

(iii) The mean values of the suggested weightages were fixed for parameters.

The rating scales, weightages for the selected parameters were thus fixed. The selected water quality parameters, weighting factors and rating curve equations used are presented in Table 6.8.

The raw data of physico-chemical parameters, stationwise, was stored in computer (DEC 20, Roorkee University Regional Computer Centre) through a software developed. The flow chart for the program involved in the calculation of Horton's index is illustrated in Fig. 6.2 and the program developed is given in Appendix 5.

6.2.2 MC DUFFIE'S RIVER POLLUTION INDEX:

Mc Duffie and Haney (1973) have proposed a simple index which would provide a measurement and picture of river water quality at any instant, the trends over a time and a way to compare different rivers as well. The River Pollution Index has been applied on a test basis using the data from Newyork State's Water Quality Surveillance Net Work and from other sources, and has been calculated for streams located on the Susquehanna, Genesee, Dalaware, Moliawk and Hundson rivers. On Susquehanna river, the index reflected the impact of the sewage outfall at Binghampton, New York, by showing distinct upstream and downstream differences (Ott, 1978b).

In Mc Duffie's River Pollution Index, the sub-index for the ith parameter is based on the ratio of the measured concentration to its natural level. The natural level is the normal value of

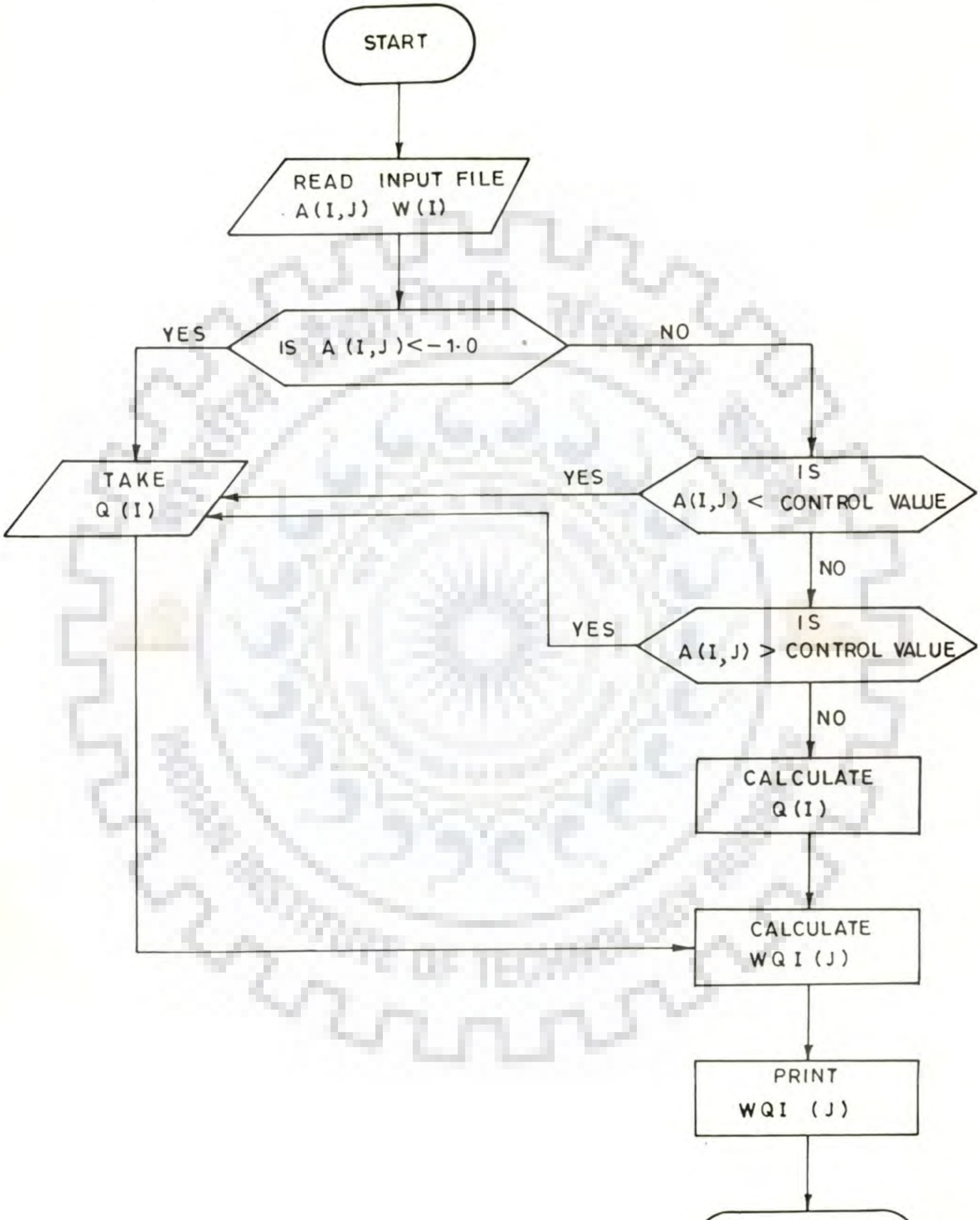


FIG. 6·2 – FLOW CHART FOR THE CALCULATION OF HORTON'S INDEX

TABLE 6.8 SELECTED WATER QUALITY PARAMETERS, WEIGHTAGE FACTORS AND RATING EQUATIONS USED IN PRESENT STUDY

PARAMETER	UNIT	WEIGHT	RATING		RATING CURVE EQUATION
			100 (X1)	400 (X2)	
pH	-	2.5	7.0	9.0	$Qp^{H}(I) = \{30/49[p^{H}(I)-7]\} + 100$
Total Diss. Solids	mg/l	2.5	10.0	500.0	QTDS(I) = {30/49[TDS(I)-10]} + 100
Bicarbonates	mg/l	3.0	20.0	300.0	QBicarbonates = {30/28[Bicarb(I)-20]} + 100
Carbonates	mg/l	1.5	1.0	20.0	Qcarbonates = {15.79[Carb(I)-1]} + 100
Chlorides	mg/l	3.0	5.0	30.0	Qchlorides = {12[Cl(I)-5]} + 100
Sulfates	mg/l	3.5	10.0	200.0	Qsulfates = {15.79[Sulfate(I)-10]}+100
Calcium	mg/l	3.0	10.0	200.0	Qcalcium = {15.79[Calcium(I)-10]}+100
Magnesium	mg/l	3.0	2.0	50.0	QMagnesium = {6.25[Magnesium(I)-2]}+100
Sodium	mg/l	3.0	2.0	10.0	QSodium = {37.5[Sodium(I)-2]} + 100
Cadmium	µg/l	4.0	0.0	50.0	QCadmium = {6[Cadmium(I)]} + 100
Manganese	µg/l	3.5	50.0	100.0	QManganese = {6[Manganese(I)-50]}+100
Nickel	µg/l	3.5	5.0	100.0	QNickel = {3.15[Nickel(I)-5]} + 100
Total anions	me/l	2.0	1.0	10.0	QTotal anions = {33.3[Total A(I)-1]} + 100
Total cations	me/l	2.0	1.0	10.0	QTotal cations = {33.3[Total C(I)-1]} + 100

the ith parameter in 'good' or 'unpolluted water'. Sub-index is calculated as

$$I_i = 10\,[X/XN]_i$$

X = Observed value of the ith parameter

XN = Normal value of the ith parameter

The multiplication by 10 is a scaling factor to make the sub-index to vary from 10 (natural level) to 100 (highly polluted level).

River Pollution Index was calculated as

$$RPI = \frac{10}{n + 1} \; {}_{i=1}\Sigma^{n} I_i$$

n = Number of parameters included

The purpose of multiplying factor (10/n + 1) is to make the index vary from 100 to 1000 on an increasing scale.

In the present study the original formulations were applied on the selected parameters from the opinion poll for the index calculation. The X_1 values fixed for the ith parameter in Horton's index of the present study were taken as the natural or normal value of the ith parameter in the River Pollution Index. Sub-index functions are shown mathematically in Table 6.9.

A computer program was developed to calculate the River Pollution Index. Flow chart of the computer program is given in Fig. 6.3. and the program developed is given in Appendix 6.

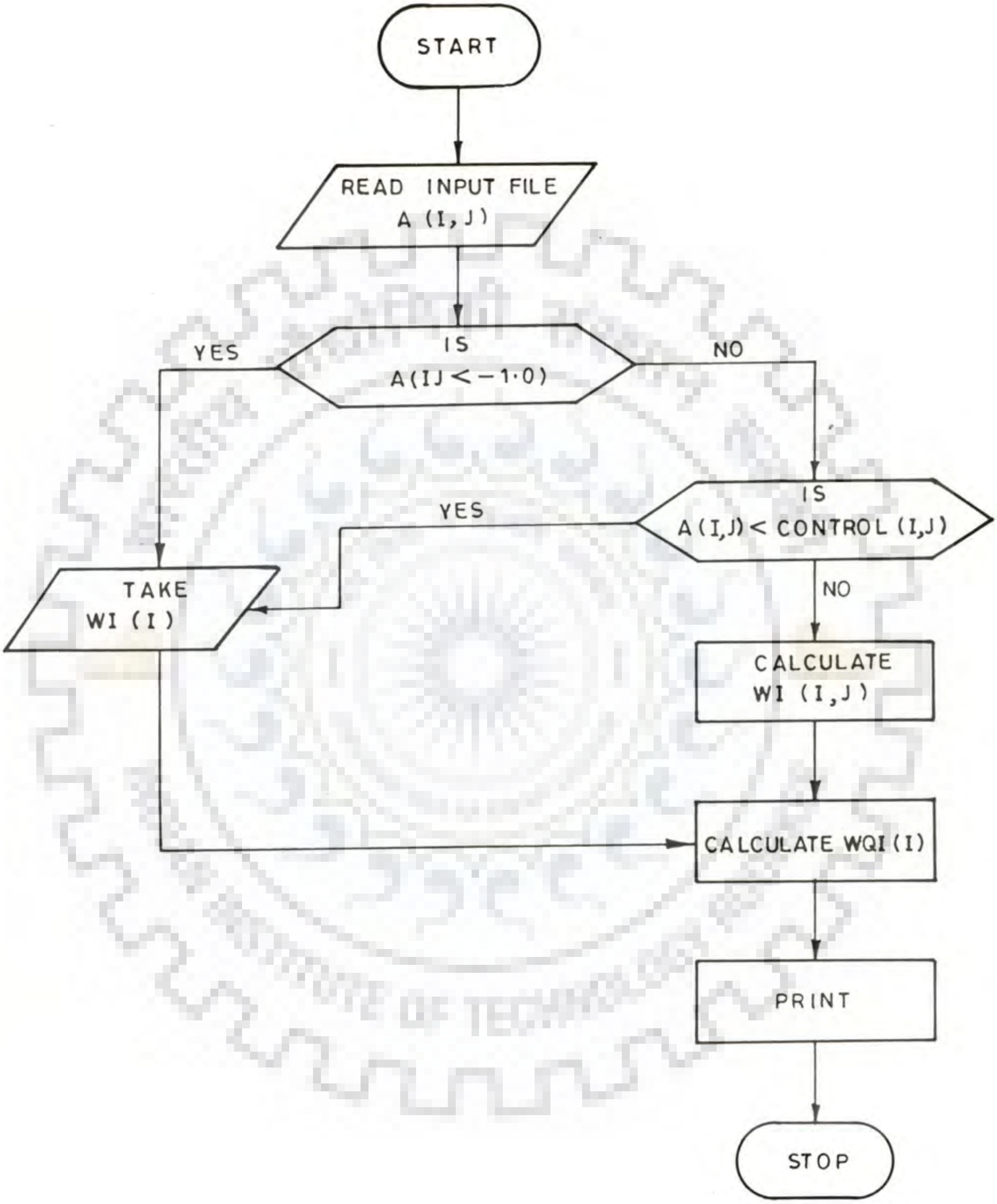


FIG. 6·3 – FLOW CHART FOR THE CALCULATION OF MC DUFFIE'S DUFFIE'S RIVER POLLUTION INDEX

TABLE 6.9 MATHEMATICAL FUNCTIONS FOR SUB-INDICES OF RIVER POLLUTION INDEX IN THE PRESENT STUDY

S.No.	PARAMETER	SUB-INDEX FUNCTION	
1.	p^H	$Qp^H(I) = p^H(I)\ [10/7]$	I=1,n
2.	Total dissolved solids	QTDS(I) = [TDS(I)	I=1,n
3.	Bicarbonates	QBicarb.= Bicarbonate(I)/2	I=1,n
4.	Carbonates	QCarb. = Carbonate(I) x 10	I=1,n
5.	Chlorides	Qchl. = Chloride(I) x 2	I=1,n
6.	Sulfates	Qsulf. = Sulfate(I)	I=1,n
7.	Calcium	QCal. = Calcium(I)	I=1,n
8.	Magnesium	QMagn. = Magnesium(I) x 5	I=1,n
9.	Sodium	QSod. = Sodium(I) x 5	I=1,n
10.	Cadmium	QCad. = Cadmium(I) x 10	I=1,n
11.	Manganese	QMang. = Manganese(I)/5	I=1,n
12.	Nickel	QNickel = Nickel(I) x 2	I=1,n
13.	Total anions	QTA = Total A (I) x 10	I=1,n
14.	Total cations	QTC = Total C (I) x 10	I=1,n

6.2.3 STATISTICAL APPROACHES:

Numerical approaches to calculate WQI, based on statistical analysis, have been suggested in the literature to evaluate and interprete the water quality data. The statistical approaches, by and large, have the advantage that they incorporate fewer subjective assumptions than the traditional indices, however, they are more complex and often difficult to apply. Recent literature enlightens the importance of these approaches in calculation of Water Quality Indices. Among these approaches, factor analysis was applied to the Yodo river system (Shoji et al, 1966) to examine the inter relationships among 20 variables. The principal component analysis was also applied for development of two Water Quality Indices by Schaeffer and Janardan (1977). In 1974, Harkin presented a methodology based on the rank order observations. A WQI for Chao Phraya river, Thailand was calculated by Lohani (1984) by using factor analysis. Box-Jenkins time series analysis in combination with non-parametric transforms were used by Lohani (1987) for monthly water quality data of Chung Kang river.

Among the statistical approaches, the method used by Harkin was considered in the present study.

6.2.3.1 Harkin's Index:

Harkin's approach was based on a distribution free statistical procedure for mapping p-measurements on an objective onto a line so that existing differences in location in p-space can be observed and more clearly defined. The only hindrance in this method was that the numbers generated in one evaluation cannot be directly compared with those generated by different run. In such cases, the two sets of raw data must be combined and a new evaluation of the total data set has to be made.

Procedures Followed to Calculate Harkin's Index for Ganga and Song Rivers:

The procedure adopted to calculate Harkin's index in the present study is summarized in the following steps.

(1) The parameter used in the calculation of mineral indices of present study were considered for the Harkin's index also, with the exception of p^H.

(2) For each parameter, a minimum point was chosen as a control value based on opinion poll.

(3) The values of ith water quality parameter observed in Ganga and Song rivers were arranged in an ascending order. These included values of tributaries Mandakini, Nandakini and Bhagirathi as well. The observations were ranked including the control value. The observations which were equal or lesser than the control were considered as tied ranks. Similarly, the repeated values of the observations were also considered as tied ranks. For each set of tied ranks the rank value was the average of the assigned ranks. The

number of ties and the number of values constituting a tie were accounted in the calculation of standard rank variance. The ranking procedure followed for manganese is presented in Table 6.10 as an example.

(4) The standard rank variance was computed for the ith parameter using the equation

$$S_i = \frac{1}{12\ n} \left[(n^2-n) - {}_{i=1}\Sigma^{q_i} (t^3-t)_k\right]^{\frac{1}{2}}$$

Here n = Number of values of ith parameter

t = Number of ties (repeated values)

q = Number of separate occurrence of ties

(5) For each parameter the transforms were calculated as

$$Z_{ij} = \frac{R_{ij}-R_{ic}}{S_i}$$

Here R_{ij} = Rank of jth observation of ith parameter

R_{ic} = Rank of control value of ith parameter

S_i = Standard rank variance of ith parameter

The transforms calculated for manganese in the present study was given in Table 6.11 as an example.

(6) Harkin's index value was computed by the equation

$$WQI_i = {}_{i=1}\Sigma^{n}\ Z_{ij}^2$$

TABLE 6.10 RANKING PROCEDURES OF MANGANESE

Value	Rank	Average Rank	Value	Rank	Average Rank	Value	Rank	Average Rank	Value	Rank	Average Rank
C 50	1	34	37	51	34	124	101		350	151	151.5
2	2	34	36	52	34	130	102	102.5	350	152	151.5
6	3	34	38	53	34	130	103	102.5	375	153	
6	4	34	39	54	34	131	104		400	154	156.5
7	5	34	39	55	34	132	105		400	155	156.5
7.5	6	34	40	56	34	135	106		400	156	156.5
7.5	7	34	40	57	34	138	107		400	157	156.5
8	8	34	42	58	34	140	108		400	158	156.5
8	9	34	43	59	34	145	109		400	159	156.5
8.5	10	34	44	60	34	150	110	110.5	405	160	160.5
8.5	11	34	45	61	34	150	111	110.5	405.5	161	160.5
8.5	12	34	45.5	62	34	157	112	112.5	410	162	
8.7	13	34	47	63	34	157	113	112.5	415.5	163	
9	14	34	48.5	64	34	168.5	114		417	164	
11	15	34	50	65	34	175	115		420	165	
11	16	34	50	66	34	175.5	116		441	166	
11	17	34	50	67	34	176	117		461	167	
11.5	18	34	52	68		200	118	121	465	168	
11.5	19	34	58	69		200	119	121	500	169	171
12	20	34	59	70		200	120	121	500	170	171
12.5	21	34	62.8	71		200	121	121	500	171	171
14	22	34	63	72	72.5	200	122	121	500	172	171
14	23	34	63	73	72.5	200	123	121	500.5	173	171
14.5	24	34	69	74	74.5	200	124	121	512	174	
15	25	34	69	65	74.5	210	125		520	175	
15	26	34	70	76	76.5	250	126	127	550	176	176.5
18	27	34	70	77	76.5	250	127	127	550.5	177	176.5
20	28	34	71	78		250	128	127	559	178	
20	29	34	73	79		259	129		600.5	179	
20	30	34	75	80	80.5	264	130		650	180	180.5
20	31	34	75	81	80.5	265	131		650	181	180.5
21	32	34	81	82		275	132	132.5	665.5	182	
21	33	34	87	83		275	133	132.5	675.5	183	
21.3	34	34	88	84		280	134				
22	35	34	91	85		289	135				
22.5	36	34	95	86		300	136	140			
23	37	34	96	87		300	137	140			
24	38	34	99	88		300	138	140			
24	39	34	100	89	90.5	300	139	140			
25	40	34	100	90	90.5	300	140	140			
25	41	34	100	91	90.5	300	140	140			
27.5	42	34	100.5	92	90.5	300	142	140			
28	43	34	102	93		300.5	143	140			
30	44	34	106	94		300.5	144	140			
30	45	34	107.2	95		310.8	145				
30	46	34	110	96		318	146				
30.5	47	34	114	97		325	147	147.5			
33	48	34	115	98		325	148	147.5			
34	49	34	118.5	99		332	149				
35	50	34	120	100		350	150				

Table 6.11 Transforms (Manganese)

m=183 52.3

Stations	Aug85	Oct85	Dec85	Feb8	Apr86	Aug86	Oct86	Dec86
SONG RIVER								
1.Sahashradhara (Baldi)	7.85	4.10	3.16	NA	NA	5.00	NA	NA
2.Sahashradhara (Sulfur spring)	8.11	7.07	4.10	NA	NA	5.18	NA	NA
3.Sahashradhara (Baldi A/C)	8.00	5.99	3.54	NA	NA	5.09	NA	NA
4.Maldevta U/S (Bandal)	5.50	6.08	NA	NA	NA	3.54	NA	NA
5.Maldevta U/S (Song A/C)	1.78	5.51	4.10	NA	NA	4.10	NA	NA
6.Maldevta D/S (Baldi)	7.85	5.51	NA	NA	NA	5.51	NA	NA
7.Raipur	6.27	5.00	4.50	NA	NA	1.71	NA	NA
8.Gularghati	7.69	4.71	4.10	NA	NA	1.90	NA	NA
9.Doiwala	6.81	4.10	3.16	0.00	0.00	0.00	0.00	0.00
10.Raiwala (Tawa)	1.17	1.78	2.50	0.00	0.00	0.00	2.14	1.17
11.Raiwala (Song A/C)	4.71	1.78	1.78	0.00	0.79	4.10	3.03	1.32
12.Sstyanarayana	4.10	2.30	1.78	0.00	0.66	3.65	1.78	1.17
....	.....	.....	.....	.....	.....	.....	.....	....
GANGA RIVER								
1.Nandaprayag (Alaknanda B/C)	NA	1.06	0.00	0.00	2.06	6.56	0.00	0.00
2.Nandaprayag (Nandakini)	NA	0.54	0.00	0.00	0.00	1.54	0.00	0.00
3.Nandaprayag (Alaknanda A/C)	NA	1.50	0.00	0.00	0.00	6.18	0.00	0.00
4.Rudraprayag (Alaknanda B/C)	NA	0.60	0.00	0.00	0.44	3.37	0.00	0.00
5.Rudraprayag (Mandakini)	NA	1.50	0.00	0.00	0.00	2.34	0.00	0.00
6.Srinagar	NA	0.74	0.00	0.00	0.00	4.83	0.00	0.00
7.Devprayag (Alaknanda B/C)	NA	1.79	0.00	0.00	0.00	7.16	0.00	0.00
8.Devprayag (Bhagirathi)	NA	0.00	0.00	0.00	0.00	1.36	0.00	0.00
9.Devprayag (Alaknanda A/C)	NA	2.25	0.00	0.00	0.00	0.00	0.00	0.00
10.Rishikesh	NA	1.71	0.00	0.00	1.45	6.37	0.00	0.00
11.Satyanarayana	3.44	0.00	1.27	0.00	0.71	3.16	NA	0.00
12.Balawali	NA	1.03	0.00	1.64	0.84	4.58	0.91	0.00
13.Bijnor	NA	1.31	2.00	0.00	0.95	1.95	3.23	0.88
14.Garhmukteshwar	NA	1.59	0.99	0.66	0.47	6.50	0.00	0.00
15.Anupshahar	NA	1.78	0.79	2.14	0.42	5.80	0.00	0.00
16.Rajghat	NA	2.52	0.00	0.00	2.00	7.58	0.00	NA

6.3 COMPARISON OF THE MINERAL INDICES CALCULATED AND THE TREND IN THE STUDY AREA

To get more insight into the mineral transport in the Upper Ganga Basin and to visualize the contribution of heavy metals in the index value, the indices were calculated separately by including and excluding heavy metals.

6.3.1 TREND OF MINERAL INDICES IN GANGA RIVER:

Perusal of Table 6.12 to 6.14 illustrates the calculated indices without heavy metals in Ganga river of the study area. And Table 6.15 to 6.17 contain the index values observed with heavy metal included in the calculation. The Fig. 6.4 to Fig. 6.6 illustrates the seasonal variations in the index values observed in Ganga river during the study period from Dec. 1984 to Dec. 1986. the observed index values and the figures clearly project the similarity in trends for the three indices calculated and a significant increase at Satyanarayana. The extent of the increase or decrease observed was not similar, which is due to the difference in formulations. In Horton's index the rating scale was fixed between 100-400. In case the observed value was lower than the fixed minimum value, the rating value was 100, and if the observed value was more than the maximum value, the rating value was 400. Whereas in the Mc Duffie's index the actual value was taken to calculate the index and the values were high. On the otherhand, Harkin's index was calculated on the basis of

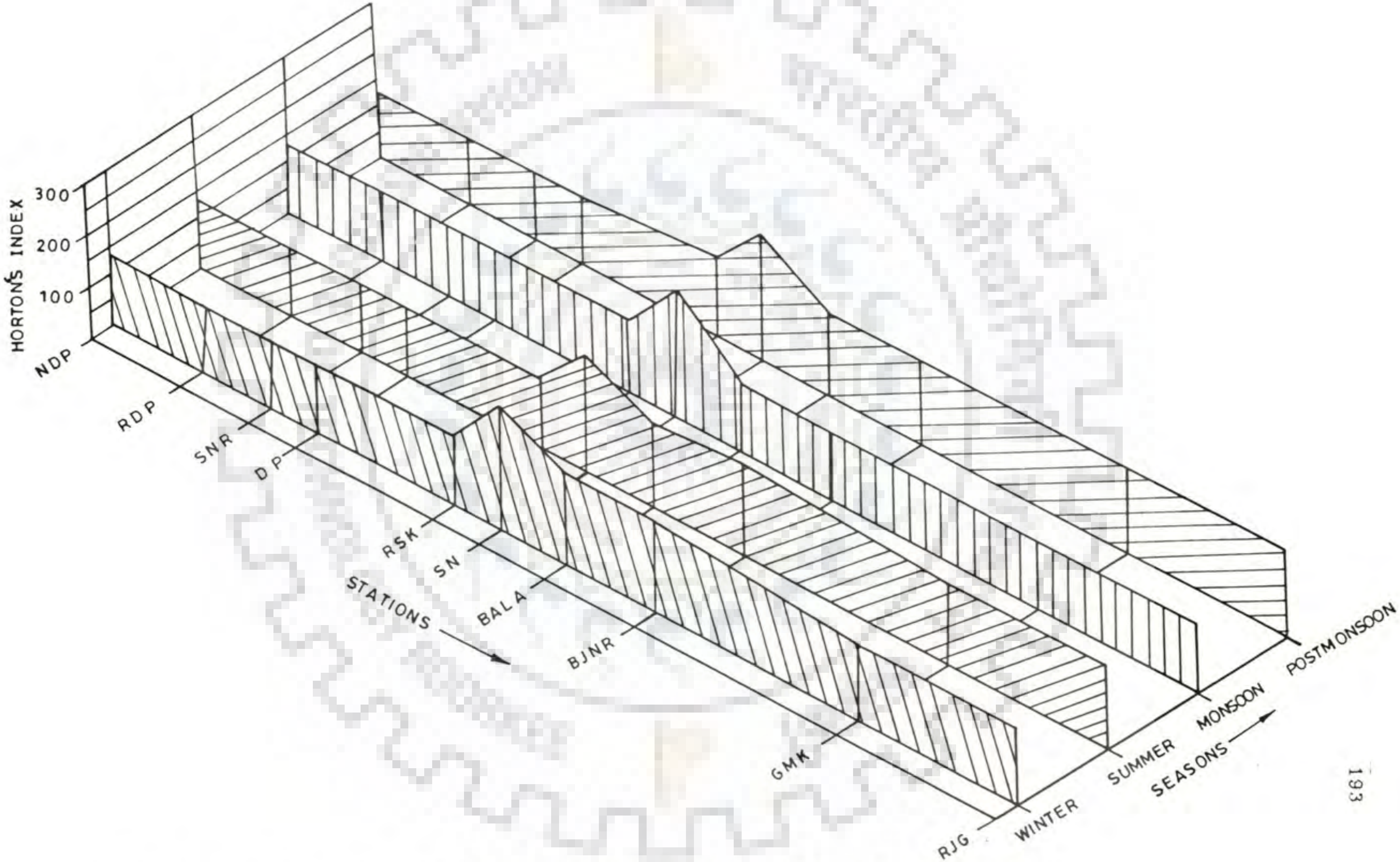


FIG. 6·4— VARIATIONS IN MEAN HORTON'S INDEX VALUES IN GANGA RIVER

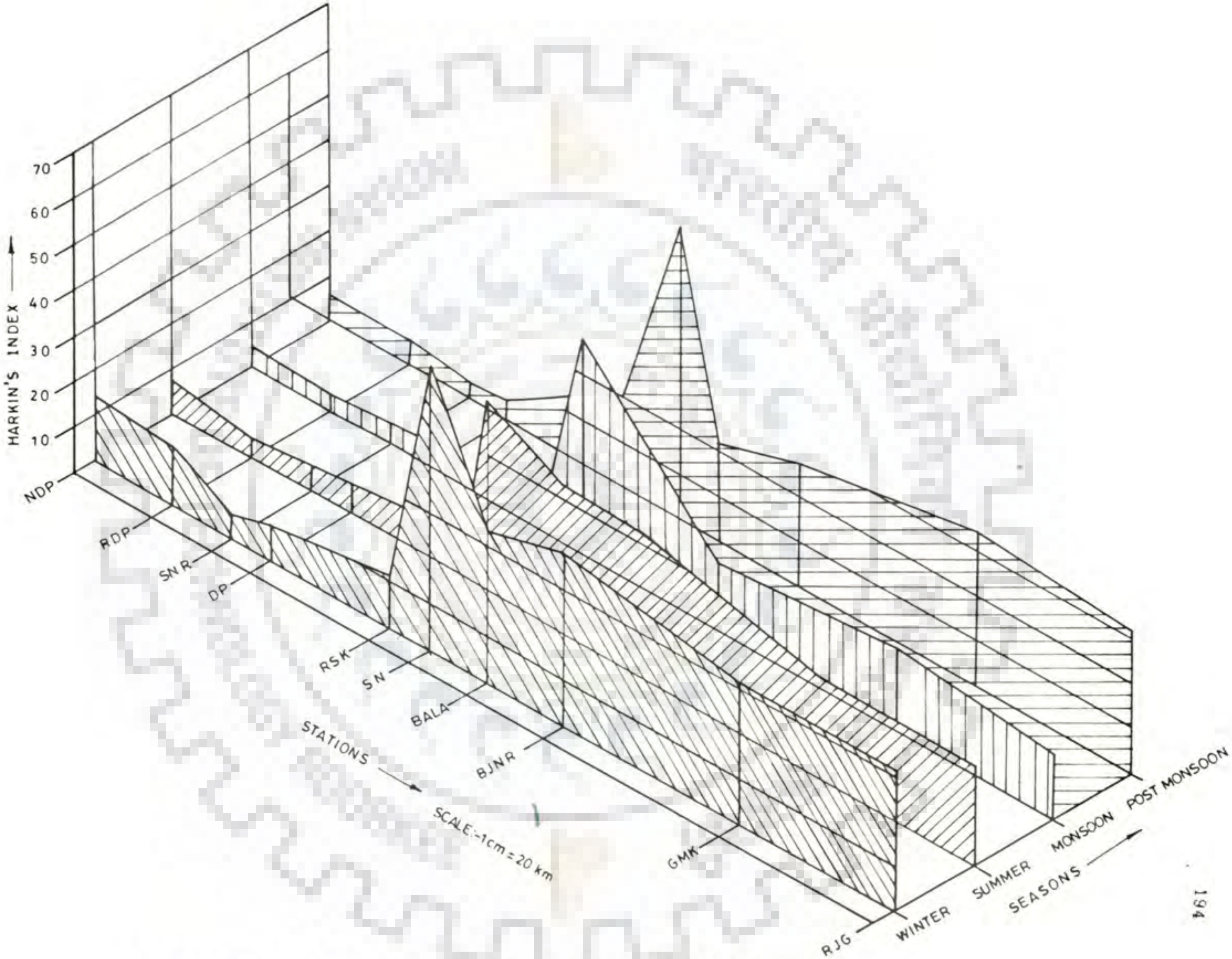


FIG. 6·5—VARIATION IN HARKIN'S INDEX VALUES IN GANGA RIVER

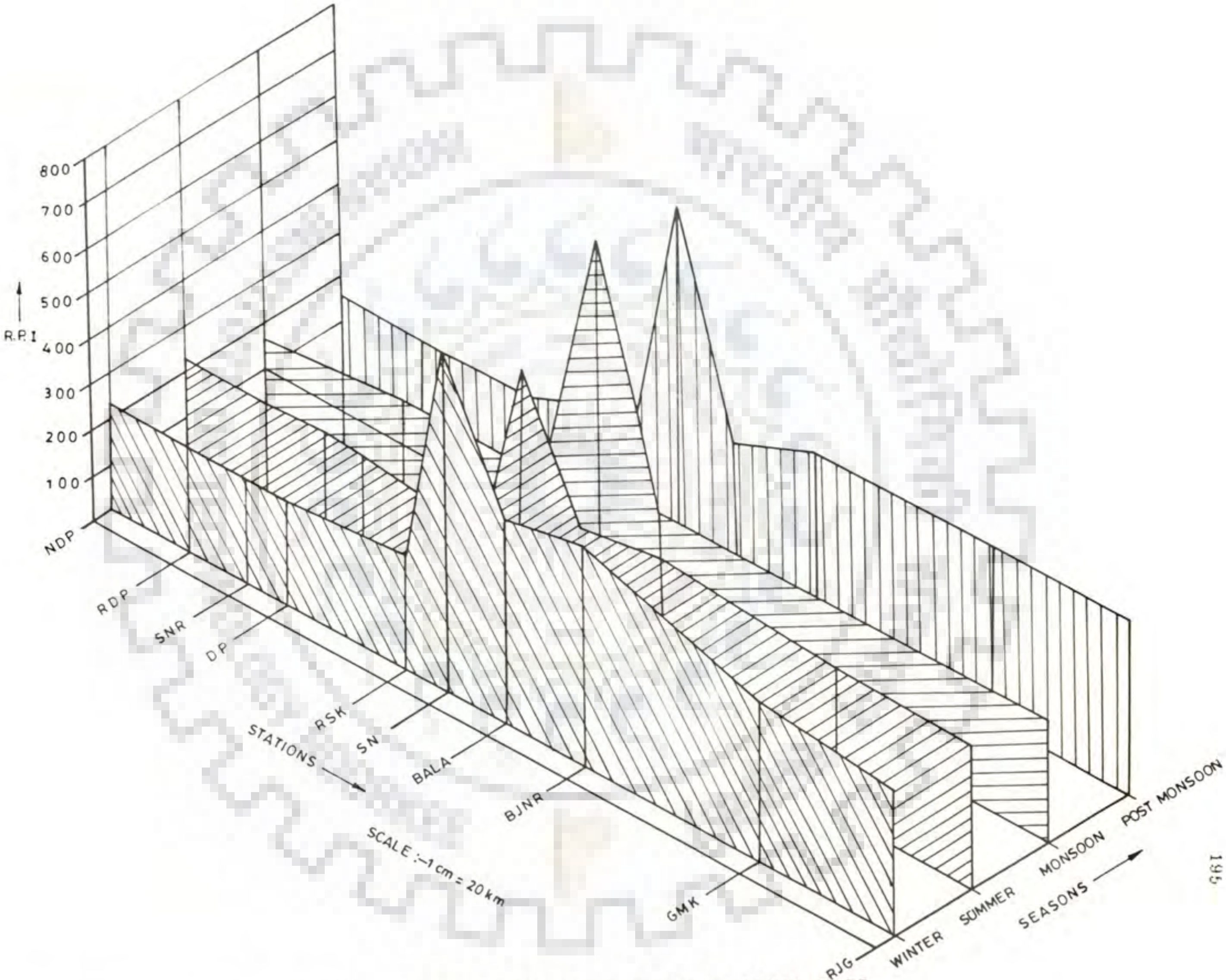


FIG. 6·6–VARIATION IN MEAN RIVER POLLUTION INDEX VALUES IN GANGA RIVER

TABLE 6.12 HORTON'S INDEX VALUE (without heavy metals) OBSERVED IN GANGA RIVER DURING THE PERIOD Dec. 1984 to July 1985

STATIONS	DEC. 84	JAN. 85	FEB. 85	MARCH 85	APR. 85	MAY 85	JULY 85
1. NANDPRAYAG B/C	127.2	*	129.6	140.5	123.0	138.1	NA
2. NANDPRAYAG Nandakini	132.0	133.5	136.6	127.3	133.9	129.3	NA
3. NANDPRAYAG A/C	124.1	126.1	133.8	134.1	126.6	132.7	NA
4. RUDRAPRAYAG B/C	123.2	130.6	127.1	128.3	127.9	128.1	NA
5. RUDRAPRAYAG Mandakini	110.8	117.0	121.5	121.8	121.7	112.1	NA
6. SRINAGAR	133.2	127.5	136.5	140.7	132.6	129.3	NA
7. DEVPRAYAG B/C	144.0	135.2	140.5	131.7	118.1	137.8	NA
8. DEVPRAYAG Bhagirathi	129.4	127.1	124.0	136.2	123.7	137.7	NA
9. DEVPRAYAG A/C	134.4	128.4	134.8	133.9	113.9	139.9	NA
10. RISHIKESH	128.8	130.1	136.1	128.9	131.4	131.3	128.1
11. SATYANARAYANA	236.9	239.9	242.4	266.4	173.4	195.4	221.8
12. BALAWALI	185.1	187.3	181.2	176.6	153.4	142.1	NA
13. BIJNOR	180.6	183.3	182.1	180.2	174.3	150.7	NA
14. GARHMUKTESHWAR	146.8	148.7	151.7	147.5	155.8	144.6	133.3
15. ANUPSHAHR	143.3	151.4	147.6	153.5	160.3	142.5	125.9
16. RAJGHAT NARORA	145.1	146.8	149.9	153.6	153.1	141.1	129.3

(CONTINUED)

TABLE 6.12 CONTINUED

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 96	AUG. 86	OCT. 86	DEC. 86
1.NANDPRAYAG B/C	NA	114.1	142.9	132.3	129.4	112.2	133.5	139.0
2.NANDPRAYAG Nandakini	NA	120.8	143.7	130.4	136.8	125.9	133.2	144.0
3.NANDPRAYAG A/C	NA	147.3	140.3	136.0	136.5	150.3	134.9	139.2
4.RUDRAPRAYAG B/C	NA	116.3	146.6	131.2	132.1	127.6	123.3	139.4
5.RUDRAPRAYAG Mandakini	NA	125.1	134.2	124.8	123.7	117.0	123.4	126.9
6.SRINAGAR	NA	116.4	135.1	137.1	136.0	126.6	130.9	130.1
7.DEVPRAYAG B/C	NA	122.2	140.6	131.5	134.2	124.8	129.0	136.8
8.DEVPRAYAG Bhagirathi	NA	125.0	131.9	132.1	131.1	122.5	135.7	137.2
9.DEVPRAYAG A/C	NA	123.4	127.9	130.7	136.3	126.8	133.8	136.9
10.RISHIKESH	136.3	151.8	141.6	135.8	136.8	122.0	134.2	138.0
11.SATYANARAYANA	182.4	240.4	213.4	194.9	231.3	291.2	231.4	222.0
12.BALAWALI	138.5	150.0	175.5	183.2	157.5	128.0	165.1	176.4
13.BIJNOR	137.2	150.0	165.9	189.5	166.2	126.1	177.5	201.5
14.GARHMUKTESHWAR	142.7	148.3	162.9	170.1	157.8	128.5	182.9	159.0
15.ANUPSHAHR	138.3	139.0	157.3	153.0	162.0	127.2	180.6	189.9
16.RAJGHAT NARORA	136.3	143.1	163.3	157.7	159.2	132.6	183.9	164.2

B/C = Before confluence
A/C = After confluence
NA = Analysis wasn't done

TABLE 6.13 R.P.I. VALUE (without heavy metals) OBSERVED IN GANGA RIVER DURING THE PERIOD (Dec. 1984 to July 1985)

STATIONS	DEC. 84	JAN. 85	FEB. 85	MARCH 85	APR. 85	MAY 85	JULY 85
1. NANDPRAYAG B/C	294.2	*	213.9	236.2	156.7	213.2	NA
2. NANDPRAYAG Nandakini	223.4	250.8	255.8	244.5	237.7	198.0	NA
3. NANDPRAYAG A/C	180.2	219.0	256.8	222.9	204.7	215.6	NA
4. RUDRAPRAYAG B/C	174.8	255.6	221.5	206.5	215.6	228.8	NA
5. RUDRAPRAYAG Mandakini	126.4	177.0	224.0	151.8	152.4	148.8	NA
6. SRINAGAR	205.5	217.6	269.3	265.1	210.4	219.7	NA
7. DEVPRAYAG B/C	271.1	256.2	291.0	208.7	209.5	238.8	NA
8. DEVPRAYAG Bhagirathi	196.3	236.4	236.4	226.7	208.8	227.0	NA
9. DEVPRAYAG A/C	238.1	232.5	266.1	252.3	195.0	235.5	NA
10. RISHIKESH	256.3	244.3	304.3	216.0	216.4	172.2	183.0
11. SATYANARAYANA	750.6	735.8	893.7	836.4	453.2	529.9	713.1
12. BALAWALI	504.5	470.2	427.8	290.1	334.5	260.8	NA
13. BIJNOR	491.8	460.4	450.2	372.1	411.6	291.4	NA
14. GARHMUKTESHWAR	351.9	303.6	324.8	334.3	363.2	295.0	242.6
15. ANUPSHAHR	369.8	313.9	313.4	344.6	460.2	253.2	246.1
16. RAJGHAT NARORA	322.2	285.9	324.6	322.7	386.8	252.9	243.9

(CONTINUED)

(TABEL 6.13 CONTINUED)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 96	AUG. 86	OCT. 86	DEC. 86
1.NANDPRAYAG B/C	NA	99.0	261.8	214.3	189.9	161.9	191.6	239.6
2.NANDPRAYAG Nandakini	NA	127.8	225.8	200.7	227.9	179.5	183.0	237.2
3.NANDPRAYAG A/C	NA	102.9	222.4	231.9	266.4	166.9	191.7	260.0
4.RUDRAPRAYAG B/C	NA	84.8	194,5	199.9	216.1	183.1	200.2	238.2
5.RUDRAPRAYAG Mandakini	NA	171.0	262.7	149.1	178.0	123.1	142.8	154.1
6.SRINAGAR	NA	112.3	235.3	229.4	212.6	176.6	188.0	178.9
7.DEVPRAYAG B/C	NA	114.1	226.3	202.6	202.2	179.0	186.1	216.3
8.DEVPRAYAG Bhagirathi	NA	129.8	216.2	197.6	194.1	178.0	204.4	215.1
9.DEVPRAYAG A/C	NA	118.2	201.9	201.5	222.9	170.9	199.1	231.5
10.RISHIKESH	232.3	282.7	231.4	222.5	223.1	169.5	206.2	245.3
11.SATYANARAYANA	579.0	755.0	649.5	730.9	630.8	1062.1	780.0	693.5
12.BALAWALI	285.6	259.0	359.0	421.4	311.7	229.6	366.8	424.8
13.BIJNOR	299.5	265.7	397.9	519.6	345.2	232.9	492.2	543.8
14.GARHMUKTESHWAR	327.3	305.7	383.6	386.7	304.6	220.4	472.9	329.4
15.ANUPSHAHR	329.1	265.2	333.1	313.3	317.1	220.4	471.4	345.4
16.RAJGHAT NARORA	306.1	300.7	336.5	292.3	306.4	244.7	478.8	359.0

NA = Sampling was not done
B/C = Before confluence
A/C = After confluence

TABLE 6.14 HARKIN'S INDEX VALUE (without heavy metals) OBSERVED IN GANGA RIVER DURING THE PERIOD (Aug. 1985 to Dec. 1986)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 96	AUG. 86	OCT. 86	DEC. 86
1.NANDPRAYAG B/C	NA	0.22	15.2	8.0	2.5	3.0	5.5	12.7
2.NANDPRAYAG Nandakini	NA	1.73	20.6	4.9	7.8	5.3	8.5	12.3
3.NANDPRAYAG A/C	NA	0.23	15.9	12.3	7.0	4.5	7.3	13.9
4.RUDRAPRAYAG B/C	NA	2.01	18.9	5.4	3.8	3.0	7.3	14.4
5.RUDRAPRAYAG Mandakini	NA	2.10	6.8	0.7	2.3	0.6	0.2	1.0
6.SRINAGAR	NA	2.40	9.6	7.6	5.5	5.0	4.2	1.8
7.DEVPRAYAG B/C	NA	0.94	14.5	6.7	4.0	6.8	3.6	7.3
8.DEVPRAYAG Bhagirathi	NA	0.83	5.8	5.8	4.4	4.5	10.7	10.2
9.DEVPRAYAG A/C	NA	1.00	9.9	4.1	6.3	5.6	7.3	10.9
10.RISHIKESH	8.65	27.90	15.2	7.0	8.9	3.7	12.2	12.3
11.SATYANARAYANA	34.80	53.10	58.0	68.5	47.0	59.1	67.3	62.6
12.BALAWALI	14.00	16.40	35.6	31.6	33.6	19.2	26.6	40.8
13.BIJNOR	13.70	20.50	34.4	35.3	32.5	17.6	35.1	41.6
14.GARHMUKTESHWAR	24.20	24.40	32.7	30.9	22.9	13.8	44.0	30.0
15.ANUPSHAHR	15.50	18.60	24.0	23.2	23.5	9.2	42.3	33.4
16.RAJGHAT NARORA	15.50	20.90	30.9	26.7	21.3	15.5	43.4	35.4

NA = Sampling was not done
B/C = Before confluence
A/C = After confluence

TABLE 6.15 HORTON'S INDEX VALUE (including heavy metals)

OBSERVED IN GANGA RIVER (during the period Aug.85 to Dec.86)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 86	AUG. 86	OCT. 86	DEC. 86
1. NANDPRAYAG (B/C)	NA	152.9	142.6	129.8	155.1	137.1	137.6	134.7
2. NANDPRAYAG Nandakini	NA	135.8	128.1	122.0	132.4	147.8	140.7	138.3
3. NANDPRAYAG (A/C)	NA	147.3	140.3	136.0	136.6	150.3	140.5	130.2
4. RUDRAPRAYAG (B/C)	NA	132.2	143.8	134.2	131.2	150.3	129.8	132.1
5. RUDRAPRAYAG Mandakini	NA	134.4	132.8	139.8	121.9	138.8	123.7	135.3
6. SRINAGAR	NA	130.4	133.4	142.1	129.0	164.7	137.3	123.1
7. DEVPRAYAG (B/C)	NA	154.9	148.5	138.2	124.4	150.3	142.2	127.3
8. DEVPRAYAG Bhagirathi	NA	131.9	129.9	143.0	130.4	151.5	130.8	131.3
9. DEVPRAYAG (B/C)	NA	154.2	137.8	129.8	145.6	158.6	141.0	152.3
10. RISHIKESH	136.3	182.1	138.2	137.6	152.8	144.4	132.0	159.6
11. SATYANARAYANA	196.8	231.5	234.6	217.9	221.9	296.0	200.3	194.9
12. BALAWALI	133.8	189.2	162.5	199.1	172.3	152.5	214.6	156.8
13. BIJNOR	132.7	172.7	176.2	180.9	175.4	148.8	180.9	200.2
14. GARHMUKTESHWAR	137.1	159.0	172.3	182.2	165.0	161.3	167.4	149.4
15. ANUPSHAHR	133.7	164.2	163.2	170.0	151.8	151.3	169.8	168.4
16. RAJGHAT NARORA	131.9	191.2	159.6	158.5	172.8	169.7	181.1	156.4

B/C : Before confluence
A/C : After conflucne
NA : Analysis was not done

TABLE 6.16 R.P.I. VALUE (with metals) IN GANGA RIVER DURING THE PERIOD 1985 to Dec. 1986)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 96	AUG. 86	OCT. 86	DEC. 86
1. NANDPRAYAG B/C	NA	215.1	282.8	229.7	281.6	251.5	219.7	261.9
2. NANDPRAYAG Nandakini	NA	252.8	308.9	157.6	219.0	215.2	306.0	314.6
3. NANDPRAYAG A/C	NA	197.7	282.5	282.5	267.5	215.8	219.6	228.9
4. RUDRAPRAYAG B/C	NA	155.7	318.2	285.3	213.4	261.7	200.6	244.7
5. RUDRAPRAYAG Mandakini	NA	211.8	284.6	360.8	182.6	160.9	164.2	224.3
6. SRINAGAR	NA	154.3	243.4	304.7	203.8	421.9	300.5	158.9
7. DEVPRAYAG B/C	NA	206.1	337.6	269.4	216.6	311.5	339.1	189.2
8. DEVPRAYAG Bhagirathi	NA	195.9	214.0	288.8	216.9	240.1	219.7	219.8
9. DEVPRAYAG A/C	NA	204.8	291.2	263.2	354.6	357.1	379.8	222.2
10. RISHIKESH	232.8	415.5	249.7	269.1	319.9	455.2	303.9	268.2
11. SATYANARAYANA	541.3	852.4	611.9	660.0	642.8	1022.9	705.8	589.6
12. BALAWALI	271.3	546.6	340.1	451.0	422.9	283.8	680.5	354.1
13. BIJNOR	284.2	341.4	365.0	529.1	356.3	291.3	441.7	536.6
14. GARHMUKTESHWAR	309.8	380.5	372.9	449.4	446.2	371.1	443.3	336.6
15. ANUPSHAHR	312.0	317.4	341.8	334.2	300.6	323.6	496.0	349.0
16. RAJGHAT NARORA	290.3	577.4	375.4	351.4	327.4	475.0	795.1	339.0

B/C = Before confluence
A/C = After confluence
NA = Analysis wasn't done

TABLE 6.17 HARKIN'S INDEX VALUE (with metals) OBSERVED IN GANGA RIVER DURING THE PERIOD (Aug. 1985 to Dec. 1986)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 96	AUG. 86	OCT. 86	DEC. 86
1.NANDPRAYAG B/C	NA	7.9	20.5	9.4	7.9	11.0	9.7	14.7
2.NANDPRAYAG Nandakini	NA	8.1	25.2	5.4	9.5	8.6	14.3	17.4
3.NANDPRAYAG A/C	NA	8.0	19.7	15.4	8.1	13.1	13.0	14.1
4.RUDRAPRAYAG B/C	NA	7.9	21.9	11.5	4.9	8.8	8.9	13.8
5.RUDRAPRAYAG Mandakini	NA	7.9	8.9	9.0	3.8	3.7	2.8	7.1
6.SRINAGAR	NA	6.3	12.5	14.5	5.9	15.2	8.5	2.0
7.DEVPRAYAG B/C	NA	8.9	21.8	12.5	7.3	17.18	11.0	11.2
8.DEVPRAYAG Bhagirathi	NA	6.4	6.8	13.0	6.8	10.5	11.9	10.6
9.DEVPRAYAG A/C	NA	8.9	16.8	9.0	12.5	11.5	13.7	11.0
10.RISHIKESH	8.6	34.2	17.5	10.7	10.9	11.5	12.6	15.8
11.SATYANARAYANA	38.2	61.4	61.6	71.7	53.0	66.9	68.3	63.1
12.BALAWALI	20.0	22.4	42.1	38.8	39.2	27.3	33.7	40.8
13.BIJNOR	14.0	26.4	40.4	37.7	35.2	22.2	38.4	45.3
14.GARHMUKTESHWAR	13.7	36.7	34.4	38.5	28.4	27.3	45.9	31.9
15.ANUPSHAHR	24.2	25.7	28.5	27.6	24.6	17.8	45.7	35.3
16.RAJGHAT NARORA	15.5	34.7	38.3	32.9	30.7	31.3	49.7	35.4

B/C = Before Confluence
A/C = After Confluence
NA = Sampling was not done

non-parametric transformations. Due to these existing differences in formulations the indices, as expected showed difference in ranges, though the trends are similar.

In general, the index values (Fig. 6.4 to Fig. 6.6) were more or less constant in upper reaches, whereas in the lower reaches the impact of Song river was clearly visible, which is supported by the trends of the mineral parameters as discussed in earlier chapters. The Winter and post-monsoon months, in general, carry more mineral load in Ganga river as compared to summer and monsoon months.

The difference in index values in Ganga river, with and without heavy metals, are presented in Table 6.18. The similarity in trend and the significance of heavy metal contribution in the index value is evident in Fig. 6.7, in which the spatial variations of mean index values are illustrated.

6.3.2 TREND OF MINERAL INDICES IN SONG RIVER:

The index values observed in Song river, with and without heavy metals, are presented in Table 6.19 to 6.24. The trend of the these indices was similar with difference in magnitude due to the differences in formulations. From the profiles, Fig. 6.8 to Fig. 6.10, it is visible that the mineral quality of Song river is maintained throughout the year. However, the important points where the increase in mineral input was observed were Raipur and Satyanarayana. At the former location Baldi river meets Song and

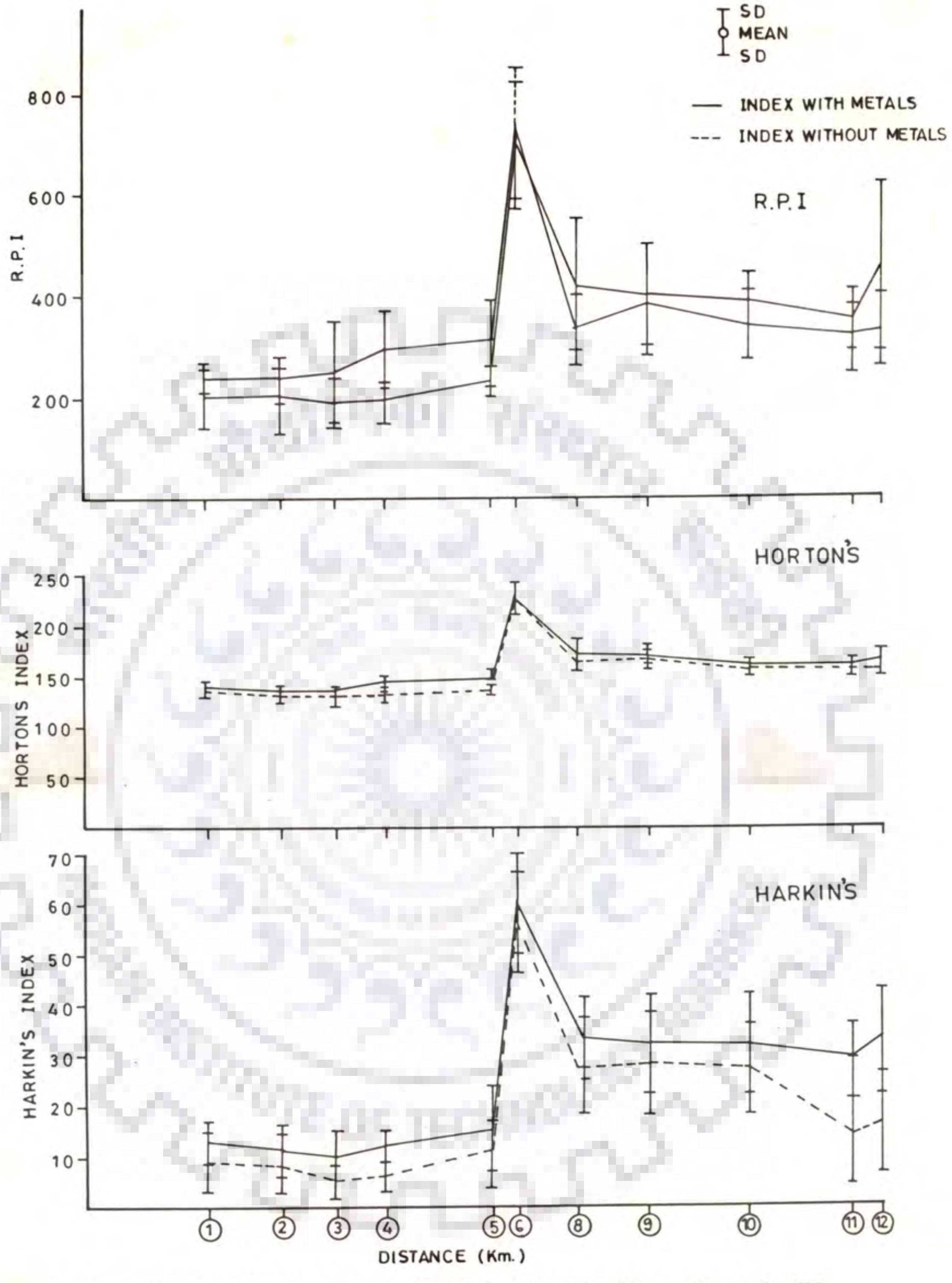
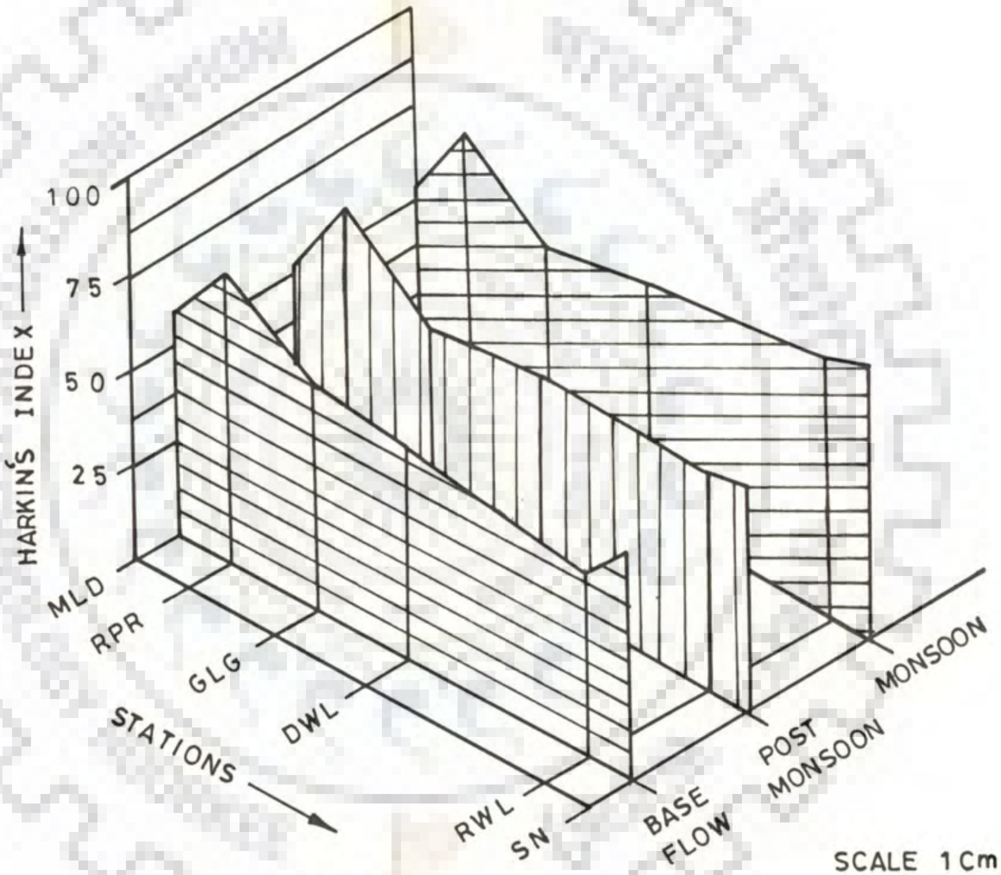
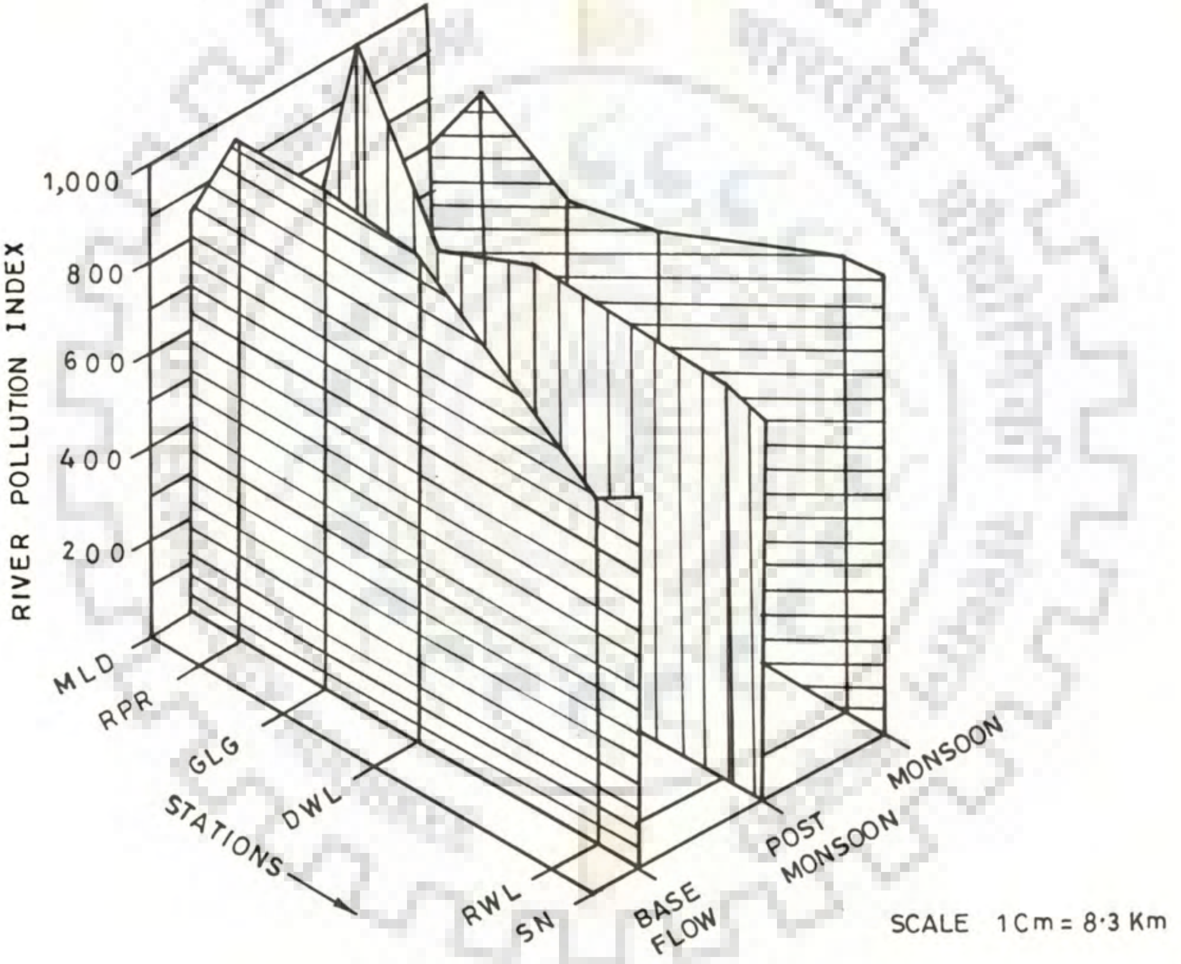


FIG. 6·7—VARIATIONS IN MEAN INDEX VALUES IN GANGA RIVER



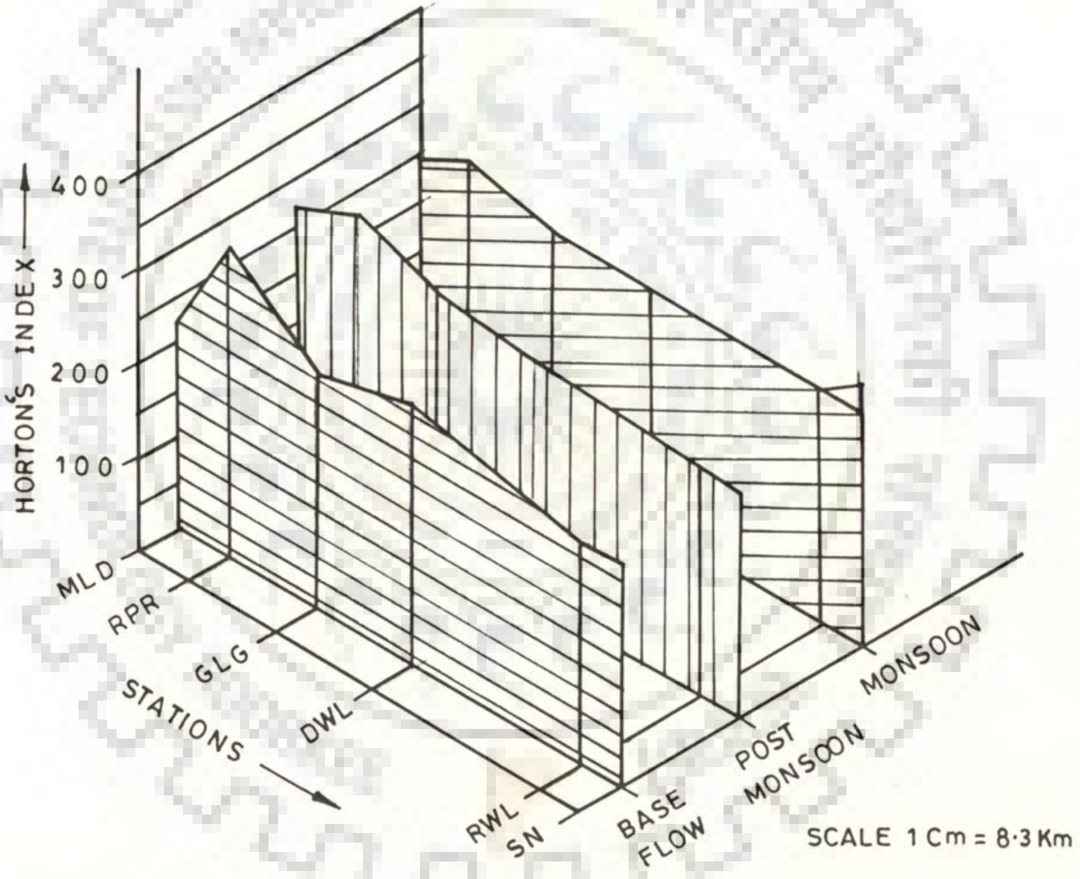
SCALE 1 Cm = 8·3 Km

FIG. 6·8—VARIATION IN HARKIN'S INDEX VALUES IN SONG RIVER



SCALE 1Cm = 8·3 Km

FIG. 6·9—VARIATION IN RIVER POLLUTION INDEX VALUES IN SONG RIVER



SCALE 1 Cm = 8·3 Km

FIG. 6·10–VARIATIONS IN MEAN HORTON'S INDEX VALUES IN SONG RIVER

TABLE 6.18 COMPARISON OF THE CALCULATED MINERAL INDICES IN GANGA RIVER

(July 1985 to December 1986)

STATIONS	HARKIN'S				HORTON'S				RIVER POLLUTION INDEX			
	With Metals		With Out Metals		With Metals		With Out Metals		With Metals		With Out Metals	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
1.NANDPRAYAG B/C	11.6	4.5	6.7	5.5	141.8	10.1	129.1	11.7	248.9	28.2	194.0	53.5
2.NANDPRAYAG Nandakini	12.6	8.9	8.7	6.2	135.0	8.5	133.5	8.7	253.7	59.7	197.4	38.1
3.NANDPRAYAG A/C	13.1	4.1	8.7	5.6	140.1	6.9	140.7	5.9	242.1	34.8	206.0	57.5
4.RUDRAPRAYAG B/C	11.0	5.5	7.8	6.4	136.4	7.6	130.9	10.0	239.9	54.8	202.4	63.4
5.RUDRAPRAYAG Mandakini	6.1	2.6	1.9	2.3	132.4	6.9	125.0	5.1	227.0	72.7	168.7	45.2
6.SRINAGAR	9.3	4.9	5.1	2.7	137.1	13.6	130.3	7.2	255.4	95.3	190.4	41.7
7.DEVPRAYAG B/C	11.4	6.7	6.4	4.2	140.8	11.6	131.3	6.5	267.0	63.8	189.5	36.9
8.DEVPRAYAG Bhagirathi	9.4	2.7	6.0	3.4	131.5	5.4	130.8	5.3	227.9	29.8	190.7	29.9
9.DEVPRAYAG A/C	11.9	2.7	6.4	3.4	146.2	10.7	130.8	5.1	296.1	69.6	192.3	37.9
10.RISHIKESH	15.2	8.2	12.0	7.3	147.8	16.6	137.0	8.2	314.3	80.4	226.6	32.2
11.SATYANARAYANA	60.5	10.6	56.3	11.2	224.2	32.8	225.9	32.9	707.1	163.5	735.1	148.1
12.BALAWALI	33.2	8.5	27.2	9.8	172.6	26.7	159.6	19.7	418.8	139.5	331.8	73.3
13.BIJNOR	32.5	10.6	28.8	10.1	170.9	20.9	164.2	25.6	392.9	98.5	387.1	120.2
14.GARHMUKTESHWAR	32.1	9.5	27.9	8.8	161.7	13.8	156.5	16.8	388.7	52.8	341.4	74.4
15.ANUPSHAHR	28.7	8.4	23.7	10.3	159.0	12.7	155.9	21.5	354.3	59.5	324.4	72.3
16.RAJGHAT NARORA	33.6	9.5	26.2	9.9	165.1	18.0	155.0	16.9	478.9	165.4	331.8	70.7

TABLE 6.19 HORTON'S INDEX VALUES (without heavy metals) OBSERVED IN SONG RIVER (During the period July 85 to Dec.86)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 86	AUG. 86	OCT. 86	DEC. 86
1.SAHASHRADHARA Baldi B/C	261.5	273.7	342.8	NA	NA	341.4	NA	NA
2.SAHASHRADHARA Sulfur Spring	364.1	360.2	360.9	NA	NA	360.3	NA	NA
3.SAHASHRADHARA Baldi A/C	334.4	356.9	364.7	NA	NA	315.4	NA	NA
4.MALDEVYA Bandal	252.4	276.9	NA	NA	NA	253.8	NA	NA
5.MALDEVTA Song	256.3	225.4	260.4	NA	NA	251.0	NA	NA
6.MALDEVTA Baldi	333.4	343.5	NA	NA	NA	297.9	NA	NA
7.RAIPUR	268.0	285.1	282.1	NA	NA	268.4	NA	NA
8.GULARGHATI	251.6	257.9	262.1	NA	NA	251.8	NA	NA
9.DOIWALA	260.1	257.9	223.7	261.8	213.6	260.7	258.4	272.1
10.RAIWALA Tawa	256.4	298.1	233.1	236.6	224.9	248.0	212.3	201.6
11.RAIWALA Song	277.2	232.6	218.6	237.9	224.3	284.5	252.1	247.5
12.SATYANARAYANA	298.7	233.0	235.2	235.4	250.5	309.1	250.1	256.1

B/C = Before Confluence

A/C = After Confluence

N.A. = Analysis wasn't done

TABLE 6.20 RIVER POLLUTION INDEX VALUES (without heavy metals) OBSERVED IN SONG RIVER (During the period July 85 to Dec.86)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 86	AUG. 86	OCT. 86	DEC. 86
1.SAHASHRADHARA Baldi B/C	916.2	865.7	1456.6	NA	NA	1238.9	NA	NA
2.SAHASHRADHARA Sulfur Spring	7693.3	8523.5	8849.7	NA	NA	7021.5	NA	NA
3.SAHASHRADHARA Baldi A/C	1294.3	1676.5	2343.3	NA	NA	1307.6	NA	NA
4.MALDEVYA Bandal	768.9	947.4	NA	NA	NA	749.5	NA	NA
5.MALDEVTA Song	741.3	624.0	834.5	NA	NA	761.8	NA	NA
6.MALDEVTA Baldi	1232.0	1487.6	NA	NA	NA	1211.9	NA	NA
7.RAIPUR	821.2	1044.9	975.9	NA	NA	913.6	NA	NA
8.GULARGHATI	934.9	789.6	778.4	NA	NA	771.6	NA	NA
9.DOIWALA	822.1	826.1	687.8	607.4	721.9	837.8	818.4	900.1
10.RAIWALA Tawa	837.5	629.7	602.7	700.6	582.0	827.4	620.8	595.2
11.RAIWALA Song	933.4	747.2	556.4	630.6	584.4	952.5	763.9	748.4
12.SATYANARAYANA	1011.2	696.1	680.8	662.8	740.0	1095.7	743.9	754.7

B.C. = Before Confluence

A.C. = After Confluence

N.A. = Analysis wasn't done

TABLE 6.21 HARKIN'S INDEX VALUES (without heavy metals)

OBSERVED IN SONG RIVER (During the period July 85 to Dec.86)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 86	AUG. 86	OCT. 86	DEC. 86
1. SAHASHRADHARA Baldi B/C	62.8	73.0	76.7	NA	NA	72.6	NA	NA
2. SAHASHRADHARA Sulfur Spring	85.8	85.8	88.7	NA	NA	81.5	NA	NA
3. SAHASHRADHARA Baldi A/C	73.2	88.1	86.9	NA	NA	75.1	NA	NA
4. MALDEVYA Bandal	61.3	55.8	NA	NA	NA	60.5	NA	NA
5. MALDEVTA Song	53.8	44.1	57.8	NA	NA	51.9	NA	NA
6. MALDEVTA Baldi	73.1	78.0	NA	NA	NA	72.7	NA	NA
7. RAIPUR	63.0	70.9	75.8	NA	NA	58.4	NA	NA
8. GULARGHATI	54.0	56.0	59.4	NA	NA	56.6	NA	NA
9. DOIWALA	58.2	54.4	58.7	38.4	59.5	57.5	62.3	72.9
10. RAIWALA Tawa	63.4	44.2	46.8	40.1	50.3	58.3	58.6	44.3
11. RAIWALA Song	71.5	51.4	44.6	49.3	47.6	64.3	63.4	67.0
12. SATYANARAYANA	72.4	53.8	59.2	54.2	58.0	72.4	64.0	66.3

TABLE 6.22 HORTON'S INDEX VALUES (including heavy metals) OBSERVED IN SONG RIVER (During the period July 85 to Dec.86)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 86	AUG. 86	OCT. 86	DEC. 86
1. SAHASHRADHARA Baldi B/C	304.7	298.4	349.7	NA	NA	341.4	NA	NA
2. SAHASHRADHARA Sulfur Spring	373.3	370.4	355.4	NA	NA	365.2	NA	NA
3. SAHASHRADHARA Baldi A/C	351.2	367.9	373.7	NA	NA	373.1	NA	NA
4. MALDEVYA Bandal	290.3	308.5	NA	NA	NA	291.3	NA	NA
5. MALDEVTA Song	293.1	270.2	296.2	NA	NA	273.4	NA	NA
6. MALDEVTA Baldi	350.5	357.9	NA	NA	NA	313.4	NA	NA
7. RAIPUR	301.9	314.6	312.3	NA	NA	302.1	NA	NA
8. GULARGHATI	283.8	278.5	238.5	254.7	191.2	226.4	241.1	251.1
9. DOIWALA	283.8	278.5	238.5	254.7	191.2	226.4	241.1	251.1
10. RAIWALA Tawa	248.2	292.5	231.8	207.8	199.6	226.6	204.3	196.1
11. RAIWALA Song	276.3	251.5	224.2	210.7	213.1	279.3	238.6	234.0
12. SATYANARAYANA	286.8	246.0	232.2	207.4	229.1	297.6	233.3	236.6

A/C = After Confluence

B/C = Before Confluence

N.A. = Analysis wasn't done

TABLE 6.23 RIVER POLLUTION INDEX VALUES (including heavy metals) OBSERVED IN SONG RIVER (During the period July 85 to Dec.86)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 86	AUG. 86	OCT. 86	DEC. 86
1. SAHASHRADHARA Baldi B/C	2386.3	1479.2	2151.9	NA	NA	1837.8	NA	NA
2. SAHASHRADHARA Sulfur Spring	8181.3	8118.8	7486.5	NA	NA	6571.2	NA	NA
3. SAHASHRADHARA Baldi A/C	2791.5	2275.9	3002.0	NA	NA	1912.8	NA	NA
4. MALDEVYA Bandal	1868.3	2686.7	NA	NA	NA	1612.3	NA	NA
5. MALDEVTA Song	1752.9	1355.9	1910.9	NA	NA	1362.8	NA	NA
6. MALDEVTA Baldi	2572.9	2110.7	NA	NA	NA	1876.2	NA	NA
7. RAIPUR	2064.9	2282.6	1845.5	NA	NA	1708.2	NA	NA
8. GULARGHATI	1468.0	1141.9	876.1	NA	NA	1295.3	NA	NA
9. DOIWALA	1124.3	1124.3	743.5	549.2	645.5	1034.3	689.4	744.0
10. RAIWALA Tawa	771.1	757.0	672.2	616.5	532.3	812.5	529.9	502.8
11. RAIWALA Song	996.7	924.5	598.5	580.1	557.5	995.3	668.8	632.7
12. SATYANARAYANA	1009.0	833.5	659.9	592.9	668.0	1107.2	641.8	630.4

TABLE 6.24 HARKIN'S INDEX VALUES (with heavy metals)

OBSERVED IN SONG RIVER (During the period July 85 to Dec.86)

STATIONS	AUG. 85	OCT. 85	DEC. 85	FEB. 86	APR. 86	AUG. 86	OCT. 86	DEC. 86
1. SAHASHRADHARA Baldi B/C	87.4	95.0	93.0	NA	NA	89.8	NA	NA
2. SAHASHRADHARA Sulfur Spring	111.5	112.0	106.2	NA	NA	101.1	NA	NA
3. SAHASHRADHARA Baldi A/C	97.1	113.2	105.1	NA	NA	91.5	NA	NA
4. MALDEVYA Bandal	77.0	76.8	NA	NA	NA	74.6	NA	NA
5. MALDEVTA Song	96.5	68.1	87.6	NA	NA	70.7	NA	NA
6. MALDEVTA Baldi	95.5	101.3	NA	NA	NA	89.8	NA	NA
7. RAIPUR	84.8	79.4	97.4	NA	NA	75.4	NA	NA
8. GULARGHATI	75.0	72.5	72.5	NA	NA	72.1	NA	NA
9. DOIWALA	75.5	67.4	66.7	40.1	61.6	64.2	62.4	72.9
10. RAIWALA Tawa	69.9	51.9	55.0	55.5	51.8	65.1	50.7	45.5
11. RAIWALA Song	83.2	60.3	50.7	51.4	51.0	74.0	66.7	68.5
12. SATYANARAYANA	81.3	61.9	63.9	55.6	61.2	81.6	66.0	67.5

A/C = After Confluence

B/C = Before Confluence

N.A. = Analysis wasn't done

Bangla Rao at the latter location.

Table 6.25 compares the contribution of heavy metals in the index values. The mean index values in Fig. 6.11 clearly indicate the prominence of heavy metals in the index value in the upper reaches of Song river i.e. between Maldevta and Gularghati. This observation can easily be attributed to the richness of minerals in this area.

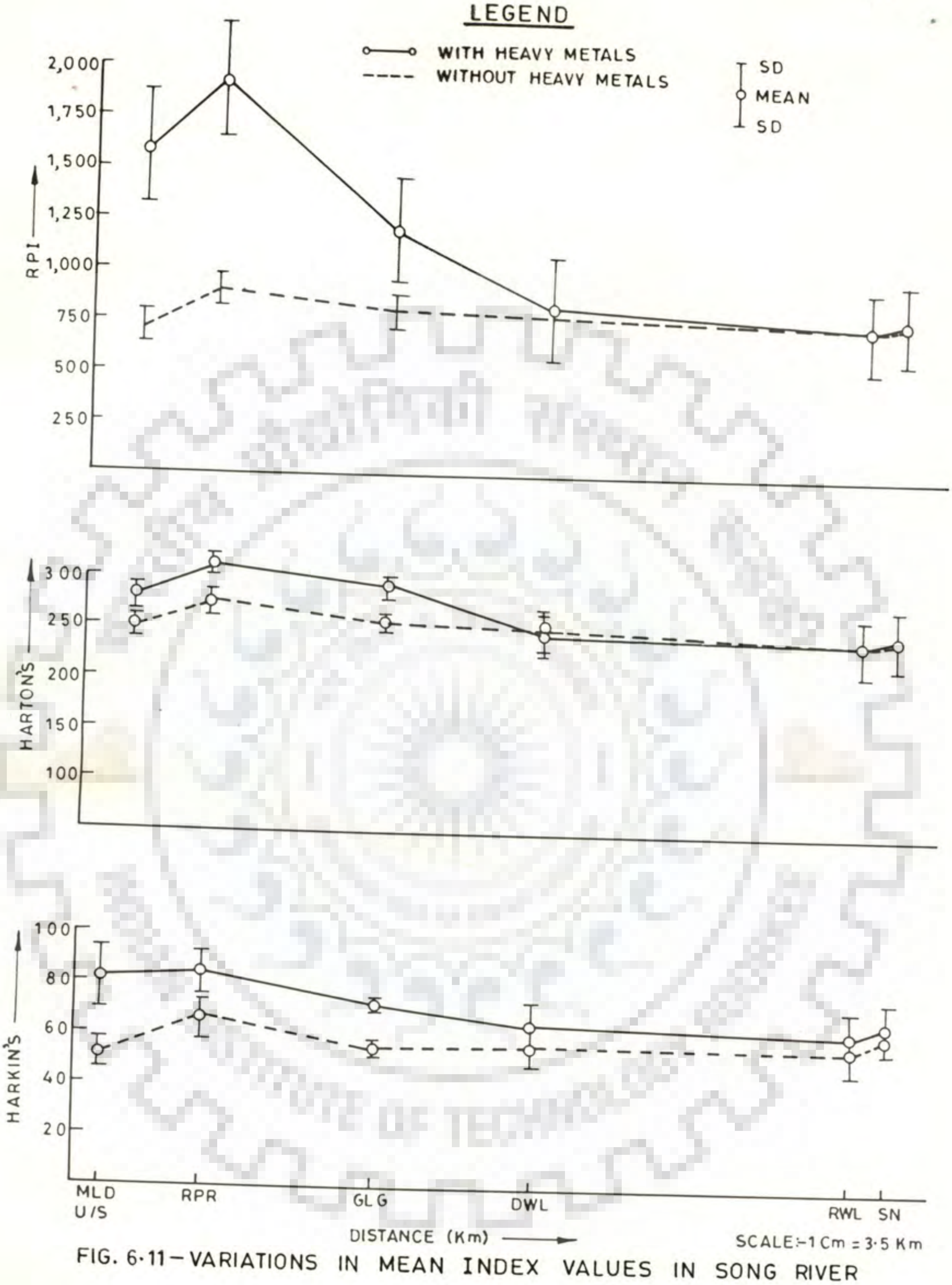


FIG. 6·11—VARIATIONS IN MEAN INDEX VALUES IN SONG RIVER

TABLE 6.25 COMPARISON OF THE CALCULATED MINERAL INDICES IN SONG RIVER

(July 1985 to December 1986)

STATIONS	HARKIN'S				HORTON'S				RIVER POLLUTION INDEX			
	With Metals		With Out Metals		With Metals		With Out Metals		With Metals		With Out Metals	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
1.SAHASHRADHARA Baldi B/C	90.6	3.1	71.1	6.2	323.6	25.8	304.8	43.3	1963.8	395.3	1119.3	279.0
2.SAHASHRADHARA Sulfur Spring	107.7	5.1	85.5	3.0	366.1	7.9	364.1	1.8	7589.5	747.9	8022.0	825.7
3.SAHASHRADHARA Baldi A/C	101.7	9.4	80.8	7.8	357.5	16.6	342.8	22.3	2495.5	493.9	1655.4	491.6
4.MALDEVTA Bandal	76.1	1.3	59.2	3.0	296.6	10.2	261.0	13.7	2055.7	561.2	821.9	109.1
5.MALDEVTA Song	80.7	13.6	51.9	5.7	283.2	13.3	248.3	15.7	1598.1	277.6	740.4	87.3
6.MALDEVTA Baldi	96.5	5.7	74.6	2.9	340.6	23.8	324.9	23.9	2186.6	354.5	1310.6	107.3
7.RAIPUR	84.2	9.6	67.0	7.8	307.7	6.7	275.9	9.0	1975.3	252.1	948.9	79.3
8.GULARGHATI	73.0	1.3	56.5	2.2	282.0	11.0	255.8	5.1	1195.3	251.1	818.6	77.9
9.DOIWALA	63.9	10.8	57.7	9.6	245.7	29.4	251.0	20.7	831.8	227.5	777.7	96.2
10.RAIWALA Tawa	55.7	8.0	49.5	7.8	225.9	32.9	238.9	29.8	649.3	121.9	674.5	103.8
11.RAIWALA Song	63.1	12.1	57.4	10.2	240.9	26.3	246.8	23.8	744.3	192.9	739.6	147.9
12.SATYANARA-YANA	67.4	9.4	63.1	6.8	248.1	30.6	258.5	29.4	767.8	194.4	798.1	162.4

7.0 CONCLUSIONS

From the work presented in this dissertation on "Mineral Load and Transport in Upper Ganga Basin" the following significant observations emerge as worth mentioning:

1. Maximum mineral load is added by the tributary Song followed by Nandakini and Bhagirathi. Bhagirathi emerges out to be the highest contributor of suspended solids.

2. The stretch between Rishikesh and Haridwar is found to be the most critical zone as the salt-loading and salt-concentrating effects are prominant.

3. The profiles of physico chemical parameters, mineral quality indices and PCA reveals the classification of Ganga river in the study area into mineralized and non-mineralized zones.

4. The spatial and temporal variations of mineral parameters indicate the presence of mineralization in the study area, but the concentrations clearly indicate that can not be explored for economic purposes.

5. No distinct man made source to increase the mineral load is observed in the mineralized zone of Ganga i.e. from Satyanarayana to Rajghat Narora.

6. The mineral quality indices calculated in the present study convey the same information indicating that any one of these indices can represent the overall mineral quality in the rivers.

7. The mineal profiles of Song river indicate the qualitative and quantitative gradient of mineral deposits int the Song river stretch.

8. The dissolved trace metal concentration in Ganga river does not exceed the W.H.O. limits at any occassion, however, in the sediments may exceed at some specific locations.

9. In Song river the total and dissolved metal concentrations are high, but they are observed within the W.H.O. limits before the confluence of Song with Ganga river. This emphasises that the addition of Song waters to Ganga river is not alarming.

REFERENCES

Abbas, N. and Subramanian, V.: Erosion and sediment transport in the Ganga river basin (India). Journal of Geol. Society of India, 69,173-182(1984).

Abdulla, M.I. and Royle, L.G.: Heavy metal content of some rivers and lakes in Wales. Nature (London) 238,329-330(1972a).

Abdulla, M.I., Royle, L.G. and Morris, A.W.: Heavy metal concentrations in coastal waters, Nature (London) 235,158-160(1972b).

Abdulla, M.I. and Royle, L.G.:d Cadmium in some British coastal and freshwater environments. Proc. Int. Symp. "problems of the contamination of Man and his environment by mercury and cadmium", Luxembourg, 1973, 69-81 (1974).

Aubert, H. and Pinta, M.: Trace Elements in Soil. Development in Soil Science Series 7, Elsevier Publishing. 2nd Impression (1980).

Bhargava, D.S.: Use of water quality index for river classification and zoning of Ganga river. Env. Poll. Series-B. An Internation Jnl. England,6,51-67(1983).

Bhargava, D.S.: Expression for drinking water supply standards. J. of Environmental Engineering, American Society of Civil Engineers, 3(III),(1985).

Bikshamiah, G. and Subramanina, V.: Chemical and Sediment Mass Transfer in Godavari River Basin in India. Journal of Hydrology, 46, 331-342(1980).

Brown, M. Robert, Nina I. McClelland, Roff A. Deininger and Ronald, G. Tozer.: A water quality index-do we dare?. Water and Sewage Works,117(10), 339-343(1970).

Cargo, D.N. and Mallory, B.F.: Man and His Geologic Environment. Reading. Massachusetts. Addison-Wesley (1974).

Dasgupta, S.P.(1984):(ed.) Basin Sub-basin Inventory of Water Pollution. The Ganga Basin Part-II. Central Board for Prvevention and Control of Water Pollution, New Delhi.

Davis, C. John.(1973): Statistics and data analysis in Geology. John Wiley and Sons, Inc NewYork. pp.472-532.

Doval, S.C. and Saklani, P.S.: Geology of Alaknanda valley. Him. Geol. 10,178-190(1980).

Durrum, W.H., Hem, J.D. and Heidel, S.G.: Reconnaissance of selected minor elements in surface waters of the United States, U.S.Geol. Surv. Circular 634,49(1971).

Durrum, W.H. and Hafty, J.: Implementations of the minor element content of some major streams of the world. Geochim. Cosmochim. Acta. 27,1-11(1963).

Forstner,U.and Wittman,G.T.W.: Metal Pollution in the aquatic environment. 2nd edition. pp.159-160, Springer Verlag (1983).

Garlaschi, G., Schalsch, E.B., Vergara, I. and Chang, A.C.: Trace metals in sediments of Mapocho river, Chile. Envr. Tech. Letters 6,405-414(1985).

Gibbs, R.J.: The Geo-chemistry of Amazon River System-I The factors that control the salinity and the composition of the suspended solids. Geol. Soc. American Bull., 78,1203-1232(1967).

Gibbs, R.J.: Mechanisms controlling world water chemistry. Science, 170,1088-1090(1970).

Gibbs, R.J.: Water Chemistry of the Amazon River. Geochim. Cosmochim. Acta, 36,1061-1066(1972).

Gibbs, R.J.: Sites of river-derived sedimentation in the ocean. Geology, 9,77-80(1980).

Gilbert, F.A.(1947): Mineral nutrition and the balance of life. Norman Oklahoma, University of Oklahoma Press.

Groot, A.J. de.: Heavy metals in Dutch delta. In Interaction between sediments and freshwater, Golterman H.L. (ed.). Junk and Pudoc 104-107(1977).

Handa, B.K.: Geochemistry of the Ganga River, Indian Geohydrology, 2,71-7(1972).

Harkins, Ralph D.: An objective water quality index. J. Water Pollution Control Federation, 46(3),588-591(1974).

Hitchan, B., Levinson, A.A. and Reeder, S.W.: Regional variation of river water composition resulting from halite dissolution, Mackenzie river drainage basin, Canada. Water Resources Research, 5,1395-1403(1969).

Hitchan, B. and Krouse, H.R.: Hydro geo-chemistry of the surface waters of the Mackenzie river drainage basin-III. Stable isotopes of oxygen, carbon and sulfur. Geochim. Cosmochim. Acta, 36,1337-1357(1972).

Horton, R.K.: An index number system for rating water quality. J. Water Pollution Control Federation, 37(3),300(1965)

Inhoff, K.R., Kopp, P. and Dietz, F.: Heavy metals in Ruhr river and their budget in the catchment area. Prog. Wat. tech. 12,735-749(1980).

James, I. Drever(1988): The Geochemistry of natural waters, 2nd edition, Prantice Hall, Englewood Cliffs, New Jersey, pp.328-329.

Konovalov, G.S.: Transport of microelements by the most important rivers of U.S.S.R. (engl. translation by M. Fleischer). Dokl. Akad. Nauk. USSE 129,912-915(1969).

Konavalov, G.S., Nazarova, L.N.: Mapping trace metals in river water (russ.). Gidrokhim Mater. 62,37-43(1975).

Kopp, J.F. and Kroner, R.C.: Tracing water pollution with an emission spectrograph J. Wat. Pollu. Contr. Fed. 39,1659(1967).

Kumar, G., Prakash, G. and Singh, K.N.: Geology of Devprayag Dwartga area. Garhwal, Chamoli and Almora districts, Kumaon Himalayas, Uttar Pradesh. Him. Geol. 4,321-346(1974).

Kumar, G. and Agarwal, N.C.: Geology of Srinagar-Nandprayag area (Alaknanda Valley), Chamoli, Garhwal, Tehri Garhwal districts, Kumaon Himalayas, Uttar Pradesh. Him. Geol. 5,29-59(1975).

Lohani, B.N.(1984): Environmental Quality Management, South Asian Publishers, New Delhi.

Lohani, B.N.: Water quality index for Chao Phraya river. J. of Environmental Engineering, American Association of Civil Engineers, 110(6),1163-1176(1984).

Lohani, B.N.: Water quality data analysis in Chung Kang river. J. of Environmental Engineering, American Society of Civil Engineers, 113(1),186-195(1987).

Marvin Grosswith(1980): Science Digest, pp.131-150.

Maier, F.J.(1971): Fluorides in water. In water quality and treatment, 3rd edition, pp.97-440, Mc Graw Hill, New York.

McDuffie, B. and Hanery Jonathan, T.: A proposed river pollution inde presented at the spring 1973 meeting of the ACS, Division of water, air and waste chemistry, NewYork (April, 1973).

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

Milliman, I.D. and Meade, R.H.: Worldwide delivery of river sediment to the ocean. Journal of Geology, 71,1-21(1983).

N.A.S.(Feb.1985): Planning for environmental indices- a report of the Planning Committee on Environmental Indices, National Academy of Sciences, Washington, D.C.

Nathaneil, W.R., Richard L.S. and Richard Bull: The relationship of minerals commonly found in drinking water to Arteriosclerosis and hyper tension in Pigeons. Journal of American Water Works Association, 74(12),656-659(1982).

Negi, S.S., Sinha, A.K. and Pandey, B.K.: A priliminary report on othe geology and structure of the Rudraprayag-Tilwara-Mayoli area of Garhwal Himalayas. Him. Geol. 10,211-219(1980).

Nriagu, J.O.(1980): In Zinc in the environment Part-II, John Wiley and Sons.

Ott, Wayne R.(1978a): Water quality indices-a survey of indices used in the United States, US E.P.A., Washington, D.C. EPA 600/4-78-005(Jan. 1978).

Ott, Wayne R.(1978b): Environmental indices-theory and practice. Ann. Arbor Science Publishers, Inc. Michigan(1978).

Peake, E., Baker, B.L. and Hodgson, G.W.: Hydro chemistry of the surface waters of the Mackenzie river drainage basin, Canada-II. The contribution of amino acids, hydrocarbons and chlorines to the Beufort sea by the Mackenzie river system. Geochim. Cosmochim. Acta,36,867-883(1972).

Pories, W.J., Strain, W.H. and Rob, C.G.(1971): Zinc deficiency in delayed health and chronic disease. In environmental geo chemistry in health and disease, eds. H.L.Cannon and H.C.Hopps, pp.73-95. Geol. Soc. of America Memoir 123.

Prasad, A.S.(1976): (ed.) Deficiency of Zinc in man and its toxicity. In trace metals in human and health and desease, Vol.1, Academic Press, New York.

Rao, K.L.(1975): Indias Water Health. 1st Edition, Orient Longmann, New Delhi, pp.255.

Rao, P.N. and Pati, U.C.: Geology and tectonics of Bhilangana Valley and its adjoining parts, Garhwal Himalays, with special reference to the Main Central Thrus. Him. Geol. 10,220-233(1980).

Reddy, M.M.: A preliminary report: Neutrients and metals transported by sediments within the Genesee river watershed, New York, U.S.A. In: Proc. Int. Symp. Interaction between sediments and freshwater, Armsterdam 1976. Golterman, H.L. (ed.) Wageningen/The Hague/Pudoc/Junc B.V. Publ. 1977 pp.63-67.

Reddy, M.M.: Final report, sediment neutrient and metal and water column heavy metal characterization in the Geenesee River. Part of the Geenesee river pilot watershed study for PLUARG TASK-C. New York State Deptt. of Environmental Conservation, Alabany, New York and International joint commission for Great lakes Windsor, Ontario, Canada (1978).

Reeder, S.W., Hitchan, B. and Levinson, A.A.: Hydro chemistry of the surface waters of Mackenzie river drainage basin, Canada-I. Factors controlling the inorganic composition. Geochim. Cosmochim. Acta, 36,181-192(1972).

Robindra, R. and Negi, S.S.: Observations on Alaknanda tragedy, Him. Geol. 9(II),724-733(1979).

Saikia, D.K.(1987): Occurrence and Transport of heavy metals in Upper Ganga basin, Ph.D. Thesis, University of Roorkee, Roorkee (India).

Sakai, H., Kojima, Y and Saito, K.: Distribution of heavy metals in water and sieved sediments in the Toyohira river, Wat. Res. 20(V),559-567(1986).

Saklani, P.S.: Lithostratigraphy and structure of the area between Bhagirathi and Bhilangana rivers, Garhwal Himalayas. Him. Geol. 2,342-355(1972).

Sarin, M.M., Borole, D.V. and Krishnaswamy S.: Geochemistry and geochronology of sediments from Bay of Bengal and equatorian Indian oceans. Proceedings of Indian Academy of Sciences, 312,538-541(1979).

Sarin, M.M. and Krishnaswamy, S.: Major ion chemistry of Ganga-Brahmaputra river system. Nature. 312,538-541(1984).

Saucer, H.I. and Brand, F.R.: Geographic Patterns in the risk of dying. In environmental geochmistry in health, eds. H.L.Cannon and H.C.Hopps, pp.131-150. Geological Soc. of America Memoir 123(1972).

Saxena, P.B., Bahukhandi, P.C. and Pandey, B.K.: A study of landsliding and its land depletion in the Alaknanda valley of Garhwal Himalayas. Him. Gel. 9(II),716-723(1979).

Shaeffer, David J. and Kananur G. Janardan: Communicating environmental information to the public: A new water quality index. J. Environ. Edn., 8(4),18-26(1977).

Sharma, C.B. and Ghose, N.C.: Pollution of the river Ganga by Municipal Waste: a case study from Patna. Journal of

Geol. Soc. of India, 30, 369-385(1987).

Shoji, Hikaru, Takeo Yamamoto and Tazakaku Nakamura.: Factor analysis on stream pollution of the Yodo river system. Air and Water Pollution International Journal, 10,291-299(1966).

Singh, R.L.(1987): (ed.) India, a regional geography, National Geographical Society of India, Varanasi, 2nd edition.

Singhal, B.B.S., Mathur, R.P., Singhal, D.K., Mathur, B.S., Minocha, V.K., Seth, A.K. and Sinha, S.K.: Effects of industrial effluents on the water quality of River Hindon, District Saharanpur, U.P. Journal of the Geological Society of India, 30(5),356-368(1987).

Sinha, U.K.(1986): Ganga Pollution and health hazard. Inter India Publ., New Delhi, India.

Smith, I.C. and Carson, B.L. (eds.): Trace metals in the environment vol.6.Cobalt. Ann Arbor Science (1984).

Spencer, J.M.: Geological influence on regional health problems. The Texas journal of science, 21,459-469(1970).

Srivastava, R.N. and Ahmad, A.: Geology and structure of Alaknanda Valley, Garhwal Himalayas. Him. Geol.

(I),225-254(1979).

Stallard, R.F. and Edmonc, J.M.: Geo chemistry of the Amazon-2. The influence of Geological weathering of environment on the dissolved load. J. Geophys. Res., 88(C-14), 9671-9687(1983).

Subramanian, V. and Dalavi, R.A.: Some aspects of stream erosion in the Himalayas. Himalayan Geol.,8(II),822-834(1979a).

Subramanian, V.: Chemical and suspended sediment characteristics of rivers in India. Journal of Hydrology, 4,37-55(1979b).

Subramanian, V.: Environmental geochemistry of Indian river basins- a review. Journal of Geol. Soc. of India, 29(2),205-220(1987a).

Subramanian, V., Gricken, R.V. and Vant Deck, L.(1987): Heavy metal distribution in the sediments of Ganga and Brahmaputra rivers. Env. Gel. Water Sci., 9(2),93-103(1987b).

Subramanian, V., Sitasawad, R., Abbas, N. and Jha, P.K.: Environmental geology of the Ganga river basin. Journal of Geol. Soc. of India, 30,335-355(1987c).

Train, R.E.(1979): Quality criteria for water, Castle House Publ. Ltd.

UNESCO (1969): Discharge of selected rivers of the world. UNESCO, Paris, pp.70.

Vernet, J.P., Rapin, F. and Scolari, G.: Heavy metal content of lake and river sediment in Switzerland. In Interaction between sediments and freshwater. Golterman H.L. (ed.). Junk and Pudoc. pp. 390-397 (1977).

Vivian, C.M.G. and Massie, K.S.: Trace metal in waters and sediments of river Tawe, South Wales, in relation to local sources, Envirn. pollut. 14,47-61(1977).

Wariyar, T.V.(1986): Water quality indexing of river Ganga between Rishikesh and Hardwar, M.E. Thesis, Civil Engg. Department, University of Roorkee.

Warmick, S.L. and Bell, H.L.: The accute toxicity of some heavy metals to different species of aquatic instects. J. Water Pol. Contr. Fed., 41, 28-284(1969).

WHO (1984): Guidelines for drinking water quality, volume 1, recommendations. W.H.O., Ganeva.

White, K.D. and Tittlebaum, M.E.: Metal distribution and contamination in sediments. Jl. Env. Engg. A.S.C.E. 111(2),161-175(1985).

William C.Blackman,Jr., Jim V.Rouse, George R.Schillinger and William H.Shafer,Jr.: Mineral Pollution in the Colorado River Basin. J. Water Poll. Contr. Fed., 45(7),1517-1557(1970).

Williams, S.L., Aulenbach, D.B. and Clesceri, N.L.: Sources and distribution of trace metals in aquatic environment. In Aqueous environmental chemistry of metals, Rubin, A.J. (ed.) Ann Arbor Science Publ. Inc. Michigan, 1974, pp.76-127.

APPENDICES

APPENDIX-1

```
C                    TOTAL DISSOLVED SOLIDS
11,7,11
1,2,5
7,11
16.4,13,16.4,19.6,94.35,346.5,130.9,115.6,166,133.6,166.8
91.8,179.6,108.3,92.4,90.8,295.2,120.5,135.6,208,137.4,129
118.2,101,113,95,106,284.6,158.8,255.4,157.8,160,135.2
161,121.6,93.2,100.4,102.6,281,148.82,144,135,132,132
56.43,61.38,58.9,57.38,61.74,329.82,106.42,110.4,108.45,103.5,103.5
60,73.8,70.7,72,80,320,170.8,268.82,175.5,165.65,174.5
134.2,102.4,81.5,114.1,124.9,240,159.2,202.1,136.3,140,144
```

APPENDIX-2

```
C                  STATION  :  NANDAPRAYAG
1
18,7,18
1,1
7,18
7.6,23.78,16.4,38.21,.14,4,10,11.29,3.52,2.0001,2.08,300,178,0,115,70,0,27
8.55,150,91.8,56.88,1.89,11.52,10,21.13,4.26,2.0003,0.106,39,65,11,8.5,22,20,23
8.49,172.09,118.2,48.42,1.4,7.92,15,18.59,4.57,2.0002,0.468,42,128,12,7,12,26,6
8.26,269.89,161,64,1.37,4.8,10,18.9,4.81,2.0003,0.489,32,62,3.6,40,18.8,18.8,6
8.14,90.95,56.43,54.57,.7,5.25,10,15.53,5.89,2.03,24.05,70,92,11,417,0,12.5,23
8.44,98,60,56.01,1.45,3.42,20,18.34,6.11,2.0002,0.379,51,147,11,8,37,6,7
8.45,126,134.2,65.32,1.73,6.06,10,17.39,7.17,2,0.160,40,66.9,1.7,22,0.00,6,13.3
^Z
```

APPENDIX-3

```
C                    MONTH  :  DECEMBER, 1985
18,11,18
1,1
11,18
8.55,150,91.8,56.88,1.89,11.52,10,21.13,4.26,2.0001,0.106,39,65,11,8.5,22,20,23
8.72,221,79.6,60.85,3,10.6,10,18.21,7.03,2.0002,1.57,66,117,7,20,25,0.00,20
8.15,159,108.3,74.61,1,0.5,15,20.4,7.21,2.0003,0.106,121,113,0.00,14,35,17,12
7.88,142,92.4,58.5,0.41,7.2,10,20.03,4.5,2.0004,0.363,30,146,8,23,55,12,8
8.7,142,90.8,52.28,2.46,7.2,15,15.66,7.84,2.0005,0.417,49,112,4,34,25,7,11
8.4,418,295.2,156.82,3.7,6.48,100,54.72,22.49,10,0.300,58,97,9,102,14,14,26
8.74,182.5,120.5,88.64,4.57,9.21,30,29.51,10.82,5,4.55,105,48,0.00,37,31,16,15
7.8,210.56,135.6,118.26,0.7,8.46,50,39.7,15.4,3,1.03,123,151,0.00,140,16,23,18
8.59,297.96,208,79.76,2.91,7.2,30,29.71,8.54,3.001,1.73,17,106,5,95,12,24,15
8.53,214.77,137.4,87.19,2.77,5.18,25,31.43
```

APPENDIX-4

```
**************************************************************************
C*********************************************************************
C*********************************************************************
**************************************************************************
C         THIS IS A PROGRAM FOR PRINCIPAL COMPONENTS ANALYSIS
C         THIS PROGRAM ACCEPTS AN N BY M MATRIX WHERE N IS THE NUMBER
C         OF OBSERVATIONS AND M IS THE NUMBER OF VAIRABLES.  IF THE
C         FIRST OPTION IS 1, AN M BY M MATRIX OF COVARIANCES BETWEEN
C         COLUMNS WILL BE COMPUTED.  IF THIS OPTION ISC


C*********************************************************************
**************************************************************************
C*********************************************************************
**************************************************************************
C         THIS IS A PROGRAM FOR PRINCIPAL COMPONENTS ANALYSIS
C         THIS PROGRAM ACCEPTS AN N BY M MATRIX WHERE N IS THE NUMBER
C         OF OBSERVATIONS AND M IS THE NUMBER OF VAIRABLES.  IF THE
C         FIRST OPTION IS 1, AN M BY M MATRIX OF COVARIANCES BETWEEN
C         COLUMNS WILL BE COMPUTED.  IF THIS OPTION IS 2, AN N BY N
C         MATRIX OF COVARIANCES BETWEEN ROWS WILL BE COMPUTED. IF THE
C         OPTION IS 0, THE PROGRAM CALLS EXIT, AS THE PROGRAM LOOPS
C         BACK AND RESTARTS AFTER COMPLETION OF AN ANLYSIS.  IF THE
C         SECOND OPTION IS 1, A STANDARDIZED COVARIANCE(CORRELATION)
C         MATRIX IS CREATED.  IF THIS OPTION IS 2, A RAW COVARIANCE
C         MATRIX IS CREATED.
C*********************************************************************
**************************************************************************
C
C         FORMAT OF CONTROL CARD
C         COLUMN 1-3;0=END OF JOB
C                    1=DO NOT TRANSPOSE INPUT DATA MATRIX
C                    2=TRANSPOSE INPUT DATA MATRIX
C*********************************************************************
**************************************************************************
C
C         COLUMN 4-6;1=CALCULATE CORRELATION MATRIX
C                    2=CALCULATE COVARIANCE MATRIX
C*********************************************************************
**************************************************************************
C
```

```
C**********************************************************************
 **********************************************************************
      DIMENSION X(50,20),A1(50,20),A2(50,20),SCORE(50,20)
      DIMENSION A11(50,20)
      OPEN(UNIT=1,FILE='PCA.DAT')
      OPEN(UNIT=2,FILE='PCA.OUT')
C     MD=11
C     ND=7
C     MM=11
C     READ CONTROL CARD
C      WRITE(*,222)
C222   FORMAT(' WRITE THE NUMBER OF DATA SETS PLEASE')
      READ(1,*)NDS
      DO 888 KKK=1,NDS
      WRITE(*,*)KKK
      READ(1,*)MD,ND,MM
1     READ(1,1000) ITRANS, ISIM,
      IF(ITRANS.LE.0) GO TO 999
C     READ AND PRINT INPUT DATA MATRIX
      CALL READM(X,N,M,ND,MD,KKK)
C     CALL PRINTM(X,N,M,ND,MD)
C     WRITE(2,2001)
C     IF CORRELATION MATRIX IS TO BE CALCULATED, STANDARDIZE INPUT
C     DATA MATRIX AND PRINT STANDARDIZED DATA MATRIX
      IF(ISIM.NE.1) GO TO 2
      CALL STAND(X,N,M,ND,MD)
C     CALL PRINTM(X,N,M,ND,MD)
C     WRITE(2,2006)
C     TRANSPOSE INPUT DATA MATRIX (IF REQUIRED)
2     IF (ITRANS.NE.2) GO TO 3
      MT=M
      IF(N.GT.M) MT=N
      DO 110 I=1,MT
      DO 110 J=1,MT
      XS=X(I,J)
      X(I,J)=X(J,I)
      X(J,I)=XS
110   CONTINUE
```

```
      MT=M
      M=N
      N=MT
C     CALCULATE AND PRINT SIMILARITY MATRIX
3     IF(ISIM.EQ.1) CALL RCOEF(X,N,M,ND,MD,A1,MM)
      WRITE(2,2002)
      CALL RCOEF(X,N,M,ND,MD,A1,MM)
      CALL PRINTM(A1,M,M,MM,MM)
      WRITE(*,699)
699   FORMAT('   CALL COV')
      IF(ISIM.EQ.2) CALL COV(X,N,M,ND,MD,A1,MM)
C     CALL PRINTM(A1,M,M,MM,MM)
      WRITE(*,799)
799   FORMAT(' CALLED')
C     WRITE(2,2007)
C     CALCULATE EIGEN VALUES AND EIGEN VECTORS
      CALL EIGENJ(A1,A2,M,MM)
C     MOVE EIGEN VALUES TO FIRST COLUMN AND CALCULATE SUM OF THEM
      SUME=0.0
      DO 100 I=1,M
      A1(I,1)=A1(I,I)
      SUME=SUME+A1(I,1)
100   CONTINUE
C     CALCULATE PERCENT CONTRIBUTION OF EACH EIGEN VALUE
      SUMEE=0.0
      DO 101 I=1,M
      A1(I,2)=A1(I,1)*100.0/SUME
      SUMEE=SUMEE+A1(I,1)
      A1(I,3)=SUMEE*100.0/SUME
101   CONTINUE
C     PRINT EIGEN VALUES AND PERCENT CONTRIBUTION
      WRITE(2,2003)
      CALL PRINTM(A1,M,3,MM,MM)
C     PRINT EIGEN VECTORS
      WRITE(2,2004)
      CALL PRINTM(A2,M,M,MM,MM)
C     CALCULATE AND PRINT SCORES
```

```
              CALL MMULT(X,A2,SCORE,N,M,M,ND,MD,MM,MM,ND,MD)
C             CALL PRINTM(SCORE,N,M,ND,MD)
C             WRITE(2,2005)
C             GO TO 1
1000          FORMAT (2I5)
2001          FORMAT(1H,4X,'INPUT DATA MATRIX-',1X,
            1 'COLUMNS=VARIABLES,ROWS=OBSERVATIONS')
2007          FORMAT(1H,'VARIANCE-COVARIANCE MATRIX')
C2002         FORMAT(1H,4X,'CORRELATION MATRIX')
2003          FORMAT(1H,4X,'COLUMN 1=EIGEN VALUES',2X,
            1 'COLUMN 2=PERCENT OF TRACE',/,
            2 5X,'COLUMN 3=CUMMULATIVE PERCENT OF TRACE')
2004          FORMAT(1H,4X,'PRINCIPAL AXIS MATRIX/-',1X,
            1 'COLUMNS=EIGENVECTORS, ROWS=VARIABLES')
2005          FORMAT(1H,4X,'PRINCIPAL COMPONENT SCORES-',1X,
            1 'COLUMNS=EIGENVECTORS, ROWS=OBSERVATIONS')
2006          FORMAT(1H,4X,'STANDARDIZED INPUT DATA MATRIX-',1X,
            1 'COLUMNS=VARIABLES, ROWS=OBSERVATIONS')
2002          FORMAT(1H,4X,'CORRELATION MATRIX')
888          CONTINUE
999          STOP
             END
C             SUBROUTINE TO CALCULATE EIGEN VALUES AND EIGEN VECTORS OF AN
C             NXN SYMMETRIX MATRIX.
C             UPON COMPLETION THE EIGEN VALUES ARE STORED IN THE DIAGONAL
C             ELEMENTS OF MATRIX A (IN DESCEND ORDER).  THE EIGEN
C             VECTORS ARE STORED BY COLUMNS IN MATRIX B.
C             EIGEN VALUE A(I,I) CORRESPONDS TO EIGEN VECTOR (B(I,J),J=1,N)
              SUBROUTINE EIGENJ (A,B,N,N1)
              DIMENSION A(50,20),B(50,20)
C             CALCULATE INITIAL AND FINAL NORMS
C             SET B TO IDENTIFY MATRIX
              ANORM=0.0
              DO 100 I=1,N
              DO 101 J=1,N
              IF (I-J) 2,1,2
1             B(I,J)=1.0
```

```
          GO TO 101
2         B(I,J)=0.0
          ANORM=ANORM+A(I,J)*A(I,J)
101       CONTINUE
100       CONTINUE
          ANORM=SQRT(ANORM)
          FNORM=ANORM*1.0E-09/FLOAT(N)
C         INITIAL INDICATORS AND COMPUTE THRESHOLD
          THR=ANORM
23        THR=THR/FLOAT(N)
3         IND=0.0
C         SCAN DOWN COLUMNS FOR OFF-DIAGNONAL ELEMENTS GREATER THAN OR
C         EQUAL TO THRESHOLD
          DO 102 I=2,N
          I1=I-1
          DO 103 J=1,I1
          IF(ABS(A(J,I))-THR) 103,4,4
C         COMPUTE SIN AND COX
4         IND=1
          AL=-A(J,I)
          AM=(A(J,J)-A(I,I))/2.0
          AO=AL/SQRT(AL*AL+AM*AM)
          IF (AM) 5,6,6
5         AO=-AO
6         SINX=AO/SQRT(2.0*(1.0+SQRT(1.0-AO*AO)))
          SINX2=SINX*SINX
          COSX=SQRT(1.0-SINX2)
          COSX2=COSX*COSX
C         ROTATE COLUMNS I AND J
          DO 104 K=1,N
          IF (K-J) 7,10,7
7         IF (K-I) 8,10,8
8         AT=A(K,J)
          A(K,J)=AT*COSX-A(K,I)*SINX
          A(K,I)=AT*SINX+A(K,I)*COSX
10        BT=B(K,J)
          B(K,J)=BT*COSX-B(K,I)*SINX
```

```
          B(K,I)=BT*SINX+B(K,I)*COSX
104       CONTINUE
          XT=2.0*A(J,I)*SINX*COSX
          AT=A(J,J)
          BT=A(I,I)
          A(J,J)=AT*COSX2+BT*SINX2-XT
          A(I,I)=AT*SINX2+BT*COSX2+XT
          A(J,I)=(AT-BT)*SINX*COSX+A(J,I)*(COSX2-SINX2)
          A(I,J)=A(J,I)
          DO 105 K=1,N
          A(J,K)=A(K,J)
          A(I,K)=A(K,I)
105       CONTINUE
103       CONTINUE
102       CONTINUE
          IF(IND) 20,20,3
20        IF (THR-FNORM) 25,25,23
C         SORT EIGEN VALUES AND EIGEN VECTORS
25        DO 110 I=2,N
          J=I
29        IF(A(J-1,J-1)-A(J,J)) 30,110,110
30        AT=A(J-1,J-1)
          A(J-1,J-1)=A(J,J)
          A(J,J)=AT
          DO 111 K=1,N
          AT=B(K,J-1)
          B(K,J-1)=B(K,J)
          B(K,J)=AT
111       CONTINUE
          J=J-1
          IF(J-1) 110,110,29
110       CONTINUE
          RETURN
          END
C         SUBROUTINE TO PRINT A MATRIX HAVING N ROWS AND M COLUMNS
          SUBROUTINE PRINTM (A,N,M,N1,M1)
          DIMENSION A(50,20)
```

```
C         PRINT MATRIX OUT IN STRIPS OF 10 COLUMNS
          DO 100 IB=1,M,10
          IE=IB+9
          IF (IE-M) 2,2,1
1         IE=M
C         PRINT HEADINGS
2         WRITE(2,2000) (I,I=IB,IE)
          DO 101 J=1,N
C         PRINT ROWS OF MATRIX
          WRITE (2,2001) J,(A(J,K),K=IB,IE)
101       CONTINUE
100       CONTINUE
          RETURN
2000      FORMAT(10X,10I12)
2001      FORMAT(5X,I5,10F12.4)
          END
C         SUBROUTINE FOR MULTIPLICATION OF MATRIX A BY MATRIX B TO
C         GIVE MATRTIX C.  A IS L ROWS BY N COLUMNS.  B IS N ROWS BY M
C         COLUMNS, AND C WILL BE L ROWS BY M COLUMNS.
          SUBROUTINE MMULT(A,B,C,L,N,M,NA,MA,NB,MB,NC,MC)
          DIMENSION A(50,20),B(50,20),C(50,20)
          DO 100 I=1,L
          DO 101 J=1,M
          C(I,J)=0.0
          DO 102 K=1,N
          C(I,J)=C(I,J)+A(I,K)*B(K,J)
102       CONTINUE
101       CONTINUE
100       CONTINUE
          RETURN
          END
C         SUBROUTINE TO STANDARDIZE THE COLUMNS OF A DATA MATRIX
          SUBROUTINE STAND(X,N,M,N1,M1)
          DIMENSION X(50,20)
C         STANDARDIZE EACH COLUMN OF THE MATRIX
          DO 100 I=1,M
C         IF(I.EQ.9)GO TO 100
```

```
C        CALCULATE MEAN AND STANDARD DEVIATION OF COLUMN
         SX=0.0
         SXX=0.0
         DO 101 J=1,N
         SX=SX+X(J,I)
         SXX=SXX + X(J,I)**2
101      CONTINUE
         XM=SX/FLOAT(N)
C        WRITE(*,*)SX,SXX,I
         SD=SQRT((SXX-SX*SX/FLOAT(N))/FLOAT(N-1))
C        WRITE(*,*)SX,SXX,SD
C        SUBROUTINE MEAN FROM EACH ELEMENT IN COLUMN,THEN DIVIDE RESULT
C        BY THE STANDARD DEVIATION
         DO 102 J=1,N
         X(J,I)=(X(J,I)-XM)/SD
C        WRITE(*,*)X(J,I)
102      CONTINUE
100      CONTINUE
         RETURN
         END
C        SUBROUTINE TO CALCULATE THE MATRIX OF CORRELATION BETWEEN
C        COLUMNS OF DATA MATRIX X.
         SUBROUTINE RCOEF(X,N,M,N1,M1,A,M2)
         DIMENSION X(50,20),A(50,20)
         AN=N
C        CALCULATE CORRELATION COEFFICIENT BETWEEN COLUMNS I AND J
         DO 100 I=1,M
         DO 100 J=1,M
C        IF(I.EQ.9.AND.J.EQ.9)GO TO 100
C        DO 100 J=1,M
         SX1=0.0
         SX2=0.0
         SX1X1=0.0
         SX2X2=0.0
         SX1X2=0.0
C        CALCULATE SUMS, SUMS OF SQUARES AND SUM OF CROSS-PRODUCT
C        OF COLUMNS I AND J.
```

```
      DO 101 K=1,N
      SX1=SX1+X(K,I)
      SX2=SX2+X(K,J)
      SX1X1=SX1X1+X(K,I)**2
      SX2X2=SX2X2+X(K,J)**2
      SX1X2=SX1X2+X(K,I)*X(K,J)
101   CONTINUE
C     CALCULATE CORRELATION COEFFICIENT AND STORE IN MATRIX A.
C     WRITE(*,*)SX1,SX2,SX1X1,SX2X2,SX1X2
      R=(SX1X2-SX1*SX2/AN)/
     1 SQRT((SX1X1-SX1*SX1/AN)*(SX2X2-SX2*SX2/AN))
C     WRITE(*,*)R
      A(I,J)=R
      A(J,I)=R
100   CONTINUE
      RETURN
      END
C     SUBROUTINE TO CALCULATE THE MATRIX OF VARIANCE AND COV-
C     ARIANCES BETWEEN COLUMNS OF DATA MATRIX.
      SUBROUTINE COV(X,N,M,N1,M1,A,M2)
      DIMENSION X(50,20),A(50,20)
      WRITE(*,966)
966   FORMAT('     CALLED COV')
      AN=N
      AN1=N-1
C     CALCULATE VARIANCE-COVARIANCE BETWEEN COLUMNS I AND J.
      DO 100 I=1,M
      DO 100 J=1,M
C     ZERO THE SUMS
      SX1=0.0
      SX2=0.0
      SX1X2=0.0
C     CALCULATE SUMS AND SUM OF CROSS-PRODUCTS
      DO 101 K=1,N
      SX1=SX1+X(K,I)
      SX2=SX2+X(K,J)
      SX1X2=SX1X2+X(K,I)*X(K,J)
```

```
101     CONTINUE
C       CALCULATE VARIANCE-COVARIANCE AND STORE IN MATRIX A.
        A(I,J)=(SX1X2-SX1*SX2/AN)/AN1
        A(J,I)=A(I,J)
100     CONTINUE
        RETURN
        END
C       SUBROUTINE TO READ A MATRIX HAVING N ROWS AND M COLUMNS
        SUBROUTINE  READM(A,N,M,N1,M1,KK)
        DIMENSION A(50,20)
C       READ SIZE OF MATRIX
        READ(1,1005) N,M
C       READ MATRIX ONE ROW AT A TIME
        DO 100 I=1,M
        READ  (1,*)(A(I,J),J=1,M)
100     CONTINUE
        RETURN
1005    FORMAT (2I5)
1006    FORMAT(10F8.2)
        END
C*****************************************************************************************
*********************************************************************************************
```

APPENDIX-5

```
***************************************************
C       THIS PROGRAMME IS TO CALCULATE THE
C       MINERAL INDEX
*****************************************************
        DIMENSION PH(30),ORP(30),COND(30),DIS(30)
        DIMENSION HCO3(30),CO3(30),CL(30),SO4(30),APO4(30)
        DIMENSION ANO3(30),ANO2(30),ANH3(30),CA(30)
        DIMENSION AMG(30),ANA(30),AK(30),FE(30)
        DIMENSION PB(30),ZN(30),CD(30),AMN(30)
        DIMENSION ANI(30),CO(30),CU(30),STA(30)
        DIMENSION TA(30),TC(30)
        DIMENSION QPH(30),QDIS(30),QHCO3(30),QCO3(30)
        DIMENSION QCL(30),QSO4(30),QCA(30),QAMG(30)
        DIMENSION QANA(30),QCD(30),QAMN(30),QANI(30)
        DIMENSION QTA(30),QTC(30),WQI(30)
        DIMENSION WQPH(30),WQDIS(30),WQHCO3(30),WQCO3(30)
        DIMENSION WQCL(30),WQSO4(30),WQCA(30),WQAMG(30)
        DIMENSION WQANA(30),WQCD(30),WQAMN(30),WQANI(30)
        DIMENSION WQTA(30),WQTC(30),WI(30)
        DIMENSION WPH(30),WDIS(30),WHCO3(30),WCO3(30),WCL(30)
        DIMENSION WSO4(30),WCA(30),WAMG(30),WANA(30),WCD(30)
        DIMENSION WAMN(30),WANI(30),WTA(30),WTC(30)
        OPEN (UNIT=21,DIALOG)
        OPEN (UNIT=22,DIALOG)
        READ (21,9)(STA(I),I=1,30)
9       FORMAT  (30A1)
        READ (21,*) N
        READ (21,*) ((PH(I),ORP(I),COND(I),DIS(I)
        1,HCO3(I),CO3(I),CL(I),SO4(I),ANO3(I),ANO2(I)
        2,ANH3(I),APO4(I),CA(I),AMG(I),ANA(I),AK(I),FE(I)
        3,PB(I),ZN(I),CD(I),AMN(I),ANI(I),CO(I)
        4,CU(I),TA(I),TC(I)),I=1,N)
        WRITE(22,10)(STA(I),I=1,30)
10      FORMAT (5X,'STATION:',30A1//)
        WRITE (22,11)
11      FORMAT (27X,'AUG.85',2X,'OCT.85',2X
        1,'DEC.85',2X,'FEB.86',2X,'APR.86',2X,'JULY86',2X
```

```
     2,'OCT.86',2X,'DEC.86'//)
      DO  35 I=1,30
      WPH(I)=2.5
      IF (PH(I).EQ.-1.1.OR.PH(I).EQ.-1.0) GO TO 101
      IF (((PH(I)-7)/2.0).GT.1) GO TO 201
      IF (((PH(I)-7.0/2.0)).LT.0) GO TO 202
      QPH(I)=(150*(PH(I)-7.0))+100.0
 50   WQPH(I)=WPH(I)*QPH(I)
      WDIS(I)=2.5
      IF (DIS(I).EQ.-1.1.OR.DIS(I).EQ.-1.0) GO TO 102
      IF (((DIS(I)-10.0)/490.0).GT.1) GO TO 203
      IF (((DIS(I)-10.0)/490.0).LT.0) GO TO 204
      QDIS(I)=(0.61*(DIS(I)-10.0))+100.0
 51   WQDIS(I)=WDIS(I)*QDIS(I)
      WHCO3(I)=3.0
      IF (HCO3(I).EQ.-1.1.OR.HCO3(I).EQ.-1.0) GO TO 103
      IF (((HCO3(I)-20.0)/240.0).GT.1) GO TO 205
      IF (((HCO3(I)-20.0)/240).LT.0) GO TO 206
      QHCO3(I)=(1.25*(HCO3(I)-20.0))+100.0
 52   WQHCO3(I)=WHCO3(I)*QHCO3(I)
      WCO3(I)=1.5
      IF (CO3(I).EQ.-1.1.OR.CO3(I).EQ.-1.0) GO TO 104
      IF (((CO3(I)-1.0)/19.0).GT.1) GO TO 207
      IF (((CO3(I)-1.0)/19.0).LT.0) GO TO 208
      QCO3(I)=(15.8*(CO3(I)-1.0))+100.0
 53   WQCO3(I)=WCO3(I)*QCO3(I)
      WCL(I)=3.0
      IF (CL(I).EQ.-1.1.OR.CL(I).EQ.-1.0) GO TO 105
      IF (((CL(I)-5.0)/25.0).GT.1) GO TO 209
      IF (((CL(I)-5.0)/25.0).LT.0) GO TO 210
      QCL(I)=(12*(CL(I)-5.0))+100.0
 54   WQCL(I)=WCL(I)*QCL(I)
      WSO4(I)=3.5
      IF (SO4(I).EQ.-1.1.OR.SO4(I).EQ.-1.0) GO TO 106
      IF (((SO4(I)-10.0)/190.0).GT.1.) GOTO 211
      IF (((SO4(I)-10.0)/19.0).LT.0.) GO TO 212
      QSO4(I)=(1.6*(SO4(I)-10.0))+100.0
```

```
55      WQSO4(I)=WSO4(I)*QSO4(I)
        WCA(I)=3.0
        IF (CA(I).EQ.-1.1.OR.CA(I).EQ.-1.0) GO TO 107
        IF (((CA(I)-10.0)/190.0).GT.1.) GO TO 213
        IF (((CA(I)-10.0)/190.0).LT.0) GO TO 214
        QCA(I)=(1.6*(CA(I)-10.0))+100.0
56      WQCA(I)=WCA(I)*QCA(I)
        WAMG(I)=3.0
        IF (AMG(I).EQ.-1.1.OR.AMG(I).EQ.-1.1) GO TO 108
        IF (((AMG(I)-2.0)/48.0).GT.1) GOTO 215
        IF (((AMG(I)-2.0)/48.0).LT.0) GO TO 216
        QAMG(I)=(6.25*(AMG(I)-2.0))+100.0
57      WQAMG(I)=WAMG(I)*QAMG(I)
        WANA(I)=3.0
        IF (ANA(I).EQ.-1.1.OR.ANA(I).EQ.-1.0) GO TO 109
        IF (((ANA(I)-2.0)/8.0).GT.1) GO TO 217
        IF (((ANA(I)-2.0)/8.0).LT.0) GO TO 218
        QANA(I)=(37.5*(ANA(I)-2.0))+100.0
58      WQANA(I)=WANA(I)*QANA(I)
        WCD(I)=4.0
        IF (CD(I).EQ.-1.1.OR.CD(I).EQ.-1.0) GO TO 110
        IF (((CD(I)-0)/50).GT.0) GO TO 219
        IF (((CD(I)-0)/50).LT.1) GO TO 220
        QCD(I)=(6*(CD(I)-0.0))+100.0
59      WQCD(I)=WCD(I)*QCD(I)
        WAMN(I)=3.5
        IF (AMN(I).EQ.-1.1.OR.AMN(I).EQ.-1.0) GO TO 111
        IF (((AMN(I)-50.0)/50.0).GT.0) GO TO 221
        IF (((AMN(I)-50.0)/50.0).LT.0) GO TO 222
        QAMN(I)=(6*(AMN(I)-50.0))+100.0
60      WQAMN(I)=WAMN(I)*QAMN(I)
        WANI(I)=3.5
        IF (ANI(I).EQ.-1.1.OR.ANI(I).EQ.-1.0) GO TO 112
        IF (((ANI(I)-5.0)/95.0).GT.1) GO TO 223
        IF (((ANI(I)-5.0)/95.0).LT.0) GO TO 224
        GANI(I)=(3.16*(ANI(I)-5.0))+100
61      WQANI(I)=WANI(I)*QANI(I)
```

```
      WTA(I)=3.0
      IF (TA(I).EQ.-1.1.OR.TA(I).EQ.-1.0) GO TO 113
      IF (((TA(I)-1.0)/9.0).GT.1) GO TO 225
      IF (((TA(I)-1.0)/9.0).LT.0) GO TO 226
      QTA(I)=(33.3*(TA(I)-1.0))+100
62    WQTA(I)=WTA(I)*QTA(I)
      WTC(I)=3.0
      IF (QTC(I).EQ.-1.1.OR.QTC(I).EQ.-1.0) GO TO 114
      IF (((TC(I)-1.0)/9.0).GT.1) GO TO 227
      IF ((TC(I)-1.09/9.0).LT.0) GO TO 228
      QTC(I)=(33.3*(TC(I)-1.0))+100
63    WQTC(I)=WTC(I)*QTC(I)
      GO TO 90
101   QPH(I)=-0.000
      GO TO 50
201   QPH(I)=400.0
      GO TO 50
202   QPH(I)=100.0
      GO TO 50
102   QDIS(I)=-0.000
      GO TO 51
203   QDIS(I)=400.0
      GO TO 51
204   QDIS(I)=100.0
      GO TO 51
103   QHCO3(I)=-0.000
      GO TO 52
205   QHCO3(I)=400.0
      GO TO 52
206   QHCO3(I)=100.0
      GO TO 52
104   QCO3(I)=-0.000
      WCO3(I)=0.0
      GO TO 53
207   QCO3(I)=400.0
      GO TO 53
208   QCO3(I)=100.0
```

```
          GO TO 53
105       QCL(I)=-0.000
          GO TO 54
209       QCL(I)=400.0
          GO TO 54
210       QCL(I)=100.0
          GO TO 54
106       QSO4(I)=-0.000
          GO TO 55
211       QSO4(I)=400.0
          GO TO 55
212       QSO4(I)=100.0
          GO TO 55
107       QCA(I)=-0.000
          GO TO 56
213       QCA(I)=400.0
          GO TO 56
214       QCA(I)=100.0
          GO TO 56
108       QAMG(I)=-0.000
          GO TO 57
215       QAMG(I)=400.0
          GO TO 57
216       QAMG(I)=100.0
          GO TO 57
109       QANA(I)=-0.000
          GO TO 62
217       QANA(I)=400.0
          GO TO 62
218       QANA(I)=100.0
          GO TO 62
110       QCD(I)=-0.000
          GO TO 59
219       QCD(I)=400.0
          GO TO 59
220       QCD(I)=100.0
          GO TO 59
```

```
 111      QAMN(I)=-0.000
          GO TO 60
 221      QAMN(I)=400.0
          GO TO 60
 222      QAMN(I)=100.0
          GO TO 60
 112      QANI(I)=-0.000
          GO TO 61
 223      QANI(I)=400.0
          GO TO 61
 224      QANI(I)=100.0
          GO TO 61
 113      QTA(I)=-0.000
          GO TO 62
 225      QTA(I)=400.0
          GO TO 62
 226      QTA(I)=100.0
          GO TO 62
 114      QTC(I)=-0.000
          GO TO 63
 227      QTC(I)=400.0
          GO TO 63
 228      QTC(I)=100.0
          GO TO 63
 90       WI(I)=(WPH(I)+WDIS(I)+WHCO3(I)+WCO3(I)+WCL(I)+WSO4(I)
          1+WCA(I)+WAMG(I)+WCD(I)+WANA(I)+WAMN(I)+WANI(I)+WTA(I)
          2+WTC(I))
          WQI(I)=((WQPH(I)+WQDIS(I)+WQHCO3(I)+WQCO3(I)+WQCL(I)
          1+WQSO4(I)+WQCA(I)+WQAMG(I)+WQANA(I)+WQCD(I)+WQAMN(I)
          2+WQANI(I)+WQTA(I)+WQTC(I))/WI(I))
          TYPE *,WQI(I)
 35       CONTINUE
          WRITE(22,12) (QPH(I),I=8,N)
          WRITE(22,13) (QDIS(I),I=8,N)
          WRITE(22,14) (QHCO3(I),I=8,N)
          WRITE(22,15) (QCO3(I),I=8,N)
          WRITE(22,16) (QCL(I),I=8,N)
```

```
      WRITE(22,17) (QSO4(I),I=8,N)
      WRITE(22,18) (QCA(I),I=8,N)
      WRITE(22,19) (QAMG(I),I=8,N)
      WRITE(22,20) (QANA(I),I=8,N)
      WRITE(22,21) (QCD(I),I=8,N)
      WRITE(22,22) (QAMN(I),I=8,N)
      WRITE(22,23) (QANI(I),I=8,N)
      WRITE(22,24) (QTA(I),I=8,N)
      WRITE(22,25) (QTC(I),I=8,N)
      WRITE(22,40) (WQI(I),I=8,N)
12    FORMAT('QPH',24X,20F8.2)
13    FORMAT('QDIS',23X,20F8.2)
14    FORMAT('QHCO3',22X,20F8.2)
15    FORMAT('QCO3',23X,20F8.2)
16    FORMAT('QCL',23X,20F8.2)
17    FORMAT('QSO4',21X,20F8.2)
18    FORMAT('QCA',24X,20F8.2)
19    FORMAT('QAMG',22X,20F8.2)
20    FORMAT('QANA',22X,20F8.2)
21    FORMAT('QCD',23X,20F8.2)
22    FORMAT('QAMN',22X,20F8.2)
23    FORMAT('QANI',23X,20F8.2)
24    FORMAT('QTA',23X,20F8.2)
25    FORMAT('QTC',23X,20F8.2)
40    FORMAT('WQI',22X,20F8.2)
      STOP
      END
```

APPENDIX-6

```
*****************************************************
C        THIS PROGRAMME IS TO CALCULATE THE
C        MINERAL INDEX (RPI)
******************************************************
         DIMENSION PH(30),ORP(30),COND(30),DIS(30)
         DIMENSION HCO3(30),CO3(30),CL(30),SO4(30)
         DIMENSION ANO3(30),ANO2(30),ANH3(30),CA(30)
         DIMENSION AMG(30),ANA(30),AK(30),FE(30)
         DIMENSION PB(30),ZN(30),CD(30),AMN(30)
         DIMENSION ANI(30),CO(30),CU(30),STA(30)
         DIMENSION TA(30),TC(30),APO4(30)
         DIMENSION QPH(30),QDIS(30),QHCO3(30),QCO3(30)
         DIMENSION QCL(30),QSO4(30),QCA(30),QAMG(30)
         DIMENSION QANA(30),QCD(30),QAMN(30),QANI(30)
         DIMENSION QTA(30),QTC(30),WQI(30)
         DIMENSION WQPH(30),WQDIS(30),WQHCO3(30),WQCO3(30)
         DIMENSION WQCL(30),WQSO4(30),WQCA(30),WQAMG(30)
         DIMENSION WQANA(30),WQCD(30),WQAMN(30),WQANI(30)
         DIMENSION WQTA(30),WQTC(30),WI(30)
         DIMENSION WPH(30),WDIS(30),WHCO3(30),WCO3(30),WCL(30)
         DIMENSION WSO4(30),WCA(30),WAMG(30),WANA(30),WCD(30)
         DIMENSION WAMN(30),WANI(30),WTA(30),WTC(30)
         OPEN (UNIT=21,DIALOG)
         OPEN (UNIT=22,DIALOG)
         READ (21,9)(STA(I),I=1,30)
9        FORMAT (30A1)
         READ (21,*) N
         READ (21,*) ((PH(I),ORP(I),COND(I),DIS(I)
         1,HCO3(I),CO3(I),CL(I),SO4(I),ANO3(I),ANO2(I)
         2,ANH3(I),APO4(I),CA(I),AMG(I),ANA(I),AK(I),FE(I)
         3,PB(I),ZN(I),CD(I),AMN(I),ANI(I),CO(I)
         4,CU(I),TA(I),TC(I)),I=1,N)
         WRITE(22,10)(STA(I),I=1,30)
10       FORMAT (5X,'STATION:',30A1//)
         WRITE (22,11)
11       FORMAT (27X,'AUG.85',2X
         2,'OCT.85',2X,'DEC.85',2X,'FEB.86',2X
```

```
        3,'APR.86',2X,'JULY86',2X,'OCT.86',2X,'DEC.86'//)
        DO  35 I=1,10
        IF (PH(I).EQ.-1.1.OR.PH(I).EQ.-1.0) GO TO 101
        QPH(I)=10*(PH(I)/7.0)
50      IF (DIS(I).EQ.-1.1.OR.DIS(I).EQ.-1.0) GO TO 102
        QDIS(I)=10*(DIS(I)/10.0)
51      IF (HCO3(I).EQ.-1.1.OR.HCO3(I).EQ.-1.0) GO TO 103
        QHCO3(I)=10*(HCO3(I)/20.0)
52      IF (CO3(I).EQ.-1.1.OR.CO3(I).EQ.-1.0) GO TO 104
        QCO3(I)=10*(CO3(I)/1.0)
53      IF (CL(I).EQ.-1.1.OR.CL(I).EQ.-1.0) GO TO 105
        QCL(I)=10*(CL(I)/5.0)
54      IF (SO4(I).EQ.-1.1.OR.SO4(I).EQ.-1.0) GO TO 106
        QSO4(I)=10*(SO4(I)/10.0)
55      IF (CA(I).EQ.-1.1.OR.CA(I).EQ.-1.0) GO TO 107
        QCA(I)=10*(CA(I)/10.0)
56      IF (AMG(I).EQ.-1.1.OR.AMG(I).EQ.-1.1) GO TO 108
        QAMG(I)=10*(AMG(I)/2.0)
57      IF (ANA(I).EQ.-1.1.OR.ANA(I).EQ.-1.0) GO TO 109
        QANA(I)=10*(ANA(I)/2.0)
58      IF (CD(I).EQ.-1.1.OR.CD(I).EQ.-1.0) GO TO 110
        QCD(I)=10*(CD(I)/50.0)
59      IF (AMN(I).EQ.-1.1.OR.AMN(I).EQ.-1.0) GO TO 111
        QAMN(I)=10*(AMN(I)/50.0)
60      IF (ANI(I).EQ.-1.1.OR.ANI(I).EQ.-1.0) GO TO 112
        QANI(I)=10*(ANI(I)/5.0)
61      IF (TA(I).EQ.-1.1.OR.TA(I).EQ.-1.0) GO TO 113
        QTA(I)=10*(TA(I)/1.0)
62      IF (QTC(I).EQ.-1.1.OR.QTC(I).EQ.-1.0) GO TO 114
        QTC(I)=10*(TC(I)/1.0)
        GO TO 90
101     QPH(I)=0.000
        GO TO 50
102     QDIS(I)=0.000
        GO TO 51
103     QHCO3(I)=0.000
        GO TO 52
```

```
104   QCO3(I)=0.000
      GO TO 53
105   QCL(I)=0.000
      GO TO 54
106   QSO4(I)=0.000
      GO TO 55
107   QCA(I)=0.000
      GO TO 56
108   QAMG(I)=0.000
      GO TO 57
109   QANA(I)=0.000
      GO TO 58
110   QCD(I)=0.000
      GO TO 59
111   QAMN(I)=0.000
      GO TO 60
112   QANI(I)=0.000
      GO TO 61
113   QTA(I)=0.000
      GO TO 62
114   QTC(I)=0.000
90    WI(I)=(QPH(I)+QDIS(I)+QHCO3(I)+QCO3(I)+QCL(I)+QSO4(I)
      1+QCA(I)+QAMG(I)+QCD(I)+QANA(I)+QAMN(I)+QANI(I)+QTA(I)
      2+QTC(I))
      TYPE *,WI(I)
      WQI(I)=0.666*WI(I)
      TYPE *,WQI(I)
35    CONTINUE
      WRITE(22,12) (QPH(I),I=1,N)
      WRITE(22,13) (QDIS(I),I=1,N)
      WRITE(22,14) (QHCO3(I),I=1,N)
      WRITE(22,15) (QCO3(I),I=1,N)
      WRITE(22,16) (QCL(I),I=1,N)
      WRITE(22,17) (QSO4(I),I=1,N)
      WRITE(22,18) (QCA(I),I=1,N)
      WRITE(22,19) (QAMG(I),I=1,N)
      WRITE(22,20) (QANA(I),I=1,N)
```

```
         WRITE(22,21) (QCD(I),I=1,N)
         WRITE(22,22) (QAMN(I),I=1,N)
         WRITE(22,23) (QANI(I),I=1,N)
         WRITE(22,24) (QTA(I),I=1,N)
         WRITE(22,25) (QTC(I),I=1,N)
         WRITE(22,39) (WI(I),I=1,N)
         WRITE(22,40) (WQI(I),I=1,N)
12       FORMAT ('QPH',24X,20F8.2)
13       FORMAT ('QDIS',23X,20F8.2)
14       FORMAT ('QHCO3',22X,20F8.2)
15       FORMAT ('QCO3',23X,20F8.2)
16       FORMAT ('QCL',24X,20F8.2)
17       FORMAT ('QSO4',23X,20F8.2)
18       FORMAT ('QCA',24X,20F8.2)
19       FORMAT ('QMG',24X,20F8.2)
20       FORMAT ('QNA',24X,20F8.2)
21       FORMAT ('QCD',24X,20F8.2)
22       FORMAT ('QMN',24X,20F8.2)
23       FORMAT ('QNI',24X,20F8.2)
24       FORMAT ('QTA',24X,20F8.2)
25       FORMAT ('QTA',24X,20F8.2)
39       FORMAT ('WI(I)',24X,20F8.2)
40       FORMAT('WQI',23X,20F8.2)
         STOP
         END
```