HYDROCHEMICAL STUDY IN THE PENCH VALLEY COAL MINE AREA, MADHYA PRADESH

A THESIS

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

By

MOHAMMED IRFAN ULLAH

DEPARTMENT OF EARTH SCIENCES
UNIVERSITY OF ROORKEE
ROORKEE - 247 667 (INDIA)

FEBRUARY, 1995

Gratis

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **HYDROCHEMICAL STUDY IN THE PENCH VALLEY COAL MINE AREA, MADHYA PRADESH** in fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy**, submitted in the **Department of Earth Sciences, University of Roorkee**, is an authentic record of my own work carried out during the period from February 1989 to February 1995 under the supervision of Dr. V.K.S. Dave and Dr. S.S. Srivastava.

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

M. Irfan ullah
(MOHD. IRFAN ULLAH)

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

Date: February 24, 1995

(Dr.V.K.S. Dave)
Professor
Deptt. of Earth Sciences
University of Roorkee
ROORKEE-247667

(Dr.S.S.Srivastava)
Professor
Deptt. of Earth Sciences
University of Roorkee
ROORKEE-247667

The Ph.D. Viva-Voce examination of **Mr. Mohd. Irfan Ullah**, Research Scholar, has been held

on 22-1-1996.

Signature of Supervisors(s)

Signature of External Examiner

ABSTRACT

The area under study is a part of Pench Valley Coalfields and lies in Chhindwara district of Madhya Pradesh, India. The geographic co-ordinates of the region are 22°10'-15' latitudes and 78°40'-50' longitudes, a small region which can be classed as rural. The river Pench flows west to east in this sector which is joined in by three tributaries from the north. Typical deccan trap morphology dominates, giving an overall rugged appearance to the area.

The presence of coal has promoted mining industry for over a century and a highly developed mining infrastructure is working in the region. The topmost workable coal seam is nearing exhaustion but the II and III horizons are under production. The geochemistry of Pench area has undergone a great change as a result of regular coal mining. The groundwater which is accumulated in the mines is constantly pumped out in order to facilitate working. This water in most cases is directly poured into the river Pench through crudely constructed drains or naturally available streams. The continual large scale pumping onto the surface, in general, results in drop of water table and even complete drying of wells in summer; thereby depriving the local inhabitants to resort to easily available, effluent, minewater drains for fulfilling their basic needs. Such a practice of directly utilizing the untreated minewater for irrigation and occasionally even for drinking purposes *(when there remains no other source of water available nearby)* has gained popularity under binding human needs for bare necessities. This has become quite common in the past few years, and has led us to study mine related effects on the natural environment and the response of natural environment to adjust to the changed physico-chemical conditions. Moreover, the size of the area being in few tens of square kilometers demands a pin pointed study to depict the behaviour of major and trace elements in the recent geological setup.

The main concern of the present study was to monitor and evaluate the impact of mining over the environmental health and ensuing geochemical degradation of the surroundings. The study was taken up with the objectives to look for the behaviour of major and trace elements responsible for human health, with special attention towards effects of mining on soils, waters and on the inhabitants.

After a thorough reconnaissance survey, the sampling sites were selected to be monitored for pre- and post-monsoon periods for the Groundwater, Surfacewater and Minewater. Samples of all the waters were drawn for two consecutive years *(1991 & 1992)* for assessing the trace elements and other water quality parameters.

The soils were surveyed and representative samples were picked up to undergo cold extraction *(leaching)*. The leachate was then analyzed to imbibe the soil chemical responses to the variety of waters pervading the region. The laboratory results are thus compared to the natural soils. Spatial variation of different parameters has also been attempted to, by virtue of *Isocon* maps, so that the variations within the region are focused in and pointed out which are generally overlooked.

Finally, an assessment is made to evaluate the area based on water and soil responses for the behaviour of trace elements and other water quality parameters. Hence, the study presents a fundamental picture of the ongoing geochemical variations and interprets their future trends so that adequate grasp is made in time.

ACKNOWLEDGEMENT

I am thankful to none but 'Allah' alone, who is 'Alive' and is the only 'Master' of the Universe. Who shaped the things in a manner that I am able to complete the work summarized in this document. Who only, provided hundreds of helping hands to bring it in this form. Who framed vicissitudes, so that we are judged accordingly as we perform.

I express my especial gratitudes to Prof. V.K.S. Dave, for his meekness, simplicity, honesty and the knowledge which provided me confidence to fend for myself during the tenure of research work. I wish to acknowledge Prof. D.C. Singhal, for his firmness on words and moral soundness which will always be an example to me and my allies.

The last moment help, generosity, and above all the humanity, of which I am emotionally indebted, and I wish to endorse it so that it is remembered on and on, is heartily acknowledged for Prof. S.S. Srivastava. The work would have died in cupboard, had not he been there with encouragement and fraternal understanding.

I am grateful to the faculty and staff of the department of Earth Sciences, from whom I have learnt and benefited immensely during my stay.

I wish to express my personal gratefulness to Dr. C.K. Jain, for making valuable suggestions in this work.

I am further obliged to the help provided to me, time to time, by the officials and workers of various government agencies of my own country.

I acknowledge the captivating surroundings of Himalaya which kept my working spirit alive. I wish to acknowledge the combination of toughness and beauty it has offered to me alongwith the truth of companionship - I share with my mates.

The acknowledgement would remain incomplete if I do not mention the fateful developments as part of my stay.

The mockery of a helpless, under the clutches of, so called, imparters of knowledge and learning. The sway of pendulum between the hope and dismay. The shimmering gleam of fortune playing hide and seek, and big shadows trying to cover it for their vested interests. The world of hollow pride and the ego unleashed to the fullest. The greed of worldly benefits and the ruthless indifference to the cause. The suppression of truth under the hypocritical veils of condescence. The moments longer than aeons, and the spates of sorrow and pain.

Time and tide wait for none, so are the years gone by.

The silent help, brotherly support and bonds of fellowship offered by Furqanullah Bhai and whole of his family, specially, at the moment when it was needed most is acknowledged with indebtedness and sincere regards.

I am short of words to express my feelings for my friend Pankaj, a man upright and good, who stood besides me as my mate during the toughness and troubles and was always the first whenever I sought help. Bhabhijan, is especially acknowledged along-with Didi, Jija ji and Kids.

I wish to quote a few names for whom I have no words appropriate enough to show my formal/informal feelings as they are truly special : Dada (Semwal), Sardar (Amarjeet), Kirru (Kiran) & Bhabhi, Dharmu, P.K., Sharma ji (Janakraj), Bharti, Scientist (Vijay), Shikari (Verma Ji), Sanjeev Sharma, Tarun Raghuvanshi, Guddu Bhaiya (Anurag) & Bhabhi, Uncle (Prof.Nayak) & Auntie, Tasneem, Hamid, Imran, Baureek, Dr. A.K. Seth, Dr. P.K.S. Chauhan, H.N. Sinha, Abid, Izhar, Zulfi, Nepal, Abdullah, Ghazi, Dhall, Sreen, Saurabh, Sarun, Tara, Satyaki, Pachchu, Yogi, Nayar, Dinesh Mohan (WRL), Mehdi, Amersingh, Baburam and all Soccer friends.

Financial support for the study was generously provided by the Council of Scientific and Industrial Research (CSIR) which is gratefully acknowledged.

Lastly, but not the least, I am obliged to Messrs. Sanjay and Atul (Santosh and Atul Printers) for the unrestricted and extraordinary help they have offered in final touches and printing of this work.

The truth is, parents are above all, so are my sisters loving, caring and true well-wishers. With this I conclude.

M. Irfan Ullah

CONTENTS

CHAPTER 1
INTRODUCTION

GENERAL

In Madhya Pradesh, coal mining has been carried out since over a century and a sizable rate of production is achieved over a period of time. However, most of the mining is done manually. In a number of mines both underground and open cast mining are being resorted to, without adequate planning; thus the environmental imbalance exits in many of these mining areas. The natural waters of area get contaminated by mine water which may result in occurrence of diseases amongst the mining personnel as well as other inhabitants. However, no scientific study was available to decipher such geoenvironmental disorders, if at all they existed.

OBJECTIVE

In the recent past there had been a thrust over nonconventional, interdisciplinary studies which are of applied nature. The present study has been taken up with the objectives to ascertain adverse effects of coal mining on the geochemistry of soils and waters in Pench Valley Coal mine area of Western Coalfields Limited Madhya Pradesh and it's influence on the inhabitants. The behaviour of selected trace elements responsible for human health was also monitored in the natural waters and soils of the area.

THE AREA OF STUDY

Location And Accessibility

The Pench Valley Coal mining area is situated in the northwest of Chhindwara town between 22° 10'-15'N latitudes and 78°40'-50' longitudes and falls within the administrative limits of Chhindwara district of Madhya Pradesh, India. Parasia is the prominent settlement of this region which in fact is an important colliery township. The mining headquarters, miners main hospital and other such offices are located in and around this very township. The Parasia is connected with Chhindwara by 25 kms. long stretch of road and railways, and it falls on the Nagpur-Panchmarhi proposed highway which passes through Chhindwara. Chhindwara being the largest township of the region is well linked from Nagpur *(128 kms.)* and Jabalpur *(215 kms.)* by road. Apart from railway connections from Amla and Nagpur, the bus route is the most important means of approach to the region. *(Fig. 1.1 & 1.2)*

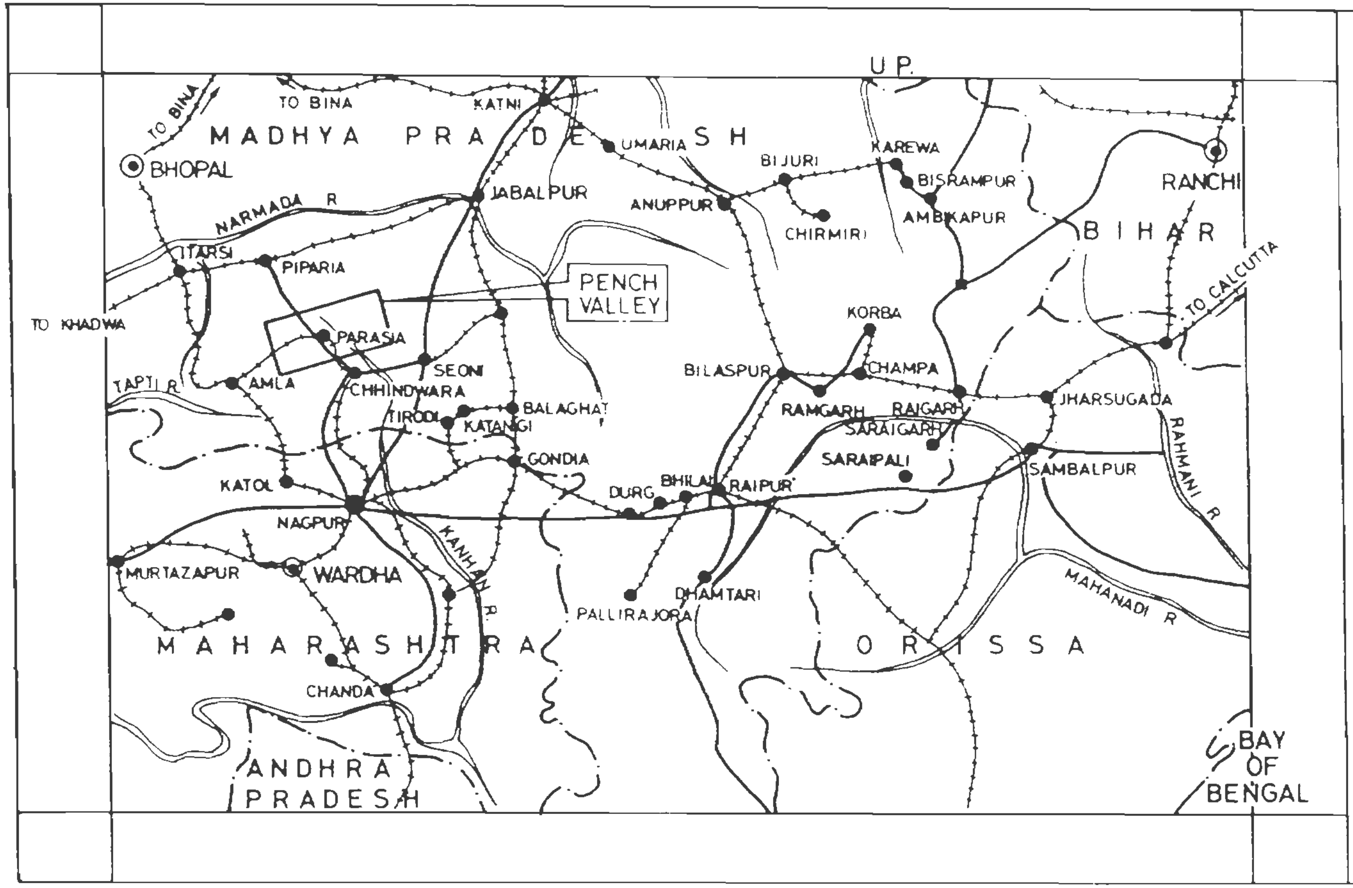
Climate

General

The Pench valley region, situated within 720m and 900m msl altitude, witnesses comparatively milder tropical climate than the neighboring areas to the south and east having attitude of 300m msl or so.

Rainfall

The annual rainfall of the district is 1269.1 mm. About 85% of the annual rainfall is received during mid June to September, July being the rainiest month. On an average there are 64 rainy days *(i.e. rainfall ≥ 2.5 mm.)* in a year in this province. *(Climate of Madhya Pradesh, 1981)*



N

ACCESSIBILITY MAP OF PENCH VALLEY AREA

LEGEND

ROADWAYS	——
STATE BOUNDARY	—·—·—
RIVER	═
RAILWAY LINE	+++++

(NOT TO SCALE)

FIG.1.1

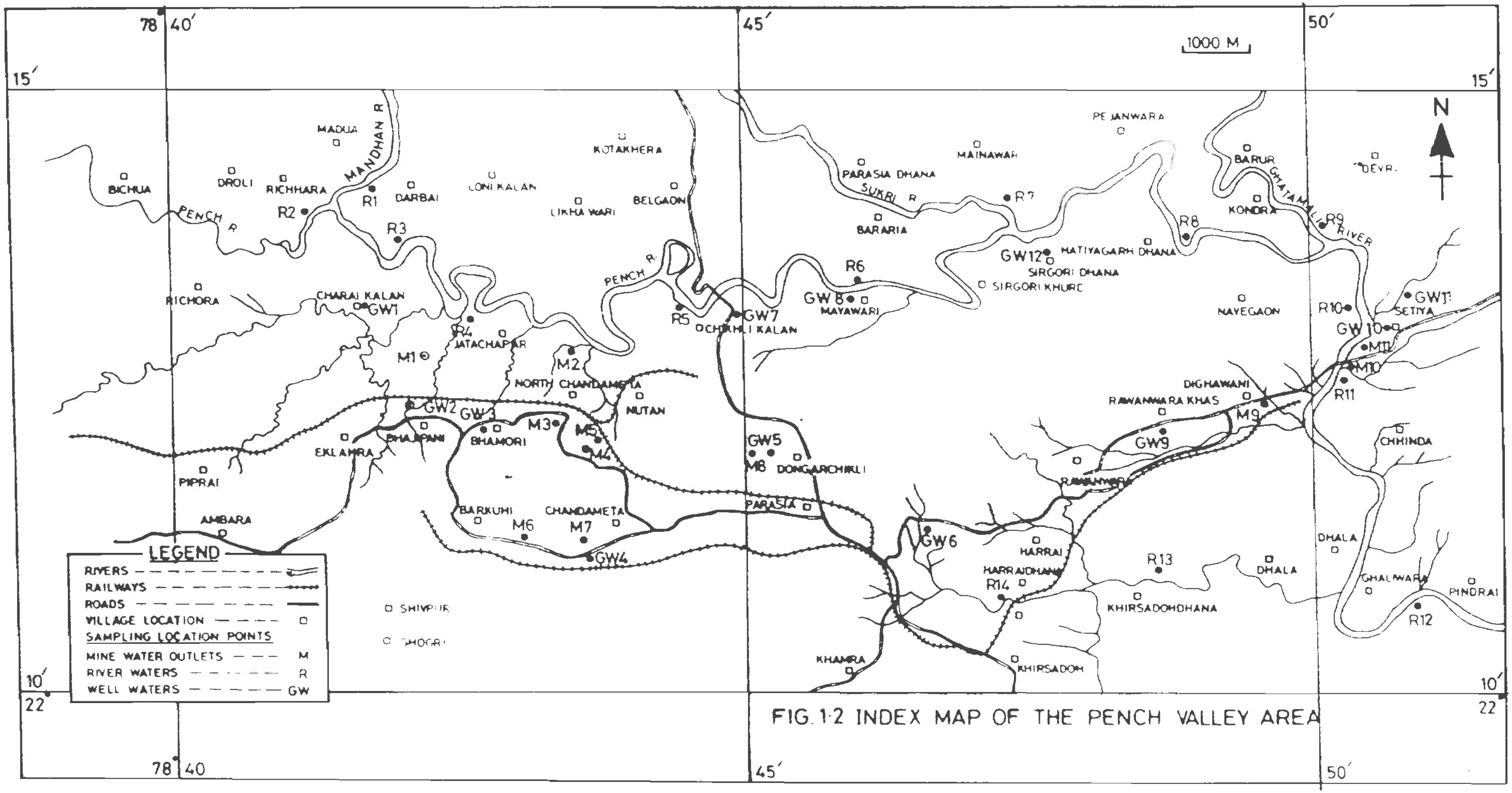


FIG. 1·2 INDEX MAP OF THE PENCH VALLEY AREA

Temperature

Summer season starts in March. May is the hottest month with the mean daily maximum temperature at 39.4°C and mean daily minimum temperature at 26.1°C. With the onset of the monsoon in the district by about the middle of June there is an appreciable drop in temperatures and the weather becomes pleasant. After the withdrawal of the monsoon by about the end of September or early in October, there is a slight increase in day temperatures but nights become progressively cooler. After October there is a rapid decrease in both the day and night temperatures. January is generally the coldest month with the mean daily maximum temperature at 25.5°C and the mean daily minimum at 10.6°C. Nights are comparatively colder in December than in January. During the cold season the district is sometimes affected by cold waves in the wake of western disturbances passing across north India. On such occasions the minimum temperature may drop down to about 3°C.

Humidity

The relative humidity during the southwest monsoon is high generally exceeding 70 per cent. Humidity decreases in the post-monsoon season. The driest part of the year is the summer season with relative humidities less than 25 per cent in the afternoons. *(Climate of Madhya Pradesh, 1981)*

Winds

Winds are generally light with some increase in force during the latter part of the summer and monsoon seasons. In the southwest monsoon season, winds blow mostly from directions between southwest and northwest. In the post-monsoon and cold seasons, winds are mainly from directions between north and northeast. In the summer season, winds blow mainly from directions between west and north.

Special Weather Phenomena

Depressions originating in the Bay of Bengal in the monsoon season move in some westerly direction and pass through or in the neighborhood causing widespread heavy rain and gusty winds. Some of the storms and depressions of the post-monsoon season from the Bay of Bengal also affect the district. Thunderstorms occur in the period March to September. Occasional sand or dust storms occur during summer. *(Climate of Madhya Pradesh, 1981)*

Landuse

About half of the region is occupied by the underground mines. The road side stretches near Rawanwara, Rawanwara Khas, Dighawani and Sethiya are being worked out by open cast. The waste land atop underground mines is occupied by both scattered cultivation and open scrub. The vegetation is sparse on hills. Most crop fields run parallel to the river Pench in the valley extending up to the northern rim. The southern region is devoid of crops where the stony outcrops of Basalt and Granites sustain only sparse vegetation and thorny bushes. The region is well drained in dendritic pattern. The rugged terrain of the northern flank suffers proper transportation and the going gets tough in rainy and post-monsoon seasons.

There are three major soil types covering the region which are the weathering products of three major categories of rocks found in the region viz. Basalt, Sandstones and Granites.

The seasonal rainfall and the nature of soils provide for a variety of vegetation ranging from grasses and thorny trees to deciduous trees of commercial significance like *Sagon (teak), Sal, Haldu, Tendu, Saj, Khair, Semal, Aonla, Chironji, Bans (Bamboo), and Babool.*

The population is dominated by local tribes and clans viz. *Gonds, Korkus, Halbas, Bharais and Raj Gonds*. The region is predominantly rural in character. The villages are small in size *(population = about 500)* in consonance with the nature of the broken country with scattered development. There are relatively dispersed type of settlements with clusters of compact and semi compact settlements in the fertile valleys and flat plateau lands. Both, the type and patterning show dominant control of terrain, in consonance with soil, hydrography, vegetation cover and the nature of general development. The Landuse and Landcover map, given in fig. 1.3 is marked, in addition, with mine layouts. The names of collieries with corresponding number in the map is given as follows :

1. Eklehra Colliery.
2. Barkuhi Colliery.
3. West Barkuhi Colliery.
4. Mohan Colliery.
5. Jatachhapar (Bahamori) Colliery.
6. North Chandameta Colliery.
7. Chandameta Colliery.
8. Newton Chickli Colliery.
9. East Dongar Chickli (EDC) Colliery.
10. Rawanwara Khas Colliery.
11. Rawanwara Colliery.

Occupation

Mining being the only largest industry of the region, the occupation of the major populace is mining related only. Hence, the mining community dominates all others. Apart from this, a considerable faction still prefers the family tradition of peasantry.

On the whole, the labor class outcasts the bourgeois and elites within population.

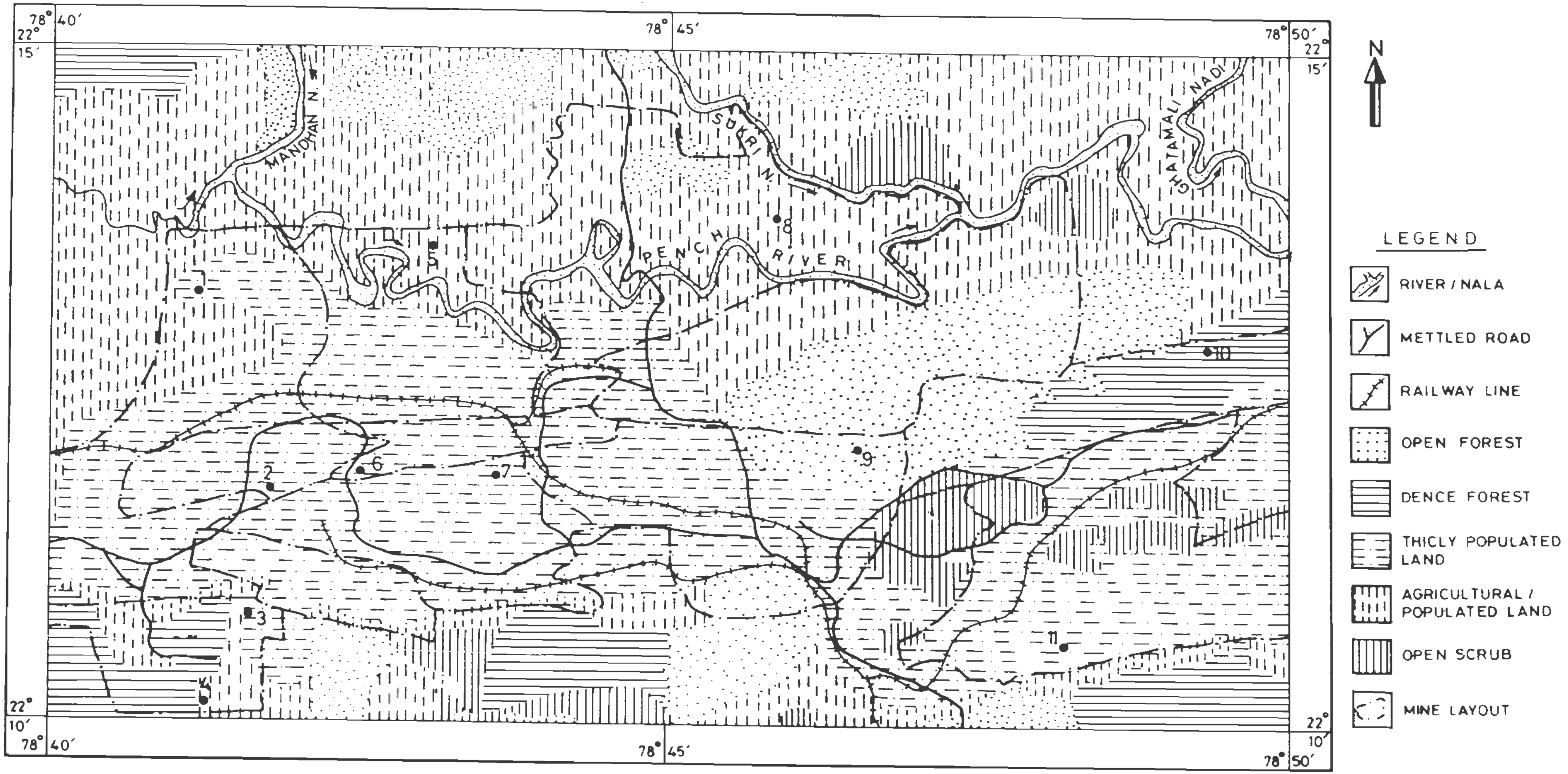


FIG. 1·3 LANDUSE AND LANDCOVER MAP

CHAPTER 2
GEOLOGY

PREVIOUS WORK

The earliest discovery of coal in the Pench Area was made by *Jerdon and R.H. Shankey* who visited the area around 1852. They were followed shortly after by *Hislop and Hunter (1852)*. The first geological traverse was carried out by *J.G. Medlicott* in 1856. Eventually, during the period from 1854 to 1857, *H.B. Medlicott* who was seconded for duty as Professor of Geology at the Thompson College of Engineering, Roorkee, assisted *J.G. Medlicott* in the field work in the Satpura Basin among many areas, whenever he was free from teaching work. It would be interesting here to quote that according to *Holland (1926 pp.78)* the name "Gondwana System" was first proposed by *H.B.Medlicott* in 1872 in his report on the "Satpura Basin". Professor *D.K. Chakravarti,* in one of his writings *(1981)* wishes, *"It would have been more proper for Medlicott to use. in place of Barakar, a local name, Pench, a nala in which he recognized rocks of Barakar type with the lower coal-measures are best developed". A.Sapwith* estimated the reserves of coal in the area in 1867. The whole area was surveyed by *Jones* in 1884-86 and *Hobson* carried out systematic sampling in 1924. *W.D. West and C.S. Fox* resurveyed the area between 1923-25. In the post independence period, *T.K. Chandra, A.K.Srivastava* and *P.K. Ghosh (Jr.)* carried out detailed mapping of Pench-Kanhan Valley Areas during 1958 to 1960 with the object of demarcating potential blocks for increased production. The Geological Survey of India has been engaged in regional assessment of coal resources by drilling and large scale mapping since 1960. The Coal India Ltd. *(Central Mine Planning and Design Institute)* carried out detailed exploration in Rawanwara Khas

(1976) and Shivpuri (1979). Currently Mineral Exploration Corporation Ltd. *(MECL)* is engaged in detailed exploration in a number of blocks viz. Sirgori, Newton Chikli, East Dongar Chikli, Sukri, Sial Ghoghri and in further east towards Haranbhata. In depth sedimentological studies of the Gondwana Formations of Pench Valley have been carried out by *Qidwai and Casshayap (1971, 74, 75, 78)* which second the fitness of fluviatile model for Pench Valley successions based on grain size characteristics as against lacustrine model postulated by earlier workers for the Gondwanas.

TOPOGRAPHICAL SETUP

Physiography

The physiography of coal fields is defined by an undulating country flanked on the north by plateau areas comprising trap covered hills. The most prominent feature of the Satpura region is considered Mahadeva Range located further to the north. The magnificence of the scenery of the Mahadeva Hills is recorded by *Crookshank (1936)* as follows : "*One imagines the holy man toiling up the path beneath the cliffs oppressed by the wonderful works of God and weighed down by the puniness of men. One thinks of "Him" as he reaches the top and the mighty mass of Mahadeo bursts on his astonished gaze falling in silent ecstasies before the masterpiece of nature*".

The Pench area invariably forms part of Satpura Hills. Hillocks and hills dominate the local physiography, and combine to constitute a more or less flattened landform, widely known as Deccan plateau. Basalt, which envelopes the huge tracts of central India giving rise to high Deccan Plateau, rests atop the hills and mounds imparting key role in shaping the face of the Earth. The landform is dominated by typical deccan trap morphology marked by flat topped hills with lateral erosion, boulder covered surfaces and spheroidal weathering. A thick layer of reddish black soil known as black cotton soil generally efface the rock exposures, but it is not rare to locate outcrops on slopes and cut sections. *(Fig. 2.1)*

Drainage

The area typically shows rugged topography with close, dendritic river system. River Pench flows west to east which is joined by three important tributaries namely Mandhan, Sukri and Ghatmala from North. There is no perennial river, however, and all the main rivers can be classed in intermittent category. The valley is occupied by various ephemeral tributaries and gullies which feed to river Pench. The rivers are usually in spate during the peak rainy months of August & September.

LITHO-STRATIGRAPHY AND STRUCTURE

Satpura Region

Geology

Satpura Gondwana basin occupies a unique position in peninsular India. It is the western most Gondwana basin and caters to the coal requirement of western India. Leaving aside the economic aspect of this area, the Satpura basin displays a fascinating geological history in the sedimentary records of Gondwana Sequence which span a wide expanse of geologic time from Permian to Cretaceous. The Gondwana Sequence is unique in many respects. Its homogeneity from top to bottom, the fidelity with which it has preserved the history of the land surface of a large segment of the earth for such a vast measure of time, the peculiar mode of its deposition in slowly sinking faulted troughs into which the rivers of the Gondwana country poured their detritus and the preservation of valuable coal-measures lying undisturbed among them stamp these rocks with striking individuality among the geological successions of India. *(Wadia, 1975)*

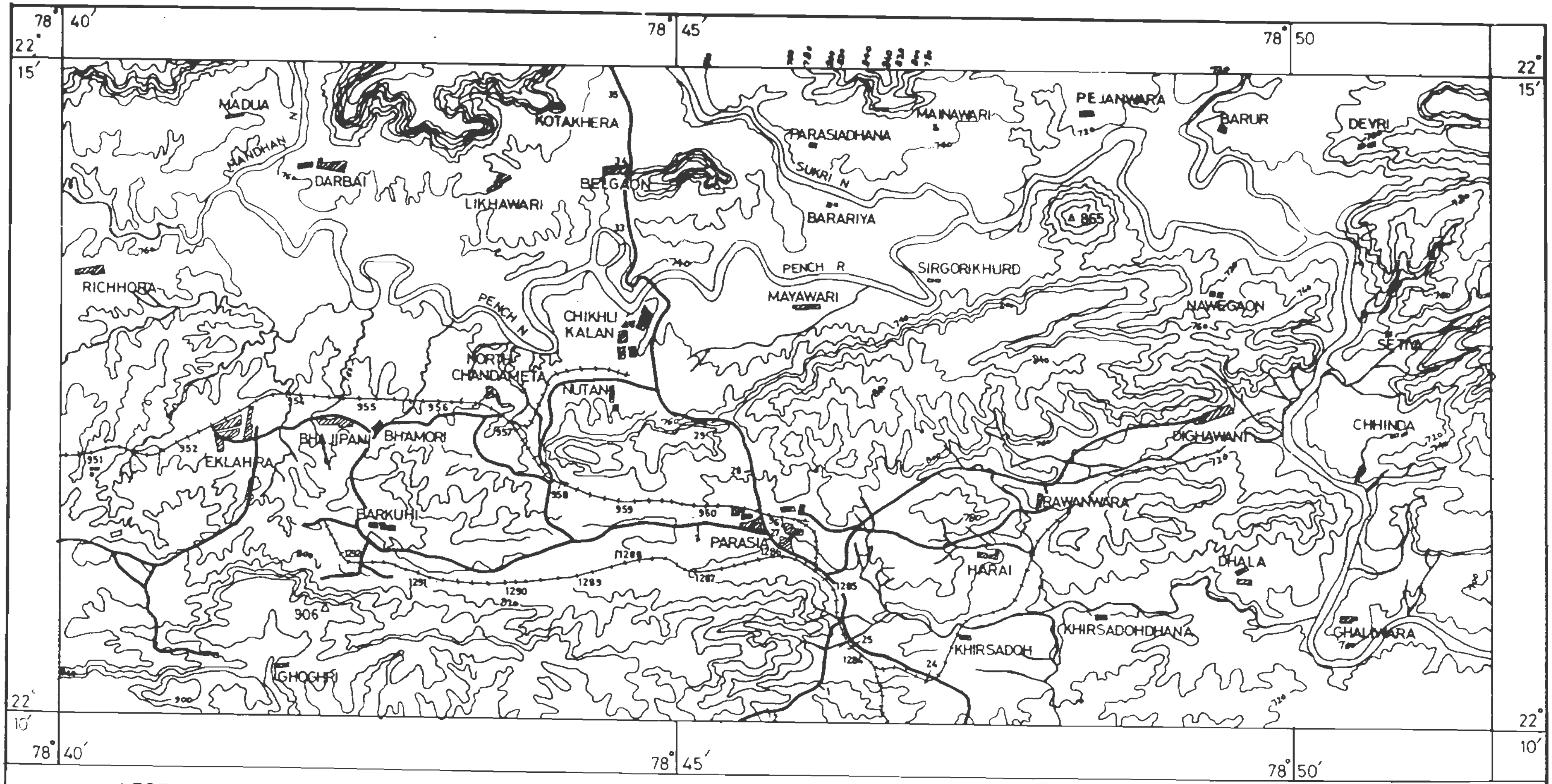
The Gondwana sequence does not conform to the universal geologic time scale, rather it is having its own placement and division in the Geologic time-span. They have been informally designated a position in the standard stratigraphic terminology. However, the tripartite classification of Gondwana roughly fitted to the International Standards so that the lower, middle and upper Gondwana was roughly corresponds to Permian, Triassic and Jurassic systems respectively. *(Ravindra Kumar, 1985)*. We have adopted two fold classification of Gondwanas modified by *Robinson (1967)* in which the boundary *(dividing upper and lower Gondwanas)* was brought down at the base of Panchet formation. Thus in this scheme the lower Gondwanas are mainly Palaeozoics and upper Gondwanas are mainly Mesozoics. *(Table 2.1)*

Table No. 2.1

Generalized Classification of Gondwana Sequence : Satpura Region

Upper Cretaceous to Palaeocene	Deccan Trap	
Upper Cretaceous	Lameta Formation	
Lower Cretaceous to Upper Jurassic	Jabalpur Group	
	——Unconformity——	
Upper Triassic	Bagra Conglomerate	
	——Unconformity——	
Middle Triassic	Denwa Clays	Mahadeva Group
Lower Triassic	Panchmarhi Sst.	
	——Unconformity——	
Upper Permian	Bijori Formation	
Middle Permian	Motur Formation	
Lower Permian	Barakar Formation	
	Karharbari Member	
Upper Carboniferous	Talchir Formation	
	——Unconformity——	
	——Precambrian Base——	

(After Sastry et.al., 1979, and modified after Raja Rao, 1983)



LEGEND

VILLAGE LOCALITIES ▨
RIVER
ROAD
RAILWAYS
CONTOURS
CONTOUR INTERVAL 20 m

km 1 0 1 2 3 km

N

FIG.2·1 PHYSIOGRAPHIC MAP OF PENCH VALLEY AREA

Mode of Origin

The most important fact regarding the Gondwana sequence is its mode of origin. The formation of thousands of meters of river and stream deposits in definite linear tracts can not be explained on any other supposition than the one already briefly alluded to. (*Wadia, 1975*). The pattern of sedimentary infilling in the Satpura trough flanking the Narmada lineament provides an insight into the geodynamic behaviour of this zone of crustal weakness.

There are two views regarding the mechanics of deposition. According to one view, the sedimentation was confined to river valley grabens and was contemporaneous with faulting and continuous sinking. The other view holds that the basins of depositions were originally wider but the rocks are preserved only in down faulted grabens. *(Ravindra Kumar, 1985)*. It is, this sinking of the loaded troughs that tended to guard the Gondwana rocks against denudation to which they would certainly have subjected.

It was the spasmodic tectonism which led to down sinking of the Gondwana troughs by means of a series of step faults, progressive with time. It is very difficult to trace the surface expression of these step faults in the field as these are strike slip faults. The time transgresssive nature of Gondwana sequence is generally explained by virtue of shifting lateral boundaries of the environment and vertical subsidence due to tectonism. Based on this, the deposition of Gondwanas has been termed "Tectono-environmental phenomenon". *(Chakravarti, 1981)*

Climate of Deposition

The Gondwana Sequence has beautifully preserved the marks of several climatic changes in its rocks. The boulder bed at its base tells us of the cold of a Glacial Age at the commencement of the deposition, an inference that is corroborated by the presence of green colored bands, undecomposed feldspar grains and faceted boulders. It slowly transforms to a warmer, vegetation supportive climate, probably of tropical nature as evidenced by the presence of thick coal seams in the strata of succeeding epoch. A reversion of cold climate is recorded by the presence of undecomposed, frost disintegrated clastics in Bijori formation. The Panchmarhi Sandstones represent almost barren and desertified arid climate with ferruginous sandstones.

Structure

The Satpura region is an old rift valley demarcated by parallel faults both to the north and south. The Gondwana formations form a part of a vast *inlier* exposed by the denudation of the bedded volcanic of the Deccan Trap. The magnitudes of the faults on two major sides are very unequal. The rectilinear outline of the Satpura Gondwana Basin can be ascribed to the effect of faults, which trend roughly in east-west direction. The Gondwana formations preserved in this linear trough show a broad synclinal structure with lower Gondwana beds cropping out on either flanks. The lower Gondwanas of southern part dip northwards. Southern boundary of the basin in Chhindwara district is also defined over a considerable length by a fault. In addition to some major faults a series of parallel faults running ENE-WSW affect the Gondwana Sediments to varying degrees. The most striking feature about these intrabasinal faults is that in most cases they have down-throws to the north. This has a considerable bearing on the economics of mining coal. The Satpura basin like most other basins of Gondwana is free of folding disturbances. *(Fig. 2.2)*

Pench Area

Pench Valley is jointly treated with Kanhan Valley in most studies. According to *Fox (1934)* the coal bearing rocks lying within the drainage area of the river Pench

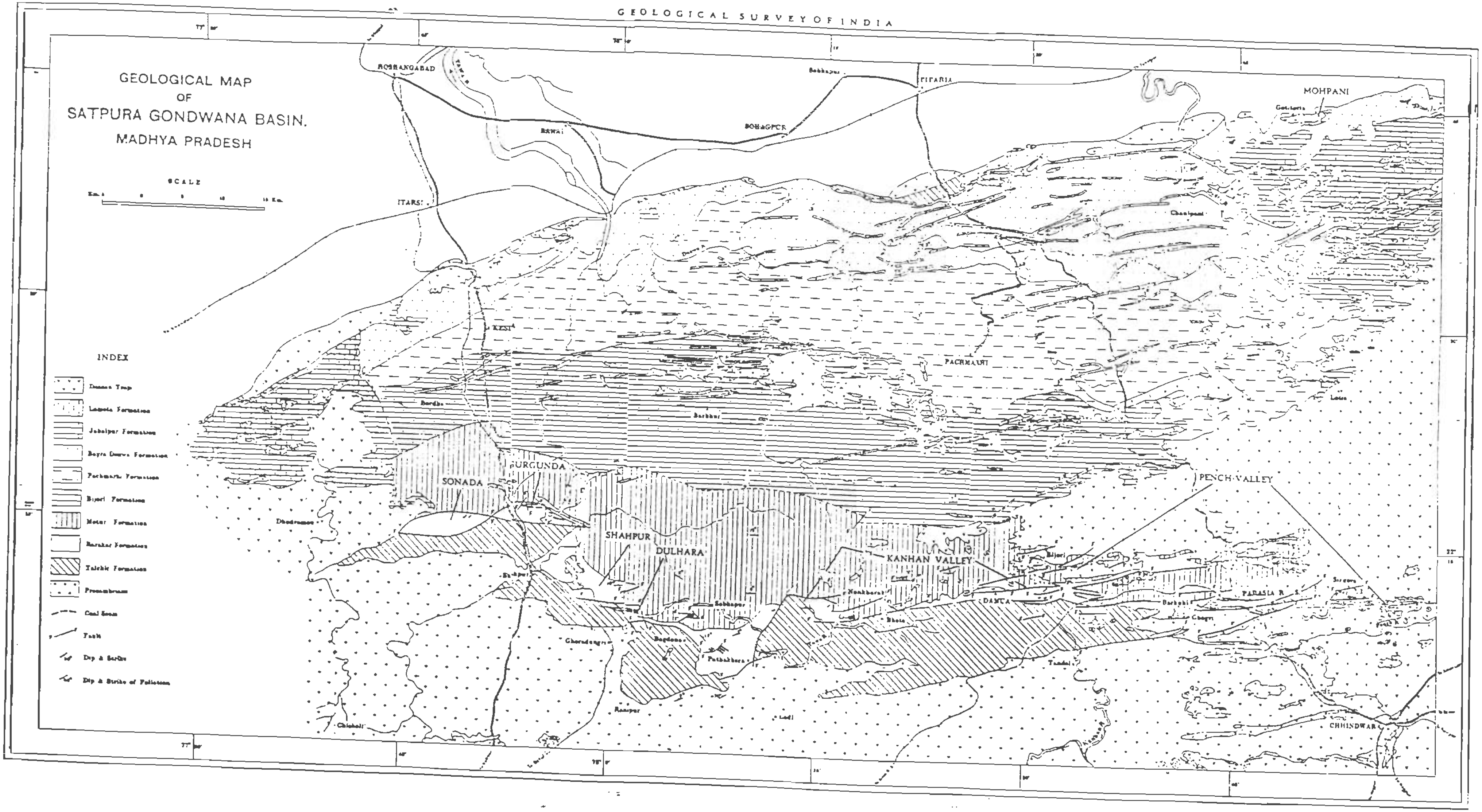

GEOLOGICAL SURVEY OF INDIA
GEOLOGICAL MAP
OF
SATPURA GONDWANA BASIN.
MADHYA PRADESH
SCALE
INDEX
Deccan Trap
Lameta Formation
Jabalpur Formation
Bagra Denwa Formation
Pachmarhi Formation
Bijori Formation
Motur Formation
Barakar Formation
Talchir Formation
Precambrian
Coal Seam
Fault
Dip & Strike
Dip & Strike of Foliation
HOSHANGABAD
ITARSI
BABAI
SOHAGPUR
PIPARIA
MOHPANI
KESLA
PACHMARHI
SONADA
SURGUNDA
SHAHPUR
DULHARA
KANHAN VALLEY
PENCH VALLEY
DAMUA
PARASIA R.
Bijori
CHHINDWARA

Fig. 2.2

form the "Pench Valley Coalfield", while those within river Kanhan, further west, form "Kanhan Valley Coalfield". But the continuous extension of Gondwanas, possibly as part of the same sedimentary basin, seems to justify their common treatment.

Geology

The lowest member of the Gondwana, the Talchir, rests unconformably on the Archaeans and is exposed in the southern portion of the Barakar Rocks that occur in a long strip running east-west, but their exposures are generally met with only in the nala sections. The rocks of Motur formation are found in northern portions of the coalfield. At places they are overlapped by Deccan Trap. The rocks of Bijori and Mahadeva are totally absent from the Pench Area. Moturs are directly overlain by Jabalpurs which extend in patches over a wide area in the eastern part, and are easily recognized by the multicolored pebbles. Deccan Trap has covered major portions of the area to the north. The coal measures are exposed in narrow disconnected patches and are best developed between Barkuhi (22° 11′: 78° 48’) and Parasia (22° 11′: 78° 46′). *(Table 2.2)*

Table 2.2

The Stratigraphic Succession of the Pench Valley Area

Recent	Alluvium
Upper Cretaceous	Deccan Trap
Lower Cretaceous to upper Jurassic	Jabalpur Group
——Unconformity——	
Middle Permian	Motur Formation
Lower Permian	Barakar Formation
Upper Carboniferous	Talchir Formation
——Unconformity——	
——Precambrian Basement——	

After Chandra, 1977

The Precambrian Basement : The metamorphic rocks occur all along the northern and southern margins of the Satpura Gondwana basin. Inliers of metamorphic rocks are also noted within the Talchir sediments near Harradhana. The Precambrian rocks cropping out along the southern margin comprise granite gneiss, hornblende schists, mica schists, quartzites, limestones, pegmatites and quartz veins. *(Raja Rao, 1983)*.

Talchir Formation : The Talchir is as usual defined by a tillite, which comprises dispersed clasts of quartzite, jasper, granite gneiss, hornblende schist, amphibolite, banded quartz, jasper rock, mica schist and phyllite. The tillite is well exposed near Khirsadoh and is usually overlain by pale, greenish yellow, fine grained sandstones with dispersed clasts. Study of the dimensional fabric of the clasts within the tillite *(Casshayap and Qidwai, 1971)* in the south-eastern part of the Pench Valley has indicated that the ice transport was from SE to NW. *(Raja Rao, 1983)*.

Barakar Formation : The Barakar Formation crops out in narrow linear stretches in the southern part of the basin. In the easternmost part, comparatively small patches of Barakar rocks occur near Sirgora. Further west, a large continuous patch extends from Rawanwara to Dighawani. This continues upto Barkuhi through Parasia. To the west of Barkuhi, Barakar beds crop out near Ambara and Ghogri, where Moturs are brought against the Barakars by an oblique fault. Medium to coarse grained sandstones, carbonaceous shales, grey shales and coal seams constitute the Barakar sediments. Over a large part of the Valley, the Barakar/Talchir contact is faulted. Elsewhere, the Talchir sediments appear to pass upward into Barakar Formation with no unconformity. Based on the pattern of vertical variation, the Barakar Formation may be broadly subdivided into lower and upper members. The distinguishing feature of the lower member is the absence of any thick band of coal, while development of workable coal seams characterize the upper member. Analysis of cross bedding dip azimuthal data by *Casshayap and Qidwai* (1971) reveal that the streams had a sinuous regimen and a north-westerly direction of flow. Over the major part of the Pench Valley, it maintains more or less similar thickness except at the eastern extremity around Sirgora, where an attenuated thickness of 78 m to 125 m has been recorded. *(Raja Rao, 1983).*

Motur Formation : This formation overlies the Barakar with a gradational contact and is considered equivalent to the Barren Measures of the type area. The formation has been named after the village of Motur, located 18 km SSE of Panchmarhi, on the main Satpura highland. In the Pench Valley area, the formation comprises buff to red clay, coarse to fine grained feldspathic sandstone, greenish grey shale, carbonaceous shale and coal laminae. Here argillaceous units form the bulk of the clastic fill. The system of streams which laid down the Motur sediments has a north-westerly direction of flow *(Casshayap and Qidwai, 1970).* It is visualized that the major channels responsible for the deposition of Motur sediments were located in the middle part of the Satpura basin. The Pench Valley formed a typical backswamp area of this fluvial network where a thick pile of top stratum was deposited. *(Raja Rao 1983).*

Jabalpur Formation : The youngest Gondwana sequence in the Satpura Basin is referred to as the Jabalpur Formation. The Jabalpur beds consist of mainly massive sandstones alternating with white clays and conglomerates. The conglomerates are distinguished by the presence of numerous jasper pebbles. The contact of the Jabalpur beds with the underlying Gondwana sediments is marked by a pronounced unconformity. *(Raja Rao, 1983)*

Deccan Trap : The Deccan traps cover large tracts to the north of Pench-Kanhan valley. The boundary of the trap generally follows the contours of the hill. The commonest type of Deccan Trap is fine grained, jointed basalt. Under the microscope, the remarkable feature of this rock is the presence of glomero-porphyritic patches of augite. Another type is massive basalt in which olivine can be distinguished at places. In addition there area few flows of porphyritic basalts. Dykes are very common in the Satpura basin. Most of the dykes and sills occur in Barakar and Motur Formations. *(Raja Rao, 1983)*

Based on the borehole data of Mineral Exploration Corporation Limited the "Average Lithologic Thickness" of the four major mining blocks *(in meters)* of the area is as follows:

Table No. 2.3

	Sial Ghogri	*Shivpuri*	*Sethia*	*E.Dongar Chikli*
Alluvium	6.00	3.00	7.61	3.75
Deccan Trap	84.33	26.45	74.12	73.80
Jabalpurs	8.02	9.43	15.38	22.68
Moturs	82.34	-	106.48	107.89
Barakars	75.49	47.39	73.75	51.63
Talchirs	-	75.50	21.48	-

Structure

The Pench-Kanhan valley coalfield is made up of a homoclinal succession of rocks trending ENE-WSW with the dip varying from 5^0 to 15^0 towards north. This overall disposition is modified by a local basin near Eklehra and Barkuhi. The most important feature of the field is a prominant fault exposed along the margin of the Archaean rocks. Besides, the coalfield is traversed by a number of prominent faults, running approximately ENE-WSW, more or less along the strike of the formation. The fault zones have prominent topographic expressions in the form of linear ridges composed of sheared and silicified sandstones, platy quartz, etc. Fracturing of rocks and slicken slides are quite common. In Sial Ghoghri and Rawanwara collieries, the dip is towards north-east to east. To the south of Eklaira and North Chandameta, the dips are towards south-east to south-west. Compared to the western part, the eastern area is more intricately faulted near Khirsadoh and Rawanwara. Though most of the faults have downthrows towards north, several faults with southerly downthrows resulting in the repetition of Barakar strata within the Motur area have been reported *(Chandra, 1977)* from Eklaira-Bhamori and Rawanwara-Sethia areas. One such fault, with down-throw towards south, has been observed over a length of about 20 km. extending from Ambara in the west to Harrai in the east. Two more faults with southerly throws have been recorded within the Motur Formation between Chikli Kalan, Sirgori Khurd and Belgaon. The downthrows of these are estimated to be between 60 m. and 100 m. *(Fig. 2.3)*

Coals

In the Pench Valley the coals occur in Barakar formation as in other parts of India. As a whole, five coal seams occur in a column of 50 m. to 80 m. thickness within a 250 m. thick strata of Barakar Formation. Excepting Seam No. I (Main Seam), the other seams are discontinuous and occur in patches.There are only three important coal seams; the Top Seam is 2.1-7.6 m. thick, the second seam is 1.2-2.1 m. and the third 1.1-1.52 m. The partings between Seams No. 1 and 2 and between seams No. 2 and 3 vary from 13.7 m. to 19.8 m and from 18.3 to 24.4 m. respectively. Only in one colliery namely, Jatachapar, all the three seams are being worked at present. In other collieries generally the upper two seams are being worked. Though the thickness of Seam No. 1 *(Top Seam)* varies from 2.1 to 7.6 m., the working section is generally the bottom 2.4-3.0 m. thick portion. Seam. No. 1 in this coalfield is extensively worked, and in most of the collieries there are plans to develop the Seams No. 2 and 3. It has been noticed that Seam No. 1 is generally encountered at a depth of 30-38 m. from the base of the Motur in almost all the cases. Regarding Seam No.2, it is fairly continuous. Another 1.2 m. seam is met with at Eklehra colliery, from where it continues eastwards. This new seam *(Seam No.3)* has been proved in Newton Chikli, Chandameta, Barkuhi, Jatachapar and Bhamori collieries. At East Dongarchikli, Seams

No. 1 and 2 are being mined but seam No. 3 is yet to be proved at greater depths. It appears that as the Top Seam extends eastwards it gets split up into two or more sections of varying thickness. In the Rawanwara-Dighawani area, the number of coal seams increases but the seams vary in thickness, extent and parting. This might have resulted due to splitting up of the Top Seam. Precise correlation of the seams in this area which is also highly disturbed can, however, be made only after carrying out systematic exploratory work. *(Raja Rao, 1983 & Chandra, 1977)*

Coal Quality

The Pench Valley coals are low rank, high volatile and usually non coking in nature. The Central Fuel Research Institute *(C.F.R.I)* Dhanbad has carried out analyses of the three seams from some of the collieries. *(Indian Coals 1979)*. According to them, the moisture and the ash contents of Seam No. 1 in the Pench Valley vary from 1.7 to 9.2 per cent (at 60 per cent R.H.) and 16.8 to 29.7 per cent (on dry basis) respectively. The Second Seam in the Pench valley has 6.5-8.4 per cent moisture *(at 60 per cent R.H.)* and 16.6-26.4 per cent ash *(on dry basis)*. Analysis of third Seam, available only from Jatachapar colliery, shows that the quality of coal is better than that of Seam No. 2 *(the second Seam)*, as it shows 6.3 per cent moisture *(at 60 per cent R.H.)* and 14.8 percent ash *(on dry basis)*.

Table 2.4

Analysis of Sulphur and Ash Content of Pench Valley Coal

Area :-	*EDC*	*NC*	*NCDM*	*JTC*	*BHM*	*EKL*
Sulphur	0.5	0.5	0.4	0.5	0.6	0.5
SiO_2	59.1	62.2	58.8	56.80	60.00	61.2
Al_2O_3	21.1	22.2	22.8	21.7	22.5	.7
Fe_2O_3	10.0	7.2	12.7	12.4	4.8	.6
TiO_2	1.6	1.6	1.7	1.6	1.2	.6
P_2O_5	0.3	0.1	0.1	0.1	0.3	.0

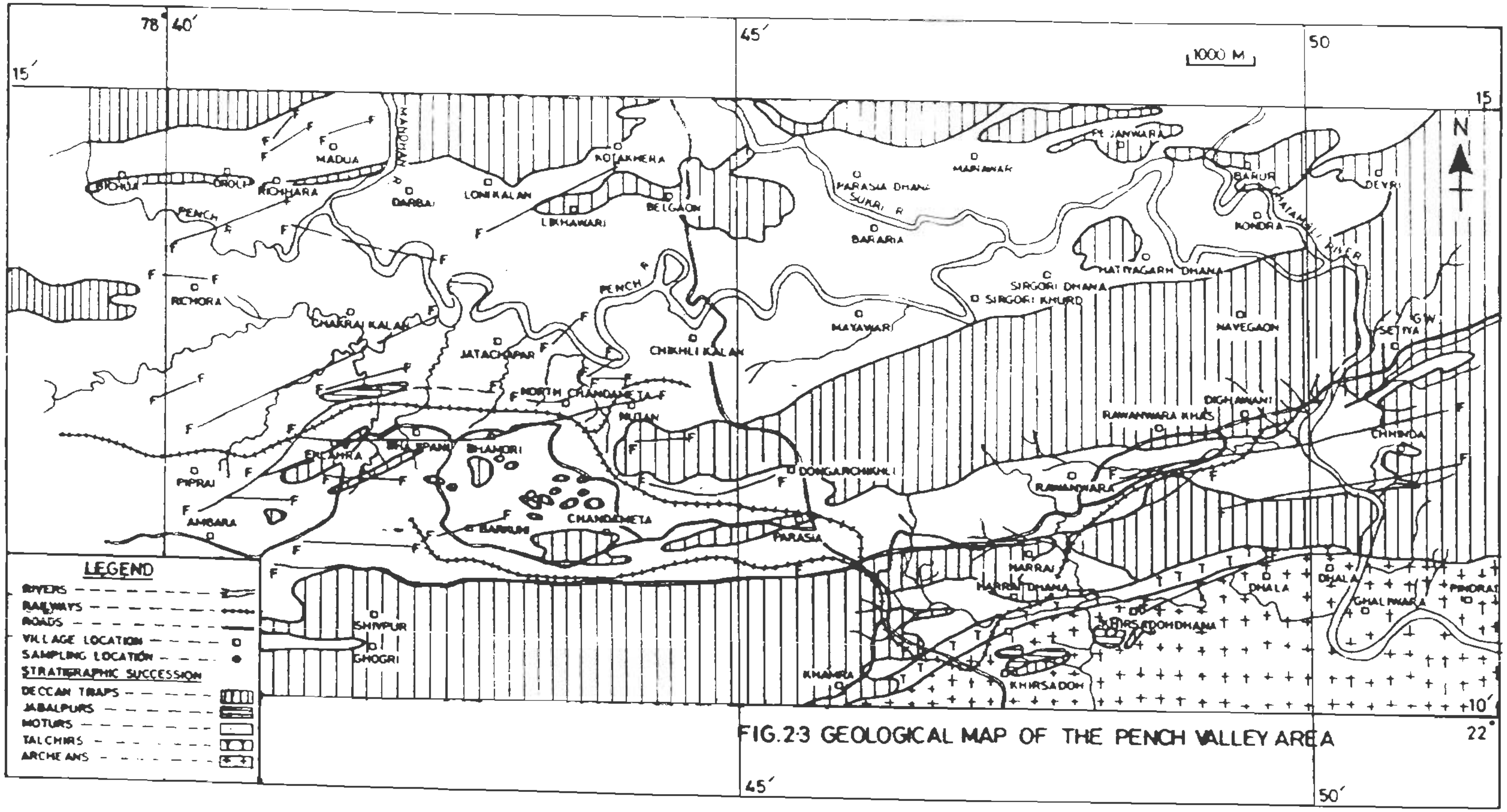


FIG.2.3 GEOLOGICAL MAP OF THE PENCH VALLEY AREA

MnO	0.1	0.1	0.1	-	0.2	-
CaO	2.1	1.4	1.5	0.7	1.9	.6
MgO	1.0	0.8	0.8	0.6	0.8	.2
SO_3	1.3	1.0	0.9	0.4	0.8	.0
Alkalis	2.4	3.4	2.6	2.5	1.1	.5

all values are in %
(After Indian Coals, 1979)

Coalfield Development and Production Perspectives

Formal mining in the Pench-Kanhan valley started in the year 1905, and about 1170 tons of coal was prodused in that year. In the course of the last 50 years, there has been an increasing tempo of mining activity in this coalfield, and it has become one of the main coal producing centers of Madhya Pradesh. The credit for the development of this coalfield, particularly in the early years of the present century, goes to *M/s. Shaw Wallace & Co.* An area of about 14.0 km. in length from Dighawani to Eklehra is extensively developed, where workings have gone more than 150 m. in depth. In Jatachapar and Newton Chikli, underground mining has gone beyond the Pench river. In most of the collieries of Pench area, the Top Seam is extensively exhausted. *(chandra, 1977)*

Table 2.5

Coal Production Perspective for Pench Valley Area

Area in Sq.km.	Coal reserves Million Tons G.S.I. Assesment, 1-1-88.	Coal Production Million Tons	
		1989-90	1994-95
500.00	1520.45	4.27	3.75

(After Baliga, 1988)

CHAPTER 3

HYDROGEOLOGY

PREVIOUS WORK

Among the earliest traces of hydrogeological investigations in this province, a bleak record is available of the visit of *Dr. A.G. Jhingran* during April-May 1942. He investigated the problem of water supply in Chhindwara town and analyzed the waters chemically. In his work salinity was reported as one of the major problems. In 1946, *Mr. P.K. Chatterji,* of GSI investigated the water potential in Pench - Kanhan valley coal fields over a stretch of 30 miles from east to west. He records that majority of wells derive water from the cracks and fissures in overlying Deccan Trap rocks excepting few wells which draw water from Barakar Sandstones around collieries. Most of the wells were dry during his visit. In 1958 *Mr. A.K. Roy,* of GSI visited Junordeo, to select a well site for hospital. He recommended dug well in Gondwana sandstones. In 1973-74, the State Ground Water Survey *(SGWS)* prepared a report on the Geohydrology of Chhindwara district, in which the broad picture of the Pench area is available in much generalized form. *Davis (1974)* has compared the log probability plot of specific capacity index *(specific capacity of wells divided by thickness of saturated basalt, penetrated by wells in percentage)* of the deccan traps of Chhindwara and Betul districts with the basalts of Washington area of USA. He has concluded that basalts of Chhindwara and Betul are less permeable, and have lower specific capacity. In *(1979) Uhl Jr.* analyzed the data such as yield, depth, depth of overburden and aquifer depth, statistically, according to rock type and topography. He used the data of over 500 tube wells drilled by ELC water development project. This study revealed that the wells drilled in valleys and flat uplands were the most productive and average well yields in the crystalline rocks *(90.0 lit/min.)* were greater than in basalt *(65.5 lit/min.)* and sandstone *(36.7 lit/min.)*. Topographic locations and fracturing are the predominant factors affecting well yields in all the rock types. The study shows agreement with Davis' results. It was in 1979-80 that Central Ground Water Board *(CGWB)* launched its detailed investigation and a report was compiled by Mr. L. M. Mothghare on the *"Systematic Hydrogeological Studies in Parts of Wainganga Basin Chhindwara District. (M.P.)"* but out of 12 selected hydrograph stations within the district only one falls in Pench area. Then in 1988 the State Ground Water Survey *(SGWS)* prepared a detailed report and discussed the groundwater potential for the year 1988. The *SGWS* has four permanent hydrograph stations in the Pench area, out of which two are monitored every month and the remaining two are monitored thrice the year. Annexure 3.1 shows the monthly records from December 1989 to December 1992 and Annexure 3.2 shows thrice the year records from 1984 to 1992.

The reassessment for the Parasia Block

Net Annual Recharge (in MCM) in 1986 - 102.50 in 1988 - 107.70	**Ground Water Balance (in MCM)** in 1986 - 82.41 in 1988 - 88.74
Net Annual Draft (in MCM) in 1986 - 20.09 in 1988 - 18.96	**Storage (in %)** in 1986 - 19.60 in 1988 - 17.60
Rate of Development (in %) in 1986 - 0.26 in 1988 - 0.98 **Specific yield (in %)**	**Stage of Development in 1993 (in %)** as per 1986 records - 21.42 (predicted) as per 1988 records - 22.50 (predicted) **- 2**

(Courtesy : State Ground Water Survey, M.P.)

Rationale

In order to study the signature of waters in coal mine locality one is required to take notice of the considerable disturbance that man has inflicted towards the natural hydrogeologic equilibrium. Hydrogeology, is one such domain which undergoes principal modifications due to mining. The abode of water gets pierced and punctured, blasted and blown as if a calamity has struck. The once balanced system of aqua regime is thrown into anarchy. The independent members of the water regime suffer in quality, and a revolting entity emerges out of them in the form of minewater. It is therefore incumbent to deal the subject under three separate heads namely Surfacewater, Groundwater and Minewater.

Surfacewaters

The river Pench is the principal drainage of the area which is fed by three tributaries from the north, draining mainly through Deccan Trap country. It exhibits excellent structural control while passing through the region. River Pench constitutes an elongated valley running east-west which incidentally is parallel to the strike of Gondwana rocks. The valley is confined to north by Deccan Traps and to south by crystalline basement. The underlying gondwanas are possessed with mutually perpendicular, diagonal fractures which are developed due to down warping simultaneous with deposition. The faults are parallel to the strike but a few can be located running parallel to these fracture sets. *Uhl Jr., (1979)* has also observed congugate sets of lineaments, bearing N40°W and N5°W, which are normal to the strike of Satpura Hills and exert some control on drainage. The river Pench, more or less, follows the trend of two fracture patterns acquiring typical zig-zag bends while it flows through most parts of area. Fig. 3.D evinces a comparison of different river segments to the general fracture trends highlighting the structural control. The arrows in the figure merely depict the generalised fracture patterns found within the region. These trend lines have only be placed adjescent to the river course to demonstrate the excellent control it exhibits over the river geometry. *(Raja Rao, 1983)*

The Pench, being an intermittent type of river, appears to be of perennial nature, as the traces of water remain present in the form of narrow drain throughout the year. The reason being the constant outpour of minewater drawn from the surrounding mines. A close observation of figs. 3.1 & 3.2 reveals that the river Pench is gaining from the north and is losing to the south, near Charai Kalan, a situation encountered as a result of mining.

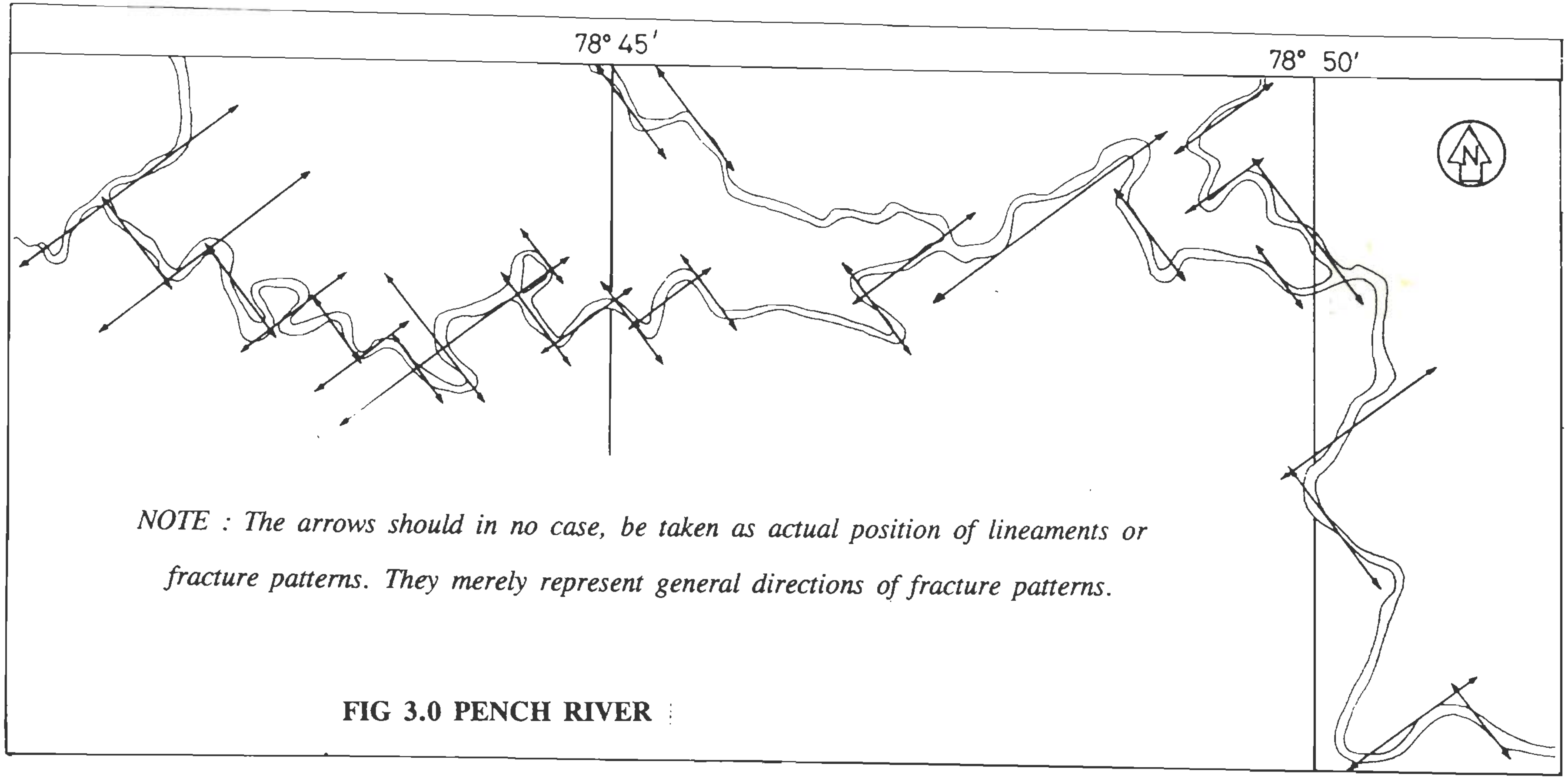
Groundwater

The groundwater, as such, is a dynamic body encountering ever-changing physico-chemical setups while at move. In order to adjust to such changes the chemical composition of the water keeps on changing frequently; which actually controls the traffic of element transport to a major extent. As evinced through the figs. 3.2 & 3.3 the general groundwater movement within the area is towards the east.

The groundwater hydrogeology of the Pench valley area is further divided into three categories for the convenience of the study. It is intended, in this head to project a generalized understanding of the pre-mining scenario of the groundwater. The ambience has also been considered in order to give weight to the observations.

Groundwater in Igneous Crystalline Rocks

Crystalline granites and gneisses occupy a very small portion of the area in the south-east. The groundwater exists only in upper layers of the compact rocks within the zone of weathering to a depth of 15 meter from the surface. In some cases



NOTE : The arrows should in no case, be taken as actual position of lineaments or fracture patterns. They merely represent general directions of fracture patterns.

FIG 3.0 PENCH RIVER

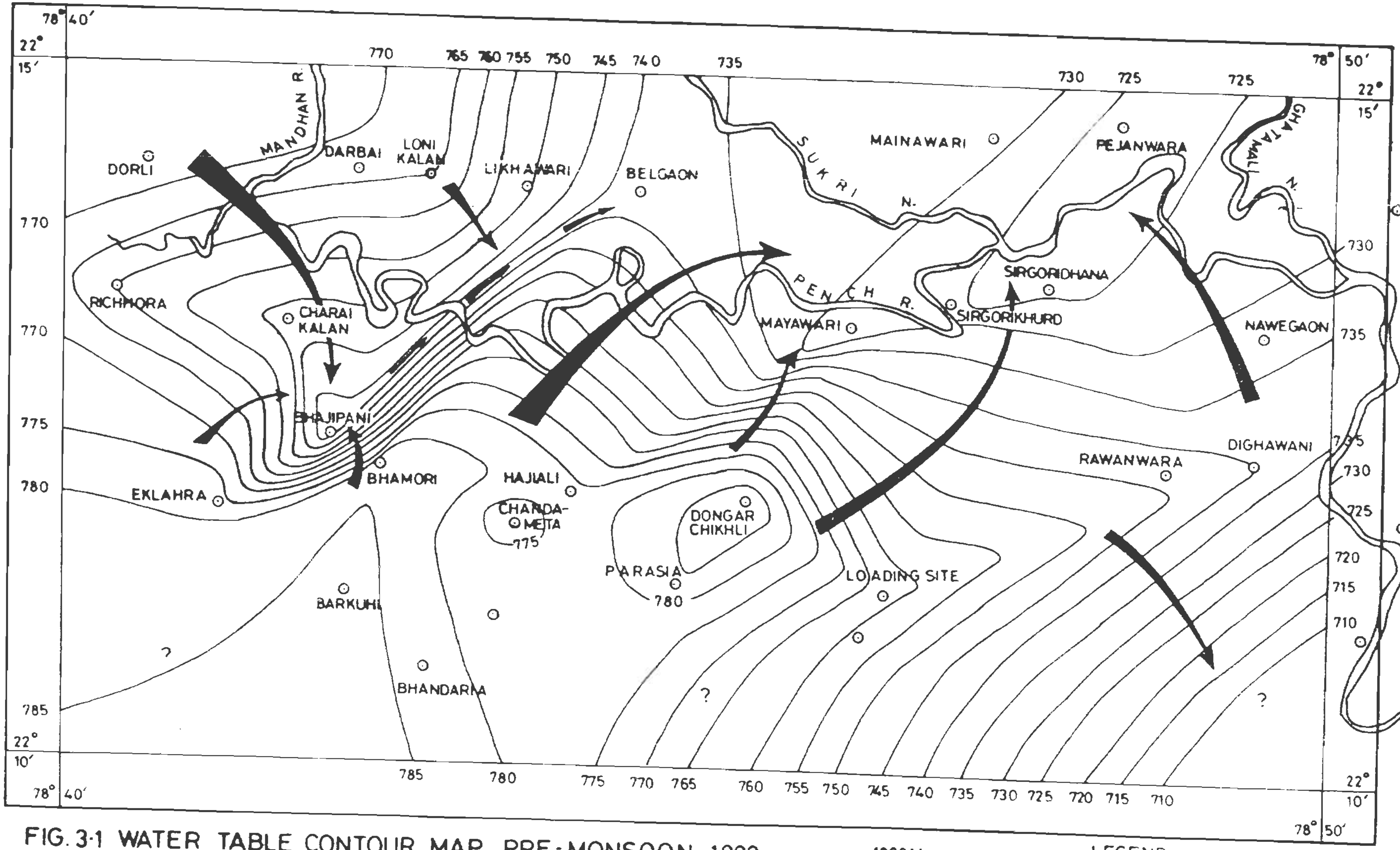


FIG. 3·1 WATER TABLE CONTOUR MAP; PRE-MONSOON, 1992

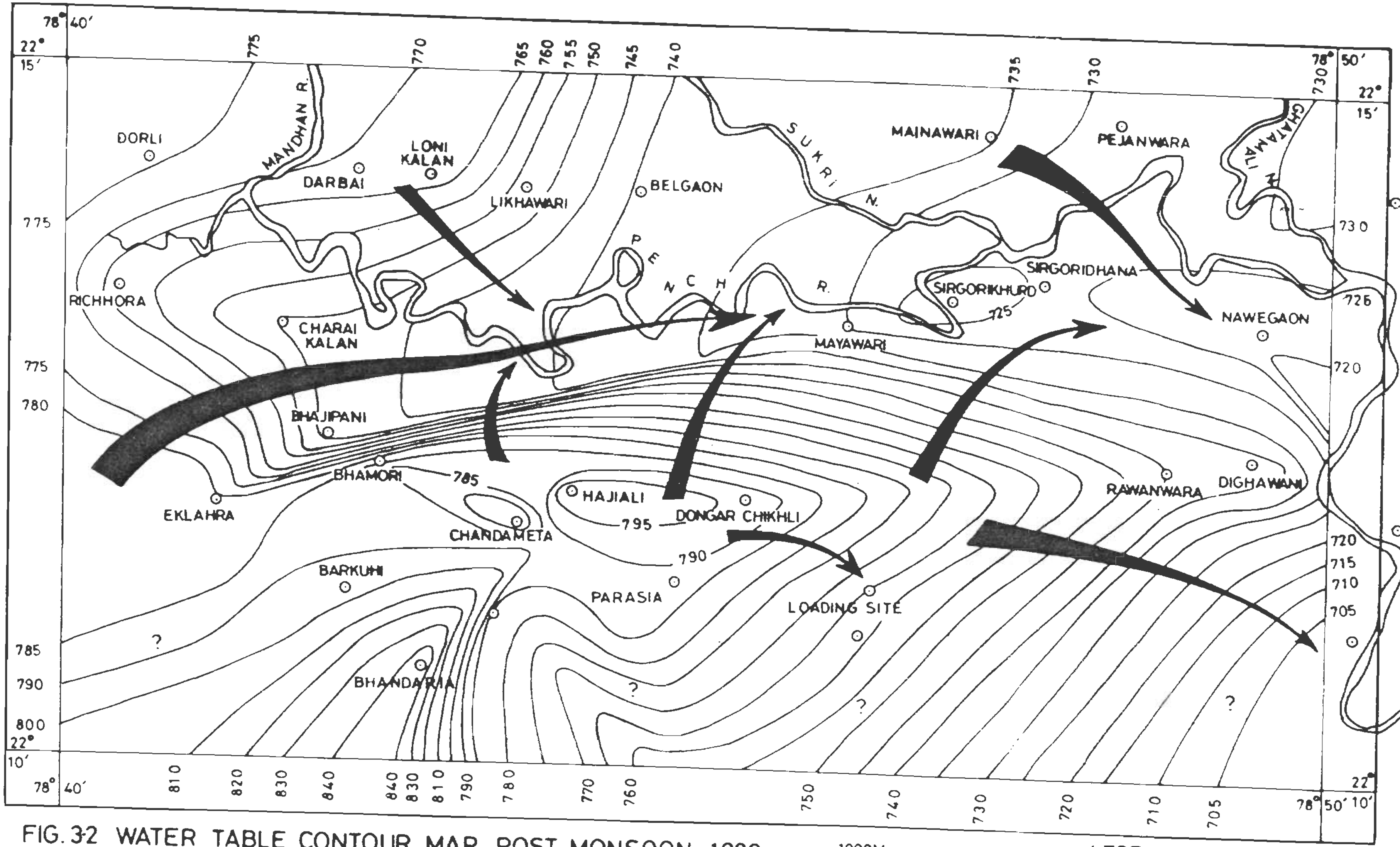


FIG. 3·2 WATER TABLE CONTOUR MAP; POST-MONSOON, 1992

LEGEND

○ OPEN WELL HYDROGRAPH STATION

770 WATER TABLE ELEVATION CONTOUR (M)

➡ FLOW LINE

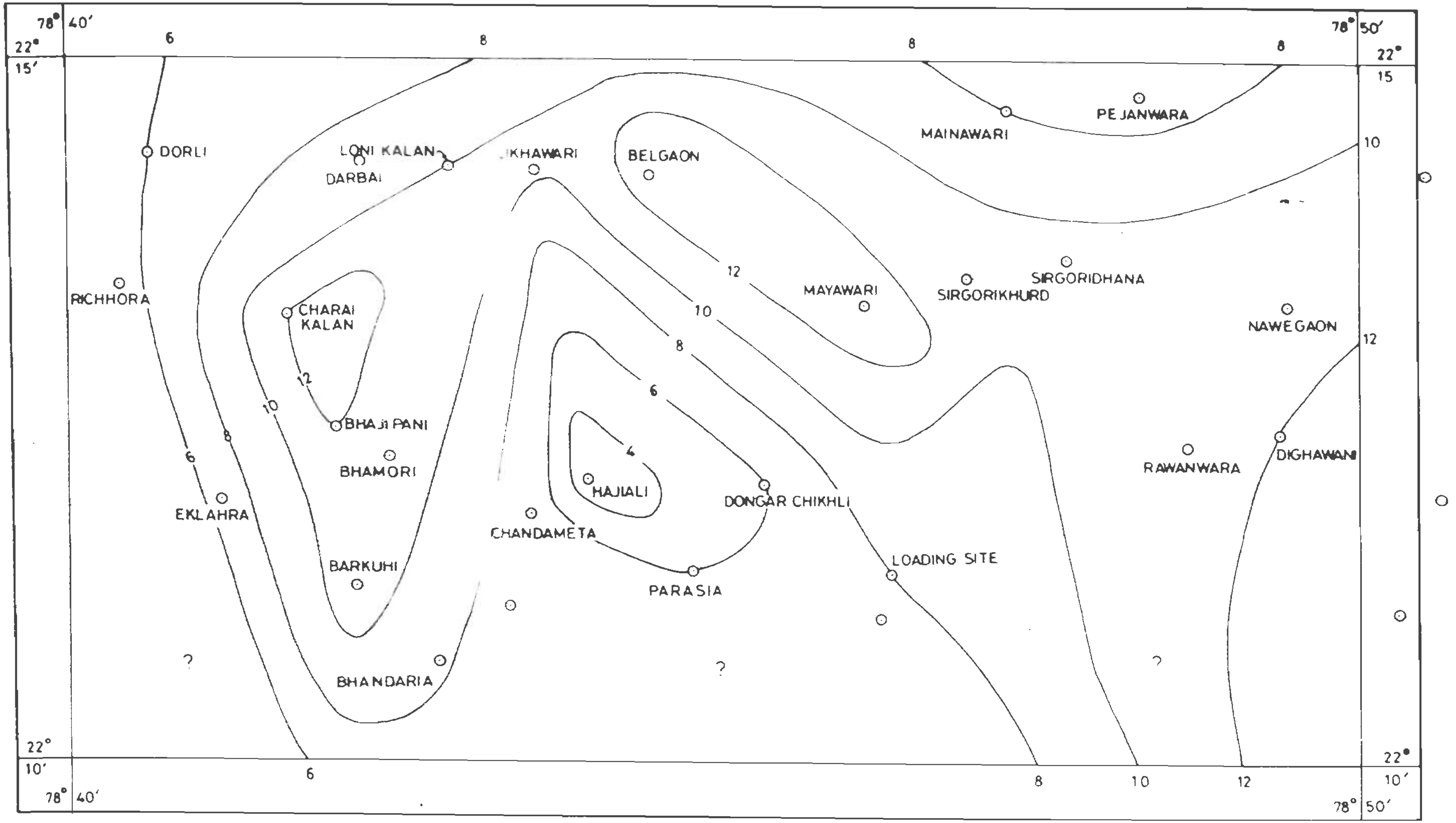


FIG. 3·3 DEPTH TO WATER TABLE MAP; PRE-MONSOON, 1992 where the foliations are present the groundwater finds easy way and becomes a good source of utility but the resources of groundwater in crystallines are meager and most of the wells go dry in summer. The depth to water ranges from 1 to 14 meters *(bgl)* and the general depth of wells ranges from 4 to 15 meter *(bgl)*. The seasonal fluctuation is observed from 2 to 6 meter. There are no specific foliation trends, though some discreet fissures can be located near the intrusives which yield moderate discharge of groundwater round the year.

Groundwater in Sedimentary Rocks

The sedimentary outcrops occupy major part of the area. The sandstones are the most prominent lithomember among the sedimentaries which is intercalated with a variety of shale and coal bands. The sandstones can be classed into two, one is coarse grained, friable, sometimes ferruginous; the other is fine grained, compact, sometimes quartzitic and is commonly found in the lower horizons, in the eastern fringe of the area. Bands of shale usually alternate every 15-20 meter forming good aquifuge. The vadose water spans to a depth of 15 meter yielding good discharge. The depth of wells varies from 4 to 25 meters *(bgl)*. There are three important confined aquifers. The first is encountered between 40-45 meter depth within coarse sandstone; the second is tapped between 50-60 meter within hard sandstone yielding lower than the first, and the third one is within the contact between sedimentaries and crystalline basement *(sometimes the tillite layer)* which is usually located below 70 meter depth yielding substantial water.

As a whole, the supply within sedimentary rocks is profuse but the resources are depleting due to paucity of recharge. The State Ground Water Survey *(1988)* has reported a drop of 5 to 8 meters or even more in the water level, within the previous decade. This observation is antithetic to the one made by *Stone (1990)*. He found that the recharge increases by 80% to 90% in mining localities, compared to the undisturbed areas, which is mainly attributed to the subsidence of excavated blocks and large scale open cast mining offering wide extending recharge surfaces. But the Pench area exhibits a difference that it spans in a well drained river valley patched up with surface undulations which hardly spare ample opportunity to the atmospheric precipitation and surface runoff to seep into the ground storage. Further, there are very few open cast pits/mines in the region, as the coal exists deep, and the majority of exhausted mines still await depillaring and subsidence.

Groundwater in Volcanic Rocks

Deccan basalt is the second important rock type which is abundant in the Pench valley area. It occupies almost all hill tops and highlands as a crown on the head. At the same time it has extraordinary potential of storage and supply of water. Many hill top wells and fringing springs owe their existence apparently to this very source. It has consolidation joints and inherent vesicles. The multiplicity of flows have rendered the margins excoriated which are either simple joints or sometimes occupied by the intratrappeans. At places, the discordant igneous bodies have produced extensive fracture zones which are abundant in the lower surfaces. Apart from all, the zone of weathering penetrates to about 20-25 meter and has a significant bearing over the ground water. As a whole, it has good supply of water but storage falls low in comparison to sedimentary rocks. The depth of water ranges from 2 to 13 meter *(bgl)* and the depth of wells ranges from 3 to 16 meter *(bgl)*. There is huge variation of groundwater flow below the land surface due to localised mining alterations. The typical groundwater mound near village Dongar Chikli *(Fig. 3.3 & 3.4)* is a result of the presence of basalts as the capping over the hillocks.

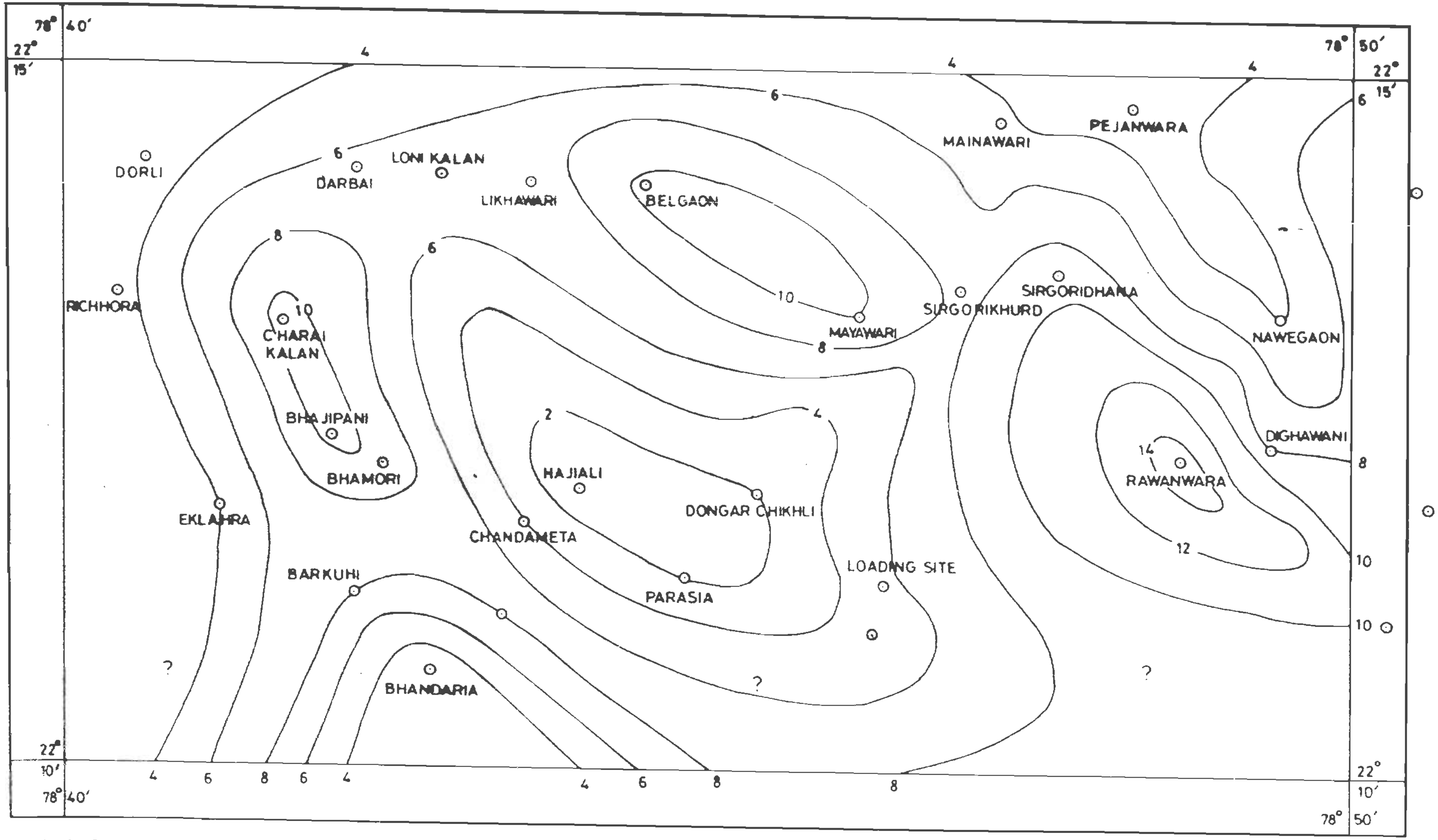


FIG. 3·4 DEPTH TO WATER TABLE MAP; POST-MONSOON, 1992

Minewater

It has drawn its appellation from its very place of existence, a faction of ground water commune, which owes its origin to human interferences. The mining activity is known to cause drastic changes in the subsurface environment. The solid surface has been punctured and large scale aeration of the rock mass has taken place; thereby changing the "anaerobic" medium to "aerobic". The atmospheric oxygen in presence of ground water causes the oxidation of the "sulphides" *(such as Pyrite, Mercasite and Pyrrhotite)* which are generally found associated with coals as accessory minerals. *(Stumm & Morgan, 1970)*. The sulphides (S_2^{2-}) are thus oxidized to sulphates (SO_4^{2-}) and free H^+ ions are released in aqueous phase along with (Fe^{2+}) ferrous ions, which become principal causes in generating the acidity in the waters. The released ferrous ions (Fe^{2+}) are then oxidized to ferric (Fe^{3+}) which then hydrolizes to form insoluble ferric hydroxide releasing more acidity to the stream and coating the stream bed with reddish yellow deposit. *(Singer & Stumm, 1970)*

As per the following well known reaction :-

1) $FeS_2(s) + 7/2\ O_2 + H_2O \longrightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+$ *(Acidity)*

2) $Fe^{2+}\ (aq) + 1/4\ O_2 + H^+ \xrightarrow{\text{Bacteria}} Fe^{3+} + 1/2\ H_2O$

3) $Fe^{3+}\ (aq) + 3\ H_2O \longrightarrow Fe(OH)_3\ (s) + 3\ H^+$ *(Acidity)*

It is clear from the above reactions that for "each" mole of 'Iron sulphide', "four" moles of 'acid' are produced. Hence, the minewater is the acid groundwater in another sense.

It actually represents all waters which come in contact with aerated coals and coaliferous substances within mines, and since the mines are wide extending, the major part of groundwaters invariably forms minewater. In Pench area almost all mines suffer the nuisance of minewater, varying greatly in quality and quantity from place to place. The minewater exists in a thoroughly hodge-podge hydrogeologic regime, drawing water from nearly all confined and unconfined aquifers. The underground mines are like interconnecting drains which accumulate water from a vast region at a lower portion. In Pench area this water is accumulated towards northern extremes following dip slopes and is pump-lifted, 20 to 140 meters, to be released into the river Pench. The Western coal fields has reported following approximate annual draft of water from

Barkuhi	=	4.4826	million gallons
Eklehra	=	144.065	million gallons
Bhamori	=	321.30	million gallons
Chandameta	=	806.15	million gallons

Estimated by daily hours of pumping in 1979.
Courtesy Mothghare 1979-80.

A glance over Fig. 3.1 to 3.4 fairly shows the extent of variation, the mining and drawdown activity has afflicted towards the groundwater movement. The effect is so pronounced that it is evident in the post-monsoon scenario too. A prominent groundwater trough is maintained throughout the year in the western part of the area and an increased groundwater flow gradient is encountered within localized zones, especially in the neighborhood of mines. The steep gradient near Bhajipani and Bhamori is the result of Jatachhapar and Chandameta mines which are working at the maximum depth of 140 - 180 *(mbgl)*. These drawdown gradients are steep near the mine down slope faces and decrease rapidly with distance away from mine. The secondary porosity and permeability due to fracturing is believed to accelerate the drawdown locally. The northern parts which are relatively safe from the mining show normally spaced contours - indicative of moderate flow.

The flow lines, more or less, represent a generalized flow pattern within the area. It is worthwhile to mention here that the minewater is not directly polluting the groundwater, rather it is the surfacewater which receives direct supply of minewater through artificial sources. Figs. 3.3 & 3.4 reveal that the Pench area has well marked pockets of groundwater trough which prevail quite explicitly, in the vicinity of mines. Three peculier troughs *(near Bhajipani, Mayawari and Rawanwara)* are the result of extensive pumping to facilitate miming. Mine induced lowering is encountered in the sedimentary strata whereas the basalt mounds appear to be least affected. Majority of the wells falling in the sedimentaries suffer lowering and enhanced annual fluctuation in the Water Table. A large number of well yield mud and a still more go complete dry with the advent of summers.

As a whole the shortage of well water poses acute problem to the inhabitants which apparently is a result of human activity.

CHAPTER 4
WATER QUALITY

PREVIOUS WORK

The water quality of the area has been, time to time, recorded by two prominent agencies in the past 20 years. Scanty record, in incomplete form, is available from the ELC *(Evangelical Lutherian Church)* Water Development Project based at Betul (MP) for the Pench area from 1974 to 77. An analysis of five wells is available from Central Ground Water Board *(CGWB)* for the year 1979. The data of water quality from State Groundwater Survey *(SGWS)* has not been reproduced here following doubtful accuracy and discrepancy with other sources. *(Annexure 4.1a)*

As such no detailed in depth assessment of water quality of this region is available, The Western Coal Fields Limited *(WCL)* is said to have conducted some surveys in this regard but the reports are not available to outside agencies, for ready reference.

INTRODUCTION

Rationale

The rationale of monitoring water quality is to precisely account the changes inflicted towards the environmental health under the influence of coal mining. Verily, the water quality does considerably affect the environmental health, as the water forms important channel way for the supply of nutrients to living beings. It is thus imperative to define the water quality in a manner that its relation and response to the coal mining becomes apparent within Pench area. This approach to assessment of postmining water chemistry requires a thorough understanding of several geochemical and mining processes as well as the development of a number of analytical techniques. The inventory involved soil survey, geologic mapping, development of groundwater flow network, geohydrological and geochemical studies.

The following pages discuss the types of water prevalent in the area with detailed comments on the parameters measured under direct field investigation, and results generated within laboratory, under strict technical control based on the Standard Analytical Procedures given by *Standard Methods 1985-89*. The actual data is given in Annexure 4.1. The presentation follows the recommendation of *Standard Methods (1989)* i.e. the last digits are uncertain.

Every parameter is discussed individually first, followed by a word on their joint behavior with others. This is done in order to project the water quality status of the region, in terms of standard criterion, before a comment is made on the complex nature of Trace Elements.

Isocon maps *(Iso-concentration maps)* are added as part of study to every parameter. Different Isocon maps for each water component were drawn for both pre & post-monsoon seasons to project the unique picture associated with every individual parameter discussed.

Hopps (1973) discussed in detail the view of displaying the data in map forms. In his view, for the most part environmental factors are neither evenly nor uniformly distributed, that is why the Isopleth *(contour type)* maps constitute the best tools to portray their spatial distribution. Isopleth maps have great advantage of freely expressing quantitative aspects in a manner that dramatically indicates both the values of functions and their rates of change from one area to another. At the same time it, nowadays, has become simple to prepare such maps after the advent of computer programs with many facilities. A scale of 1:25000 or 1:50,000 is recommended for Isocon maps. *(Erdelyi & Galfi, 1988)*. The accuracy of such maps greatly depends on the equal spacing and density of sample points; but in natural working conditions, however, the equally spaced sample locations are rarely possible as the wells are usually confined to the pockets of human settlements. Since, we have used Isocon maps over surfacewaters too, a care must be employed while interpreting them. In case of surfacewaters the significance of Isopleth is valid only over the stretches of waterbodies, which in this case is river. Hence, the river overlay must be kept in mind while interpreting, as the meaning of contour lines is limited only over the river pathway. There is no meaning, however, of the Isopleth which extends beyond the waterbodies over the land, due to automatic grid extrapolation by the computer program, which doesn't allow control over suppressing the grid expansion. Further, the independent streams deserve independent treatment.

Sampling Program

The sampling program for waters included pre-monsoon and post-monsoon schedules to closely record the peak water quality variations within the region, and regular monitoring was performed for three consecutive years under these fixed schedules. The data for the year 1990 was later discarded following the sudden rains which had marred the pre-monsoon schedule, considerably. In this study the term pre-monsoon refers to March and April and Post-monsoon refers to October & November : the periods, when the region witnesses minimum rainfall over the year *(IMD, 1965, & Climate of Madhya Pradesh 1981)*

Sample Point Locations

Fixed sample locations were selected to be monitored repeatedly based on the reconnaissance, giving due weightage to the Geologic, Geographic, Mining and Accessibility factors.

Groundwater : Only those shallow dug wells were selected which were used extensively by a majority population for drinking purpose or those wells which were supplying the water to the local people through automobile tankers. Most of the wells are either dried up or yield minewater contaminated reddish water causing Yellowboy in summers, hence are not preferred for drinking purpose. Since the data was needed for both pre- & post-monsoon, so only those wells were chosen which don't go dry in summers. Moreover, because of the mining only a few wells are available which provide good quality alongside quantity, therefore only twelve, select wells, enjoying the liking of the people due to taste, color or other simple qualities were chosen for regular monitoring which were located within the mining area or nearby.

Though the government has provided tube wells fitted with hand pump at most places but they suffer poor maintenance and time to time wear and tear. A few have proved to be failure in due course of time when the sub-ground mines advanced under their toe. In such a condition the major load is always shared by the conventional dug wells or dug wells fitted with additional hand pumps, so we had to limit ourselves to dug wells only. Further, the purpose of quality assessment was mainly to know the quality of the water which affect population health on the whole, hence the choice of wells was strictly limited.

Surfacewater : A good amount of drinking water is supplied through pipelines from river after filtration. The river was sampled before it enters the region and little downstream of the points where minewater is mixed, and at the confluence of rivers at more or less equal intervals. The surfacewater quality upgradient from mine gives baseline quality and downgradient gives alterations due to mining operations. Other streams were also sampled which originate in the area and principally survive due to mine discharges and carry minewater to the river Pench. The samples were taken from the top six inch depth from the central part of the rivers since all the rivers are knee deep or less. It must be kept in mind here that the river Pench which seems to be of perennial type, is actually an intermittent river behaving as perennial, principally because of mine discharges.

Minewater : All the working minewater outlets were sampled. A few of them shifted location with extending mines towards the North, along dip slope. The samples were either collected from underground minewater pits directly or were taken from the outlet site when the pumping completed a run of 1/2 an hour. This was done to avoid sampling which contains enhanced iron content due to pipe and pump corrosion on the spot. But still at few spots the intake pipes, made up of iron, kept dipping inside the pit which must have altered the iron content and a little higher iron is expected due to pipe corrosion. But since the study deals with overall existing framework we prefer not to employ any correction to the higher amount of iron on those stray locations. Our concern is the geochemistry of the working environment as a whole which includes complete mining activity, working in normal manner with actual framework. Table 4.1, below, gives the description of minewater outlet points.

Table 4.1

Sample No.	Location	Seam	Utility
M1	Jatachhapar	3rd coal seam	Open Field Irrigation
M2	North Chanda Meta	3rd coal seam	External Public Use
M3	Bhamodi	3rd coal seam	External Public Use
M4	Jatachhapar	3rd coal seam	Open Field Irrigation

M5	Chandameta	2nd coal seam	Open Field Irrigation
M6	Barkuhi	1st coal seam	External Public Use
M7	Barkuhi	Mixed	Open Field Irrigation
M8	Dongar Chikli	3rd coal seam	Open Field Irrigation
M9	Dighawani	3rd coal seam	Open Field Irrigation
M10	Sethia	Open cast mine	Open Field Irrigation
M11	North Sethia	Open cast mine	Open Field Irrigation

Sampling Method

Samples were collected in plastic containers following the standard criterion i.e. by adding HNO_3 *(conc.)* prior to the sample in the containers, to bring down the pH below 2 ; excepting the samples for Alkalinity, Chloride and Sulfate which were refrigerated separately, without the addition of any preservative, and all were analyzed within recommended time Limit. *(Standard Methods, 1985-89)*

All the samples were first filtered with Whatman 42 filter paper on the spot followed by, within a few hours, filtering with 0.45 μm Membrane filter. Hence, all the samples are expected to contain the elements in dissolved state, though there is a fair chance of colloidal presence which can also pass through 0.45 μm pore size. *(Kelly, 1988, Hem, 1985, Edmunds, 1981)*. At this point, it is worth to note from *Morrison (1972)* that the actual particle size cutoff remains unknown because, as sediments collect on the membrane, it generally filters more effectively than does the membrane itself. Further, the filtered sample which is stabilized by acidification, generally dissolves the colloidal material that might be present and minimizes the adsorption on container walls too. *(Hem, 1985)*.

The amount of samples for the determination of trace elements was one liter, and an equal amount was sampled for major elements too.

Sample Preparation

Quite obviously, the minimum pretreatment of samples is the goal of the Analysis. Nondestructive or direct methods are the most desirable because they minimize contamination and loss problems. The preconcentration steps are often required to attain adequate sensitivity, and separation/addition steps may be required to eliminate/suppress the effect of interfering species. In general, the minimization of pretreatment steps always remains the guiding principle for the sample preparation. *(Morrison, 1972)*. Hence, throughout the present work an especial precaution was taken to shun the preconcentration steps as much as possible and the results are reported on normally attainable sensitivities wherever possible.

Analytical Standards

No ready made water standards were used because of the economic constraints and unaffordably long procurement time. Thus all the trace elements were analyzed with the lab-prepared standards which contained major element proportions similar to the groundwater composition with a little higher Sulfate to take care of matrix effect.

Moreover, no fixed composition could be outlined to select any specific water standard, and it was quite cumbersome to use one specific standard for each type of water, so it was opted to work with lab prepared standard solutions as per the recommendation of the *Standard Methods (1989)*. Hence a weeny bit care can be employed by hypercritical workers before using the present data.

Analytical Methods

The summary of Analytical Methods with their specifications is given in Annexure 4.2. The dilution correction was duly employed wherever needed. Since, the large dilution factors magnify small errors on final calculation, it was avoided by substituting the use of AAS *(Perkin Elmer, 2380)* with ICPA *(Plasmalab, 8440, Labtam, Australia)* as the latter offers larger range of linearity. However, the higher running cost restricted the use of ICPA to only a few elements. Both the instruments are equipped with computerized digital and graphical displays of linearity and standard deviation. The analysis were performed by skilled operators in the presence of the author. Further, in natural samples, it is very difficult to have the amounts of dissolved components vary within the optimum concentration range for detection. Hence, at times, the concentration ranges far below the optimum ones were dealtwith by scale expansion and by maneuvering the adsorption signals.

HYDROGEN ION ACTIVITY (pH)

Rationale

pH is an important parameter in assessing water quality. Quite often it is used to ascertain few other important factors which are no less important in characterizing the quality. Further it governs the solvent properties of water and the extent of physico-chemical relations between the water and solid mass such as corrosion, scaling etc. pH greatly affects the toxicity and metal complexing capacity of certain water constituent and plays an important role in controlling the dissolved concentration of elements. Biological activity has also shown relation to pH.

There is an on going debate on the futility of measuring pH as against *acidity*. Few eminent workers have drawn attention over the fact that pH is an intensity factor measuring the concentration or activity of hydrogen ion whereas, what is more important in natural condition is not the concentration alone but the availability of hydrogen ions to neutralize bases; i.e. its excess over other ions. This is refereed to as *total acidity*. Despite these reservations however, there is still a fairly good linear relationship between the pH and logarithm of *total acidity* in Acid Mine Waters. *(Fig. 4.1)*. *(Kelly, 1988)*

We have, therefore, preferred for practically simpler, easy to measure, conventional way of measuring the pH instead of *Acidity*, under the difficult working conditions of the field.

To the present work apart from all aforementioned benefits the pH speaks of mobility of elements and has a considerable bearing on their geochemical behavior.

Geographic Distribution of pH *(Based on Isocon maps)*

Within Groundwater : On the whole it is observed that the pH tends to be little acidic in pre-monsoon period than the Post-monsoon. In summer it touches a minimum of 6.5 and in spring it reaches a maximum of 8.2. A glance over the Groundwater Iso-pH map *(Annexure 4.3a)* provides a picture, indicating that the flanking wells of mine free location are tending to be less acidic, rather basic, than the ones falling in the mining area. The contours of the lowest pH values close near the south central region, where the first coal seam can be reached within 3-5 meter from the ground surface as it is the up dip side of the gently dipping coals. The shallow open wells are sometimes found resting on coal beds, in this part of the area; and most such wells have been abandoned following water loss due to underground mining.

Within Surfacewater : The surfacewater bodies also show the same response as the groundwaters. The pH behaves normal in most parts excepting only a few specific spots where the minewater meets the surfacewater. Downstream from the mixing points the main river finally regains its original pH when it comes out of the region - from the South-East. In the Surfacewater Iso-pH map *(Annexure 4.4a)* the points R4, R11, R14 clearly represent mixing points. The effect of minewaters on surfacewater is more subdued in spring season compared to summer, and the pH regain of the main river is quite fast.

Within Minewater : Almost all the minewaters are acidic, with pH being further low in summers. In post-monsoon the minewater tends to be neutral but still at a few locations it touches pH = 5. In Minewater Iso-pH map *(Annexure 4.5a)* we notice two clear pH lows within the mining region. The acidity is maintained highest in the central region where the mines are fairly exhausted in upper levels and the third coal seam is at work in the underground.

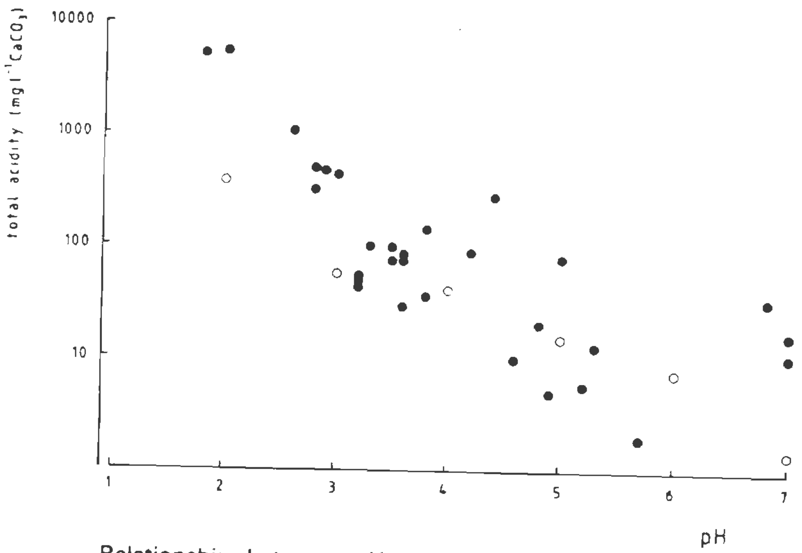
Discussion

It is noted clearly that the effect of minewater is quite subtle on the wells selected, probably because they are shallow and often do not penetrate or touch the coal seams. It is, therefore, safer for the people to draw water from shallower wells than from deeper ones within the mining territory. The atmospheric precipitation has significant effect in calming down the acidity as revealed through the comparison of pre- & post-monsoon data, that the acidity is found considerably lowered in post-monsoon.

The anomalous behaviour of well 'W5' had reason to make it different from the rest. It is located within vesicular basalt which is jointed and weathered, and a small minewater drain passes near by. The drain-water finds easy way to the well through the joints and vesicles. It is this drain , which keeps it alive, even in the dry spells of summer, when others die of diminishing source. The effect is so substantial that it influences the well even in the post-monsoon and keeps the pH down.

Relationship between pH and acidity

pH	*Total acidity (mg litre^{-1} $CaCO_3$)*	*Reference*
Field measurements		
2·6	1130	Koryak *et al.* (1972)
3·0	456	
3·8	146	
4·8	21	Roback and Richardson (1969)
5·3	13	
3·2	44	
7·0	11	
8·1	8·3	Carrithers and Bulow (1973)
4·4	300	
5·0	82	
7·0	17	
7·4	9·9	
8·0	6·9	
8·2	7·8	
3·3	104	Warner (1971)
3·3	139	
3·3	130	
3·8	46	
3·5	77	
3·6	75	
4·2	91	
4·6	10	
5·7	2	
2·9	408	
2·8	509	
3·5	100	
4·9	5	
5·2	6	
1·8	5800	Sheath *et al.* (1982)
2·0	6000	
2·8	320	
3·6	30	
Laboratory measurements		
1·0	647	Bell (1971)
2·0	393	
3·0	59	
4·0	42	
5·0	15	
6·0	7·6	
7·0	2·1	
7·8	1·5	



Relationship between pH and total acidity, based on values measured in the field (closed circles) by Roback and Richardson (1969), Warner (1971), Koryak *et al.* (1972), Carrithers and Bulow (1973), and Sheath *et al.* (1982), and in the laboratory (open circles) by Bell (1971). Regression equation: $y = 3{\cdot}44 - 0{\cdot}39x$, $r^2 = 0{\cdot}68$; $p < 0{\cdot}001$.

Fig. 4.1
(After Kelly 1988)

In well 'W6', the pre-monsoonal rise in acidity can be attributed to the blowing westerly summer winds which bring about fulsome fall of coal dust from the nearby coal loading site, located in the west. The dust has been examined to cause sufficient acidity. In post-monsoon the wind is mild and the dust suppressed due to high relative humidity resulting in normalcy of pH value.

As such any direct relationship between pH of drinking water and the human health is impossible to ascertain because the pH is so closely associated with other aspects of water. The *WHO (1984)* has recommended 6.5-8.5 as the guideline value, recognizing well that some problems could even arise with pH levels below 7. Since almost all the elements get mobile in lowered pH due to increase in solubility, the toxicity too gets affected. However, the view of scientists vary categorically about the effect of toxicity in relation to the pH. *(Shehata et al., 1982, Tanaka et al., 1982 & Rai et al., 1980)*. Among the factors affecting metal toxicity, the environmental variable most often considered in addition to the concentration of metal itself, is pH. Many workers consider that pH induces changes in toxicity due to changes in speciation. It is believed that it is the ionic form of metals which is the most toxic, hence any change in speciation *(due to pH)* which increases the amount of free ions may be expected to increase the apparent toxicity. In addition, decrease in pH will decrease the proportion adsorbed on to particulates. *(Kelly, 1988)*.

One of the most important effects of low pH is to destroy the Bicarbonate buffer system, a feedback mechanism which controls the magnitude of shifts in pH. Below a pH of about 4.2 all Carbonate and Bicarbonate is converted to Carbonic acid. This readily dissociates to water and free Carbon Dioxide which may be lost to the atmosphere. The water loses its capacity to buffer changes in pH. Once destroyed, the

Alkalinity of a water body may take some time to recover even if no further acid is added to the system.

In Pench area most of selected ground water wells supply the water within *WHO (1984)* limits - some ofcourse touching the lower periphery of pH *(i.e. 6.5)*. The surfacewater bodies have a mixed response but the minewater almost invariably fall out of the *WHO (1984)* limits. In summers, all the water with poor alkalinity and pH tending low are of concern, as reported in a typical drinking water supply with low alkalinity and fairly low pH that had resulted in high levels of Lead due to Lead plumbing. *(McFarren, 1977)*.

As a whole it can be inferred that the shallow well water can be used fairly, with caution in summers, and the minewater ought to be avoided altogether, while surfacewater can be resorted to away from mining locality.

TOTAL DISSOLVED SOLIDS (TDS)

Rationale

Water Quality not only takes care of harms associated with intake but also pays due regard to some aesthetic facts which concerns the liking and disliking of humanbeings. Another aspect, related to this is corrosion or incrustation, for which pH serves as the mechanism and TDS serves as the cause. Certain components of TDS, such as Chlorides, Sulfates, Magnesium, Calcium and Carbonates, are found to affect corrosion or incrustation in water distribution systems. TDS is a chemical parameter, unlike suspended solids, dissolved solids *(TDS)* will not be deposited in quiescent stretches of the stream as a result of velocity reduction alone. Other changes in conditions i.e. Temperature, Carbon Dioxide, pH or Dissolved Oxygen, can well decrease the solubility of some types of dissolved solids and result in their transformation to suspended materials which may then come out of suspension.

It is an enveloping term and speaks of combined behaviour of all dissolved solids irrespective of their individual behaviour. The purpose of this is to define, in general, overall quality of waters.

It is losing importance since other more precise understanding of individual constituents is getting clearer to us. The system is going more for specific pinpointed approach than to broader ones.

Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable taste and raised cost of additional treatment.

The physiological effects, directly related to TDS, include laxative effects principally from Sodium Sulfate and Magnesiums Sulfate. *Moore (1952)* reported that 62% of the respondents indicated laxative effects associated with the consumption of water of the wells having Sulfate range 1000 - 1500 mg/L, and nearly one fourth reported difficulty when concentrations ranged from 280-500 mg/L.

The *WHO (1984)* fixed upper limit to 1000 mg/L and *Train (1979)* has given the following classification.

Table 4.2
Dissolved Solids Hazard for Irrigation Water (mg/L)

Water from which no detrimental effects will usually be noticed....	500
Water which can have detrimental effects on sensitive crops........	500-1,000
Water that may have adverse effects on many crops and requires careful management practices......................................	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices......................................	2,000-5,000

(After Train, 1979)

Accuracy of Results

The measured TDS values were compared with calculated ones and the values falling outside the 0 - 15% range of error were discarded.

Geographic Distribution of TDS *(Based on Isocon maps)*

With Groundwater : TDS clearly is seen to rise in the mining region. The wells of peripheral region show less TDS values than the ones located within mining area. Well 'W5' which has been affected by minewater shows the highest TDS values with contours closing in. Another well 'W9' which also falls in mining region encounters similar rise. It is interesting to see that the variation of TDS within the region shows remarkable similarity with pH. Further, a comparison of Iso-TDS maps *(Annexure 4.3a)* reveals that pre-monsoon values are higher than post-monsoon.

Within Surfacewater : The picture of surfacewaters is compatible to the groundwaters and the regional variation shows similar trends. Points R4 & R14 are the spots where direct minewater is mixed with surfacewater hence are showing exceptionally high values. On the whole the river is getting enriched in dissolved solids as it passes through the region and the values of the last point *(R12)* has gone higher to the first point *(R1)* where it entered the region.

Within Minewater : The TDS values of minewater are nearly double the values of surface/groundwater. The variation follows similarity to pH trends demonstrating the good control of pH over TDS. It is interesting that, in the eastern part, the steep gradient demonstrates the difference of two kinds of minewater. The points M10, M11 indicates open cast mines and M9 indicates underground. It is, thus, clear that the open cast mines are comparatively less rich in TDS. The Iso-TDS maps *(Annexure 4.5a)* indicate not much change in Pre-& Post-monsoon scenario.

Discussion

A common statement can be made here that the TDS is beautifully controlled by pH and the minewater has sound capability in altering the TDS levels of other waters. The open cast mines have relatively moderate pH ranges and hence are yielding lower TDS proportions. Fig. 4.2 show the plot of variation of TDS Vs pH. It can be noticed that the broad trend is linear.

HARDNESS

Rationale

Water Hardness is caused by the polyvalent metallic ions dissolved in water. In fresh waters these are principally Calcium, and Magnesium, although, other metals such as Iron and Manganese contribute to an appreciable extent.

Hardness in freshwater frequently is distinguished as Carbonate and non Carbonate fractions. The Carbonate fraction is chemically equivalent to the Bicarbonates present in water. Since Bicarbonates generally are measured as Alkalinity, the Carbonate Hardness usually is considered equal to the Alkalinity.

The effect of Hardness on freshwater fish and other aquatic life appear to be related to the specific ions causing the Hardness rather than Hardness itself.

In the last 20 years there has been a considerable research in drinking water Hardness and cardiovascular disease. Statistical studies have revealed highly significant inverse relationship but the precise nature of water components involved is still not known. *(Fraser, 1984)*

It can only be said that cardiovascular disease is influenced by water Hardness, or by some factor closely associated with it, which could be either harmful factor in soft water or a protective factor in hard water. However, there does not appear any justification at present for recommending water Hardening. *(shaper et al., 1983)*. Hence, there is very little reliable epidemiological evidence available to support the fixing of allowable upper limits for drinking water quality. In practice it is preferred to err on the safer side, and most standards include a large factor of safety against the harmful effects of chemicals. The *WHO (1984)* has thus recommended guideline value of 500 mg/L.

It is fairly common to encounter the waters containing up to 100 mg/L of Calcium. The sources containing over 200 mg/L are rare. Like wise the Magnesium is common upto 10 mg/L and is rare over 100 mg/L. *(NRC, 1977 and Marier et al., 1979)*.

While there are evidence of the incidences of *Urolithiasis* in areas having Calcium 300-500 mg/L, the artificially softened waters on the other hand are found to contain higher Sodium concentration which results in higher blood pressure. *(WHO 1979)*

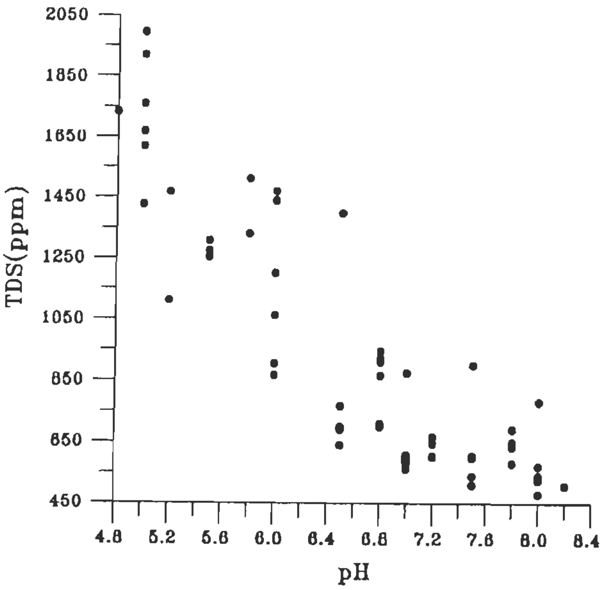
Water Hardness has strong ameliorating effects on the toxicity of most metals towards plants. Like Hydrogen ions, several workers have suggested competition for binding sites as the most likely mode of action of Calcium in ameliorating metal toxicity. *(stokes, 1983)*. Differential effects of Calcium on different metals may also be explained by this. The greater the affinity of a metal for binding sites the less the expected effect of Calcium in moderating its effects. *(Kelly, 1988)*

The Hardness reported here is calculated by the equation *(After Standard Methods, 1989)*.

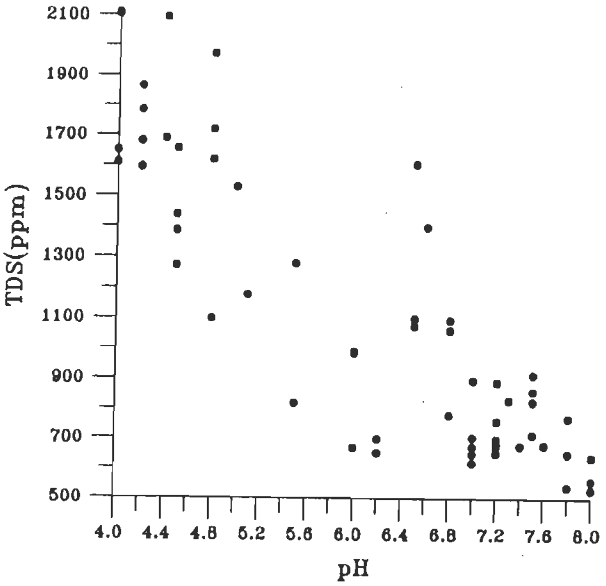
$$\text{Hardness, mg equivalent } CaCO_3/L = 2.497\ [Ca, mg/L] + 4.118\ [Mg, mg/L].$$

The geographic distribution is dealt separately for Ca, Mg and Bicarbonate under the 'Major Constituents'.

FIG. 4.2



VARIATION OF TDS IN RELATION TO pH
IN POSTMONSOON PERIOD



VARIATION OF TDS IN RELATION TO pH
IN PREMONSOON PERIOD

Discussion

The Hardness varies considerably within the regional waters. Majority, surfacewaters and minewaters show non Carbonate dominion whereas the groundwaters exhibit moderate to high Carbonate Hardness. The reason is the groundwaters are normally not affected by mines since the mines are fed by them. The minewater acidity counters the Bicarbonates and results into non Carbonate Hardness, thereby influencing the surfacewaters too.

The Hardness varies from moderate *(230 mg/L $CaCO_3$)* to as high as *(1168 mg/L $CaCO_3$)* which is far above *WHO (1984)* limits. Further, the Alkalis *(Ca & Mg)* dominate over Bicarbonates in almost all waters indicating the absence of temporary Hardness.

Therefore, a precaution is recommended against the use of waters demonstrating very high values of Hardness for drinking purpose. At the same time, the waters can be considered free from Bicarbonate hazard for irrigation.

MAJOR CONSTITUENTS

Rationale

Major constituents for the present work are defined as those commonly present in concentrations exceeding 1.0 mg/L. Iron and Manganese, though, are found to exceed but there preponderance is restricted to minewaters only. Therefore, the major constituents invariably remain Calcium, Magnesium, Sodium, Potassium, Sulfate, Bicarbonate and Chloride ions.

The dissolution and precipitation of every single constituent, at a particular point within time and space, has an extended significance within a mutually intricate system of continual chemical balancing. In fact, the chemical nature of natural waters is ever changing due to ongoing reactions within and between water and solid phase.

Hence, the chemical components have specific importance in interpreting the environmental balance.

The primary purpose of analyzing waters for major constituents is to fit them into the standard diagrammatic classification so that a broad picture based on their chemical nature is furnished. Further, a regional mapping of individual constituent is attempted to assess the spatial variation of each one. Since every constituent is vital from the environmental health point of view, their behavioral aspects are spelt out by virtue of their occurrences.

It must be noted that there is a categorical difference between the above two approaches. The diagrammatic classification is attempted on percent epm proportions which provide assessment based on relative prevalence of constituents whereas the Isocon mapping provides insight over actual concentrations prevailing, and their spatial distribution.

Accuracy of Results

The analysis was subjected to Ion balancing and the data falling beyond 0 - 10% range of error was discarded. Around 95% of the results fall within 0 - 10% range and a fairly good number of results, out of total samples, are within 5% range of error.

Classification of Waters

A number of graphical methods are in vogue for representing the chemical quality data of natural waters. Amongst these the trilinear plotting system has won popularity. *Hill-Piper* diagram has been widely used to study the similarities and differences in the composition of waters and to classify them into certain chemical types. However, the classification of water by this diagram is not specific.

The given diagram *(Fig. 4.3 a-f)* is a modification of the *Hill-Piper* diagram *(after Romani, 1981)*. The difference being in the shape of the three fields of study. Instead of equilateral triangles, right angled isosceles triangles have been used for plotting cations and anions. The advantage is that the resulting central field is square, instead of diamond shaped. Also the plotting in right angled triangles is comparatively easier.

The two right angled triangles, one for cations and other for anions, are essentially used for classification of waters. The three sides of each triangle, divided into 100 equal parts, represent the percentage reacting values *(epm %)* of cation and anion groups. The proportion of the principal cation and anion, in terms of percentage reacting values *(epm %)*, are plotted in each triangle and the type of water found out, on the basis of the position of plotting in respective field.

The cation and anion triangles are subdivided into 7 fields each, giving the following types of waters :

FIELD DESCRIPTION

C1	:	Calcium type
C2	:	Magnesium type
C3	:	Sodium type
C4	:	Sodium - Calcium type
C5	:	Calcium - Magnesium type
C6	:	Sodium -Magnesium type
C7	:	Calcium - Magnesium - Sodium type
A1	:	Bicarbonate type
A2	:	Sulfate type
A3	:	Chloride type
A4	:	Chloride - Bicarbonate type
A5	:	Bicarbonate - Sulfate type
A6	:	Chloride - Sulfate type
A7	:	Bicarbonate - Sulfate - Chloride type

Discussion

A careful glance over fig. 4.3 a & b for the years 1991 and 1992, reveals that majority of the wells have Calcium-Sulfate *(C1A2)* type of waters, with only a few plotting in the field of Calcium-Bicarbonate-Sulfate *(C1A5)* type. It is otherwise known that the ones plotting in *(C1A5)* type are generally free of minewater influence as they belong to minefree locations.

The groundwaters of post-monsoon period show a minor increase in Bicarbonate content causing a general drift towards the *(A1)* field i.e. the Sulfate tends to reduce in post-monsoon.

A bit higher Magnesium content is evident in well 'W5' which is located within basalts and has shown acidity. This can be attributed to the relatively higher mobility of Mg ion as compared to Ca ion at lowered pH, due to minewater influence.

The surfacewater plots of fig. 4.3 c & d of 1991 and 1992, show one distinct cluster of R1, R2 & R3 plotting differently from the rest. Others, which belong to the mining region show a little higher Sulfate compared to the ones from minefree locations. Thus the effect of minewater influence, though subtle, is discerned within surfacewaters. Like groundwaters, the surfacewaters, also, classify in the Calcium-Sulfate *(C1A2)* type, but in comparison to the groundwater the participation of Mg & Na + K ions within surfacewaters is a little higher.

The minewater plots, as shown in fig. 4.3 e & f of 1991 and 1992, have in common very high Sulfate content due to Sulfide presence within coals. However, the participation of Ca ion is shared by Mg & Na + K ions, causing a shift in the nature of few samples from the field C1 to C5 and C7. The higher Mg & Na + K ions are found related to minewater. Since, the minewater has significant bearing over surfacewaters this rise of Mg & Na + K ions can be felt within surfacewaters also.

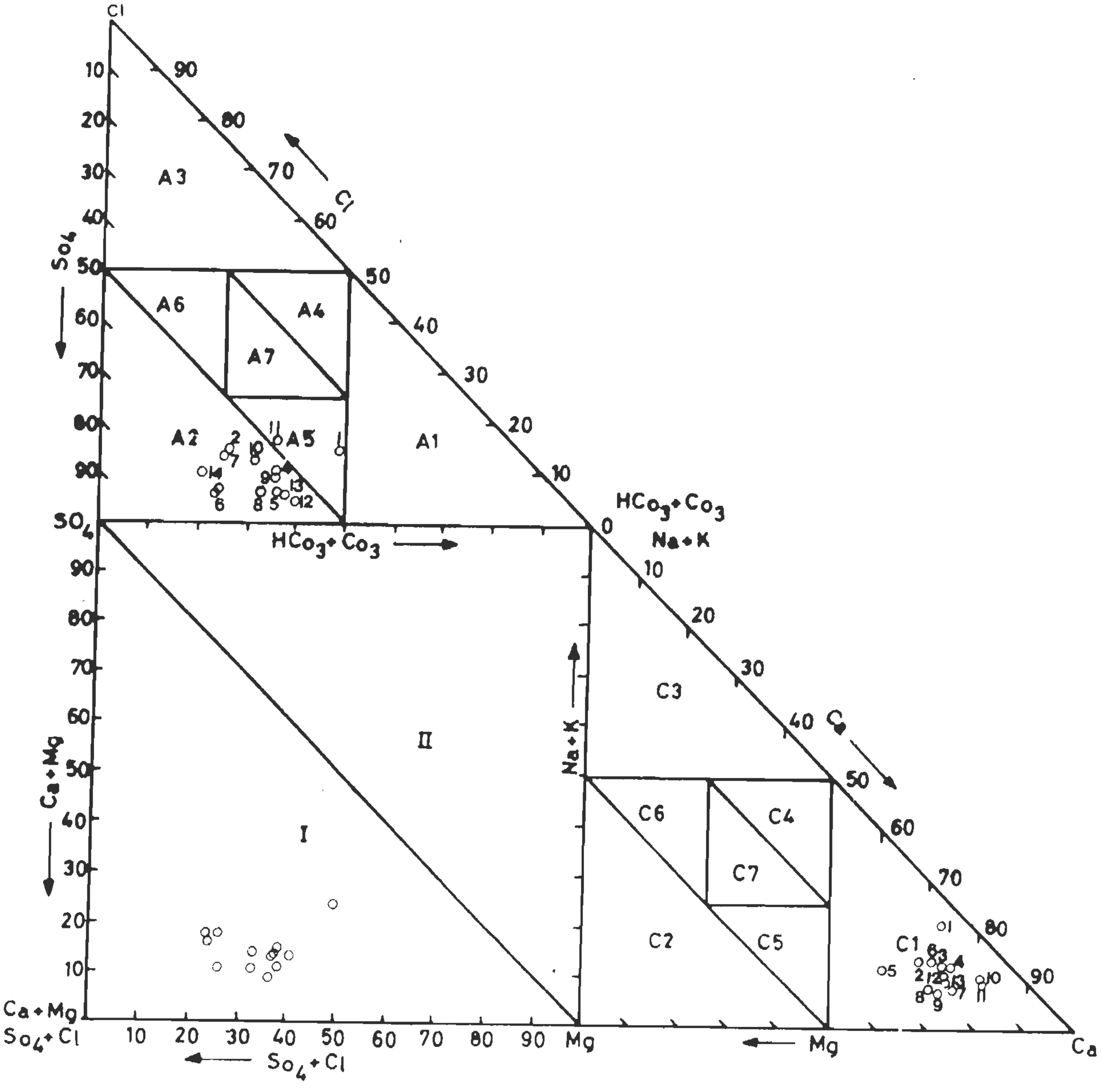


FIG.4.3a MODIFIED HILL-PIPER DIAGRAM FOR THE GROUNDWATERS :

PREMONSOON 1991 (After Romani,1981)

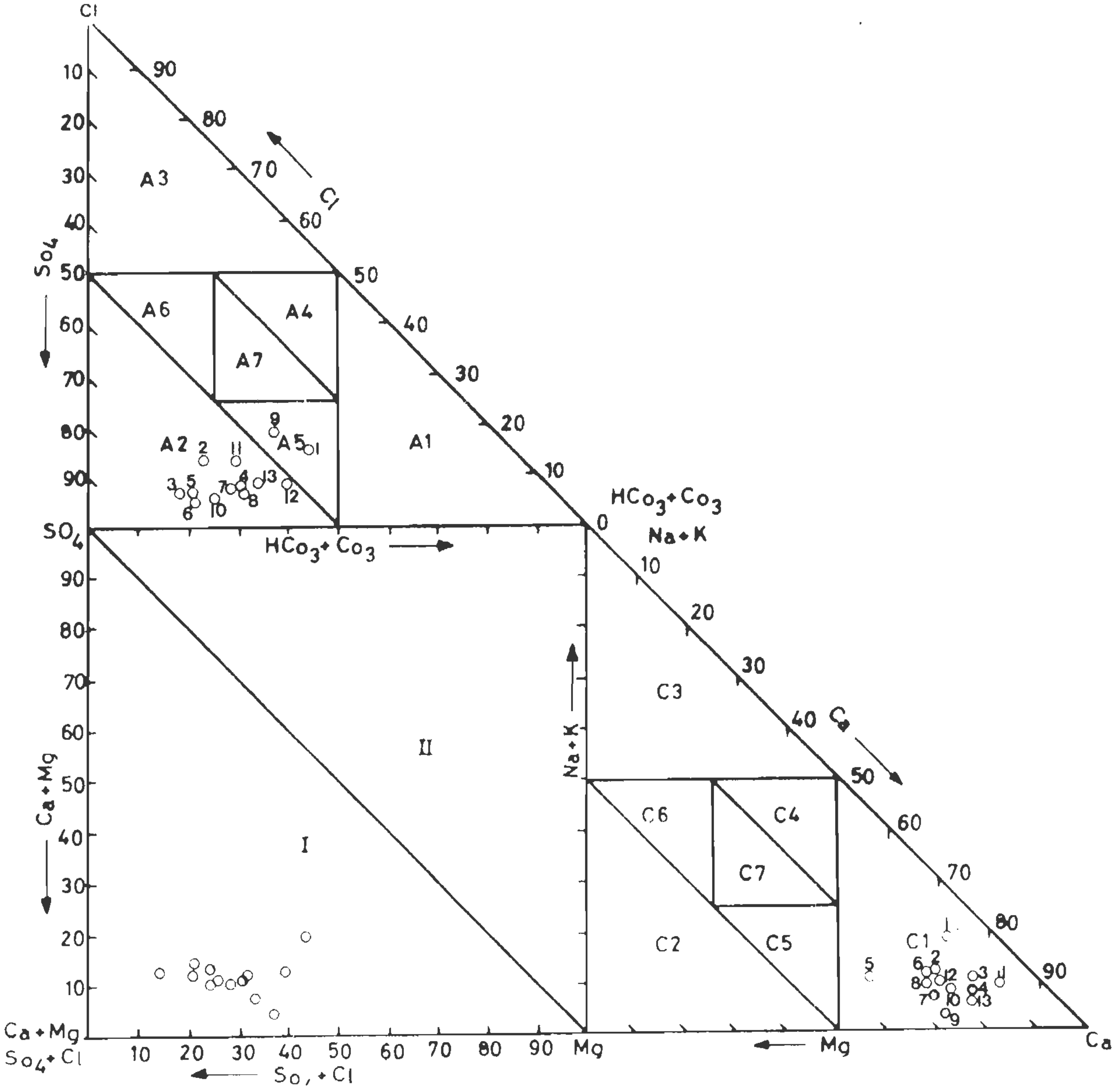


FIG.4.3a.MODIFIED HILL-PIPER DIAGRAM FOR THE GROUNDWATERS : PREMONSOON 1992 (After Romani,1981)

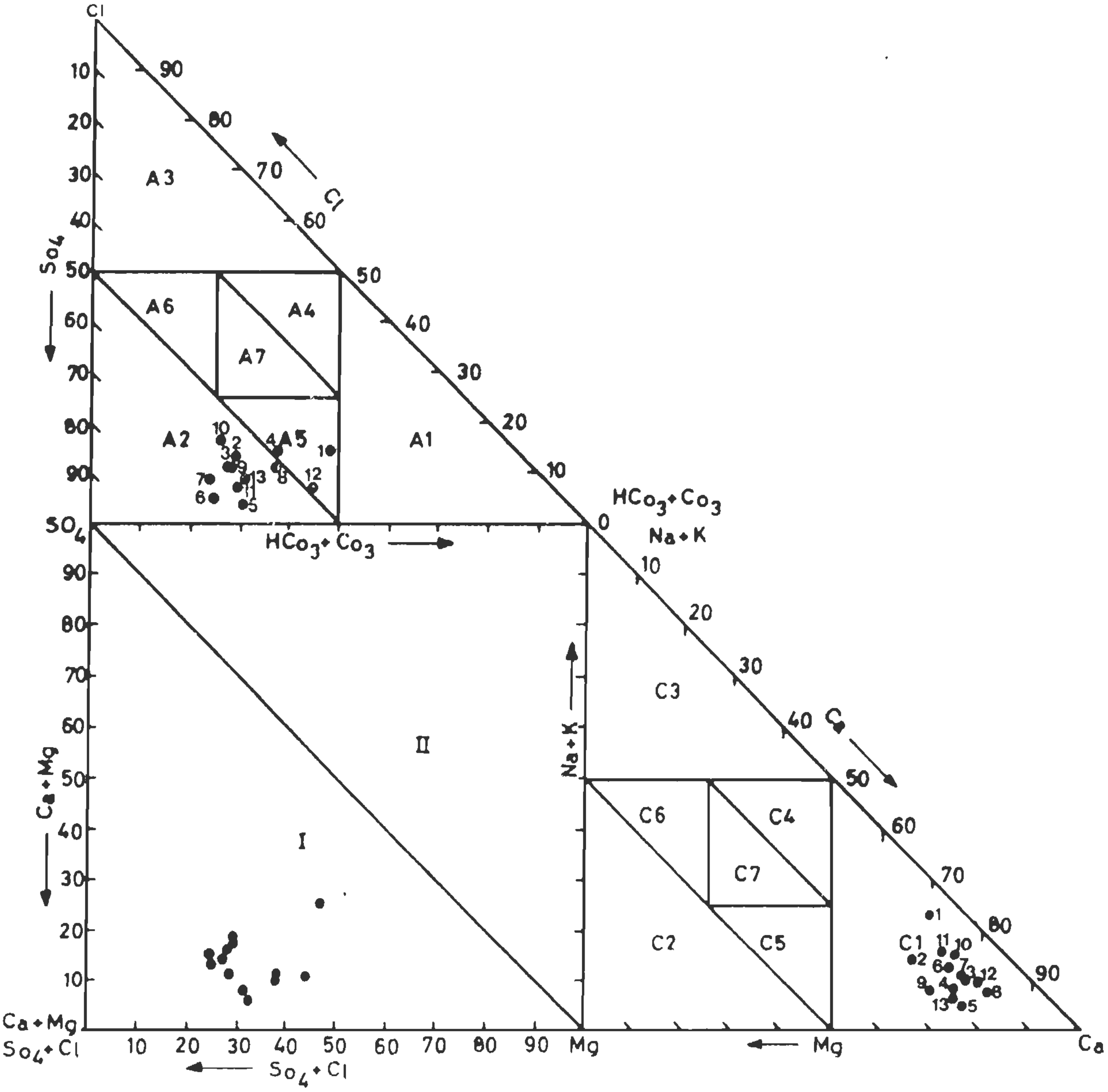


FIG.4.3b.MODIFIED HILL-PIPER DIAGRAM FOR THE GROUNDWATERS : POSTMONSOON 1991 (After Romani,1981)

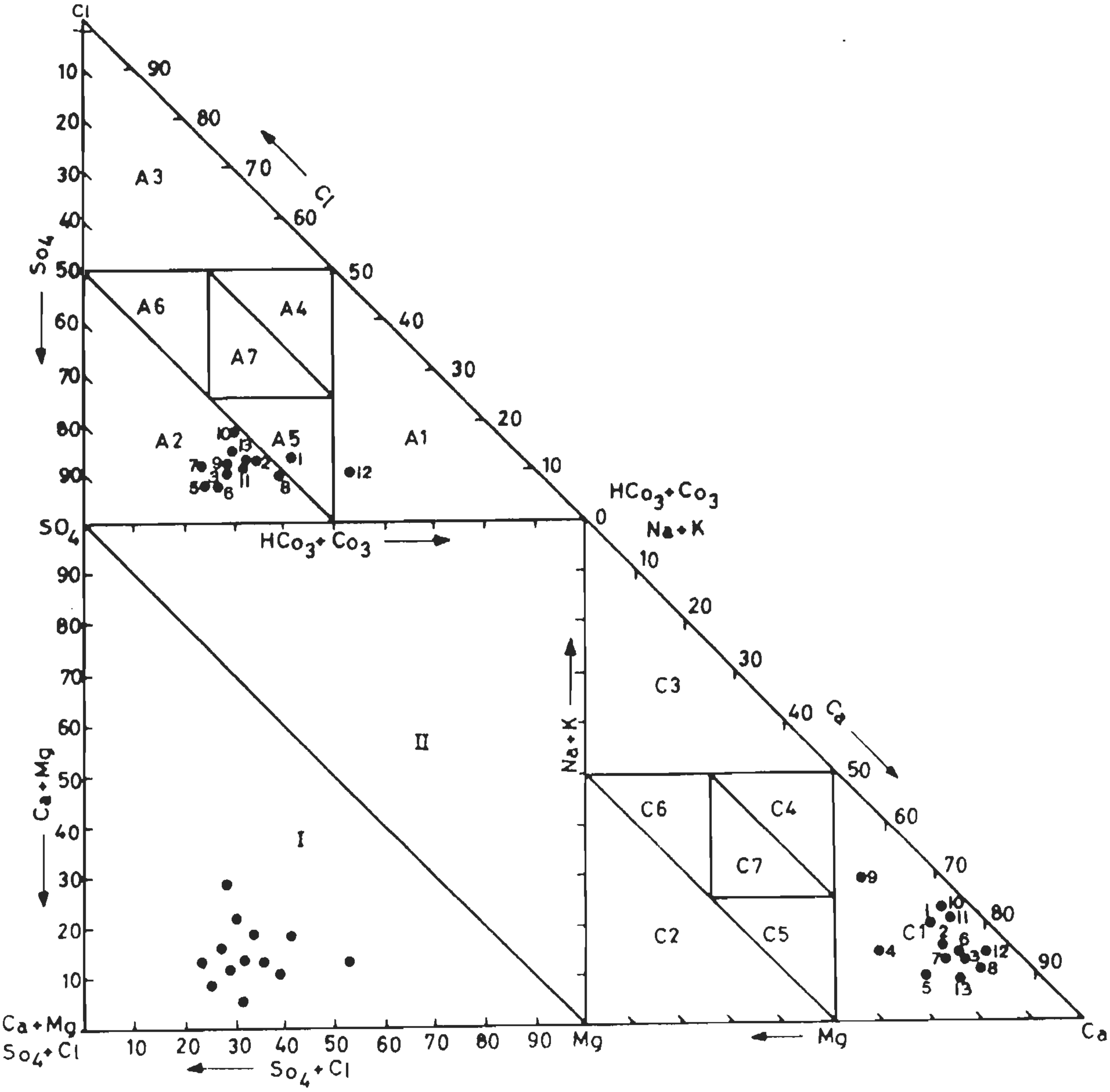


FIG. 4.3b. MODIFIED HILLPIPER DIAGRAM FOR THE GROUNDWATERS : POSTMONSOON 1992 (After Romani,1981)

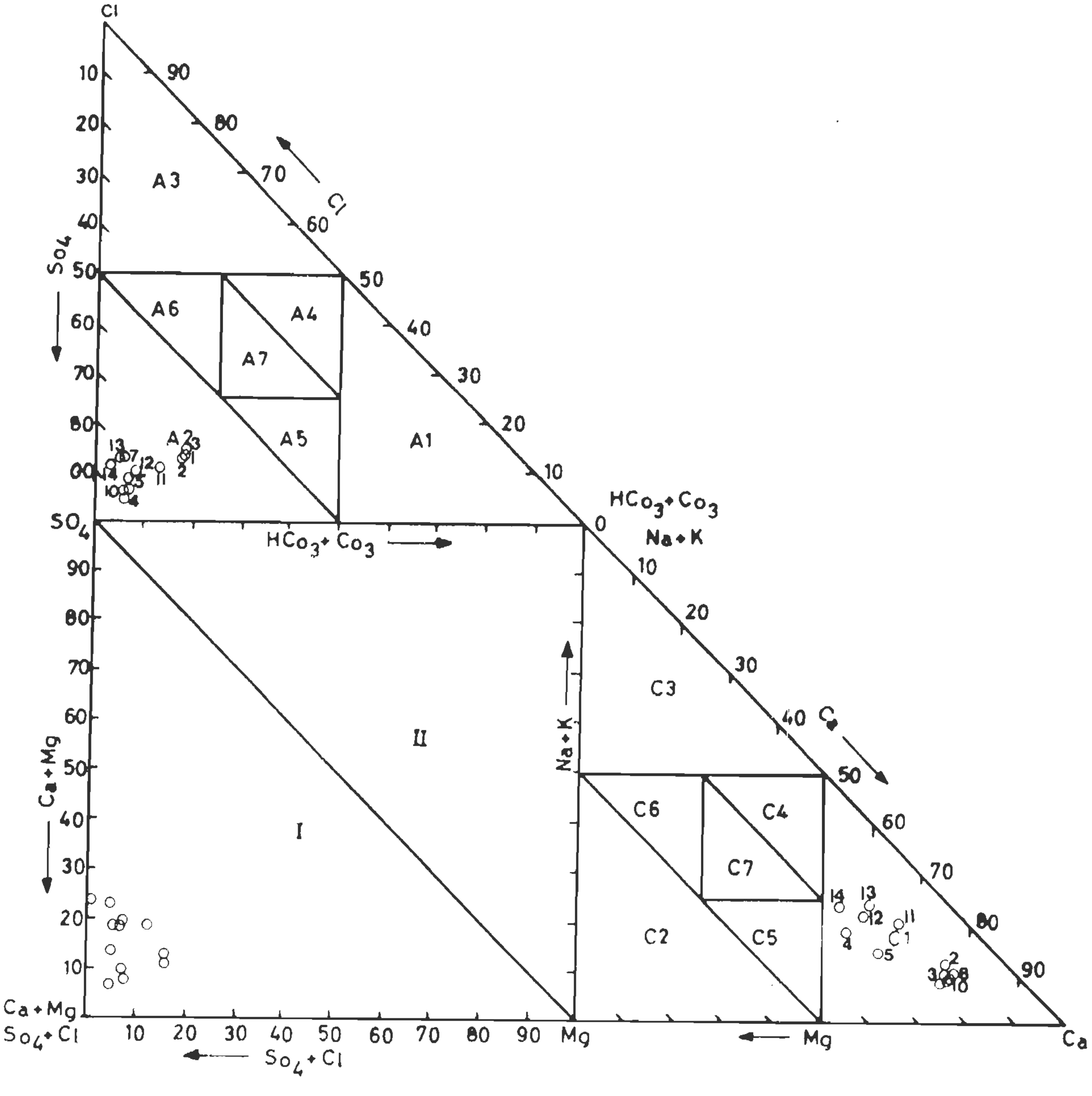


FIG. 4.3c. MODIFIED HILLPIPER DIAGRAM FOR THE SURFACEWATERS: PREMONSOON 1991 (After Romani,1981)

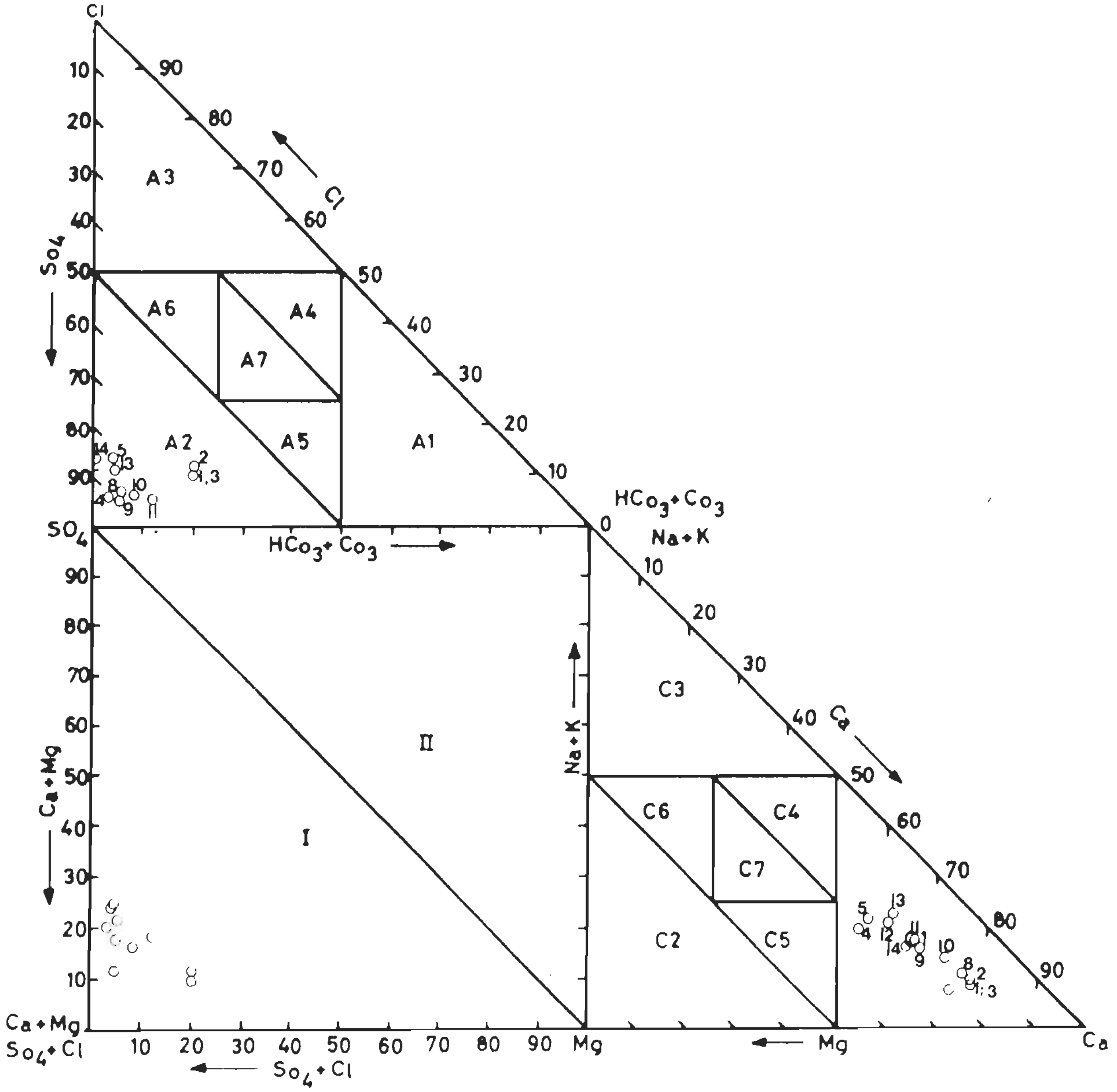


FIG. 4.3c. MODIFIED HILLPIPER DIAGRAM FOR THE SURFACEWATERS: PREMONSOON 1992 (After Romani,1981)

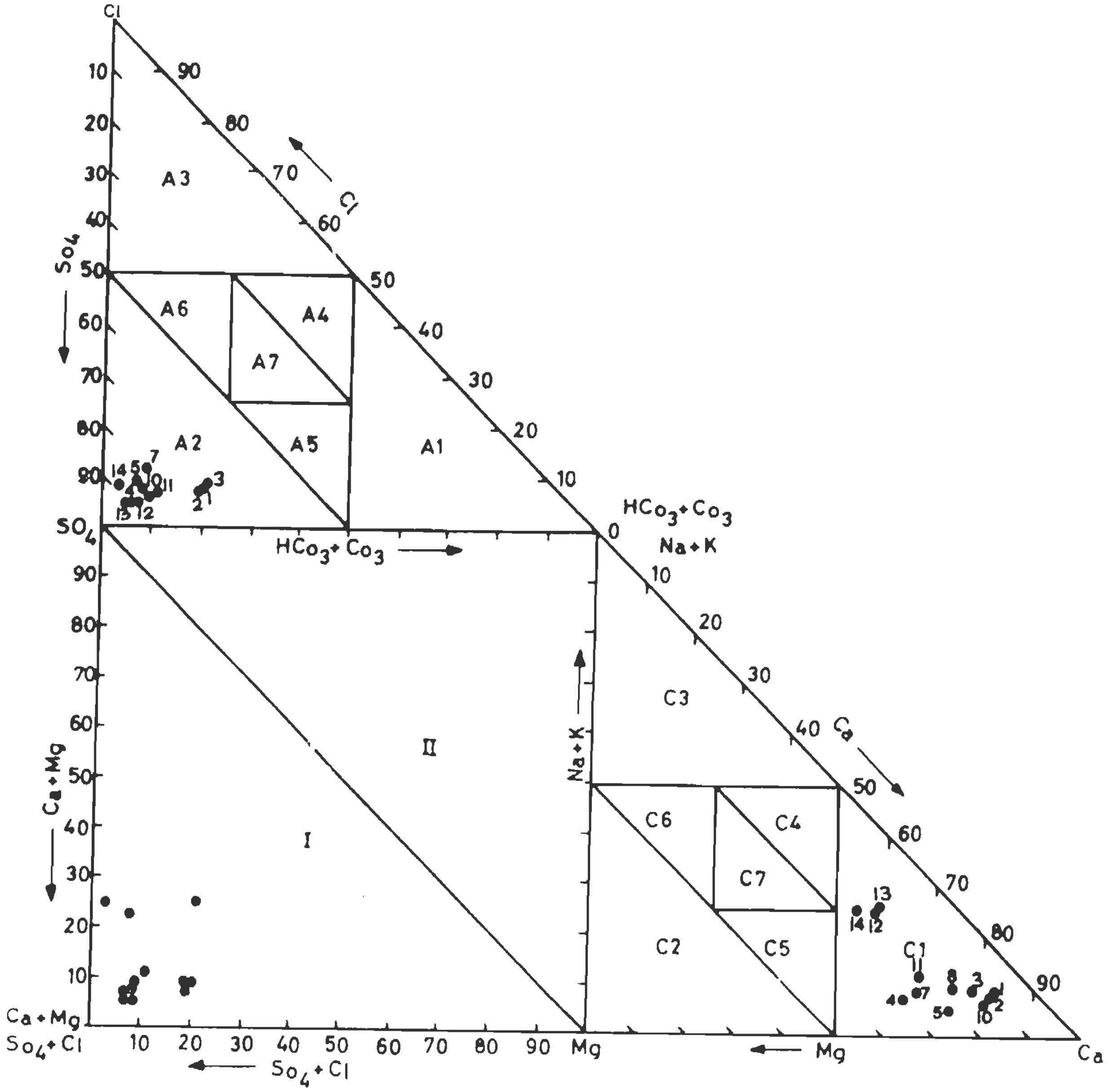


FIG. 4.3d. MODIFIED HILLPIPER DIAGRAM FOR THE SURFACEWATERS: POSTMONSOON 1991 (After Romani,1981)

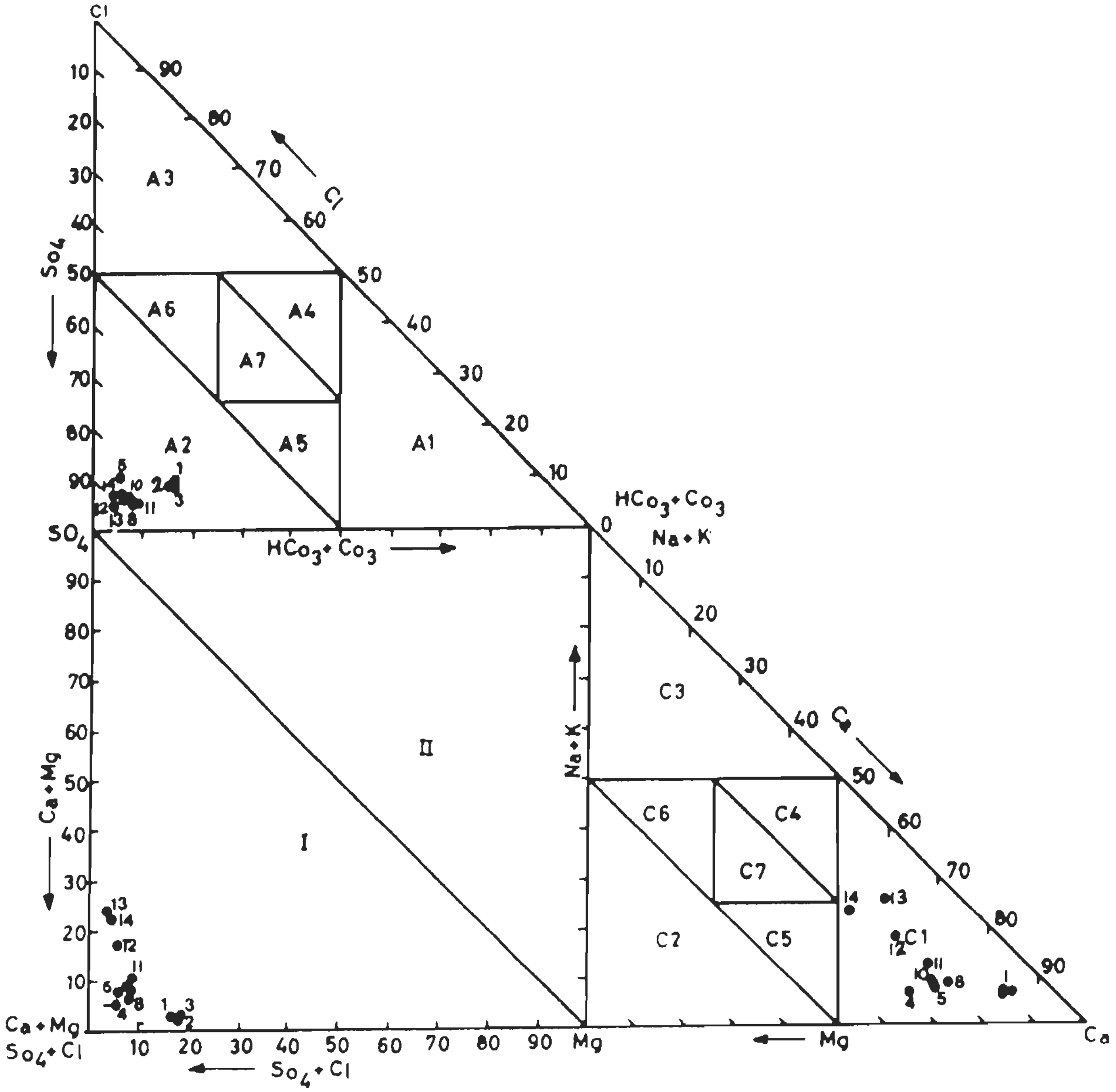


FIG. 4.3d. MODIFIED HILLPIPER DIAGRAM FOR THE SURFACEWATERS: POSTMONSOON 1992 (After Romani,1981)

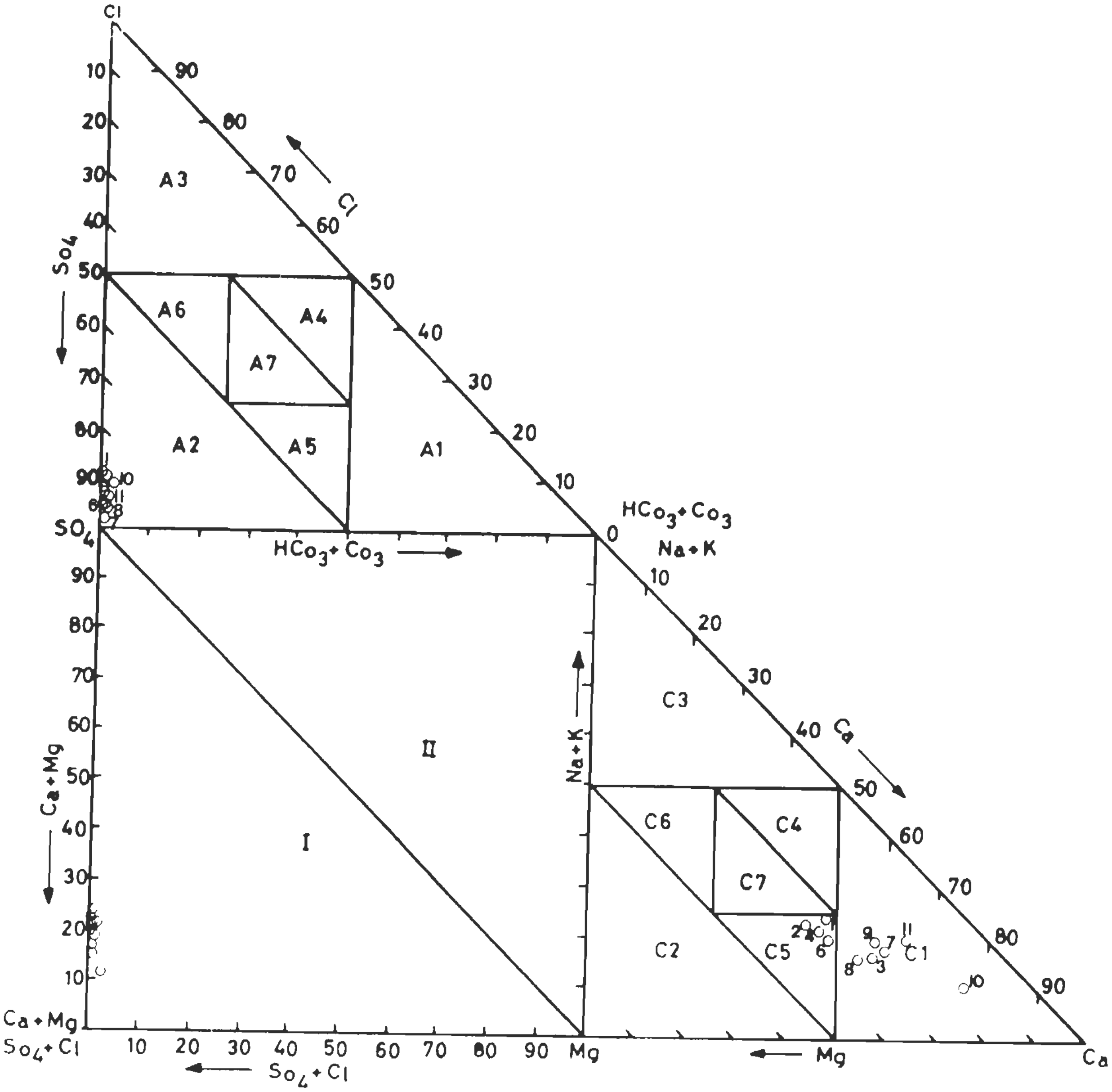


FIG. 4.3e. MODIFIED HILLPIPER DIAGRAM FOR THE MINEWATERS : PREMONSOON 1992 (After Romani,1981)

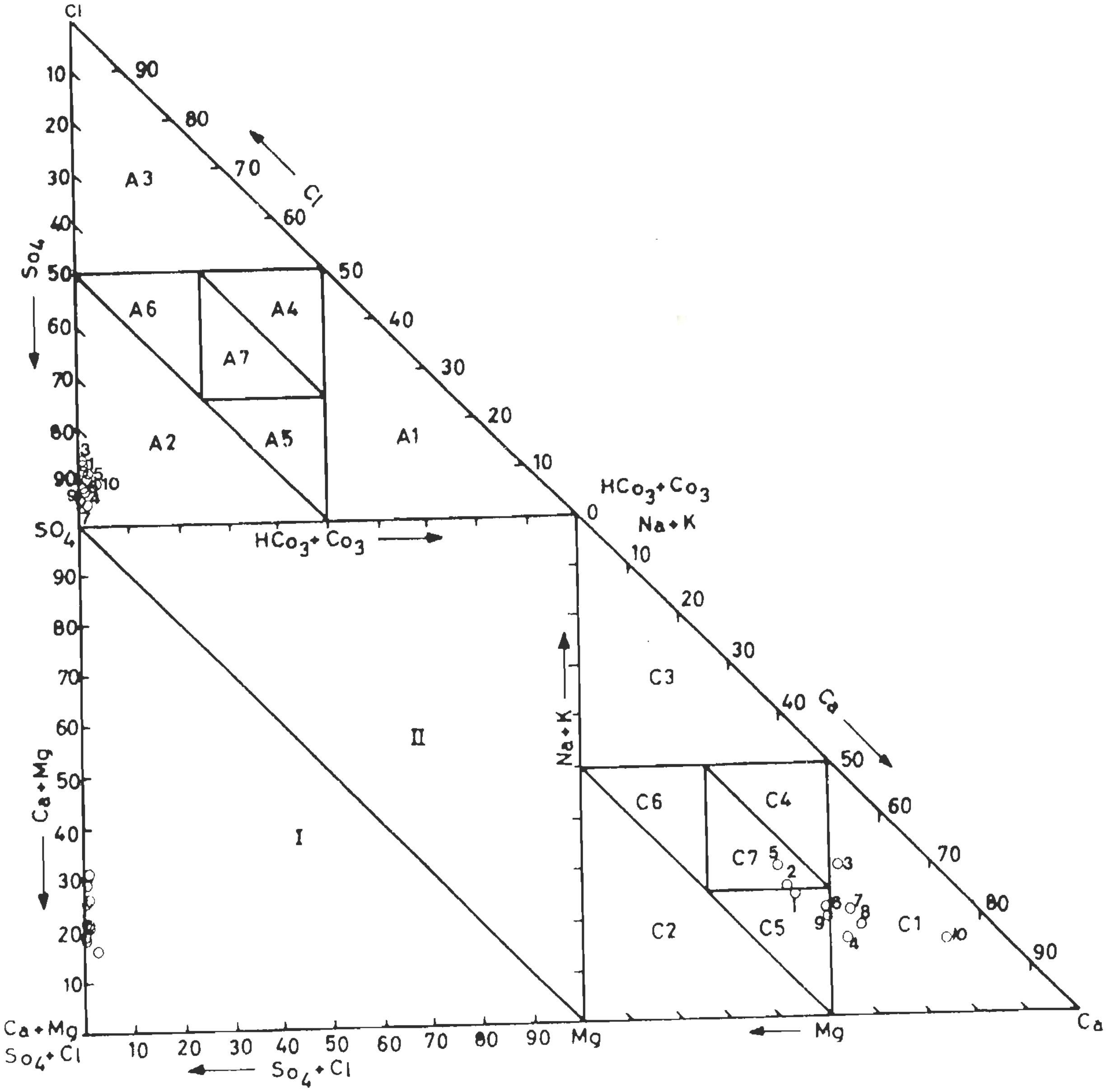


FIG. 4.3e. MODIFIED HILLPIPER DIAGRAM FOR THE MINEWATERS : PREMONSOON 1991 (After Romani,1981)

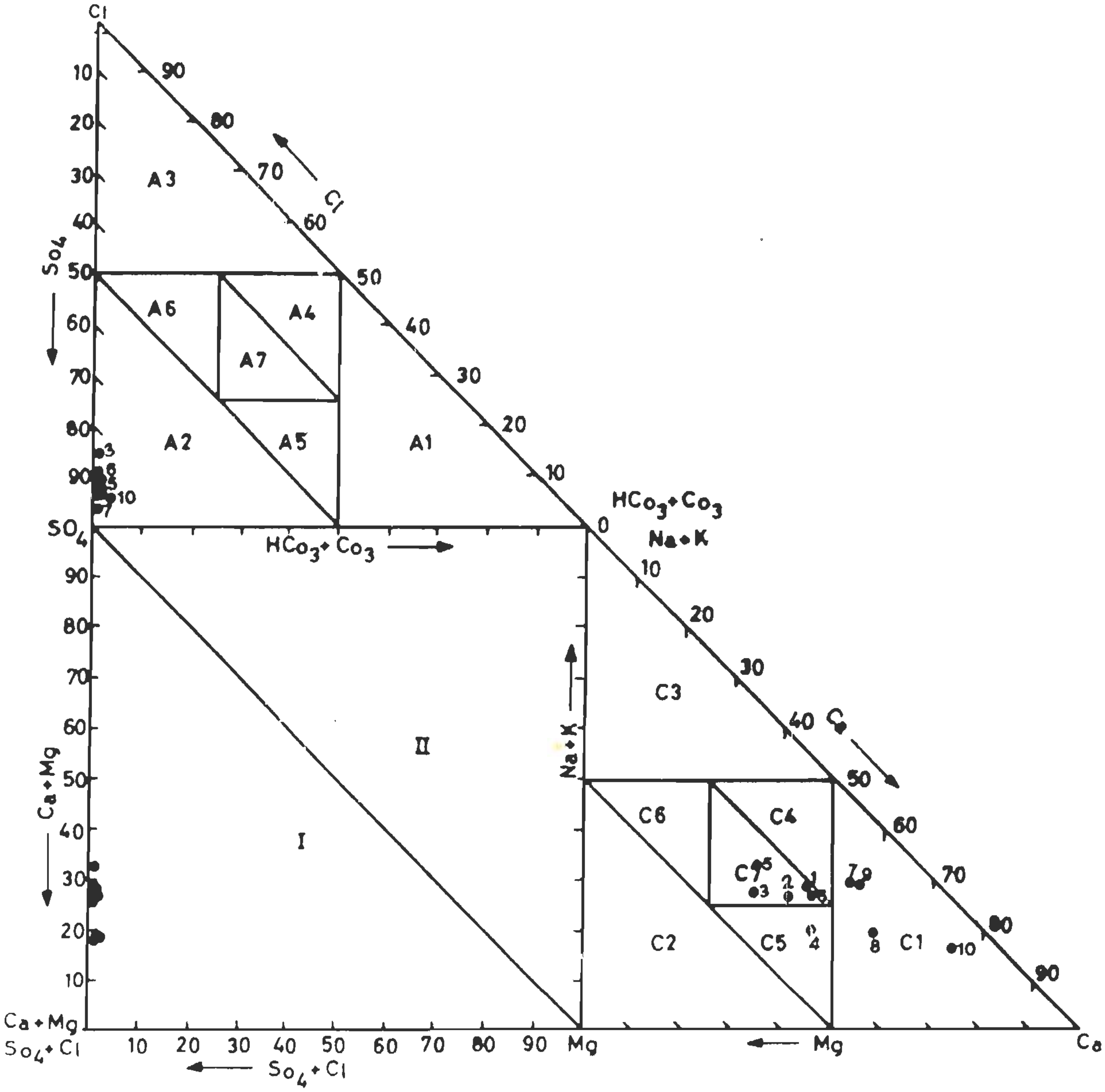


FIG. 4.3f. MODIFIED HILLPIPER DIAGRAM FOR THE MINEWATERS: POSTMONSOON 1991 (After Romani,1981)

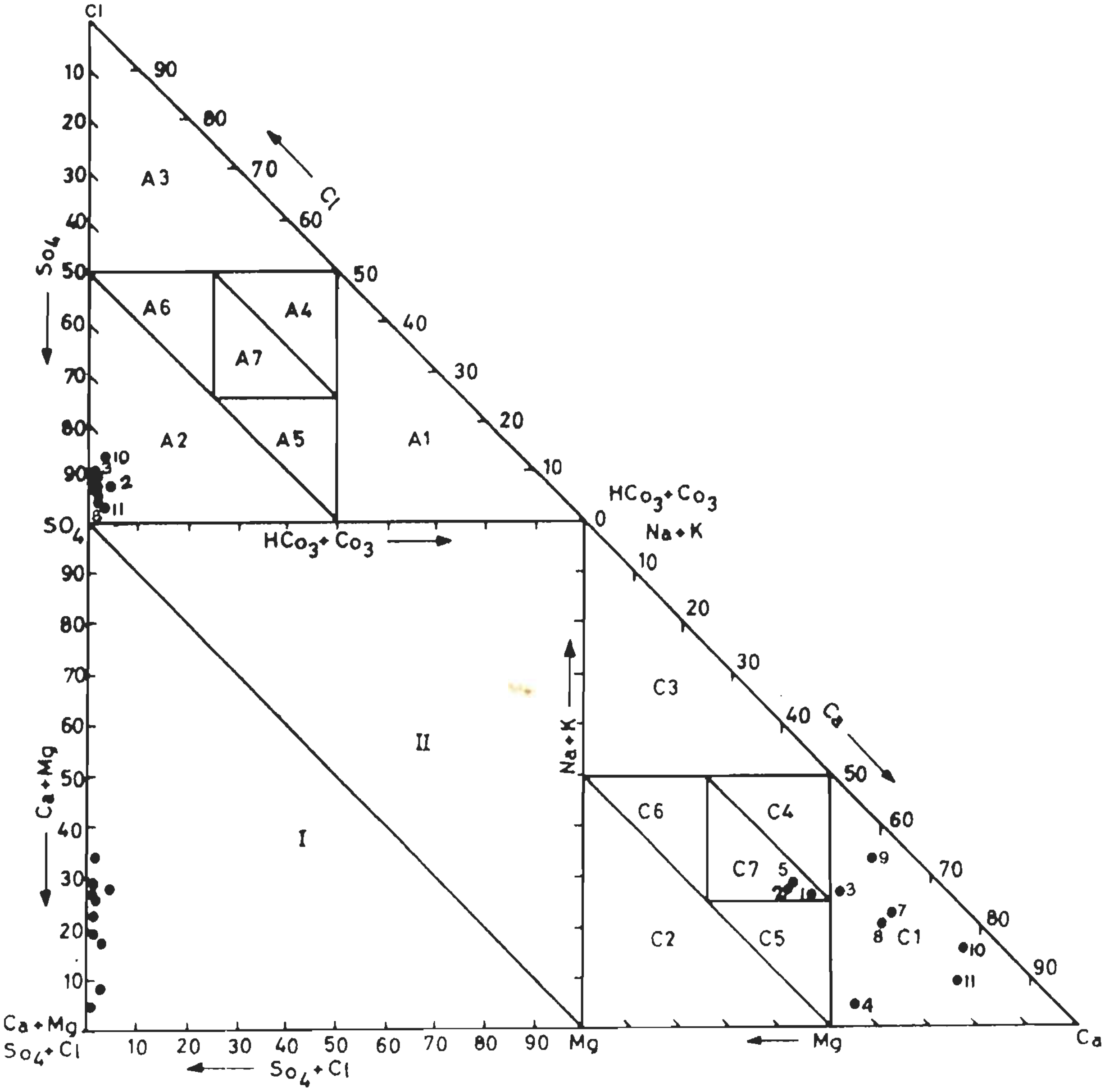


FIG. 4.3f. MODIFIED HILLPIPER DIAGRAM FOR THE MINEWATERS:
POSTMONSOON 1992 (After Romani,1981)

On the whole the following broad conclusions can be drawn :

- All the three types of waters plot more or less similarly within the diagram.
- The relative participation *(epm)* of major constituents is noticed quite similar within all the three types of waters, though the actual concentration *(ppm)* varies drastically.
- The cations show least scatter in the groundwaters and maximum scatter in minewater, indicating the varied nature of minewaters with respect to cation participation.
- Abnormally high Sulfate is a sufficient indication of minewater influence.
- It is the surfacewater which is affected more by minewater compared to groundwater.
- In general, the increase in the percentage reacting values *(epm %)* of Mg, Na + K & SO_4 ions can be taken as indicators for minewater influence.
- No water is found to have temporary hardness causing Bicarbonate hazard hence the waters can be considered safe in this respect.

Comparison of Waters

The water chemistry can be plotted in different ways, and most methods are based on expressing the chemical composition relative to geochemical equilibria *(Hem, 1985)*. Our choice is evinced in fig. 4.4, to find out a clear-cut relationship between the three types of waters inhabiting the region.

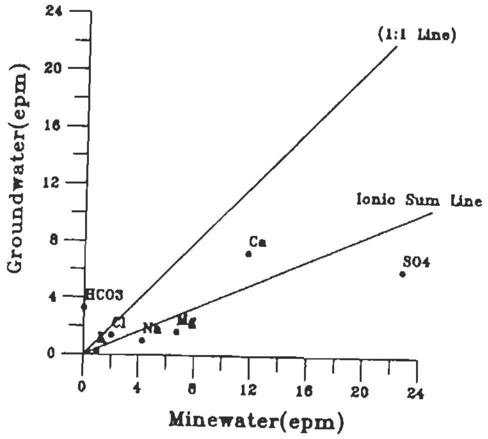
The chemistry of different waters in areas of similar geologic settings is compared by plotting the reacting values *(epm)* of each constituent in an xy diagram. The deviation of each chemical component from the **Ionic Sum Line** *(line of proportional composition)* gives information about the differences in the compositions of the two waters. If, the composition of both the waters is identical the Ionic Sum Line would overlap the 1:1 line. The deflection of Ionic Sum Line towards one, would mean higher participation of chemical components in that water. Each, individual, ion would plot close to Ionic Sum Line if their relative participation *(or proportional composition)* behaves similarly, or else the point would shift away from the Ionic Sum Line, indicating higher equivalent concentration in that water.

Discussion

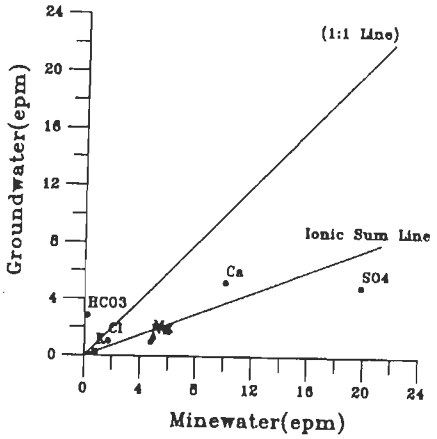
It is seen that the groundwaters have relatively higher HCO_3 and Ca ions compared to minewaters whereas the SO_4 ion dominates in minewaters. The minewaters have little more Na and Mg ions than groundwaters. It is interesting that the Mg ions tends to be high in comparison to Ca ion within minewater. The post-monsoon values come little nearer to Ionic Sum Line indicating that the nature of two waters become a bit more similar during post-monsoon. The surfacewater *Vs* minewater plot has a difference that HCO_3 shows no more dominance. The Ca ion remains high in surfacewater and SO_4 dominates in minewaters and both the ions come close to Ionic Sum Line during post-monsoon. The deflection of Ionic Sum Line towards minewater, in both the cases, indicates very high participation *(probably due to acidity)* of all the constituents within minewaters.

In nature, usually, the groundwaters are found to have higher solute content than surfacewaters. i.e. the Ionic Sum Line falls in the side of groundwater in comparison to surfacewater. But, in this region the Ionic Sum Line falls in the side of surfacewater, indicating the impact of minewater mixing on the surfacewater, that it attains the concentration higher than that of groundwater. Further, the dominance

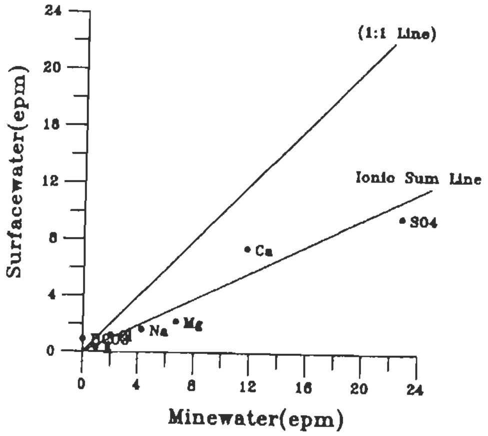
FIG.4.4



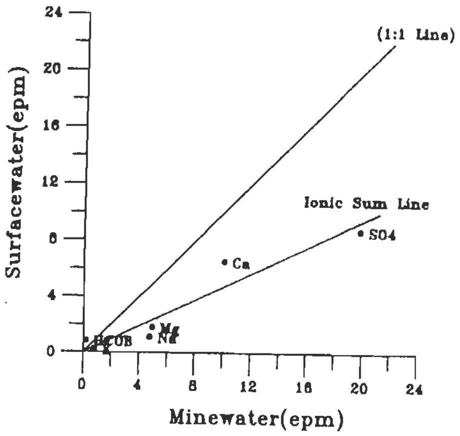
COMPARISON OF GROUNDWATER WITH MINEWATER ; PREMONSOON PERIOD



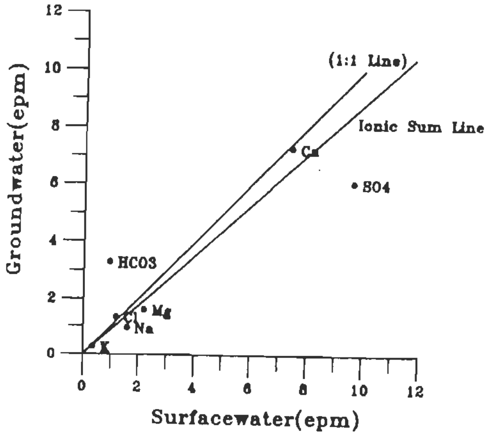
COMPARISON OF GROUNDWATER WITH MINEWATER ; POSTMONSOON PERIOD



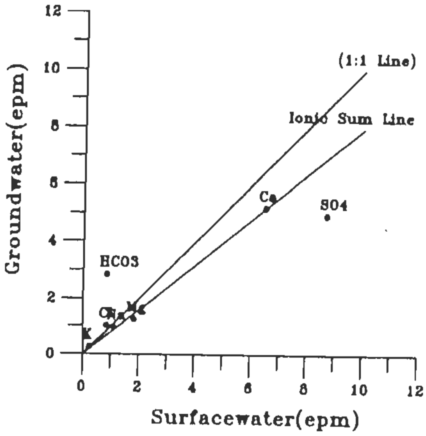
COMPARISON OF SURFACEWATER WITH MINEWATER ; PREMONSOON PERIOD



COMPARISON OF SURFACEWATER WITH MINEWATER ; POSTMONSOON PERIOD



COMPARISON OF SURFACEWATER WITH GROUNDWATER ; PREMONSOON PERIOD



COMPARISON OF SURFACEWATER WITH GROUNDWATER ; POSTMONSOON PERIOD of HCO_3 ion in groundwater and SO_4 ion in surfacewater indicates a behaviour confirming the influence of minewater over the surfacewater.

Geographic Distribution of Major Constituents *(Based on Isocon maps)*

Within Groundwater : A cursory glance on Annexure 4.3 would yield that there isn't much change in pre-and post-monsoon scenario. It, eventually, speaks of the stability, attained within the region, while it passed through considerably long lapse of time since the advent of mining : a sort of balance, within ongoing changes and the nature's power to counter them. The regional picture remains, more or less, similar which alludes toward the existing broad homogeneity *(devoid of perceptibly sharp variations)*. It is enough, an argument, for the suitability of choosing only two sampling seasons over the year.

As known already that the mines are laid East-West through the central part of region, and the Northern & Southern flanks constitute minefree portions. We see that, almost, all the constituents tend to be high in the mining region and their concentration withers away toward the flanks. This general excess of constituents in shallow groundwaters is, at times, the result of minewater percolations reaching the wells as in the case of 'W5' which can, as well, be expected in other cases too. Further, it is expected that the wells falling towards the downflow directions and the one's in the vicinity of minewater drains, will have the potential impact.

The post-monsoonal samples show dilution due to atmospheric precipitation which affects homogeneously throughout the region, and the constituents are found to be within the *WHO (1984)* Limits.

The Calcium to Magnesium ratio is low within mining region and increases away from mines. This, relative excess in the Magnesium content within mine locality indicates enhanced mobility of Magnesium to that of Calcium ion.

Though the Calcium tends to be the predominant cation in most natural freshwaters, the solubility of most of its compounds happens to be lower than the Magnesium compounds.

In the present case, the acidity probably brings, the more mobile, Magnesium compounds into solution relatively faster than Calcium; and the Calcium slowly regains later. Therefore, the preponderance of Calcium over Magnesium is gradually attained as we go away from mining, may be because of the lower geochemical abundance of Magnesium.

Further, the minerals with ion exchange capability adsorb Magnesium only slightly more firmly than Calcium so that the low Magnesium content can occasionally be attributed to cation exchange, within minefree locations.

Within Surfacewater : As known already, that the river Pench, which is the main surfacewater body of the region, drains west to east. The sample locations R1 to R12 are taken along the downstream from this very river which enters the region at R2 and leaves the region at R12. Another stream which is sampled first at R14 joins the river Pench, via R13, a little before the point R12. *(Refer fig. 1.2).*

As a rule, the water quality upgradient from the mine gives baseline quality and downgradient gives changes or alterations due to mining operations.

Annexure 4.4 reveals that there is sudden increase of almost all the constituents at the location R4, but the river gradually recovers further downstream. It must be noted that R4 is the point where the mine discharge is directly pumped into the river. A few more mine discharges join the river Pench between the locations R4 and R5. Hence, we notice that the recovery improves only after point R5. Though, at point R11 the open cast mine discharge meets the river, but it does not affect the ambient constituent load of the river, to a considerable degree.

Another stream which receives the mine drainages from the central region shows up as carrying very high constituent load. This also recovers significantly prior to meeting the river Pench just before point R12. It is further observed that the constituent load at R12 is more during pre-monsoon than the post-monsoon, i.e. the river Pench regains faster in post-monsoon. The mixing of stream water does, to an extent, alters the constituent load prior to point R12 during pre-monsoon, but it recovers well in advance during post-monsoon and causes no significant change at R12.

The Sodium salts being highly mobile remain in solution longer than others. Hence, we notice that the concentration of Sodium is not easily brought down in the river Pench when it leaves the region.

The Sodium & Potassium are relatively high in the stream water *(at R14)* and tend to affect the composition of river water in both *(pre- & post-monsoon)* seasons. Further, the mining region yields more Sodium & Potassium than the minefree locations.

The Bicarbonates are lowered when the river enters the region. The river resumes its natural Bicarbonate level further down stream. It is interesting to note that, at the spots where the minewater joins surfacewater, the Bicarbonates are consumed heavily as seen at R4 and R14.

The relatively high content of Chloride, like many other constituents, remains high in the river for a longer distance in pre-monsoon than the post-monsoon. The sulfate shoots high at R4 and R14 and remains, more or less, same in both the seasons, while there is not much change in its concentration.

The Calcium to Magnesium ratio behaves similar to groundwater i.e. the minewater mixing into surfacewater brings the Ca/Mg ratio considerably down. The ratio has more or less similar geographic distribution in both the seasons.

Within Minewater : In an attempt to find out the behaviour of different constituents within the minewaters of the region we have plotted the Isopleths. The absence of any minewater outlet in the central region has made the extrapolation, in that particular part, weak as the distance between control points is substantial. The minewater of this region has been diverted internally to other mines, from where it is finally discharged on to the surface.

On the whole, there is no fixed trend for individual constituents and different parts of mines are noticed to have different components dominating. Since, the mines are ever expanding, the newer exposed surfaces keep on affecting the composition of minewater. Since, the nature is diverse, we notice haphazard localized variations. The points M1 to M4 discharge water from all the three coal seams along with M8 whereas, M10 and M11 discharge the water from open cast mines which are found yielding comparatively very low constituent load.*(Annexure 4.5)*.

The Calcium is high and increases in the central part. The open cast mines are found to be low in Calcium release. On the whole, the prevailing range of Calcium is considerably high, in both the seasons. The Magnesium also has the similar behaviour changing a bit in post-monsoon. Sodium and Potassium both are high in deeper mines except in M8. Chloride concentrates in the down dip direction while Bicarbonate though, insignificant, goes down. Sulfates are highest in the middle part probably the Sulfide mineralization is more in central region. The Calcium to Magnesium ratio within minewater has nothing much to say apart from being very low.

General Discussion

The post-mining quality of water takes a considerable influence from the overburden. The water which infiltrates and migrates through this zone of vadoze water into the groundwater zone does, to an extent, accounts for the changes in water chemistry. A few prominent reactions controls the water chemistry in this kind of framework, which can be summarized as follows :

1. Oxidation of Pyrite.
2. Dissolution of Carbonate minerals.
3. Precipitation of Ferric Hydroxide.
4. Precipitation of Gypsum.
5. Cation Exchange.
6. Loss of Bicarbonate buffer.
7. Coprecipitation and adsorption of Trace Constituents Over the Oxides and Hydroxide.

While studying the chemical properties of overburden material *Everett (1985)* concluded that the materials having higher clay content have a greater tendency to be Sodic. However, the release, transport and accumulation of Na depends on the occurrence of Calcite, Gypsum and Cation exchange capacity of overburden.

The occurrence of Gypsum depends primarily on the occurrence of Pyrite and the rate and frequency at which water containing Dissolved Oxygen contacts Pyrite. All of the important geochemical processes that determine the chemistry of groundwater in the study area are primarily operative above the groundwater; the chemistry of the groundwater, regardless of the age and distance that the water has traveled, is determined by the geochemical processes that occur during recharge. *(Moran et al., 1978)*.

During exceptional recharge events, Gypsum and other soluble salts are transported to the water table, resulting in high concentrations of Sulfates. The existence of Gypsum is the result of the concentration of Calcium Sulfate due to evapotranspiration of groundwater in the unsaturated zone. The existence of the Calcium and Sulfate can be primarily attributed to the oxidation of Pyrite and the dissolution of Calcite. *(Groenewold et al., 1980)*.

The major limitation to understanding the post-mining groundwater quality is accurate determination of the amount of Carbonate, Pyrite, and Gypsum in the overburden. Although existing analytical techniques may show an absence of Carbonate, Pyrite, or Gypsum, this cannot be taken as positive evidence of the absence of these minerals. Thus, long-term post-mining groundwater quality prediction is extremely speculative.*(Everett, 1985)*.

In summary, the current research in Pench area has centered on a more indepth understanding of the geochemical reactions that could occur in the region. These reactions and inter-reactions that occur during the evolution of the post-mining quality are extremely complex. The system is dynamic and no single equation can define it. Changes in constituent levels will occur in the waters in response to recharge from major precipitation events. If, the oxygen levels in the spoils increase it may result in increased oxidation of Pyrite. This process has been found to occur up to 5 years after mining was completed. *(Palmer & Cherry, 1979)*. The geohydrological setting is complex and no simple answer will suffice to quantitatively assess post-mining impact.

TRACE CONSTITUENTS

Rationale

It would be apt, at the outset, to mention that there prevails a confusion regarding the use of term *"trace"*, it's propriety and implication. The terms *"minor"* and *"trace"* used in reference to solutes in natural water, cannot be precisely defined. Commonly, these terms are used for substances that always or nearly always occur in concentrations less than 1.0 mg/L. Thus, for practical purposes, other terms such as *trace elements, trace metals, trace inorganics, heavy metals, micro elements and micro nutrients* will be treated as synonymous with the term *'trace constituents'*. The history of research on minor constituents of natural water is punctuated by discoveries that some supposedly insignificant trace constituents were actually or potentially of vital importance to human health, plant nutrition, or other areas of general interest *(Hem, 1985)*.

The choice of elements in the present study was governed by the possibility of element presence in that particular enviro-setup and the availability of desired laboratory and instrumental facility, at the place of working. The prime factor, however, was elements' relation to the environmental health, in some way or the other. Based on the above criterion, Iron, Manganese, Nickel, Cobalt, Chromium, Copper, Zinc, Lead, Mercury and Fluoride were finally selected to be monitored within the Pench region. Though, Arsenic deserved to be included in the above list because of its expected association with Pyrites in the form of Arsenopyrite *(A Sulfide accessory mineral, often found alongwith Pyrite)* found commonly in coal deposits. The exclusion of Arsenic from the above list owes to the following reasons :

1. Arsenic has very poor solubility in water. Arsenates (As^{5-}) dominate in the pH range of 3 - 7 in the form of monovalent oxyanion ($H_2AsO_4^-$) and the divalent

species of Arsenate (As^{5-}). ($HAsO_2^-$) takes over from pH 7 to 11. In solution within water the stable forms are Arsenate (As^{5-}) & Arsenites (As^{3-}) oxyanions *(Hem, 1985)*, whereas the trivalent forms are more toxic than Pentavalent forms both to Mammals & Aquatic species. *(Train, 1979).*

2. Further, it has been documented that the mobility of Arsenic is enhanced in the basic conditions. *(John Kwong, 1989).*
3. Adsorption by Hydrous Iron Oxide or, coprecipitation *(Matisoff et al., 1982 & Davis, 1981)* or combination with Sulfide in reduced conditions, appear to be major inorganic factors that can maintain concentrations of Arsenic at very low levels in water. *(Hem, 1981).*
4. Unavailability of hydride generation unit in analytical instrumentation.

I prefer to quote a few excerpts from *Cargo & Mallory (1974)* for which I have no better substitute in order to focus on the subject which they aptly called *"Medical Geology"*.

> *Because our knowledge of the roles of trace metals in various biological systems has expanded rapidly, we have started to focus our attention on their role in human metabolism. We are finding that trace elements are necessary in growth, the healing process, and many metabolic processes - in short, they are essential if man is to function at an optimum. Indeed, they are probably involved in longevity and in the aging process and, hence, with life itself.*
>
> *Evidence indicates that the essential trace elements (like vitamins, their organic counterparts) participate in a variety of enzymatic actions. However, since they cannot be synthesized or metabolized, the trace elements are in many respects more important than vitamins. If they are not present in the environment in usable forms and in the quantities needed, life suffers and dies : either excesses or deficiencies of trace elements can be lethal.*
>
> *All elements, including the trace elements, are released into the environment through the process of chemical weathering. However, we should point out that since the concentration of trace elements is not the same in all rocks, no weathering, no matter how intensive, can release an element which is not present.*
>
> *When considering trace element concentrations, it is impossible to speak of the "environment" in general terms. There is often a marked difference in these concentrations among bedrock, soil, and waters in a given area. In addition, there is a wide variation of element distribution and concentration within a particular rock group. Hence, concentration can be reasonably considered only in terms of averages...*

It has been borne out by experimental evidence that the role of trace constituents in living systems follows the pattern of natural availability and abundance of the same constituents occurring in nature. In some cases, trace constituents have a powerful, directive influence on the biologic functions within the human body, because the trace constituents have been observed to work as catalysts in enzymatic activity. *(Forstner & Wittmann, 1981).*

Coal mining affects the mobility of trace constituents in water, chiefly, because of the acid dissolution. Many trace elements which are feebly present in natural waters get overwhelmingly mobilized along with others and pose a number of problems, right from their toxicity to deficiency. Other prominent reactions, active in mining region, also affect the availability and distribution of many of the trace constituents as the mining is synonymous with large scale changes in the environment.

Principally, the purpose of the forthcoming discussion is to evaluate the impact of mining on the geochemistry of trace elements, in a small region. The behaviour of trace elements is studied in the peculiar setting, the region offers. Thereof, an assessment is made of their distribution in different water types with the motive that it can be fitted to other similar Coal Mine settings extending further East & West as the extension of same chain of deposition, after a little modification.

Further, one is required to go through the description under another subhead entitled "Major Constituents" prior to commencing on this part. Many a points mentioned there have extended significance in this section and must be kept in mind before a reading is made.

Geographic Distribution of Trace Constituents *(Based on Isocon Maps)*

Fluoride : Annexure 4.6 a, shows that Fluoride content increases, away from the central mining region, in both Pre- & post-monsoon seasons within groundwaters. Post-monsoon has an effect of dilution and the overall Fluoride content goes further down in the shallow groundwaters.

In surfacewaters, Fluoride increases after point R4 and then decreases after R7 till the point R9. A slight increase is again seen around point R11 only during pre-monsoon. In the post-monsoon these variations becomes very subtle.

Within minewaters *(Annexure 4.6 b)* we see a distinct ring of Fluoride high closing around the deeper mines. The Fluoride content goes quite high and even crosses the *WHO (1985)* guidelines *(1.5 mg/L)*. In an individual case during pre-monsoon it shoots as high as around 5mg/L.

Discussion : It is, thus, obvious that the rise in surfacewater Fluoride content owes to the minewater, which first meets the river at R4. The water in deeper mines, probably, encounters the Fluoride containing minerals and dissolves the Fluoride at low pH. This Fluoride solute when meets the surfacewater, containing high concentration of Calcium ion, either complexes with it to form equilibrium with respect to Fluoride *(cf.Hem, 1985)* or binds over the Ferric Hydroxide surface. The Hydroxide ions could even be replaced by Fluoride ions in a pH dependent fashion, on the Ferric Hydroxide precipitate *(Yellow boy). Hem (1985)* expressed *"because of similarity of charge and radius, Substitution of Fluoride for Hydroxide ions at mineral surfaces is an obvious possibility"*. Further, there are enough evidences that high Fluoride content is found in low Calcium waters having high pH values.*(cf.Hem, 1985)*.

Chromium : Annexure 4.6 b & c, show that the Chromium increases in the down flow direction towards North central part, within groundwaters. During post-monsoon the concentration goes below detection limit, hence could not be plotted in map form.

In surfacewater, the amount reaches 10μg/L at R4 and gradually decreases till the river Pench leaves the region at R12, during pre-monsoon. But, in post-monsoon it doesn't go higher than 2μg/L at R4 and becomes non detectable, in the further stretch of river Pench.

Maximum Chromium content is seen in the M6 located in the South-West which gradually decreases in the down flow towards North and North-East, during pre-monsoon. But, in post-monsoon there is marked reduction in Chromium content which gets well within *WHO (1985)* guideline value *(50 μg/L)*.

Discussion : Chromium is found rarely in natural waters. Although, the Chromium has oxidation states ranging from Cr^{2-} to Cr^{6+}, the trivalent form is found most commonly in nature. The Chromium as Cr^{3+} is not likely to be present in waters of pH 5 and above because the hydrated oxide is very sparingly soluble.*(Train, 1979)*. The Chromium is recognized as an essential trace element form humans. Trivalent Chromium may be nutritionally essential with a safe and relatively innocuous level of 0.02 mg/day.*(John De Zuane, 1990)*. *USEPA (1989)* has given 100 μg/L as the maximum contaminants level.

In the present case though as point the Chromium levels go as high as 200 μg/L the overall quality of minewater, down the flow, is well within the guideline values of *WHO & USEPA*. Hence, the water of M6 point should not in any case be directly used for drinking purposes especially during pre- monsoon. Further, it must be considered unsafe even for aquatic biota.

Manganese : Annexure 4.6 c & d, reveals that in groundwaters, Manganese tends to be high around 'W9'. The 'W9' is the well, about which we have already known of minewater influence through the major element plots. In comparison to pre-monsoon, the post-monsoon values are quite low.

In surfacewaters, like all other constituents the Manganese comes into surfacewater at the points R4 and R14, both known for minewater mixing. Manganese, however is not dominant around R11 where the open cast minewater meets the river. The stream affects the river water composition prior to R12.

Annexure 4.6 d & e, gives the scenario of how the Manganese behaves in the minewaters. Deeper mines show very high values especially in pre-monsoon around the western part. Monsoon brings down the value to a tolerable level in post-monsoon. During post-monsoon the increase in Manganese content becomes more systematic towards the down flow direction in the North.

Discussion : Manganese is vital micro-nutrient for both plants and animals. When Manganese is not present in sufficient quantities, plant exhibit Chlorosis or failure of proper leaves development, and animals show reduced reproductive capacity and deformed or poorly maturing young.*(Train, 1979). WHO (1984)* has classified it in the Aesthetic Criterion and has recommended 0.05 mg/L *(maximum acceptable)* and 0.5 mg/L *(maximum allowable)* limits. Manganese is not known to be a problem in water, consumed by livestock, even at higher concentrations.

At concentrations of slightly less than 1 mg/L to a few milligrams per liter, Manganese may be toxic to plants, from irrigation water applied to soils with pH values lower than 6.0.*(Train, 1979)*. Problems may develop with long term *(20 year)* continuous irrigation on other soils with water containing about 10 mg/L of Manganese.*(NAS, 1974)*. Manganese is often present to the extent of more than 1 mg/L in streams that have received acid drainage from coal mines. Manganese usually persists in the water for greater distances downstream from the pollution source than the Iron contained in the drainage inflows. *(Hem, 1985)*. Manganese bearing natural waters precipitate Manganese oxides at solid solution interfaces located in oxidizing fronts. Manganese oxides are known for their content of trace metals. Adsorption, cation exchange, and coprecipitation are mechanisms for uptake of trace metals by these oxides. Coprecipitation can occur through at least three mechanisms :

(1) Substitution of Zn^{2+} for Mn^{2+} in the Mn_3O_4 structure to produce a solid solution series ranging in composition from Mn_3O_4 to $ZnMn_2O_4$.

(2) Cobalt oxidation at the surface of βMnOOH to produce Cobalt enrichment in the Manganese oxide structure and

(3) Manganese *Vs* Nickel, Cobalt, and Lead redox interactions that control and create mixtures of distinct mineral forms of oxides of these metals. *(Lind C.J. et al., 1987)*.

In the present case the Manganese is quite higher than the *WHO (1984)* acceptable limits even in the groundwaters, during both pre- & post-monsoon. In pre-monsoon these values even go higher than the maximum allowable limits. It is evident that the minewater is the prime source of Manganese rise and the wells being affected by minewater show higher Mn content.

The surfacewater, demands caution if continually used for irrigation for long term, due to higher Manganese content which may prove toxic to plants. The surfacewater is also expected to cause incrustation, straining and bitter taste.

The exceptionally high Manganese content in minewater makes it unsuitable for irrigation due to possible toxic effects over plants.Further, there is good possibility that the Manganese precipitate, onto the irrigated land, would cause coprecipitation of other metal ions, especially Cobalt, Lead, Zinc, Copper and Nickel.*(cf.Hem, 1985)*.

Iron : Annexure 4.6 e & f, show that the Iron in the shallow groundwater increases in the downflow direction, the highest being in the W7 in both the seasons. The Iron content of W9, also, is relatively high compared to other wells of flanks. There is no change in the behaviour of Iron in the post-monsoon except that the values are lowered.

Within surfacewaters, though the Iron increased as usual at R4 and R14. We clearly notice that the base values are attained very fast. The river Pench regains the original Iron level before it leave the region at R12.

In minewaters, we observed exceptional rise in Iron content at M5, whereas the adjacent points M3 & M4 yield relatively low Iron. On the whole, there is very high supply of Iron within minewaters.

Discussion : Iron is an essential trace element required by both plants and animals. The Ferrous (Fe^{2+}) and the Ferric (Fe^{3+}) Irons are of primary concern to aquatic environment. The Ferrous is prevalent in oxygen free *(re ducing)* water, generally the minewaters. The Ferric is insoluble but can sometimes exist in colloidal forms. *WHO (1984)* has classified it in the Asthetic Criterion and has fixed the guideline value to 0.3 mg/L. The excess of Iron is deplored for staining, incrustation and objectionable taste. The properties of Iron are quite similar to Manganese. Based on field observations principally, a criterion of 1 mg/L Iron for freshwater aquatic life is believed to be adequately protective.*(Train, 1979)*. Iron at exceedingly high concentrations has been reported to be toxic to livestock and to interfere with the metabolism of Phosphorus.*(NAS, 1974)*. If, conditions are favourable for oxidation of the Pyrites and neutralization within the drainage, precipitation of Ferric Hydroxide may occur close to the outflow from the mine; but in other cases it may not take place until much further downstream or where the acid stream joins a less acid river which can dilute the acidity and trigger the deposition.

In the above case the Iron is higher than the *WHO* criterion within the mining region but it seldom touches the values around 1 mg/L, in shallow groundwaters. Though, we have seen that both the wells W5 and W9 are influenced by minewater, W5 does'nt show marked increase as compared to W9. Probably, the Iron gets precipitated quite before within the minewater drain which passes nearby; hence, the minewater which reaches W5 is relatively free of Iron. Contrastingly, in W9 and W7 probably the minewater approaches from within and becomes the cause of high Iron.

Since, the Ferric hydroxide is always the first to precipitate we find the faster improvement in river water further downstream. These precipitates are seen widely throughout the river course and especially near the R4 and R14 points.

The abnormally high Iron in M5 is, probably, because of the source of Iron met by the minewater. The mine must have run through an Iron Sulfide rich horizon which falls in the way of minewater in that particular mine.

Cobalt : The Cobalt is below the limits of detection in the groundwaters. The Annexure 4.6 f & g, show surfacewater plots. R14 is the only point which shows the trace of Cobalt in the whole region, which quickly elopes away, probably, alongwith Iron & Manganese, when they get precipitated.

In the minewater the Cobalt reaches up to a few hundreds of micrograms per liter, especially around M4 and M5. Monsoon brings it sufficiently down and the trend changes towards downflow with slight increase during post-monsoon. M9 is another point which has a little presence of Cobalt.

Discussion : Cobalt is an essential element in plant and animal nutrition especially for ruminant animals, since it is a component of vitamin B-12. Coprecipitation or adsorption of Cobalt by oxides of Manganese and Iron appears to be an important factor in controlling the amounts that can occur in solution in natural water.*(Hem, 1985)*.

In the present case, it is clear that the amount of Cobalt which is found in minewater varies between 10 μg/L to 50 μg/L, but when it reaches the surfacewater the concentration goes down to below detection Limt. In other words, the mobile Cobalt which comes along with minewater gets precipitated along with Iron & Manganese and pose the problems of availability, to the water, followed by plants and animals. A probable deficiency of Cobalt is, therefore, expected in all those regions which are irrigated by minewaters.

Nickel : Annexure 4.6 g & h, show the behaviour of Nickel in shallow groundwaters. W2 and W5 show higher Nickel content in pre-monsoon, but during Post-monsoon W2 is seen to possess highest concentration.

Interestingly, the behaviour of Nickel is quite similar to Cobalt and at Rl4, only, we find detectable presence of Nickel. Though, it is seen that the amount of Nickel is a bit higher to that of Iron it also becomes non detectable within a short span.

The Nickel content of minewater is shown in Annexure 4.6 h & i. Nickel is seen to be high in the western part during pre-monsoon. During post-monsoon, the Nickel content of point M8 is seen to increase for no apparent reason, whereas all other components tend to decrease in post-monsoon.

Discussion : Nickel is somewhat more abundant in crustal rocks than Cobalt. The chemistry and chemical behaviour of Nickel is quite similar with that of Cobalt. The only difference being that Nickel has a little higher concentration in natural waters in comparison to Cobalt.*(cf.Hem, 1985)*. Nickel salts are soluble and can occur as a leachate. Nickel occurs, virtually, in a variety coals, alongwith a number of other trace elements and is retained largely in the ash when the coals is burned.*(Nielsen, 1977)*. Based on the available data *Train 1979* concluded as follows :

1. Nickel in water is toxic to plant life at concentrations as low as 500 μg/L.
2. Nickel adversely affects the reproduction of a fresh water crustacean at concentrations as low as 95 μg/L.
3. Concentrations of Nickel at or below 100 μg/L should not be harmful to irrigated plants or marine and fresh water aquatic organisms.

Hence, in the Pench region the Nickel in groundwaters & surfacewaters can be considered safe for both plants and animals.

Direct use of minewater can be harmful to the irrigated plants during both the pre- and post-monsoon seasons. The amount of Nickel present in most minewaters can be toxic to plants.

Copper : Annexure 4.6 i & J, show the behaviour of Copper in the waters of Pench region. The Copper is present in lower amounts in the shallow groundwaters of the region, and doesn't show a significant variation in pre- & post-monsoon. Copper is more or less similarly destributed over the region.

In surfacewaters, apart from points R4 and R14 it is below detection Limit *(shown as 0.00)*. Values of Copper, in surfacewaters, is lower than the groundwaters except at point R14, during pre-monsoon. Presence of Copper is detected around R5 also, in the post-monsoon.

Two Copper highs are seen within minewaters, one around M5 another around M9, during the pre-monsoon. Copper amount becomes diluted in the post-monsoon.

Discussion : The Copper is present, in the nature, as Sulfides, Oxides and Carbonates, and is an essential element in plant and animal metabolism, since it is required in many enzymatic reactions. Some of the ore species that are important as ore minerals also contain Iron *(e.g. Chalcopyrite, malachite etc.).* Copper in natural waters is not known to have an adverse effect on humans. The toxicity of Copper to aquatic life is dependent on the Alkalinity and pH, because the Copper ions form complexes with anions present, which in turn, affect toxicity. The critical effect of Copper appears to be its greater toxicity to young or juvenile fish. The minimum reported concentration of Copper that begins to exhibit toxicity to some agricultural plants is 100 μg/L.*(Train, 1979).*

The adsorption or coprecipitation of Copper with Ferric Oxyhydroxides can bring about even lower solubility limits. Copper is found to be present in concentrations as great as a few hundred mg/L in acid drainage from metal mines. When the acidity of such solutions is neutralized, the Copper is mostly precipitated.*(Hem, 1985).* Effects of coal mine drainage on water chemistry are most evident when flow stages are low, that the Copper may exceed 100μg/L.*(cf.Hem, 1985).*

In the Pench region, the groundwaters and surfacewaters are well within the natural limits of Copper expected. The minewaters, especially during the pre-monsoon and even in the post-monsoon, are of concern if used for irrigation. The presence of Ferric Hydroxide precipitates are expected to be the cause of apparent absence of Copper from the surfacewater systems. Therefore, there is possibility of Copper deficiency, in the plants and animals of the region, who happen to use minewater irrigated diet. Copper deficiency, leading to severe anaemia and neutropenia, principally affects premature and small babies who may, therefore, be particularly vulnerable in Copper deficient areas. *(Moynahan, 1979)*. Depigmentation of hair may be a mainfestation of Copper deficiency *(in Kwashirkor disease)*. The periodic banding within hair, found in central America, may reflect fluctuation in the Copper availability, possibly associated with the local geochemistry. *(Moynahan, 1979)*.

Zinc : Annexure 4.6 J, K & l, show the behaviour of Zinc in the natural waters. The Zinc is low in pre-monsoon groundwaters and is very low during the post-monsoon.

In surfacewater, the Zinc is found slighty more at RII. In general, along the larger portion of river Pench it maintains a more or less similar value. During the post-monsoon R14 shows slight rise. The minuscule variation of such an order can well be expected within natural system and can not be ascribed to any significant factors of concern.

Within minewaters, there appears significant amount of Zinc in deeper mines during pre-monsoon, which reduces to a great extent during post-monsoon. The overall trend of variation remains similar in both seasons.

Discussion : Zinc is an essential and benefical element in human metabolism. As with Cobalt the Zinc has the ability to occupy low symmetry sites in enzymes, and can therefore function as an essential constituent of several of them. *(Forstner & Wittmann, 1983)*. Zinc is usually found in nature as sulfide; it is often associated with sulfides of other metals, especially Lead, Copper, Cadmium, and Iron. Many of the Zinc salts are highly soluble in water; others are not *(Carbonate, Oxide and Sulfide)*.

Although a transition element, it differs in having only one oxidation state and no unfilled level in the valency shell of the ion, which may account for its presence at the active site or in close associatioin with nofewer than 90 mammalian enzymes of differing activities.*(Moynahan, 1979)*. Excess of Zinc in water has not been reported harmful to humanbieng but the deficiency in childern leads to growth retardation. The manifestation of Zinc deficiency in adults may range from simple loss of taste and apetite to the loss of libido.*(cf.Moynahan, 1979)*.

The toxicity of Zinc compounds to aquatic animals is modified by several environmental factors, particularly, Hardness, Dissolved Oxygen and Temperature. Alkaline Earth metals have been found to be antagonistic to the action of Zinc salts, and certain heavy metals are synergistic in soft waters. Both an increase in temperature and a reduction in D.O. increase the toxicity of Zinc. The Zinc present at the levels within the Pench region is considered to be safe fram toxicity to plants.*(cf.Train, 1979)*.

It is seen that the waters of Pench region are low in the Zinc. Moreover, the presence of Ferrihydroxides are supposed to inhibit the further mobility of Zinc, which can attirbute to Zinc deficiencies, in long term. As seen clearly that the higher levels of Zinc in minewater, do not to that extent affect the Zinc levels of surfacewaters is enough testimony of ongoing similar mechanism of absorption or coprecipitation within the region.

Cadmium : Annexure 4.6, I, depicts the behaviour of Cadmium, within the waters of Pench region. In all the shallows groundwaters, Cadmium is below detection limit, except in W7, where a trace of Cadmium is seen only during pre-monsoon.

In surfacewater, there are three distinct spots R4, R11 and R14 which show the traces of Cadmium. The Cadmium soon dwindles to below detection limit within a short distance. In post-monsoon we could not detect the element.

Within minewaters, we find no significant high except those deeper mines. Underground mines show more or less similarity in Cadmium content.

Discussion : Cadmium, is biologically nonessential, nonbeneficial element recognised to be of high toxic potential. The body content of Cadmium steadily increases with age, sequestered mainly in the liver and kidneys from where it is discharged very slowly.*(cf.Moynahan, 1979 & Train, 1979).*

Cadmium occurs in nature, chiefly, as sulfide salt, frequently in association with Zinc, Copper and Lead ores. Chlorides, Nitrates and Sulfates of Cadmium are soluble in water i.e. the Cadmium precipitates at high pH : as the Carbonates and Hydroxides are insoluble.*(John De Zuane, 1990).* It is found, though, in low concentrations within rocks, coals and petroleum. It's relative occurence in surfacewater is less than the groundwater. Accumulations of Cadmium in soils in the vicinity of mines may result in high local concentrations in nearyby waters. Cadmium from a mining waste entering a stream in Japan was stated by *Kobayashi (1969)* to have caused deterioration of the bones of farmers and their families who had eaten rice grown in fields irrigated with that stream water.

There is no evidence that the normal levels in drinking water cause health problems in man. However, *WHO 1984* has recommended 5 µg/L *(0.005 mg/L)* as the guideline value. At this concentration about one quarter of the total Cadmium absorbed might be derived from water.*(WHO, 1984).*

In the Pench region the pre-monsoon Cadmium levels call for concern in the light of preceding discussion. W7 is the main svpply well for the drinking water, from which the drinking water is supplied through mobile tanker. The river water for irrigation can be harmful to a few plants where the soils are poor in Zinc or the Maganese Oxide precipates are absent.*(cf.Train, 1979 & Hem, 1985)*. The minewater too, is expected to cause the similar effect. Hence, should be shunned even for the irrigation purposes.

CHAPTER 5
SOIL LEACHING

INTRODUCTION

Rationale

A range of processes control the dispersion or concentration of elements after they are released by natural or human induced processes, within geologic environment. Leaching can be defined as the natural removal of soluble material *(in solution)* from the upper to lower soil horizons. Constituent load that leaches out of soil may enter the groundwater system and be dispersed or diluted. If, the material is sufficiently abundant or toxic or otherwise harmful, it also may contaminate the groundwater. In areas where leaching is rampant the soils may become nutrient-poor because of there removal.

In the current study, we are interested in this very process of leaching, simply, because the region witnesses large scale modification in the functional geo-chemistry of micro nutrients. *Everett (1985) & Palit (1991)*, has efficiently indicated that the cold extraction method of different kinds can prove to be quite legitimate in indicating the relationship between the relative composition of the major and minor constituents in the prediction of spoil water quality. The acidity produced within mines poses major concern, because the acidity of waters can cause serious problems ranging from problems of growth and reproduction of animals to the problems of augmented leaching of nutrients from top soils and the ensuing reduction in soil fertility. *(Forstner & Wittmann, 1983)*. It is now well understood that the mobility of Fe, Mn and most other elements is more at lower pH range. Excessive leaching of such elements result in deficiencies which in turn causes defects in growth. Such acid minewaters when mixed with other waters, alter their physical & chemical properties which are dependent on relative volume, ambient acidity, buffer capacity and other prominent reaction mechanisms.

The groundwater which is accumulated in the mines is constantly pumped out in order to facilitate the working. This water in most cases is directly poured into the river Pench through crudely constructed drains. The continual large scale pumping onto the surface, in general, results in the drop of water table and even complete drying of wells in summers; thereby depriving the local inhabitants from well water for both irrigation and drinking purposes. This has laid indirect compulsion on the inhabitants to resort to easily available, effluent, minewater drains for fulfilling their basic needs. Such a practice of directly utilizing the untreated minewater for irrigation, external use and occasionally even for drinking purposes *(when there is no other source of water available nearby)* has gained popularity under binding human needs for bare necessities. This has become quite common in past few years, and has led us to study the effect of minewater on *(top)* soils in the laboratory and compare with the field results. The study presents simple observations of the subtle effect of minewater on the soil fertility.

Present work discusses the results of natural free leaching of trace elements from the soils of the Pench Valley Area, under simulated laboratory conditions, by cold extraction method. The behaviour of different soil types have been studied in detail at three pH values. The study shows that the common minewater is capable of depleting the soils of nutrients, to an extent, that the soils become nutrient deficient.

Methodology

The area was surveyed for major soil varieties and it was found that largely three types of soil predominate - controlled mainly by the surface and sub-surface lithology. As a whole, the Basalt top soils *(produced due to weathering of Basalts)* constitute the major soil cover in the area. However, at a few places patches of Sandy top soils *(produced due to weathering of Sandstones)* and Granitic top soils *(produced due to weathering of Granites)* are also seen.

The representative soil samples were collected by grab sampling from the top six inch layer *(i.e. Grass root depth)* of the soil. The grab samples were taken from a number of points and mixed together to give a generalized representation.

The samples were classified in following eight groups after a reconnaissance survey of the area :

1) Granite Top Soils *(S1)*.
2) Sandy Top Soils *(S2)*.
3) Sandy Top Soils *(S3)*, *(from Open Cast Mine)*.
4) Basalt Top Soils *(S4)*, *(from Hill Top)*.
5) Basalt Top Soils *(S5)*, *(from Foot Hill)*.
6) Basalt Top Soils *(S6)*, *(from River Plain)*.
7) Mine Water Soaked Basalt Top Soils *(S7)*, *(from Tilth Field)*.
8) Coal dust *(S8)*, *(from coal loading site)*.

All the soil samples were as such subjected to cold extraction for a period of two weeks at normal Laboratory temperature. For this 50 gms. of soil was immersed in 100ml water and was operated on ultrasonic disintegrator thus yielding maximum possible contact surface area for trace element leaching. The extract was then filtered first by Whatman 42 filter paper, followed by 0.45μm Membrane filter and was analyzed for trace elements. This experiment was simultaneously carried out for three different setups with :

1) Double Distilled Water.
2) Double Distilled Water Normalized to pH = 4.5 by H_2SO_4.
3) Double Distilled Water normalized to pH = 3.5 by H_2SO_4.

It must be noted that this experiment was carried out with double distilled water as a medium. A due consideration, therefore, is required while applying the results to naturally available mineral waters, because the presence of other soluble species affect the water-rock/soil interaction considerably.

To study the effect of induced water acidity over the soils, the pH values of the water extractant were so fixed to envelop the deemed annual fluctuation. The upper limit was kept at pH = 3.5 - the acidity expected around the Pyrite grain; and the lowest limit was kept at pH = 7. A third medial value was chosen to imitate the most common minewater acidity found within the area i.e. pH = 4.5.

RESULTS AND DISCUSSION

Table 5.1 provides results of chemical analyses of leachates from different soil types at different pH values. For comparison and better understanding they are plotted in the form of bar diagrams, shown in figs. 5.1 - 5.9. Different elements have different leaching trends which is closely monitored to evaluate their behaviour.

Iron and Manganese

The results of leached Fe and Mn *(from different soils)* at pH = 7 are shown in Fig.5.1. Granite soils *(S1)* show very high yield of Fe & Mn *(more than 6 times the others)* which may be due to the presence of less stable *(easily soluble)* element comp-

Table 5.1

Trace Elements Data For Soil Leaching Experiment At pH = 7.

Elements	S1	S2	S3	S4	S5	S6	S7	S8
Cr	ND	ND	ND	ND	ND	ND	ND	ND
Mn	20.15	0.14	0.171	1.495	0.198	0.153	ND	3.343
Fe	21.8	2.60	ND	0.202	0.049	0.503	ND	0.037
Co	ND	ND	ND	ND	ND	ND	ND	ND
Ni	0.142	0.099	ND	0.038	ND	ND	ND	0.207
Cu	0.04	0.017	0.013	0.039	0.018	0.022	ND	0.015
Zn	0.155	0.006	ND	ND	ND	ND	ND	0.280
Cd	0.06	ND	0.03	ND	ND	ND	ND	ND
Pb	0.061	ND	ND	ND	ND	ND	ND	ND

Trace Elements Data For Soil Leaching Experiment At pH = 4.5.

Elements	S1	S2	S3	S4	S5	S6	S7	S8
Cr	0.123	ND	ND	ND	ND	ND	ND	ND
Mn	338.5	117	1.281	109.5	70.5	226.5	9.67	210
Fe	244.5	36.9	0.176	17.8	16.3	23.7	4.23	13.8
Co	0.201	0.196	0.024	0.082	0.024	0.05	0.04	0.212
Ni	0.622	0.669	0.438	0.254	0.180	0.382	ND	1.498
Cu	0.382	0.158	0.044	0.076	0.061	0.068	0.011	0.120
Zn	0.216	0.023	0.043	0.003	0.008	0.009	ND	4.363
Cd	0.31	0.06	0.06	0.12	ND	0.05	ND	0.09
Pb	0.144	0.016	0.037	0.076	0.042	0.091	ND	0.021

Trace Elements Data For Soil Leaching Experiment At pH = 3.5.

Elements	S1	S2	S3	S4	S5	S6	S7	S8
Cr	0.641	0.385	ND	0.769	ND	0.513	ND	1.156
Mn	564.23	230.48	2.026	220.43	96.83	369.63	26.49	343.42
Fe	438.00	60.08	0.361	86.42	22.43	48.36	15.68	62.00
Co	1.08	1.06	0.08	4.04	0.08	2.52	0.286	2.46
Ni	0.651	0.823	0.081	1.89	0.193	2.82	0.019	3.81
Cu	0.612	1.03	0.063	3.24	0.022	2.28	0.024	2.83
Zn	2.28	0.481	0.087	1.21	0.053	0.720	0.012	10.44
Cd	0.48	0.137	0.08	0.25	0.028	0.158	ND	0.633
Pb	0.321	0.107	0.072	0.178	0.093	0.281	ND	0.098

AT pH = 7

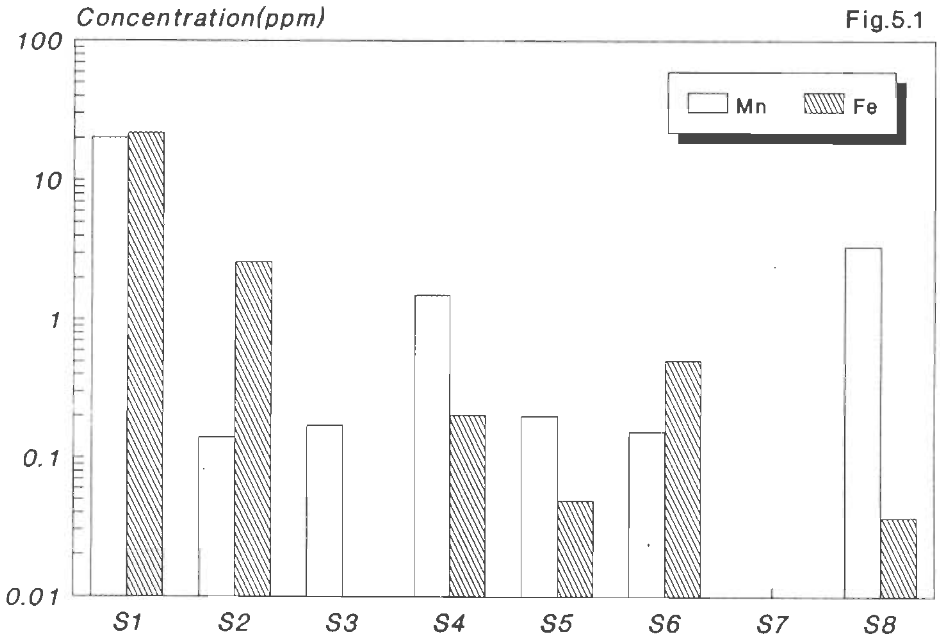


Fig.5.1

AT pH = 7

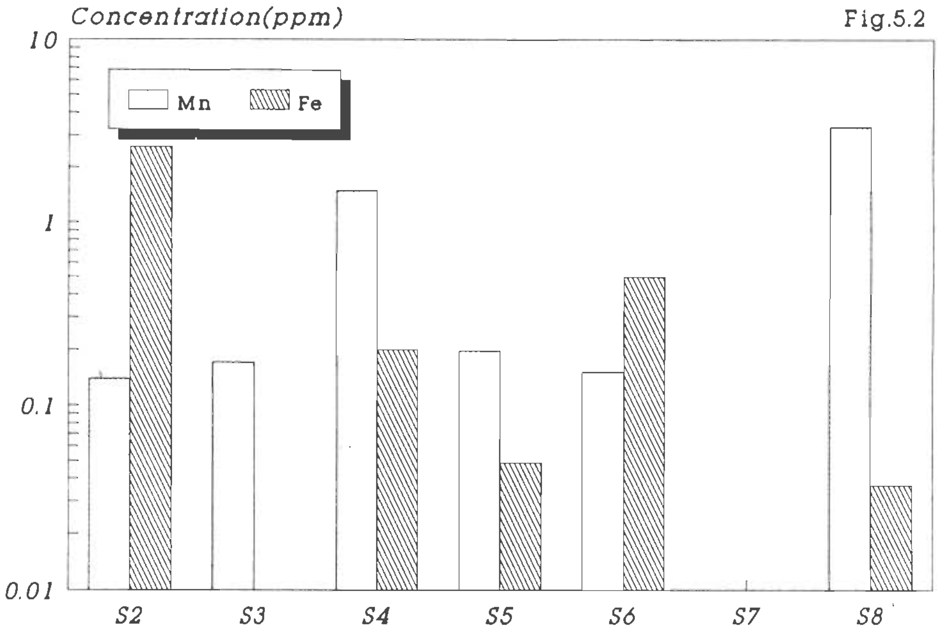


Fig.5.2

lexes in the soil. To enhance the representation of other soil types Granite top soils have been omitted in the second plot of Fig.5.2. It is interesting to note that mine-water soaked Basalt top soils *(of the tilth field) (S7)* show extremely low yield for Fe & Mn, which is indicative of its depleted nature. The behaviour of Fe & Mn at pH = 4.5 is shown in Fig.5.3. Soils *(S3)* and *(S7)* show relatively low yield indicating depletion. The soils *(atop open cast mine) (S3)* seem to be more extensively leached as compared to minewater soaked soils *(of tilth field) (S7)*. The results at pH = 3.5 are shown in Fig.5.4. A general look on Figs.5.1 - 5.4 reveals that more Mn participate into solution as compared to Fe, in almost all pH ranges, which conforms to the observations of *Hem (1972)* excepting only two soils i.e. in the case of *(S1)* and *(S6)* at pH = 7. He established that *"for almost any Eh and pH within the water stability field, more Manganese will be in solution than Iron at equilibrium"*. Fig.5.5 shows total depletion of Fe & Mn atop O.C. mine - a clear proof of exaggerated nutrient depletion from sandy top soils due to mining induced leaching. The depleted soils show negligible yield at all three pH ranges. Fig.5.6 depicts that 'unlike Sandy top soils, Basalt top soils being mafic in nature do not easily get depleted in Fe and Mn.

Discussion :

Granite Top Soils (S1) : The seemingly abnormal behaviour of Granite top soils, in releasing comparatively higher Fe & Mn than Basalt top soils, being parentally low in mafic content deserves explanation, which can be attributed to two probable causes :

1) In case, if the elements are bound to silicate structure, their release may be so slow that a very low amount comes into solution and the plants and animals suffer deficiency, though they are abundant in the parent rock. This is often the case in areas underlain by Iron rich rocks in which the Fe occurs as

AT pH = 4.5

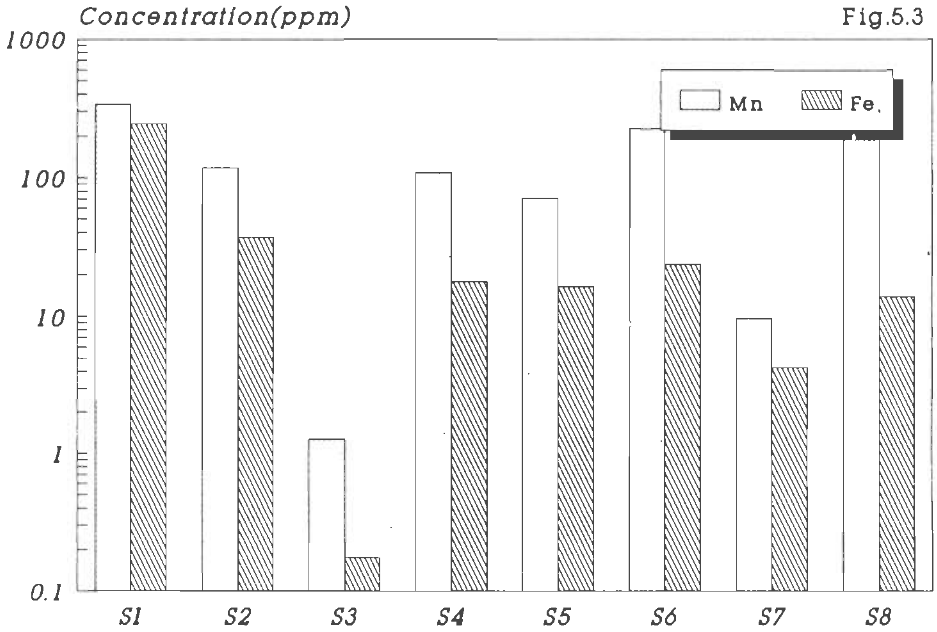


Fig.5.3

AT pH = 3.5

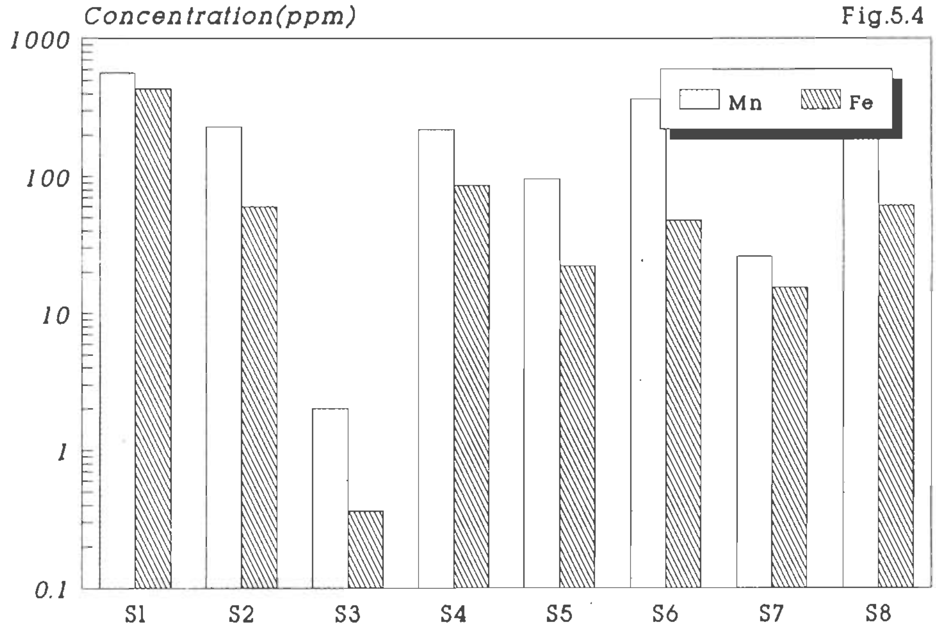
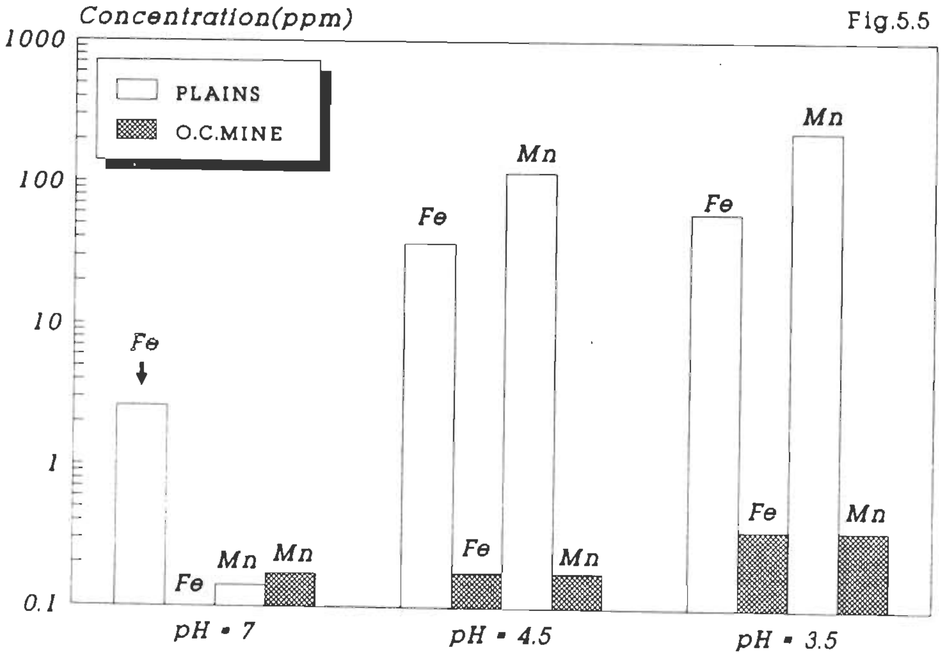


Fig.5.4

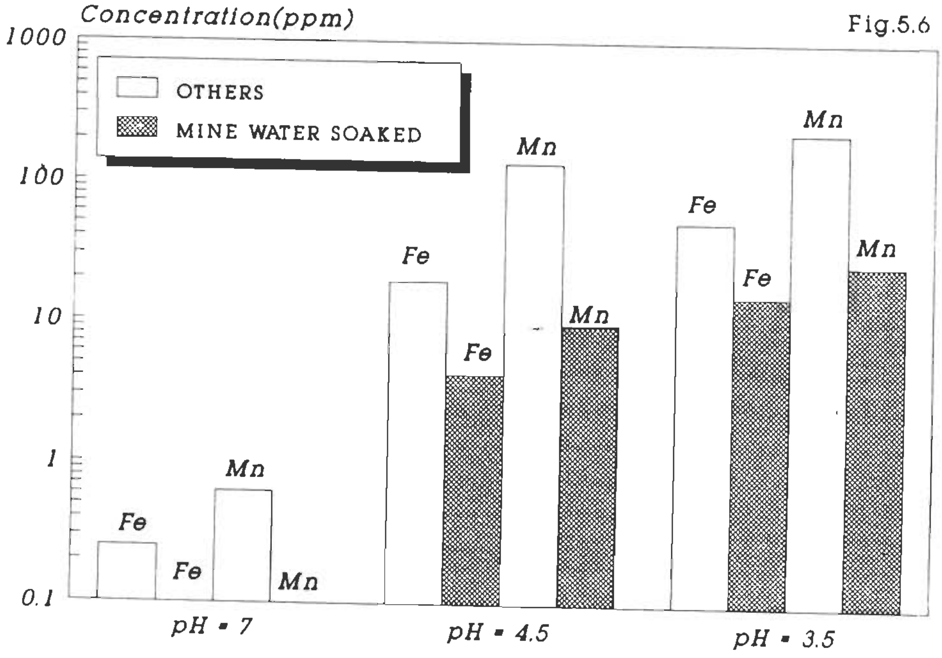
SANDY SOILS OF PLAINS VS SANDY SOILS OF OPEN CAST MINE

Fig.5.5



MINE WATER SOAKED VS OTHER BASALT SOILS OF PENCH VALLEY

Fig.5.6



insoluble Fe_2O_3. If, however, the element is found in less stable form, the availability may pose no problem at all, though it may be poor in parent rock, as in the case of Magnesium *(Mg)* in Carbonate system.*(Hem, 1972)*. Therefore, the yield of Fe & Mn can be more, even though, the original content may not be as high as those of mafic rocks.

2) The Granite top soils do not occupy the mining area rather they are situated away in relatively fresher environmental setup and the soils might have been freshly weathered ones. On the other hand, the rest of the soils as well rocks must have undergone the effects of mining induced acid rains in due course of time. Hence, the ambient leachable elemental concentration is subdued in them.

In a study, conducted to search for good indicators of weathering in different rock types, weathered granitic rocks were analyzed with special reference to the behaviour of Iron during granitic weathering. It was reveled that the Biotite content clearly decreases following the weathering. On the other hand, the FeO(OH) content increases following the weathering. The decrease of Biotite content and the increase of FeO(OH) content can be hence taken as indicators of weathering degree. Moreover it was hypothesized that Iron in Biotite was dissolved into water and then precipitated as FeO(OH) around Biotite.[1]

It is obvious from the figs. 5.1 - 5.5, that the dissolution of Iron and Manganese increases manifold with the increase of water acidity, even at a commonly attained pH range of the Pench Valley Area i.e. at pH = 4.5.

Sandy Top Soils (S2) : Sandy top soils of the plains are the weathering product of sandstones. No reason could be assigned to the increased yield of Iron to that of

---

[1] Nagano, T. & Nakashima, S., (1989). Water Rock Interaction. (ed.) Miles. Balkema, pp. 511-513.

Mn. The release of Mn at pH = 7 is very low but at pH = 4.5 it goes too high, indicating that the Iron and Manganese are present in less stable forms and are mobilized easily with increasing acidity. As a whole the Iron seems to be in comparatively low ambience in these soils.

Sandy Top Soils of Open Cast Mine (S3) : It is considered that these soils were profusely leached ones because of the water acidity generated within and outside mine dumps, due to the probable presence of fine Pyrite grains mixed with coal and coal dusts. The negligible yield, even, on increasing acidity exhibits total depletion of nutrients from soils.*(Fig.5.5)*.

Basalt top Soils (S4, S5, S6) : As a whole the Basalt soils behave somewhat moderately to yield Iron and Manganese into solution. It is interesting to note that the foot hill soils *(S5)* are least yielding among the Basalt soils; whereas the river plain soils, are found to contain more mobile complexes of Iron and Manganese.

Two reasons could be attributed to this :

a) Firstly, it is probably due to the secondary enrichment through incoming waters from the highlands, which enriches the nutrient poor soils through evapotranspiration. In such cases the deposited metals are in a poorly stable phase and gets mobilized easily with little change in the chemistry.

b) Secondly, when the chemical weathering of Mafic Igneous Rocks takes place, the stable metal complexes are broken and transformed into less stable forms. Hence, a properly weathered and digested soil is expected to yield more metal ions into the aqueous phase than less weathered ones. The elemental release from Basalt top soils is slow and consistent, thereby offering a better resistance to the attack on nutrients from foraying minewater. Average Basalt top soils yield about 25 times more Iron and about 100 times more Mn at pH = 4.5 to that of pH = 7.

Mine Water Soaked Basalt Top Soils (S7) : As mentioned earlier these soils are of those tilth fields where the minewater is utilized for irrigation. It is important to assess the probable mechanism which resulted in the loss of nutrients from these soils, because the normal Basalt top soils have considerable buffer capacity which offers significant resistance to acid waters against ion release. As we know that the buffering capacity of soils and natural waters is mainly due to the presence of Carbon Dioxide species within the pH range of 5 to about 9.5 or 10 *(Forstner and Wittmann, 1983)*. But continual long term exposure to acid waters gradually results in slow loss of this buffering capacity and finally the nutrients start getting mobilized which, in turn, render the soils depleted. The Basalt top soils being Mafic in nature contain very high amount of Iron and Manganese. Therefore, even at highly depleted status some elemental yield can be noticed at higher acidity.

Coal Dust (S8) : The performance of Coal Dust is similar to that of Basalt top soils except at pH = 7; where the boosted Manganese participation is the outcome of minor increase in acidity, generated during the experimentation. The presence of fine Pyrite grains with coal dust produced acid which brought down the pH from 7 to 6.

Chromium Cobalt and Nickel

For the purpose of this discussion Chromium, Cobalt and Nickel are considered together among the transition metals, for their mutual similarity in chemical behaviour. Two of these, Iron & Manganese, have already been considered previously. Other's are either rare or have not been found environmentally much significant for plants and animals.

Discussion :

Chromium and Cobalt are below the detection limit in leachates at pH = 7, and only show up at pH = 4.5 & 3.5 in different soils *(Fig. 5.7 - 5.9)*, whereas the Nickel is noticed at pH = 7.

This very nature exhibited by the above metals is quite in consonance with their natural availability and abundance i.e. the Nickel out lasts the other two. However, Nickel alongwith the other two is not found in the soils S3, S5, S6 & S7, and shows up significantly low in S4 soils. Thus, it is fair to postulate that easily leachable metal ions are already exhausted from these soils. Hence, at the pH = 7 or above, there are chances of total absence of these elements from the reach of plants and animals.

Evidently, we notice, that Nickel is leached in relatively highest amount from the Coal Dust (S6) followed by Granite Top Soils (S1), Sandy Top Soils (S2) and Basalt Top Soils (from Hill top) (S4).

This relatively low release from Basalt Top Soils (from Hill Top) (S4) can be attributed to Nickel's affinity towards the Ferro-magnesian minerals present in mafic rocks in a considerable amount, whereas the Granite Top Soils (S1) and Sandy Top Soils (S2) are expected to be low in Ferro-magnesian minerals.

At pH = 4.5 (Fig.5.8) we find the presence of all the three metals. Chromium is seen only within Granite Top Soil (S1) leachates, and is absent from the rest. However, the release to the extent of more than 100 μg/L should not be ignored, seeing to the pernicious character of Chromium towards the living beings.

Cobalt registers it's presence almost in all the soil leachates even within (S7). Somehow, it shows up lowest in Sandy Top Soils (S3) indicating the Cobalt poor nature, of the soil. In all other soil types the Cobalt has similar concentration which can not be termed as harmful.

Nickel, again, is released in the highest amount from Coal Dust (S8) and is absent from (S7), indicating that the Nickel is virtually exhausted from this soil. The Basalt Top Soils which are not touched by minewater, yield substantial amount of Nickel. Release of Nickel can be explained by the similar reasoning as explained before.

At pH = 3.5 we see that the release of most elements have increased substantially but if falls short of the release of Iron & Manganese to a great degree. All the three metals range between negligible to as high as 5 mg/L.

Chromium remains below detection limit in (S3), (S5) and (S7). It can virtually be said that the Chromium is eliminated from the soils. Two out them have explicitly come in contact with minewater. Hence, we can infer the long term impact of minewater over Chromium. On the other hand, very high release of Chromium at pH = 3.5 is of concern, though the acidity seldom touches this level of pH within this region.

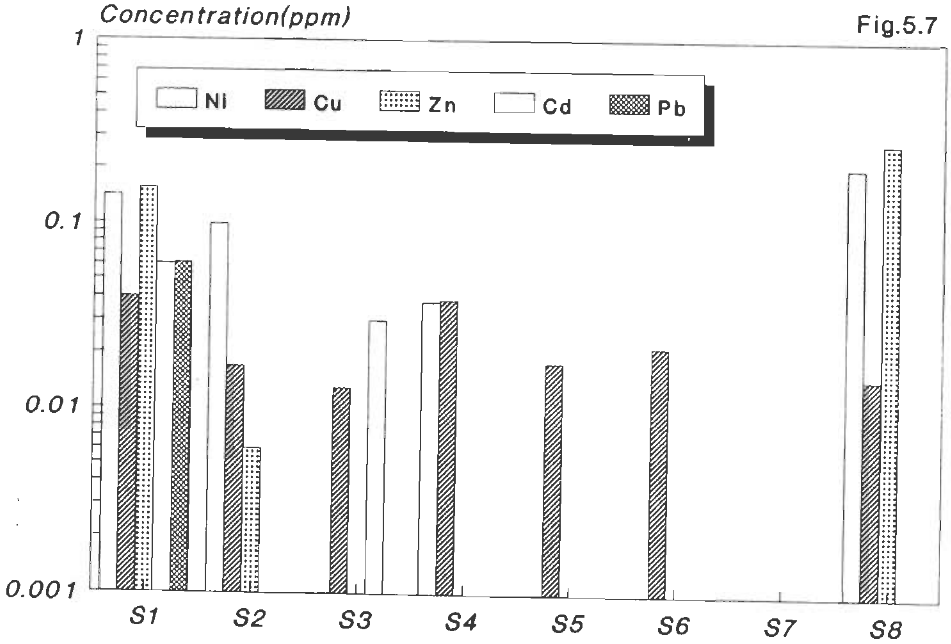
Copper, Zinc, Cadmium and Lead

The elements, considered here, are those which are at the end of transition series in the periodic table, with the inclusion of lead. All of them are of concern for their direct/indirect influence on the life forms. Their availability in soils *(in leachable form)* and in water *(as solutes)* is important from the environmental health point of view, and their behaviour in the soils of mining environment, therefore, is being attempted here.

Discussion : A careful glance of Fig.5.7 reveals that apart from Granite Soil (S1), none has all the four elements in their leachate.

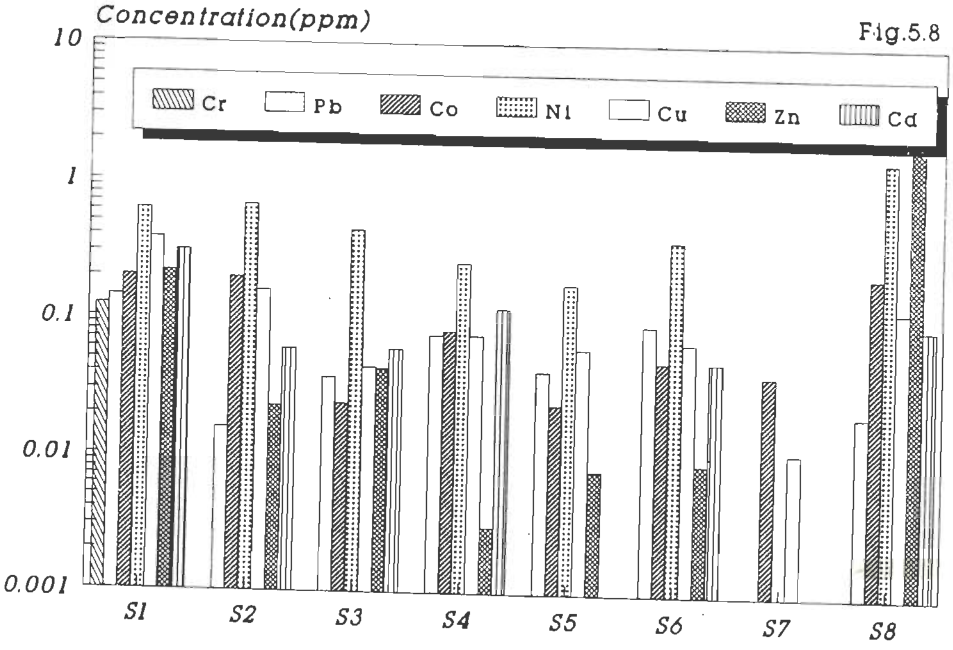
AT pH = 7

Fig.5.7



AT pH = 4.5

Fig.5.8



AT pH = 3.5

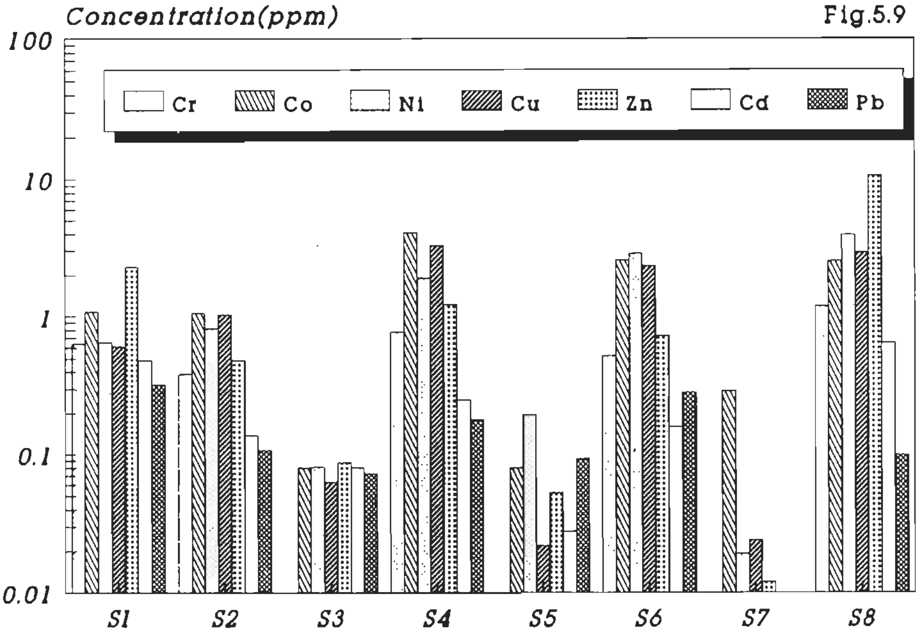


Fig.5.9

Legend

S1 = Granite Top Soils
S2 = Sandy Top Soils
S3 = Sandy Top Soils (Open Cast Mine)
S4 = Basalt Top Soils (Hill Top)
S5 = Basalt Top Soils (Foot Hill)
S6 = Basalt Top soils (River Plain)
S7 = Basalt Top Soils (Mine Water Soaked)
S8 = Coal Dust

Copper marks its presence in all the soils except (S7), where it is below detection level, and soils S5, S6, S7 doesn't have any contribution for Zinc, Cadmium, and lead, in the leachate at normal pH.

Absence of zinc in the major soil types poses a concern for probable Zinc deficiency enveloping major part of region, whereas it is present within Coal Dust (S6) and Granite Top Soils (S1). The presence of Cadmium in (S3) could not be related to any reason. Spot contamination while sampling could be a possibility, as this stray value doesn't find support from other indirect checks. Lead is found highest in the Coal Dust (S8) followed by Granite soil (S1).

There is not much difference at pH = 4.5 in the behaviour of these elements from the transition metals.(Fig.5.8). The trends are similar in most cases. Copper participates ubiquitously in all with more or less equal variation Zinc is released maximum from Coal Dust (S8). Cadmium maintains its high release in (S1) which tells of its presence in the (S1) soils. Mafic soils, too, release higher Cadmium with increasing acidity. Lead also maintains more or less equal participation and can be explained by the similar reasons as for other elements. At pH = 3.5 (Fig. 5.9) we notice that the Coal Dust takes the overall leadership in yielding higher amounts of elements which speaks of its richness in the metal concentration.

Minewater influenced soils maintain depleted status as, not much participation is seen with rising acidity. Coal Dust is of concern for leaching which may cause toxicity to few plants.

Granite soils are found to be nutritionally more enriched and should support good life at normal pH, whereas the presence of minewater would put it in the soil of concern, as toxic elements, also, are easily mobilized and are available, in good amount. Basalt Soils are relatively safer of the impact of minewater and Sandy Soils qualify next.

CONCLUSION

The annual fluctuation has gone high and the lowering of water table is rampant. A large number of wells go complete dry since the mining has cut across all the aquifers and has drained the deeper ones too. At places where the underground mines are resting deep, the shallow wells, sometimes are little affected and survive longer than others.

The effect of large scale pumping is so intense that it boldly shows up in contour maps. Even the monsoons, fall short to completely ameliorate the abnormality. However, the general groundwater movement follows the river course (i.e. west-east), but the mining has caused tremendous disturbance to the flow regime within the region. It can be compared well with limestone territory having conduit flows which happen to drastically affect the movement of groundwater. As observed, the groundwater feeds to mines, which makes the chances of groundwater contamination with that of minewater very poor. But of course, the surfacewaters are substantially altered by the mixing of minewaters. The surfacewaters which are normally low in solute concentrations are so enriched that the Ionic sum is remarkably brought close to groundwaters.

The pH was found simply useful in inferring the effect of mining. It was further observed that the pH of water is brought down from otherwise higher values *(around 8)* within the range of acidity *(pH = 4 - 6.5)*, whenever and wherever the mines influenced it. However, the shallow wells were found within the tolerable limits *(pH = 6.5 - 8.5)*. The hardness on the other hand is very high *(200 - 1000 mg/L)* and the alkali prevalence classify it as permanent hardness. The TDS ranges from moderate to as high as 2000 mg/l of some of the minewaters, which are unsafe for many crops. The post-monsoon TDS is little low compared to pre-monsoon indicating dilution due to precipitation. The major factor in pushing the TDS values up, within the range of brackish waters, is the sulfate *(110 - 1370 mg/L)* and the cause of its excess can be traced in the presence of accessory sulfide minerals associated with coals and carbonaceous sediments.

Broadly, the waters of the region can be classed as Calcium Magnesium Sodium Sulfate type ranging from Calcium Magnesium Sulfate to Calcium Sodium Sulfate types. The carbonates are low *(0 - 110 mg/L)* indicating low buffering capacity of the surfacewaters.

Mercury and Iodide are absent. Among other elements Iron and manganese are present in very high amounts. Fluoride and Nickel are also noticed alongwith Cobalt, Zinc and Copper in relatively higher proportions.

A number of elements which are classified in the category of "Aesthetic Criterion" *(WHO 1984)*, when looked from a changed perspective - as essential nutrients for growth of plants and animals, their role become important, especially when their normal behaviour is exceptionally affected due to some external reasons.

It has been unequivocally confirmed in the present study that even at a commonly attained acidity (i.e. pH = 4.5), in the coal mining area of Pench Valley, the Iron, Manganese and few others are overwhelmingly mobilized into the solution. Sometimes even resulting in total elimination of leachable metal ions from the solid phase. This poses severe concern for the soil fertility yardsticks, that initial augmented leaching of elements can become cause of harmful effects over plants and animals; and later on the same leached out soils would behave unproductive or would promote deficiencies in the plants followed by animals and human beings !

Another important point of concern is the deposition of ferric hydroxide on the soil surface in minewater irrigated fields and around minewater spillages. This is because, the moment, water comes onto the surface it undergoes few chemical changes to accommodate to the changed enviro-setup. A part of Iron gets precipitated in the form of $Fe(OH)_3$ as the stability field of $Fe(OH)_3$ *(solid)* is attained. The dissolution of carbon dioxide usually in the form of bicarbonate, sometimes results in formation of stable solids of low solubility. These complex ions normally tend to increase the solubility of the metals, because the total solubility is the summation of all the various solute species that can exist at equilibrium. Also, the observations of other workers that the oxidized sediments have much greater adsorptive power than reduced sediments, lend support to the idea that element oxides play a significant role in influencing the distribution and the transport of a variety of metal ions. They proposed that the hydrous oxides of Iron and Manganese in general furnish principal control in the fixation of Co, Ni, Cu and Zn in soils and fresh water sediments. A fixation of such a kind is quite capable of inhibiting the supply of nutrients to the plants, specifically in the fields which are irrigated by minewater. Complaints to this effect are endorsed from profusely minewater irrigated fields near pumping station in Jatachhapar village of the Pench area. The crop production has been affected compared to adjacent fields.

Acidity plays a significant role in the mobility of ions. In one hand the change of pH can cause the precipitation of hydrous oxides and on the other it can increase the mobility. The waters of the Pench area are low in "carbonate" and the pH values range between 6.5 to 8 in surfacewaters, speaking of low "buffering capacity" of waters. In other words the continual mixing of minewater could, in due course, bring down the pH well within the limits of acidity.

In gist one can fairly infer from current investigations that in the Pench area the acidic waters are quite capable of drawing augmented metal contents from the soils which come in their contact and will go on depleting the elements for decades altogether. The drainage system with low buffering capacity is expected to render helping hand in transporting the solutes to greater distances. And when the minewater outlets are shifted from one place to another with expanding mines, deposited hydrous oxides would become the main cause for inhibiting the supply of trace elements to plants. This would in turn cause nutrient deficiency in the crops, grazing animals and tribal inhabitants who draw their food from the local produce.

ANNEXURES

Annexure 3.1

TABLE - 1

Permanent Hydrograph Station : PARASIA

Latitude & Longitude : 22° 48'8" - 78° 37'5"
Total Depth : 16.80 m
Diameter : 2.80 m
Reduced Level (RL) of ground surface : 660.00 m
Owner : Janpad
Location Hints : Left Side of Bus Stand
Measuring Point : 0.62 m above RL

Sr. No.	Month & Year	Depth of Water Table from measuring point *(in meters)*
1.	Dec. 89	11.20
2.	Jan. 90	11.25
3.	Feb. 90	11.40
4.	Mar. 90	16.35
5.	Apr. 90	15.25
6.	May. 90	13.90
7.	Jun. 90	13.60
8.	Jul. 90	12.90
9.	Aug. 90	6.68
10.	Sep. 90	5.40
11.	Oct. 90	6.30
12.	Nov. 90	3.90
13.	Dec. 90	5.55
14.	Jan. 91	7.35
15.	Feb. 91	11.30
	Mar. 91	11.55
17.	Apr. 91	11.60
18.	May. 91	11.90
19.	Jun. 91	12.10
20.	Jul. 91	11.80
21.	Aug. 91	9.90
22.	Sep. 91	9.70
23.	Oct. 91	9.80
24.	Nov. 91	9.85
25.	Dec. 91	10.15
26.	Jan. 92	10.50
27.	Feb. 92	11.05
28.	Mar. 92	11.70
29.	Apr. 92	13.90
30.	May. 92	14.20
31.	Jun. 92	9.10
32.	Jul. 92	9.00
33.	Aug. 92	1.80
34.	Sep. 92	2.80
35.	Oct. 92	3.00
36.	Nov. 92	4.90
37.	Dec. 92	6.70

TABLE - 2

Permanent Hydrograph Station : KOSMI
Total Depth : 12.70 m
Diameter : 4.90 m
Reduced Level (RL) of ground surface : 660.80 m
Owner : Janpad
Location Hints : Right Side of Chhindwara Parasia Road
Near Mahaveer Temple
Measuring Point : 0.30 m above RL

Sr. No.	Month & Year	Depth of Water Table from measuring point *(in meters)*
1.	Dec. 89	11.05
2.	Jan. 90	11.15
3.	Feb. 90	12.20
4.	Mar. 90	12.70 dry
5.	Apr. 90	12.70 dry
6.	May. 90	12.70 dry
7.	Jun. 90	12.70 dry
8.	Jul. 90	12.45
9.	Aug. 90	7.20
10.	Sep. 90	5.45
11.	Oct. 90	6.10
12.	Nov. 90	7.10
13.	Dec. 90	8.20
14.	Jan. 91	9.40
15.	Feb. 91	10.20
	Mar. 91	10.40
17.	Apr. 91	10.50
18.	May. 91	11.05
19.	Jun. 91	11.75
20.	Jul. 91	11.50
21.	Aug. 91	9.05
22.	Sep. 91	8.90
23.	Oct. 91	9.20
24.	Nov. 91	10.15
25.	Dec. 91	10.40
26.	Jan. 92	10.90
27.	Feb. 92	11.15
28.	Mar. 92	11.30
29.	Apr. 92	12.70 dry
30.	May. 92	12.70 dry
31.	Jun. 92	12.70 dry
32.	Jul. 92	12.70 dry
33.	Aug. 92	6.00
34.	Sep. 92	5.80
35.	Oct. 92	5.90
36.	Nov. 92	7.15
37.	Dec. 92	9.80

Annexure 3.2

TABLE - 3

Permanent Hydrograph Station : PARASIA
Total Depth : 16.80 m
Diameter : 2.80 m
Reduced Level (RL) of ground surface : 660.00 m
Owner : Janpad
Location Hints : Left Side of Bus Stand
Measuring Point : 0.62 m above RL
Average Fluctuation = 6.95 m
Data for the Depth of Water Table from measuring point (in meters)

Year	February	Premonsoon	Postmonsoon	Fluctuation
1984	16.10	dry	8.20	> 8.75
1985	12.50	13.60	8.40	5.20
1986	-	16.75	9.25	7.50
1987	15.25	dry	8.25	> 8.70
1988	16.25	16.65	7.05	9.60
1989	10.40	16.60	10.90	5.70
1990	11.40	13.62	3.80	9.82
1991	11.55	12.10	9.80	2.30
1992	11.70	14.10	9.10	5.00

TABLE - 4

Permanent Hydrograph Station : KOSMI
Total Depth : 12.70 m
Diameter : 4.90 m
Reduced Level (RL) of ground surface : 660.80 m
Owner : Janpad
Location Hints : Right Side of Chhindwara Parasia Road
Near Mahaveer Temple
Measuring Point : 0.30 m above RL
Average Fluctuation = 4.26 m
Data for the Depth of Water Table from measuring point (in meters)

Year	February	Premonsoon	Postmonsoon	Fluctuation
1984	9.40	11.50	8.00	3.50
1985	9.30	10.60	7.50	3.10
1986	-	11.30	6.30	5.00
1987	9.50	11.65	9.15	2.50
1988	12.55	dry	7.15	> 5.20
1989	10.85	dry	9.40	> 3.30
1990	dry	dry	7.00	> 5.70
1991	10.40	11.75	10.00	1.75
1992	11.30	dry	9.60	> 3.10

TABLE - 5

Permanent Hydrograph Station : AMBADA
Total Depth : 11.90 m
Diameter : 2.10 m
Reduced Level (RL) of ground surface : 815.84 m
Owner : Janpad
Location Hints : Right Side of Parasia Junordeo Road
Measuring Point : 0.70 m above RL
Average Fluctuation = 3.72 m
Data for the Depth of Water Table from measuring point (in meters)

Year	February	Premonsoon	Postmonsoon	Fluctuation
1984	5.95	10.60	6.40	4.20
1985	8.60	9.10	6.60	2.50
1986	-	10.65	3.15	7.50
1987	5.60	10.75	7.20	3.55
1988	10.55	dry	9.50	> 2.40
1989	10.85	11.10	8.30	2.80
1990	7.90	8.40	3.40	5.00
1991	8.20	9.40	7.00	2.40
1992	8.20	9.60	6.50	3.10

TABLE - 6

Permanent Hydrograph Station : RAWANWARA
Total Depth : 10.40 m
Diameter : 2.85 m
Reduced Level (RL) of ground surface : 632.02 m
Owner : Janpad
Location Hints : Right Side of Chhindwara Parasia Road
Behind Coal Separating Machine
Measuring Point : 0.85 m above RL
Average Fluctuation = 4.25 m
Data for the Depth of Water Table from measuring point (in meters)

Year	February	Premonsoon	Postmonsoon	Fluctuation
1984	5.10	8.40	5.80	2.60
1985	6.90	7.70	5.90	1.80
1986	-	8.50	3.20	5.30
1987	5.00	8.70	4.10	4.60
1988	6.50	8.30	3.80	4.50
1989	6.25	10.00	2.40	7.60
1990	6.70	9.20	3.75	5.45
1991	7.60	9.30	5.30	4.00
1992	8.40	8.85	6.45	2.40

Annexure 4.1a.

DEEP WELL DATA OF EVANGELICAL LUTHERIAN CHURCH WATER DEVELOPMENT PROJECT

Location	Rawanwara	Rawanwara	Rawanwara	Rawanwara	Rawanwara	Chandameta	Chandameta
Rock Type	Basalt	Sandstone	Sandstone	Basalt	Sandstone	Sandstone	Sandstone
Aquifer Depth (m)	21,65	92,127	104,138	57,60,81	33,95,138	111,206	15,69
Sampling Date	Sep.1974	Oct.1974	Oct.1974	Nov.1974	Jan.1976	Nov.1974	Nov.1974
Source	Tube Well	Tube Well	Tube Well	Tube Well	Tube Well	Tube Well	Tube Well
pH	6.7	6.5	6.5	8.5	9.05	7.2	7.5
T.D.S. (mg/L)	460	...	...	...	...	...	...
Calcium(mg/L)	96.10	80.10	56	184.2	60.07	244	52.06
Magnesium(mg/L)	34	9.7	17	38.87	12.14	77.67	9.71
Sodium(mg/L)	0.637	0.797	0.932	0.488	0.9624	...	1.68
Sulfate(mg/L)	110	25	40	0.0	0.0	295	30
Chloride(mg/L)	6.0	3.0	3.0	2.5	2.0	10	3.5
Fluoride(mg/L)	0.97	0.95	1.0	0.2	0.8	0.05	0.0

SHALLOW WELL DATA OF EVANGELICAL LUTHERIAN CHURCH WATER DEVELOPMENT PROJECT

Location	Rawanwara	Rawanwara	Rawanwara	Eklehra	Eklehra	Newton	Newton
Rock Type	Sandstone	Basalt	...	...	...	...	...
Sampling Date	Mar.1977	Mar.1977	May.1977	Mar.1977	May.1977	Mar.1977	May.1977
Source	Open Well	Open Well	Open Well	Mine*	Mine*	Mine*	Mine*
pH	7.3	7.5	7.4	7.02	6.0	7.1	6.65
T.D.S. (mg/L)	370	570	390	1270	605	1480	1035
Calcium (mg/L)	112.13	110.12	84.1	149	152.18	108	204.24
Magnesium (mg/L)	7.29	12.15	19.44	20.30	51.02	109.31	38.87
Sodium (mg/L)	7.19	5.16	9.0809	11.03	9.645	9.31	13.878
Sulfate (mg/L)	35	75	210	560	600	890	800
Chloride (mg/L)	15.0	10.0	150	160	200	100	260
Fluoride (mg/L)	0.8	0.82	1.1	0.4	0.4	1.1	1.7

SHALLOW WELL DATA OF CENTRAL GROUND WATER BOARD

Location	Barkuhi	Barkuhi	Ambara	Likhawari	Chandameta
Rock Type	Gondwanas	Gondwanas	Gondwanas	Gondwanas	Deccan Trap
Sampling Date	1979	1979	1979	1979	1979
Source	Well Water	Well Water	Well Water	Well Water	Well Water
pH	7.8	8.0	7.3	7.1	7.2
T.D.S. (mg/L)	1090	1040	1100	400	710
Calcium (mg/L)	200	200	260	100	130
Magnesium (mg/L)	12	24	54	6	48
Sodium (mg/L)	87	81	57	19	21
Potassium (mg/L)	12	12	5	< 1	< 1
Bicarbonate (mg/L)	165	103	244	317	378
Sulfate (mg/L)	605	576	677	120	200
Chloride (mg/L)	36	36	64	32	32
Hardness $CaCO_3$mg/L	550	600	875	274	525

**Wells influenced by Mine-water.*

Annexure 4.1b

MAJOR CONSTITUENTS DATA PRE-MONSOON 1991.

Location/Source	GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8
Rock Type	Basalt	Sandstone	Sandstone	Basalt	Sandstone	Sandstone		
pH	8.0	7.3	7.5	7.0	6.6	6.8	7.2	8.0
T.D.S. (mg/L)	530	830	654	705	1400	840	760	590
Calcium (mg/L)	97.8	159.52	139.8	138.48	235.87	168.5	155.9	118.7
Magnesium (mg/L)	5.96	25.65	18.58	16.29	64.55	22.34	20.04	21.7
Sodium (mg/L)	26.49	34.94	29.16	21.38	56.32	38.06	18.89	17.11
Potassium (mg/L)	12.99	14.64	12.44	11.73	15.25	13.17	12.12	8.03
Sulfate (mg/L)	117.9	351.8	372.54	363.9	697.28	445.66	333.96	275.7
Bicarbonate (mg/L)	212	173	148	209	304	169	170	270
Chloride (mg/L)	38.99	69.48	28.15	37.22	48.21	27.6	59.91	25.14
Hardness $CaCO_3$mg/L	268.7	503.9	425.6	412.9	854.8	512.7	471.8	385.8

Location/Source	GW9	GW10	GW11	GW12	GW13	R1	R2	R3	R4	R5
pH	7.5	7.6	8.0	8.0	8.0	7.0	7.2	7.2	5.5	6.5
T.D.S. (mg/L)	915	618	560	520	595	675	688	678	1280	1100
Calcium (mg/L)	172.8	139.7	117.2	100.9	115.7	138.5	137.5	139.3	192.6	181.6
Magnesium (mg/L)	33.92	10.3	8.2	12.8	16.23	14.71	15.68	15.07	56.65	42.06
Sodium (mg/L)	21.26	21.72	16.33	16.82	11.93	21.84	22.07	22.04	61.49	42.87
Potassium (mg/L)	9.39	10.47	8.77	8.01	10.27	8.95	8.56	8.47	18.72	14.19
Sulfate (mg/L)	347.5	264.4	185.6	206.3	226.8	333.2	334.2	330.2	770.4	649.3
Bicarbonate (mg/L)	270	187	166.9	176	182	114.3	110.6	110.8	35.45	39.1
Chloride (mg/L)	52.09	46.78	48.92	16.98	25.59	43.25	45.75	45.37	48.21	42.54
Hardness $CaCO_3$mg/L	571.2	391.2	326.4	304.7	355.7	406.4	407.9	409.9	714.2	626.7

Location/Source	R7	R8	R10	R11	R12	R13	R14	M1	M2	M3
pH	7.2	7.8	6.0	6.2	7.0	6.0	4.8	4.0	4.2	4.5
T.D.S. (mg/L)	690	652	670	653	896	985	1100	1650	1680	1440
Calcium (mg/L)	138.3	133.7	140.0	116.3	145.7	166.6	157.8	187.9	183.7	184.7
Magnesium (mg/L)	16.53	11.91	14.95	14.34	31.00	28.08	41.45	86.68	88.74	39.69
Sodium (mg/L)	19.54	21.15	20.46	36.32	53.93	58.39	69.54	98.16	111.2	100.2
Potassium (mg/L)	8.99	7.82	8.6	11.53	20.73	29.50	32.63	42.01	48.36	43.24
Sulfate (mg/L)	385.8	369.2	426.0	353.3	524.3	591.0	683.5	987.6	1082	807.9
Bicarbonate (mg/L)	32.2	41.8	40.9	70.1	67.9	27.7	0.0	0.0	0.0	0.0
Chloride (mg/L)	42.54	31.93	19.85	36.31	45.73	66.64	57.78	87.91	83.66	84.72
Hardness $CaCO_3$mg/L	413.4	382.9	411.1	349.5	491.5	531.6	564.7	826.1	824.1	624.6

Location/Source	M4	M5	M6	M7	M8	M9	M10
pH	4.2	4.0	5.0	4.8	4.4	4.0	5.5
T.D.S. (mg/L)	1785	1610	1530	1620	2095	2105	820
Calcium (mg/L)	267.74	186.85	210.82	227.66	307.82	284.77	172.34
Magnesium (mg/L)	93.49	88.38	73.55	63.70	90.69	100.74	15.56
Sodium (mg/L)	83.68	141.38	95.63	90.34	109.66	104.6	37.01
Potassium (mg/L)	33.58	37.94	22.24	27.56	33.08	63.75	12.81
Sulfate (mg/L)	1170	1052	978.6	1009	1333.8	1293.9	509
Bicarbonate (mg/L)	0.0	0.0	12.5	8.7	0.0	0.0	17.2
Chloride (mg/L)	87.2	86.85	75.15	41.12	74.44	82.24	42.54
Hardness $CaCO_3$mg/L	1053.5	830.5	829.3	830.8	1142.1	1125.9	494.4

Annexure 4.1c.

MAJOR CONSTITUENTS DATA POST-MONSOON 1991.

Location/Source	GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8
Rock Type	Basalt	Sandstone	Sandstone	Basalt	Sandstone	Sandstone		
pH	8.0	7.5	7.8	7.8	6.8	7.8	7.8	8.2
T.D.S. (mg/L)	480	600	570	635	1100	638	692	510
Calcium (mg/L)	83.87	106.82	108.90	122.64	207.31	141.26	137.45	108.6
Magnesium (mg/L)	5.10	18.62	10.42	15.32	30.37	13.56	12.05	7.30
Sodium (mg/L)	25.28	20.20	15.31	18.65	19.55	28.40	21.90	12.22
Potassium (mg/L)	11.60	10.20	8.10	11.00	9.10	10.20	8.30	6.21
Sulfate (mg/L)	117.68	230.55	222.43	204.61	459.43	322.84	312.20	172.7
Bicarbonate (mg/L)	185	156	132	206	272	154	149	165
Chloride (mg/L)	32.54	37.90	30.60	47.50	28.90	28.40	36.70	32.20
Hardness $CaCO_3$mg/L	230.4	343.4	314.8	369.3	642.7	408.6	392.8	301.2

Location/Source	GW9	GW10	GW11	GW12	GW13	R1	R2	R3	R4	R5
pH	7.5	8.0	8.2	8.2	8.0	7.0	7.0	7.0	6.0	6.8
T.D.S. (mg/L)	900	572	508	490	550	584	579	575	867	866
Calcium (mg/L)	164.9	110.2	91.98	98.24	110.4	124.0	124.9	123.4	158.0	169.1
Magnesium (mg/L)	28.33	8.83	8.27	6.11	14.90	8.18	10.00	11.02	42.19	27.96
Sodium (mg/L)	20.00	23.29	19.50	14.05	11.70	14.50	13.00	14.90	18.50	12.50
Potassium (mg/L)	12.20	11.10	10.50	4.80	8.63	4.50	4.50	4.50	8.00	9.50
Sulfate (mg/L)	359.7	214.7	215.6	156.2	223.6	267.6	218.6	269.5	558.6	524.2
Bicarbonate (mg/L)	212	135.2	126.8	188	146	93.90	93.60	92.90	36.80	39.60
Chloride (mg/L)	49.20	52.30	23.40	20.80	29.40	23.70	24.90	26.80	26.50	36.80
Hardness $CaCO_3$mg/L	528.4	311.5	263.7	270.5	337.0	343.3	353.1	353.5	568.3	537.4

Location/Source	R7	R8	R10	R11	R12	R13	R14	M1	M2	M3
pH	7.0	8.0	7.2	6.5	6.5	6.8	6.0	5.5	5.0	5.8
T.D.S. (mg/L)	608	524	602	640	768	945	1062	1274	1620	1330
Calcium (mg/L)	114.7	107.4	122.4	115.7	116.2	146.7	151.8	154.0	179.6	150.1
Magnesium (mg/L)	25.11	14.02	10.29	20.63	21.75	22.92	39.64	50.74	84.68	99.28
Sodium (mg/L)	13.75	14.30	11.50	19.95	44.50	65.00	66.50	97.00	115.0	112.0
Potassium (mg/L)	11.00	8.02	8.0	7.50	19.00	18.10	16.00	31.00	48.00	38.00
Sulfate (mg/L)	343.4	336.6	349.6	372.3	480.3	582.6	666.0	795.4	1010	713.3
Bicarbonate (mg/L)	39.40	40.20	38.60	52.30	36.40	39.60	28.20	10.00	8.20	7.50
Chloride (mg/L)	39.87	19.62	22.30	23.10	21.40	33.47	52.12	53.18	61.00	90.30
Hardness $CaCO_3$mg/L	389.8	325.9	348.0	373.9	379.7	460.7	542.3	593.5	797.2	783.6

Location/Source	M4	M5	M6	M7	M8	M9	M10
pH	4.8	5.0	6.0	6.5	5.0	6.0	7.2
T.D.S. (mg/L)	1735	1426	1438	1398	1920	1470	646
Calcium (mg/L)	219.95	143.90	178.96	196.95	311.71	224.84	113.03
Magnesium (mg/L)	94.17	79.74	68.43	34.60	66.72	29.86	10.54
Sodium (mg/L)	102.00	142.50	115.00	116.00	106.80	117.50	33.50
Potassium (mg/L)	23.50	26.00	25.00	21.75	28.00	37.20	5.50
Sulfate (mg/L)	1097	963.52	901.06	892.41	1205.60	941.40	410.66
Bicarbonate (mg/L)	12.60	9.10	10.80	9.7	15.60	13.8	21.3
Chloride (mg/L)	73.7	59.26	34.60	21.70	57.20	49.60	17.90
Hardness $CaCO_3$mg/L	937.0	687.7	728.7	634.3	1053.1	684.4	325.6

Annexures 4.1d.

MAJOR CONSTITUENTS DATA PRE-MONSOON 1992.

Location/Source	GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8
Rock Type	Basalt	Sandstone	Sandstone	Basalt	Sandstone	Sandstone		
pH	7.8	7.2	7.2	7.5	6.5	6.5	7.5	8.0
T.D.S. (mg/L)	540	890	788	715	1605	906	860	640
Calcium (mg/L)	99.49	167.82	136.27	140.52	255.49	159.12	153.4	114.0
Magnesium (mg/L)	8.1	22.41	14.34	17.44	93.44	26.14	31.17	19.94
Sodium (mg/L)	20.9	80.5	27.82	18.0	49.00	36.55	23.5	16.55
Potassium (mg/L)	15.2	10.30	11.73	9.4	13.90	9.78	10.0	15.64
Sulfate (mg/L)	146.49	402.98	550.79	305.0	827.57	437.83	373.2	270.8
Bicarbonate (mg/L)	198	183	130.6	190	293	163.51	202	165.9
Chloride (mg/L)	38.45	57.46	26.94	28.44	51.48	26.59	40.32	24.10
Hardness $CaCO_3$mg/L	281.8	511.3	399.3	422.7	1022.7	505.0	511.4	366.8

Location/Source	GW9	GW10	GW11	GW12	GW13	R1	R2	R3	R4	R5
pH	7.8	7.5	7.2	7.8	7.8	7.2	7.2	7.4	5.1	6.0
T.D.S. (mg/L)	970	825	700	545	579	678	653	678	1178	990
Calcium (mg/L)	181.8	161.9	153.7	102.2	110.8	133.3	131.9	133.3	161.5	162.4
Magnesium (mg/L)	46.06	21.54	8.69	15.32	15.56	15.92	15.33	15.92	53.35	40.88
Sodium (mg/L)	14.60	23.90	20.8	17.32	12.64	16.3	16.80	16.84	59.44	58.6
Potassium (mg/L)	4.81	8.2	7.00	8.60	8.21	9.00	10.0	9.00	16.00	14.00
Sulfate (mg/L)	313.2	386.2	286.7	191.1	224.7	319.9	304.5	319.9	731.5	584.5
Bicarbonate (mg/L)	310.0	176.2	177.8	184.3	164.3	112.2	113.5	112.2	26.20	30.20
Chloride (mg/L)	90.28	23.4	43.49	20.91	23.04	33.61	37.56	33.61	41.24	69.21
Hardness $CaCO_3$mg/L	643.6	493.0	419.6	318.3	340.7	398.4	392.5	398.4	623.0	573.9

Location/Source	R8	R9	R10	R11	R12	R13	R14	M1	M2	M3
pH	7.0	8.0	7.0	6.2	6.8	6.5	4.5	4.2	4.2	4.5
T.D.S. (mg/L)	650	640	620	700	1060	1075	1274	1595	1866	1388
Calcium (mg/L)	135.8	119.4	121.9	123.8	181.0	168.9	210.8	214.0	222.44	218.2
Magnesium (mg/L)	16.79	19.21	16.13	17.45	34.53	30.59	39.20	76.65	105.65	60.59
Sodium (mg/L)	20.50	24.60	22.30	36.00	60.50	55.80	45.80	100.1	110	60.30
Potassium (mg/L)	7.00	8.50	7.50	9.00	17.00	19.00	20.00	45.00	48.00	36.50
Sulfate (mg/L)	409.7	391.9	373.2	401.5	629.7	494.6	706.5	1004	1174.4	911.6
Bicarbonate (mg/L)	28.00	35.9	44.50	73.8	68.30	37.20	0.0	0.0	0.0	0.0
Chloride (mg/L)	21.18	17.46	17.51	19.73	48.11	69.26	87.53	93.52	88.35	45.70
Hardness $CaCO_3$mg/L	408.2	377.2	370.8	381.0	594.2	547.7	687.8	850.0	990.5	794.4

Location/Source	M4	M6	M7	M8	M9	M10	M11
pH	4.8	4.4	4.5	4.00	4.8	6.8	6.8
T.D.S. (mg/L)	1974	1690	1656	2110	1720	780	1095
Calcium (mg/L)	254.00	219.00	259.15	302.00	272.95	147.81	186.40
Magnesium (mg/L)	108.08	83.22	58.03	100.74	63.43	15.11	26.90
Sodium (mg/L)	115.20	86.00	84.00	100.0	87.13	24.50	62.00
Potassium (mg/L)	49.00	32.00	18.00	25.00	45.00	8.00	15.00
Sulfate (mg/L)	1259.85	1050.43	1052.35	1372.73	1053.79	442.84	681.56
Bicarbonate (mg/L)	0.0	0.0	8.00	11.2	0.0	11.8	0.00
Chloride (mg/L)	70.84	42.93	23.65	57.67	91.40	35.37	35.21
Hardness $CaCO_3$mg/L	1079.3	889.5	886.1	1168.9	942.8	431.3	576.2

Annexure 4.1e.

MAJOR CONSTITUENTS DATA POST-MONSOON 1992.

Location/Source	GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8
Rock Type	Basalt	Sandstone	Sandstone	Basalt	Sandstone	Sandstone		
pH	8.0	7.2	7.2	7.8	6.8	8.0	8.0	8.2
T.D.S. (mg/L)	540	605	545	650	985	706	670	520
Calcium (mg/L)	89.92	102.32	105.81	103.55	194.21	137.07	119.4	109.4
Magnesium (mg/L)	8.79	15.79	9.24	29.92	36.50	12.16	12.45	8.16
Sodium (mg/L)	28.70	22.43	14.95	21.75	28.68	26.21	26.31	12.44
Potassium (mg/L)	9.2	7.63	8.60	10.07	9.73	9.39	6.36	7.04
Sulfate (mg/L)	166.19	215.66	225.16	253.60	488.77	313.49	283.7	174.8
Bicarbonate (mg/L)	168	162	126.3	188	235	163.51	122	173.9
Chloride (mg/L)	31.30	34.10	25.52	38.90	30.8	26.23	39.60	24.10
Hardness CaCO$_3$mg/L	260.7	320.5	302.3	381.8	635.2	392.3	349.4	306.8

Location/Source	GW9	GW10	GW11	GW12	GW13	R1	R2	R3	R4	R5
pH	7.0	7.5	7.5	8.0	8.2	7.0	7.0	7.0	6.0	6.8
T.D.S. (mg/L)	875	540	510	460	530	600	590	594	905	710
Calcium (mg/L)	112.3	99.4	89.4	91.9	103.8	127.5	133.9	127.5	152.7	138.4
Magnesium (mg/L)	19.91	5.53	5.43	5.84	13.01	9.67	8.97	9.67	43.12	26.89
Sodium (mg/L)	59.69	28.72	22.10	14.48	11.95	11.82	12.15	11.82	14.98	13.10
Potassium (mg/L)	17.16	13.25	11.76	4.3	7.43	5.87	5.12	5.87	7.200	8.78
Sulfate (mg/L)	348.2	187.3	183.0	109.6	217.5	296.8	302.6	298.7	537.6	414.9
Bicarbonate (mg/L)	197.0	135.8	129.2	196.5	133.1	39.6	91.20	89.60	32.90	33.60
Chloride (mg/L)	46.30	50.20	25.60	19.50	28.00	28.1	31.20	28.10	44.10	36.50
Hardness CaCO$_3$mg/L	362.4	271.0	245.6	253.5	312.8	358.2	371.3	358.2	558.9	456.3

Location/Source	R8	R9	R10	R11	R12	R13	R14	M1	M2	M3
pH	7.2	7.5	7.8	6.5	6.5	6.8	5.2	5.5	5.0	6.0
T.D.S. (mg/L)	645	606	581	690	700	922	1112	1254	1760	1200
Calcium (mg/L)	123.5	109.4	105.8	114.5	109.3	153.4	159.2	153.3	196.12	178.4
Magnesium (mg/L)	21.08	20.84	20.56	19.89	22.23	23.53	46.72	58.49	90.24	42.15
Sodium (mg/L)	14.86	13.26	12.22	19.23	33.89	69.28	73.43	83.37	140.31	83.91
Potassium (mg/L)	8.15	7.75	7.48	7.59	8.76	17.21	16.36	23.13	24.41	41.27
Sulfate (mg/L)	386.7	347.7	332.8	372.4	401.5	602.9	708.5	775.7	1101.3	774.2
Bicarbonate (mg/L)	36.00	37.40	38.40	44.60	34.80	26.50	39.30	15.60	102.0	5.5
Chloride (mg/L)	21.10	19.70	20.80	23.70	24.20	30.10	43.80	53.50	60.50	67.10
Hardness CaCO$_3$mg/L	395.2	359.0	348.8	367.8	364.5	479.9	589.9	623.7	861.3	619.0

Location/Source	M4	M6	M7	M8	M9	M10	M11
pH	5.0	5.8	5.5	5.0	5.2	7.0	6.8
T.D.S. (mg/L)	1670	1512	1308	1996	1468	562	914
Calcium (mg/L)	202	176.75	209.22	321.12	232.41	111.82	175.35
Magnesium (mg/L)	93.21	73.64	30.02	64.78	22.01	6.26	27.43
Sodium (mg/L)	15.12	109.92	87.36	101.83	129.23	26.15	23.00
Potassium (mg/L)	21.79	37.64	16.93	41.27	49.42	5.70	11.23
Sulfate (mg/L)	1029.78	929.88	827.09	1284.82	958.65	308.36	555.20
Bicarbonate (mg/L)	9.8	12.10	11.60	18.30	12.70	14.40	19.20
Chloride (mg/L)	84.90	63.10	44.30	49.40	58.20	41.20	18.30
Hardness CaCO$_3$mg/L	888.2	744.6	646.0	1068.6	671.0	305.0	550.8

Annexure 4.1f.

TRACE ELEMENT DATA PRE-MONSOON 1991. (In mg/L)

Sample No.	Fluoride	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Cadmium
GW1	0.481	ND	0.054	0.391	ND	0.039	0.08	ND	ND
GW2	0.302	ND	0.306	0.306	ND	0.068	0.071	ND	ND
GW4	0.210	ND	0.097	0.294	ND	0.042	0.076	ND	ND
GW5	0.341	ND	0.073	0.197	ND	0.084	0.091	ND	ND
GW7	0.175	ND	0.373	1.680	ND	0.057	0.036	0.069	0.067
GW9	0.168	ND	0.772	0.883	ND	0.052	0.059	0.087	ND
GW10	0.984	ND	0.171	0.197	ND	0.073	0.049	ND	ND
GW11	0.573	ND	0.014	0.111	ND	0.062	0.062	ND	ND
R1	0.011	ND	0.059	0.015	ND	ND	ND	0.021	ND
R2	0.009	ND	0.075	0.059	ND	ND	ND	0.008	ND
R3	0.013	ND	0.084	0.022	ND	ND	ND	0.009	ND
R4	0.398	0.023	1.292	1.60	ND	ND	0.024	0.010	0.061
R5	0.403	ND	0.345	1.35	ND	ND	ND	0.02	ND
R7	0.624	ND	0.040	0.051	ND	ND	ND	ND	ND
R8	0.153	ND	0.113	0.191	ND	ND	ND	0.009	ND
R9	0.202	ND	ND	0.018	ND	ND	ND	0.007	ND
R10	0.229	ND	0.176	0.510	ND	ND	ND	0.025	ND
R11	0.331	ND	0.075	0.586	ND	ND	ND	0.167	0.036
R12	0.287	ND	1.560	0.807	ND	ND	ND	0.030	ND
R13	0.564	ND	0.299	0.874	ND	ND	0.073	0.024	ND
R14	0.601	ND	1.632	3.14	0.042	0.201	0.091	0.007	0.046
M1	1.30	0.024	10.72	7.10	0.081	0.650	0.045	1.10	0.061
M2	2.08	0.016	7.87	7.65	0.079	0.825	1.241	1.17	ND
M3	2.98	0.043	5.50	10.06	0.064	1.712	0.021	0.691	0.08
M4	4.75	0.068	19.80	8.41	0.038	0.900	0.036	1.51	0.076
M5	5.10	0.075	20.50	30.77	ND	2.06	1.410	1.98	0.083
M6	2.03	0.175	14.52	2.60	0.052	1.861	0.363	2.47	0.084
M7	0.881	ND	8.508	9.31	0.031	1.24	0.099	0.854	0.041
M8	3.09	0.022	3.52	11.36	0.067	1.150	0.821	0.77	0.059
M9	2.54	ND	8.99	16.03	0.075	0.50	1.341	0.400	0.073
M10	0.642	ND	1.22	1.29	0.012	0.523	0.982	0.006	ND

Annexure 4.1g.

TRACE ELEMENT DATA POST-MONSOON 1991. (In mg/L)

Sample No.	Fluoride	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Cadmium
GW1	0.046	ND	0.021	0.389	ND	ND	0.060	ND	ND
GW2	0.149	ND	0.099	0.266	ND	0.085	0.061	ND	ND
GW4	0.159	ND	00.074	0.136	ND	0.057	0.070	ND	ND
GW5	0.230	ND	0.072	0.176	ND	0.062	0.065	ND	ND
GW7	0.167	ND	0.012	0.570	ND	0.022	0.072	0.009	ND
GW9	0.132	ND	0.301	0.351	0.008	0.041	0.066	ND	ND
GW10	0.766	ND	0.077	0.365	ND	0.021	0.068	ND	ND
GW11	0.239	ND	ND	0.007	ND	0.069	0.065	ND	ND
R1	0.008	ND	0.022	0.043	ND	ND	ND	0.020	ND
R2	0.0034	ND	0.009	0.066	ND	ND	ND	0.009	ND
R3	0.033	ND	0.011	0.067	ND	ND	ND	0.007	ND
R4	0.100	0.006	0.224	0.383	ND	ND	ND	0.086	ND
R5	0.241	ND	0.065	0.448	ND	ND	0.068	0.033	ND
R7	0.200	ND	0.004	0.031	ND	ND	ND	ND	ND
R8	0.092	ND	0.008	0.129	ND	ND	ND	0.004	ND
R9	0.086	ND	ND	ND	ND	ND	ND	ND	ND
R10	0.118	ND	0.008	0.131	ND	ND	ND	ND	ND
R11	0.141	ND	0.003	0.136	ND	ND	ND	0.007	ND
R12	0.107	ND	0.013	0.215	ND	ND	ND	0.005	ND
R13	0.303	ND	0.079	0.168	ND	0.007	0.061	ND	ND
R14	0.295	ND	0.068	0.262	ND	0.113	0.068	0.003	ND
M1	0.680	0.013	6.051	4.606	0.035	0.453	0.017	0.1935	ND
M2	1.63	0.010	7.63	2.62	0.068	0.692	0.261	0.2549	ND
M3	2.80	0.015	0.065	2.30	0.014	0.215	0.09	0.2166	ND
M4	3.25	0.012	0.099	3.207	ND	0.685	0.012	0.3706	ND
M5	3.28	0.015	4.36	10.30	ND	0.886	0.113	0.2646	ND
M6	1.34	ND	1.38	5.190	ND	0.798	0.093	0.3133	ND
M7	0.209	ND	0.476	1.324	0.007	0.191	0.046	0.0404	ND
M8	1.65	0.014	5.06	16.91	0.052	0.931	0.200	0.0763	ND
M9	1.56	ND	3.82	07.14	0.033	0.304	0.189	0.0656	ND
M10	0.149	ND	0.091	0.419	ND	0.118	0.018	0.0018	ND

Annexure 4.1h.

TRACE ELEMENT DATA PRE-MONSOON 1992. (In mg/L)

Sample No.	Fluoride	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Cadmium
GW1	0.846	0.002	0.028	0.275	ND	0.092	0.016	ND	ND
GW2	0.264	ND	0.079	0.385	ND	0.100	0.041	0.0130	ND
GW4	0.199	0.008	0.092	0.270	ND	0.030	0.033	ND	ND
GW5	0.301	0.010	0.061	0.110	ND	0.103	0.051	ND	ND
GW7	0.217	0.015	0.427	1.095	ND	0.069	0.067	ND	0.044
GW9	0.188	0.006	0.824	0.726	ND	0.063	0.029	0.057	ND
GW10	0.893	0.008	0.159	0.215	ND	0.048	0.018	0.0150	ND
GW11	0.972	0.005	0.006	0.093	ND	0.071	0.050	ND	ND
R1	0.009	0.012	0.085	0.008	ND	ND	ND	0.149	ND
R2	0.008	0.009	0.063	0.021	0.011	ND	ND	0.015	ND
R3	0.009	0.007	0.076	0.023	ND	ND	ND	0.0148	0.053
R4	0.004	0.004	1.973	1.76	0.021	0.033	0.019	0.0150	ND
R5	0.495	0.005	0.721	0.914	0.015	ND	ND	0.0188	ND
R7	0.694	0.008	0.008	0.041	ND	ND	ND	0.0238	ND
R8	0.092	0.006	0.102	0.099	0.006	ND	ND	0.0380	ND
R9	0.103	0.007	ND	0.024	ND	ND	ND	0.0080	ND
R10	0.213	0.007	0.319	0.078	0.010	ND	ND	0.0370	ND
R11	0.698	ND	0.021	0.634	ND	ND	ND	0.247	0.062
R12	0.698	ND	0.143	0.816	ND	ND	ND	0.0208	ND
R13	0.607	ND	0.671	0.675	ND	ND	ND	0.0186	ND
R14	0.742	0.005	1.09	2.981	0.179	0.021	0.086	0.0192	0.062
M1	1.41	ND	9.94	7.215	0.675	0.075	0.029	1.1493	0.068
M2	1.71	0.015	9.60	11.06	0.778	0.085	1.019	1.0978	ND
M3	3.66	0.053	1.32	6.154	1.164	0.073	0.087	1.0071	0.071
M4	5.06	ND	11.25	4.56	0.781	0.084	0.028	2.1434	0.067
M5	4.68	0.089	16.41	30.41	1.33	ND	1.201	0.961	0.092
M6	1.88	0.204	9.69	15.11	0.959	0.080	0.059	1.1978	0.059
M7	0.60	0.011	8.63	10.18	1.159	0.014	0.017	0.3396	0.061
M8	2.11	ND	2.29	10.18	1.046	0.020	0.019	0.745	0.068
M9	2.14	ND	1.14	16.12	0.290	0.045	1.093	0.092	0.066
M10	0.805	ND	2.10	2.143	0.852	0.008	0.753	0.0068	ND

Annexure 4.1i.

TRACE ELEMENT DATA POST-MONSOON 1992. (In mg/L)

Sample No.	Fluoride	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Cadmium
GW1	0.032	ND	0.024	0.138	ND	ND	0.041	ND	ND
GW2	0.079	ND	0.104	0.203	ND	0.079	0.060	ND	ND
GW4	0.099	ND	0.093	0.165	ND	0.012	0.053	ND	ND
GW5	0.186	ND	0.124	0.097	ND	0.023	0.039	ND	ND
GW7	0.127	ND	0.028	0.893	ND	0.053	0.045	ND	ND
GW9	0.124	ND	0.176	0.638	ND	0.041	0.027	ND	ND
GW10	0.895	ND	0.096	0.189	ND	0.013	0.065	ND	ND
GW11	0.334	ND	0.033	0.078	ND	0.021	0.034	ND	ND
R1	ND	ND	0.019	0.003	ND	ND	ND	ND	ND
R2	ND	ND	0.012	0.006	ND	ND	ND	0.02	ND
R3	ND	ND	0.024	0.006	ND	ND	ND	0.015	ND
R4	0.063	ND	0.398	0.872	ND	ND	0.024	0.011	ND
R5	0.217	ND	0.126	0.625	ND	ND	ND	0.044	ND
R7	0.173	ND	0.094	0.031	ND	ND	ND	ND	ND
R8	0.015	ND	0.006	0.092	ND	ND	ND	0.048	ND
R9	0.059	ND	0.007	0.052	ND	ND	ND	ND	ND
R10	0.081	ND	ND	0.063	ND	ND	ND	ND	ND
R11	0.111	ND	0.004	0.049	ND	ND	ND	0.006	ND
R12	0.069	ND	0.007	0.048	ND	ND	ND	0.008	ND
R13	0.405	ND	0.011	0.069	ND	ND	ND	0.007	ND
R14	0.398	ND	1.071	0.972	0.015	ND	ND	0.179	ND
M1	0.099	ND	2.150	2.050	0.045	0.384	0.014	0.201	ND
M2	0.986	0.009	5.390	6.590	ND	0.439	0.106	0.2431	ND
M3	1.860	0.031	0.082	1.980	ND	0.236	0.009	0.1989	ND
M4	3.600	ND	3.148	3.865	ND	0.518	0.008	0.2764	ND
M5	3.540	0.007	4.280	14.53	ND	0.479	0.098	0.2234	ND
M6	1.490	0.078	1.270	4.790	ND	0.392	0.038	0.2949	ND
M7	0.177	ND	0.531	3.060	0.017	0.899	0.015	0.0071	ND
M8	2.160	ND	1.240	2.680	0.014	0.920	0.018	0.0692	ND
M9	0.894	ND	0.925	2.070	ND	0.208	0.667	0.0431	ND
M10	0.067	ND	0.592	0.967	ND	0.202	0.042	0.0021	ND

Annexure 4.2
SUMMARY OF ANALYTICAL METHODS, INSTRUMENTS AND SPECIFICATIONS.

S.N.	Parameter	Method	Instrument	Precision[1] *(Coefficient of Variation) (in %)*	Accuracy[2] *(Relative Error) (in %)*	No. of Replicate Determination *(n)*
1.	Alkalinity	Titrimetric	-	5.6	0.9	2
2.	Ca	Titrimetric	-	8.6	1.3	5
3.	Cd	Atomic Emission	ICPA[6]	5.3	1.9	5
4.	Cl^-	Titrimetric	-	4.5	1.6	5
5.	Cr	Atomic Emission	ICPA	4.8	2.7	5
6.	Co	- do -	ICPA	5.8	0.5	5
7.	Cu	- do -	ICPA	6.7	4.1	5
8.	F^-	ISE[4]	Ion Analiser[5]	4.5	1.6	5
9.	Fe	Atomic Emission	ICPA	4.2	2.9	5
10.	Pb	Atomic Absorption	AAS[3]	12.6	8.2	5
11.	Mg	- do -	AAS	11.5	7.5	5
12.	Mn	- do -	AAS	12.3	5.5	5
13.	Hg	Cold Vapor	AAS	0.2	26	5
14.	Ni	Atomic Emission	ICPA	19.2	7.4	5
15.	K	Flame Emission	Flame Photo Meter	14.9	4.5	5
16.	Na	- do -	- do -	13.4	2.3	5
17.	SO_4^{--}	Gravimetric	-	4.2	2.0	3
18.	Zn	Atomic Emission	ICPA	3.6	1.2	5
19.	pH	Electrometric	pH Meter	-	± 0.1 unit	
20.	TDS	Gravimetric	-	-	-	-

---

[1] Coefficient of Variation (Cv) = $\frac{100\ \sigma}{\bar{x}}$

[6] Labtam, Inductively Coupled Plasma Analyser.

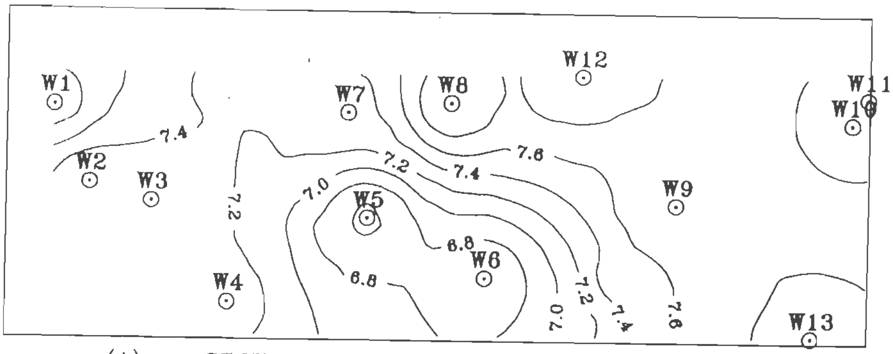
[2] Relative Error = $\frac{\text{Mean Error}}{\text{True Value}} \times 100$ [Where, M.E. = $\bar{x}$ - T.V.]

[4] Ion Selective Electrode.

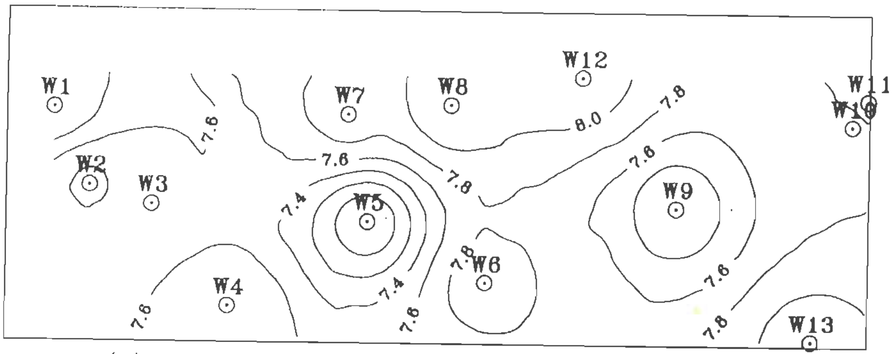
[5] Orion Expandable Ion Analiser EA 940.

[3] Atomic Absorption Spectrophotometer (Perkin Elmer 2380).

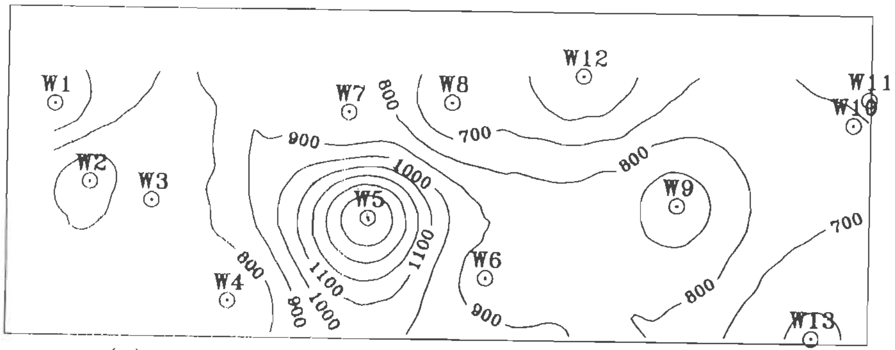
Annexure 4.3a



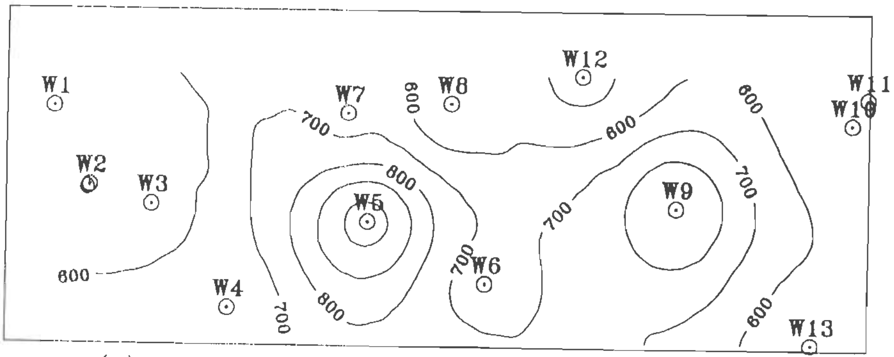
(A) GROUNDWATER ISO-pH MAP ; PREMONSOON



(B) GROUNDWATER ISO-pH MAP ; POSTMONSOON

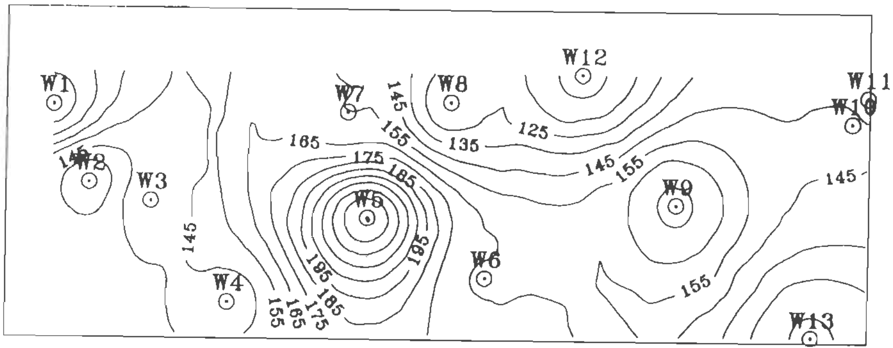


(C) GROUNDWATER ISO-TDS MAP ; PREMONSOON

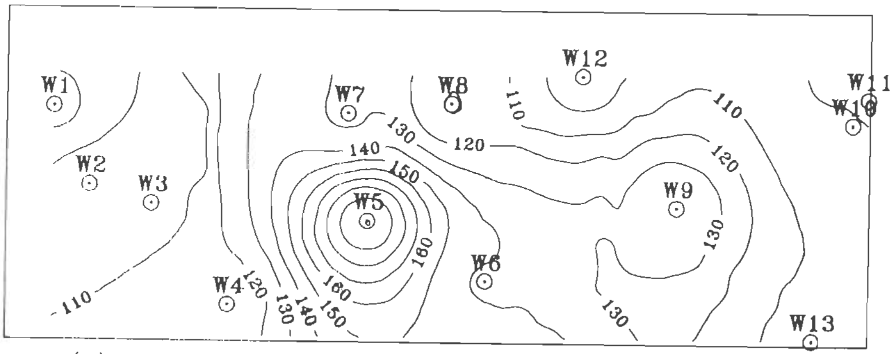


(D) GROUNDWATER ISO-TDS MAP ; POSTMONSOON

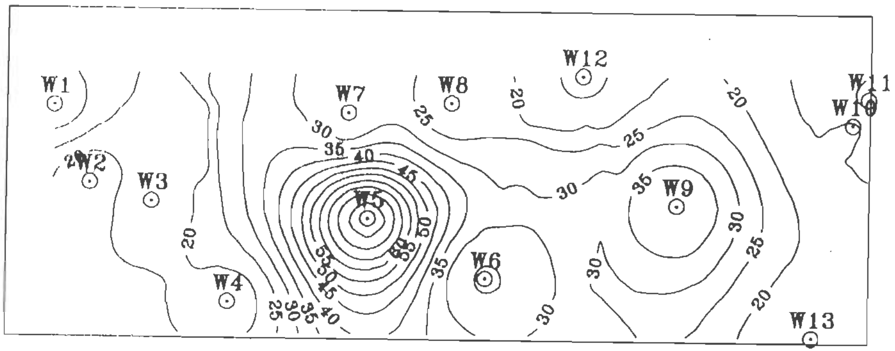
Annexure 4.3b



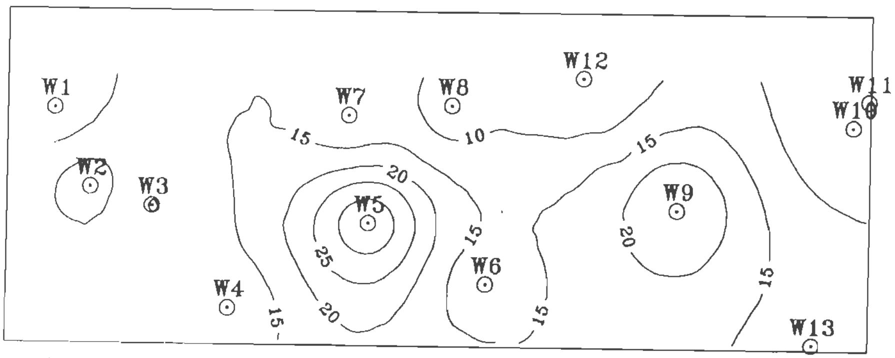
(A) GROUNDWATER ISO-CALCIUM MAP ; PREMONSOON



(B) GROUNDWATER ISO-CALCIUM MAP ; POSTMONSOON

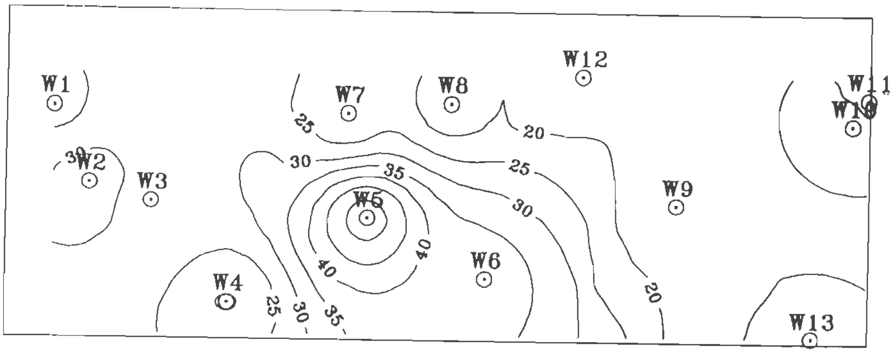


(C) GROUNDWATER ISO-MAGNESIUM MAP ; PREMONSOON

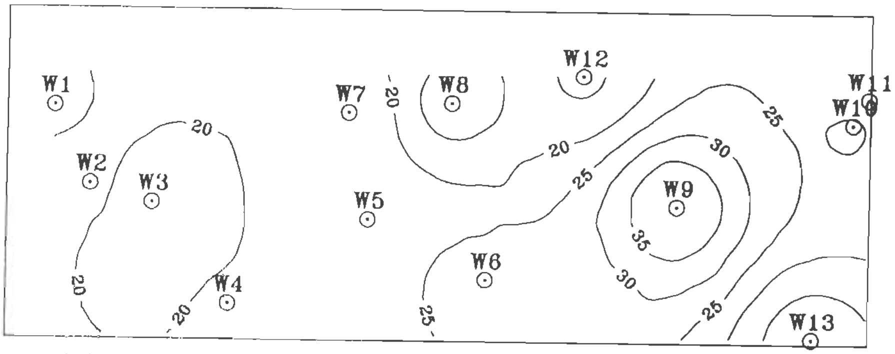


(D) GROUNDWATER ISO-MAGNESIUM MAP ; POSTMONSOON

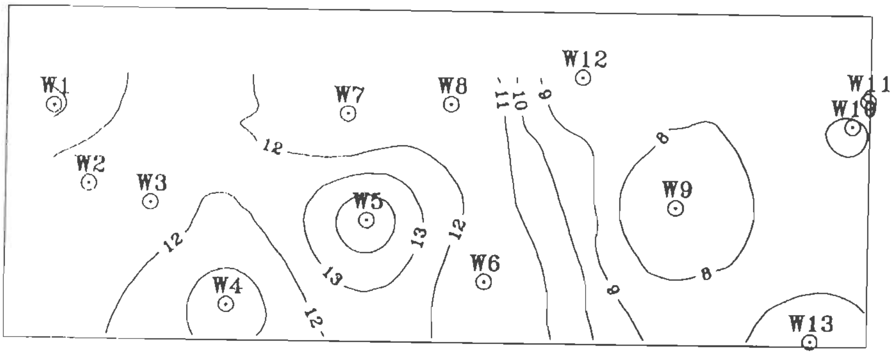
Annexure 4.3c



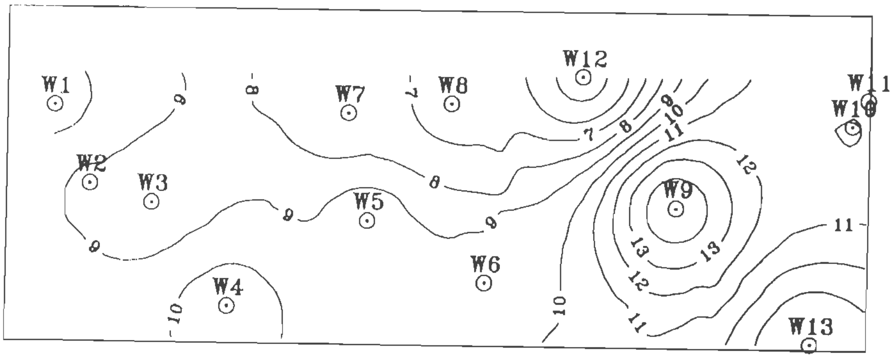
(A) GROUNDWATER ISO-SODIUM MAP ; PREMONSOON



(B) GROUNDWATER ISO-SODIUM MAP ; POSTMONSOON

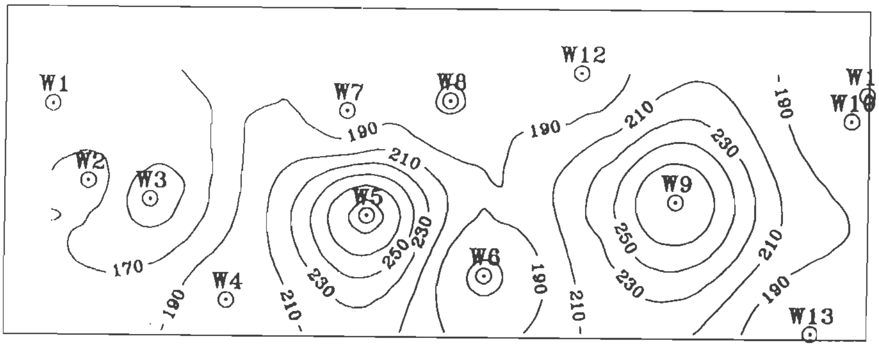


(C) GROUNDWATER ISO-POTASIUM MAP ; PREMONSOON

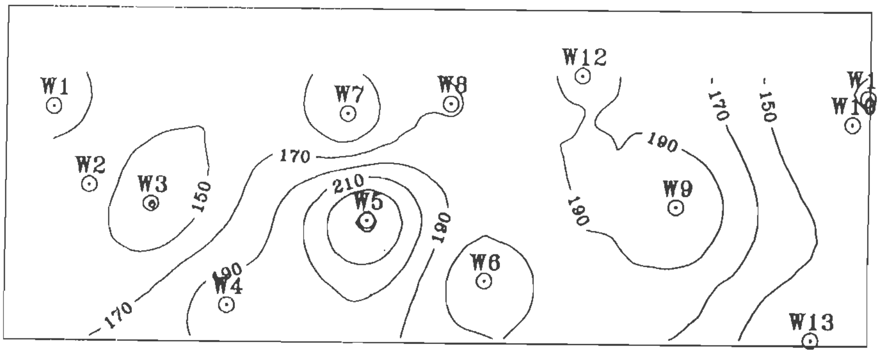


(D) GROUNDWATER ISO-POTASIUM MAP ; POSTMONSOON

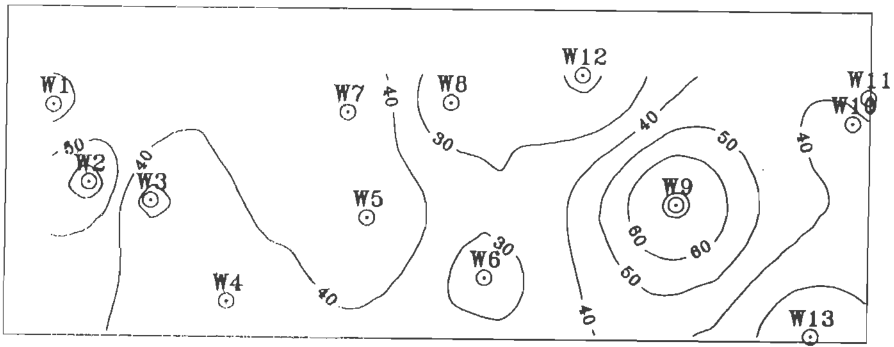
Annexure 4.3d



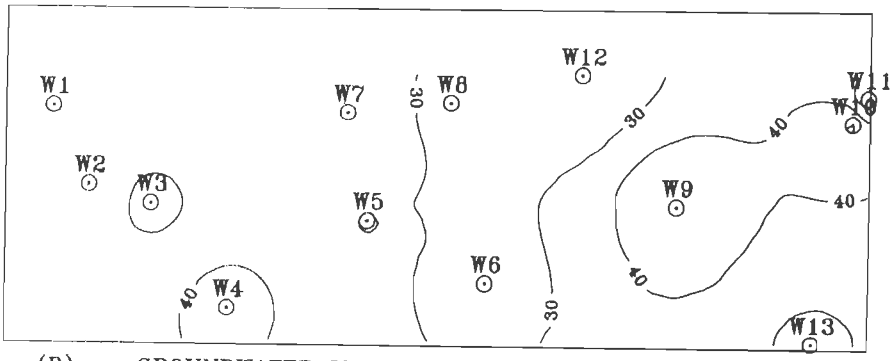
(A) GROUNDWATER ISO-BICARBONATE MAP ; PREMONSOON



(B) GROUNDWATER ISO-BICARBONATE MAP ; POSTMONSOON

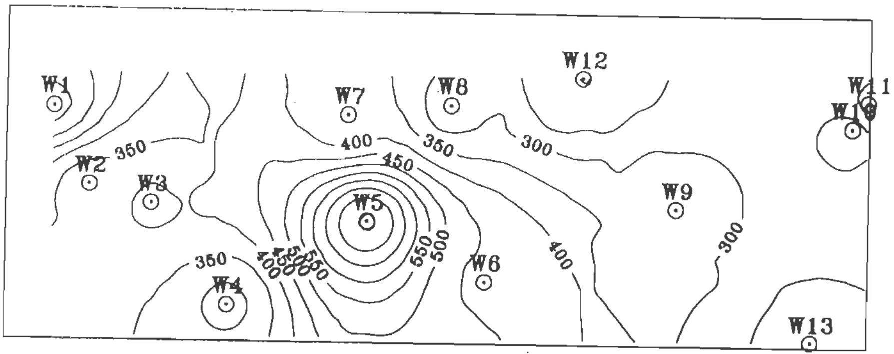


(C) GROUNDWATER ISO-CHLORIDE MAP ; PREMONSOON

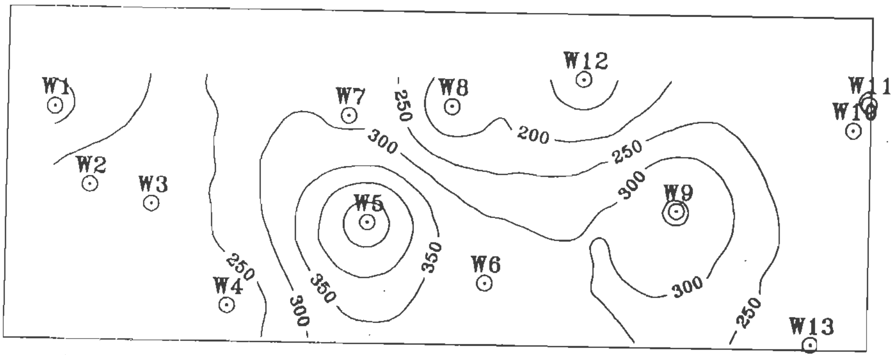


(D) GROUNDWATER ISO-CHLORIDE MAP ; POSTMONSOON

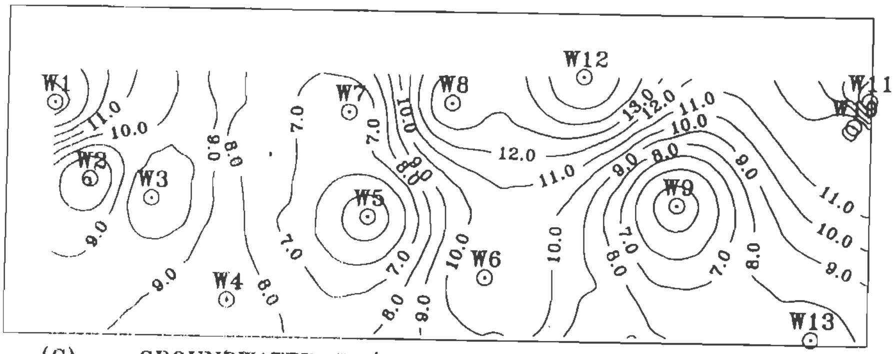
Annexure 4.3e



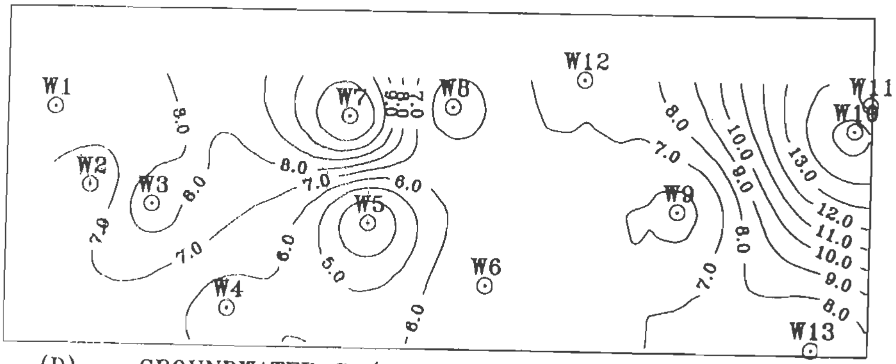
(A) GROUNDWATER ISO-SULFATE MAP ; PREMONSOON



(B) GROUNDWATER ISO-SULFATE MAP ; POSTMONSOON

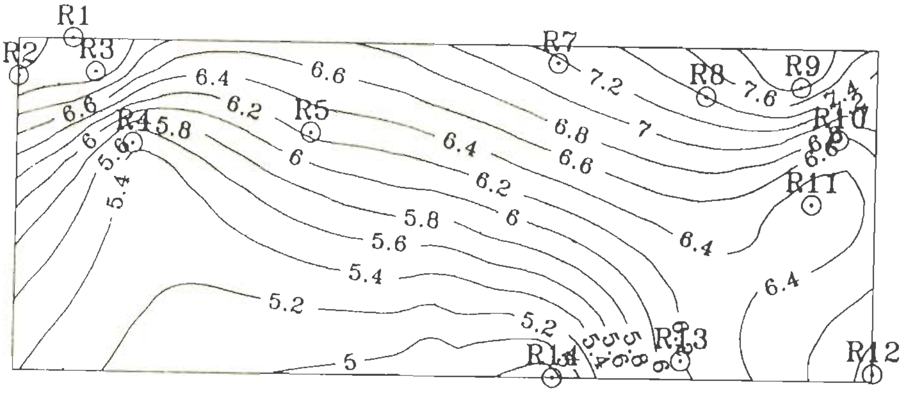


(C) GROUNDWATER Ca/Mg CONTOUR MAP ; PREMONSOON

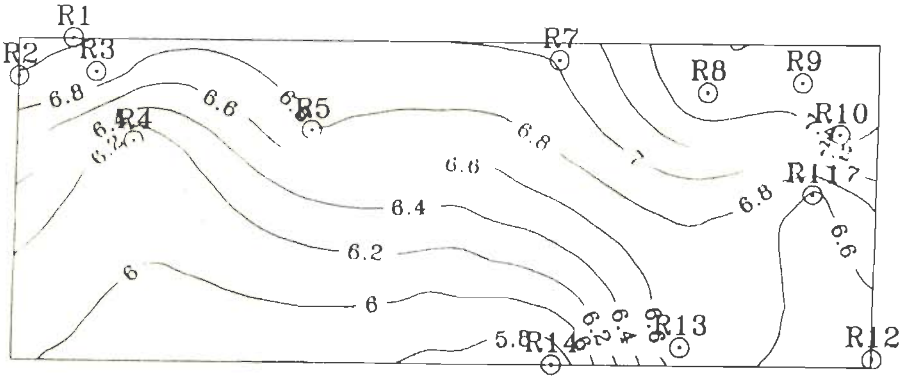


(D) GROUNDWATER Ca/Mg CONTOUR MAP ; POSTMONSOON

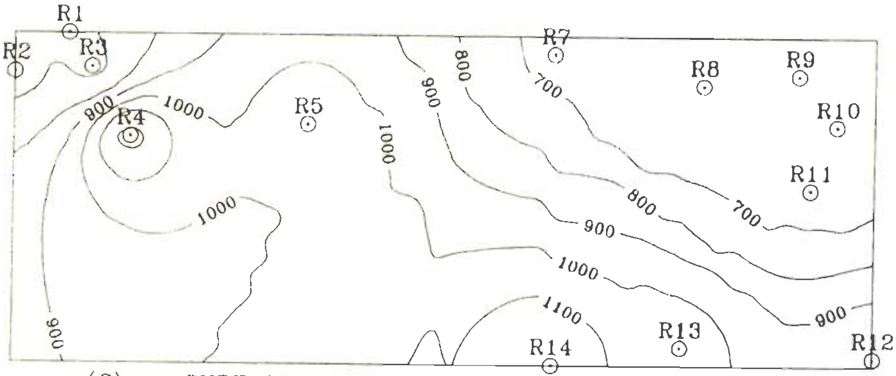
Anneexure 4.4a



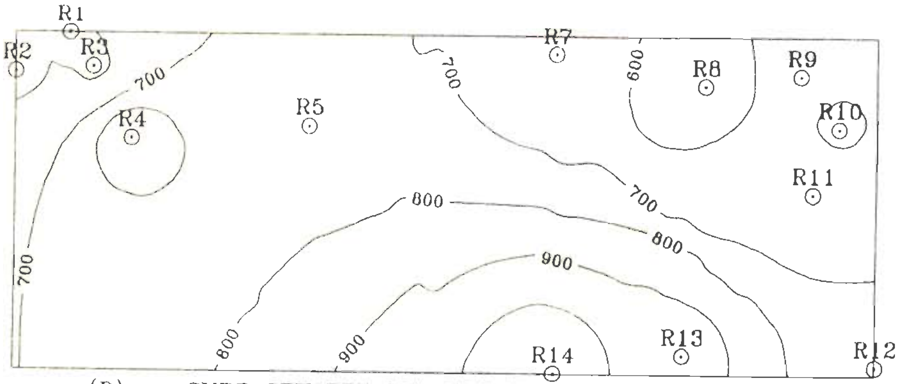
(A) SURFACEWATER ISO-pH MAP ; PREMONSOON



(B) SURFACEWATER ISO-pH MAP ; POSTMONSOON

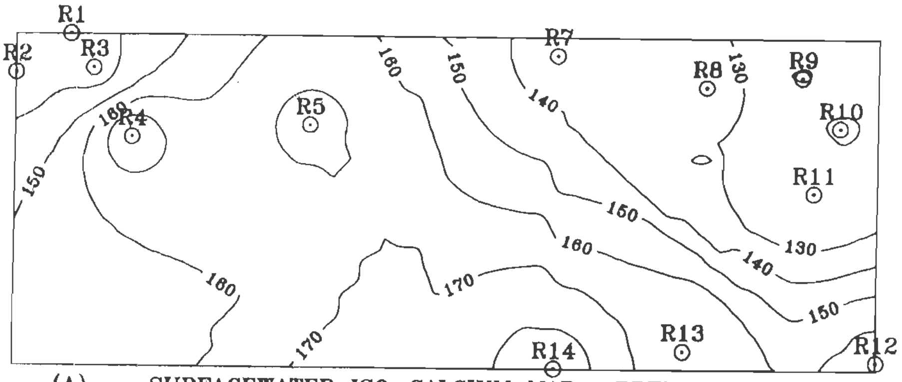


(C) SURFACEWATER ISO-TDS MAP ; PREMONSOON

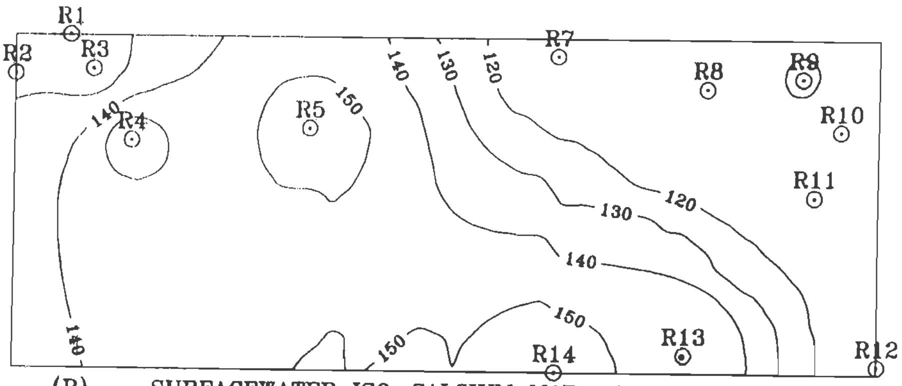


(D) SURFACEWATER ISO-TDS MAP ; POSTMONSOON

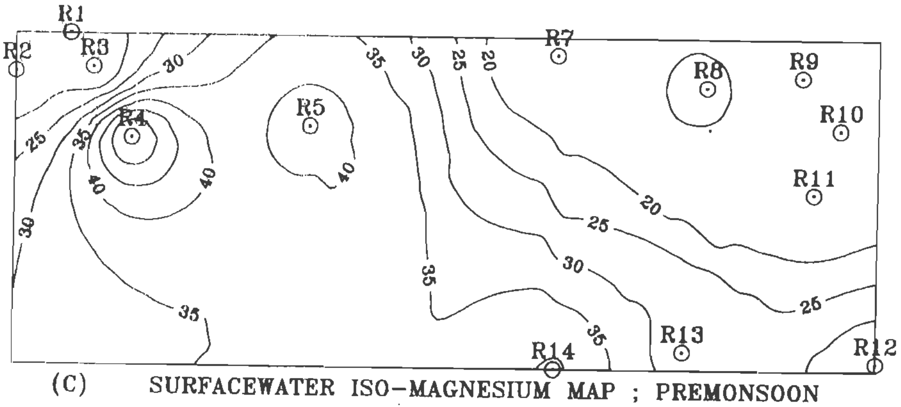
Annexure 4.4b



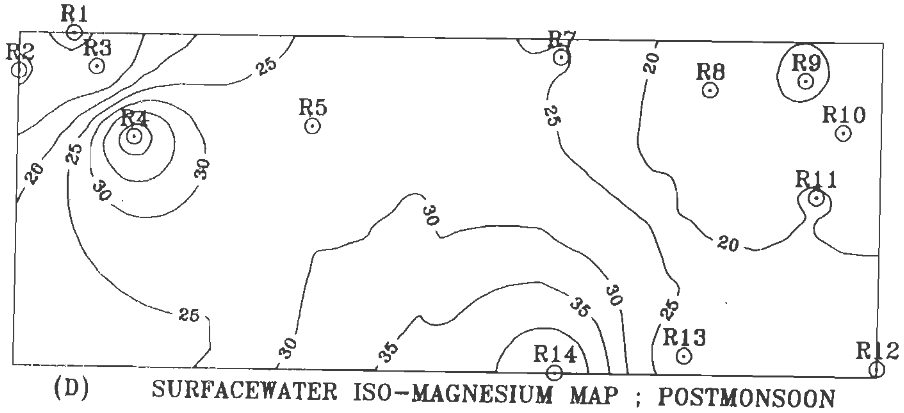
(A) SURFACEWATER ISO-CALCIUM MAP ; PREMONSOON



(B) SURFACEWATER ISO-CALCIUM MAP ; POSTMONSOON

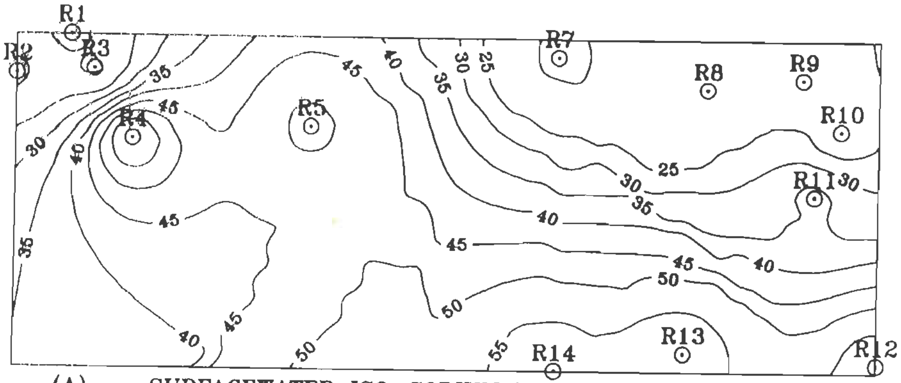


(C) SURFACEWATER ISO-MAGNESIUM MAP ; PREMONSOON

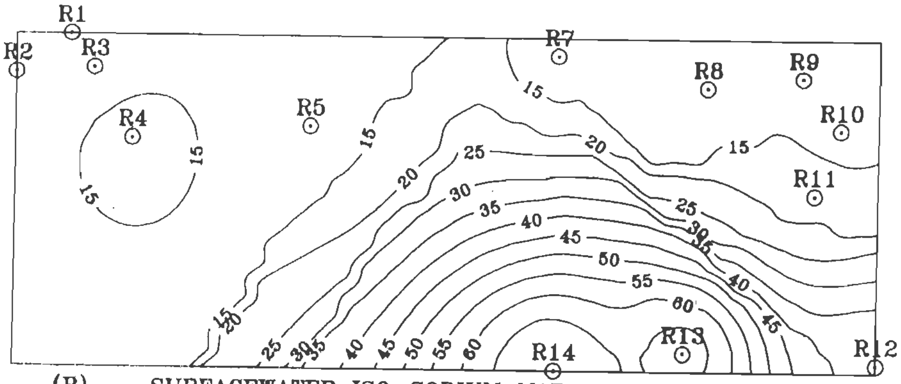


(D) SURFACEWATER ISO-MAGNESIUM MAP ; POSTMONSOON

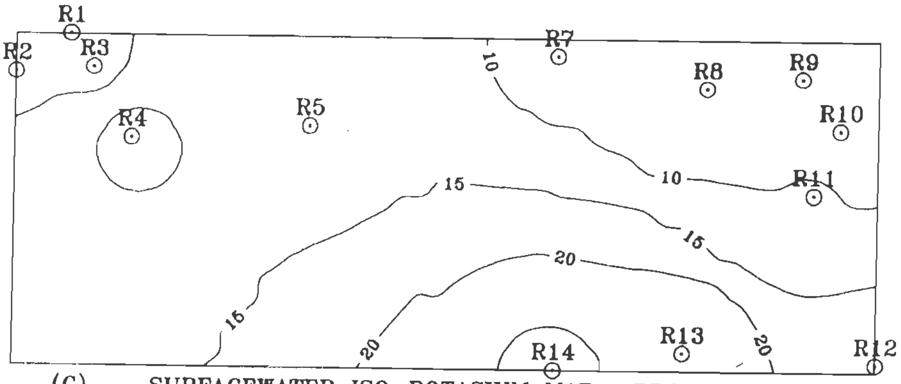
Annexure 4.4c



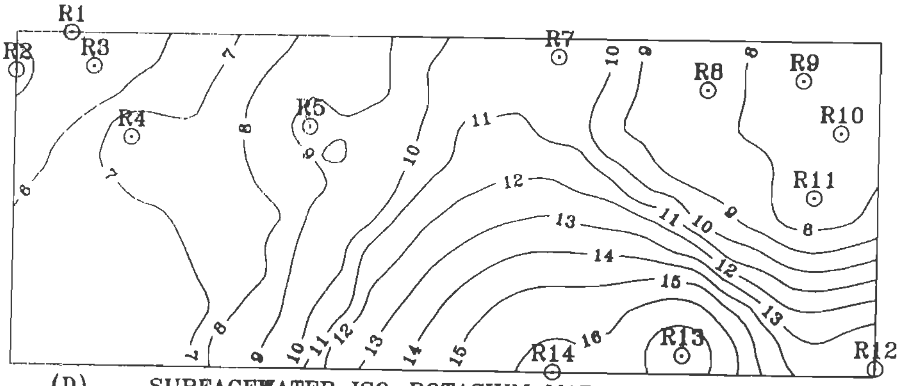
(A) SURFACEWATER ISO-SODIUM MAP ; PREMONSOON



(B) SURFACEWATER ISO-SODIUM MAP ; POSTMONSOON

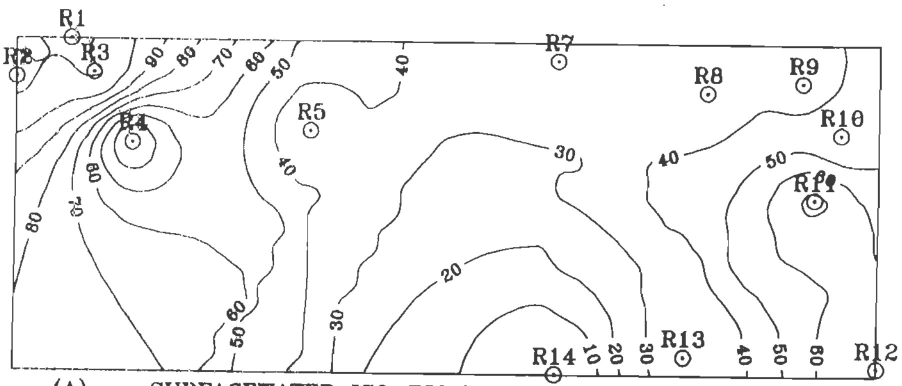


(C) SURFACEWATER ISO-POTASIUM MAP ; PREMONSOON

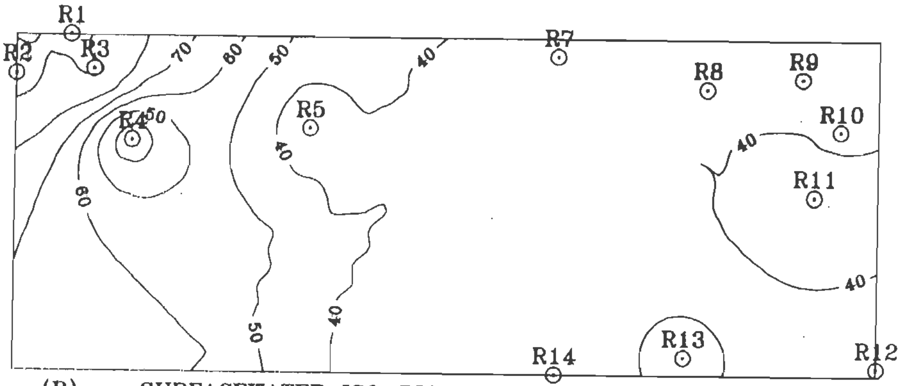


(D) SURFACEWATER ISO-POTASIUM MAP ; POSTMONSOON

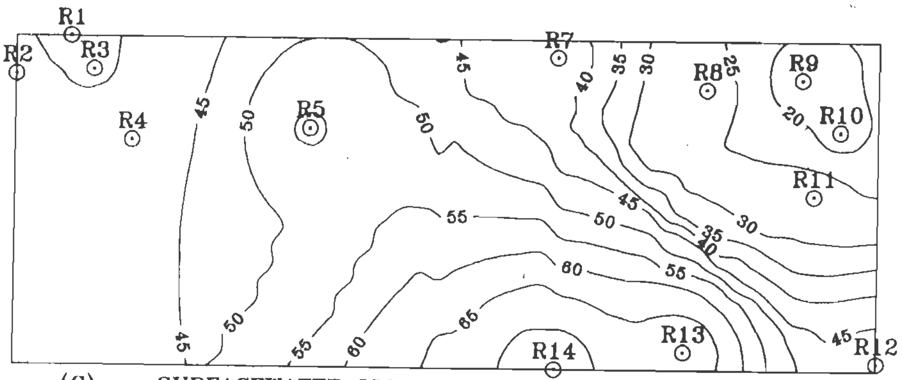
Annexure 4.4d



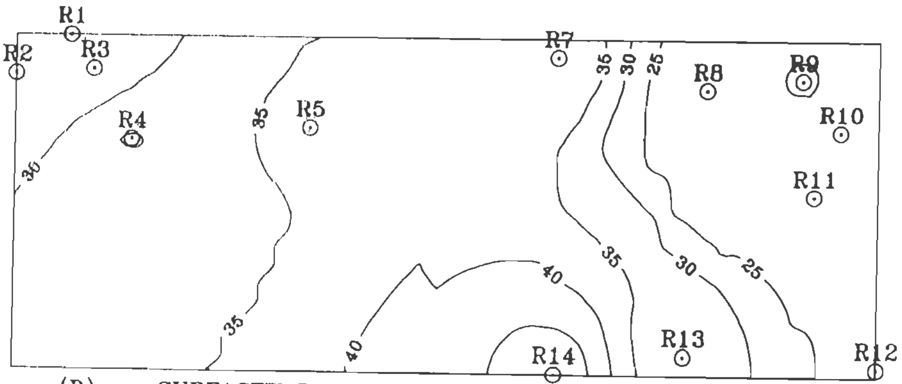
(A) SURFACEWATER ISO-BICARBONATE MAP ; PREMONSOON



(B) SURFACEWATER ISO-BICARBONATE MAP ; POSTMONSOON

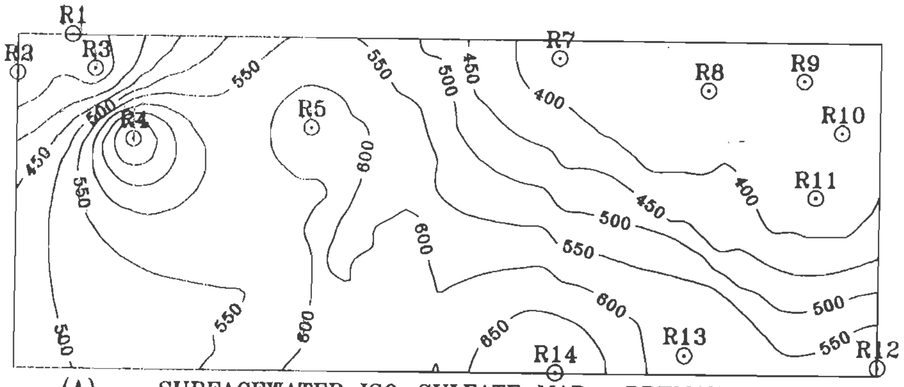


(C) SURFACEWATER ISO-CHLORIDE MAP ; PREMONSOON

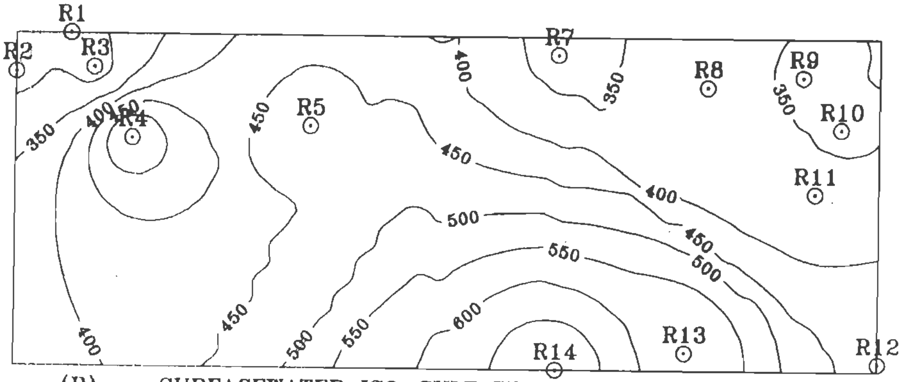


(D) SURFACEWATER ISO-CHLORIDE MAP ; POSTMONSOON

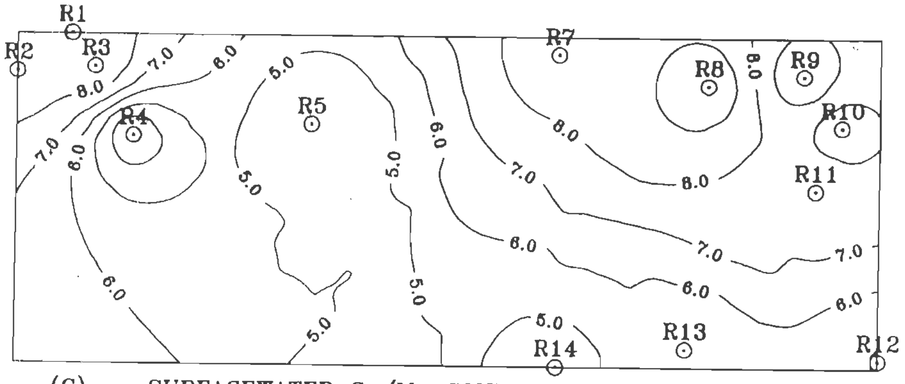
Annexure 4.4e



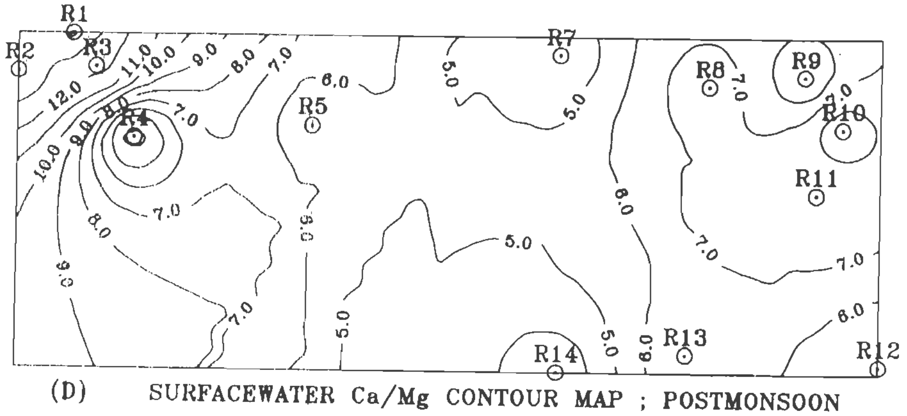
(A) SURFACEWATER ISO-SULFATE MAP ; PREMONSOON



(B) SURFACEWATER ISO-SULFATE MAP ; POSTMONSOON

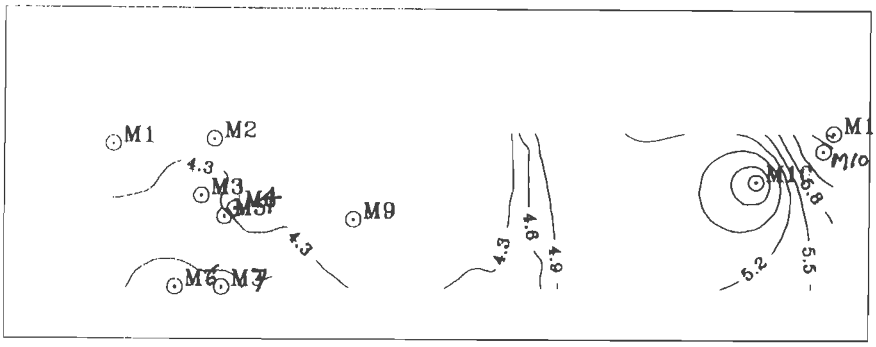


(C) SURFACEWATER Ca/Mg CONTOUR MAP ; PREMONSOON

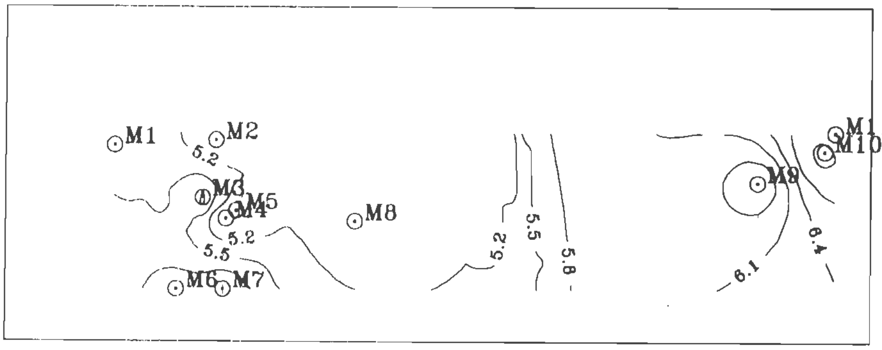


(D) SURFACEWATER Ca/Mg CONTOUR MAP ; POSTMONSOON

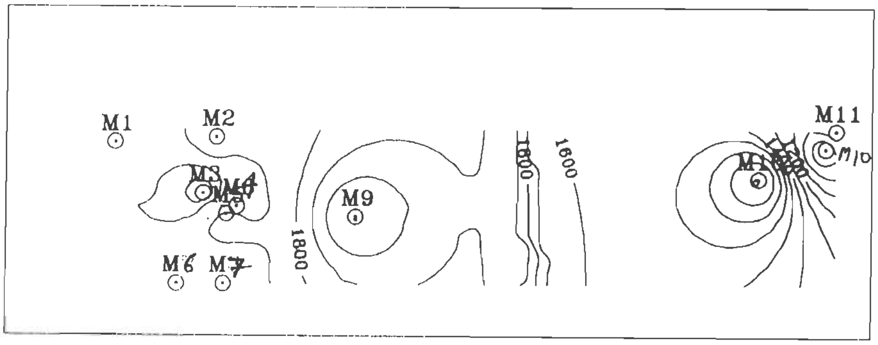
Annexure 4.5a



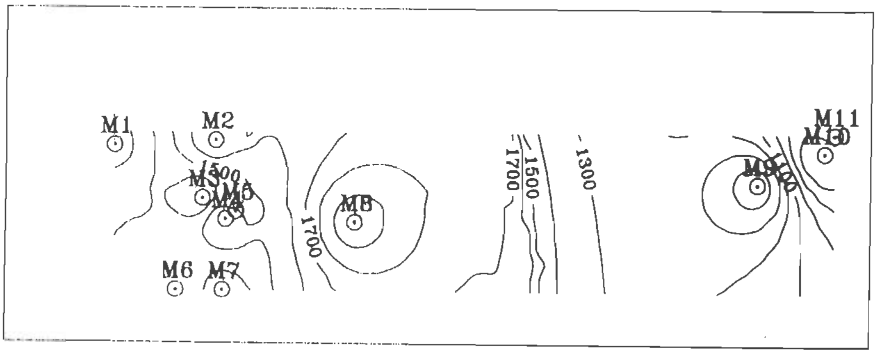
(A) MINEWATER ISO-pH MAP ; PREMONSOON



(B) MINEWATER ISO-pH MAP ; POSTMONSOON

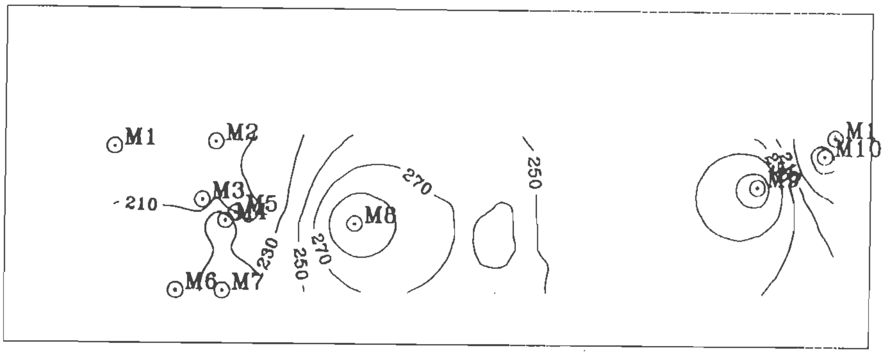


(C) MINEWATER ISO-TDS MAP ; PREMONSOON

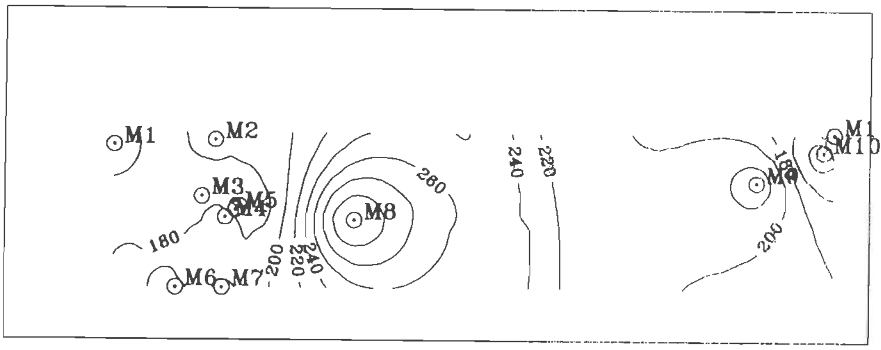


(D) MINEWATER ISO-TDS MAP ; POSTMONSOON

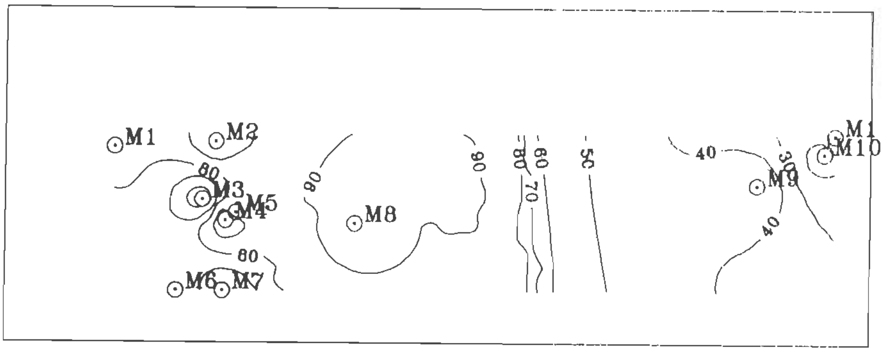
Annexure 4.5b



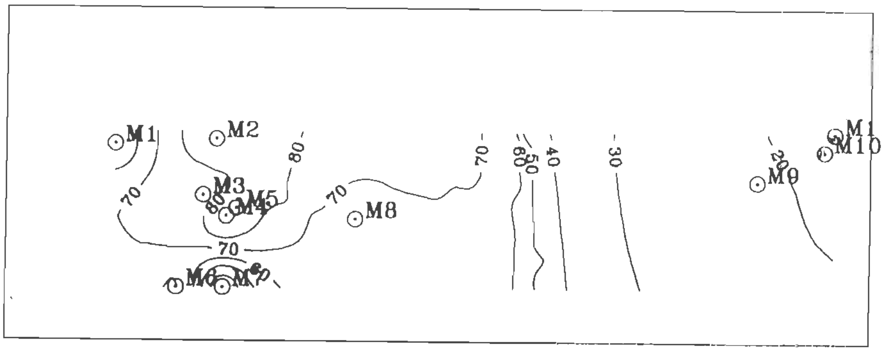
(A) MINEWATER ISO-CALCIUM MAP ; PREMONSOON



(B) MINEWATER ISO-CALCIUM MAP ; POSTMONSOON

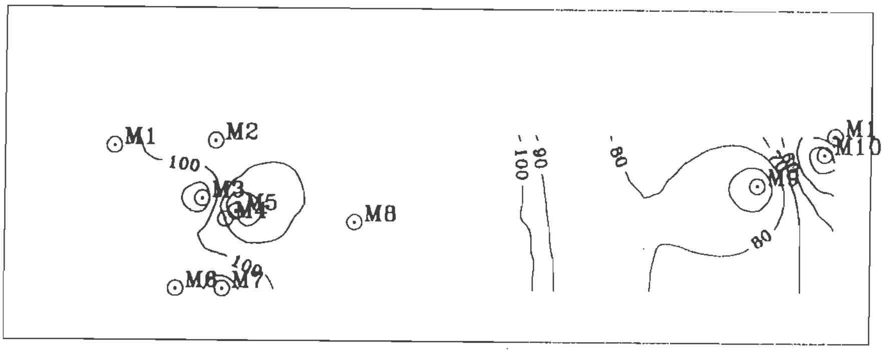


(C) MINEWATER ISO-MAGNESIUM MAP ; PREMONSOON

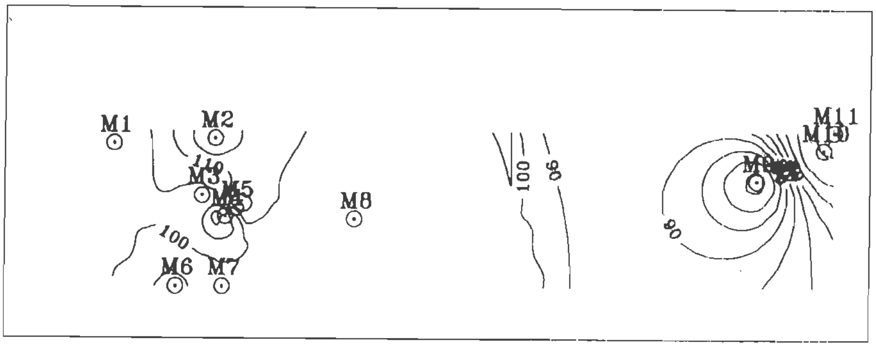


(D) MINEWATER ISO-MAGNESIUM MAP ; POSTMONSOON

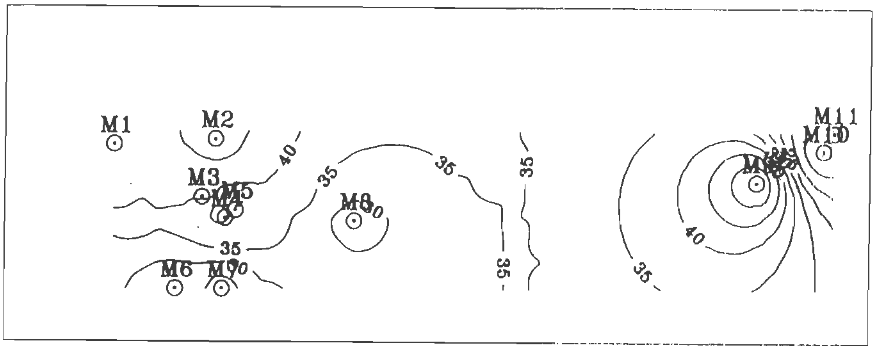
Annexure 4.5c



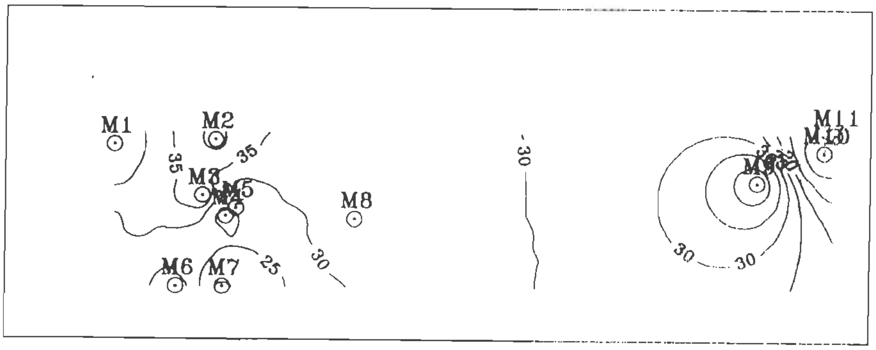
(A) MINEWATER ISO-SODIUM MAP ; PREMONSOON



(B) MINEWATER ISO-SODIUM MAP ; POSTMONSOON

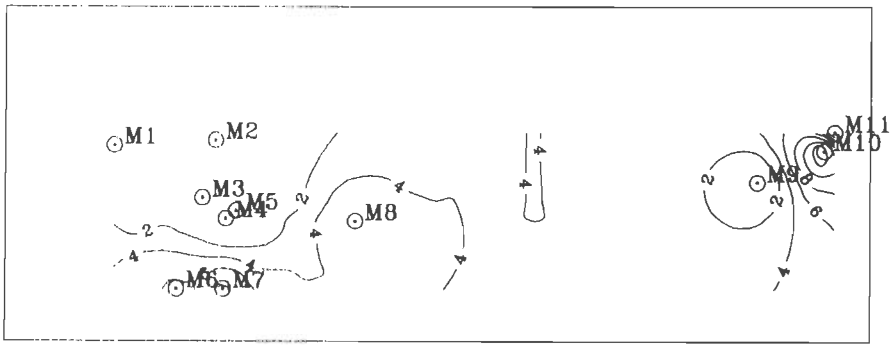


(C) MINEWATER ISO-POTASIUM MAP ; PREMONSOON

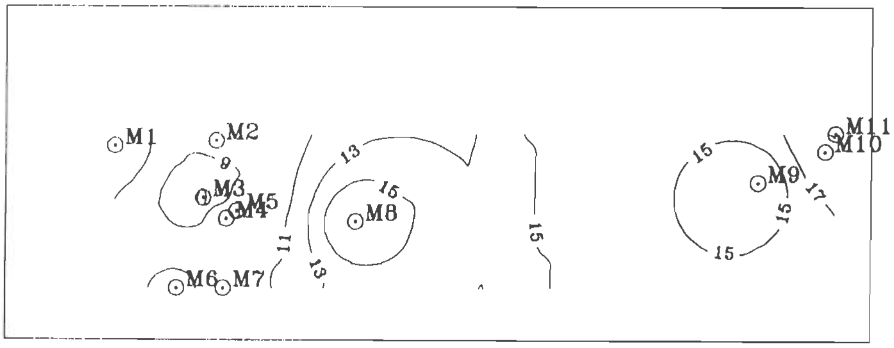


(D) MINEWATER ISO-POTASIUM MAP ; POSTMONSOON

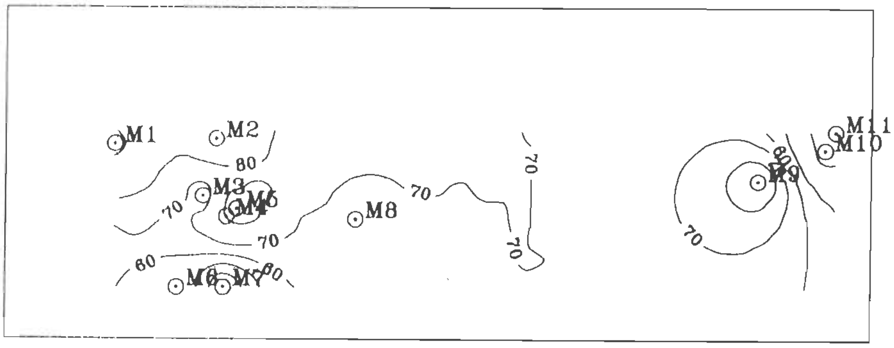
Annexure 4.5d



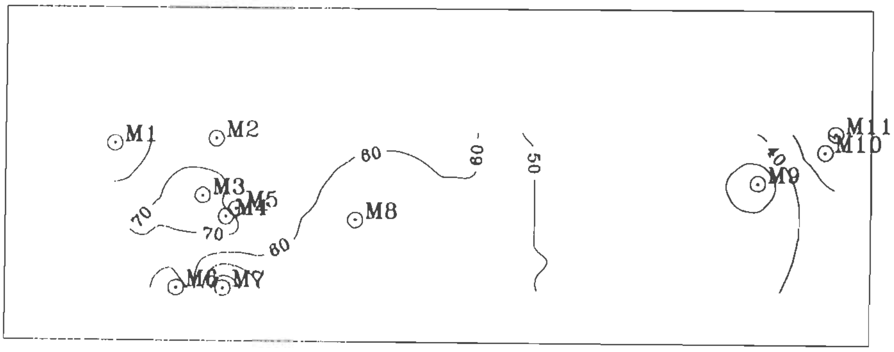
(A) MINEWATER ISO-BICARBONATE MAP ; PREMONSOON



(B) MINEWATER ISO-BICARBONATE MAP ; POSTMONSOON

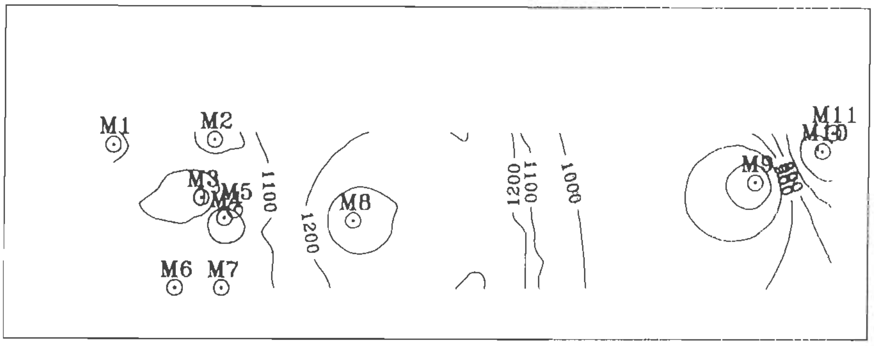


(C) MINEWATER ISO-CHLORIDE MAP ; PREMONSOON

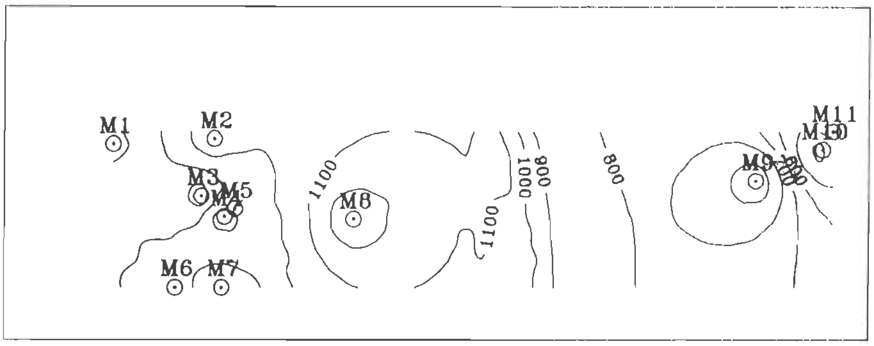


(D) MINEWATER ISO-CHLORIDE MAP ; POSTMONSOON

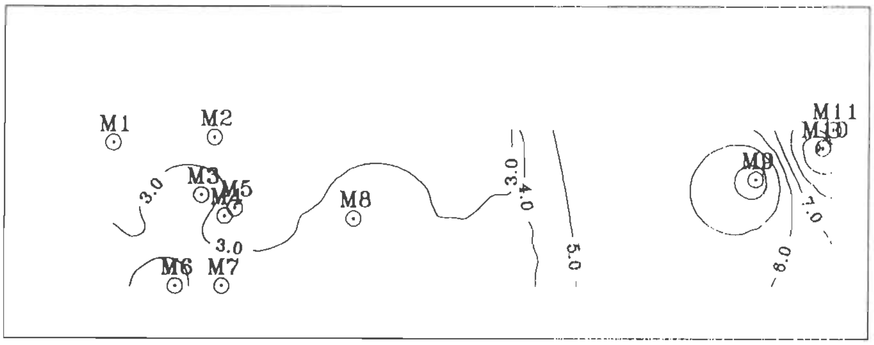
Annexure 4.5e



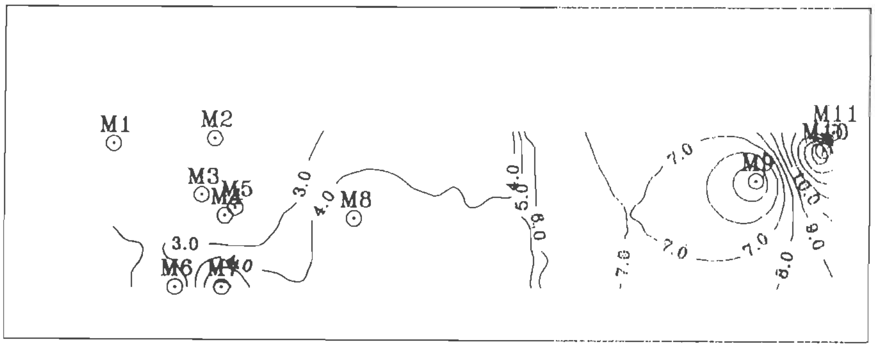
(A) MINEWATER ISO-SULFATE MAP ; PREMONSOON



(B) MINEWATER ISO-SULFATE MAP ; POSTMONSOON

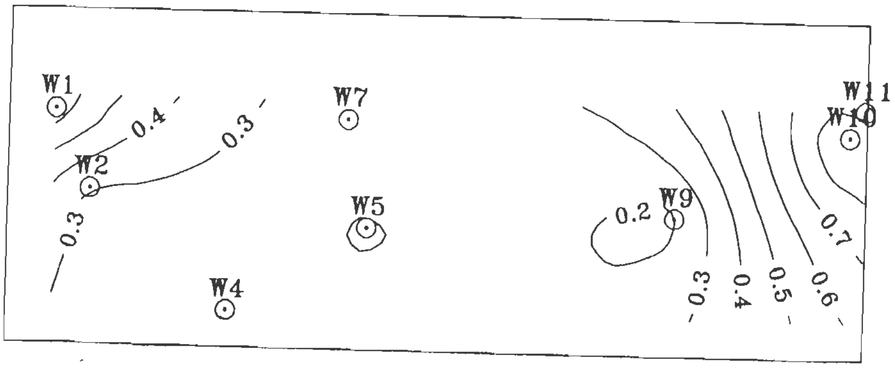


(C) MINEWATER Ca/Mg CONTOUR MAP ; PREMONSOON

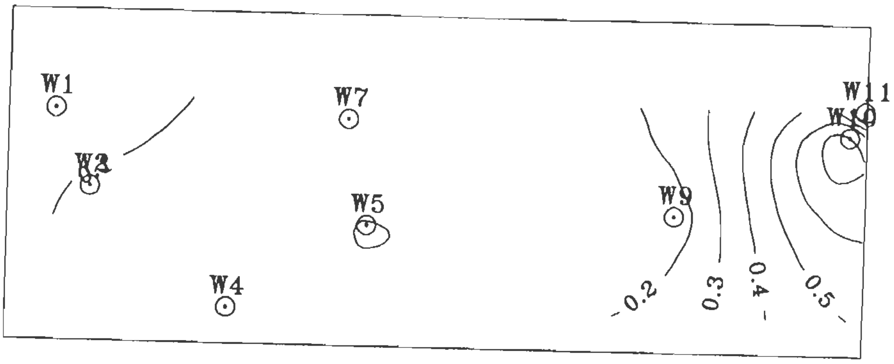


(D) MINEWATER Ca/Mg CONTOUR MAP ; POSTMONSOON

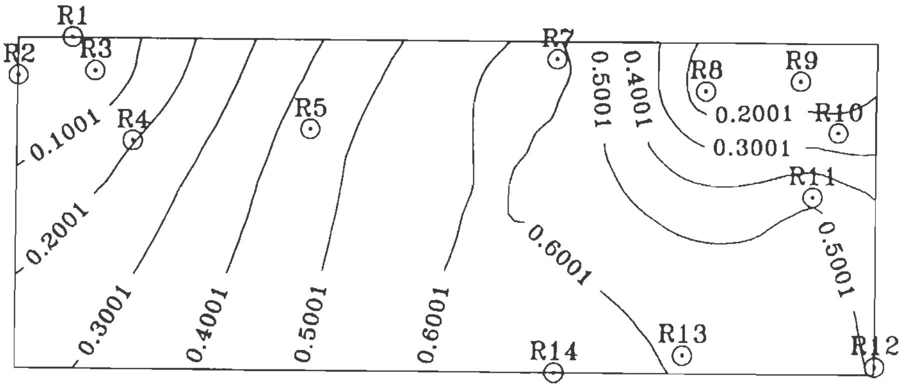
Annexure 4.6a



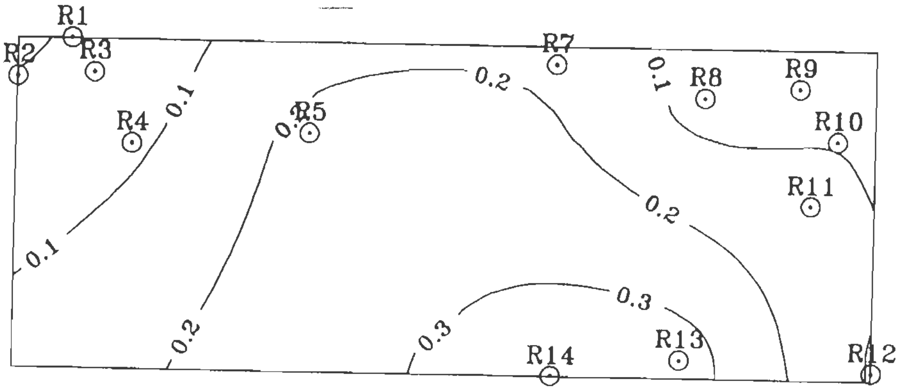
GROUNDWATER ISO-FLUORIDE MAP ; PREMONSOON



GROUNDWATER ISO-FLUORIDE MAP ; POSTMONSOON

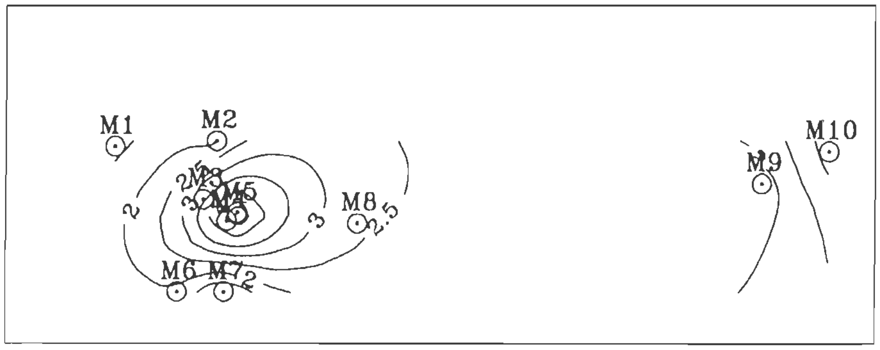


SURFACEWATER ISO-FLUORIDE MAP ; PREMONSOON

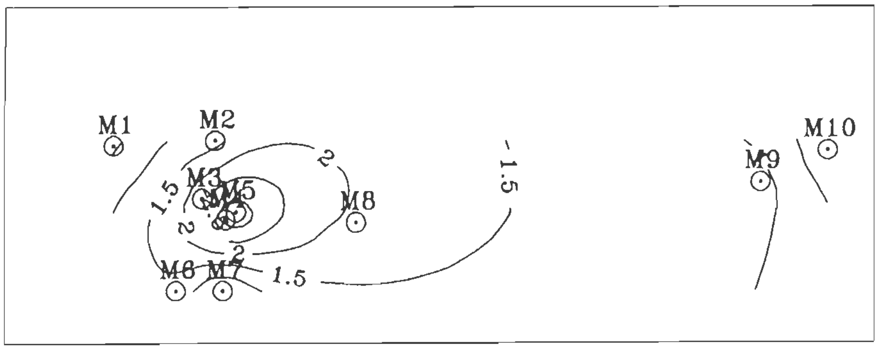


SURFACEWATER ISO-FLUORIDE MAP ; POSTMONSOON

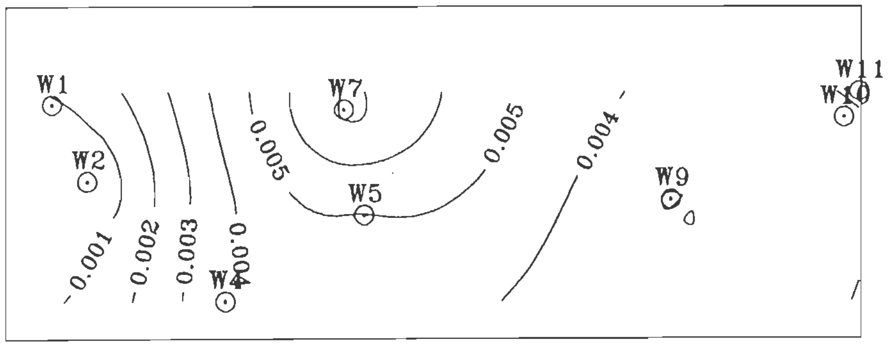
Annexure 4.6b



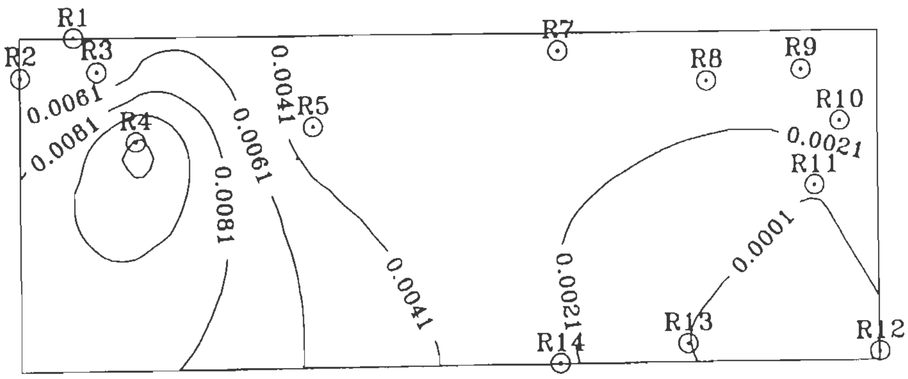
MINEWATER ISO-FLUORIDE MAP ; PREMONSOON



MINEWATER ISO-FLUORIDE MAP ; POSTMONSOON

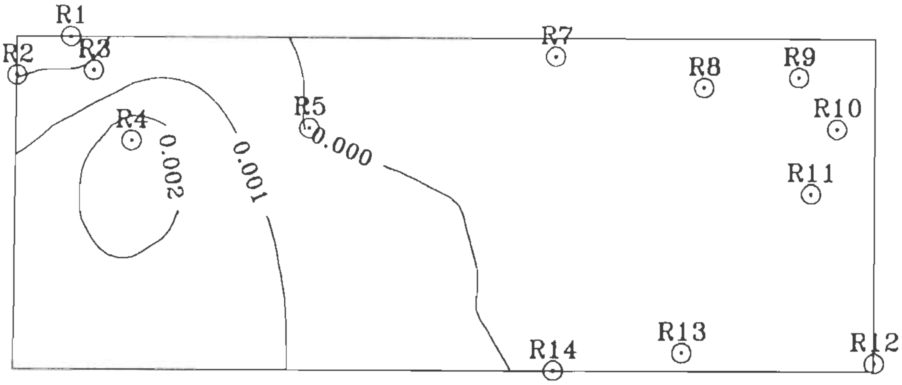


GROUNDWATER ISO-CHROMIUM MAP ; PREMONSOON

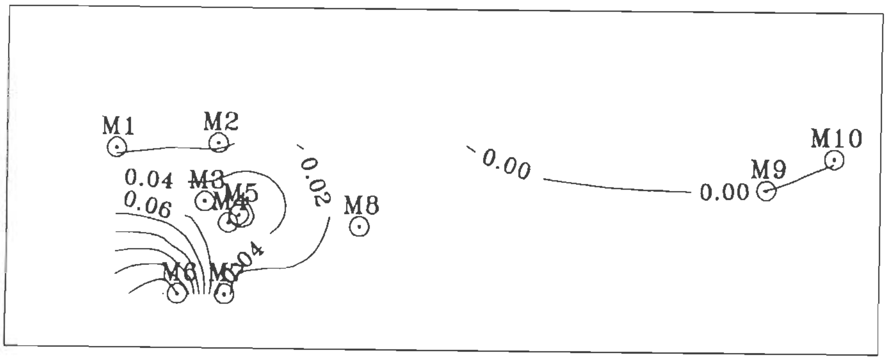


SURFACEWATER ISO-CHROMIUM MAP ; PREMONSOON

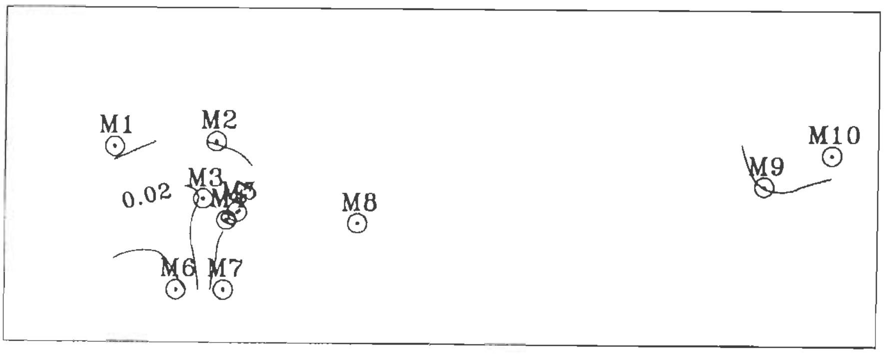
Annexure 4.6c



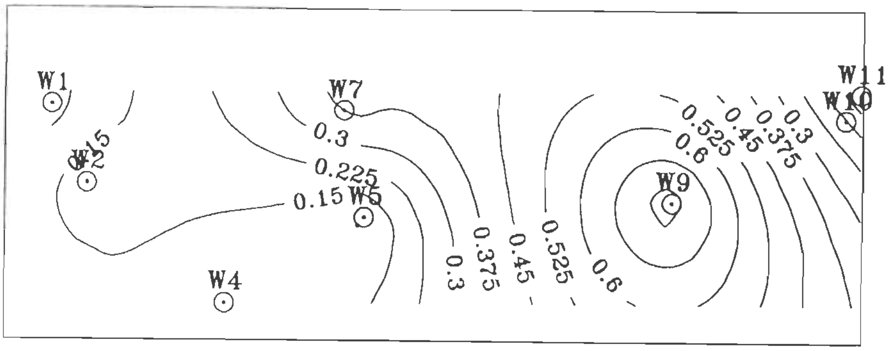
SURFACEWATER ISO-CHROMIUM MAP ; POSTMONSOON



MINEWATER ISO-CHROMIUM MAP ; PREMONSOON

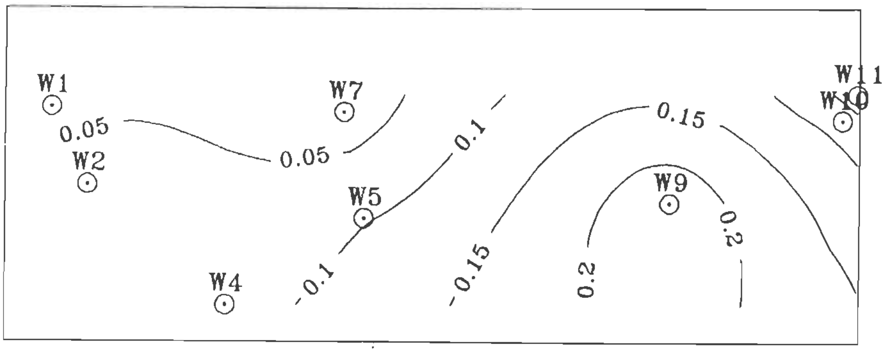


MINEWATER ISO-CHROMIUM MAP ; POSTMONSOON

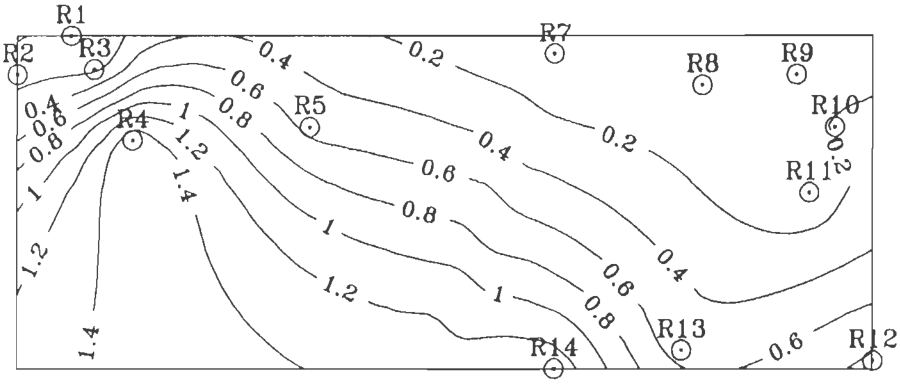


GROUNDWATER ISO-MANGANESE MAP ; PREMONSOON

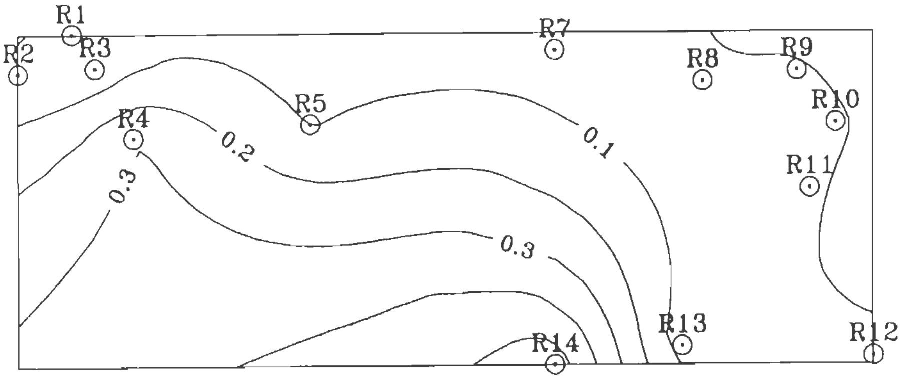
Annexure 4.6d



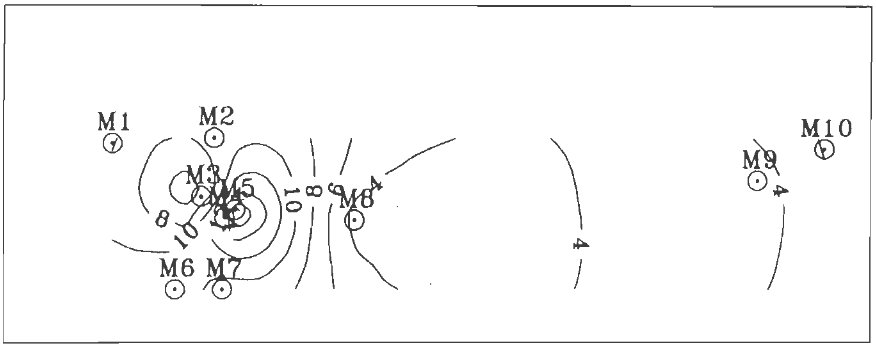
GROUNDWATER ISO-MANGANESE MAP ; POSTMONSOON



SURFACEWATER ISO-MANGANESE MAP ; PREMONSOON

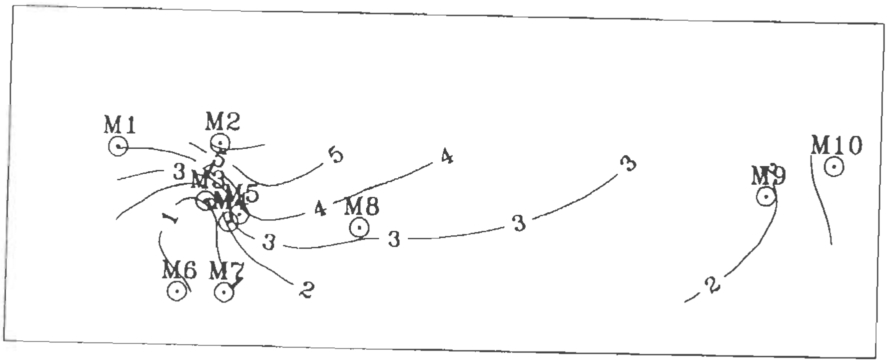


SURFACEWATER ISO-MANGANESE MAP ; POSTMONSOON

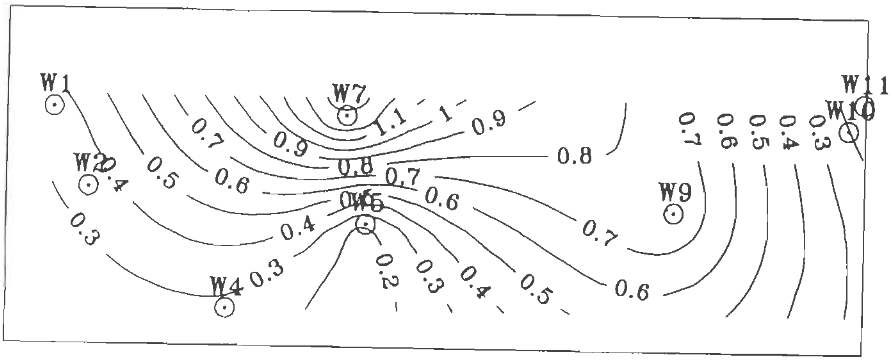


MINEWATER ISO-MANGANESE MAP ; PREMONSOON

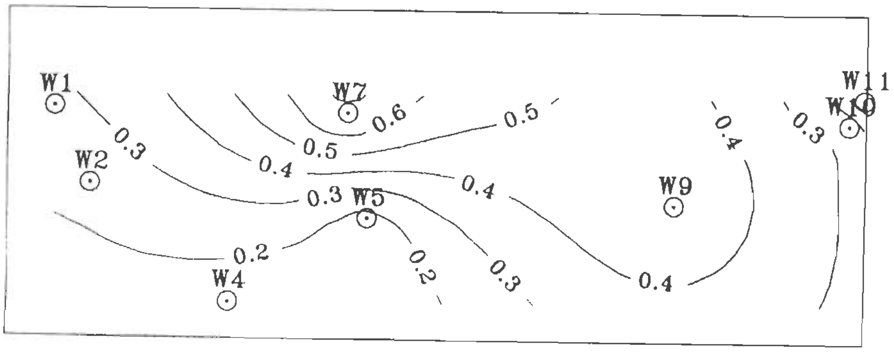
Annexure 4.6 e



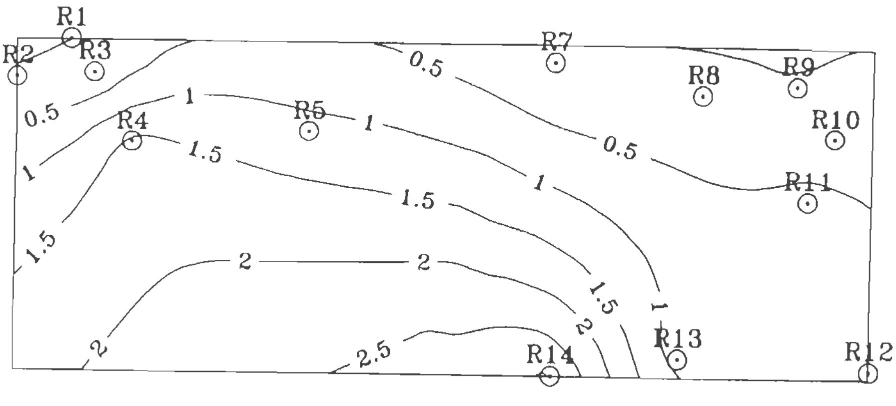
MINEWATER ISO-MANGANESE MAP ; POSTMONSOON



GROUNDWATER ISO-IRON MAP ; PREMONSOON

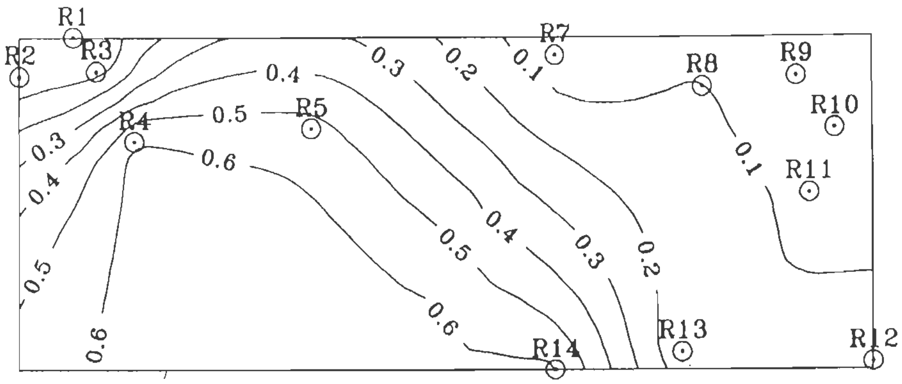


GROUNDWATER ISO-IRON MAP ; POSTMONSOON

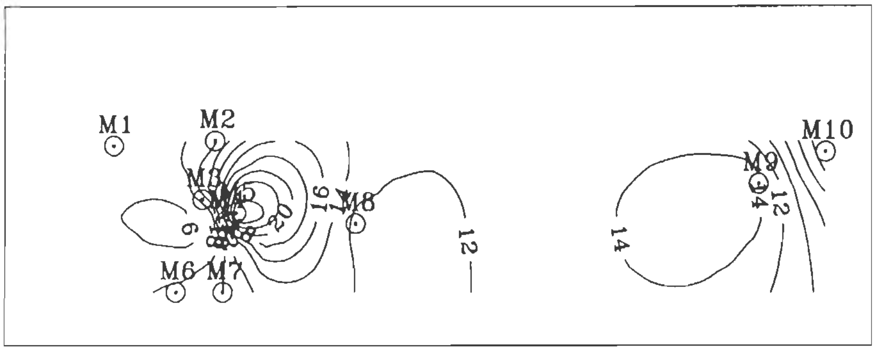


SURFACEWATER ISO-IRON MAP ; PREMONSOON

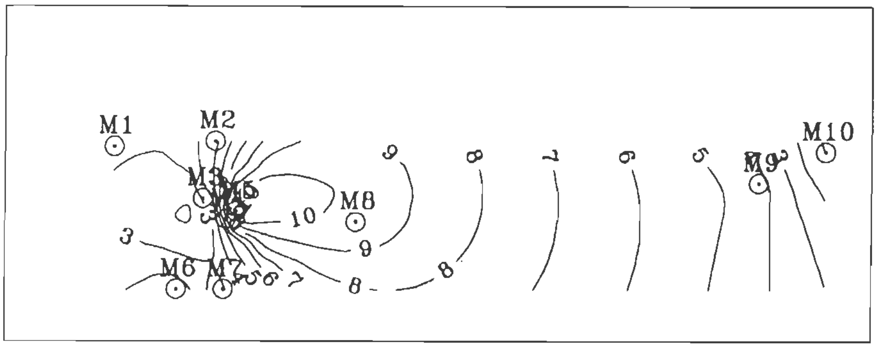
Annexure 4.6 f



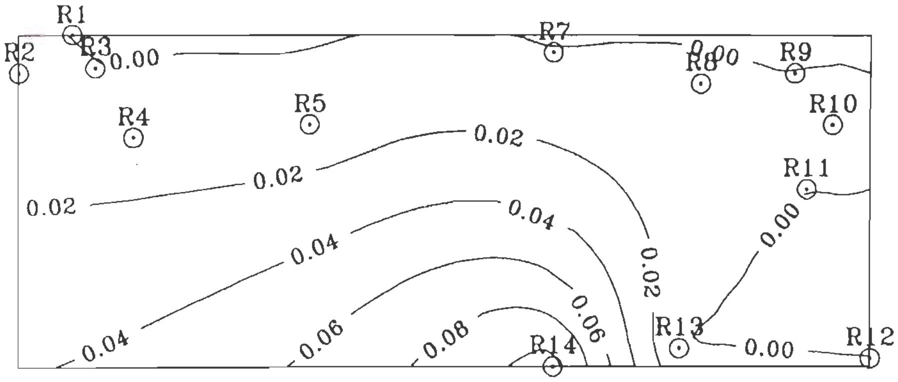
SURFACEWATER ISO-IRON MAP ; POSTMONSOON



MINEWATER ISO-IRON MAP ; PREMONSOON

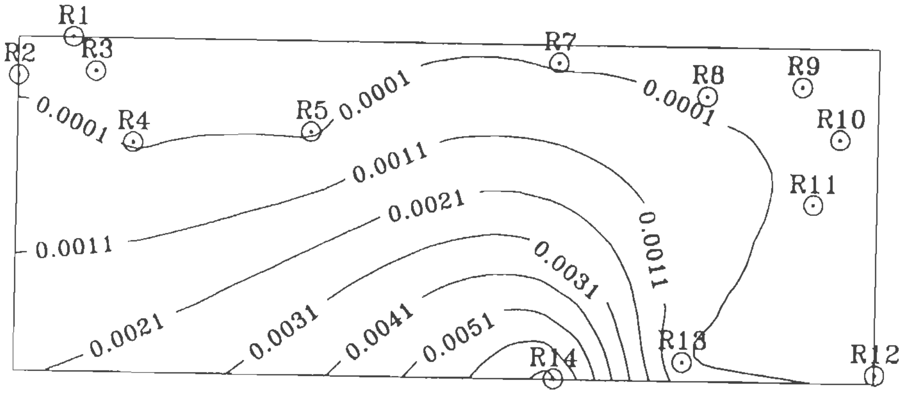


MINEWATER ISO-IRON MAP ; POSTMONSOON

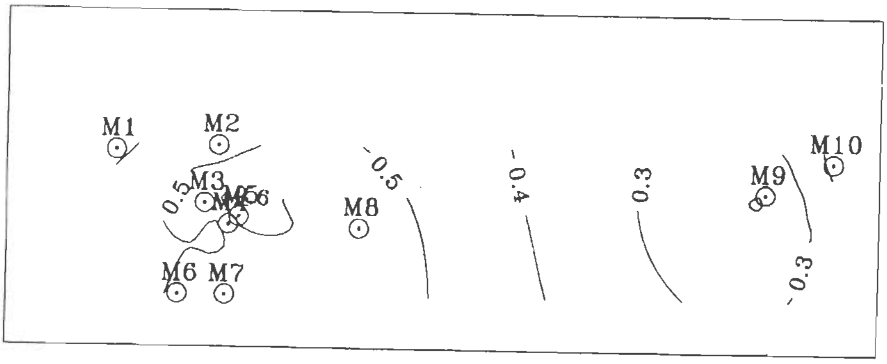


SURFACEWATER ISO-COBALT MAP ; PREMONSOON

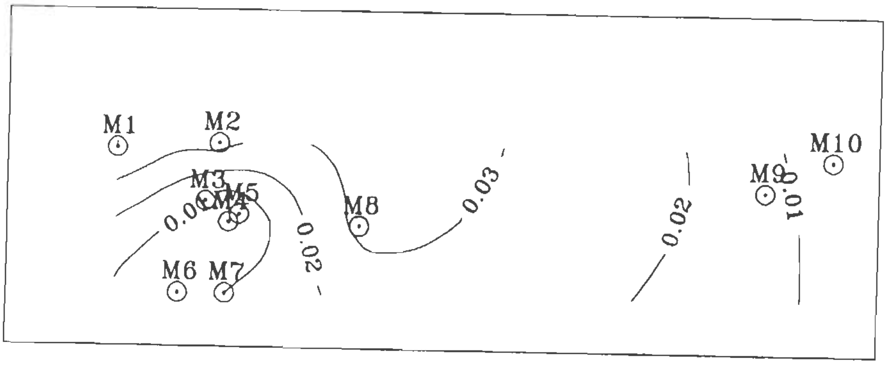
Annexure 4.6 g



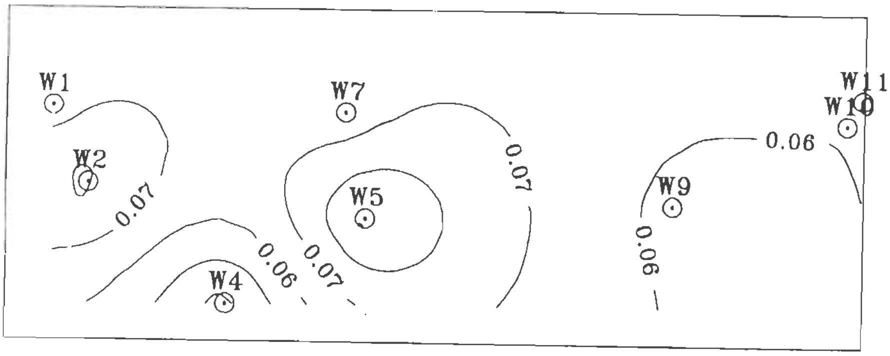
SURFACEWATER ISO-COBALT MAP ; POSTMONSOON



MINEWATER ISO-COBALT MAP ; PREMONSOON

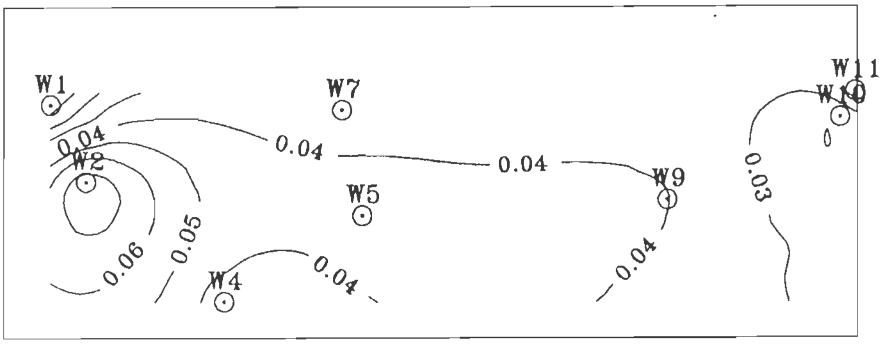


MINEWATER ISO-COBALT MAP ; POSTMONSOON

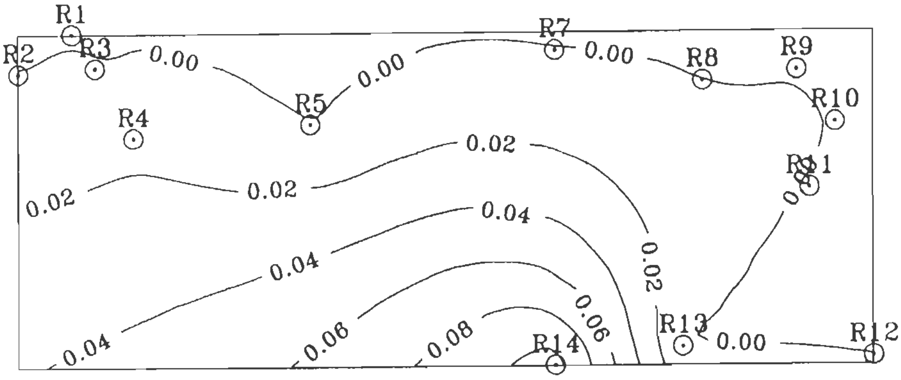


GROUNDWATER ISO-NICKEL MAP ; PREMONSOON

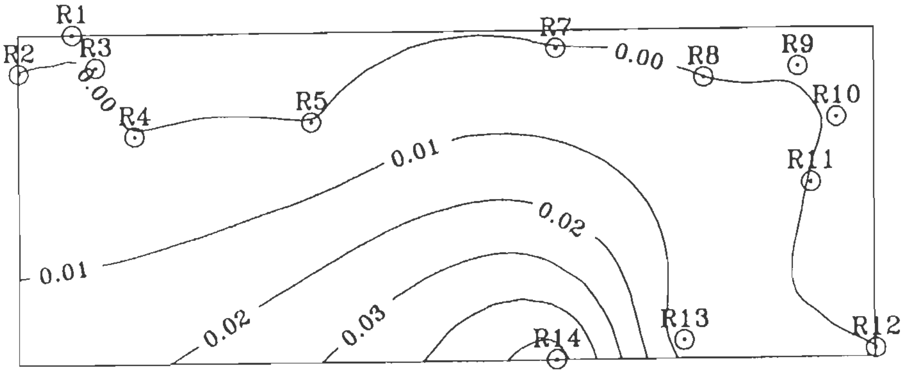
Annexure 4.6 h



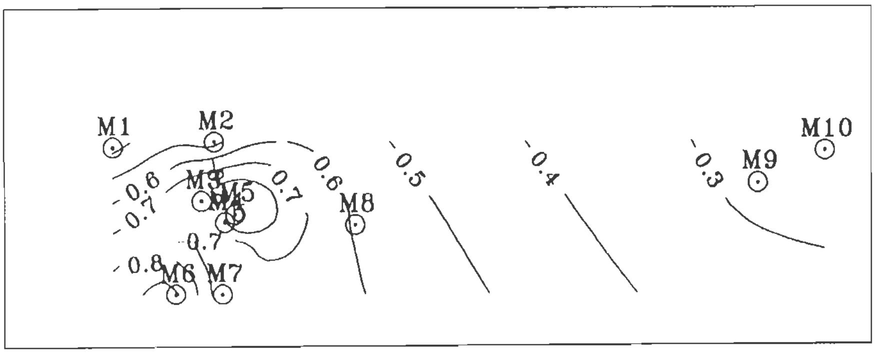
GROUNDWATER ISO-NICKEL MAP ; POSTMONSOON



SURFACEWATER ISO-NICKEL MAP ; PREMONSOON

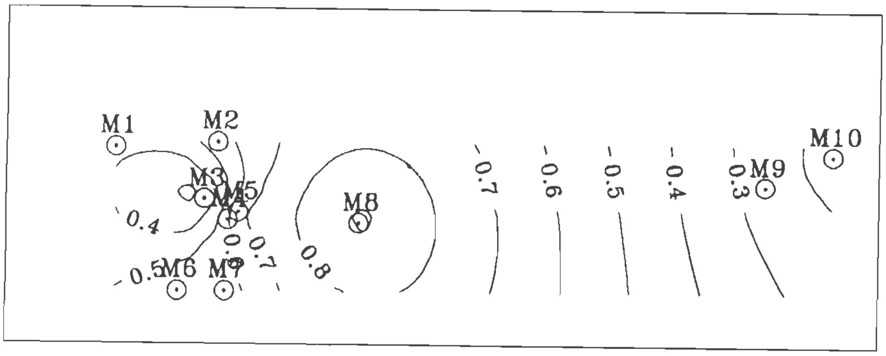


SURFACEWATER ISO-NICKEL MAP ; POSTMONSOON

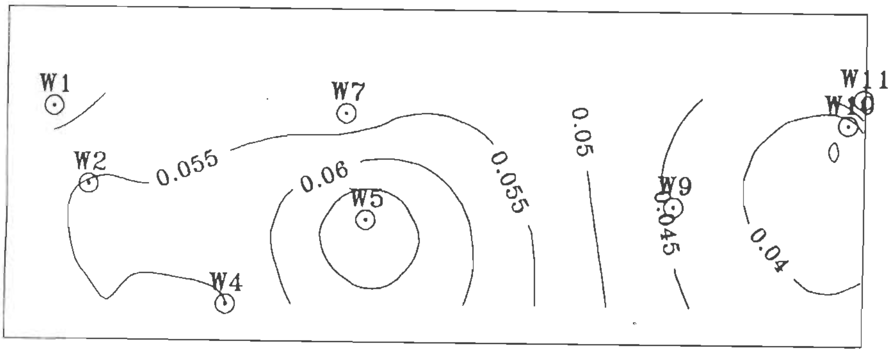


MINEWATER ISO-NICKEL MAP ; PREMONSOON

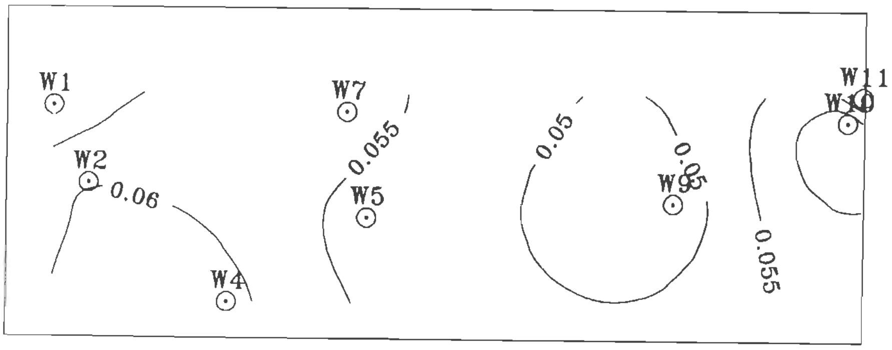
Annexure 4.6 i



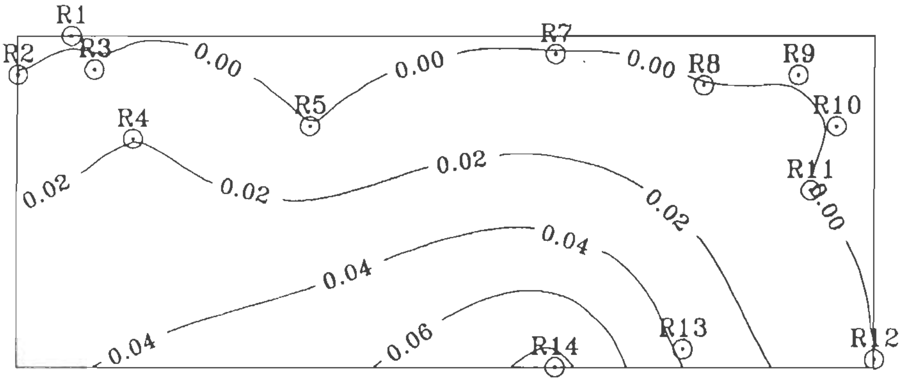
MINEWATER ISO-NICKEL MAP ; POSTMONSOON



GROUNDWATER ISO-COPPER MAP ; PREMONSOON

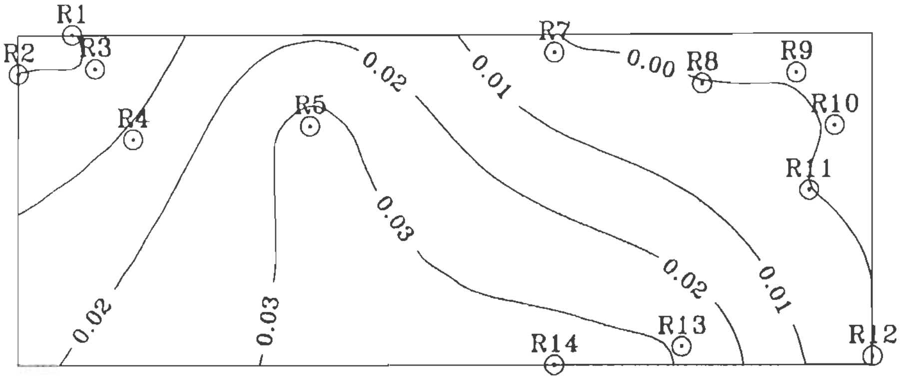


GROUNDWATER ISO-COPPER MAP ; POSTMONSOON

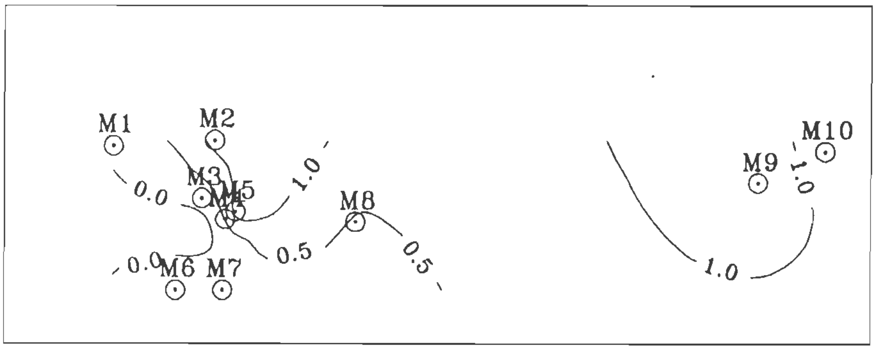


SURFACEWATER ISO-COPPER MAP ; PREMONSOON

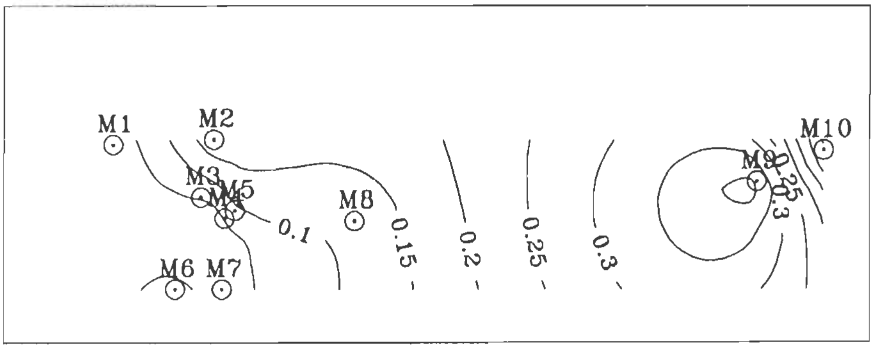
Annexure 4.6 j



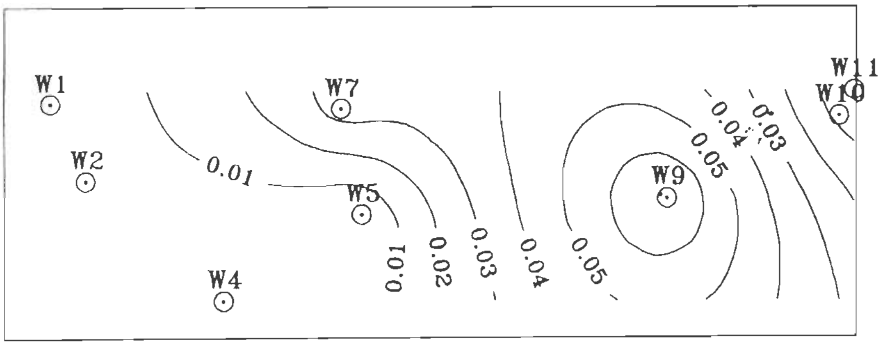
SURFACEWATER ISO-COPPER MAP ; POSTMONSOON



MINEWATER ISO-COPPER MAP ; PREMONSOON

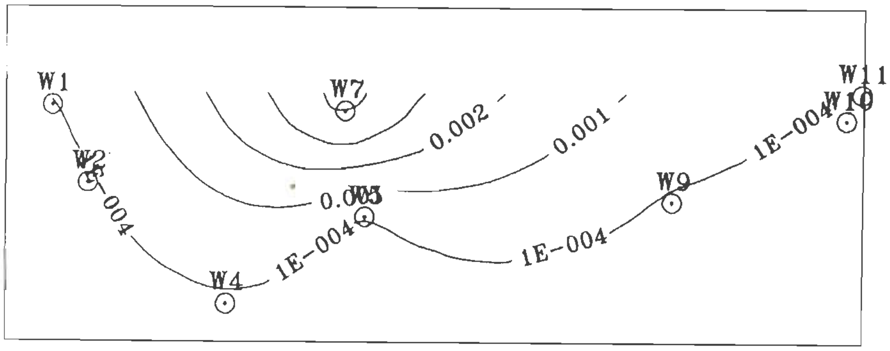


MINEWATER ISO-COPPER MAP ; POSTMONSOON

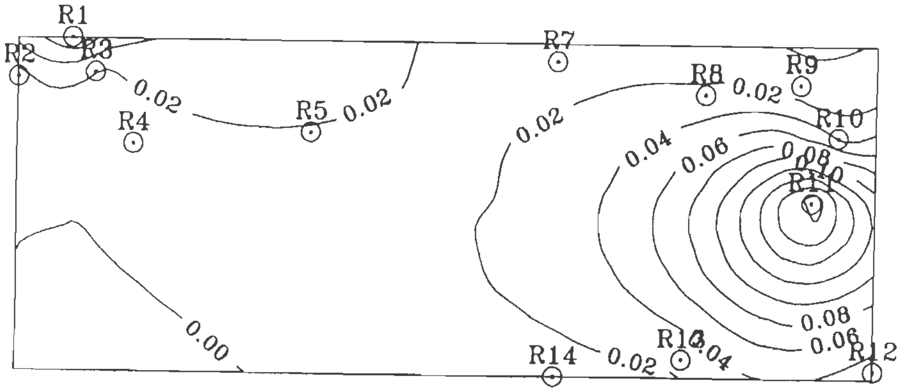


GROUNDWATER ISO-ZINC MAP ; PREMONSOON

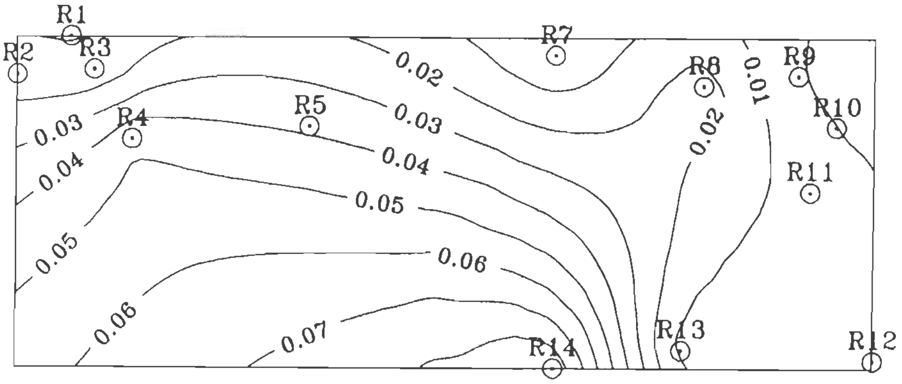
Annexure 4.6 k



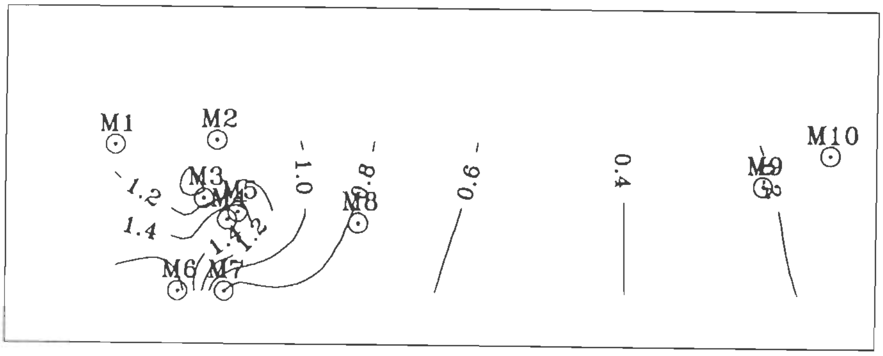
GROUNDWATER ISO-ZINC MAP ; POSTMONSOON



SURFACEWATER ISO-ZINC MAP ; PREMONSOON

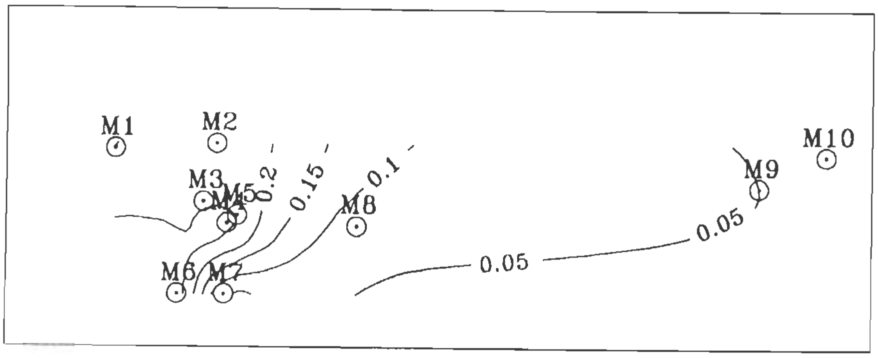


SURFACEWATER ISO-ZINC MAP ; POSTMONSOON

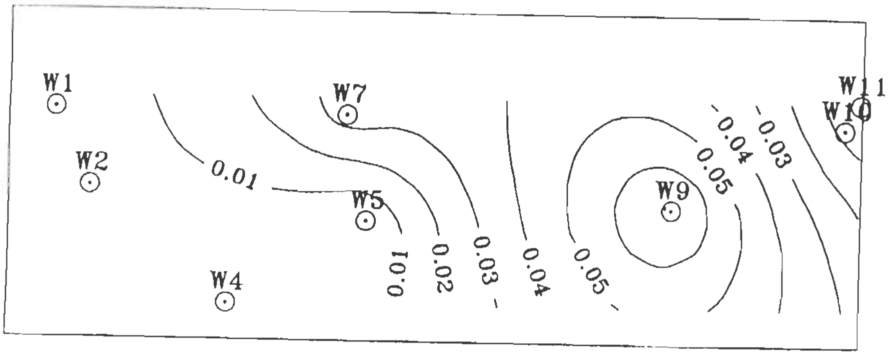


MINEWATER ISO-ZINC MAP ; PREMONSOON

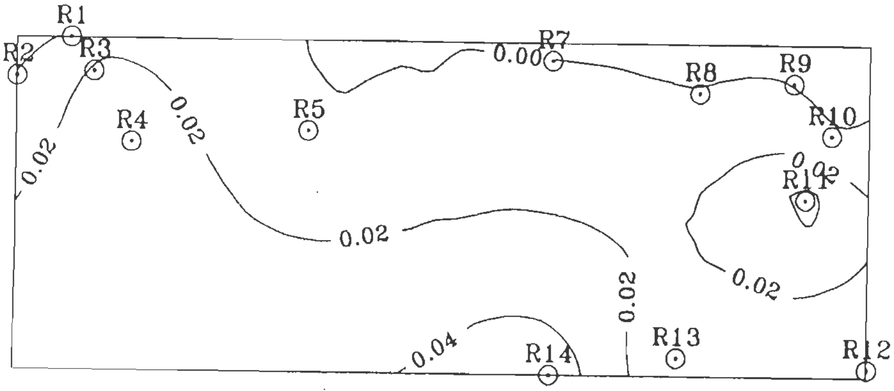
Annexure 4.6 1



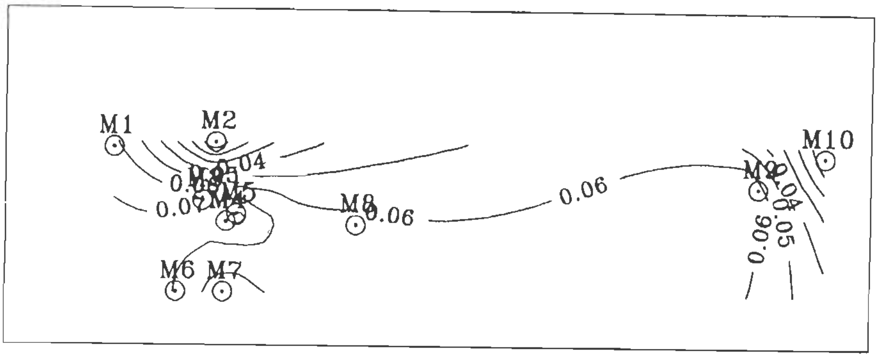
MINEWATER ISO-ZINC MAP ; POSTMONSOON



GROUNDWATER ISO-CADMIUM MAP ; PREMONSOON



SURFACEWATER ISO-CADMIUM MAP ; PREMONSOON



MINEWATER ISO-CADMIUM MAP ; PREMONSOON

REFERENCES

REFERENCES

Ahmed, F., (1960). The Gondwana Basin of Sedimentation in India. G.S.I. Rec. Vol.86, part 3, pp. 523-536.

Ahmed, M.U., (1973). Coal Mining and its Effects on Water Quality. Water for the Human Environment. Vol.1, Proc. of the First World Congress on Water Resources Chicago Illinois. USA. pp. 81-91.

Aldous, P.J. & Smart, P.L., (1988). Tracing Groundwater Movement in Abandoned Coal Mined Aquifers Using Fluorescent Dyes. Ground Water. Vol.26, No.2. pp. 172-178.

Andelman, J.B., (1973). Incidence, Variability and Controlling Factors for Trace Elements in Natural Fresh Waters. (ed.) Singer, P.C., Trace Metals and Metal Organic Interactions in Natural Waters.

Anderson, A.R., et al., (1993). pH, Aluminum & Calcium Concentrations of Streams Draining Acidic Soils of Calcareous Till at Kershope, Cumbria. Jour. of Hydrology. Vol. 149, pp. 27-37.

Anonymous, (1973-74). Geohydrological Report Chhindwara Distt., State Ground Water Survey, Madhya Pradesh.

Anonymous, (1988). Geohydrological Report : Reassessment of Ground Water Potential for the Year 1988. State Ground Water Survey, Chhindwara Distt., Madhya Pradesh.

Baliga, B.P., (1988). Environmental Problems of Coal Mining in India and their Management. All India Seminar on Environmental Problems of Mining and their Management organized by Environmental Planning and Coordination Organization (EPCO) Bhopal.

Balance, R.C. and Olson, B.H., (1980). Water Quality & Health. (ed.) Gower, A.M., Water Quality in Catchment Ecosystems. pp. 173-192.

Banerjee, I., (1978). Fluvial Model in Gondwana Sedimentation. Geological History of the Platform Areas of India. Quart. Jour. of Geol. Min. Met. Soc. India. Vol.5, No.1, pp. 37-49.

Barnes, H.C. & Romberger, S.B., (1968). The Chemical Aspect of Acid Mine Drainage. Jour. of Water Pollution Control Federation. Vol. 40, pp. 371-384.

Bell, H.L., (1971). Effect of Low pH on the Survival & Emergence of Aquatic Insects. Water Research. Vol.5, pp. 313-319.

Benoit, R.J., (1971). Self Purification of Natural Waters. (ed.) Ciaccio, Water & Water Pollution Handbook. pp. 223-258.

Bose, M.K., (1983). The Deccan Volcanic Province. Indian Jour. of Earth Sciences. Special Issue, pp. 45-53.

Campbell, P.G.C. & Stokes, P.M., (1985). Acidification & Toxicity of Metals to Aquatic Biota. Canadian Jour. of Fisheries & Aquatic Science. Vol. 42, pp. 2034-2049.

Canon, H.L. & Hopps, H.C., (1971). Environmental Geochemistry in Health & Disease. The Geological Society of America. Memoir - 123.

Cargo, D.N. & Mallory, B.F., (1974). Medical Geology. Man and His Envrionment. pp. 439-475.

Carrithers, R.B. & Bulow, F.J., (1973). An Ecological Survey of the West Fork of the Obey River, Tennessee with Emphasis on the Effect of Acid Mine Drainage. Jour. of the Tennessee Academy of Science. Vol. 48, pp. 65-72.

Casshyap, S.M. & Qidwai, H.A., (1971). Palaeocurrent Analysis of the Lower Gondwana Sedimentary Rocks, Pench Valley Coalfield, Madhya Pradesh, (India). Sed. Geol. Vol.5, pp. 135-145.

Casshyap, S.M. & Qidwai, H.A., (1974). Glacial Sedimentation of Late Palaeozoic Talchir Diamictite, Pench Valley Coalfield, Central India. Bull. Geol. Soc. America. Vol.85, pp. 749-760.

Chakravarti, D.K., (1981). Gondwana Stratigraphy : Review and Revision. Quart. Jour. Geol. Min. Met. Soc. Vol. 53, No. 3 & 4, pp. 125-153.

Chaubey, V.D., (1991). Hydrogeological & Environmental Impact of Coal Mining Jhariya Coal Field India, Environmental, Water Sciences. Vol. 17, No.3, pp. 185-194.

Chandra, T.K., (1977). Pench Kanhan Tawa Valley Coalfields (Satpura Gondwana Basin). Coal Resources of India. G.S.I. Mem. Vol. 88, pp. 299-306.

Chapman, B.M., Jones, D.R. & Jung, R.F., (1983). Processes Controlling Metal Ion in Acid Mine Drainage Streams, Geochemica et Cosmochemica Acta. Vol.47, No.11, pp. 1957-1974.

Chatterjee, P.K., (1960). Annotated Index of Indian Mineral Occurrences, Part I. G.S.I. Pub. pp. 116.

Clark, G.M. & Williams, R.S. Jr., (1991). Identification of Dissolved Constituent Sources in Mine Site Ground Water Using Batch Mixing. Water Resources Bulletin. Vol.27, No.1, pp. 93-100.

Christophersen, N. et al., (1990). Evidence for Long Term Deterioration of Stream Water Chemistry & Soil Acidification at the Birkenes Catchment, Southern Norway. Journal of Hydrology. Vol. 116, pp. 63-76.

Crookshank, H., (1936). Gondwanas of North Satpura. G.S.I. Mem. Vol. 66.

Davis, J.A., Fuller, C.C. et al., (1989). Sorption & Co-precipitation of Arsenate by Ferrihydride. (ed.) Miles, Water-Rock Interaction. pp. 187-189.

Davis, S.N., (1974). Changes of Porosity and Permeability of Basalt with Geologic Time. International Symposium on Hydrology of Volcanic Rocks, UNESCO, Lanzarote, Spain.

Davis, J.A. et al., (1989). Sorption and Coprecipitation of Arsenate by Ferrihydride. (ed.) Miles, D. L., Water Rock Interaction. pp. 187-189.

Dhage, S.S. et al., (1990). Characteristics & Treatment of Acid Mine Waste Water : A Case Study. Asian Environment. Vol. 12, No. 1, pp. 9-19.

Doyle, W.H., Jr., (1981). The U.S.G.S. Coal Hydrology Program and the Potential of Hydrologic Models for Impact Assessment. USGS Open File Report No. 81-542.

Drever, J.I., (1988). The Geochemistry of Natural Waters (Second Edition) Prentice Hall Inc. USA.

Edmunds, W.M., (1981). Hydrogeochemical Investigations. (ed.) Lloyd J.W., Case Studies in Groundwater Resources Evaluation. Clarendon Press. Oxford. pp. 87-112.

Erdelyi, M. & Galfi, J., (1988). Surface and Subsurface Mapping in Hydrogeology. John Wiley & Sons.

Everett, L.G., (1985). Groundwater Monitoring Handbook for Coal and Oil Shale Development. Developments in Water Sciences. No. 24.

Forstner, U. & Wittmann, G.T.W., (1983). Metal Pollution in Aquatic Environment. pp. 258-259.

Fox, C.S., (1931). Natural History of Indian Coal. G.S.I. Mem. Vol. 57.

Ferrier, R.C. et al., (1992). Experimental Stream Acidification - the Influence of Sediments and Stream Bed Vegetation. Jour. of Hydrology. Vol.140, pp. 361-370.

Fox, C.S., (1931). The Gondwana System and Related Formations. G.S.I. Mem. Vol. 57.

Fox.,C.S., (1932). The Gondwana System and Related Formations. G.S.I. Mem. Vol. 58.

Fox, C.S., (1934). The Lower Gondwana Coalfield of India. G.S.I. Mem. Vol. 59.

Fraser, P., (1984). Epidemiology and Water Quality. Environmental Protection : Standards, Compliance and Costs. (ed.) Lack, T.J., pp 88.

Freedman , J., (1975). Trace Element Geochemistry in Health and Disease. The Geological Society of America. Special Paper No. 155.

Fuge, R., (1987). Iodine in The Environment : Its Distribution and Relationship to Human Health. In : Trace Substances in Environmental Health. XXI. (ed.) Hemphill D.D., Univ. of Missouri, Rolla, USA.

Ganju, P.N., (1955). Petrology of Indian Coals , G.S.I. Mem. Vol. 83, pp. 18-49.

Gassama, N. et al., (1993). Behaviour of Nickel and Cobalt in Natural Waters of Granitic Areas : A First Approach. Chemical Geology. Vol. 107, pp. 417-421.

Ginzburg , I.I., (1960). Principles of Geochemical Prospecting.

Gottschlich, D.E., Bell, P.R.F. & Greenfield, P.F., (1986). Estimating the Rate of Generation of Acid Drainage Products in Coal Storage Heaps. Environmental Technology Letters. Vol. 7, pp. 1-12.

Groenewold, et al., (1980). Potential Hydrogeochemical Impacts of Surface Mining in the Northern Great Plains. Symposium, on the Surface Mining Hydrology, Sedimentology and Reclaimation. University of Kentucky.

Ground Water Handbook, (1987). U.S. Environmental Protection Agency.

G.S.I. Misc. Pub., (1975). No. 30., pp. 32.

G.S.I. Rec., (1942). Vol. 79, Part 1, pp. 356.

G.S.I. Rec., (1946). Vol. 79, Part 2, pp. 839.

G.S.I. Rec., (1958). Vol. 88, Part 2.

G.S.I. Rec., (1975). Vol. 105, Part 1., pp. 391-392.

G.S.I. Rec., (1983). Vol. III, Part 1.

Gupta, S.K. et al., (1986). Status of Research on : Environmental Pollution in Mines , Mining Areas & Miners Health. CMRS Findings. Central Mining Research Station,. Dhanbad, India. pp. 31-32.

Handa, B.K., (1985). Water Quality in Fractured Rocks in Some Parts of India. Proceedings on International Workshop Rural Hydrogeology and Hydraulics in Fissured Basement Zone. Deptt. of Earth Sciences, University of Roorkee. pp. 147.

Hem, J.D., (1972). Chemical Factors that Influence the Availability of Iron and Manganese in Aqueous Systems. The Geological Society of America. Special Paper 140, pp.23.

Hem, J.D., (1972). Chemistry and Occurrence of Cadmium and Zinc in Surface Water and Ground Water. Water Resources Research. Vol. 8, pp. 661-679.

Hem, J.D., (1985). Study and Interpretation of the Chemical Characteristics of Natural Waters. USGS Water Supply Paper 2254.

Henriksen, A. & Kirkhusmo, L.A., (1982). Acidification of Groundwater in Norway. Nordic Hydrology. Vol. 13, pp 183-192.

Henton, M.P., (1981). The Problem of Water Table Rebound After Mining Activity and its Effects on Ground & Surface Water Quality. Quality of Ground Water. Proc. of International Symposium, Noordwijkerhout, Netherlands.

Hislop, S., (1964). Quart. Jour. Geol. Soc. London. Vol.20.

Holland, T.H., (1926). Indian Geological Terminology. G.S.I. Mem. VOl. 51., pp. 1-184.

Hopps, H.C., (1973). Display of Data on Map Forms, Problems of Compatibility. Geochemistry and the Environment. Vol. II, NAS. pp. 139-144.

Hutchinson, G.E., (1957). A Treatise of Limnology. Vol. I, Wiley, New York.

Hutchinson, T.C., (1974). Heavy Metal Toxicity and Synergism to Floating Aquatics. XIX Congress Intern. Assoc. Limnol., Winnipeg, Canada. Abstr. pp. 91.

I.M.D. (Indian Meteorological Deptt.), (1965). Monthly and Annual Rainfall and Number of Rainy Days. (1901-1950). Part III-B, pp. 881-882.

Indian Coals, (1979). Central Fuel Research Institute India.

Jenne, E.A., (1968). Advances in Chemistry. Series No. 73, Trace Inorganics in Water. Amer. Chem. Soc., Washington D.C. pp. 337.

John De Zuane, P.E., (1990). Handbook of Drinking Water Quality (Standards & Controls). Van Nostarnd Reinhold Pub. New York.

Johnkwong, Y.T. et al., (1989). Copper-Arsenic Mobilization and Attenuation in an Acid Mine Drainage Environment. (ed.) Miles, D. L., Water Rock Interaction. pp. 397-399.

Karanth, K.R., (1989). Hydrogeology. Tata McGraw Hill.

Karathanasis, A.D. et al., (1990). Temporal Solubility Trends of Aluminum and Iron Leached from "Coal Spoils" and Contaminated Soil Materials. Jour. Environmental Quality. Vol. 19, No.3, pp. 389-395.

Kelly, M.G., (1986). Heavy Metals and aquatic Bryophytes : Accumulation and Their Use as Monitors. Ph.D. Thesis University of Durham, England. pp. 304.

Kelly, M., (1988). Mining and the Fresh Water Environment. Elsevier Applied Science.

Kinnisburgh, D.G. & Edmunds, W.M., (1986). Maps of Susceptibility of U.K. Surface and Ground Waters to Acid Deposition in Acidity in U.K. Fresh Waters. Interim Report U.K. Acid Waters Review Group, HMSO, London. pp. 46.

Klein, L., (1962). River Pollution. Vol. II, Causes & Effects, Buttersworths London. pp. 456.

Kobayashi, J., (1969). Investigation of the Cause of the Itai-Itai Disease, 1-3, Biogoechomistry of Cadmium [in Japanese] : Nippon Kagku Zasshi. Vol. 39, pp. 286, 369, 424.

Koryark, M. et al., (1972). Riffle Zoobenthos in Streams Receiving Acid Mine Drainage. Water Research. Vol 6, pp. 1239-47.

Krishnan, M.S., (1982). Geology of India and Burma. C.B.S. Pub. & Distb.

Langan, S.J., & Wilson, M.J., (1992). Predicting the Regional Occurrence of Acid Surface Waters in Scotland Using an approach Based on Geology, Soils and Landuse. Jour of Hydrology. Vol. 138, pp. 515-528.

Lind, C.J., Hem J.D. & Robertson C.F., (1987). Reaction Products of Manganese Bearing Waters. (ed.) Averedt, R.C. & McKnight D.M., Chemical Quality of Waters and the Hydrologic Cycle. Lewis Pub. Inc. Michigan USA. pp. 270-301.

Lloyd J.W. & Heathcote J.A., (1985). Natural Inorganic Hydrochemistry in Relation to Groundwater - An Introduction.

Loeffelman, P.H. et al., (1984). A New Approach for Regulating Iron in Water Quality Standards. (ed.) Bahner, R.C. & Hansem, D.J., Aquatic Toxicology and Hazard Assessment. Eighth Symposium (1985), pp. 137-152.

Lovell, H.L., (1983). Coal Mine Drainage in the United State - An Over View. (ed.) Odendaal, P.E., Mine Water Pollution Proceedings - International Assoc. of Water Pollution Research. Water Science and Technology, South Africa. Vol. 15, No. 2 pp. 1-25.

Mahajan, G., (1989). Evaluation and Development of Ground Water. Ashish Pub. House, New Delhi.

Marier, J.R. et al., (1979). Water Hardness, Human Health, and The Importance of Magnesium. Ottawa, Canada, National Research Council (NRC).

Matisoff, G. et al., (1981). The Nature & Source of Arsenic in North Eastern Ohio Groundwater. Groundwater. Vol.20, No.4, pp. 446-456.

Matrone, G. et al., (1977). Manganese. Geochemistry & the Envrionment. Vol. 2, Part 1, NAS. pp. 29-39.

McFarren, E.F. et al., (1977). Water Quality Deterioration in the Distribution System. Kansas City, Missouri, Water Quality Technology Conference.

Medlicott, H.B., (1873). Notes on Satpura Coal Basin. G.S.I. Mem. Vol. 10., pp. 133-138.

Montgomery, H.A. & Hart, I.C., (1974). The Design of Water Sampling Programme for River Effluents. Water Pollution Control (London). Vol. 73, pp. 3-27.

Moore, E.W., (1952). Physiological Effects of The Consumption of Saline Drinking Water. NRC, Div. of Med. Sci., Bull. San. Engr., and Environment. Appendix E.

Moran, S.R. et al., (1978). Geologic, Hydrologic and Geochemical Concepts and Techniques in Overburden Characterisation for mined land Reclamation, Report of Investigation. No.63, North Dakota Geol. Survey.

Morgan, J.J. & Stumm, W., (1965). Proc. Intern. Conf. Water Pollution Research. 2nd, Tokyo. (1964). Pergamon, New York. pp. 103-31.

Morrison, G.H. et al., (1972). Analytical Methods. Geochemistry and the Environment. NAS. Vol. 1, pp. 80.

Morrison, G.H. et al., (1972). Sampling, Sample Preparation and Storage for Analysis, Geochemistry and the Environment. NAS. Vol. 1, pp. 90.

Mortimer, C.H., (1941). Journal of Ecology. Vol. 26, pp. 280.

Mothghare, L.M., (1979-80). Report on the Systematic Hydrological Studies in Parts of Wainganga Basin Chhindwara Distt. Madhya Pradesh. Central Ground Water Board India.

Moynahan, E.J., (1979). Trace Elements in Man. Environmental Geochemistry and Health, (A Royal Society discussion). (ed.) Bowie & Webb. pp. 65-79.

NAS, NAE, (1974). Water Quality Criteria, 1972. U.S. Govt. Printing Office, Washington, D.C.

Neal, C. et al., (1990). Limitations to the Understanding of Ion-Exchange and Solubility Controls for Acidic Welsh, Scottish and Norwegian Sites. Jour. of Hydrology. Vol. 116, pp. 11-23.

Neri, L.C. et al., (1974). Health Aspects of Hard and Soft Waters. Paper Presented at 94th Annual Conf. of the American Water Works Assoc. Boston, Mass., USA.

Nielsen, F.H. et al., (1977). Nickel. Geochemistry & the Envrionment. Vol. 2, Part 1, NAS. pp. 40-53.

Nockolds, S.R. & Allen, R., (1971). Trace Elements in Some Deccan Traps. (ed.). Murthy, T.V.V.G.R.K., Studies in Earth Sciences - West Commemorative Volume. Saugar. pp. 265-266.

NRC, (1977). Drinking Water and Health. Washington D.C., National Acad. of Sciences.

O'connor, J.T., (1971). Iron and Manganese. Water Quality and Treatment - A Handbook of Public Water Supplies - Prepared by the American Water Works Assoc. Inc.

Olyphant, G.A., et al., (1991). Seasonal and Weather Related Solute Controls on Solute Concentrations and Acid Drainage from Pyrite Coal Refuse Deposit in South Western Indiana (USA). Jour. of Contemporary Hydrology. Vol. 7, No. 3, pp. 219-236.

Palit, A. et al., (1991). Characterization and Utilization of Coal Ash in the Context of Indian Super Thermal Power Stations. Proceeding of International Conference. (ed.) Sahu, K.C., "Environmental Impact of Coal Utilization". pp. 153-164.

Palmer, C.D. & Cherry, J.A., (1979). Hydrogeochemical Concepts Applied to Mined Land in the Fort Union Coal Region, in Proceedings 4th Annual Meeting, Canadian Land Reclamation Assoc., Regina, Saskatchewan.

Pankaj Gupta, Thomas, M. & Venkateswaran, B., (1986). A Report on Exploration Training Programme at Parasia M.P. Deptt. of Earth Sciences, U.O.R., (unpublished).

Parsons, J.D., (1977). Effects of Acid Mine Wastes on Aquatic Ecosystems. Water, Air & Soil Pollution. Vol. 7, pp. 333-54.

Pascoe, E.H., (1949). A Manual of the Geology of India and Burma. 3rd Edn. Vol. 2.

Perelman, A.I., (1977). Geochemistry of Elements in the Supergene Zone.

Pathak, B.D., (1985). Hydrological Surveys and Ground Water Resource Evaluation in the Hard Rock Areas of India. Proceedings of International Workshop on Rural Hydrogeology and Hydraulics in Fissured Basement Zone. Deptt. of Earth Sciences, University of Roorkee.

Qidwai, H.A. & Casshyap, S.M., (1975). Sedimentation Patterns of the Fluviatile Barakar and Motur Rocks (Lower Gondwana), Pench Valley Coalfield, Madhya Pradesh. Symposium on Sediments Sedimentation and Sedimentary Environments, Delhi University. pp. 200-222.

Qidwai, H.A. & Casshyap, S.M., (1978). Grainsize Characteristics of Ancient Fluvial Deposits - An Example from Lower Gondwana (Permian) Formations, Pench Valley Coalfield, Central India. Jour. Geol. Soc. of India. Vol. 19, No.6, pp. 240-250.

Rae, G., (1978). Mine Drainage from Coal Fields in England and Wales : A Summary of its Distribution and Relationship to Water Resources. United Kingdom, Reading, Central Water Planning Unit. Technical Note. No. 24, pp. 21.

Rai, L.C. & Kumar, A., (1980). Effect of Certain Environmental Factors on the Toxicity of Zinc to Chollera Vulgaris. Microbios Letter. Vol. 13, pp. 79-84.

Raja Rao, C.S., (1983). Coal Resources of Madhya Pradesh and J & K. : Coal Fields of India. G.S.I. Bulletin. Series A. Vol. III, No. 45, pp. 155-178.

Rana, S.V.S. & Ram Prakash, (1987). Manganese in the Environment, Health and Disease : A Review. Science, Development and Environment. (ed.) Agarwal, V.P. and Rana S.V.S., Society of Bio-Sciences, Muzaffarnagar, India. pp. 203-214.

Rasmussen, L. & Sand Jensen, K., (1979). Heavy Metals in Acid Streams from Lignite Mining Areas. Science of the Total Environment. Vol. 12, pp. 61-74.

Ravindra Kumar, (1985). Fundamentals of Historical Geology and Stratigraphy of India. Wiley Eastern Ltd.

Reuss, J.O. & Johnson, J.W., (1986). Acid Deposition and the Acidification of Soils and Waters. Ecology Studies 59, Springer Verlag, New York. pp. 119.

Richards, D.B., (1987). Groundwater Deformation Manual : Coal Mine Permit Application, Vol. I,II US. Deptt. of the Interior and USGS.

Roback, S.S. & Richardson, J.W., (1969). The Effect of Acid Mine Drainage on Aquatic Insects. Proceeding of the Academy of Natural sciences of Philadelphia. Vol. 121, pp. 81-107.

Robinson, P.L., (1967). The Indian Gondwana Formations : A Review. Proc. First Symposium on Gondwana Stratigraphy. I.U.G.S. pp. 201-268.

Romani, S., (1981). A New Diagram for Classification of Natural Waters and Interpretation of Chemical Analysis Data. Quality of Ground Water. Proc. of International Symposium, Noordwijkerhout, Netherlands. pp. 743-748.

Rude, P.D. & Aller, R.C., (1993). The Influence of Mg^{2+} *on Adsorption of* F^- *by Hydrous Oxides in Sea Water. American Jour. of Science. Vol. 293, No. 1.*

Samuel, C. & Sahu, K.C., (1990). Chemical Weathering of Basalts and its Control on Heavy Metal Contamination in Soils Around Bombay. Indian Jour. of Earth Sciences. Vol. 17, No. 3-4, pp. 163-171.

Scalf, M.R. et al., (1987). Manual of Ground Water Sampling Procedures. Scientific Publishers. Jodhpur, India.

Schoeller, H., (1962). Les Eaux Soterraines. Paris, Masson. pp. 624.

Schubert, J.P. & Prodan, P.F., (1981). Groundwater Pollution Resulting from Disposal of Pyritic Coal Wastes. pp. 319-327.

Shaper, A.G. et al., (1983). Softness of Drinking Water and Cardiovascular Disease - Practical Implications of Recent Research. Health Trends. Vol.15, pp. 22-24.

Sharma, N.C. & Ram, K.S.V., (1966). Introduction of the Geology of Coal and Indian Coalfields. Oriental Publishers.

Shehata, F.H.A. & Whitton, B.A., (1982). Zinc Tolerance in Strains of the Blue Green Algae Anacystis Nidulans. British Phycological Jour. Vol. 17, pp. 5-12.

Singer, P.C. & Stumm, W., (1970). Acidic Mine Drainage : The Rate Determining Step. Science 167. pp. 1121-1123.

Singhal, B.B.S., (1985). Aquifer Parameters of Basaltic Rocks. Proceedings on International Workshop on Rural Hydrogeology and Hydraulics in Fissured Basement Zone. Deptt. of Earth Sciences, University of Rookie, pp. 21.

Standard Methods for the Examination of Water and Waste Water, (1985-89). APHA, AWWA, WEF, American Public Health Association.

Stokes, P.M., (1983). Responses of Fresh Water Algae to Metals. (ed.) Round ,F.E. & Chapman D .J., Progress in Phycological Research. Vol. 2, Elsevier, Amsterdam. pp. 87-112.

Stone, W.J., (1990). Impact of Mining on Groundwater Recharge, Navajo Coal Mine New Mexico. Mining Engineering. Vol. 42, No. 1, pp. 1267-1271.

Strain, W.H., et al., (1975). Therapies for Environmental Elemental Deficiencies and Toxic Excesses. (ed.) Jacob Freedman, The Geological Soc. of America. Special Paper 155. pp. 83.

Stumm, W. & Morgan, J.J., (1970). Aquatic Chemistry : An Introduction Emphasizing Chemical Equilibria in Natural Water. pp. 540-555.

Swaine, D.J., (1975). Trace Elements in Coals. (ed.) Tugarinov A.I., Recent Contributions to Geochemistry and Analytical Chemistry. pp. 539-550.

Tanaka, O. et al., (1982). pH Dependence of the Copper. Effect on Flowering, Growth and Chlorophyll Content in Lemna Pancicostata 6746. Plant and Cell Physiology. Vol. 23, pp. 1479-82.

Theis, T.L. & Singer, P.C., (1973). The Stabilization of Ferrous Iron by Organic Compounds in Natural Waters. (ed.) Singer, P.C., Ann Arbor Science Publishers Inc. Michigan U.S.A.

Tourtelot, H.A., (1978). Geochemical Surveys in United States in Relation to Health. Environmental Geochemistry and Health, (A Royal Society discussion). pp. 113-125.

Train, E., (1979). Quality Criteria for Water. Castle House Publications Ltd.

Uhl, V.W.,Jr., (1979). Occurrence of Groundwater in the Satpura Hills Region. Jour. of Hydrology. Vol. 41, pp. 123-141.

Vanloon, J.C. & Barefoot, R.R., (1989). Analytical Methods for Chemical Exploration. Academic Press Inc. London.

Vuceta, J. & Morgan, J.J., (1978). Chemical Modeling of Trace Metals in Freshwaters : Role of Complexation and Adsorption. Environmental Science & Technology. Vol. 12, pp. 1302-9.

Wacker, W.E.C. et al., (1977). Magnesium. Geochemistry & the Envrionment. Vol. 2, Part 1, NAS. pp. 11-28.

Wadia, D.N., (1975). Geology of India. Tata Mc-Graw Hill Pub. Comp. Ltd.

Warner, R.W., (1971). Distribution of Biota in a Stream Polluted by Acid Mine Drainage. Ohio Jour. of Sciences. Vol. 71, pp. 202-15.

Webb, J.S. & Howarth, R.J., (1978). Regional Geochemical Mapping Environmental Geochemistry and Health. (A Royal Society Discussion). pp. 84.

Wedepohl, K.H., (ed.), (1969). Handbook of Geochemistry. Vol. 2.

Weissberg, I., (1991). Characterization of Hydrological and Hydrochemical Cycles As a Tool for Evaluation of Environmental Impact of Mining in Serra Dos Carajas, Amazonia Brazil. Water Science and Technology. Vol. 24, No. 11, pp. 117-126.

W.H.O., (1979). Sodium, Chlorides and Conductivity in Drinking Water. Report of Working Group. W.H.O. Copenhegen.

W.H.O., (1984). Guide Lines for Drinking Water Quality. Vol. I-II.

Wicks, C.M. & Groves, C.G., (1993). Acidic Mine Drainage in Carbonate Terrains : Geochemical Processes and Rates of Calcite Dissolution. Jour. of Hydrology. Vol. 146, pp. 13-27.

Wiese, R.G.,Jr., Muir, I.J. & Fyfe, W.S., (1990). Trace Element Siting in Iron Sulfides from Coal, Determined by Secondary Ion Mass Spectrometry. Energy Resources. Vol. 12, No.3, pp. 251-64.

Zaihualiu, et al., (1991). Effect of Coal Mine Waters of Variable pH on Spring Water Quality : A Case Study. Environmental Geol. Water Sciences. Vol. 17, No. 3, pp. 219-225.

Zemansky, G.M., (1974). Removal of Trace Metals During Conventional Water Treatment. Jour. AWWA. Vol. 5, No. 66, pp. 600-609.

CLARIFICATIONS OF THE POINTS

1. Was any attempt made to determine the mineralogy of rocks and soils in the study area ? Otherwise, can a summary be prepared form literature survey ?

   No attempt, as such, was made to determine the mineralogy of rocks and soils because the present "Hydrochemical Study" was aimed to look for the concentrations of various elements in the aqueous phase which forms an important channel for the supply of micro-nutrients to the living beings. No additional information, however, on the detailed mineralogical composition of rocks and soils could be traced apart from the one mentioned in the extensive work compiled by Raja Rao C.S. (1983) and incorporated in the thesis on pages-14 & 15. A broad mineralogical composition compiled from the aforementioned work is as follows:

Precambrian Basement Rocks :-

Orthoclase, Alkali Plagioclase, Quartz, Amphiboles (Hornblende), Micas (Biotite).

Upper carboniferous Talchir (tillite) Rocks :

Quartz, Jasper, Amphiboles (Hornblende), Micas (Biotite), Chlorites.

Lower Permian Barakar Rocks :

Pyrite, Pyrrhotite, Marcasite, Quartz.

Middle Permian Motor Rocks :

Mineralogy, Feldspars, Quartz, Clay minerals, (Probably-Kaolinite).

Upper Jurassic to lower cretaceous Jabalpur Rocks :

Quartz, Clays (?).

Upper cretaceous Deccan Trap Rocks :

Olivines, Pyroxenes (Augite).

2. Give details of the role of coal dust in causing acidity in well W-6 (p.41).

   The coal dust from the coal loading site was brought to study the effect of leaching in the laboratory. This coal dust was found to add acidity to the leachate while conducting leaching experiments. The possible reason to this effect can be attributed to the presence of sulfide minerals normally found associated with coals as accessory minerals. The detailed mechanism is given on page no. 27 in the thesis.

3. Explain Ionic Sum Line (p.51).

The Ionic Sum Line can be defined as the line joining the Origin with the point obtained by plotting the Total Ionic Concentration of waters.

4. What are the F$^-$containing minerals in deeper mines (p.62).

Paucity of the mineralogical data prevented us to exactly pin point the minerals containing fluorine in the deeper mines. However, the occurrence of fluoride ion can be ascribed to one of the following known reasons : (after Perelman, A.I., 1977).

1. Upto 1% F$^-$ (in ash) is found in Coals & in Bitumen.
2. Acidic waters in the zone of oxidation of Chalcopyrite and Mercury mineralization contain upto 4-6 ppm of fluorine.
3. About 5 ppm of fluorine is contained in fresh water lakes in granite massifs.
4. Fluorine forms 86 minerals, which shows its great capacity for mineral formation.
5. Fluorine accumulates in acid igneous rocks.
6. Acid environments promote leaching of fluorine from soils.
7. Minerals, which contains fluorine in acid environments are relatively easily weathered.
8. Fluorite & Hornblende weather rapidly.

5. If mineralogical data (particularly clay minerals) are eventually available, can the results of soil leaching (Chapter 5) be better interpreted in terms of specific adsorption/desorption reactions ?

It would be more interesting to find out actual soil chemical properties in terms of geochemical reactions to pint point water-soil interaction mechanism which controls elemental concentrations in aqueous phase. The results of soil leaching can, thus, be better explained provided, the mineralogical data with exact chemical composition and ion exchange properties for different elements is made available, with properly defined adsorption/desorption mechanism.

In fact the study was initially planned to incorporate similar studies as suggested by Prof. Raymahashay in one of his papers entitled "*Geochemical Parameters of Aquatic Environment (1987)*. Later, the enormity of work & working constraints, associated with such studies, led the worker to limit only upto studying the hydrochemical part, with a view of taking up the aforementioned study, part by part, for individual elements in future. The present study, therefore, was envisaged as an attempt on presenting detailed account of hydrochemical aspect.

Perel'man, A.I., (1977). Geochemistry of Elements in the Supergene Zone. Keter publishing house, Jerusalem Ltd.

Raja RAo, C.S., (1983). Coal Resources of Madhya Pradesh and J & K. Coal Fields of India, GSI Bull. Series A, Vol. III, No. 45, pp. 155-178.

Raymahashay, B.C., (1987). A Comparative Study of Clay Minerals for Pollution Control. Jour. of Geol. Soc. of India, Vol. 30, No. 5, pp. 408-413.

Raymahashay, B.C., (1987). Geochemical parameters of Aquatic environment. Role of Earth Sciences in Environment. Proc. National Symposium, (ed.) Sahu K.C., IIT, Bombay, pp. 173-180.