AN INTEGRATED HYDROGEOLOGICAL STUDY OF MAHENDRAGARH DISTRICT, HARYANA, INDIA

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by

ABDULLAH TAHERI TIZRO

DEPARTMENT OF HYDROLOGY
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

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Gratis

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"AN INTEGRATED HYDROGEOLOGICAL STUDY OF MAHENDRAGARH DISTRICT, HARYANA, INDIA"** in fulfilment of the requirement for the award of the Degree of Doctor of Philosophy and submitted in the Department of Hydrology of the University is an authentic record of my own work carried out during a period from December, 1989 to March, 1995 under the supervision of **Prof. D.C. Singhal** and **Prof. A.K. Jain.**

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

(Abdullah Taheri Tizro)

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

27/3/95

Date:

(A.K. Jain)
Professor
Department of Earth Sciences
University of Roorkee
ROORKEE 247667, . INDIA

(D.C. Singhal)
Professor
Geology Department
Kurukshetra University
KURUKSHETRA 132119, INDIA
(On LFS from University of Roorkee)

The Ph.D. viva-voce examination of Mr. **Abdullah Taheri Tizro**, Research Scholar, has been held on ....20th November 1995..........

20/11/95
Signature of Supervisors

20/11/95
Signature of H.O.D.
Professor & Head
Department of Hydrology
University of Roorkee
Roorkee

20.11.95
Signature of External Examiner
(Dr B.S. Tanwar)

ABSTRACT

Mahendragarh district, Haryana, located near its border with Rajasthan, is a semi-arid area and affected almost perennially by scarcity of water. The average yearly rainfall for the Mahendragarh raingauge station, recorded for the 40 years period between 1950 to 1990, is 497mm, whereas the annual potential evapotranspiration is greater than the annual rainfall and varies between 1400 and 1660mm for the district. In recent years, situation has become alarming due to the persistent decline of the water table, probably due to the over-exploitation of groundwater and deterioration in the quality of groundwater. Keeping in view these problems, the present investigations were undertaken with the following main objectives:

(i) Geological and structural characteristics of the area

(ii) Delineation of hydrogeomorphological characters using satellite imageries, and ground checks

(iii) Evaluation of subsurface geological scenario from the available data of tube wells and Vertical Electrical Soundings (VES), newly-recorded VES profiles, identification of aquifer horizons, aquicludes and aquifuge materials

(iv) Hydrogeological conditions including water table configuration, pattern of groundwater flow, fluctuation of water table and estimation of hydraulic properties like transmissivity etc. of shallow aquifers from electrical resistivity data

(v) Groundwater quality and its hydrochemical chracterisation

(vi) Probable origin of salinity in groundwater

The rock formations of the Aravalli mountain belt belong to the Delhi Supergroup of the Precambrian age, and have been divided into the Alwar and the Ajabgarh Groups.

The Alwar Group is well exposed in the northern and western parts and comprised of an immense thickness of hard and compact quartzite, having a few bands of phyllite and mica-schist. The Ajabgarh Group is made up of calc-silicates, marbles, schists, quartzites, amphibolites, pegmatites and iron ores in the southern, southeastern and southwestern parts.

The formations strike between N-S to NE-SW and steeply dip towards NW or SE. The slate and phyllite are also common in this area. The slate is vertically dipping and sometimes intruded by pegmatite bodies. The Delhi Supergroup of rocks have been subjected to tectonic stresses and therefore, suffered extensive folding, faulting and igneous intrusions. In the north, two large folds are doubly-plunging: the Sohla-Khodana-Siswala-Anticline and the SSW-plunging Narnaul Syncline. The Sohla-Khodana-Siswala-Anticline trends NNE-SSW for a distance of at least 44 km. The core of this large fold is represented by an open, upright anticline, whereas the western limb of this fold is well represented by the longitudinal ridges. The Narnaul Syncline extends NNE-SSW for at least 15 km as a SSW-plunging open asymmetric syncline with westerly-dipping axial plane. The eastern limb of this syncline is represented by continuous exposures, whereas its western limb shows a number of digitations.

As observed on satellite imageries, and during the field study, the Ajabgarh Group have undergone intense deformation in southern parts, which has caused the development of folds, faults and joints. A series of isoclinal folds with axial

trend in NNE-SSW direction is picked up. The present study corroborates the presence of three sets of folds (designated F_1, F_2 and F_3 in chronological order) and associated structural elements. The earliest recognisable tight, sharp-hinged isoclinal folds (F_1) trend NNE-SSW. These are superposed by open, upright asymmetrical/symmetrical F_2 folds and co-axially refolded F_1 folds. The third deformation structures are open F_3 folds, with WNW-ESE axial trend and high wavelength/amplitude rates.

The rock formations exhibit characteristic jointing. The dominant directions are NE-SW (dipping 75^o W) , N 130^o-310^o (dipping 50^o NE) and N 75^o-255^o (dipping along 20^oN). NW-SE trending fractures are open tensional joints, developed perpendicular to NE-trending fold system and are of relevance in groundwater localisation and movement.

Systematic and careful visual interpretation of False Color Composites (FCC) of the IRS 1A Satellite Imageries was carried out to demarcate geomorphic/landforms, fracture traces and lineaments. The hydrogeomorphological features have been divided into following geomorphic units.

(i) Depositional features comprised of alluvial plain, sand dunes, points bars, and flood plains

(ii) Moderate structural denudational hills

(iii) Low-lying structural denudational features, e.g., inselbergs, pediplain, valley fills and vegetation anomalies

The relative hydrogeological significance of geomorphological features and NW-SE- trending lineaments has been confirmed by the productive wells, drilled along the fracture traces and lineaments.

It is inferred that study of fracture traces, and lineaments along with hydrogeomorphological features are important aids in targetting and localisation of groundwater in a geologically and structurally complicated area.

Subsurface distribution of different geological formations and groundwater conditions have been deduced from resistivity variations with depth along with other field geological evidences. A total of 54 Vertical Electrical Soundings (VES) including 10 no. of newly-recorded VES data, using Schulumberger electrode configuration, has been utilised in this work, while data have been interpreted by a computerised (Direct) technique with curve-matching for calibration purposes.

The resistivity ranges, assigned to the different subsurface formations, are 18 to 110 ohm-m for sand, 5 to 100 ohm-m for clay-sand admixtures (depending on fraction of clay), 4 to 18 ohm-m for clay, 9 to 153 ohm-m for kankar-clay mixture, 200 to 270 ohm-m for pegmatite ,40 to 200 for quartzite (weathered and semi compact), greater than 200 ohm-m for quartzite (compact), 95 to 270 ohm-m for calc-silicate rock and 665 to 800 ohm-m for slate. However, these resistivity ranges had to be utilised judiciously, keeping in view the known geology, lest it may lead to erroneous interpretation.

Depth to the bedrock is highly variable and slopes towards northeast and north in the area. As a consequence, thickness of alluvial deposits increases from south to north and from west to east. The sandy horizons in a few sections appear to be water-bearing in the northwestern parts of the area. The occurrence of saline groundwaters, as witnessed by the high EC values of groundwater, is also indicated along a few sections lines. In Madhogarh area towards NW, quartzite appears to be compact. However, the decrease in the value in resistivity in deeper zones tends to indicate fractured nature of quartzite formation, saturated with freshwater. The thickness of alluvium also increases gradually.

Hydrogeological inventory and network monitoring have indicated that the principal aquifer is made up of alluvial sands, often mixed with silt, gravel and kankar. However, groundwater also occurs in fractured rocks. Data from observation wells indicate that depth to watertable is highly variable in a wide range between 8m and 38m (bgl). It is shallow in NE parts and deepest in the NW and western parts. Further, there has been a considerable decline of watertable upto 25m in the past few years, especially in the western and southern parts. Such notable decline in watertable can be explained due to low recharge during lean rainfall years and over-exploitation of groundwater. The watertable elevation contour maps for the years 1991, 1992 and 1993 indicate that elevation of watertable varies between 226m (AMSL) to 295m (AMSL). In general, the watertable slopes towards north and northeast. The permeability of the aquifer is greater in the northern parts, whereas steeper hydraulic gradients occur towards south and northwestern parts indicating low permeability of the aquifer.

Estimation of transmissivity and hydraulic conductivity of unconfined alluvial aquifer has been attempted, using data from resistivity soundings and relationships between aquifer transmissivity and transverse resistance. However, wide variations in salinity of groundwater tend to produce conflicting results.

Computed transmissivity of the aquifer at seven localities ranges from 77 to 764.6 m^2/day and compares reasonably with the field transmissivities (118-360 m^2/day) for the corresponding locations. The RMS error in such estimates was computed to be 36.74 m^2/day, which seems to be within reasonable limits, inspite of the wide fluctuations in groundwater salinity.

Groundwater samples, procured from the open and deep wells spread over five administrative blocks over three seasonal cycles of periods, were analysed to establish quality characteristics of groundwater. The samples were analysed for major

ions like Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{-2}, SO_4^{-2}, Cl^{-} and TDS, pH and electrical conductivity (EC). pH values (7-8.5) indicate the alkaline character of groundwater. Low to very high values(650 to 5500 micro mhos/cm) of electrical conductivity indicate that the groundwater quality is marginal to saline in central, northern, southern, northwestern parts. Cl^{-} & Na^{+} are the dominant ions with concentrations varying from 60 to 2200 mg/l. Groundwater is also very hard (total hardness upto 1400 mg/l) in the northern and southern parts, whereas the alkalinity varies from 170 to 600 mg/l. The concentration of K^{+} is also considerably high and exceeds 250 mg/l at a few locations. However, other chemical constituents in groundwater seem to be generally in the permissible ranges, given by WHO and other Regulatory agencies.

The plotting of groundwater quality data on Expanded Durov's Diagram has revealed a general Na^{+}-Cl^{-}-type of groundwater, although groundwater of deeper aguifers shows high concentration of Ca^{+2} and SO_4^{-2} exhibiting dissolution or mixing character of the groundwater. In addition, the plotting of chemical data was also carried out in the Hill-piper diagram and Romani's modified Hill-piper diagram. Though the Hill-piper plots do not indicate a definite chemical character of groundwater, Romani's triangular diagrams seem to indicate mainly Na^{+} and Cl^{-}type of groundwater, followed by sodium-calcium-chloride-sulphate types.

Principal Component Analysis and Factor Analysis of groundwater have also been attempted to assess the chemical characteristics, in which epm ionic values have been utilized. However, a clear picture of dominant chemical character of groundwater has not emerged from the multivariate study, due to the limitation of these techniques to bring out the main chemical attributes of groundwater.

Apart from the major ions, the groundwater samples were also analysed for halides (I^{-}, $F^{-}$and Br^{-}). It has been observed that fluoride concentration in the

groundwater from 21 wells is higher than the optimal range, mainly in the NE, NW, SW and central parts.

Further, F^- concentration is greater in deeper aquifers when compared to the shallow ones, probably because the deeper aquifers are in the close proximity of the hard rocks containing fluorine -rich minerals. It seems that lithology of the geological formation is the major controlling factor in causing high concentration of fluoride.

As the concentration of I^- and Br^- are related to the residence time of saline waters, the I^-/ Cl^- ratios versus I^- plots show enrichment of I^- in the saline groundwater. This may be attributed to longer residence time of groundwater caused due to its entrapment within the low-permeability aquifer materials receiving low recharge. Thus, the groundwater in deeper aquifers seems to be of ancient origin.

The present work has demonstrated the usefulness of integrated hydrogeomorphological, remote sensing, geophysical and groundwater quality studies in the geologically-coomplicated terrains for understanding their hydrogeological and chemical attributes.

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Abdullah Taheri Tizro

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CHAPTER - 1

INTRODUCTION

1.1 BACKGROUND

Water is essential for sustenance of life. Lack of fresh water to drink and for use in agriculture and industry is one of the most important factors hindering development in many parts of the globe, especially in arid and semi-arid regions. Water, an important component of hydrologic cycle can occur above the ground as surfacewater and hidden beneath it as subterranean water (or groundwater). Groundwater is a renewable resource and has the remarkable distinction of being highly dependable, safe and omnipresent.

The knowledge of the occurrence, replenishment and recovery of groundwater assumes special significance in arid and semi-arid regions. Surface waters, except when brought in by rivers from elsewhere, are normally scarce, or even absent in such areas. With a few exceptions, in general, all drought prone areas in India fall under arid and semi-arid climatic zones (Singh, 1978). The Indian Meteorological Department categorises a 'year' as a 'drought year' in which rainfall deficiency is numerically equal to or greater than 25 percent of normal (Sen, 1967).

According to the UNESCO map prepared by Arid Zone Commission of the International Geographical Union, aridity has not left any continent untouched. The arid and semi arid zones of India constitute a part of the large North African-

Eurasian belt. As per estimate, more than one third of global territories are occupied by the arid zones or water scarcity area. A large part of land area in India is occupied by arid and semi-arid zones. In these areas, failure of monsoon, once too often due to vagaries of nature, creates severe scarcity of water resources. However, events have proved the sustaining capacity of groundwater supplies under such periods.

Mahendragarh district of Haryana state in India, located near its southwestern border with Rajasthan, happens to be a semi-arid area and is almost perennially affected by scarcity of water. The problem gets further aggravated due to occurrence of hard rock formations in a larger part of the area near, or above, the ground surface, due to which groundwater availability becomes rather erratic. Moreover, the situation in the area has become quite alarming in recent years due to declining water levels in the wells. During the last few decades there has reportedly been considerable decline of water table in Mahendragarh and Rewari districts (Anonymous, 1989) probably due to over exploitation of groundwater. The quality of groundwater has also deteriorated over the years so that many of the groundwater supplies do not satisfy the regulatory water quality guidelines set by various Indian and International Agencies.

1.2 AREA OF STUDY

The present study has been taken up in the Mahendragarh distt. of Haryana state in India. The district covers an area of about 1800 sq.km. between latitudes $27^{o}48'$ and $28^{o}28'$ N and longitudes $75^{o}54'$ and $76^{o}23'$ E in the southwestern parts of Haryana. The study area is bounded by Bhiwani and Rohtak districts in the north, Rewari on its east and Alwar and Jhunjhunu districts of Rajasthan towards its south and west respectively. The area lies in the Survey of India toposheets nos. 53D, 54A, 53 D/3, D/4, D/7, D/8, 54A/1 45M/13, 44P/16, 44 P/15 and is spread over five administrative blocks, viz., Mahendragarh, Kanina, Narnaul, Ateli, and Nangal Choudhry (Fig.1.1). The study area has a network of roads as well as other communications. Narnaul, the headquarter of Mahendragarh district, is connected to Delhi by a Metergauge railway line as well as an all weather metal road. The Mahendragarh town and other block headquarters of the area as well as some other villages are also well connected with each other by metal roads.

Most of the population of the area has a rural background and is mostly dependent on agriculture. The main crops grown in the area are wheat, gram, groundnut, barley, oil seeds, millet, sorghum and some vegetables. Industrially, the area is rather backward but some industries like metallic mineral products, textiles and synthetic fibre have come into existence.

1.3 METEOROLOGICAL CONDITIONS

The study area has a semi-arid climate with both the extremes hot conditions in the summer and cold during winter. The heat during summer is oppressive with maximum temperature touching about 47^{o}C, whereas in the winter, minimum temperature drops down to around 2 to 3^{o}C during nights.

The area receives over 80% of total annual rainfall in the period in the months of June to September. The annual rainfall of two raingauge stations viz. Narnaul and Mahendragarh has been considered for the analysis (Fig.1.2). The average yearly rainfall for the Mahendragarh station recorded for the 40 years period between 1950 to 1990 is 497.3 mm and the average of Narnaul station recorded for the 37 years period of 1950 to 1986 is 533.0 mm.

Fig. 1.2 illustrates the yearly variation of rainfall at these two stations. From the figure, it is observed that the years receiving precipitation less than 400mm are considered to as drought prone years for the Narnaul raingauge station. Likewise, at the Mahendragarh station, it is observed that the years receiving precipitation less than 373mm considered to be drought years. The humidity is maximum (approximately 69%) during rainy seasons i.e. July, to September. The weather usually remains dry during the other months of the year. Humidity in the months of December and January is low to moderate due to little rainfall in this periods of the year.

In the month of September, when the rainy season is over, the wind speed is minimum. The speed of wind is maximum in the months of June to October and reaches upto 8-10 km/hr. Sometimes, strong dust storms influence the visibility in the area adversely rendering it hazy. During the monsoon months, the wind directions is from the southeast and in other seasons it is dominantly northeast. Evaporation is maximum upto 12mm-13mm/day in the hot months of April, May, and June and it is lowest upto 2 to 3 mm/day in the months of January and December.

1.4 GEOMORPHOLOGY

The study area is almost a pediplain having long and narrow ridges and with inselbergs of different rocks formation, and size.Theseare isolated above the flatness of sorrounding pediplain having long and narrow ridges.The inselbergs of quartzite belonging to the Delhi formations are usually elongated and can be found as linear ridges, whereas granitic hills are more or less rounded.

The elevation of hills ranges from 381 to 651 meters above the mean sea level, with Dosi having the maximum elevation upto 651 meters located in the western part of the area. The hills and ridges are usually scattered in the study area with a larger

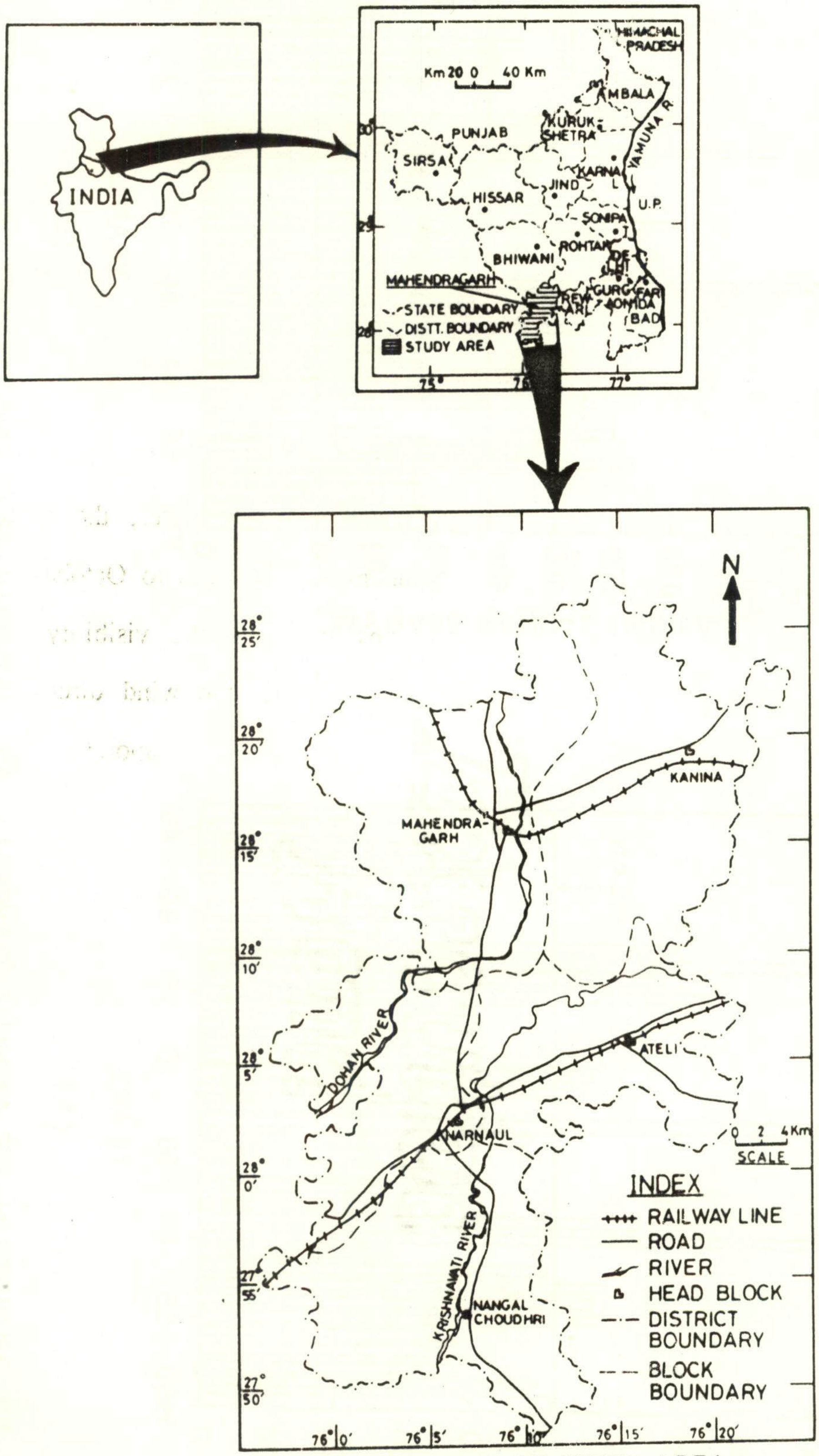


FIG. 1·1 INDEX MAP OF STUDY AREA

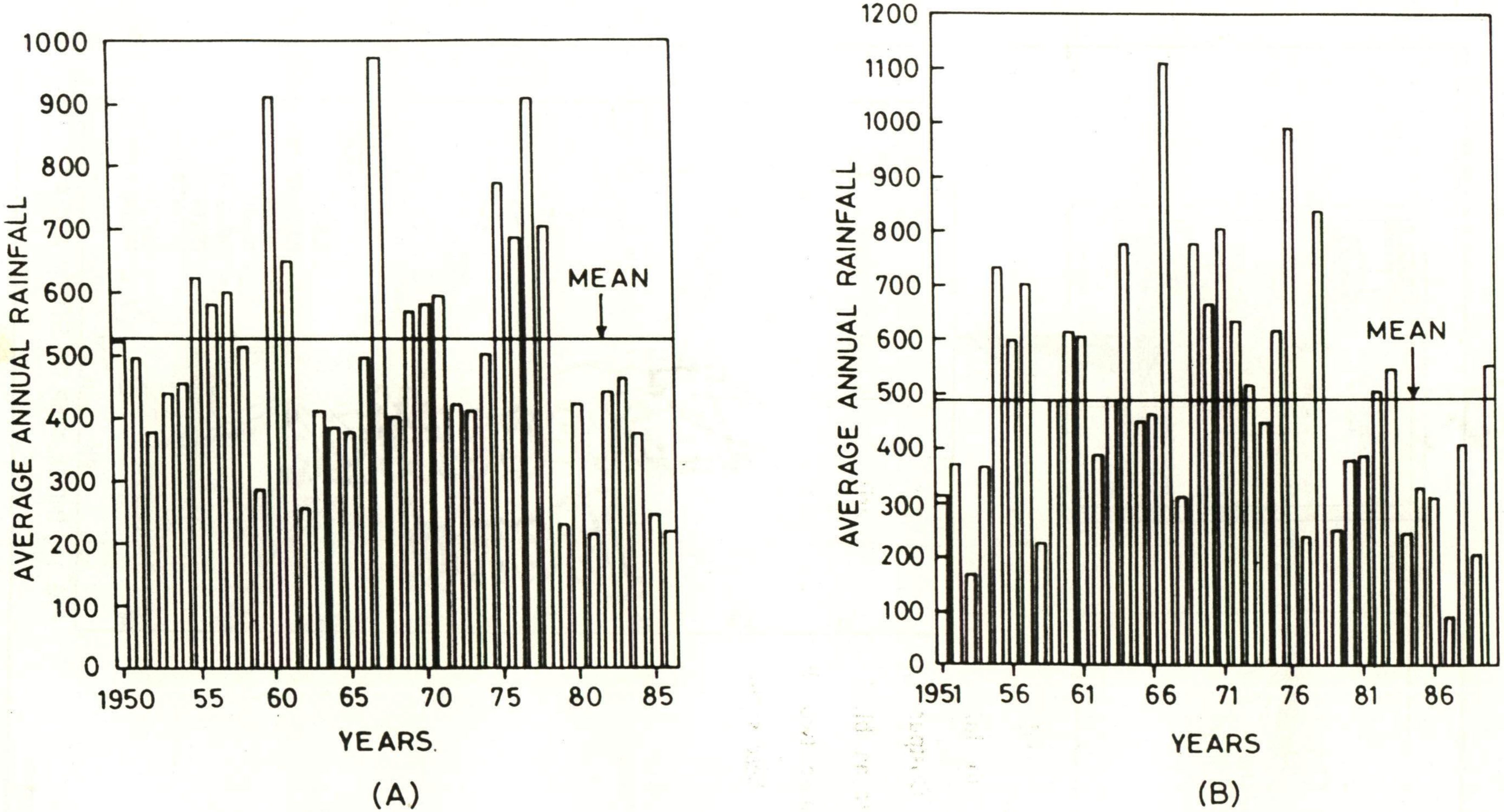


FIG. 1·2 VARIATION OF ANNUAL RAINFALL AT NARNAUL (A) AND MAHENDRAGARH STATION (B) IN (MM) concentration in the southern, southwest and north-northwestern parts. A group of scattered hills (including the famous Dosi hill) appears in the western part of Narnaul block. Two long ridges appear in the northwestern part of the area with the top of these hills being flat as observed at near Zerpur-Osmanpur area.

The study area has two main rivers i.e. Dohan and Krishnavati, but both are ephemeral in character (Fig 1.1). The Dohan river gets water in rainy season from the southern hills of Rajasthan. It originates from these neighbouring areas in the western parts and passes near Mahendragarh town and finally disappears near Bassi village due to influent seepage. The Krishnavati river enters the district from the south near Dostpur village and flows through Nangal choudhry, Narnaul, Kanina and finally Jatusanaa block (Distt. Rewari) and disappears near Zainabad village in Rewari distt. As these two rivers flow in a narrow channel, especially in the southern parts of the area, these seem to indicate certain structural control in the area.

The river valleys are V-shaped and usually covered by wind- blown sand. At the mouth of these valley's, Bajadas (plain formed by deposition of debris in fan shaped spread) are often present. In the upstream parts of these rivers in Rajasthan, dams have been constructed resulting in depletion of flows; the rain leaving little runoff in the further downstream areas. These rivers seem to become non-entities in the dry period with no water flow. Thus, at several places, the river beds are filled up by silt and sand. Many patches of the river bed are even cultivated. There are also a few minor streams, originating from the neighbouring hills which also carry water from their catchment area only during the rainy season.

The drainage patterns are dendritic in character. The erosional valleys are commonly formed between two hills, in southeastern parts. These alternate with elongated ridges, which are made up of phyllite. The erosional valleys are narrow in the upper parts of catchment areas. These are flat at the base, where the valleys are filled up by eroded sediments, brought by flowing water.

1.5 PREVIOUS WORK

The rocks of the proterozoic Delhi Supergroup are exposed as a part of the main Aravalli mountain chain, extending from Delhi southwestward through parts of Haryana and Rajasthan towards Gujarat. The Aravalli hills in the northeastern parts seem to have been almost completely covered beneath the Indo-Gangetic plains. In parts of Rajasthan,the Aravallis are largely covered by the great Thar desert (Kumar, 1985).

Attempts were made in past to study the geology of the Aravalli ranges by various workers Medlicot (1874) and Hacket (1881) were amongst the earlier geologists to take geological traverses in the region. Hacket (1881) carried out geological investigations in the Aravalli belt and mapped the various lithological units in the area. Oldham (1889) published his research work on "Itacolamite (Flexible sandstone) and its mode of appearance in the region. Bose (1906) has described granitoid gneiss and quartzite occurring in the Narnaul area while giving an account of its geology and mineral resources. He also indicated that rock formations in the area are highly disturbed.

Heron (1917, 1923, 1953) in his remarkable work in the Aravalli belt described the geology of the northeastern part of the region in which the present area of study falls. According to him, hard rock formations that occur in the region belong to the erstwhile Delhi system (now designated as Delhi Supergroup). The Delhi system rocks were divided into Alwar and Ajabgarh series (subsequently redesignated as Alwar & Ajabgarh Groups). Heron (1917), while studying the geology of the region, suggested that the Delhi Rocks have undergone folding with north-south trending axes. Saksena

(1962) noticed occurrence of paragenetic mineral deposits in the rocks of Delhi system in the Narnaul area.

Gupta (1965) discussed about the amphibolites of Khalera hills occurring in the southern parts of Narnaul area and opined that they are metamorphosed basic rocks. Kedar Narain (1966) dealt briefly with the geology and mineral resources including iron ore deposits in the district. Bhatia et al. (1967) has described the orbicular structure in the quartzite of Khalera hills.

Bublani and Mookhy (1967) have reported on the occurrence of iron ores in the Antri-Beharipur area and suggested that these have resulted from replacement of host rocks i.e., calc-silicates. Bhattacharya (1971) has studied the structures in the rocks of the Narnaul area, whereas Saksena (1973) studied iron ore deposits of the Mahendragarh District. Kanwar and Saksena (1974) studied the nature of folding in Beharipur area of Narnaul.

Maheshwari (1981) studied petrology of Alwar and Ajabgarh rocks in parts of Narnaul area of Mahindragarh Distt. Bhola and Varadarajan (1981) investigated polyphase deformation of Ajabgarh rocks around this area, whereas they (1985) also studied the deformational and crystallization history of the Delhi Group rocks. They have observed three phases of folding and distinguished them by different orientations and styles. Bhola (1989) studied petrology of regionally metamorphosed pelitic schist SSW of Narnaul.

Dey (1985)discussed the tectonic style of Delhi Supergroup of rocks outcroping in the southern part of Haryana.

Gupta (1990) gave an elaborate account of the mineral deposits in the Mahinderagarh distt. in his report on Mineral Resources of Haryana state.

Singh et al.(1989) have discussed the application of Remote Sensing Techniques in the study of distribution of micronutrients in relation to landforms in the Sahibi river Basin of Haryana.

Chopra (1990) classified the various geomorphic zones and a geological- cum geomorphological map of the Haryana and Adjoining areas based on the Multispectral landsat Imagery was given have been recognized.

The groundwater investigations in the Mahendragarh region have been carried out by Mitra and Biswas (1955) and later by Chaterji and Biswas (1967). They obtained data pertaining to the depth to water, watertable and gradient for a large number of wells therein. The partial chemical analysis and salinity determination were also performed by these workers. Apart from these investigations, hydrogeological studies, geo-physical work and monitoring of groundwater levels and quality are being carried out by Haryana State Minor Irrigation Tube wells Corporation (HSMITC). The Groundwater Cell (GWC), Haryana an Central Groundwater Board (CGWB). These agencies have also constructed and installed a number of exploratory tube wells in the area.

Kakar(1981) reported nitrate pollution of groundwater in southern and southeastern Haryana, and mentioned that nitrate levels exceeding 500 mg/l at shallow depths have been observed at several places in this region of the state.

Tanwar (1981) discussed the groundwater pollution and its protection in Haryana wherein he attempted to determine qualitative characteristics and changes through a network of monitoring stations, each covering about 15-20 km^2 area . He also discussed the possible sources of Groundwater pollution and approaches to pollution control.

1.6 SCOPE AND OBJECTIVE OF PRESENT STUDY

A review of published work on the geology and hydrogeology of the Distt. Mahendragarh reveals that a systematic approach to the hydrogeology of the area and its interpretation has been generally lacking. The present investigations have been undertaken to apply an integrated approach using geological field data remote sensing and hydrogeology, alongwith groundwater quality monitoring studies in the Mahendragarh distt. The studies incorporate resistivity sounding data and estimation of hydraulic properties of aquifers. Some of the detailed scope and objectives of present investigations are given below.

(i) Geology and strcture of the area including the joint analysis.

(ii) Hydrogeomorphological character of the region using satellite imageries to deciphere fracture traces and lineaments and their correlation with joint pattern including hydrogeological significance of geomorphological features and significance of fractures in groundwater localization.

(iii) Delineation and Distribution of different subsurface geological horizons using tubewells data and vertical electrical soundings.

(iv) Hydrological conditions of different geological formations, watertable configu-rationsa, groundwater flow patterns, fluctuation of watertable and hydraulic properties of aquifers.

(v) Groundwater quality characteristics and possible source of salinity.

1.7 METHODOLOGIES

(i) Geological field investigations of rock formations, structures, and joints.

(ii) Deciphering of fracuture traces and lineaments .from satellite imageries by visaul analysis.

(iii) Analysis and interpretation of geoelectrical data using both direct and indirect methods of interpretation.

(iv) Monitoring of groundwater levels in the field by regular observation of selected hydrograph stations. Analysis of pumping test data for obtaining hydraulic properties of aquifers by different available method.

(v) Groundwater sampling in the area of using international standard quidelines. Analysis of groundwater samples using procedures described by standard methods.

CHAPTER - 2

GEOLOGY AND STRUCTURE

In the present chapter, the regional geology of the study area along with its structural framework have been appraised. The field characters of different geological formation, as made out from the studies of geological outcrops and structures, have also been outlined.

2.1 REGIONAL GEOLOGICAL SETUP

The rocks of southwestern parts of Haryana and adjacent areas of Rajasthan form part of the NNE-SSW trending Aravalli belt. The geology of this belt is available from the excellent work of Heron (1917), who grouped the rock formations as dominantly belonging to the erstwhile Delhi System of the Precambrian age. These rocks extend right along the main axis of folding of the Aravalli mountains from near Delhi in the north, through Ajmer and Mewar to Idar and Palanpur towards the south (Fig 2.1). In the north, these are interrupted by exposed beneath the Recent to Sub-Recent alluvium. The sequence conformably lies over the gneisses of the Raialos and is, in turn, overlain unconformably by the Vindhyans. It occupies large areas, extending from Delhi to Idar in constricted and eroded, synclinal bands in the centre of the great Aravalli

Synclinorium; its fullest development being found in the main Rajputana geosyncline of Ajmer-Merwar, and Merwar state (Wadia, 1966). The prominent part of this sequeence is the Alwar quartzite, which is composed of quartzite, grit and flagstone. It is intruded by a number of basic rocks and granite bosses and laccolith, pegmatites and aplites. The Delhi "system", taken as the Proterozoic (900-1600 m.y.; Crawford, 1970) is also characterized by intense grades of metamorphism. The rocks of the Delhi "system", best developed in the Alwar region, have been divided into the Alwar "series" and the Ajabgarh "series" throughout the belt, but in the Alwa area, two additional horizons between Alwar and Ajabgarh "series" appear. These are the Hornstone Breccia and the Kushalgarh Limestone. The stratigraphic succession of the Delhi "System" of rocks as described by Heron (1917) is given in Table 2.1.

2.2 GEOLOGY OF THE STUDY AREA

The rock formations, exposed in the present study area, belong to the erstwhile Delhi System (redesignated as Delhi Supergroup) of Heron (1917). However, stratigraphical succession, adopted for the area is based on the overall geological work by Hacket (1881) and by Heron (1917), (Table 2.1). It has been observed that only the Alwar and Ajabgarh groups of rocks are present. The general strike of the rocks is NNE-SSW in conformity to the trend of Aravalli belt. The geological map of the study area, compiled from Bhola and Vardarajan (1985), Maheshwari (1981) and from the present studies, is given in Figure 2.2.

2.2.1 Alwar Group:

The Alwar Group rocks are well exposed in the northern and western parts and consist of an immense thickness of monotonous, metasediments, mainly represented by very hard and compact quartzites with occasional bands of phyllites and mica schists.

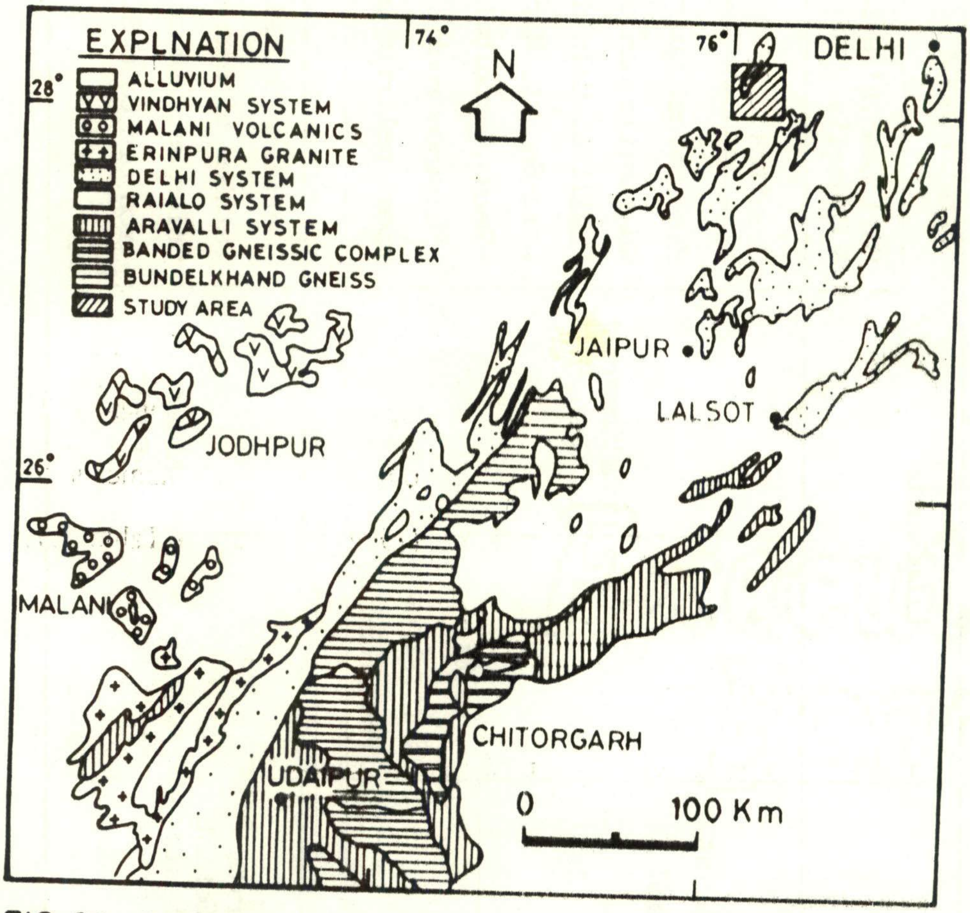


FIG. 2·1 REGIONAL GEOLOGICAL MAP (AFTER HERON, 1917)

TABLE 2.1 GEOLOGICAL SUCCESSION IN THE REGION & AROUND THE STUDY AREA

Region			Study Area		
			Lithounits		Stratigraphy
Recent (Quaternary)		Soil,Wind blown Sand Alluvium & Kankar			Soil,Sand,Alluvium,Kankar & Gravells
Delhi System (Proterozoic)	Ajabgarh Series	Slate,Phyllite,Mica-Shcist Quartzites,Sandstone and impure Limestone	Delhi Supergroup (Proterozoic)	Ajabgarh Group	Granites
					Mica-Shicst,Quartzite, Quartzitic Sandstone,Slate, Phyllite, Calc-Silicate, Calc-Shcist, Marble,Pegmatite -Veins, Amphibolite,Calc-Gneiss, Shistose rocks, Semi-pellitic bands.
	Hornstone - Breccia Kushalgarh - Limestones				
	Alwar Series	Quartzites,Arkose,Grits Conglomerates,Mica-Schist and Contempoaneous basic igneous rocks.		Alwar Group	Quartzite,Schistose Quartzites, Patches of Marbles,Calc-Gniesses,Pegmatites, Iron ore,Calc-Silicate

The quartzites are intruded by granite and pegmatite bodies. Extensive exposures of quartzites occur in the hills and ridges around Sohla, Budin, Madhogarh, Usmanpur and Mandla villages (Fig.2.2). They mainly are pale,brownish and reddish in colour. These are vitreous and break with sharp subconcoidal fractures.

The quartzites are sometime felspathic, micaceous or calcareaous in character. The micaceous varities are usually flaggy and exhibit a schistose appearance. Garnet quartzite are noticed at a few locations. A very tough and compact hematite-bearing quartzite is well exposed to the west of Rajawas village. Compact and massive hamatite is also located at places west of Sohla hills. The Alwar quartzites are highly jointed with well-developed joints.

2.2.2 Ajabgarh Group:

The Ajabgarh rocks group is exposed in the southern parts and incorporates metamorphosed calcareous, argillaceous and arenaceous rocks, associated with concordant amphibolites, pegmatites and iron ores. The formations strike N-S and NE-SW and dip are towards NW and SE (Bhola, 1985). At places, these are dominantly argillaceous and represented by mica-schists and subordinate quartzite. The slate and phyllite are common rock types and found in the SSE parts between Asarwas hills and Dhani Chaman hills (Fig.2.2). The slates are vertically dipping and sometimes intruded by pegmatite veins, which trend $N110^{o}$-$290.^{o}$ In the southern parts, the rocks are calcareous and are made up of marbles, calc-silicates and calc-schists.

Marbles are largely exposed in the Kalia-ki Pahari hills towards south, and are in contact with quartzites. Marble is also found near Islampur village, and is in contact with quartz-mica-schist and calc-schist. These strike along NNE-SSW direction, and are folded and jointed. These are white, grey, black and sometimes pinkish in colour. Amphibolite and pegmatite are associated with marble.

Two types of calc-silicate rocks are exposed in the study area: (i) calc-gneisses and (ii) calc-schists. These are seen in the southeastern parts as isolated hillocks between Donkhera and shahbazpur (Fig.2.2). These rocks are medium to coarse grained, whitish in colour and contain high percentage of Amphibolites.

The schistose rocks are exposed in the low-lying ridges in the SSW, and include biotite schists, quartz-mica-schists, and amphibolites. In the Ajabgarh group of rocks, quartzite is relatively lesser in abundance than in the Alwar Group, and is mostly found in contact with calcareous rocks. These quartzites are interlayered with mica schist, as obswderved at Kalia-Ka-Pahari hills. Quartzite trend NE-SW to NNE-SSW and dip between 45^{o}-80^{o} towards NW at most of the places. Quartzite is medium to coarse grained in character and highly jointed. Two joints sets are predominant; one is parallel to the foliation, and other normal to it. The rocks easily break along the joints. Hard and compact quartzites are observed in the Mukandpura Ki Dhani hills (Fig.2.2) with occasional recrystallization of quartz veins along the fractures within the quartzite. However, the veins are often narrow and disappear after some distance. The pegmatite veins are upto 2 meters in thickness and are composed of quartz, mica, and weathered feldspathic minerals and tourmaline.

Amphibolite bands of varying thickness and associated with quartzites, are seen at Khalia Ki Phari, Ghateser, Mukundpura and Donkehra (Fig.2.2). The former is also associated with calcarous rocks in the north near Islampur and Niyaz Alipur.

2.2.3 Granites:

The granites are exposed in the north-western parts of Narnaul area. These formations are observed around Dosi hill, Maroli and Dhanta. The granites are hard, and compact and exhibit spheroidal weathering. These are hornblende-bearing near its contact with calc-gniesses. It is biotite-rich and occasionally gnissose in character.The granites are affected by three sets of intense jointing. Though the field relationship of the granites with the country rocks is not clear, it is probable that these granites are emplaced within the Regional Narnaul Syncline, as suggested by Dey (1985).

2.2.4 Quaternary Deposits:

Quaternary deposits are represented by both Pleistocene and Recent sediments, these alluvial deposits occur as fills in the inland basins formed as a result of differential erosion of Delhi System rocks. The pleistocene deposits are the older alluvium deposits and the Recent deposits are the newer alluvium deposit. The older alluvium deposit consists of a succession of clay, clay with Kankar; silt, fine to coarse and gravel. These sediments rest upon a basement made of Delhi System rocks and are considered to be pleistocene in age.Recent deposits are represented by river alluvia, aeolian sands and talus. The river alluvium deposit consist of unconsolidated sands, silt and clay, and are confined along the courses of stream. Aeolian deposits are formed due to wind erosion and are transported from outside sources and deposit in the form of patches of variable extent Sometimes, these aeolian deposits completely bury smaller hillocks. The talus deposits are derived from the disintegration of hard rocks and don't extend to large distances from the foot hills, giving rise to the pediment areas.

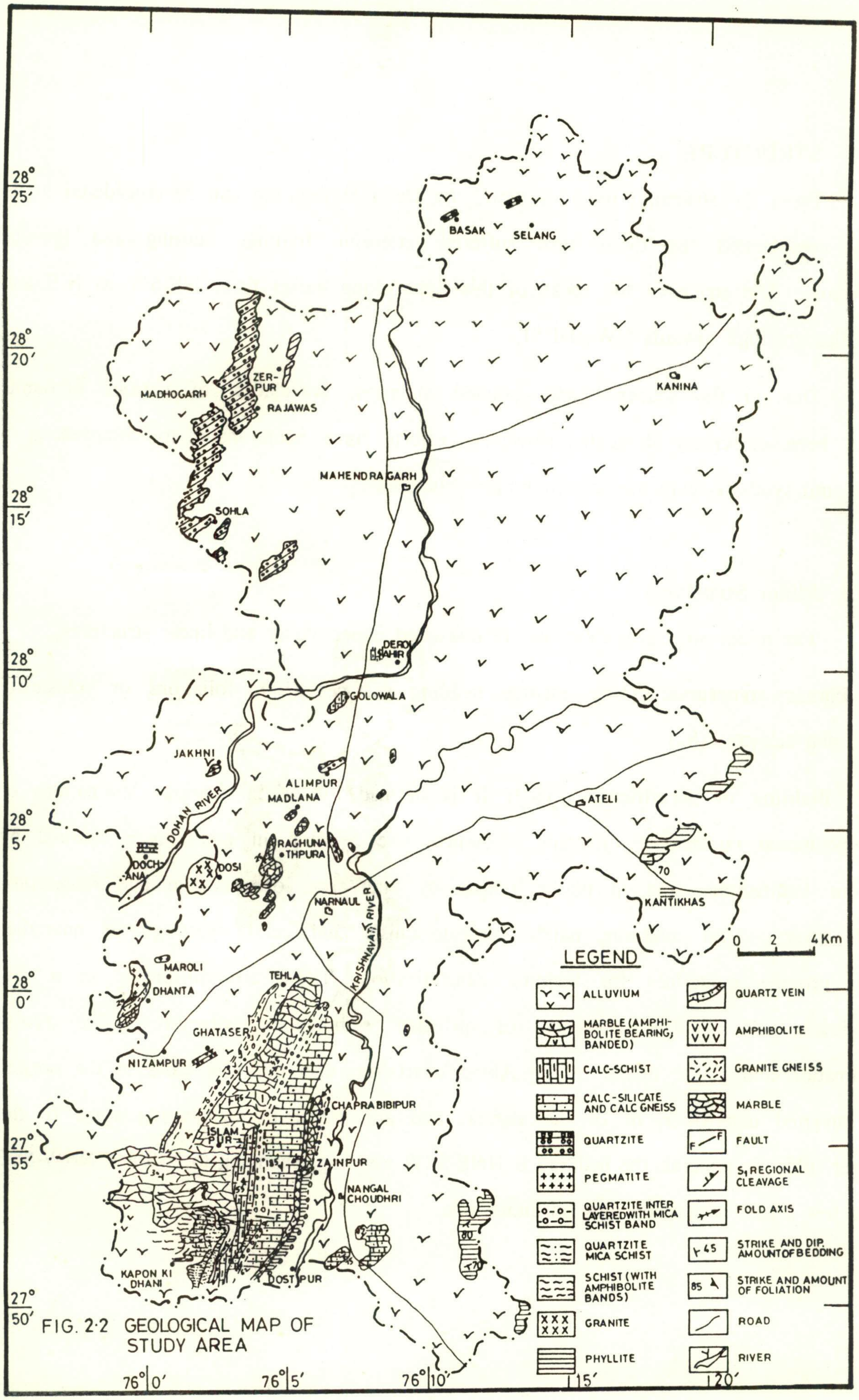


FIG. 2·2 GEOLOGICAL MAP OF STUDY AREA

2.3 STRUCTURE

From the structural point of view, the Delhi Supergroup can be considered to be very complicated, as these have suffered extensive folding, faulting and igneous intrusions. The strike of the rocks of this Supergroup varies from NE-SW to N-S and the dips are high towards NW and SE.

Due to the scattered and isolated outcrops, correlation of various lithounits have been extremely difficult. However, efforts have been made to comprehend a structural synthesis with the help of minor structures.

2.3.1 Minor Structures

The minor structural elements are discussed under planar and linear structures.

a. Planar structures: These include bedding surfaces (S_0), foliations or schistosity (S_1) and cleavage (S_2).

(i) Bedding or stratification (S_0): It is defined by original colour laminations or compositional contact of different lithounits. The bedding in quartzite is marked by colour laminations, and in pelitic schists by alternation of quartzite and micaceous-rich layers. Thin quartzite bands in calc-schists and schist partings in quartzites also provide guidelines for bedding determination. These are millimeter to a few centimeter thick. The presence of primary sedimentary structures, like cross-lamination and ripple marks in the Alwar quartzites, also provides clues to the normal or inverted disposition of of the starata, and are useful in deciphering some of the larger folds. In general, the bedding is NNE-SSW trending, changing to N-S and NNW-SSE at a few places with steep dips on either side.

(ii) **Axial plane foliation or schistosity (S_1)**, related to F_1 folding (described later), is the most common planar structure and is defined by parallelism of flaky minerals (sericite, muscovite, biotite) in pelitic schists, and flattened and stretched quartz in arenaceous rocks etc. S_1 mainly conforms to stratification S_o and the formational boundaries of the metasedimentaries. At the F_1 fold hinges, however, S_1 is at high angles to S_o. In pelitic schists, the bedding S_o is usually obliterated by the strong foliation.

(iii) Crenulation or fracture cleavage (S_2), consists of closely spaced micro-faults or fractures, developed parallel to the axial planes of F_2 folds(also described in linear strutures).The F_2 folds have resulted in the folding of schistosity (S_1) as well as bedding (S_0) planes and are accompanied by the development of crenulation cleavage (S_2), particularly at the(F_2) fold hinges.

b. **Linear structures:** These include minor folds (referred as F_1, F_2 and F_3), mineral lineation, mullions and intersection of penetrative planar surfaces.

The **minor folds** are the most important structural elements in deciphering the polyphase folding, affecting by the Delhi rocks. Three sets of mutually interfering folds (F_1, F_2 and F_3) have been recognised. Of these, the first two sets (F_1 and F_2) are co-axial and, because of their common characters, are somewhat difficult to differentiate, particularly in the non-schistose rocks.

F_1 folds are isoclinal folds with NNE-SSW trending hingges. These folds affect the S_o surfaces and are accompained by strong regional axial plane foliation (S_1). F_1 folds may be isoclinal with steeply dipping axial surfaces, sometimes reclined or even recumbent. The attitude of the axial planes of F_1 folds depends upon superposed F_2 fold geometry.

F_2 **folds** are open, upright, asymmetric as well as symmetric. These have broad hinges with high wavelength/amplitude ratio. Both axial plane foliation (S_1) and bedding (S_0) constitute the form surface of these folds (F_2), which are distinguished from F_1 folds by (a) geometry and (b) folding of form surface S_1. The F_2 folds have sub-vertical axial planes with a dominant NNE-SSW trending hinges. These occasionally change to N-S and NNW-SSE. F_2 folds plunge towards north or south. This is the most dominating folding phase and governs the outcrop pattern of the Delhi rocks. This folding has resulted in co-axial refolding of the F_1 folds with their hinges either being sub-parallel or at acute angles to each other.

The co-axial F_1/F_2 folds are superposed by a later cross-fold (F_3), the axial trend of which varies from WNW-ESE to WSW-ENE. These F_3 folds are open, with round-hinges, and small are amplitude folds with subvertical axial surfaces. The F_3 folds have caused wavy disposition of bedding planes and formational contacts and resulted in the culminations and depressions of the earlier folds. The F_3 folds show variable amount of plunge and direction because of their superimposition on already folded surface. The westward concavity of the Sohla-Khodana-Siswala anticline, manifested in the curved nature of the axial trace, is the effect of F_3 folding.

Mineral lineation is characterised by linear preferred orientation of mica flakes, graphite needles, hornblende prisms and feldspar streaks, actinolite-tremolite, calcite and stretched and flattended quartz in different rock types. Majority of mineral lineation has developed during the first deformation (F_1), as evident from their preferred alignment along regional foliation (S_1). Mineral lineation is also developed during second deformation, as evident from the occurrence of mica and stretched quartz along crenulation cleavage (S_2).

2.3.2 Major Structure

Three sizable structural features can be made out in the northern part of the are. The doubly-plunging Sohla-Khodana Siswala anticline and the SSW-plunging Narnaul syncline.(Dey,1895). However, in the area south of Narnaul, a series of isoclinal folds have been noticed.

(i) Sohla-Khodana-Siswala anticline

This doubly-plunging anticline trends NNE-SSW for at least 44 km with its northern closure around Siswala in Hissar District and the southern closure around Sohla (Fig. 2.3). The core of this macro-fold is represented by an open upright anticline, southeast of Khodana, whereas the western limb of this macro-fold is well represented by the longitudinal ridges at Un-Nangal, Mala-Sohla and Khodana-Zerpur. The eastern limbs is exposed at Kalina, Bassi, Seiling and Numbi. The overall fold pattern shows an arcuate disposition with its convexity towards west, as is apparent from the fold outline as well as the dispositon of the axial trace. This is the effect of F_3 cross-folding, which has changed the axial trend from NE-SW in the southern part through N-S in the central portion to NNW-SSE in the northern part. The doubly-plunging nature of the F_2 macro-fold is caused by the F_3 folding, which is responsible for axial culminations and depressions of the F_2 folds.

(ii) Narnaul syncline

This is disposed for at least 15 km in NNE-SSW direction and is a SSW-plunging open asymmetric syncline with westerly-dipping axial surfaces. The eastern limb of this syncline is represented by outcrops at Purani Mandi, Nasibpur. Its western limb is exposed at Dhani Umarabad, Rughunathpura, Khalra and Kanwriawas hills (Fig. 2.3). The rock exposures at Dhani Faizabad and Azimnagar represent the northern closure of

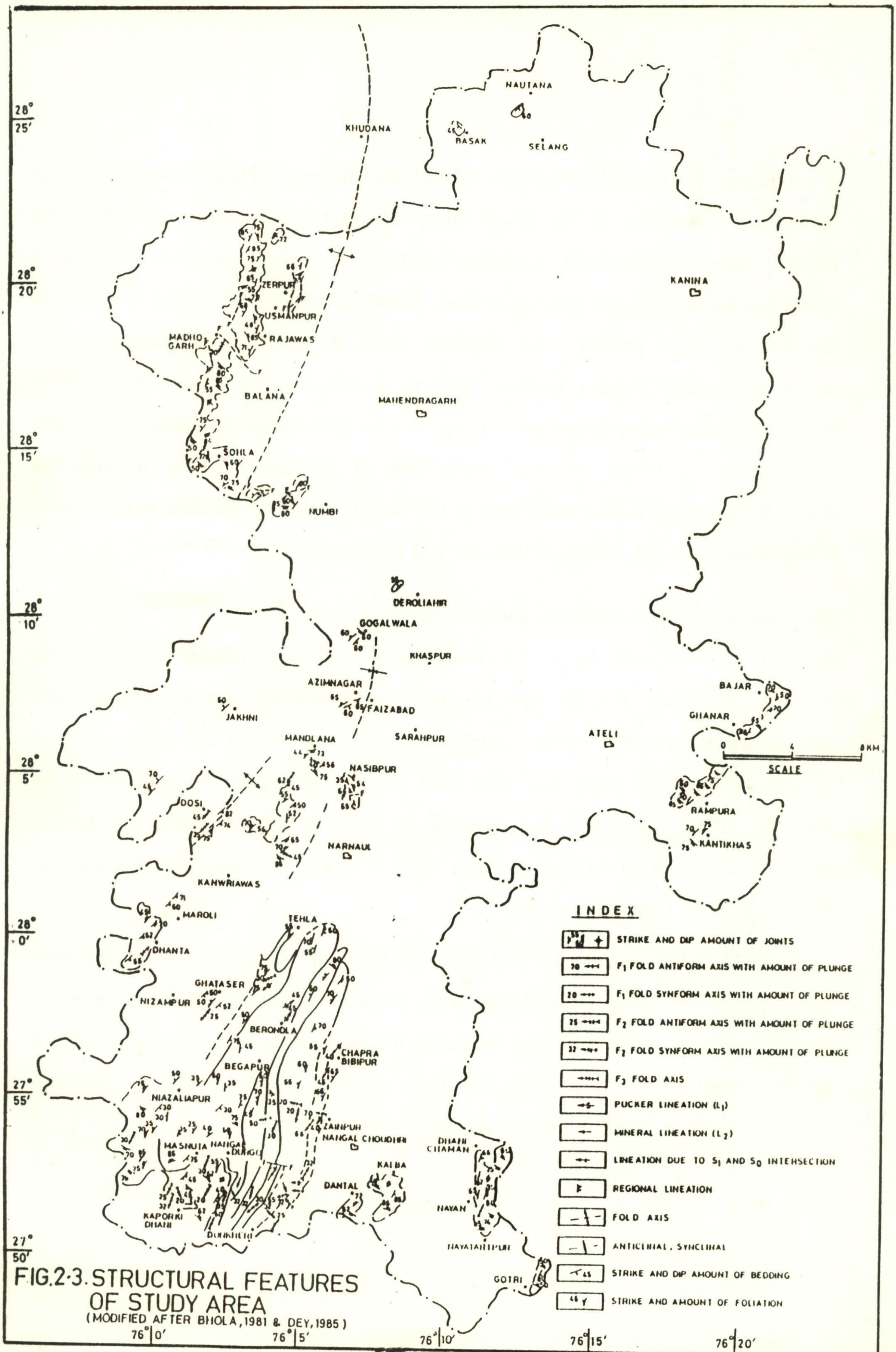


FIG.2·3. STRUCTURAL FEATURES OF STUDY AREA
(MODIFIED AFTER BHOLA, 1981 & DEY, 1985)

this syncline. At Khaspur, Mandlana, Maroli and Basirpur villages, cross-bedded and ripple-marked quartzites of the Alwar Group are exposed. The western limb of the Narnaul macro-syncline shows a number of digitations in the cluster of hills around Khalra and Kanwriawas. The granites of Dosi, Maloli and Dhanota are aligned in NNE-SSW direction and have possibly been emplaced along the corresponding anticlinal core. Within the regional Narnaul syncline, large F_1 and F_2 folds are noted particularly in the Rughnathpura-Khalra-Kanawriawas group of hills. The change in attitude of F_1 folds due to later F_2 folding is very clearly seen in the Khalra cluster of hills; the effect of F_3 folding is also manifested in the swerving of the NNE-SSW trending strata in the Dhani Umarabad, Nasibpur, Khaspur and Mandlana hills.

(iii) Isoclinal folds in southern parts:

It has been noted from the study satellite imageries, followed by field checks in the present study, that the Ajabgarh rocks in the southern part of the study area have undergone extensive tectonic disturbances, which have caused development of a set of large-scale isoclinal folds with NNE-SSW trending axial surfaces discernible in the imageries. These folds are also affected by faulting and fracturing in different directions. Along the axial line of these folds, a number of joints and fractures can also be picked up from the imageries.

Bhola (1981) emphasized that major folds in the southern parts of the study area are indistinct and any conclusion about the style of folding are drawn primarily from the study of minor folds and associated foliations. However, the present study of satellite imageries reveals that it has been possible to decipher a set of large isoclinal folds in the southern parts of the are.

CHAPTER - 3

REMOTE SENSING STUDIES

3.1 INTRODUCTION

Remote sensing is the science and art of obtaining information about an object, area or phenomenon, acquired by a device that is not in direct contact with the object, area (or phenomenon) under investigation (Lillesand and Kiefer, 1987) and its applications include diverse fields such as agriculture, crop acreage and yield estimation, drought warning and assessment, flood control and damage assessment, landuse/land cover mapping for agro-climatic planning, wasteland management, water resource management including groundwater targetting, ocean/marine resources survey and management, urban development, mineral prospecting and forest resources survey etc.

The usefulness of satellite data often lie in identifying fractures and lineaments, which are usually the zones of localisation of groundwater (Singhal et al., 1988; Sahai, et al, 1991). One of the widest application of remote sensing data, has been in the field of geomorphology which often forms good aquifers. Howe et al. (1956) described the technique of preparation of groundwater prediction maps from aerial photographs. They recognized three types of areas related to potential water-bearing formations: the most common water-bearing formations being granular materials in alluvial plain terraces, outwash deposits, moraine deposits and sandy lake beds.

Lattman and Parizek (1964) noted that wells, located on fracture traces, yielded about 10-100 times more water than the wells in similar rocks and topographical conditions away from the fractured traces. The technique of mapping of fracture traces and lineaments from aerial photographs for locating zones of higher permeability in hard rock terrains was also attempted by Parizek (1976). Moore et al. (1977) could locate high yield wells and spring alongs lineaments identified from landsat imagery in Madison country, Albana, USA. Location of high-yield wells in karst could be related to lineament on airphotos (La Riccia and Ranch, 1977). Srinivasan et al. (1977) attempted to use remote sensing technique for mineral and groundwater explorations in state of Karnataka, India. According to them, recognition of crustal fractures and, especially, the intersection of the lineament system increases the probability of groundwater localisation around the tubewells drilled near to such features.

Todd (1980) discusses the application of remote sensing in revealing fracture pattern in rocks, which could be utilized in surface investigation for groundwater. Moore (1988) explained, in general, the methodology for detection of groundwater aquifer from remote sensing imageries. Kumar and Srivastava (1991) analysed the geomorphological features through satellite remote sensing imageries coupled with geophysical electrical sounding (VES) to obtain information about spatial variation of aquifer material in area between Ganga river and Kharagpur hills, W. B., India. They categorised the area into different geomorphological classes for general groundwater prospecting as well as spatial distribution of aquifer material.

Gupta (1991) discussed the application of remote sensing in groundwater investigations in various geological terrains. He categorised various surface features and indicators for groundwater amenable to observation on remote sensing data product into the following:

(i) First order or direct indicators i.e. those groundwater parameters that are directly related to groundwater occurrence (e.g. springs, canals, ponds, lakes, rivers and soil moisture etc.).

(ii) Second order or indirect indicators i.e., those hydrological parameters, which regionally affect and, therefore, reflect the groundwater regime indirectly.These include drainage characteristics, fracture systems, soil/rock type, structure, landform etc.

A list of important indicators is given in Table 3.1.

TABLE 3.1: IMPORTANT INDICATORS OF GROUNDWATER ON REMOTE SENSING DATA PRODUCTS.

(Ellyett and Pratt 1975)

a) First order or direct indicators

1. Features associated with recharge zones: rivers, canals, lakes, ponds etc.
2. Features associated with discharge zones: springs and other sites of effluent seepage
3. Soil moisture
4. Anomalous vegetation

b) Second-order or indirect indicators

1. Topographic features and general surface gradient
2. Type of rocks-hard rock (igneous, sedimentary and metamorphic)
3. Regional structural features
4. Weathering - depth, type of soil and humus content
5. Vegetation
6. Soil moisture
7. Drainage density
8. Porosity and permeability of formation (from soil moisture and drainage density observations)
9. Fracture systems in hard rock areas
10. Special geological features like sink holes, alluvial fans, dykes, faults, shear zones, buried channels etc. which may have unique bearing on groundwater occurrence and movement
11. Extra-hydraulic continuity of formation-surface and sub-surface water divides vis-a-vis recharge and discharge zones from synoptic overviews.

The present chapter deals with the interpretation of available remote sensing data-products e.g., False color composites of the IRS-1A satellite imageries (generated from LISS-II data) for the study area. The study was carried out with the following objectives.

(i) Delineation of various geomorphic features/land forms preparation of a hydrogeomorphological map.

(ii) To demarcate fracture traces and lineaments on the imageries followed by the correlation of their frequency with the realistic structural data, collected during field checks.

(iii) Hydrogeological significance of geomorphological features and lineaments and their correlation with the fractures and faults detected in the rocks.

(iv) To examine the location of computed production wells vis a vis the localisation of fracture traces and lineaments as demarcated from satellite imageries.

(iv) To distinguish and identify fracture zones of existing open nature for locating new wells in their vicinity.

3.2 METHODOLOGY

The approach, adopted for achieving the aforementioned objectives i.e. for targetting of viable well locations from the remote sensing data, had to be devised as under:

(i) Preparation of a hydrogeomorphological map from satellite imageries.

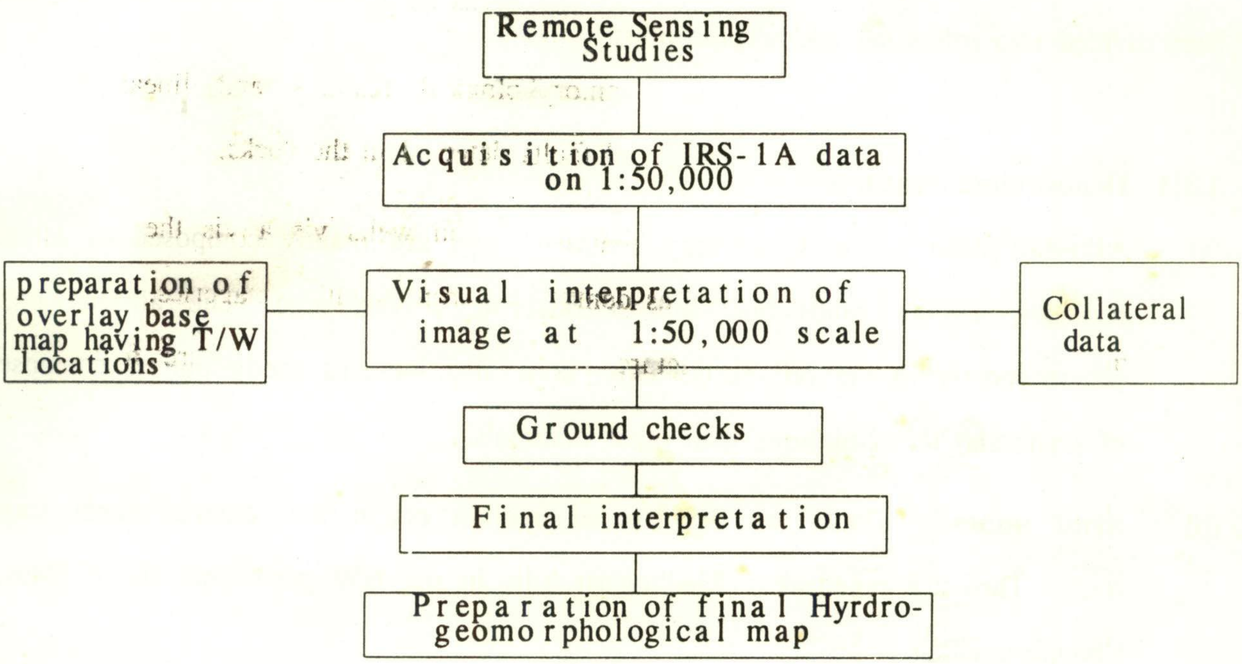
(ii) Superimposition of an overlay map, having location existing producing tubewells on the hydrogeomorphological map.

(iii) Deciphering the productive lineament and other hydrogeomorphological features by comparing the above two maps.

(iv) Attributing and correlating the genetic aspects of such hydrogeomorhic features to the kinematic of the area, as deduced from the field structural studies and frequency diagrams of demarcated fracture traces/fractures.

The preparation of hydrogeomorphological map of study area was accomplished by careful examination of FCC'S on 1:50,000 scale (Table 3.2).

TABLE 3.2: FLOW DIAGRAM FOLLOWED IN PREPARATION OF HYDROGEO-MORPHOLOGICAL MAP FROM SATELLITE IMAGERIES



3.3 STUDY OF SATELLITE IMAGERIES

During the course of present study, systematic and careful visual interpretation of satellite imageries (false color composites, FCC) was carried out to demarcate various geomorphic features like alluvial plains, sand dunes, pediplain valley fills, vegetational anomalies etc.

Geological data of the area along with other collateral data were also used in this exercise and was followed by subsequent verification from realistic field observations. Fracture traces in the consolidated rock formations along with fault and folds were also delineated on transparent overlays superposed on the FCC's, though many a times, these features had been missed during earlier ground studies. Figure 3.1 shows a hydrogeomorphological map, prepared by visual interpretation of 1:50,000 scale FCC enlargements taken by LISS-II scanner system of Indian remote sensing satellite (IRS-1A), to demarcate probable groundwater in the study area. Geomorphologically, the features, observed on the hydrogeomorphological map (**Fig. 3.1**), have been divided into following geomorphic units:

3.3.1 Depositional Features

(a) **Alluvial plain :** The Quaternary sediments and are mainly composed of alluvial deposits, aeolian sands and *Kankar* covering a vast area. The alluvial plain occurs mostly in the NE parts. Thiss zone also includes sandy plains, composed of sands and its admixtures with other materials.

(b) **Sand dunes :** These are deposits of aeolian origin and derived from source rocks. Thse are noted near Madhogarh hills in the NW parts and SE of Nangal Chaudhry village.

(c) **Point bars :** These are most conspicuous geomorphic features of the meandering streams and are developed towards the concave sides of meander bends. These grow by slow addition of individual accretions, accompanying migration of the meanders (Leopold et al., 1964). However, point bars have been observed only at few places along the course of Krishnawati river. Further, point bars of this river are not large enough due to their association with a small river and

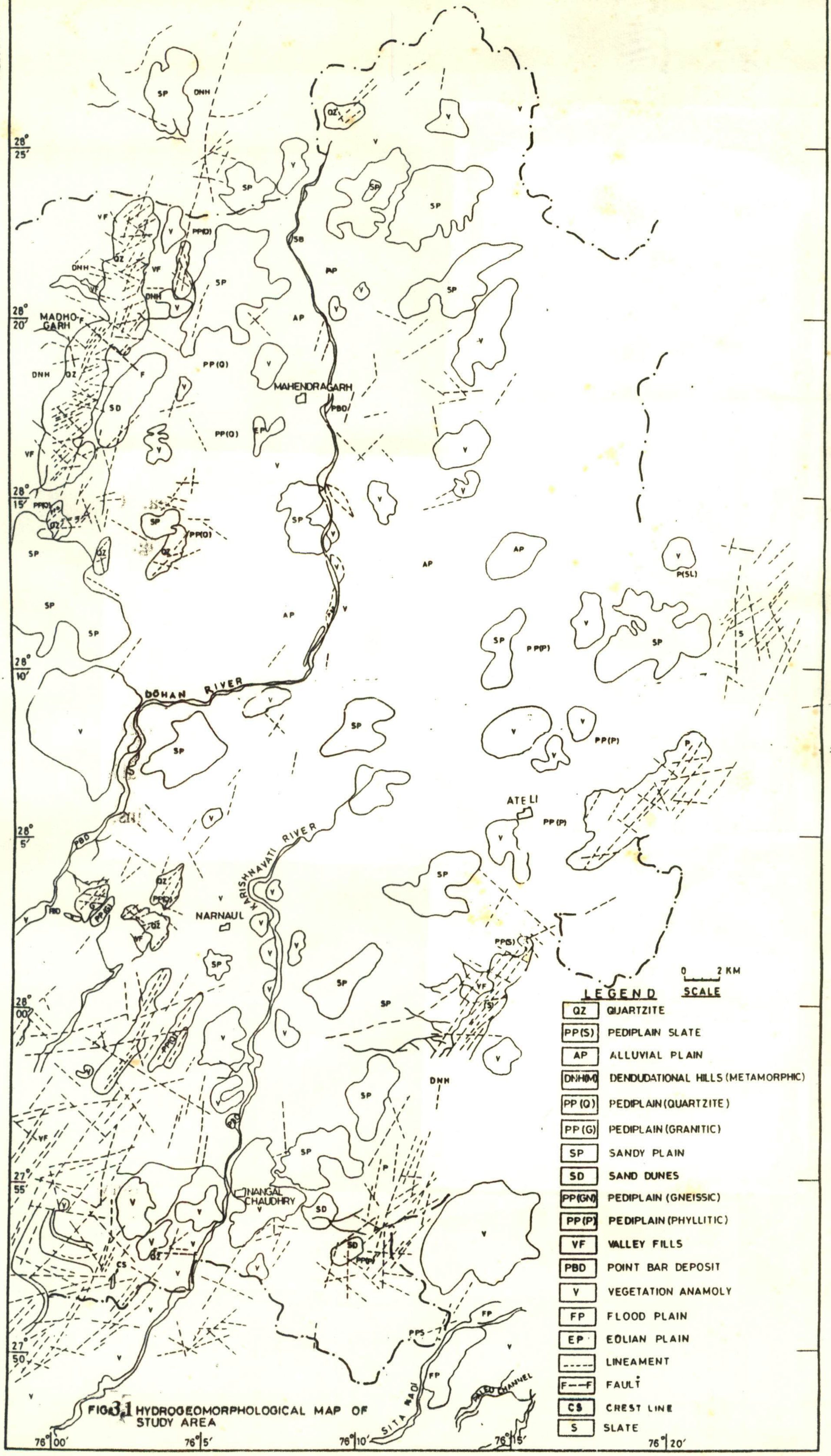


FIG. 3.1 HYDROGEOMORPHOLOGICAL MAP OF STUDY AREA

Overall view of Aravalli Mountain Belt in District Mahendragarh and adjoining areas on IRS-1A images (Nos. 53D04,53D08,54A01 and 53D03) represent aggradational features, though their groundwater potentials is likely to be moderately good.

(d) **Flood Plain:** These features are mainly formed due to channel migration and flooding a stream carrying flood plain sediments will deposit sand and gravels along it's bed, and layers of coarse sand (point bars on the concave side of the meander). The mapping of these features give clues about abandoned channels or pleochannels, channel migration etc.In the present area, these features are observed on its southeastern periphery.

3.3.2 Denudational Features

The structural upland features are exposed in the extreme NW and SSW, SSE and also central parts of the present study area. These features are distinct and can be easily picked up on the imagery as structural hills and have been divided into following geomorphic units.

(a) Moderate structural denudational hills

These highland features are manifestations of the resistant type of rocks like quartzites and are restricted to northwestern part, southwestern and southeastern parts of the area.

In the northwestern part, the moderately structural denudational hills show moderate relief, and dendritic drainage pattern. These features are traversed by long continuous fractures. One such fracture along NW-SE direction, picked up in the Madhogarh area seems to be a fault. In this region, the quartzites occur as prominent ridges and show effects of tectonic disturbances as manifested by different types of structural discontinuities. In the SSE part of the area also, the rock formations are found to be highly jointed and fractured. A major fold is seen to occur in the southern part of the study area (Fig. 3.1). The drainage pattern in these areas is dendritic and appears to be controlled by the rock structure. The Krishnawati river traversing the hilly area is narrow in character implying thereby the influence of structure on the drainage. At some places, the sinuous and curve-shaped vegetation anomalies are present in its vicinity (Fig. 3.1). The phyllites,occurring in the SE part of area, also form erosional valleys and are covered with unconsolidated, weathered material and sediments. These rocks also show moderate to high drainage density.

(b) Low lying structural denudational features

This geomorphic unit is erosional in character and comprised of metamorphic and granitic rocks exposed in the area. These features consist of the following.

(i) **Inselbergs:** These are small residual hills, which stand in isolation above the general level of surrounding erosional plains. In some parts, the inselbergs are covered with thin veneer of alluvium. In the study area, a number of inselbergs are picked up from imageries. These are confined mainly in the central part, near Narnaul (Fig. 3.1). The inselbergs are massive, highly jointed and fractured. In general, these features are composed of steeply-dipping granitoids, and quartzites which are less effected by erosional agents. As a consequence, these stand out mostly as remnants of more resistant rock formations and structural upland features, which have resisted prolonged erosion throughout the course of arid geomorphic cycle.

(ii) **Pediplain:** This is a gently-sloping erosional surface of low relief and represents degradational tendency. Such features are developed due to the process of denudation by subaerial agents including running water. This is a typical feature, developed in arid (or semi-arid) conditions and is usually covered by thin veneer of unconsolidated material often alluvium. In the study area, the pediplain has been identified all around Madhogarh hills in the north western part, around Narnaul hills as also in Kalia Ka Nangal hills. These pediplain areas are underlain by different types of compact rocks as indicated in Figure 3.1. In the SE parts, the pediplain is covered with thick veneer of alluvium, whereas in other areas, this cover is rather thin. This feature is characteristic of arid regions and tends to represent the end of arid geomorphic cycle in the area (Whitten and Brooks, 1972).

(iii) **Valley fills:** These are channel deposits, developed in the processes of pedimentation in the hard rock terrain. In the study area, the narrow channels have been filled in with sediments, brought by wind or derived from adjacent hills by running water in due course of time. In the Madhogarh area, such type of valley fills are observed to have thick cover of sediments and may serve as good zones for groundwater targetting (Fig. 3.1).

3.3.3 Miscellaneous Features:

Vegetation anomalies

These features are mostly localised in the vicinity of the rivers and streams and show sinuous curved nature reflecting their shifting character and, at places, meandering nature. Areas, occupied by these vegetational anomalies, are composed of loamy and other sandy moist soils indicating their high retention of soil moisture in the unsaturated zones. Under favorable conditions, these stretches may prove to be water-bearing.

3.4 FRACTURE TRACE AND LINEAMENT STUDIES

Main tectonic features of the area include three main episode of folding, which are affected by a set of fracture system and faults.It would ,therefore, appear from the synthesis of the structural data that the fracture system in the rock formations may also be related to the folding in the region.However, a brief general discussion of fractures in rocks will not be out of place, especially for the purpose of understanding their role in localisation of groudwater.

Tectonic deformation is the main cause of development of fractures in the hard rocks. The intensity of fracturing varies according to the rock type. Larsson (1972) and Larsson and Cederwall (1980) have emphasized importance of fractures in groundwater exploration.

On a broad basis, fractures can be categorised as tensile and shear fractures. These fractures are developed due to brittle deformation parallel to the compressional forces, or perpendicular to tensional forces. Tensional fractures are generally open and extend to greater depth and show pinching and swelling on a regional scale. If these fractures are well developed, they can act as conduits for groundwater circulation. The shear fractures are developed due to rock-mass movements along a plane. They vary in size from few centimeters to many kilometers. These are also manifested as overthrust, normal faults and strike-slip faults.

With the advent of remote sensing technology, various workers have emphasized the usefulness of aerial photographs and satellite imageries in lineament mapping for groundwater potential studies (cf., Lattman, 1958; Boyer and Mc Queen, 1964; Lattman and Parizek 1964; Trainer and Ellison 1967; Siddiqui and Parizek, 1971; Krothe and Bergeron,1981). Tiwari (1993) has discussed the prospective groundwater zones in the semi-arid climatic zone of western Rajasthan, by delineating the major lineaments from satellite imageries. His studies have resulted in identification of high yielding exploratory wells in the area.

O,Leary et al.,(1976) reviewed the usage of this term and defined the lineament essentially in the geomorphological sense of as a mappable simple or composite linear feature of a surface, whose certain parts are aligned in a rectilinear or slightly curvilinear relationship. It differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon.

In the present study, major lineaments have been mapped on the enlargements of IRS-1A satellite and the hydrogeomorphological map (Fig. 3.1). The map also includes lineaments and fracture traces in addition to the geomorphological features. It is notheworthy that most of the lineaments and fracture traces are restricted in the region south of Narnaul, Madhogarh hills and east of Ateli village. The joint patterns in the area has also been observed by field studies with the purpose of comparing their prevalent trends with those of major fracture traces and lineaments demarcated on the imageries. After such a correlation of fracture traces is established with spatial distributions of fractures in the rocks, it may be examined in the light of tectonics of the area deciphered from the history of folding of rocks.

3.4.1 Analysis of Fracture Traces and Lineaments

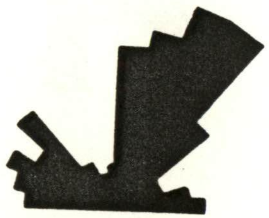
Groundwater abundance depends not only on rock types, but also on intensity of different types of tectonic activity. The existence of aquifers in hard rocks is very complex and non-uniform due to general absence of intergranulaar porosity and heterogeneity. The occurrence and movement of groundwater in such formations are restricted to the interconnected fracture systems. In this regard, mapping of fractures and lineaments can give a clue to the occurrence of groundwater in hard rock areas.

In the present study, fractures traces and lineaments, discernible in the satellite imagery were demarcated (Fig.3.1) .and the data of their orientation were classified into 18 Azimuth groups at 10^0 intervals. Azimuth-frequency diagrams were prepared for the whole area. Extensive field investigations were subsequently carried out to check the data, obtained from the imageries. To ascertain if joint-controlled linears are present in the area, field observations were made on the joint system in different rock formations, considering the intensity of fracturing within a radius of 2m around the point of observation. Azimuth-frequency diagrams were also prepared separately from these joints, observed in the different geological formations viz., calc-schist, quartzite, slate, quartzite, calc-silicate rocks and marble (Fig.3.2 and 3.3). A frequency diagram of the cumulative joints, as observed in the rock formations, was also prepared for gross comparison with that of fracture trace/ lineament, picked up from imageries (Fig. 3.4).

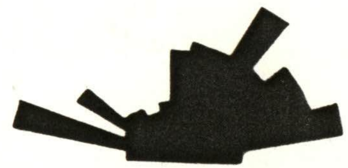
A perusal of Table 3.3 reveals that calc-schist and marble formations show development of joints mainly along NNE-SSW and WNW-ESE directions and in subordinate direction of NE-SW in the southern part of study area. The quartzite shows most frequent development of joints in NNE-SSW and N-S directions and subordinate development along of WNW-ESE and NE-SW directions. Phyllite and slate show major development of joints in NNE-SSW direction with their subordinate development in WNW-ESE directions.

FIG. 3·2 ROSSETTES SHOWING ATTITUDES OF FRACTURE TRACES / LINEAMENTS IN THE STUDY AREA

FIG. 3·3 ROSSETTES SHOWING ATTITUDES OF JOINTS IN ROCK FORMATIONS IN THE STUDY AREA



JOINTS IN ALL THE ROCK FORMATIONS



FRACTURE TRACES / LINEAMENTS

FIG. 3·4 ROSSETTES SHOWING ATTITUDES OF CUMULATIVE JOINTS AND FRACTURE TRACES/LINEAMENTS IN THE STUDY AREA.

TABLE 3.3 MAJOR AZIMUTH GROUP FOR JOINTS IN ROCKS OF THE DELHI SUPER-GROUP IN MAHENDRAGARH DISTT.

		Azimuth Group	Percentage of frequency
I	Quartzite	N21^{o}-40 ^{o}	28.8
		N270^{o}-300^{o}	25.1
II	Calc-schist	N 0^{o}-N10^{o}	13.40
		N11^{o}-30^{o}	20.9
		N31^{o}-N40^{o}	13.2
		N81^{o}-90^{o}	8.3
		N 0^{o}-N10^{o}	6.9
		N11^{o}-N50^{o}	50.8
III	Slate/ Phyllite	N301^{o}-N310^{o}	6.17

TABLE 3.4 MAJOR AZIMUTH GROUPS FOR FRACTURES TRACES AND LINEAMENTS OF DELHI SUPER GROUP ROCKS.

		Azimuth Group	Percentage of frequency
I	Quartzite	N31^{o}-40^{o}	13.9
		N71^{o}-80^{o}	14.0
II	Calc-schist	N0^{o}-N10^{o}	20.0
		N31^{o}-N40^{o}	13.0
		N21^{o}-N40^{o}	24.4
III	Phyllite/	N51^{o}-N60^{o}	12.0
	Slate	N11^{o}-N50^{o}	48.5

A comparison of synoptic azimuth grouping of fracture traces and joints, observed in the field, matches quite well and is around NNE-SSW direction. A total 28.8 percent of joints, observed in the field, matches well with a total of 24.5 percent of fracture traces in calc schist rocks, picked up from the imageries. Similarly, a total of 13.2 percent of joints in quartzite matches with 13.0% of fracture traces, picked up from imageries, whereas in phyllite 50.8 percent of joints, observed in the field, matches with with 34% of fracture traces picked up from imageries in NNE-SSW direction (Table 3.4). Also, a good correlation is observed between joints and fracture traces with percentages of 25.1 and 22.3 respectively in calc schist rocks in the WNW-ESE direction. However,the development of fracture traces of a few azimuth groups like N150^{o}-180^{o}(SSE) is poorly correlated with the joints. The reason for the above variation in the frequency of joints and fracture traces may be attributed to the possibility that observation of joints on the discrete spot readings in the field may have some subjectivity, while the imageries allow a synoptic and objective viewing. However, care should be taken in demarcating genuine fracture traces. Notwithstanding such anomalies, fracture trace and lineaments in imageries seem to offer important means to study and interpret development of fractures and faults in rock formations of an area.

3.4.2 Hydrogeological Significance of Geomorphological Features and Fracture Geometry

Water flowing into some mines and tunnels, which are hundreds (and in some cases, thousands of feet below land surface), indicates that openings at great depth are large enough to supply water to wells (Davis and Dewiest, 1966). Crystalline rocks are commonly lacking in primary porosity. However, they are able to store and circulate water through secondary pore spaces. The secondary pore spaces are developed in compact rocks due to tectonic activity and also as a result of their decomposition. Thus, groundwater abundance in compact rocks depends not only on the rock types, but also on the intensity of fracturing and the related tectonic activity. The groundwater movement as well as storativity of the fractured rock aquifers, to some extent, are restricted to interconnected fracture system. In the present study area, occurrence of groundwater seem to be influenced by varying types of geological formations, geomorphological features as well as the geometry of the fracture system related to the folding history. The occurrence of groundwater, in these formations can be studied in two parts.

(i) The area comprised of alluvial plain around Narnual in the stretches intervening between the hills, lying to the northeast of Mahendragarh town in Madhogarh ranges.

(ii) The southern rocky parts and the NW areas where hard rock terrain, comprised of weathered and fractured rocks, form the aquifers. The bedrock in this part is composed of a variety of rock formations like quartzite, phyllite, granite, marble, slate, schistose and gneissose rock.

Table 3.5 illustrates groundwater prospects within different hydrogeomorphological features of the area as described earlier in section 3.3.

It may be readily observed from this table that the main geomorphological features are alluvial plain together with sandy plain, pediplain underlain by different types of bed rocks, (viz. quartzite, granite, calc-shist rock and phyllites/slate) followed by other minor features like valley fills, denudational hills, sand dunes, point bar deposits and vegetational anomalies. Out of these, the pediplain and the denuded hills have generally little or thin veneer of alluvium and have, therefore, little hydrogeological significance. On the other hand, features like

Table 3.5

Map Symbol	Geomorphic Unit	Lithological details	Structural form	Description	Groundwater prospect
AP	Alluvial Plain	Recent alluvium comprised of admixtures of clay, silt/sand	Undulating plains	Composed of clay, slit and sand Flat terrain cultivated in some parts.	Good to excellent
DNH(M)	Denudational Hills (Metamorphic)	Predominantly quartzite, at places with granite intrusions and having thick cover of alluvium	Criss - crossed by fractures jointed etc.	Gently undulating plain with certain thickness of weathered mantle, moderate surface runoff. The wells have usually low yield and dry up.	Poor to fair (along fractures)
PP(Q)	Pediplain (Quartzitic)	Quartzite formations covered with thin veneer of alluvium	Fractured and Jointed	High relief, scarps and topographically prominent features, low to moderate drainage density,	Moderate good along fractures
PP(G)	Pediplain (Granitic)	Highly jointed granitic hills with groundwater seepage in some parts. Exhibit spheroidal weathering	Mainly fracture controlling joints	Low relief, gentle to moderate slope, low to medium dendritic drainage.	Low to moderate, good along weathred zone only
SP	Sandy Plain	Recent alluvium, composed of sand and kankar		Composed of sand, gently sloping undulating, normally barren except few patches. High permeability.	Excellent
SD	Sand Dunes	Wind blown sand		Composed of coarse to fine grained	Good
PP(P)	Pediplain (Phyllitic)	Mainly phyllite intruded with granites	Higly Jointed ,vertically dipping, weathered at surface and compact at bottom.	Steeply dipping formations in low lands, high slope with sand cover at the base of slopes	Moderate to poor

(Table 3.5 Continued)

Table 3.5 Continued

Map Symbol	Geomorphic Unit	Lithological details	Structural form	Description	Groundwater prospect
VF	Vally Fills	Unconsolidated materials like sand, silts and gravels within valleys.	Normally fractured controlled orientation	Linear depressions, partly filled by unconsolidated sediments, substantial thickness in the centre and tapering at the periphery	Good to excellent depending on the thickness of filled material
PBD	Point bar deposit	Coarse to medium sand deposit		Comprised of unconsolidated, coarse to medium sand deposits	Good,depending on the size of river meander
V	Vegetation Anamoly			Indicates presence of Good undurated material and water	
FP	Flood Plain	Well sorted, unconsolidated sediments	Unstratified	Well sorted fluvial material, may Good serve as good aquifer for open shallow dug wells only	
EP	Eollian Plain	Mainly fine to medium grained sand and silt		Mainly formed by low to high dunes with large interdunal depressions, scattered zeroxphytic vegetation	Moderate to good

alluvial plain, sandy plains, valley fills, point bar deposit, sand dunes and vegetation anomalies should have good to excellent prospects for the occurrence of groundwater, when other geological structural and hydrological factors are favourable. In this context, thickness of alluvial cover and the role of fracture system in the rocks are of relevance. Further, pediplains and fracture geometry alone would be largely responsible for localisation of groundwatear.

In the present study, it has been revealed that majority of the fractures are oriented in NE-SW and ESE-WNW directions. However, quartz and pegmatitic viens have often been observed along ESE-WNW trending fractures. This trend coincides with the F_3 trend of fold axes and seems to represent direction of tensional forces in the 3rd stage of tectonic development. Larsson (1972) and Larsson and Cederwal (1980) have described examples of tensional fractures which are usually open at depths,where localisation of groundwater along such fractures is promoted. As such, it would appear that the WNW-ESE trending fractures are on of the important set out of the system of fractures and joints in the study area. Groundwater seepages have also been noted from the WNW-ESE trending fractures in the granitic rocks occurring in the Dosi hill in the western parts of Narnaual area.

On the other hand, in the southern parts of the area, isoclinal folding is dominant, which indicates that compressive forces were predominant along E-W direction and have resulted in shear fractures and joints. In this area, occurrence of faults is also noted along E-W direction. Along these fault traces, many intersecting joints each are observed both on the imageries and in the field. However, these fractures are tight and closed in nature and are likely to remain open upto shallow depths only. As little open space is available along the shear fractures, prospects of groundwater localisation appears to be limited along such fractures (trending E-W) as was noted in

Golwa area in the southern parts. It is observed from Figure 3.5 and Table 3.6 that in a few locations, the wells drilled close to such lineaments yielded considerable quantities of groundwater (98-870 lpm).

The residual hills (inselbergs), which stand in isolation above the general ground level usually act as high run-off areas. The limited circulation of groundwater is only through the joints and fractures in the foot hills areas.

The point bars, consisting of unconsolidated sediments of coarse to medium deposits, appear to act as good sites for groundwater storage and a number of open wells already exist in these deposits. However, points bars are just appearing as minor depositional features due to small size of the rivers,on the concave inward sides of the meanders near the rivers and, therefore, potential of these landforms is rather limited.

The pediplain forms along the lowermost part of the hardrock terrain. These are characterised by dendritic and subparallel drainage pattern. Further, they are comprised of thin veneer of loose unconsolidated materials over the hard and compact formations. Therefore, they may only act as moderate catchment area along the undulating slopes. However,they will have little potential for localisation and recharge of groudwater.

The erosional valleys are irregular inshaped and usually formed within structural hills. The erosional valleys, appearing in the SE part in phyllitic uplands, are comprised of unconsolidated materials, which may yield good yield of groundwater from the wells.

3.5 SIGNIFICANCE OF FRACTURES IN GROUNDWATER LOCALISATION

The importance of fracture traces and lineament studies in groundwater localisation can examined by the location of existing production wells vis-a-vis the localisation of fracture trace and lineament, demarcated from imageries.In this context, location of successful wells, drilled by Central Groundwater Board (CGWB) within a certain period, are plotted on the Hydrogeomorphological map of the area (Fig. 3.5). Table 3.6 gives the location, aquifer lithology/drilled depth and discharge rate in the study area.

From Figure 3.5, it is clear that most of these wells having high yield are located either on the fracture traces or fall in their vicinity. However,tubewells nos. 21, 30, 31, 32, 33, 34, 35, 36, are found to be located in between fracture traces and proved to be unsucceful (Fig.3.5; Table 3.7). On the contrary , some successful pruduction wells (viz, 20, 21, 25, 26) are located close to the present-day river channels , espiceally near Krishnavati river, whereas some other wells are located in the vicinity of the intersecting lineaments. These features are indicative of the structural-hydrogeomorphological control of the localisation of groundwater in the area. Thus, it can be concluded that study of fracture traces and lineaments features from satellite imageries are important aid in targetting and localisation of groundwater in a geologically complicated area.

TABLE 3.6 DATA OF SUCCESSFUL CGWB EXPLORATORY WELLS

No. in map (Fig. 3.5)	Location of productive wells	Aquifer lithology	Drilled Depth (M)	Discharge (1pm)
1	Dahina Zainabad	Phyllite & Slate	137.46	N.A.
2	Gokalpur	Clay mixed with sand	137.55	N.A.
3	Barkoda	Sand & clay	61.8	225
4	Jant	Weathered Quartzites	143.70	548
5	Kodyana	Sand & Clay	75.00	466
6	Jaswas	Quartzites	100.60	695
7	Ateli Katkai	Sand & Clay	96.29	1200
8	Dawana	Phyllite & Slate	168.66	769
9	Padla	Phylite & Slate	160.20	398
10	Panchota	Calc-gniess Basic rocks	101.13	N.A.
11	Islampur	Calc-schist + Marble	63.29	N.A.
13	Said Alipur	-	101.00	150

Contd...

Table 3.6 Continued

14	Nangal Kalia	Calc-gniess &Calc silicate	107.00	495
16	Kultajpur	Clay, Kankar Weathered Quartzite	88.00	66
17	Thararan Ki Dhani	Weathered Quartzites	101.26	702
18	Meghot Hala	Calc-gniess & Weathered Quartzites	101.23	98
19	Hamidpur	Quartzites	55.20	871
20	Dharsan	Gravel	75.80	871
21	Dhani Ki Bhatota	Clay & Kankar	98.20	230
22	Binhari	Calc-Gneiss	104.30	870
24	Raghunathpura	Weathered Quartzites	70.75	130
25	Kamania	Calc-Silicate	72.45	150
26	Pipha Ka Nangal	Quartzites	106.35	230
27	Dhancholi	Weathered Quartzites	60.25	773

TABLE 3.7 **DATA OF UNSUCCESSFUL CGWB EXPLORATORY WELLS**

No. in map (Fig.3.5)	Location of productive wells	Aquifer lithology	Drilled Depth (M)	Discharge (lpm)
28	Bawana	clay mixed with sand	163.06	-
29	Sessote	Granite Gneiss	127.00	-
30	Mahendragarh	Clay mixed with *kankar* ,Quartzite	114.59	-
31	Segre	clay + Sand Quartzite	134.70	-
33	Bhojwas	Clay + Sand	37.49	-
34	Galaula	Clay + *kankar*	42.10	-
35	Akoda	Clay mixed with sand	160.20	-
36	God	Clay, sand and Quartzite	95.11	-
37	Nangal Kalia	Clay, sand and Quartzite	70.40	-

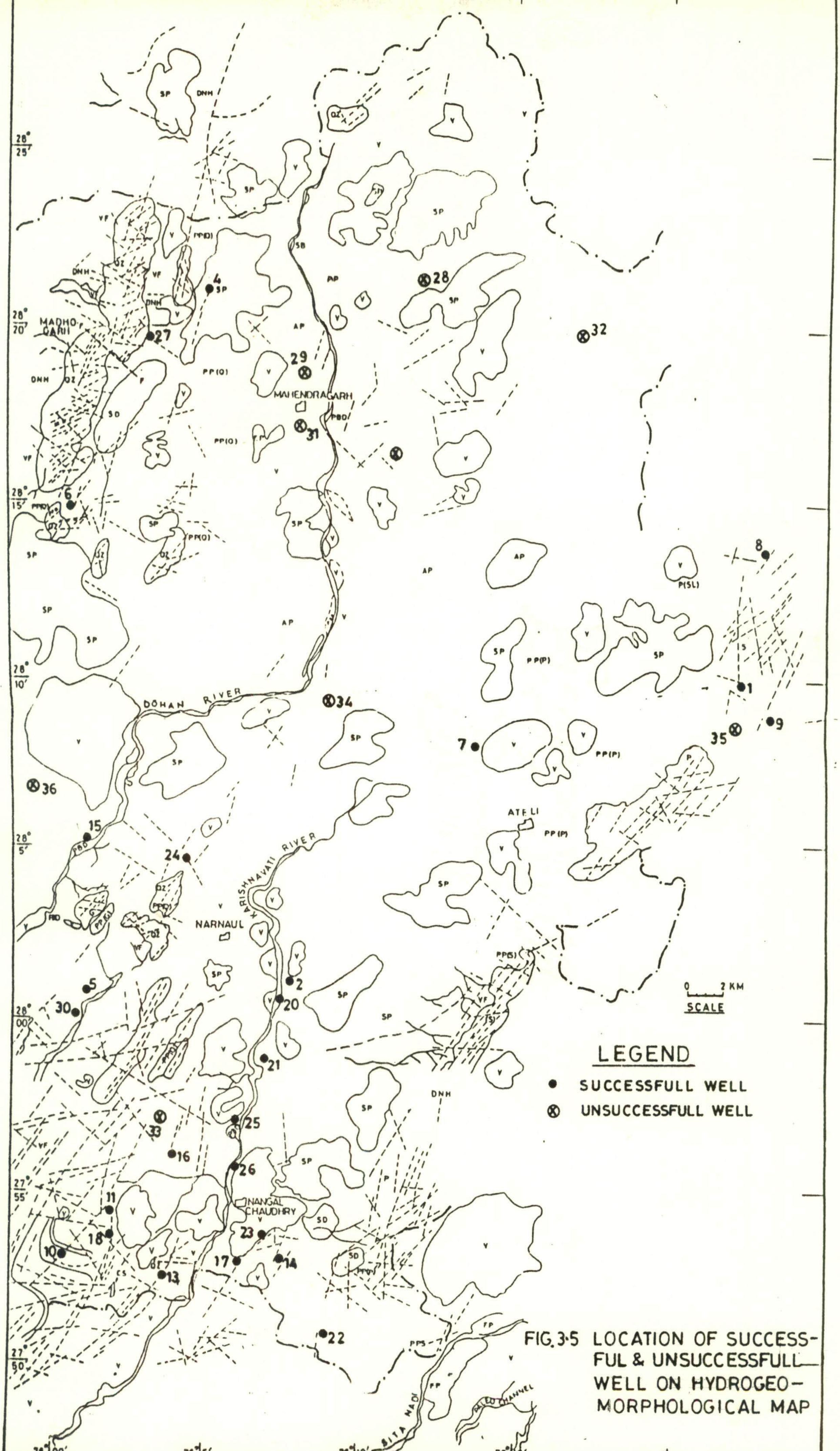


FIG. 3·5 LOCATION OF SUCCESSFUL & UNSUCCESSFULL WELL ON HYDROGEOMORPHOLOGICAL MAP

CHAPTER - 4

SUBSURFACE GEOLOGY AND HYDROGEOLOGICAL CONDATIONS

4.1 BACKGROUND

The nature and distribution of aquifers (and aquitards) in a geologic system are controlled by lithology, stratigraphy, and structure of the geologic deposits and formations (Freeze and Cherry, 1987). The lithology is the physical makeup, including the mineral composition, grain size, and texture of the sediments or rocks that make up the geologic systems. The study of subsurface geology from lithologs gives information about geologic formation, which ultimately controls the nature and distribution of aquifer. As the study of subsurface geology can often be made from lithological sections, fence diagram etc. which are prepared from available lithological data, limited availability of lithological data for an area make it difficult to study the subsurface geology and put severe constraints in compiling its holistic picture. These shortcomings can, however, be overcome by the use of geophysical data inputs.

In the present chapter, such an approach has been attempted, using the available lithological logs of existing wells and complementing the information gaps with the geophysical data. Geophysical method is an effective tool for ascertaining subsurface geologic framework of an area. Geophysical surveys can be useful in the study of most subsurface geologic problems (Keller and Frisckneclhdt, 1966; Griffiths and King, 1965; Zohdy et. al., 1974). One of the most widely used methods of geoelectric exploration is known as the resistivity methods. Modern developments in resistivity data interpretation have considerably increased the depth of investigation with reasonable accuracy up to a depth of about 500m.

The resistivity method is the most suitable method for the study of subsurface geological formations due to wide variations in resistivity of subsurface materials. In groundwater studies, the resistivity method can furnish information on subsurface geology, which might be unattainable by other geophysical methods (Zohdy et al., op.cit.). Electrical methods are unique in furnishing information concerning the depth of the fresh-salt water interface, whereas neither gravity, magnetic, nor seismic methods can provide such information.

The interpretation of geoelectric sounding data requires considerable field surface and subsurface geological information; both for realistic correlation. Availability of lithological logs of existing boreholes at selected points are particularly useful for providing controls and for confirming the results of the geophysical investigations (Singhal, 1983). A prior knowledge of the strike and dip of the formations in the surveyed area is also an important prerequisite prior to resistivity studies. For horizontally stratified earth, normally there is no problem in deciding the spread direction of the profile-line for a Vertical Electrical Sounding (VES). However, in dipping formations, the electrode spread line should be kept parallel to their strike (Bhattacharya and Patra, 1968). The trends of rivers and stream valleys are also useful in deciding the spread line of electrodes for the geoelectric sounding, as these often follow structural trends in an area. Kunetz

(1966) and Bhattacharya and Patra (op. cit.) have elegantly described the effects of dipping strata on the interpreted results of VES data.

4.2 OBJECTIVES AND METHODOLOGY

The main objective of this chapter are given below.

* To study the subsurface geology of the from available lithologs and other field truth data.
* To establish geophysical resistivity ranges for the different geological formations.
* To locate potential aquifer zones, if any, in the alluvial materials and in the weathered bedrock from the interpreted resistivity data.
* To delineate structural discontinuities like fractures and faults in consolidated formations which may form permeable zones.
* To study hydrogeological conditions.
* To ascertain, if aquifer properties like transmissivity etc. can be evaluated from the VES data for aquifer groundwater of varying salinity.
* The following approach was considered to achieve the above objectives.
* Preparation of fence diagram from available lithologs of the area and identification of information gaps.
* Recording of VES data, by using Schlumberger electrode configuration in the field.

* Interpretation of field and procured geophysical data (a) by using 2-layer master curves of Orellana & Mooney (1966), and (b) from computer techniques based on the algorithm developed by Zohdy (1989).

* Comparison of geoelectric data with lithologs of nearby wells and tubewells to assign resistivity ranges for different geological formations of the study area.

* Preparation of geoelectrical sections from the interpreted earth model data along with geological field data, including water quality.

* To identify aquifer horizons, and other water bearing layers from the geoelectrical sections, in order to know the aquifer geometry.

* Field acquisition of hydrogeological data relating to depths of groundwater, water table elevation (above the datum plane) for selected well hydrograph stations, groundwater quality and aquifer characteristics.

* Computation of Transmissivity of the unconfined alluvial aquifers and its comparison with the available field transmissivity values.

4.3 ELECTRICAL RESISTIVITY STUDIES: AN OVERVIEW

Geophysical methods have been found to be highly useful in groundwater exploration. The geoelectrical, seismic, magnetic and gravity prospecting methods can be used to reduce substantially the amount of test drilling and in selection of sites for future exploitation of groundwater. Seismic prospecting provides fairly accurate estimates of the depth to different layers and the bedrock, while gravity prospecting may be used successfully in determining broad and deep valleys, and caverns in limestones. Magnetic surveys help in the location of rocks like basic intrusives which have strong magnetic susceptibility. The success of the individual method depends on the contrasts in appropriate physical properties, of the geological materials present in the subsurface. If the variation in these properties are slight or gradational, the measurements cannot be interpreted with the desired accuracy.

A commonly adopted geophysical method for groundwater exploration is the electrical resistivity method (Geoelectrical method).The electrical resistivity of rocks and solids depends principally, upon the amount and salinity of the water present in the pores and interstices. The less porous a medium, the higher the resistivity so that the dense insoluble rocks tend to possess high resistivity and porous unconsolidated sedimentary deposits tend to show low resistivity.

In Direct current electrical prospecting, two methods are used. The first one is electrical profiling, which provides the information about the lateral variation of resistivity. The other method (vertical electrical sounding) provides information about resistivity variation with depth. In electrical profiling, the whole set up of the electrodes system with a given configuration is moved from one place to another, while in the vertical electrical sounding, the central point of electrodes configuration remains fixed as the current and potential electrodes increase in separation.

The determination of thickness of layers and their corresponding resistivities form the interpretational problem in surface electrical measurements of apparent resistivity for various current electrode spacings. The most common method for carrying such measurements is the passage into the earth of direct (or low frequency current) through current electrodes, while the response is measured across the two potential electrodes (Parasnis, 1962).

There are several electrode configurations (Telford et al., 1976), but the Schlumberger arrangement is found most suitable and it is widely used for groundwater investigations. In general, all resistivity techniques require the measurement of the apparent resistivity. The apparent resistivity is defined as the true resistivity that a homogeneous earth should posses if it had to record same potential as observed in a stratified earth thinking that the measurement was being repeated keeping electrode spacing and current exactly the same (Parasnis, 1962). The apparent resistivity for schulumberger configuration is given by

$$\rho_a = \frac{\pi}{2a}(L^2 - a^2)\frac{\Delta v}{I} \quad \text{(Dobrin, 1985)}$$

where,

L and a are the distance of current and potential electrodes from the point of observation respectively, ρ_a is the apparent resistivity and ΔV is the potential difference, I is the current.

The field apparent resistivity data for different AB/2 can be plotted on a suitable double log graph paper. This plot can be interpreted directly using a suitable computer software, or indirectly by matching with standard master curves (Orellana and Mooney, 1966).

4.3.1 Interpretation of Resistivity Data

The main purpose of interpretation of resistivity sounding data is to determine the true resistivities and thickness of different layers purely on theoretical considerations. These results are subsequently used to obtain a realistic picture of the subsurface within the known geological framework. The first part is also referred to as quantitative interpretation, while the other is known as geological interpretation.

4.3.1.1 Quantitative Interpretation

The quantitative methods are classified as indirect, and direct depending on the manner in which the layers parameters are deduced from the field apparent resistivity curves. In the indirect method, the field curve is matched with the standard master curves to obtain the layer parameters while, in the direct method, the kernal function (or some functions associated with kernal function) is obtained. Kunetz(1966) gave a brief account of various procedures developed for the evaluation of the integral Zohdy (1965), Keller and Frischknecht (1966). Bhattacharya and Patra (1968), and Koefoed (1979) have described the techniques used in the indirect interpretation. With the recent advent of fast electronic computers, a number of works has been published on the automatic method of interpreting resistivity data especially after 1973 whereby the decision regarding the adjustment of layer parameters is made by the computer (Zohdy, 1974; Sriniwas and Singhal, 1983; Zohdy, 1989). Koefoed (1979) has given a comprehensive account of various approaches of automatic interpretation of resistivity data.

Zohdy (1989) has developed computer techniques for the automatic interpretation of sounding data. This fast iterative method for the automatic interpretation of Schulumberger and Wenner sounding curves produces the interpreted depths and resistivities from shifted electrode spacing and adjusted apparent resistivities respectively. This method does not require an initial guess of the number of layers, their thickness or resistivities and it does not require any extrapolation of incomplete sounding curves.

The number of layers in the interpreted model equals the number of digitized points of the sounding curve. The resulting multilayer model is always well behaved with no thin layers of unusually high or unusually low resistivities. For noisy data, interpretation is done in two sets of iterations (two passes). Anomalous layers, created because of noise in the first pass, are eliminated in the second iteration. Such layers are eliminated by considering the best fitting curve from the first pass to be a smoothened version of the observed curve and automatically reinterpreting it (second pass). The iterative, the procedure relies on the following initial assumptions.

(i) The number of layers in the model equals the number of digitized points on the observed curve. This assumption remains unchanged throughout the iterative process.

(ii) The depths of the model layers are equal to the digitized electrode spacings which are equally spaced on a logarithmic scale.

(iii) The true resistivities of the model equal the apparent resistivities.

The iterative process is terminated when one of the following conditions is met: a prescribed minimum rms percent (less than 2 percent for field data) is obtained; a slowness in further improvement in fit is detected (less than 5 percent reduction in successive rms percent); a maximum number (30) of iterations is reached; or the rms percent increases instead of decreases. The average number of iterations is about 10.

In the present work, Zohdy's method has been utilized for the quantitative nterpretation of VES data, alongwith curve matching (in direct) technique given by Orellana and Mooney (1966).

4.4 DATA ACQUISITION AND INTERPRETATION

4.4.1 Geological Sections

(a) Section N N^{-}

Figure 4.1 shows the location of geological cross-sections used for the hydrogeological investiggations. Geological section (N N^{-}) passes across Bawana, Sessote, Mahendragarh and Derolijat villages (Fig.4.2). As observed from the figure, the sandy layer of variable thickness, which is intermixed with gravel in few locations, is underlain by a thick zone of clay formation. Though the thickness of the clay is varying from place to place, it is about 40m thick in Bawana, whereas its thickness increases to about 90m in Mahendragarh and Sessoth. Further, from this figure, it is observed that the thickness of alluvial formations in northern part is greater as compared to the southern part. The clay is underlain by a sandy horizon at Bawana and beneath it the hard rock is encountered with increasing depth towards north.

(b) Section M M^{-}

Figure 4.3 shows geological section (M M^{-}) which covers the area between Kanina khas in the north and Gokalpur in the south. From the figure, the occurence of two sandy horizons of large thickness alternating with clay beds is observed in this profile.The group of sands is again underlain by a clayey layer having a sand pinch out towards south.The tubewells end up in the hard bed rock around elevation of 130-140m above mean sea level.

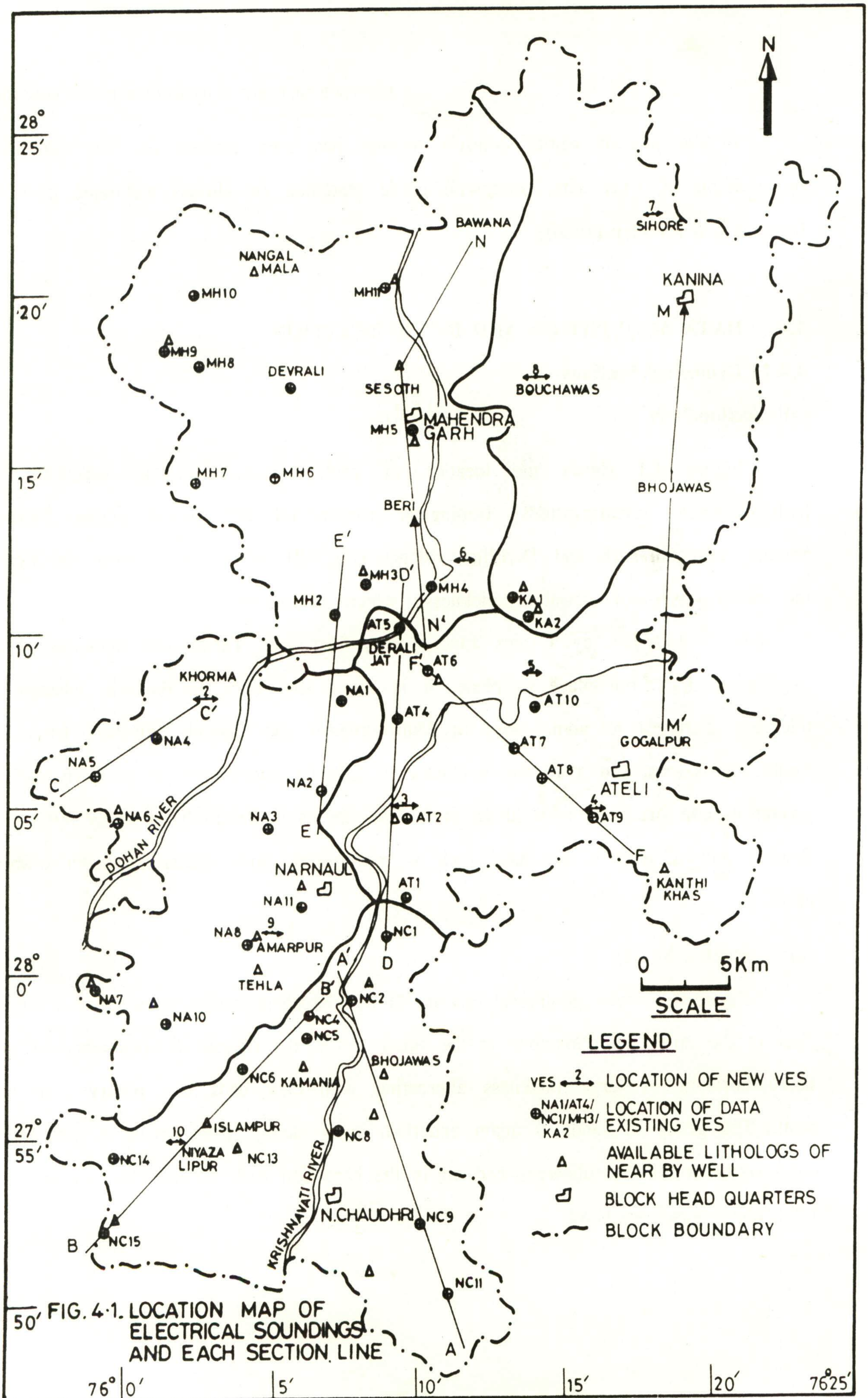


FIG. 4·1. LOCATION MAP OF ELECTRICAL SOUNDINGS AND EACH SECTION LINE

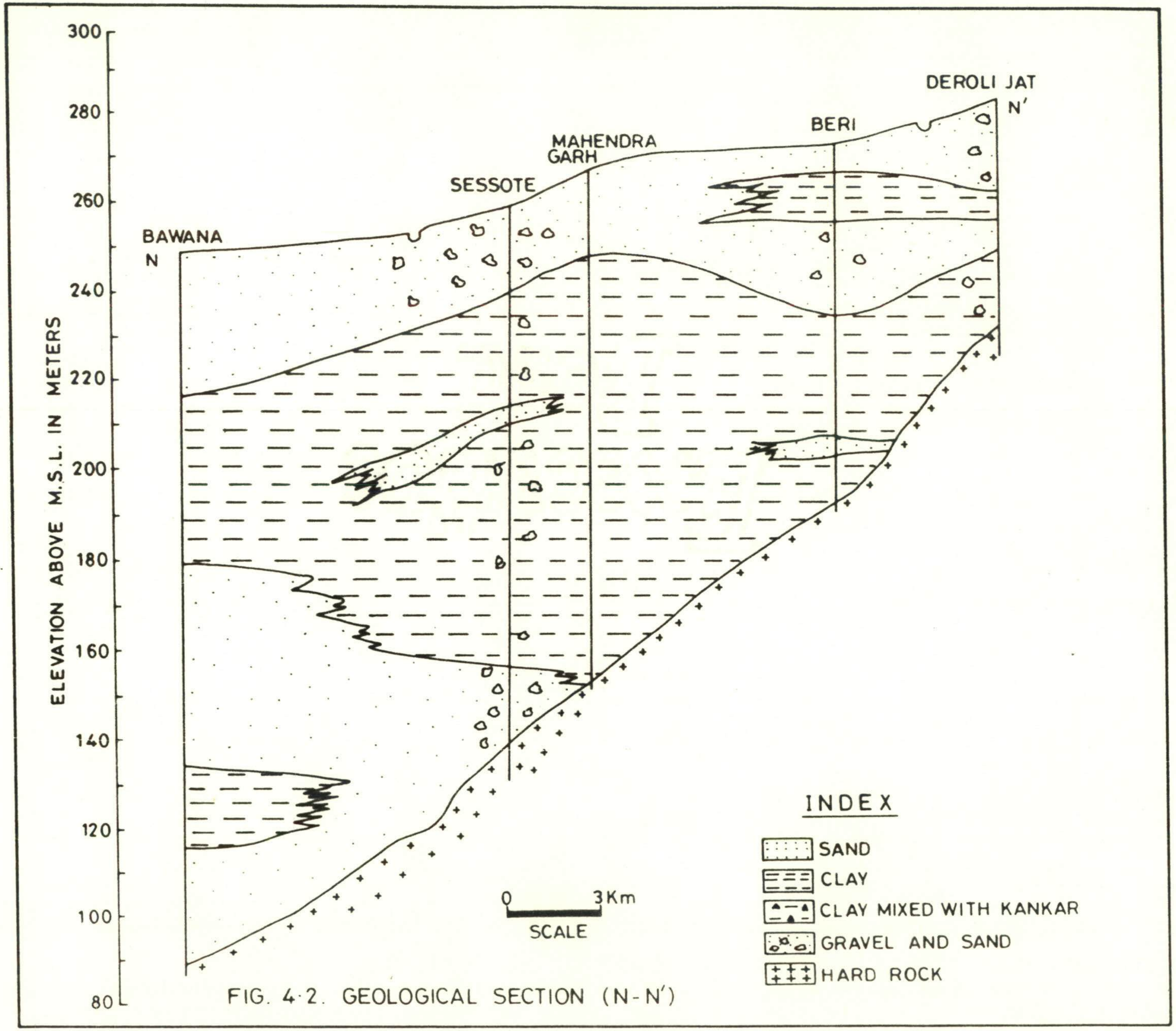


FIG. 4·2. GEOLOGICAL SECTION (N-N')

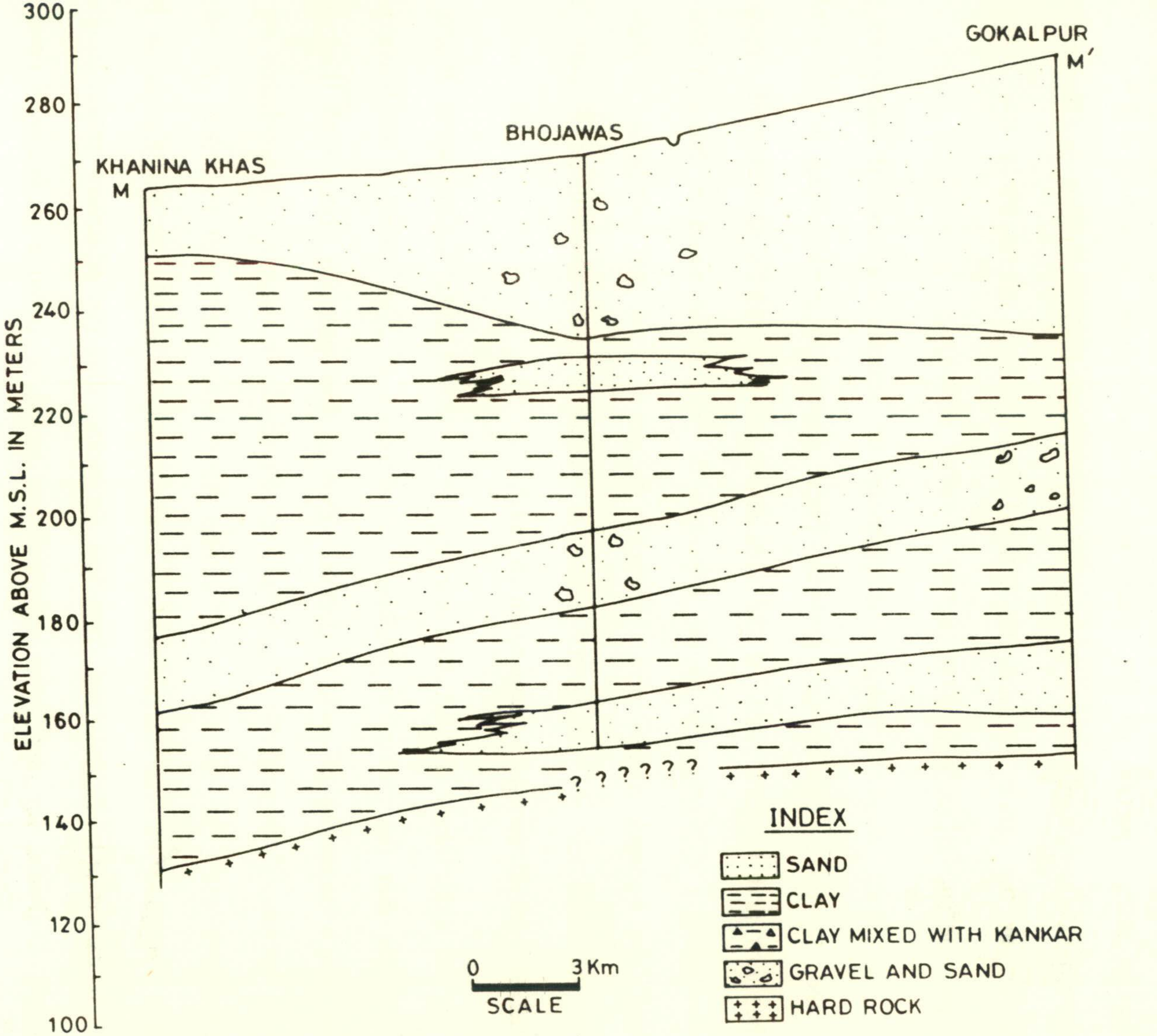


FIG. 4·3. GEOLOGICAL SECTION (M-M')

4.4.2 Subsurface Geological Framework and Information gaps:

Based on available lithological data of existing tubewells, preparation of a geological fence diagram of the study area has also been attempted (Fig.4.4) using standard procedures outlined by Moore (1968), Walton (1970), Freeze & Cherry (1987). However, as the fence diagram has utilised the lithologs of relatively few tube wells (14 no.), the subsurface geological picture is rather sketchy.

The fence diagram reveals the presence of Recent alluvium. It comprises sand, clay and intermixed kankar and gravels. These appear to predominate in the northern, northeastern and western parts of the area, whereas the underlying basement appears to be contrastingly different due to the exposure of hard rocks south of Narnaul town. In general, the bedrock slopes down towards the north, east and northeast in the area. Thus, the thickness of alluvium, which is comprised of admixtures of clay, sand, kankar and gravel increases from south to north.

The exploratory drilling was carried out by the Central Groundwater Board. The data reveals that the maximum thickness of alluvium is upto 150m in northeastern part below which basement of rock is present. Two to four granular zones with thickness of varying between 11m and 49m have been encountered. In majority of boreholes the clay predominates over the sand. Seprate kankar beds have been also recorded. At shallow depth i.e upto 30m, the proportion of sand in all the blocks except Kanina is below 50%. It can readily be inferred from the foregoing that the relatively small number of lithologs, available for the fence diagram has failed to provide a synoptic continuous geological picture of the subsurface features in the area. Accordingly, attempts are made to decipher the subsurface picture from the interpretation of the available geological data.

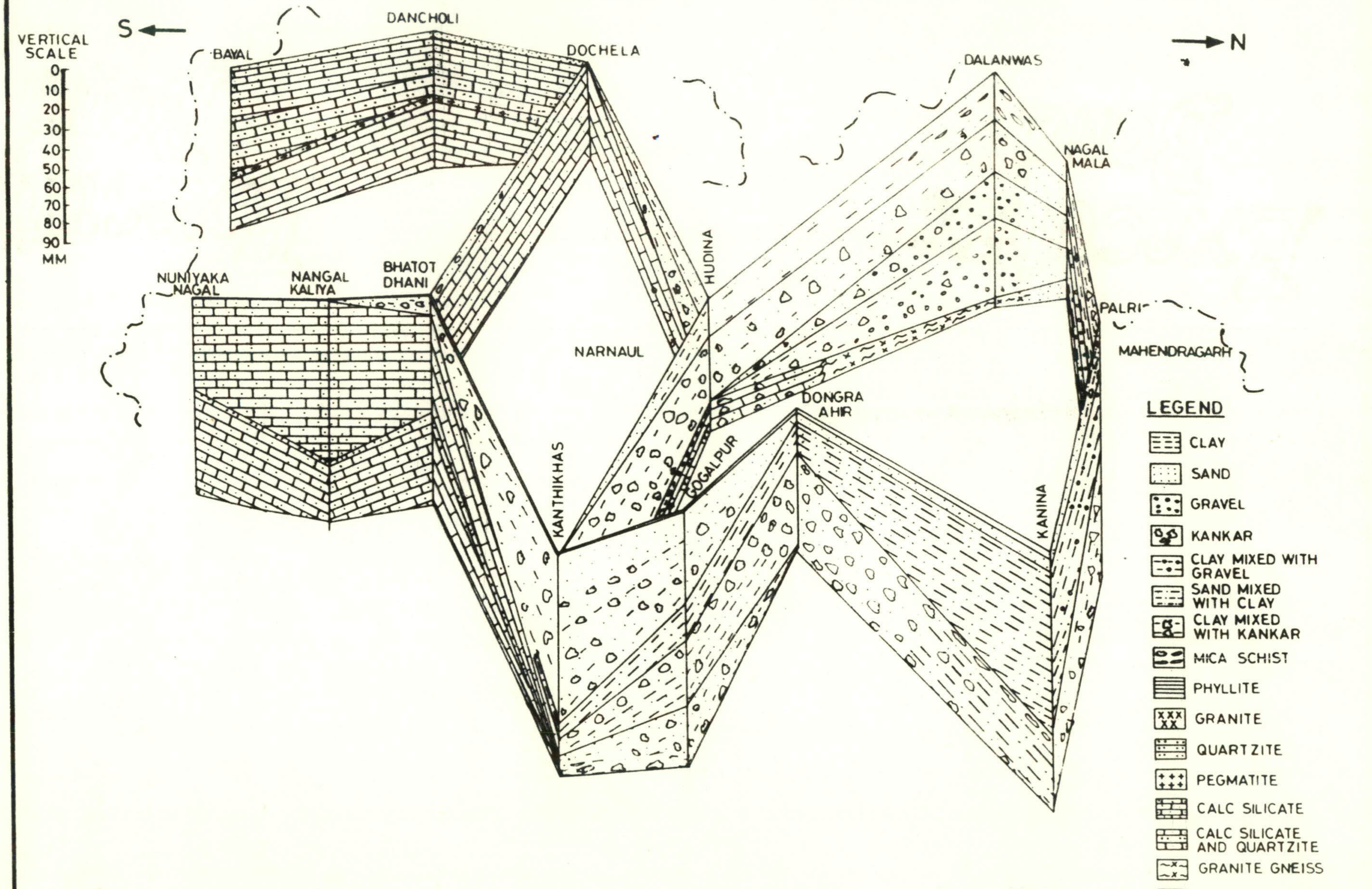


FIG. 4·4. GEOLOGICAL FENCE DIAGRAM FOR PART OF STUDY AREA

4.4.2.1 Field Geophysical Study:

In view of the gaps in the geological data due, it was considered necessary to carry out geophysical resistivity study from the freshly-generated resistivity sounding data as well as from the available VES data for the area. A total of 54 vertical electrical soundings (VES) including 10 nos. of new VES profiles were used in this study. The freshly generated data were recorded using schulumberger electrode configuration. The maximum current electrode (AB) separation was kept between 400-500 m. In addition to the new data, the existing data of 44 VES locations as available from Groundwater cell (GWC), Haryana have been considered for evaluating subsurface geological framework in the area. Figure 4.1 shows the location map of all the geoelectrical souding in the study area. The field apparent resistivity data for different values of AB/2 have been processed and the sounding data have been interpreted by indirect method (curve matching) as well as from the computer technique (cf. Zohdy, 1989). The true resistivity values and the corresponding layer thicknesses interpreted from the computer software are given in **Table** 4.1. However, it is clear from these results that the geophysical picture is available only upto depths of 50-60m below the surface. Some selected VES curves are presented in Figure 4.5 to 4.14.

4.4.2.2 Establishment of Resistivity Ranges for Geological Formations

The interpreted quantitative resistivity data of the VES soundings has been carefully compared with the lithologs of 18 tubewells located in the vicinity of the corresponding sounding points in the study area. The general distribution of resistivity ranges adopted for different geological formations in the area is based on the resistivity response of the formations obtained from these soundings. **Table** 4.2 illustrates the ranges of resistivity for different geological formations. It may be

Table 4.1 Result of Automatic Interpretation of V.E.S Data in The Study Area

LAYER	1		2		3		4		5		6		7		8		9		10		11		12		13	
V.E.S	ρ_1	h_1	ρ_2	h_2	ρ_3	h_3	ρ_4	h_4	ρ_5	h_5	ρ_6	h_6	ρ_7	h_7	ρ_8	h_8	ρ_9	h_9	ρ_{10}	h_{10}	ρ_{11}	h_{11}	ρ_{12}	h_{12}	ρ_{13}	h_{13}
NC1	14.4	0.8	15.7	1.2	17.0	1.8	19.2	2.7	23.5	4.0	27.5	5.9	25.4	8.7	17.5	12.8	12.4	18.8	14.0	27.6	20.8	40.6	17.3	59.6	3.9	+ +
NC2	29.0	0.9	25.2	1.4	34.2	2.0	55.6	3.0	32.0	4.5	94.3	6.6	78.2	9.7	49.2	14.2	30.5	20.9	24.3	30.7	27.1	45.1	41.0	66.2	67.8	+ +
NC4	142.3	0.9	103.2	1.2	83.6	2.0	84.5	3.0	91.3	4.5	76.3	6.6	59.9	9.7	73.7	14.2	131.2	20.9	217.5	30.7	265.8	45.1	228.0	66.2	144.6	+ +
NC5	31.6	0.9	56.3	1.4	67.2	2.0	46.5	3.0	18.8	4.5	6.3	6.6	4.1	9.7	5.4	14.2	9.4	20.9	18.3	30.7	35.9	45.1	70.1	66.2	142.8	+ +
NC6	78.1	0.8	108.5	1.8	55.4	2.7	55.2	4.0	55.2	4.0	26.8	5.9	62.7	8.7	151.3	12.8	273.3	18.8	360.4	27.6	411.6	40.6	552.5	59.6	1062.0	+ +
NC8	43.2	0.9	33.4	1.4	38.4	2.0	40.9	3.0	34.1	4.5	29.2	6.6	28.5	9.7	24.6	14.2	18.4	20.9	19.5	30.7	37.1	45.1	95.3	66.2	268.8	+ +
NC9	171.3	0.9	81.0	1.4	76.9	2.0	62.4	3.0	123.7	4.5	107.7	6.6	92.5	9.7	22.9	14.2	16.9	20.9	22.0	30.7	45.3	45.1	118.2	66.2	189.4	+ +
NC11	54.2	0.9	28.3	1.4	31.3	2.0	37.8	3.0	30.2	4.5	25.5	6.6	30.9	9.7	32.4	14.2	19.4	20.9	9.8	30.7	10.3	45.1	24.4	66.2	77.1	+ +
NC13	8.4	0.8	10.0	1.2	10.3	1.8	10.1	2.7	10.7	4.0	11.0	5.9	9.6	8.7	9.3	12.8	11.9	18.8	19.3	27.6	40.9	40.6	110.2	59.6	351.9	+ +
NC14	42.2	0.7	25.6	1.1	17.7	1.7	9.3	2.4	19.0	3.6	21.5	5.3	40.9	7.8	67.4	11.5	123.7	16.9	199.3	24.9	445.0	36.5	557.3	53.6	861.1	+ +
NC15	40.3	0.7	19.4	1.1	14.0	1.7	20.1	2.4	34.9	3.6	53.3	5.3	69.9	7.8	84.5	11.5	95.6	11.9	97.7	24.9	98.4	36.5	11.9	53.9	161.7	+ +
NA1	51.3	0.9	12.2	1.4	9.1	2.0	17.6	3.0	26.5	4.5	29.4	6.6	23.6	9.7	11.9	14.2	5.8	20.9	6.6	30.7	13.3	45.1	30.3	66.2	73.5	+ +
NA2	37.4	0.9	29.4	1.4	26.4	2.0	25.6	3.0	25.1	4.5	24.5	6.6	23.7	9.7	23.9	14.2	25.4	20.9	25.1	30.7	18.2	45.1	9.3	66.2	4.9	+ +
NA3	41.3	0.9	44.1	1.4	47.8	2.0	49.9	3.0	46.0	4.5	34.2	6.6	22.2	9.7	16.5	14.2	18.5	20.9	28.6	30.7	47.3	45.1	82.4	66.2	156.3	+ +
NA4	85.4	0.9	25.9	1.4	29.2	2.0	30.7	3.0	50.5	4.5	83.1	6.6	54.0	9.7	40.2	14.2	17.4	20.9	15.9	30.7	48.2	45.1	70.3	66.2	167.8	+ +
NA5	33.1	1.0	26.0	1.5	22.9	2.3	26.2	3.4	34.2	5.0	40.2	7.3	35.7	10.8	24.9	15.8	19.0	23.2	19.6	34.1	22.4	50.1	32.0	73.5	63.4	+ +
NA6	26.9	0.9	26.9	1.4	33.5	2.0	39.9	3.0	40.1	4.5	30.4	6.6	16.2	9.7	10.0	14.2	13.5	20.9	28.0	30.7	59.3	45.1	124.4	66.2	269.2	+ +
NA8	41.5	0.9	55.4	1.4	62.1	2.0	53.5	3.0	37.6	4.5	27.8	6.6	26.2	9.7	24.5	14.2	20.9	20.9	25.2	30.4	44.2	45.1	89.2	66.2	189.3	+ +
NA9	156.0	0.9	111.3	1.4	69.9	2.0	50.4	3.0	44.6	4.5	31.8	6.6	17.4	9.7	13.7	14.2	18.4	20.9	25.9	30.7	33.5	45.1	53.9	66.2	127.1	+ +
NA10	10.4	0.8	10.1	1.2	12.2	1.8	17.2	2.7	24.6	4.0	31.2	5.9	29.5	8.7	18.3	12.8	10.4	18.8	11.1	27.6	23.4	40.6	61.9	59.6	178.5	+ +
NA11	47.0	0.9	35.7	1.4	23.0	2.0	22.7	3.0	32.5	4.5	36.1	6.6	24.6	9.7	12.3	14.2	7.7	20.9	9.9	30.7	21.0	45.1	48.3	66.2	110.7	+ +
AT1	66.3	0.9	44.8	1.4	25.6	2.0	18.5	6.0	2.0	4.5	24.7	6.6	23.1	9.7	19.2	14.2	19.0	20.9	20.9	30.7	20.9	45.1	22.7	66.2	33.8	+ +
AT2	40.3	0.9	32.4	1.4	35.5	2.0	50.8	3.0	57.9	4.5	42.3	6.6	23.9	9.7	14.5	14.2	8.3	20.9	5.3	30.7	8.0	45.1	20.0	66.2	55.9	+ +
AT4	140.6	0.8	73.0	1.2	71.7	1.8	121.7	2.7	187.3	4.0	188.0	5.9	118.1	8.7	62.0	12.8	53.8	18.8	71.2	27.6	80.0	40.6	78.9	56.9	82.0	+ +

(Table 4.1 Cotinued)

Table 4.1 Cotinued

AT5	118.6	0.9	80.3	1.4	48.8	2.1	37.6	3.1	44.0	4.6	60.9	6.7	80.7	9.9	83.1	14.5	49.7	21.4	18.3	31.4	11.1	46.1	20.5	67.0	153.9	+ +
AT6	69.2	0.9	45.0	1.4	44.8	2.0	66.4	3.0	87.2	4.5	74.2	6.6	45.1	9.7	34.5	14.2	40.8	20.9	32.4	30.7	15.6	45.1	16.0	66.2	40.5	+ +
AT7	24.1	1.4	21.4	1.4	16.2	2.0	15.7	3.0	13.2	4.5	12.8	6.6	15.5	9.7	18.4	14.2	16.0	20.9	8.43	30.7	4.5	45.1	6.9	66.2	20.8	+ +
AT8	19.1	0.9	18.7	1.4	19.5	2.0	22.4	3.0	26.9	4.5	28.1	8.8	21.1	9.7	11.5	14.2	6.5	20.9	8.72	30.7	7.0	45.1	9.7	66.2	13.0	+ +
AT9	45.6	0.9	46.9	1.4	48.6	2.0	50.7	3.0	50.8	4.5	41.2	6.6	24.0	9.7	13.7	14.2	11.1	20.9	10.5	30.7	9.4	45.1	9.9	66.2	12.4	+ +
AT10	95.1	0.9	85.9	1.4	73.2	2.0	62.7	3.0	55.7	4.5	53.9	6.6	71.6	9.7	52.4	14.2	36.9	20.9	19.5	30.7	9.8	45.1	13.0	66.2	41.1	+ +
MH2	75.8	0.9	34.7	1.4	39.1	2.0	45.8	3.0	33.5	4.5	22.0	6.6	23.0	9.7	32.5	14.2	35.1	20.9	19.8	30.7	12.3	45.1	22.5	66.5	84.0	+ +
MH3	164.7	0.9	270.3	1.4	325.3	2.0	263.2	3.0	178.8	4.5	156.9	6.6	178.3	9.7	147.2	14.2	62.5	20.9	26.7	30.7	28.6	45.1	49.1	66.2	87.7	+ +
MH4	68.1	0.8	21.4	1.2	23.7	1.8	46.6	2.7	83.2	4.0	105.1	5.9	92.4	8.7	71.7	12.8	56.3	18.8	26.7	27.6	5.20	40.6	4.9	59.6	28.8	+ +
MH5	95.4	0.9	107.2	1.4	129.3	2.0	160.1	3.0	184.3	4.5	179.4	6.6	135.0	9.7	74.6	14.2	35.4	20.9	21.0	30.7	16.8	45.1	16.7	66.2	19.1	+ +
MH6	368.5	1.0	236.2	1.5	167.2	2.3	132.1	3.4	115.3	5.0	116.0	7.3	115.0	10.8	91.0	15.8	50.9	23.7	19.3	34.1	7.31	50.1	8.0	73.5	22.0	+ +
MH8	603.4	0.9	474.2	1.4	271.5	2.1	179.0	3.1	187.3	4.6	221.3	9.9	270.7	9.9	356.6	14.5	21.4	353.6	31.4	171.7	46.11	62.9	67.6	44.1	99.3	+ +
MH9	419.0	0.9	40.17	1.4	380.5	2.0	281.5	3.0	184.3	4.5	173.7	6.6	248.1	9.7	334.2	14.2	318.7	20.9	197.9	30.7	64.95	45.1	13.0	66.2	17.1	+ +
MH10	140.1	0.9	61.1	1.4	45.3	2.1	78.4	3.1	151.6	4.6	105.6	6.7	90.0	9.9	87.9	14.5	47.5	21.4	61.5	31.4	29.44	46.1	13.4	67.6	7.5	+ +
MH11	64.4	0.9	59.0	1.4	65.0	2.0	74.3	3.0	73.8	4.5	64.1	6.6	52.3	9.7	33.5	14.2	11.5	20.9	2.19	30.7	1.31	45.1	3.0	66.2	8.3	+ +
VES1	98.9	1.4	107.8	2.0	118.7	3.0	126.5	4.5	99.7	6.6	48.1	9.7	35.9	14.2	89.2	20.9	281.0	30.7	630.2	45.1	971.3	66.2	1029.0	+ +		
VES2	57.7	1.1	45.9	1.6	33.6	2.4	28.8	3.6	26.5	5.3	16.7	7.7	9.1	11.4	10.0	16.7	17.6	24.5	25.9	36.0	30.5	52.9	32.3	+ +		
VES3	2.8	1.0	3.8	1.5	5.5	2.2	8.0	3.2	12.9	4.8	20.7	7.0	26.4	10.4	22.8	15.2	15.6	22.4	14.1	32.8	22.0	48.2	44.3	+ +		
VES4	130.6	1.0	115.8	1.5	117.6	2.3	130.5	3.4	133.6	5.0	114.2	7.3	83.6	10.8	56.1	15.8	35.0	23.2	20.8	34.1	13.2	50.1	9.2	73.5	5.4	+ +
VES5	215.8	1.0	107.2	1.4	88.9	2.1	93.1	3.1	60.0	4.6	28.7	6.8	21.4	9.9	25.9	14.6	30.3	21.5	21.6	31.5	9.8	46.3	6.6	+ +		
VES6	73.8	0.9	70.1	1.4	44.3	2.0	24.3	3.0	25.0	4.5	34.1	6.6	36.4	9.7	31.9	14.2	24.6	20.9	17.4	30.7	17.1	31.6	66.2	+ +		
VES7	17.5	1.1	21.6	1.6	26.6	2.4	31.9	3.5	38.1	5.2	43.8	7.7	36.1	11.3	13.3	16.6	3.4	24.3	4.7	35.7	22.4	+ +				
VES8	119.9	1.3	165.6	1.9	193.2	2.9	180.3	2.2	140.2	6.2	104.4	9.2	36.7	13.5	75.0	19.8	49.5	29.0	22.0	42.6	11.6	62.6	8.7	91.9	1.9	+ +
VES9	35.1	1.2	19.4	1.8	18.2	2.7	24.9	4.0	26.8	5.9	18.2	8.7	12.1	12.8	14.3	18.8	23.5	27.6	37.1	40.1	66.6	59.6	153.3	+ +		
VES10	88.4	0.8	166.1	1.2	291.7	1.8	392.3	2.7	338.0	4.0	175.9	8.9	89.0	8.7	106.9	12.8	245.5	18.8	475.1	27.6	665.2	40.6	816.0	59.6	1053.0	+ +
KA1	112.0	0.9	156.0	1.4	167.8	2.0	122.2	3.0	70.2	4.5	48.4	6.6	42.3	9.7	31.9	14.2	21.1	20.9	15.1	30.7	9.9	45.1	7.5	66.2	9.1	+ +
KA2	273.3	0.9	97.4	1.4	54.2	2.0	62.6	3.0	61.7	4.5	43.8	6.6	36.8	9.7	47.6	14.2	47.9	20.9	30.1	30.7	14.6	45.1	11.4	66.2	18.8	+ +

FIG. 4·5 NANGAL NC5 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.97	31.60	9.72	4.14
1.43	56.36	14.27	5.44
2.09	67.26	20.94	9.46
3.07	46.51	30.74	18.37
4.51	18.93	45.12	35.93
6.62	6.38	66.22	70.71
		99999.00	142.87

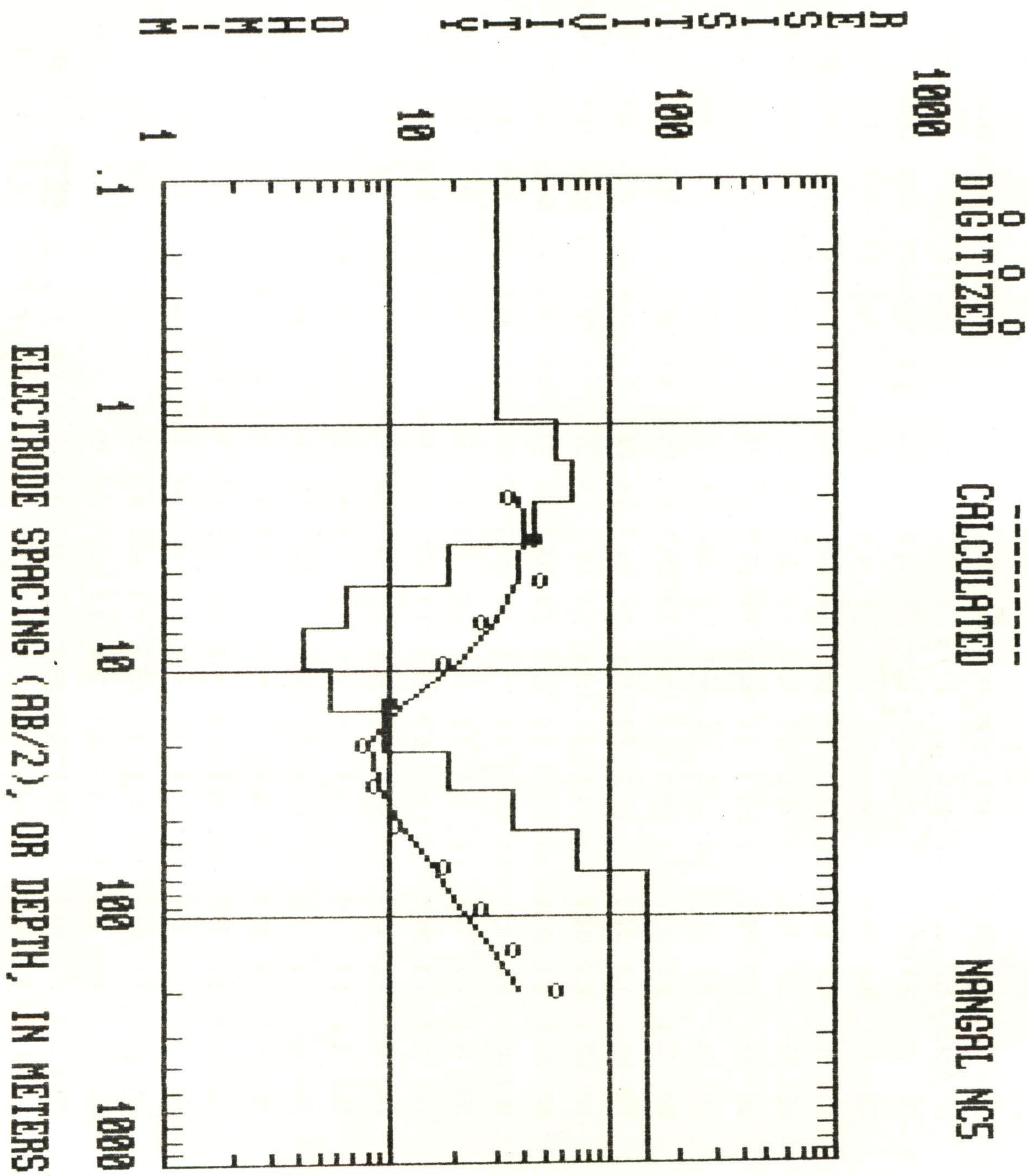


FIG. 4·6. NANGAL NC14 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.79	47.21	7.87	40.91
1.16	25.62	11.56	67.42
1.70	17.76	16.96	123.72
2.49	9.37	24.90	199.34
3.65	19.06	36.54	445.00
5.36	21.51	53.64	557.35
		99999.00	861.16

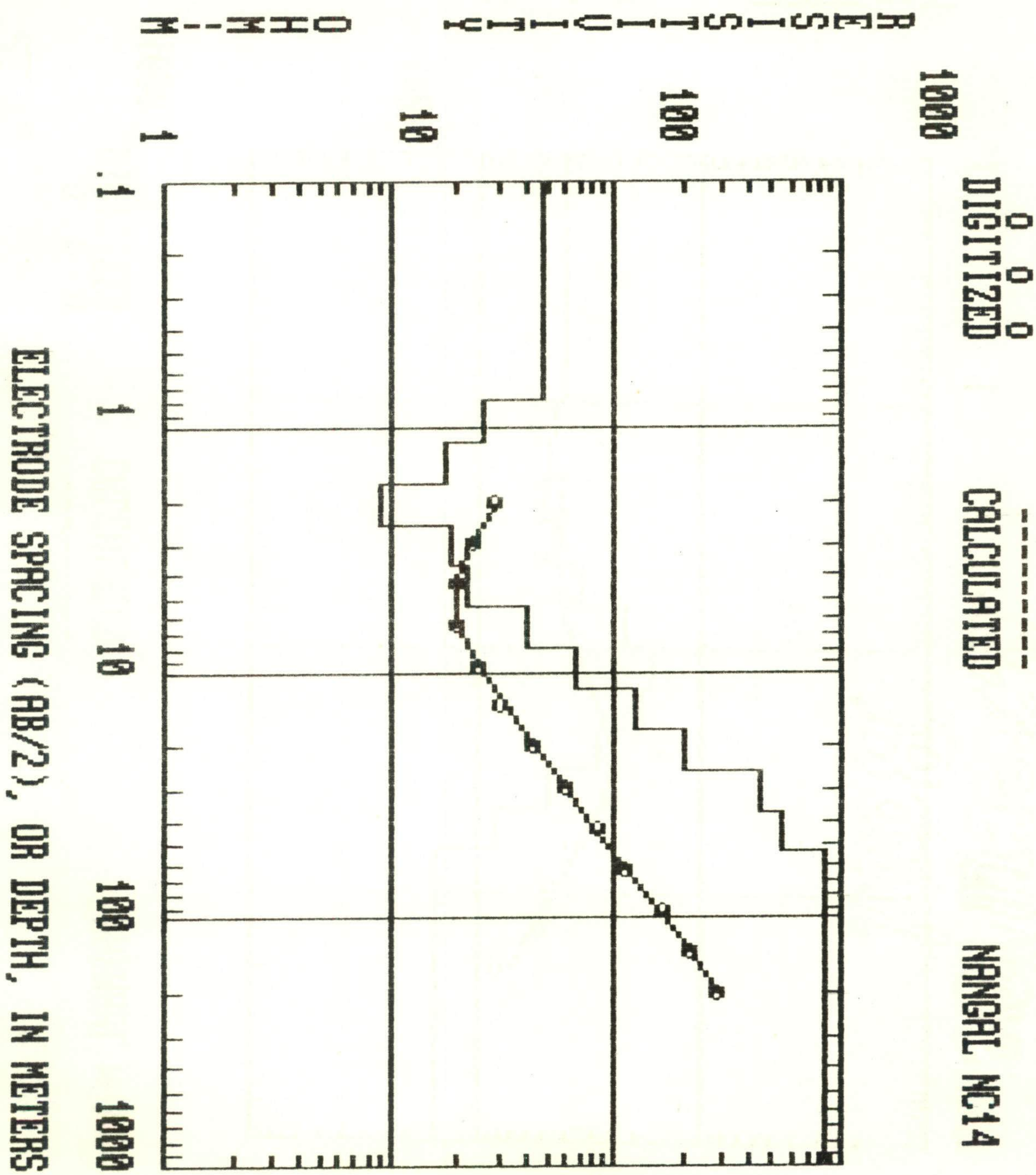


FIG. 4·7. NARNAUL NA3 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.97	41.32	9.72	22.26
1.43	44.19	14.27	16.56
2.09	47.83	20.94	18.54
3.07	49.94	30.74	28.68
4.51	46.01	45.12	47.34
6.62	34.25	66.22	82.49
		99999.00	156.37

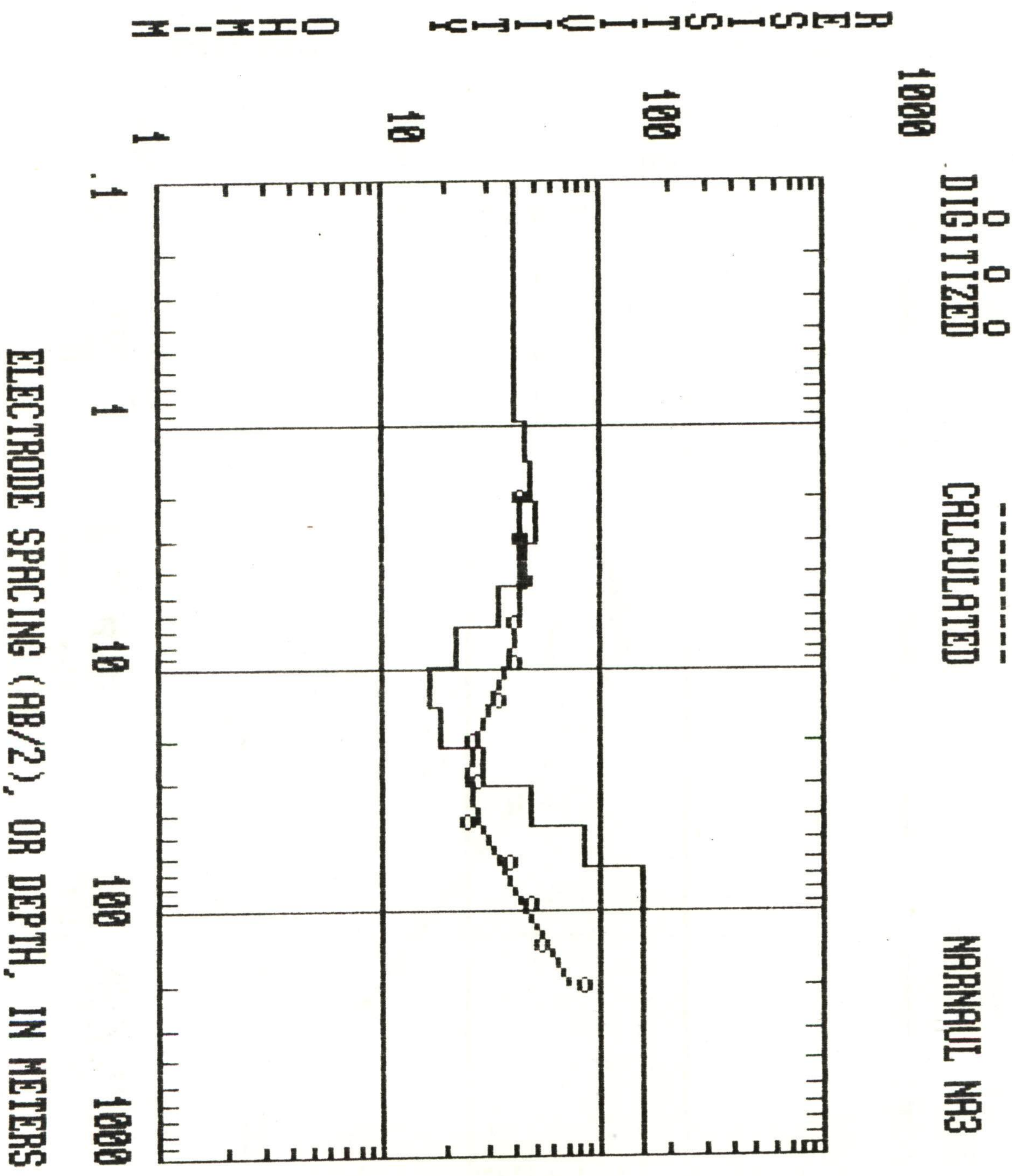


FIG. 4·8. NARNAUL NA7 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.87	23.10	8.75	17.70
1.28	19.60	12.84	24.82
1.88	17.87	18.85	36.34
2.77	17.85	27.66	47.93
4.06	17.20	40.60	58.50
5.96	15.98	59.60	72.00
		99999.00	91.76

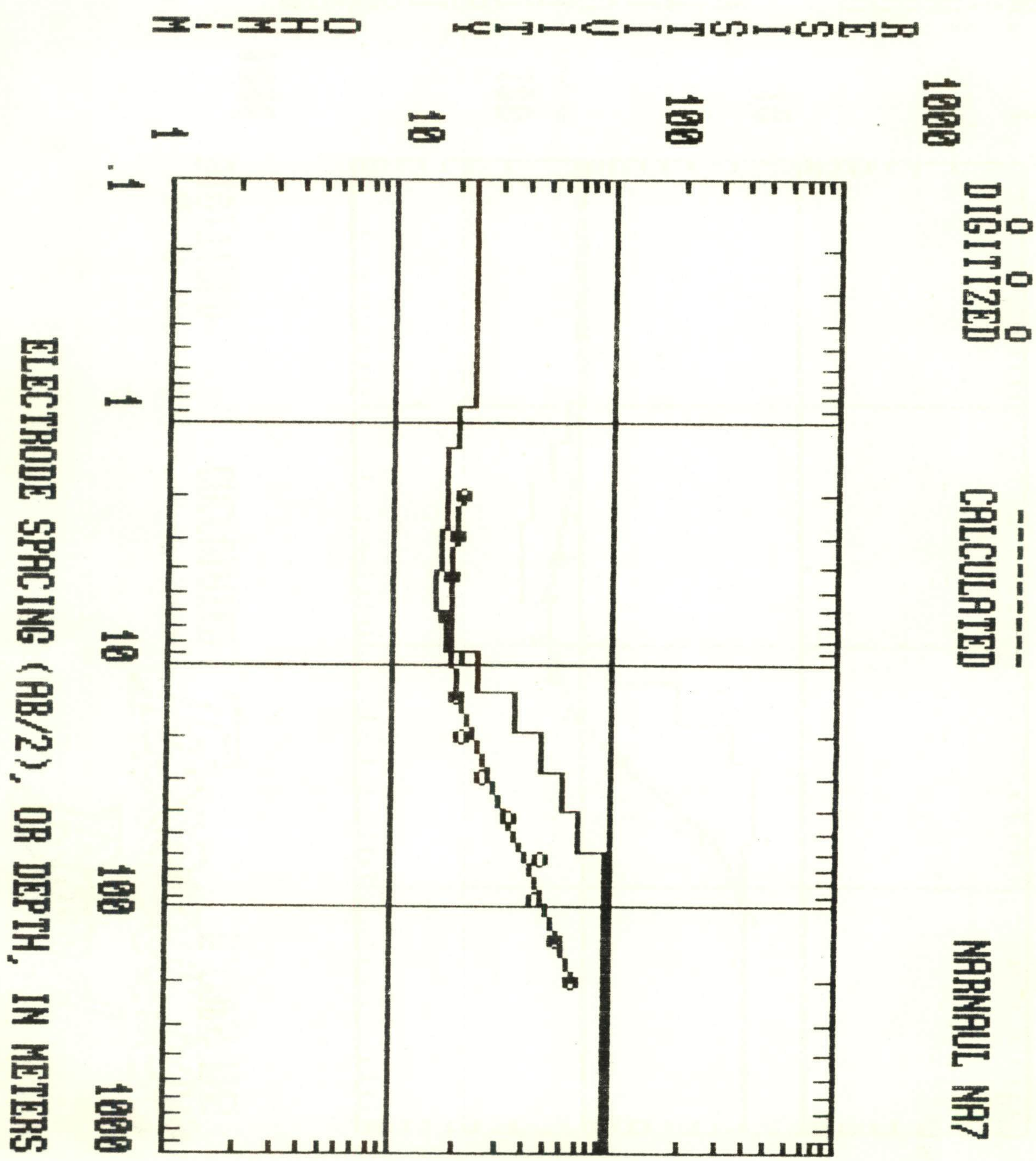


FIG.4·9. M.GARH MH5 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.97	95.40	9.72	135.03
1.43	107.23	14.27	74.65
2.09	129.39	20.94	35.44
3.07	160.12	30.74	21.00
4.51	184.38	45.12	16.86
6.62	179.45	66.22	16.77
		99999.00	19.19

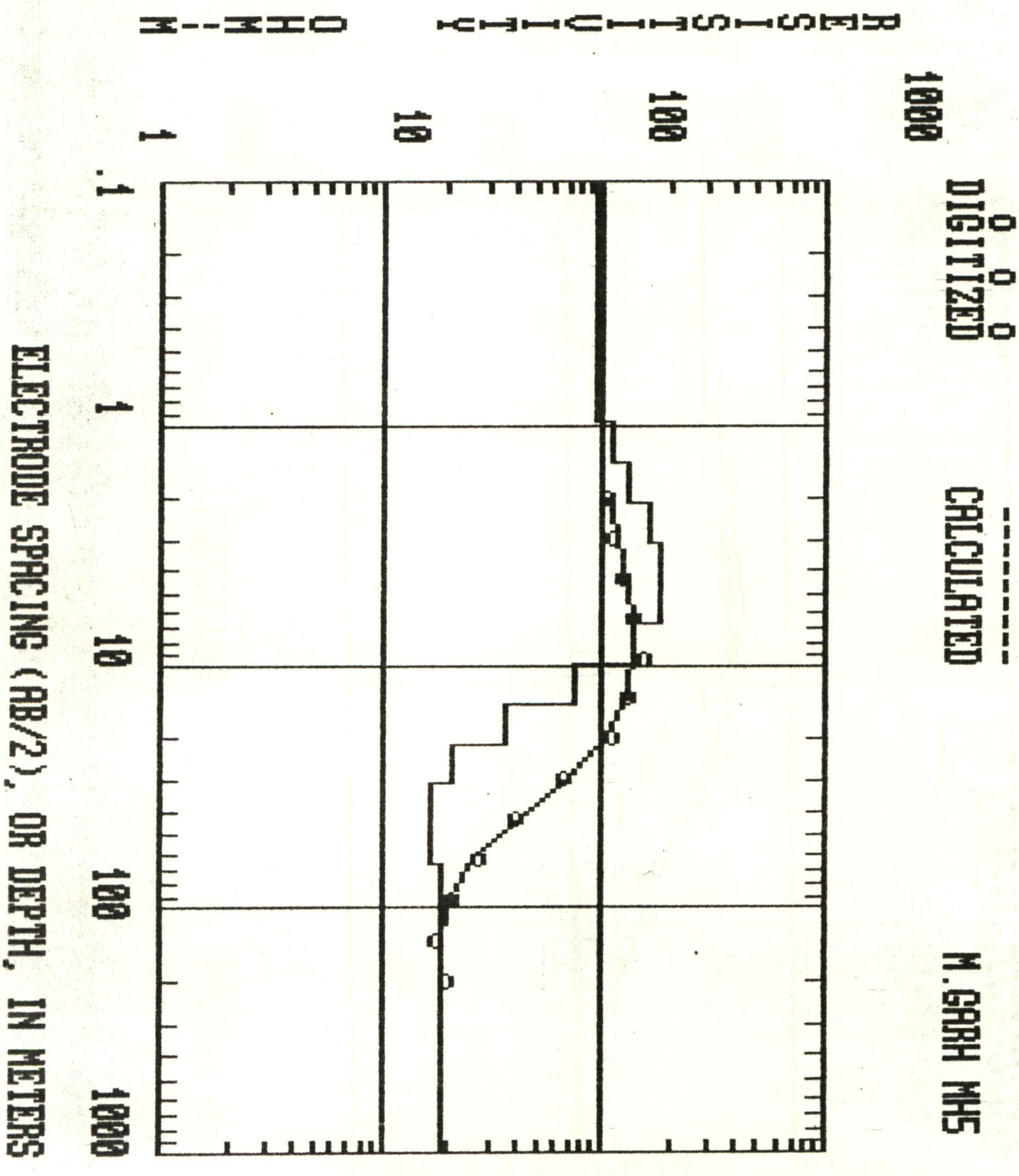


FIG. 4·10. M.GARH MH8 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.99	603.43	14.58	356.67
1.46	474.25	21.40	426.03
2.14	271.50	31.41	353.69
3.14	179.00	46.11	171.76
4.61	187.34	67.67	62.98
6.77	221.37	99.33	44.11
9.93	270.72	99999.00	61.81

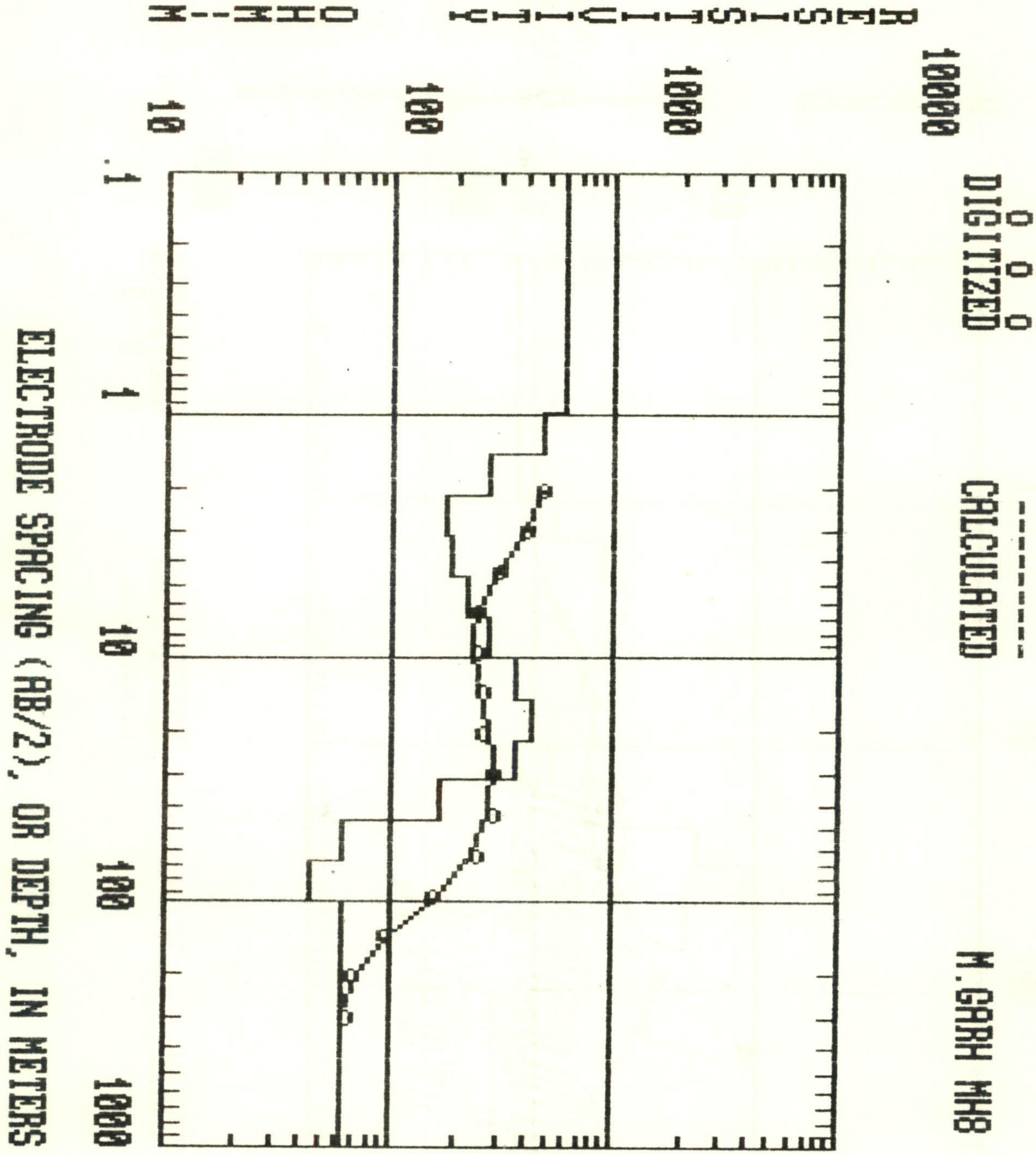


FIG.4·11. ATELI AT5 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.99	118.61	14.58	83.12
1.46	80.37	21.40	49.72
2.14	48.85	31.41	18.33
3.14	37.60	46.11	11.19
4.61	44.07	67.67	20.58
6.77	60.93	99.33	55.55
9.93	80.72	99999.00	153.86

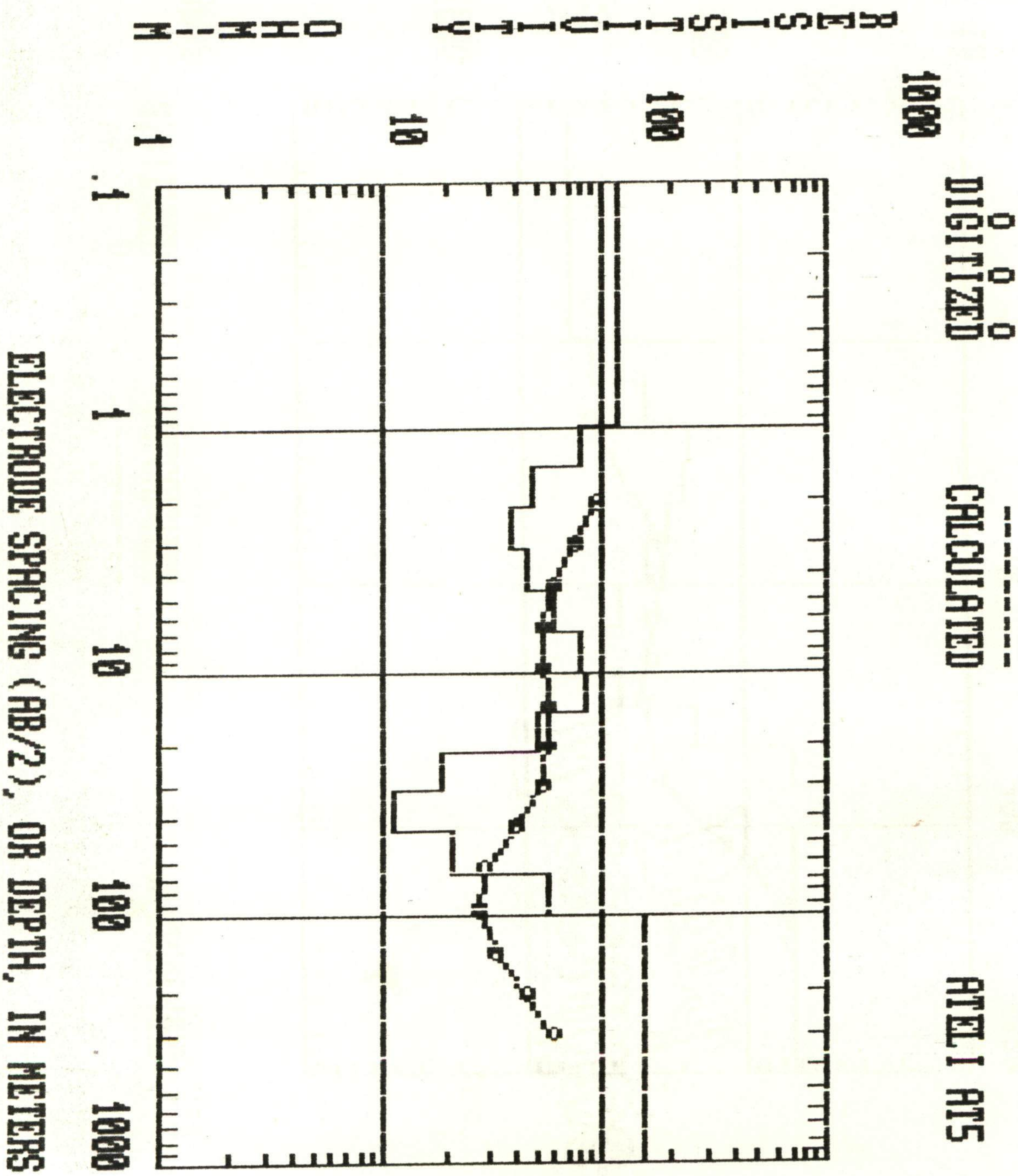


FIG. 4·12. ATELI AT8 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.97	19.18	9.72	21.17
1.43	18.71	14.27	11.52
2.09	19.56	20.94	6.50
3.07	22.44	30.74	5.72
4.51	26.91	45.12	7.07
6.62	28.14	66.22	9.70
		99999.00	13.07

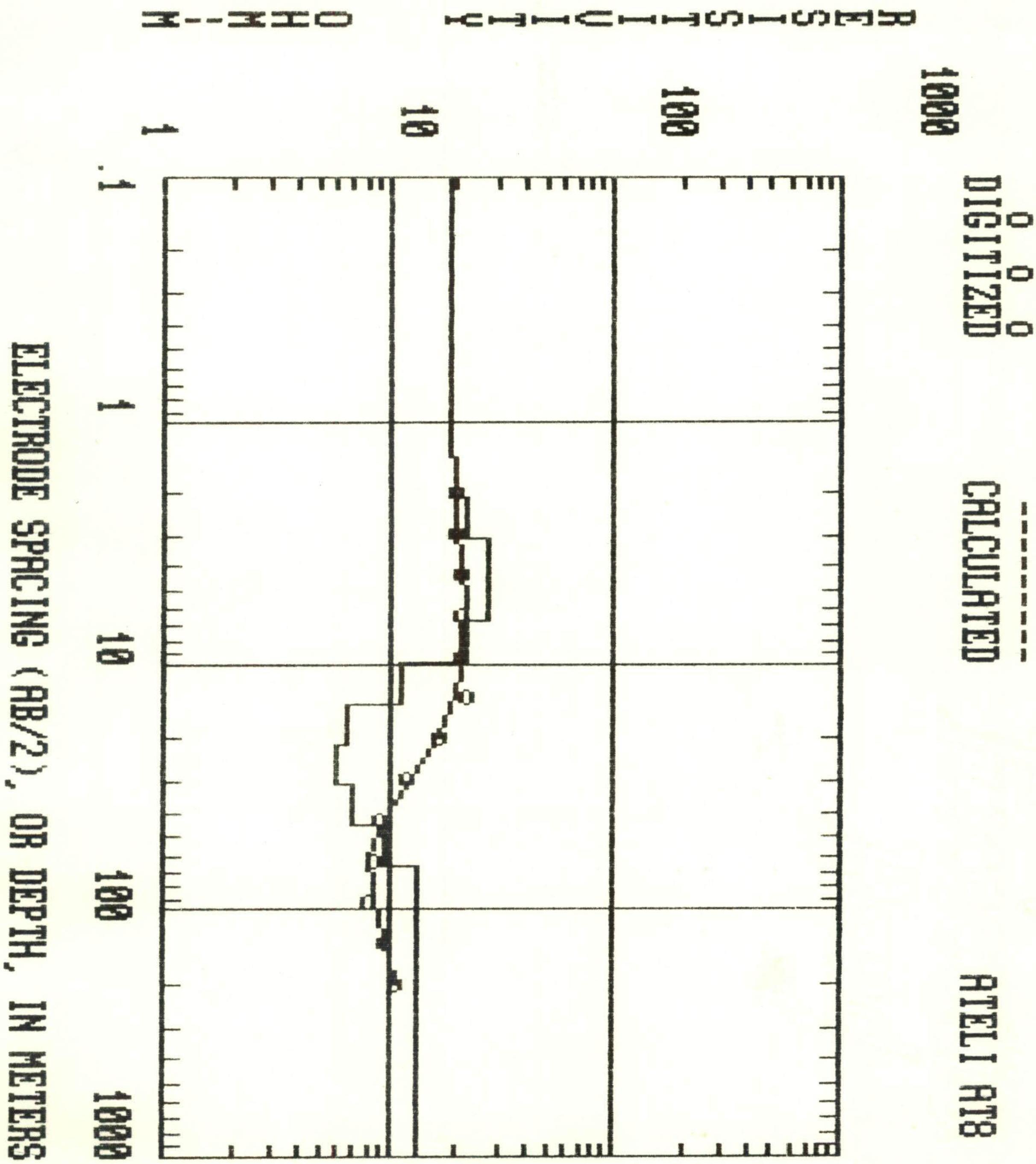


FIG.4.13. D M.GARH VES2 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
1.14	57.78	11.41	9.10
1.68	45.90	16.75	10.09
2.46	33.64	24.59	17.62
3.61	28.87	36.09	25.96
5.30	26.56	52.98	30.54
7.78	16.72	99999.00	32.32

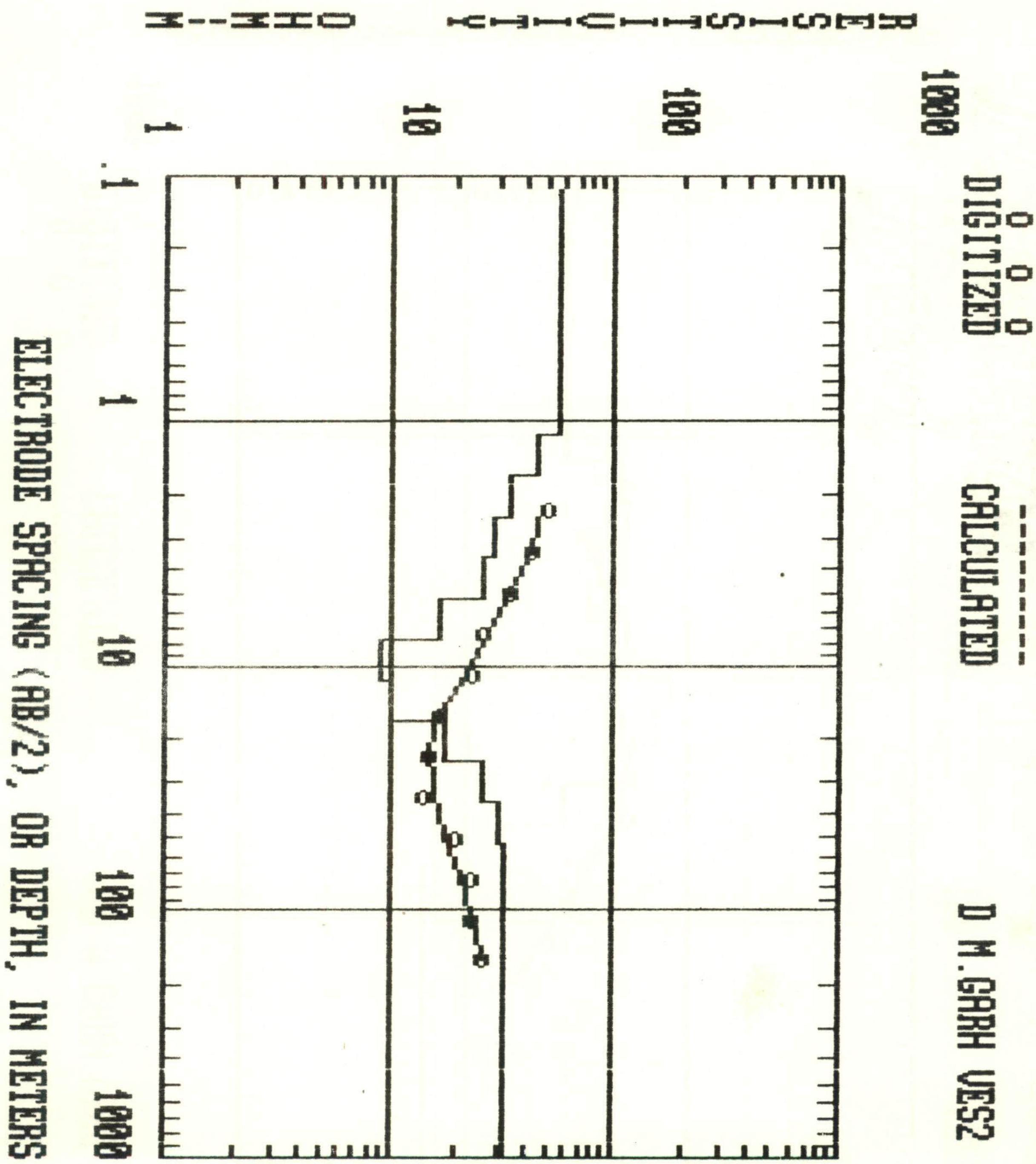


FIG.4.14. D M.GARH VES9 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
1.28	35.17	12.84	12.15
1.88	19.41	18.85	14.39
2.77	18.25	27.66	23.52
4.06	24.92	40.60	37.14
5.96	26.82	59.60	66.68
8.75	18.23	99999.00	153.38

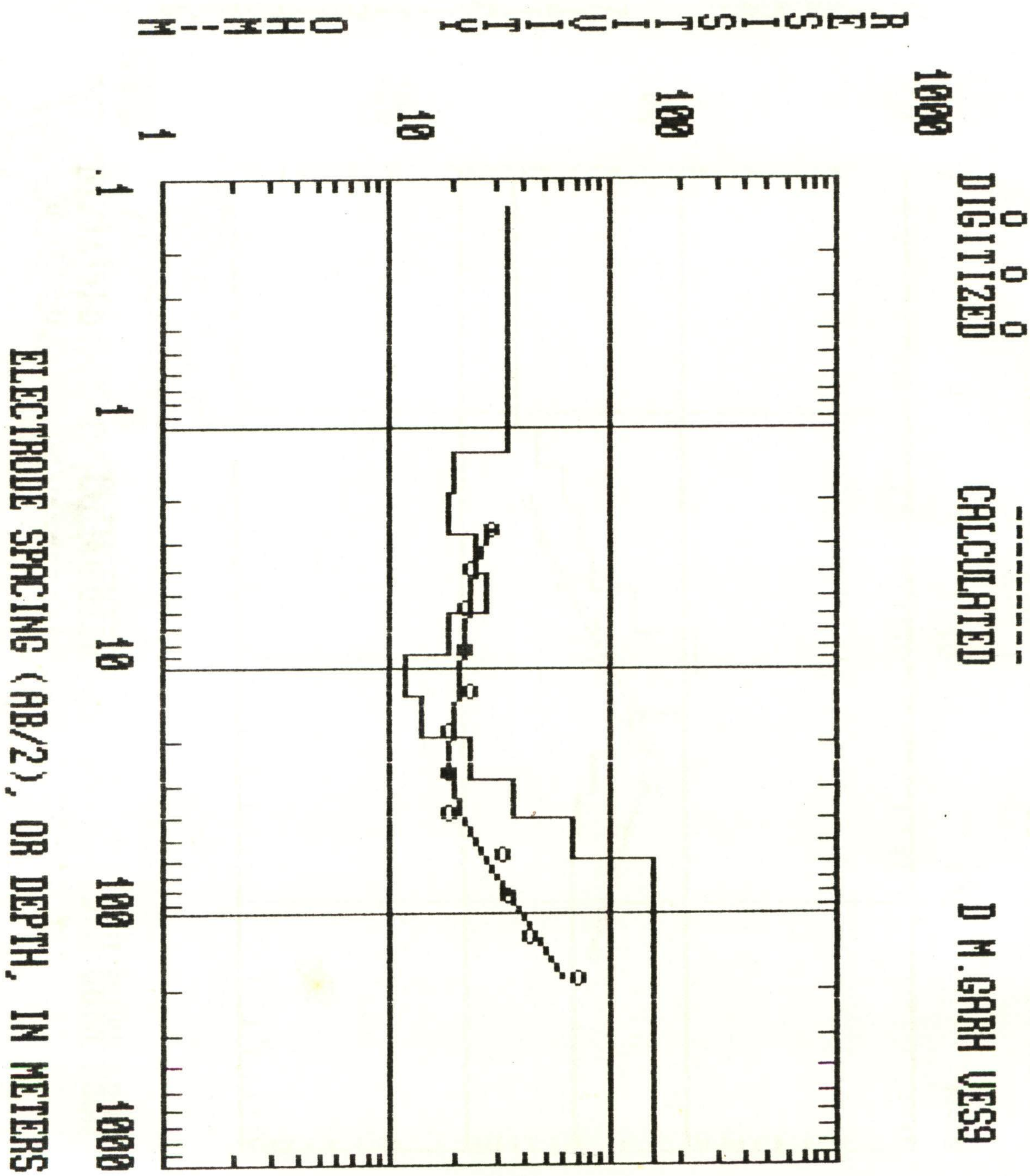


TABLE 4.2 : RESISTIVITY RANGES FOR DIFFERENT GEOLOGICAL FORMATINOS IN THE STUDY AREA

LITHOLOGY	BLOCKS, RANGES OF RESISTIVITY, ohm-m					BROAD RANGES OF RESISTIVITY, ohm-m
	N.CHOUDHRY	NARNAUL	ATELI	MAHINDRAGARH	KANINA	
TOP SOIL CLAY MIXED WITH KANKAR SAND	30	5-110	40-215	5-100	30-40	5-215
SAND	35	18-68	20-110	18-62	15	18-110
CLAY MIXED WITH SAND	-	-	5-10	76-100	-	5-100
CLAY	10-11	-	4-8	5-18	-	4-18
CLAY MIXED-WITH KANKAR	35	50-153	9-30	50-80	-	9-153
PEGMATITE	-	>200	-	200-270	-	200-270
QURTZITE WEATHERED AND SEMICOMPACT	50-475	50-100	-	50-151	-	50-475
CALC-SILICATE ROCK	95-270	100-124	-	-	-	95-270
SLATE	665-800	-	-	-	-	665-800
QUARTZITE-COMPACT	>200	40-80		-	-	>200

observed from the ranges of resistivity for different formations, that these are, in many cases, overlapping in nature, and are, thus, not exclusive for various lithologies. Accordingly, these ranges should be put to use carefully, keeping in mind the geology of the area. It is observed from **Table** 4.2 that the resistivity for sandy horizons varies from 18 to 110 ohm-m, whereas for predominantly clay zones, it shows range of 4-18 ohm-m. However, the resistivity shows increase in value wherever clay and sand contain mixtures of kankar with them. The rock formations namely calc-silicate, quartzite, and slate exhibit wider resistivity ranges i.e. 95-268, 50-475 and 665-800 ohm-m respectively. The low values in the range of resistivity for these rocks will imply their friable and weathered nature.

Using these broad ranges of resistivity, a number of geoelectrical sections have been prepared for the area so as to obtain a clear of the subsurface geological picture (**Figs**. 4.15 to 4.20). Figure 4.1 shows the location of these section lines and the position of respective sounding points. Further, contour maps showing depth to bedrock and thickness of semi-compact weathered bed rock have also been prepared (Figs. 4.21 and 4.22).

4.5 GEOELECTRICAL SECTION

The geoelectrical section along number of lines in different directions have been prepared to study the variation in lithology, as interpreted from resistivity values and to demarcate and ascertain the nature of subsurface formations present therein. In the following paragraphs, a brief description of these geoelectric sections is given.

4.5.1 Geoelectrical Section AA'

Figure 4.15 shows geoelectrical section along NW-SE profile line (AA') of the study area passing close to villages Mandhana (VES NC11), Bawaniwas (VES NC9), Nangal Kalia (VES NC8) and Khatoli Jotan (VES NC5), located in the southeastern part. In this section, data of four Vertical Electrical Soundings (VES) has been considered, but the picture upto a shallow depth (60m bgl or so) available. It is observed from the figure that the thin top soil layer (resistivity varying between 28-56 ohm-m) is underlain by a layer of clay mixed with kankar showing the resistivity range of 14-123 ohm-m. This kankar mixed clay is again underlain by a clay zone having lower resistivity of 4-18 ohm-m with its thickness varying between 5-20 m. The low resistivity of clay layer may be due its soft nature. An unsaturated sand underlies this clay layer, as indicated by resistivity of the order of 10-35 ohm-m, whereas this sand appears to be saturated at locations VES NC11 and VES NC9, as indicated by low resistivity of 10-24 ohm-m. The low resistivity value at these locations can also be a manifestation of the saline groundwater, as witnessed by the high EC values of groundwater near these locations. Beneath this sandy horizon, weathered calc-silicate (res: 77-95 ohm-m) is indicated to be present, as evidenced from its exposures at some distance towards Nangal Chaudhry Village (Fig. 4.15). The higher resistivity value (142-268 ohm-m) for this formation between VES locations NC5 and NC8 indicate the more compact nature of this rock formation.

4.5.2 Geoelectrical Section BB'

The NE-SW section line runs from Bayal (VES NC15) to Karota (VES NC 4) and consists of 4 sounding points (Fig.4.16). As seen from the section, a thin veneer of soil is underlain by clay and kankar formation (resistivity 53-98 ohm-m) with its

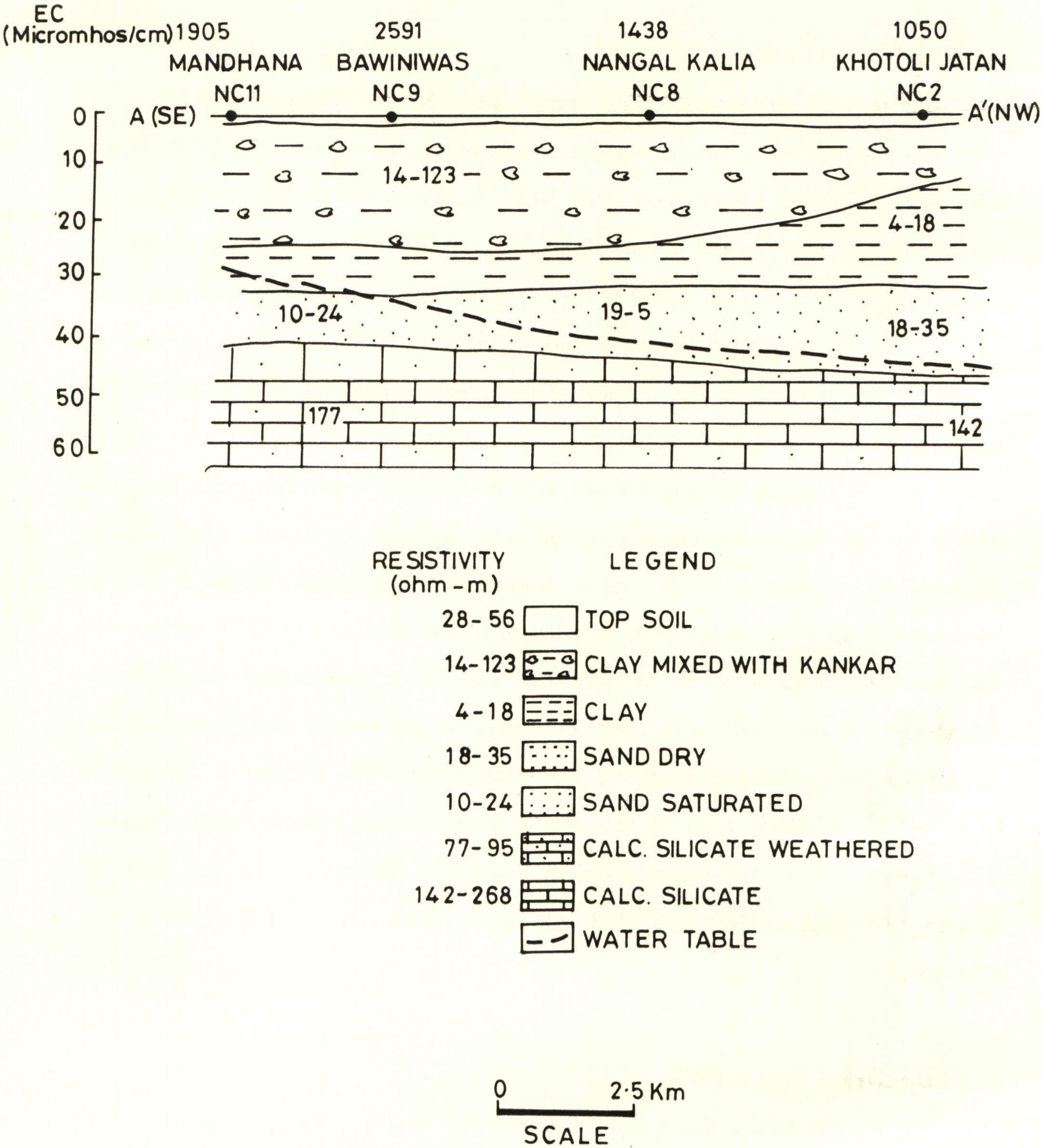


FIG. 4·15. SCHEMATIC GEOELECTRICAL SECTION (A-A')

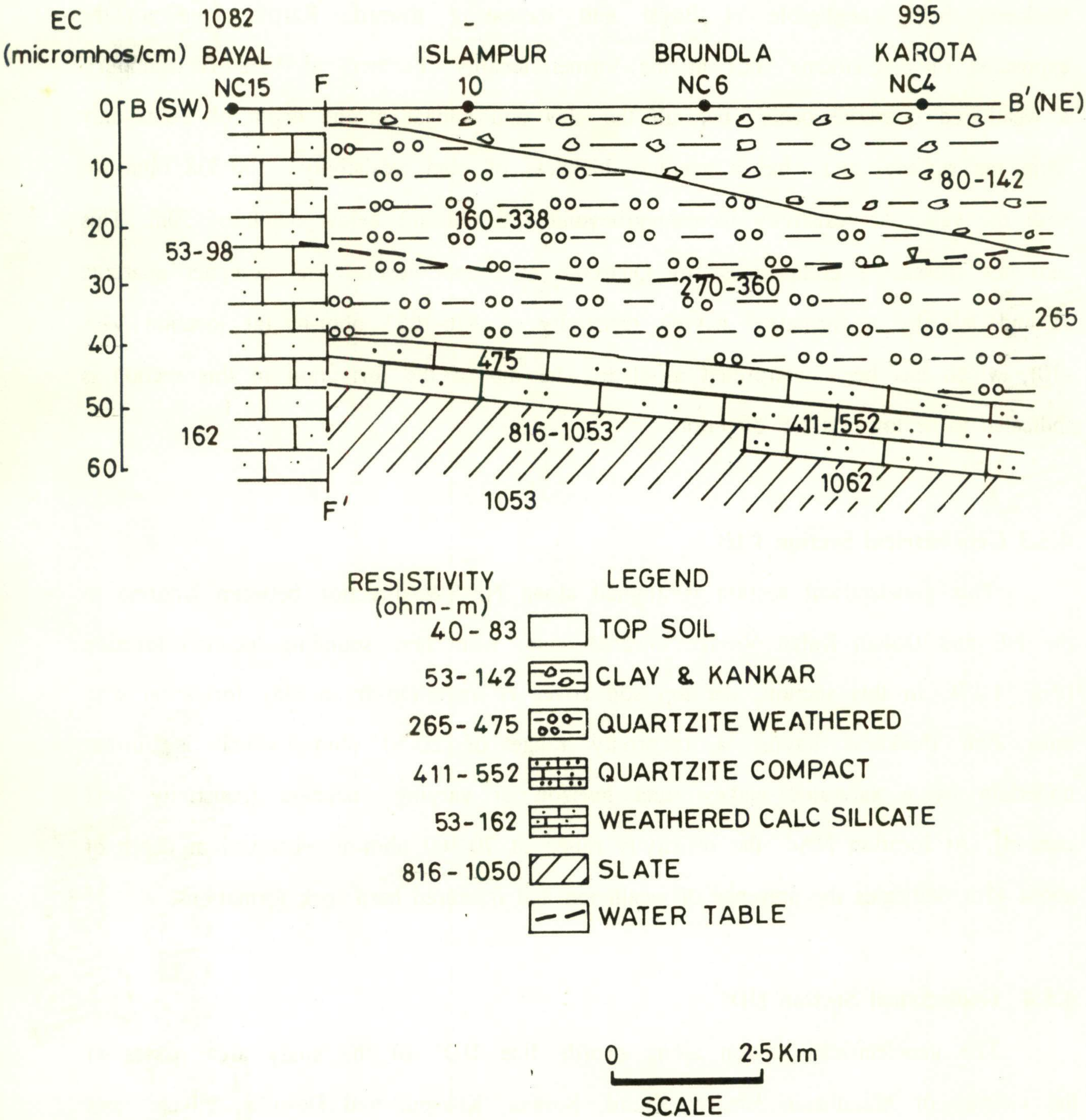


FIG. 4·16. SCHEMATIC GEOELECTRICAL SECTION (B-B') thickness being negligible at Bayal and increasing towards Karota, due to the exposures of calc-silicate rock at the former locality. Further, at VES 10(Islampur), a weathered quartzite occurs beneath the clay and kankar at the depth of 2-3m only from the surface, and has a average thickness of 40m (resistivity 160-338 ohm-m), with the value of resistivity increasing(beyond 400 ohm-m) below depth of 50m. This indicates increasing compactness of Quartzite at deeper levels. The compact quartzite is underlain by a formation having resistivity of 816-1053 ohm-m (at location VES -10), which has been interpreted as slate. The dip of the formation in this section is indicated to be towards NE direction.

4.5.3 Geoelectrical Section CC′

This geoelectrical section is aligned along NE-SW direction between Khorma in the NE and Dohan Kalan Village towards south with three sounding locationsdirection (Fig. 4.17). In this section, the top soil cover is underlain by a clay formation with upto 20m thickness having a resistivity range of 20-50 ohm-m,which is further underlain by a saturated clayey sand horizon of varying thickness (resistivity 7-32 ohm-m). At location NA4, the resistivity range of 70-160 ohm-m, observed at depth of about 45m, indicates the presence of weathered and fractured hard rock formations.

4.5.4 Geolectrical Section DD′

The geoelectrical section along profile line DD′ of the study area passes in the vicinity of Mandhana, Bhusan Khurd, Sorana, Khaspur and Derolijat villages and consists of five sounding points Fig 4.18. The geological control is provided by the tubewell at Derolijat. The thin layer of top soil is underlain by 20 - 25m thick clay and kankar (resistivity 14-153 ohm-m), which is again underlain by alternating

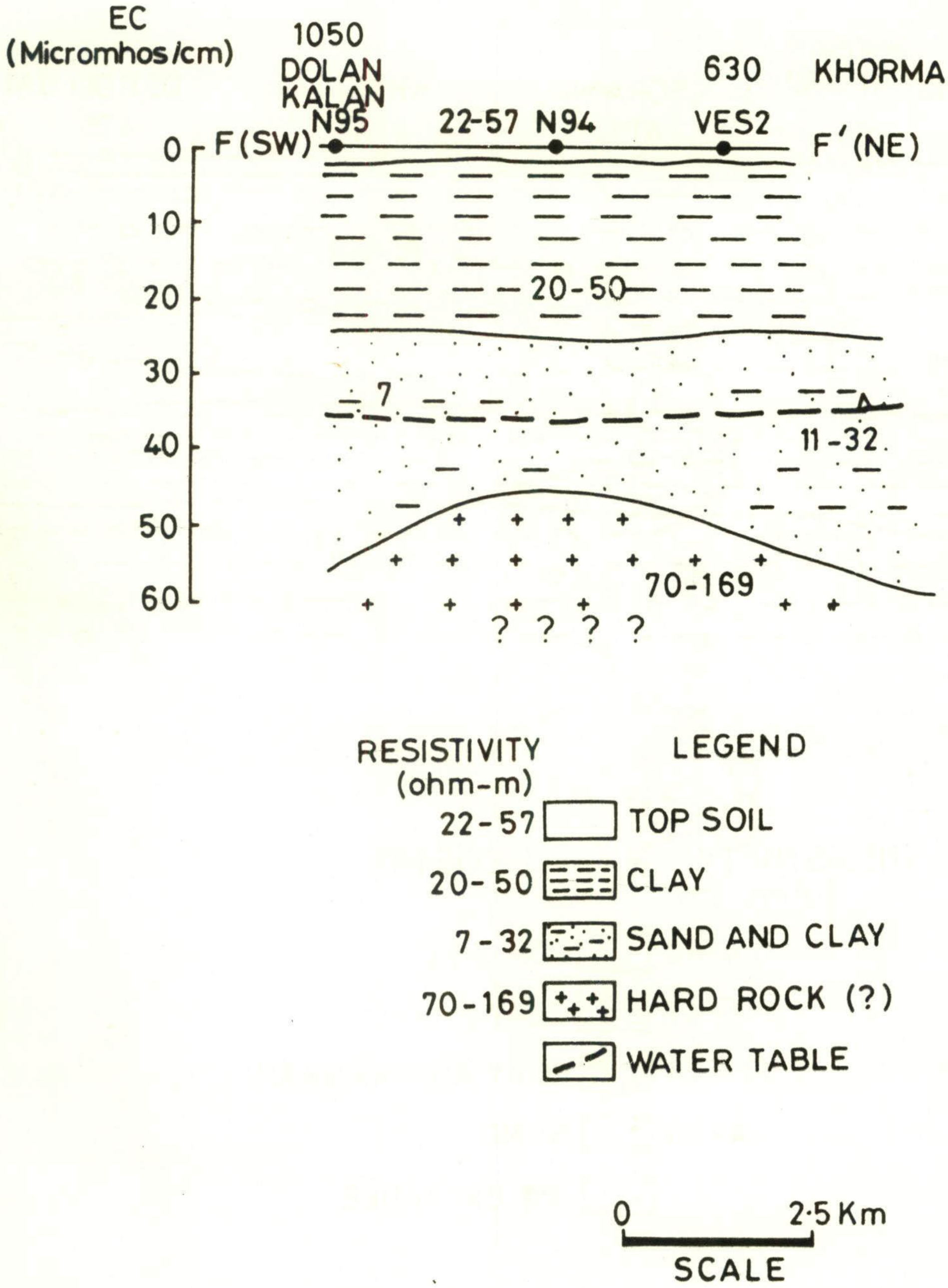


FIG. 4·17. SCHEMATIC GEOELECTRICAL SECTION (C-C')

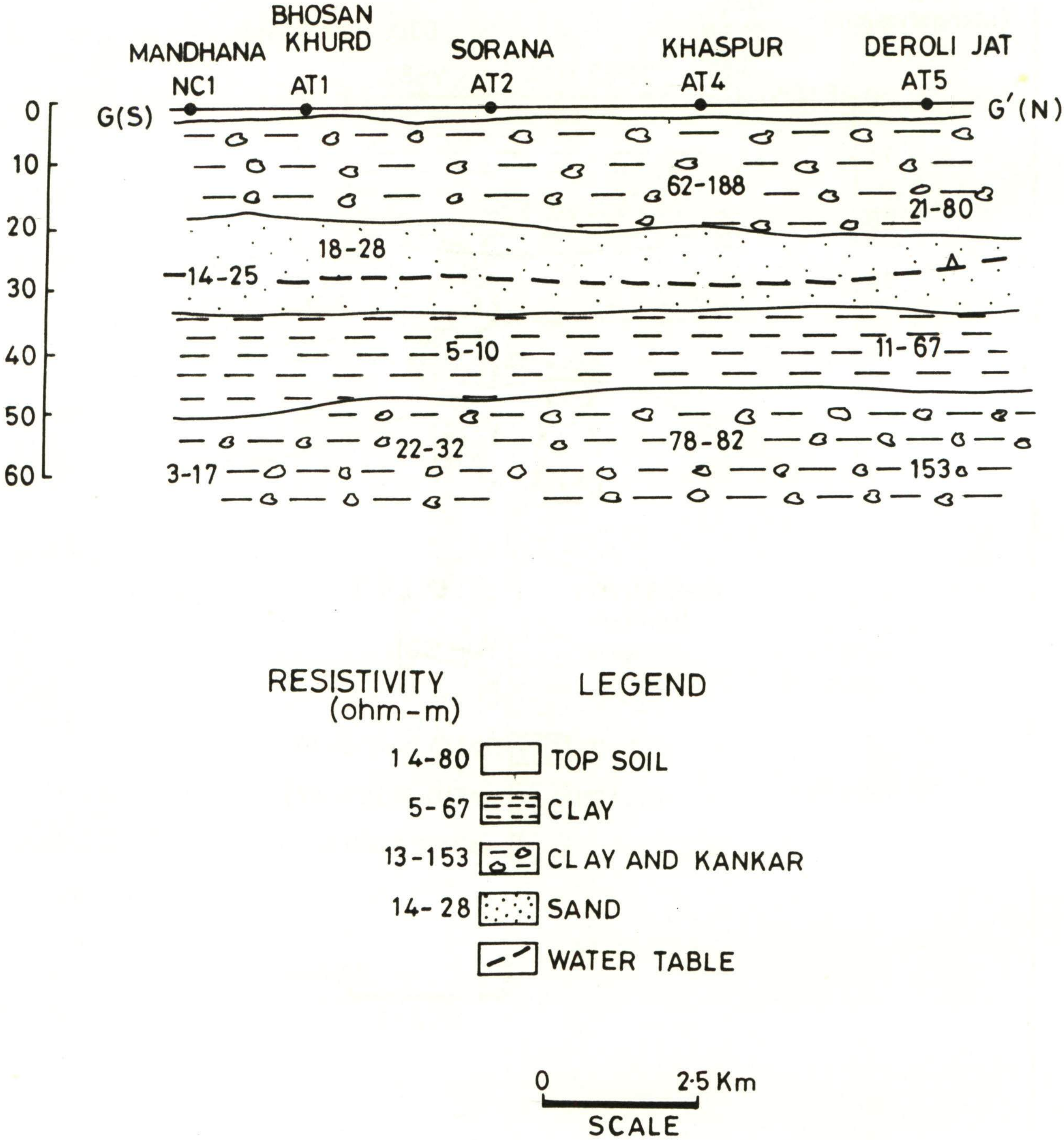


FIG. 4·18. SCHEMATIC GEOELECTRICAL SECTION (D-D′)

sequence of sandy and clayey horizons. The relatively low resistivity of the bottom clay at VES locations NC1 and AT1 (3-17 ohm-m) indicates its saturation by saline water.

4.5.5 Geoelectrical Section EE′

The section consist of four sounding points in the eastern part of the study area but here no geological control of any tubewell is available (Fig.4.19). The section, running along NNW-SSE direction, is comprised of an alternating sequence of clays and sands with a horizon of clay mixed with sand of uniform 20m thickness of about 20m. However, as the sands are saturated by relatively saline waters, the low resistivity tend to give a distorted picture of the subsurface formations.

4.5.6 Geoelectrical Section FF'

This section also consists of four sounding points and gives a limited picture of the subsurface due to shallow depth of the soundings(Fig.4.20). In this section, the thin layer of top soil, underlain by a horizon made up of clay, is about 20-25m in thickness. A thick sandy horizon (20-30 ohm-m) underlies the clayey formation and is saturated. However, at location VES.5, the drop in resistivity upto 9-13 ohm-m indicates probable saline nature of groundwater in the formations.

4.5.7 Depth to Bedrock Contour Map

Figure 4.21 shows the depth to bedrock in the study area as depicated by contour of equal depth. In preparation of this map, the resistivity ranges assigned to different formations and rock types have been utilized. As such due to the complicated geology in the area, accompanied by overlapping resistivity ranges for different

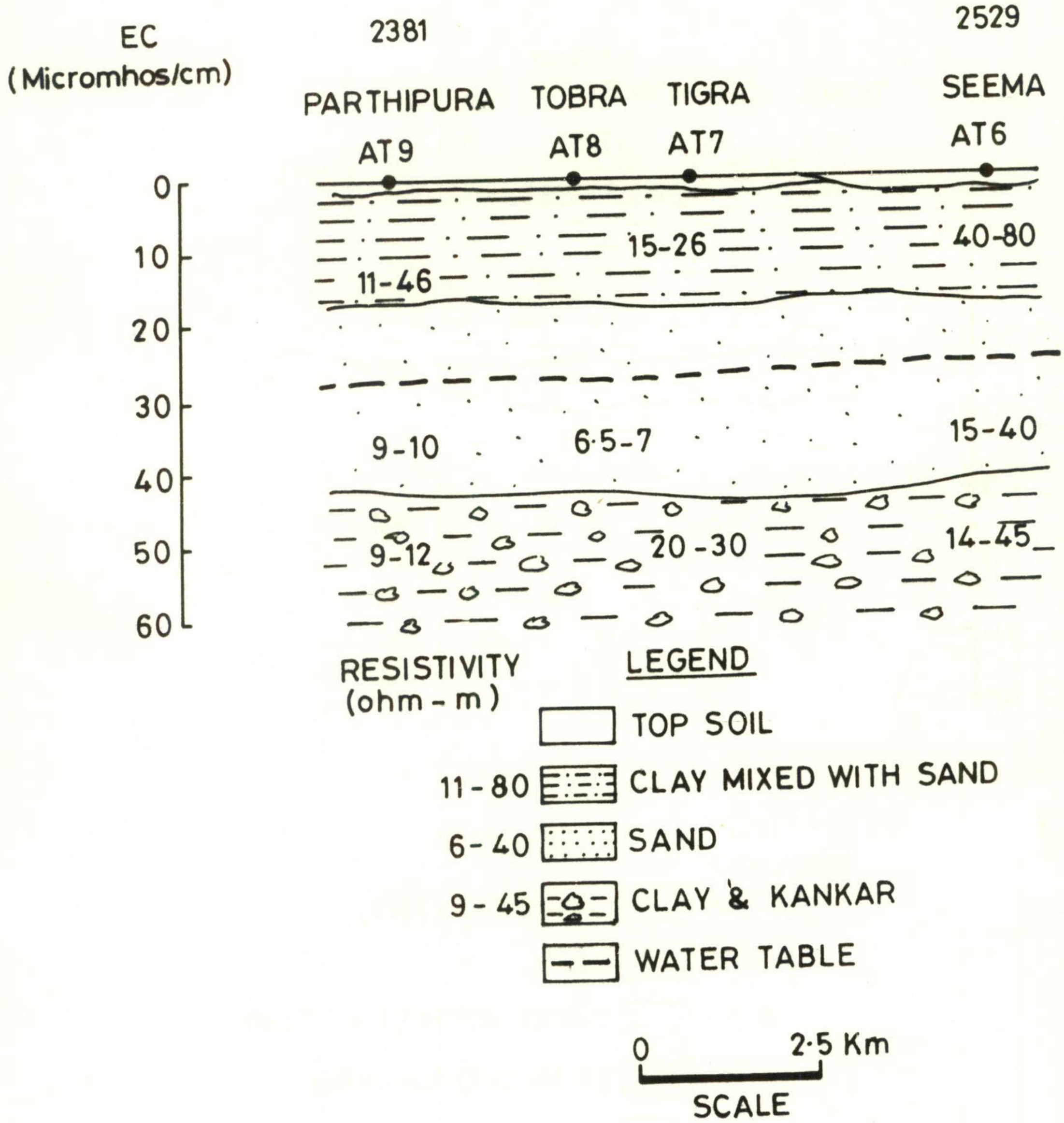


FIG. 4·19. SCHEMATIC GEOELECTRICAL SECTION (E-E′)

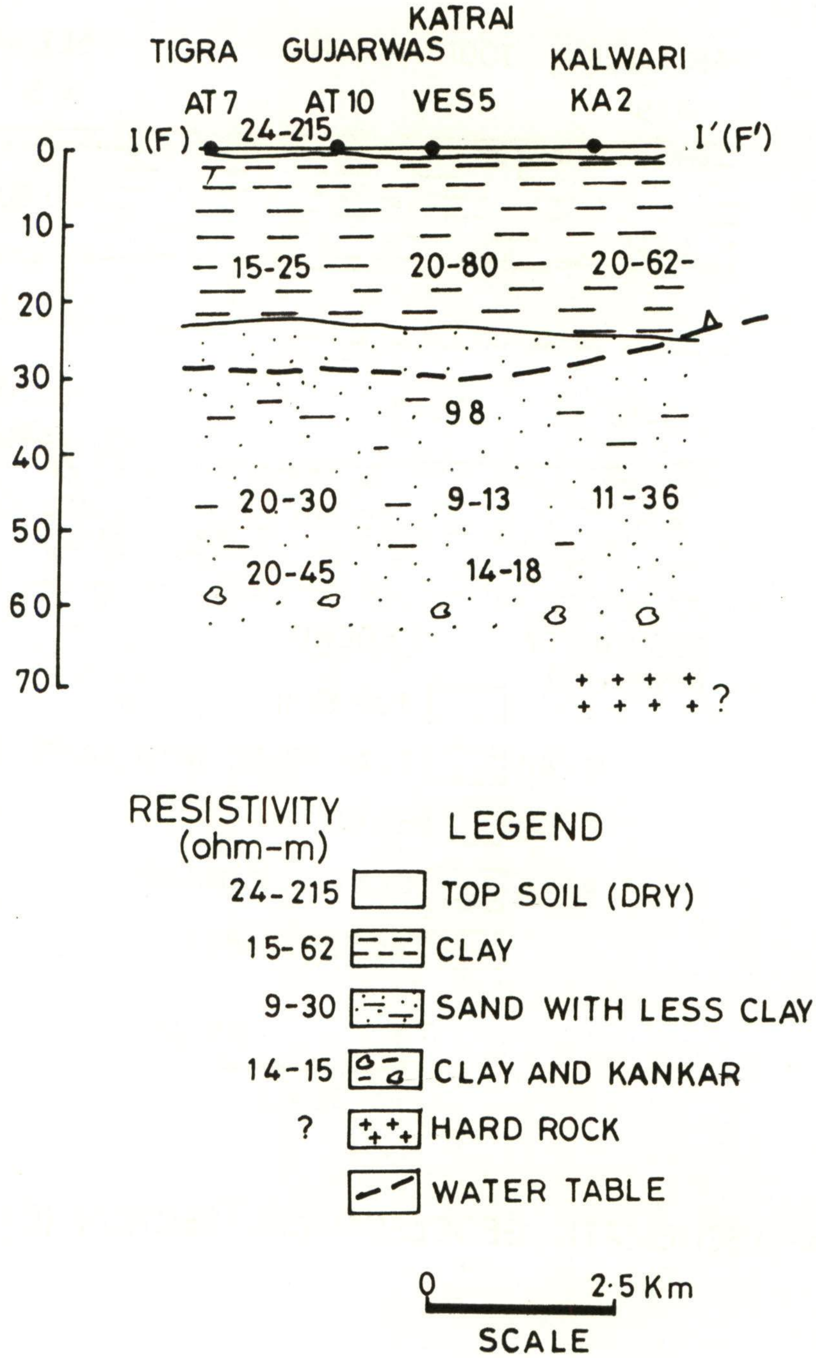


FIG. 4·20. SCHEMATIC GEOELECTRICAL SECTION (F-F')

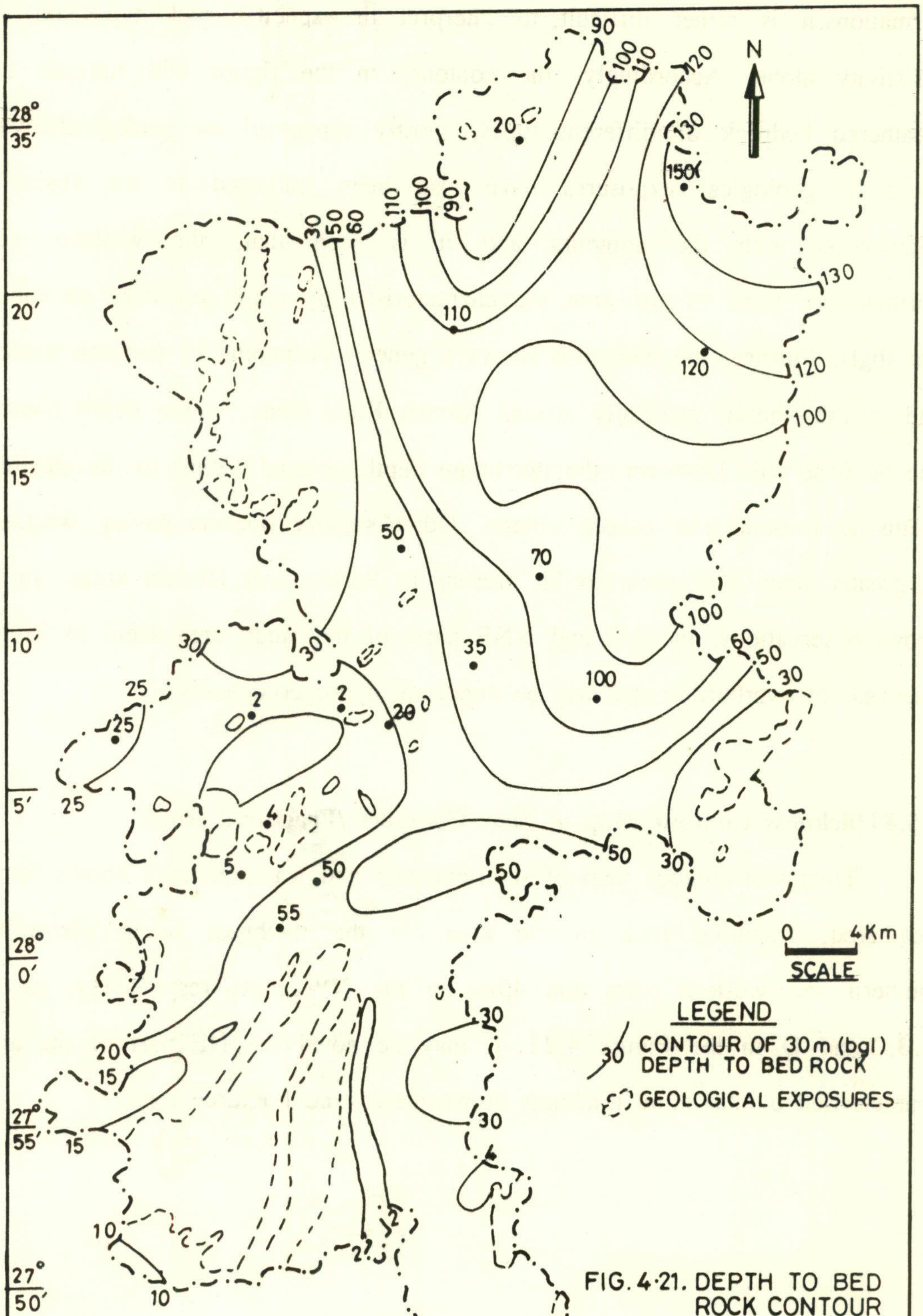


FIG. 4·21. DEPTH TO BED ROCK CONTOUR MAP formations,it is rather difficult to interpret the specific rock types on the basis of resistivity alone. Accordingly, the contours in the figure will indicate the depth to weathered bedrock of different types, mostly supported by geological evidences. The areas of geological exposures have also been indicated in the figure for proper comparison with the contours and it is seen that, the western, southern and northwestern parts of the area are characterised by depth contours of values less than 2m (bgl). Further, the map also shows a general deepening of bedrock towards northeast and northnortheast, espicially around Kanina Khas areas, where depth contour of 120m can be observed. However, the maximum depth (around 150m) to the weathered bedrock seems to present near Sihore village. Other smaller pockets having weathered bedrock at greater than 50m seem to be present in Sorana and Hudina areas. In view of the above observations, the NE and NNE parts of the study area seem to have cosiderable thickness of overburden and may be important hydrogeologically.

4.5.8Thickness Contour Map of Semi-Compact /Fractured Rock

Thickness contour map of semi-compact and fractured rock shows four maxima of weathered, fractured rock in the area, in the thichness being above 80m in the southern and western parts and 45m im the NW parts respectively, as indicated by A,B,C,and D in the Figure 4.22. It may be noted the NE part of the area which is characterised of maximum thichness of weathered and fractured rock.

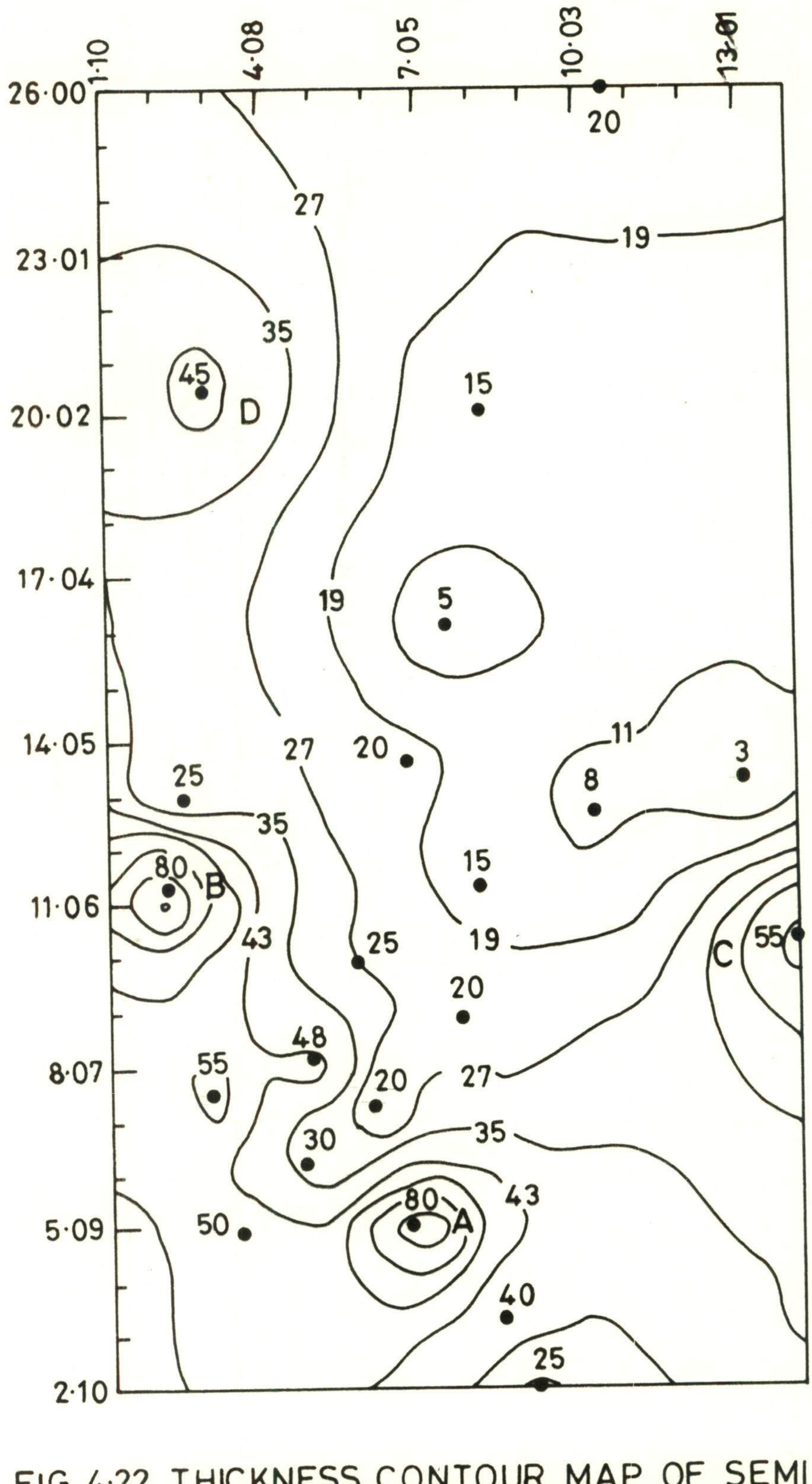


FIG. 4·22. THICKNESS CONTOUR MAP OF SEMI-COMPACT, FRACTURED ROCK AQUIFERS.

4.6 HYDROGEOLOGICAL FRAMEWORK

4.6.1 General Remarks

The occurence of groundwater in the area is controlled by diverse geological factors e.g.structures, geological seguences and stratigraphical distributions of geohyrological units (Strahler,1964). However, Davis and Dewiest (1966) also included physiographic control on the occurence of groundwater. Freeze and Cherry (1987) have considered the influence of stratigraphic, structural factors and sedimentation on the occurrence of aquifers in areas with differing geology.

4.6.2 Occurrence of Groundwater

It has already been discussed in earlier chapters that in the present study area, structural features, variations in lithology and the hydrogeomorphic features will be of consequence in controlling the occurrence and movement of groundwater. The occurrence of groundwater in the area can be studied in two parts:

(i) The southern, western and northwestern parts, where the weathered and fractured rocks formations are likely to form aquifers. Here, the structural and lithological factors seem to control the occurrence of groundwater.

(ii) The northern and northeastern parts, where the alluvial formations having large thickness may constitute the aquifer- aquiclude system. In this part, hydrogeomorphic features seem to have a key role in localisation of groundwater.

4.6.2.1 Groundwater in Hard Rock Fomations

As has been inferred in the earliar chapters, the fractures system in the rocky formations are related to the structural behaviour of the formations. It has been revealed that majority of fractures are oriented in NE-SW and WNW-ESE directions. However, WNW-ESE trending fractures are the important fractures in groundwater localisation. This trend coincides with the F3 trend of fold axes and represents direction of tensional forces. The tensional fractures are likely to be open in depth for localisation of groundwater, as illustrated by Larsson et al. (1979). Further, groundwater seepages have been noted from the WNW-ESE trending fractures in granitic rocks, occurring in Dosi hill in the western parts of Narnaul area, which is taken as an evidence of the water-bearing nature of these fractures. The pegmatite and quartz intrusions in most part of the area in hard rock terrain influence the groundwater circulation in deeper horizon, as these intrusions are mostly appearing along WNW-ESE. The wells drilled close to such lineaments yield considerable quantities of groundwater (refer Fig. 3.5 and Table 3.6). On the other hand, in the southern parts, of the area, the behaviour of isoclinal folding reveals that, the compressive forces were dominant along NW-SE direction and have resulted in shear fractures and joints. However, these fractures are more or less tight in nature and seem to remain open upto a shallow depth only. Therefore, groundwater in these types of joints will be rather of limited occurrence - as, observed in the Golwa village in the southern part.

Table 4.3 shows the summary of data of expolarotary tubewells drilled in the fractured rock formations and alluvial parts of the study area. In this table it can be seen that out of total number of 31 tubewells, only 3 wells were drilled in the Alwar Group whereas 21 were drilled in the Ajabgarh Group of rocks. The depth of tubewells in the Alwar rocks varied from 55 to 120m, whereas in Ajabgarh rocks (Calc-silicates, weathered quartzite, marble, gniesses etc.), the depth of tubewells varied in a wider range from 51-169m (bgl).

TABLE 4.3 :SUMMMARY DATA OF TUBEWELLS IN THE ALLUVIAL AND ROCKY AQUIFERS

Tube Wells	Depth Drillrd	Depth to static water level (m)	Discharge (lpm)
Alluvial formations (7 wells)	96.29-163.09	5.82-17.20	695-2911
Ajabgarh Group formattions (21 wells)	51.03-168.66	5.32-33.0	5.23-1326
Alwar Group formations (3 wells)	55.20-119.79	19.90-25.17	130-871

It was also observed that the depth of watertable in the tubewells tapping fractured aquifers varied form 5-33m (bgl) at the time of construction of tubewells, indicating a very wide variation in the depth to water levels. It was observed that the discharge of tubewells varied widely from 5 to 1326 lpm. Besides, the groundwater was found to occur at variable depth in these rocky formations implying their notable heterogeneity. The drawdown of watertable in these wells in the rocky area also shows extremely wide variations between 10m to as much as 35m. The reasons for such large variations in the drawdown seems to be the occurrence of water-bearing fractures at varying depths, besides the poor and varying specific yield of the permeable zones.

4.6.2.2 Groundwater in Alluvial Formations

Study of hydrogeomorphological feature has given a clue of geomorphological factors in controlling occurrence of groundwater in alluvial deposits. The point bars, which consist of unconsolidiated sediments of coarse to medium deposits appear to be controlling lithology for groundwater storage, through due to the small size of river and its ephemeral nature, the groundwater potential of points bars is limited. The erosional valleys, located in the SE parts, appear to possess good groundwater potential, whereas the pediments will have very poor chances for groundwater occurrence. The preparation of geological and geoelectrical sections have revealed the existence of deep groundwater in saturated granular formations at Kanina Khas, Sihore and Bhagot areas, located in the NE parts. The groundwater occurring in the deeper zones is in the confined state, as it is overlain by impermeable clay beds of considerable thickness in Mahendragarh area. However, the groundwater in NE parts occurs at shallow depth, as in Sihore. The continuous withdrawl of water does not cause any considerable decline in water table in the surrouding area.

From Table 4.3, showing the summary data of tubewells drilled in alluvium, it can be observed the the depth of water table in the wells tapping these materials varied from 5.8 to 17.2m at the time of construction of tubewells, and over the course of years, these have further declined. However, the depth of drilled tubewells in these formations is considerable, varying from 96 to 163m (bgl). Further, the discharge of tubewells in the alluvium varies from 695 to 2911 lpm indicating higher productivity of tubewells tapping the alluvial aquifers. It seem that the aquifers in allvial formation are encountered from the depth of 10m to 152m bgl, making a total of about 6-8 aquifers in the alluvial area. The main aquifer in these zones seem to be sand-clay admixures, occasionally with kankar and gravel. The drawdown of tubewells in the alluvial area also varies in a range from 6m to almost 12m, indicating significantly higher specific yield of alluvial aquifers as compared to the rocky aguifers. Khan (1990) has opined that the aguifer material in the alluvial formations in the Mahandragarh Block is uniform in nature and the ununiformity cofficient is 2.3.

4.6.3 Groundwater Conditions

The study of water level data of wells offers a useful technique for evaluating the subsurface geohydrological regimes. Different workers like Davis and Dewiest (1966), Freeze and Cheery (1987), Fetter (1988), and Karanth (1989) have dealt in detail about the methods of analyzing the water level data of wells tapping unconfined and artesian aquifers. Some of the relevant procedures for analysis of water level data involve plotting of depth to water table maps (DTW), water table contour elevation maps and water table fluctuation map, in addition to the plotting of data of water levels of well hydrograph stations for extended periods. Inspite of development new techniques involving use of computers, the above-mentioned groundwater level maps offer unique techniques for interpolation of water level data and are capable of revealing important details about the configuration, and slope of water table and overall status of groundwater development especially in homogeneous terrains characterised by the presence of alluvial aquifers. However, linear variation of elevation of water table is assumed in such interpreationsand sufficient care should be taken to account for the presence of intervening hydrological features and water bodies.

Analysis of hydrogeological data of the study area, available from Government Agencies like CGWB and HSMITC concerning the water table elevation data and its long term fluctuations, seems to provide important information regarding the hydrogeological trends especially water level behavior in the past. 83 dugewell hydrograph stations were inventoried by the Central Ground Water Board (CGWB). The depth to water table data of June 1977 and June 1986 and long term water level fluctuation between June 1977 and 1986 is given in Table 4.4. From the data, it is inferred that, the depth to water table is highly variable, being shallow in NE part and as deep as greater than 30 m bgl in western and NW parts of the area. It is also observed that the depth to water table is moderate to deep in the vicinity of hilly tract of Mahendragarh Block. The groundwater is observed to be at deeper levels of over 30m in the southernmost part of the area. Such variation in depth to water table is reported by CGWB as being due to the changes in topography of the area. During this period (June,1986) the elevation of water table (above a common datum) varied from 220.21 (AMSL) in Kanina Block located in NNE to 372.35 (AMSL) in Nangal choudhry Block, located towards south (Fig. 4.23) From this figure, it is also observed that the groundwater flows from south towards north to northeast direction.

TABLE 4.4 SUMMARY DATA SHOWING DEPTH TO WATER TABLE JUNE 1977, JUNE 1986 AND LONG TERM FLUCATUATIONS (JUNE 1977 TO JUNE 1986 (AFTER KHAN, 1990 AND HMITC DATA)

Location	Depth to water table		long term water level Fluctuations	
	June 1977	June, 1986	June (1977-1986) (After Khan, 1990)	Oct(1974-1989) (After MITC)
BLOCK MAHENDAGRAH				
1. PALI	18.79	20.10	- 1.31	-
2. ADALPUR	17.69	19.80	- 2.11	-
3. BAWANA	22.71	21.55	+ 1.16	-
4. AKODH	21.40	23.00	- 1.60	-
5. BASSI	18.00	19.00	- 1.00	-
6. ZERPUR	23.55	24.15	- 0.60	-
7. SESSOTE	23.30	27.30	- 3.92	-
8. MAHENDRAGARH	24.00	36.37	-12.37	-
9. JHOK	24.50	23.70	+ 0.80	-
10. DULOT	25.75	30.30	- 4.55	-
11. BERI	23.05	27.70	- 2.65	-
12. NANGAL -SHROHI	26.35	31.10	- 4.75	-7.7
13. DEROLI JAT	26.40	22.50	+ 3.90	-
14. BHANDUR	-	-	-	-10.18
15. GULAWALA	-	-	-	-7.25
16. JARWA	-	-	-	-3.0
17. KHODI	-	-	-	-6.43
18. KONTAL KHURD	-	-	-	-6.88
19. LAWAN	-	-	-	-5.93
20. NIMBHERI	-	-	-	-10.58
21. PATHERA	-	-	-	-4.86

Contd...

Table 4.4 Continued

BLOCK KANINA				
22. SIYANA	19.80	13.90	+ 5.00	-
23. AGIHAR	23.90	23.10	+ 0.80	-
24. KHERI	21.50	19.80	+ 1.70	-
25. SHELONG	18.00	19.35	- 1.35	-
26. JHAGRAVLI	24.87	21.17	- 3.70	-
27. MONDIAN	25.00	27.20	- 2.20	-
28. GAHAR	15.79	13.95	+ 1.84	-
29. DHANODAH	20.00	16.20	+ 3.80	-
30. LUKHI	12.49	12.06	+ 0.43	-
31. PARTAL	17.09	22.00	- 4.91	-4.96
32. KANINA	15.01	15.64	+ 6.3	-
33. BASALPUR	26.71	28.30	- 1.59	-
34 BHAGOT	-	-	-	-5.7
35. BUEHAWOS	-	-	-	+2.1
36. BAGEI	-	-	-	-3.4
37. BADAT	-	-	-	-6.5
38. MANPUR	-	-	-	-4.7
39. KAKRALA	-	-	-	-6.83
40. SIHORE	-	-	-	+7.49
BLOCK NARNAUL				
41. HUDINA	24.34	26.85	- 2.51	-4.2
42. GEHLI	18.61	23.70	- 5.09	-
43. KULTAJPUR	36.48	30.20	+ 6.28	-
44. RAGHANATPURA	22.35	24.80	- 2.45	-
45. AMARPUR -JORASI	11.72	19.00	- 7.28	-11.94
46. NARNAUL	10.38	20.35	-10.00	-5.19
47. NIZAMPUR	28.79	30.75	- 1.94	-
48. GODH	34.70	37.50	- 2.80	-

Contd...

Table 4.4 Continued

49. KHORMA	-	-	-	-14.00
50. BHANKRI	-	-	-	-10.38
51. RAMBAS	11.62	18.90	- 7.28	-
BLOCK ATELI				
52. SIMA	22.50	26.70	- 4.20	-
53. SORANA	18.82	22.00	- 3.18	-3.96
54. GUJURWAS	22.36	23.35	- 1.05	-
55. ATELI	20.23	23.35	- 3.12	-
56. CHANDPUR	29.22	31.30	- 2.08	-
57. BAHALI	28.72	32.20	- 3.48	-
58. RAMPUR	25.30	27.80	- 2.50	-
59. KANTIKHAS	19.90	23.15	- 3.25	-4.70
60. KHERI	16.43	18.60	- 2.17	-
61. BHUSAN KHURD	-	-	-	10.40
62. DEROLI AHIR	-	-	-	-7.25
63. FAIZALIPUR	-	-	-	-8.40
64. HASANPUR	-	-	-	9.00
65. KHASPUR	-	-	-	-10.39
66. PIRTHIPURA	-	-	-	-7.20
67. SALONI	-	-	-	-11.27
BLOCK NANGAL CHOUDHRY				
69. SEKHA	20.74	27.50	- 6.48	-
70. GANORI	7.08	15.05	- 7.97	-
71. KALIKA -NANGAL	7.89	19.40	-11.455	-23.10
72. AKBHARPUR	11.05	20.80	- 9.75	-
73. PANCHNOTA	4.50	9.85	- 5.35	-
74. DOSTPUR	7.41	17.95	-10.54	-
75. BINAARI	10.19	16.30	- 6.11	-

Contd...

Table 4.4 Continued

76.	BHANTAL	13.45	20.90	- 7.45	-
77.	ASARWAS	26.28	30.85	- 4.57	-
78.	BUDIWAL	5.30	11.35	- 6.05	-
79.	GOTRI	6.74	11.40	- 4.66	-
80.	RAIPUR	3.92	7.50	- 3.58	-
81.	BHAMNAWAS	3.25	9.30	- 6.05	-
82.	DURGAKA NANGAL	-	-	-	-8.35

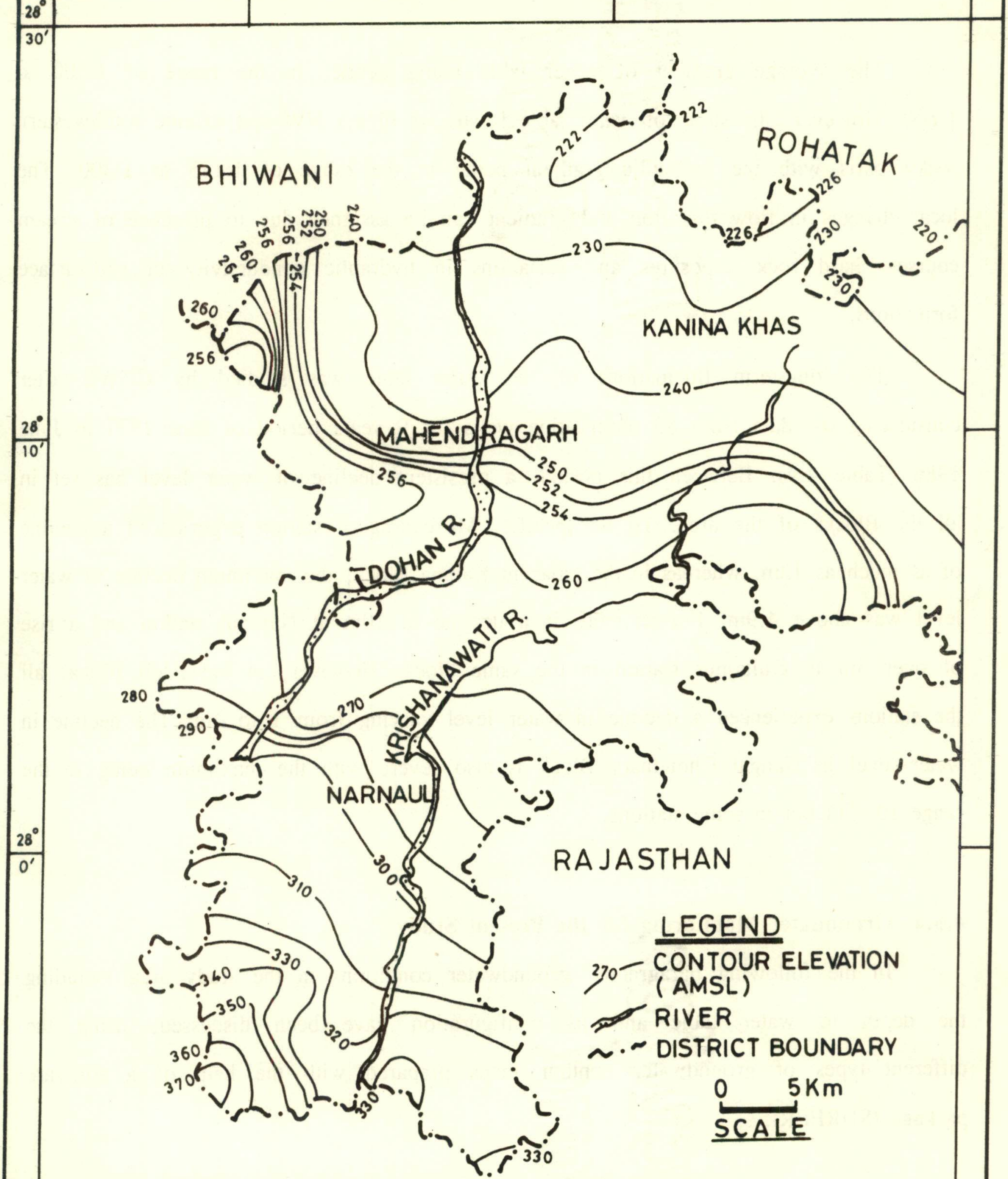


FIG.4·23. WATER TABLE ELEVATION CONTOUR MAP; JUNE, 1986 (AFTER CGWB, 1990)

The average gradient of water table being gentle, in the range of 1:500 to 1:800. However, the slope of water table is steeper in the NW and exteme southwestern rocky parts with the hydraulic gradient being in the range of 1:125 to 1:300. The local changes in flow direction and gradient can be assigned due to presence of stream courses, hard rock exposures and variations in hydraulic conductivity of sub-surface formations.

The long-term fluctuations of the water table was studied by CGWB after considering the data from 83 observation wells for 9 years period of June 1977 to June 1986 (Table 4.4). Between this period, a presistent decline of water level has set in all the Blocks of the area. To be specific, Mahendragarh station experienced a decline of as much as 12m, whereas in the adjacent Kanina Block, the maximum decline of water level was above 4.9m. Further,there is a decline of 10m at Narnaul station and a rise of over 5m in Kultajpur station in the same block. However, in the Ateli Block, all the stations experienced a decline in water level varying from 1 to 4m. The decline in water level in Nangal Choudhary Block is also severe with the maximum being in the range 10 - 11.6m in some stations.

4.6.4 Groundater Monitoring for the Present Study

In the following paragraphs, groundwater conditions in the study area including the depth to water table and its configuration have been discussed, using the different types of groundwater contour maps prepared with the help of a software package (SURFER).

4.6.4.1 Depth to Water Table (DTW) Maps

The depth to water table (DTW) contour maps have been prepared for the premonsoon and postmonsoon season of the year 1991, 1992, 1993 by considering the newly-generated data of static water level (SWL) in the open well hydrograph stations.

As shown in Figure 4.24 , in the premonsoon period of the year, 1991, the water table in the wells, usually occurs between the depth of 5.3m and 35m below ground level. Thus, the depth to water table in the study area is highly variable, being shallow between 9 and 10.3 m bgl in the NE parts, as at Sihore and Mukhi villages. Besides, it is also observed that groundwater is shallow in SW parts in hilly tracts of Ajabgarh rocks around Golwa, where minimum depth of water table of 5.30 bgl is noted.

The watertable occurs at deeper levels (28-35m) in the southern, southeastern and western parts. Several maxima occur at places like eastern Zerpur, Khorma, Nizampur, Serohi Nangal and Kanthikhas. Similarly, in the northwestern part, in the Mahendragarh Block, the water table is at considerable depth (30m bgl) especially in the vicinity of hilly tracts. However, in the Narnaul town and its vicinity, the water table is relatively at shallow depth (23m bgl). In general, the depth to the water table seems to be a mainifestation of veriable topography and lithology. In the postmonsoon season of the same year, almost same pattern of depth to water table has been recorded in the area with no appreciable changes (Fig.4.25). On the contrary, a marginal decline in watertable at few stations was noted in the postmonsoon season. Watertable is not expected rise due to monsoon recharge from the rainfall during year 1991. However, considering the annual rainfall of 260.4mm at Mahendragarh and 357.9mm at Narnaul stations, such a negligible recharge can be explained when viewed in the context of over-exploitation.

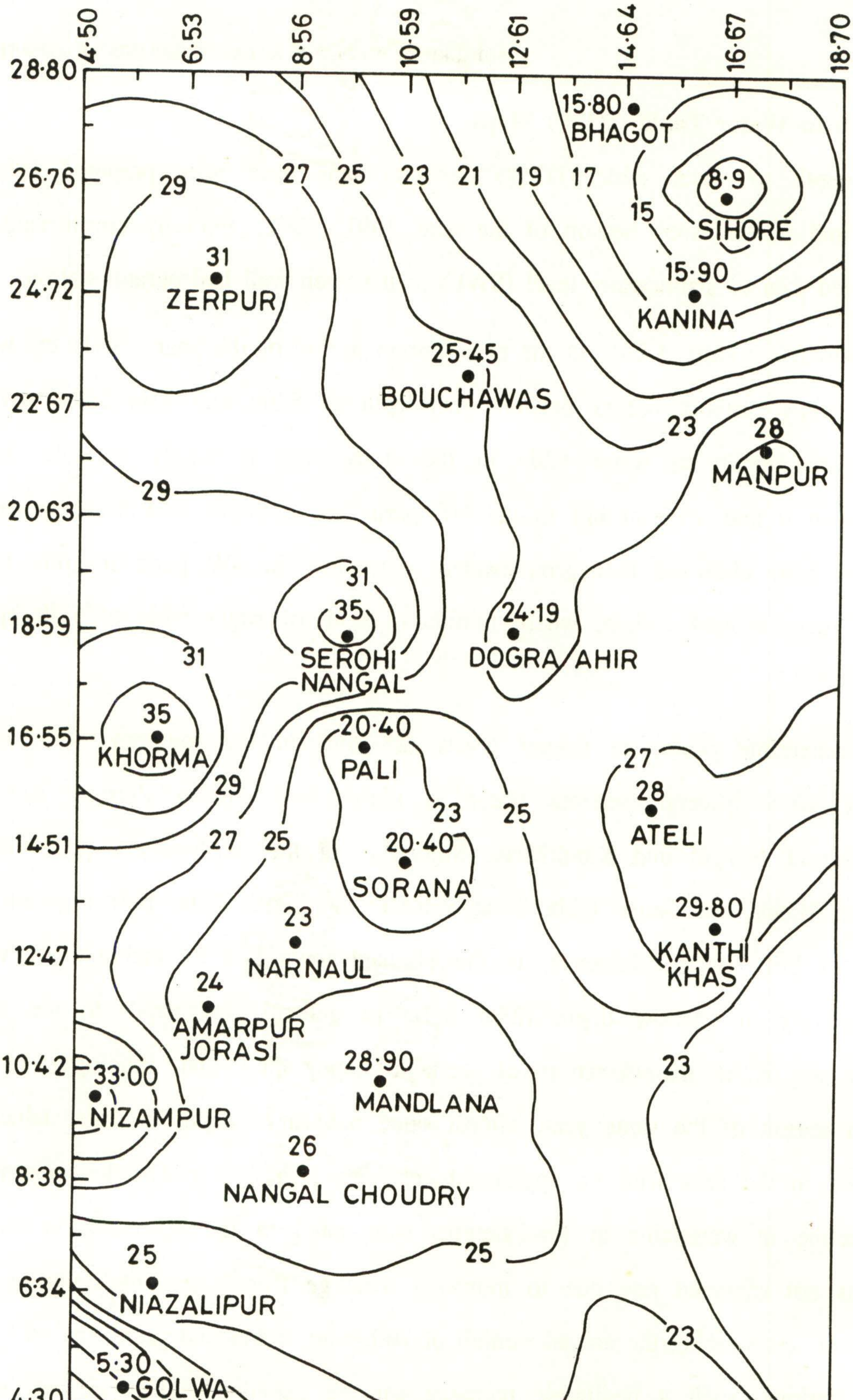


FIG. 4·24. DEPTH TO WATER TABLE CONTOUR MAP (PREMONSOON, 1991)

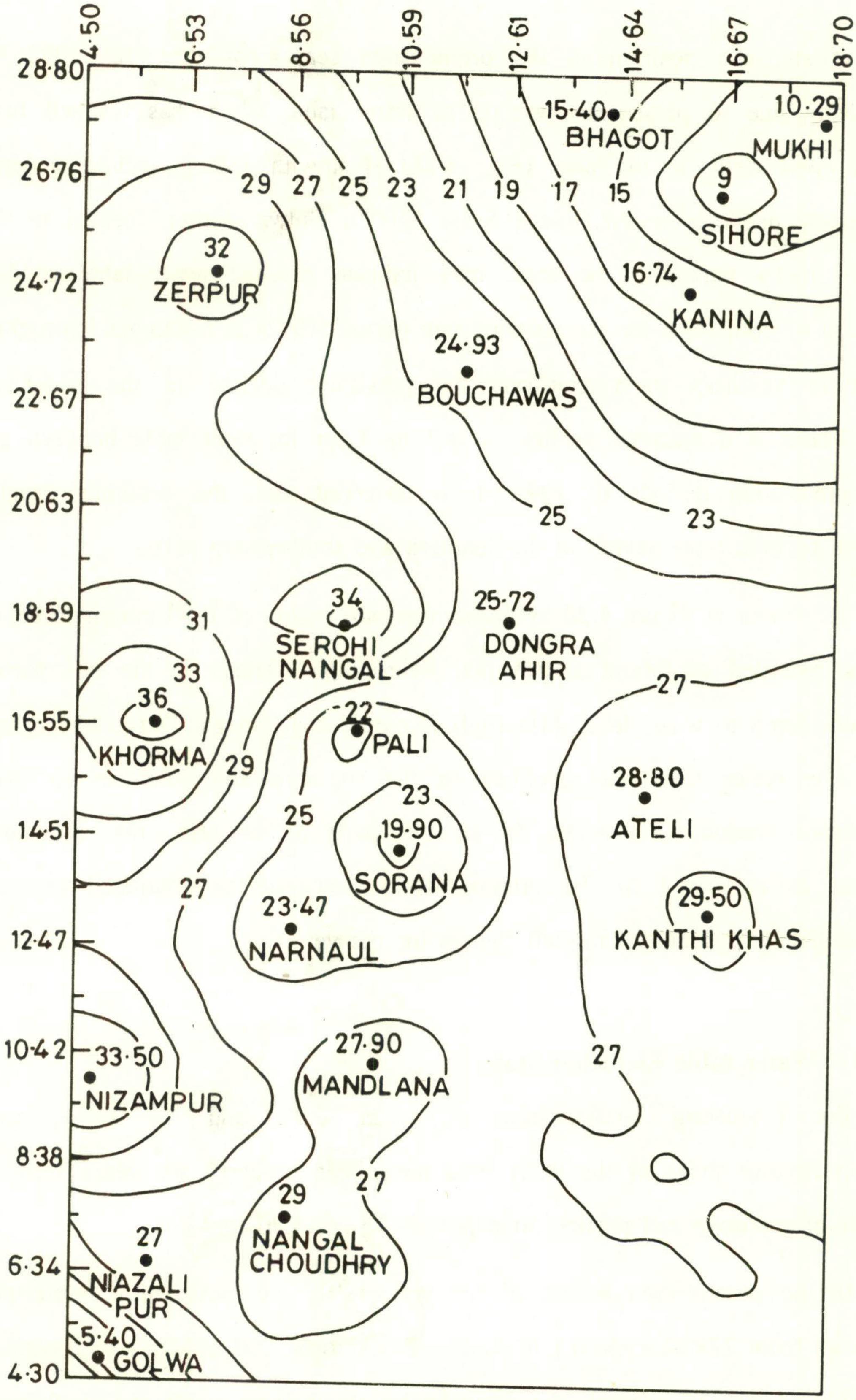


FIG. 4·25. DEPTH TO WATER TABLE CONTOUR MAP (POSTMONSOON, 1991)

Again, the position in the premonsoon season of the year 1992 has altered appreciably due to persistent lowering of water table which has resulted in drying of several open wells in the area (Fig. 4.26). Nothwithstanding such a general decline, the shallow depth to water table (5.5m bgl) in Golwa station, located in the extreme southern rocky part of the area, may indicate perched water table conditions. The maximum of 38m (bgl) for the postmonsoon period (1992) at Nizampur hydrograph station, located in southern parts confirms the persistent decline in the water table (Fig 4.27). There is a seasonal decline of 0.2 to 3.0m in water table between premonsoon and postmonsoon periods of 1992. It is observed that, the declining trend of water table has become more severe in the southern and southeastern parts.

As shown in Figure 4.28 in the premonsoon season of 1993 minimum depth of water table is recorded at Sihore and Mukhi hydrograph stations in the NE parts, whereas maximum depth to water level 41m (bgl) is recorded at Nangal Durgo hydrograph station. Again, the water level has declined in the southern and southwestern parts in the postmonsoon season, (Fig 4.29). In the NE parts of the area, the situation is almost unaltered as compared to the premonsoon period due to continued overexploitation, accompanied by low annaul rainfall figures for the year.

4.6.4.2 Water table Elevation Maps

For evaluating configuration of water table and the slope, water table elevation contour maps of the study area have been prepared for years 1991, 1992 and 1993 for premonsoon and postmonsoon periods (Figs. 4.30 to 4.35).

In the premonsoon season of the year 1991, the elevation of watertable in the area varies from 221.42 (AMSL) in Kanina Block to 317.40 (AMSL) in Nangal Choudhry Block (Fig. 4.30). In general, the groundwater flows from south and southwest to north

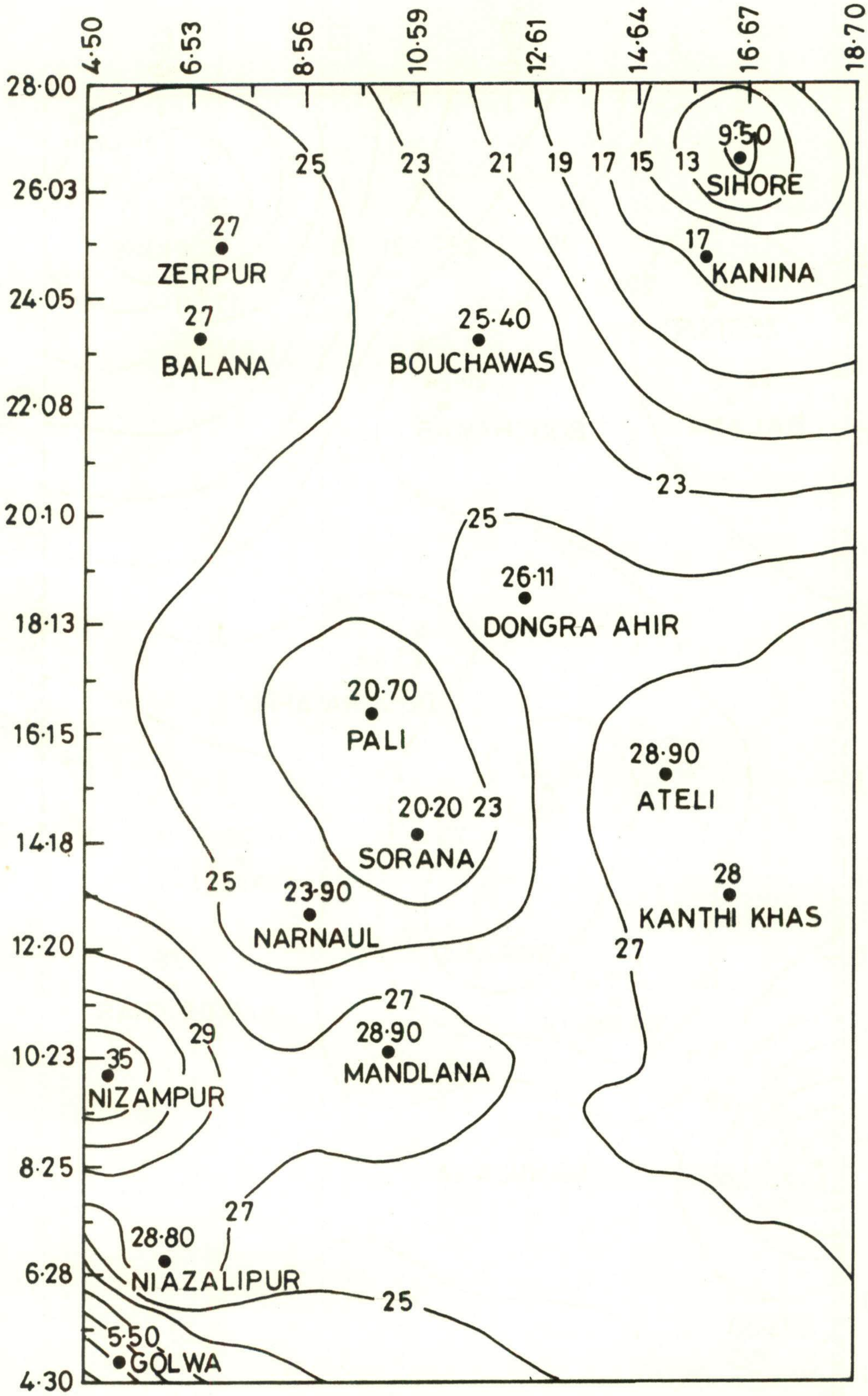


FIG.4·26. DEPTH TO WATER TABLE CONTOUR MAP (PRE MONSOON, 1992)

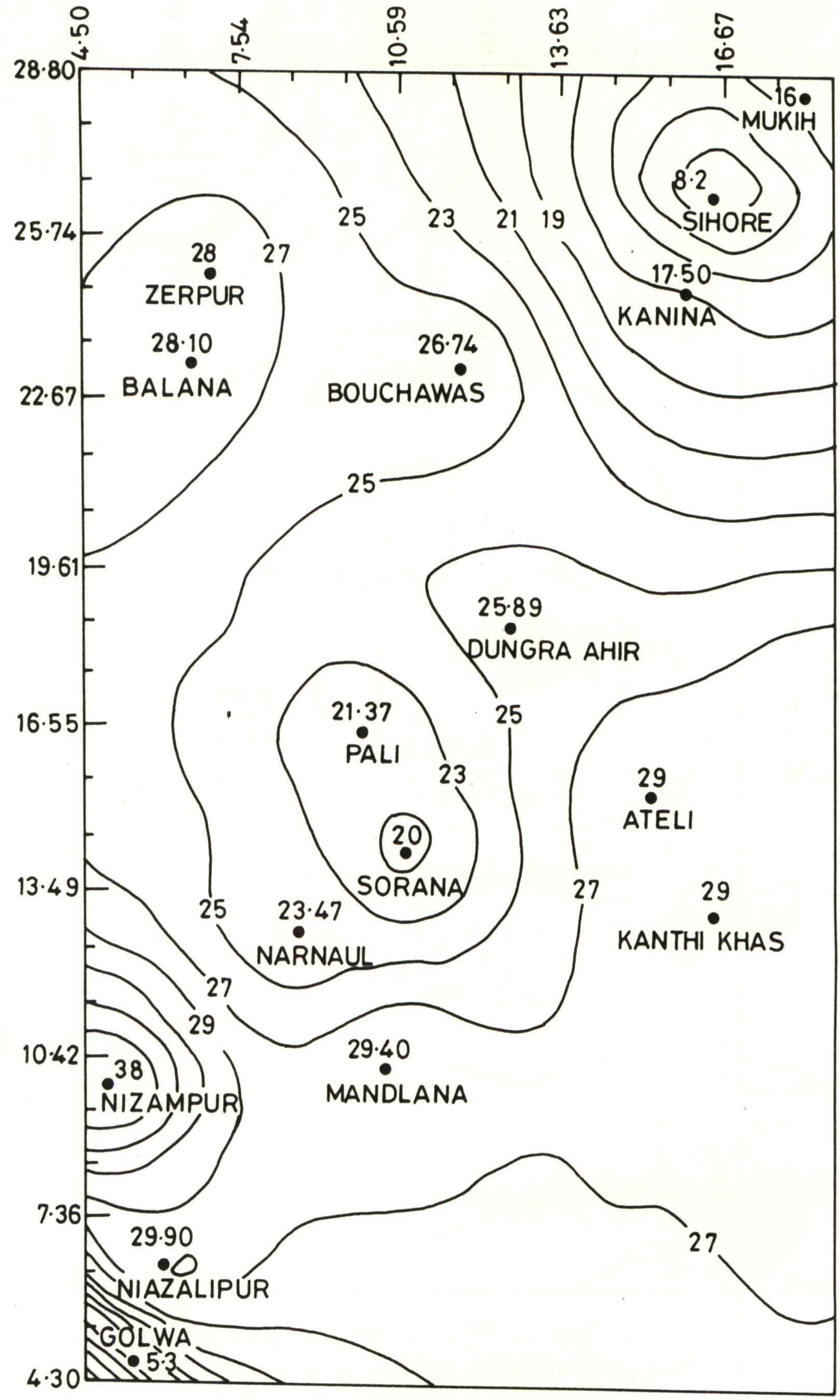


FIG. 4·27. DEPTH TO WATER TABLE CONTOUR MAP (POSTMONSOON, 1992)

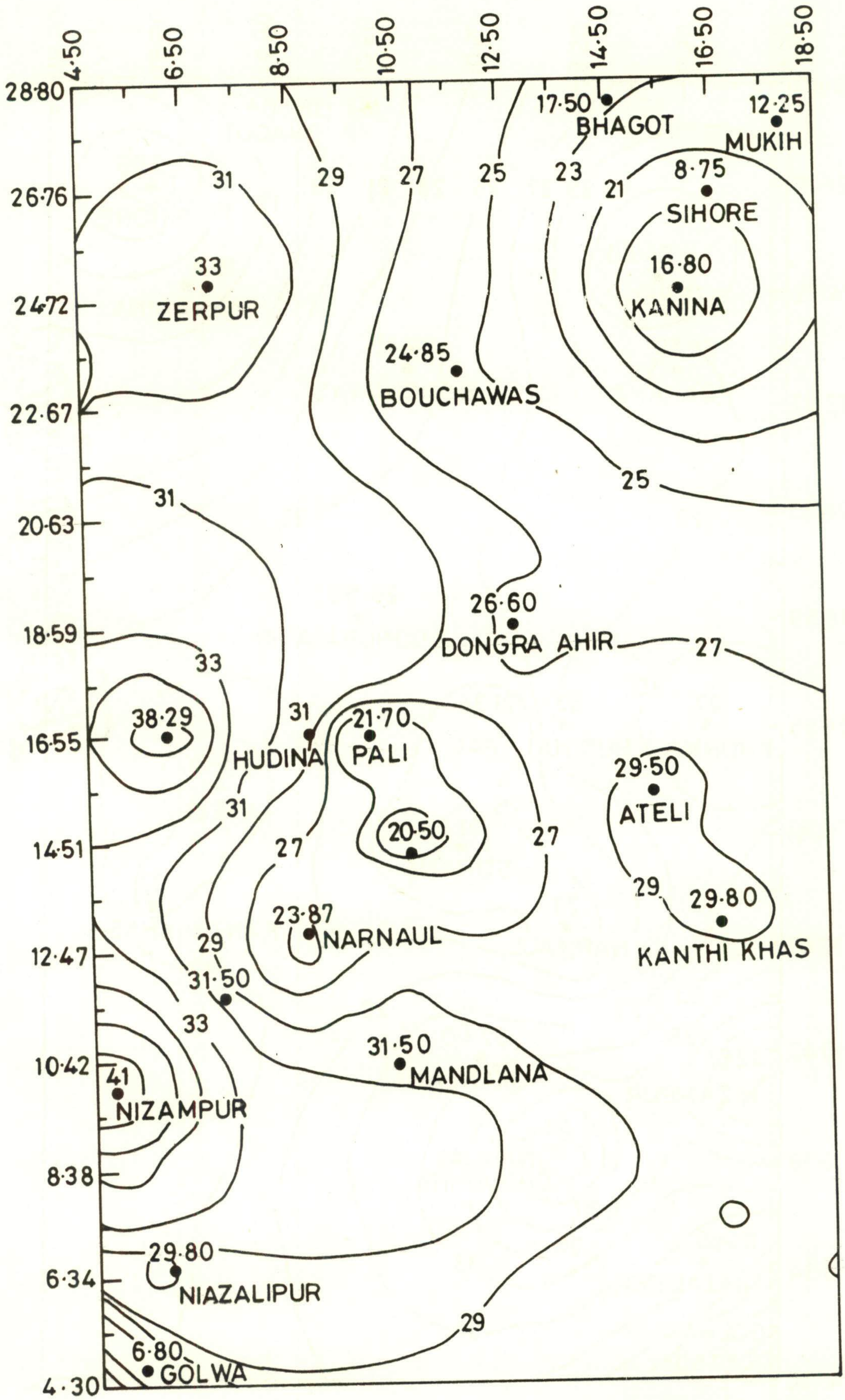


FIG. 4·28. DEPTH TO WATER TABLE CONTOUR MAP (PREMONSOON, 1993)

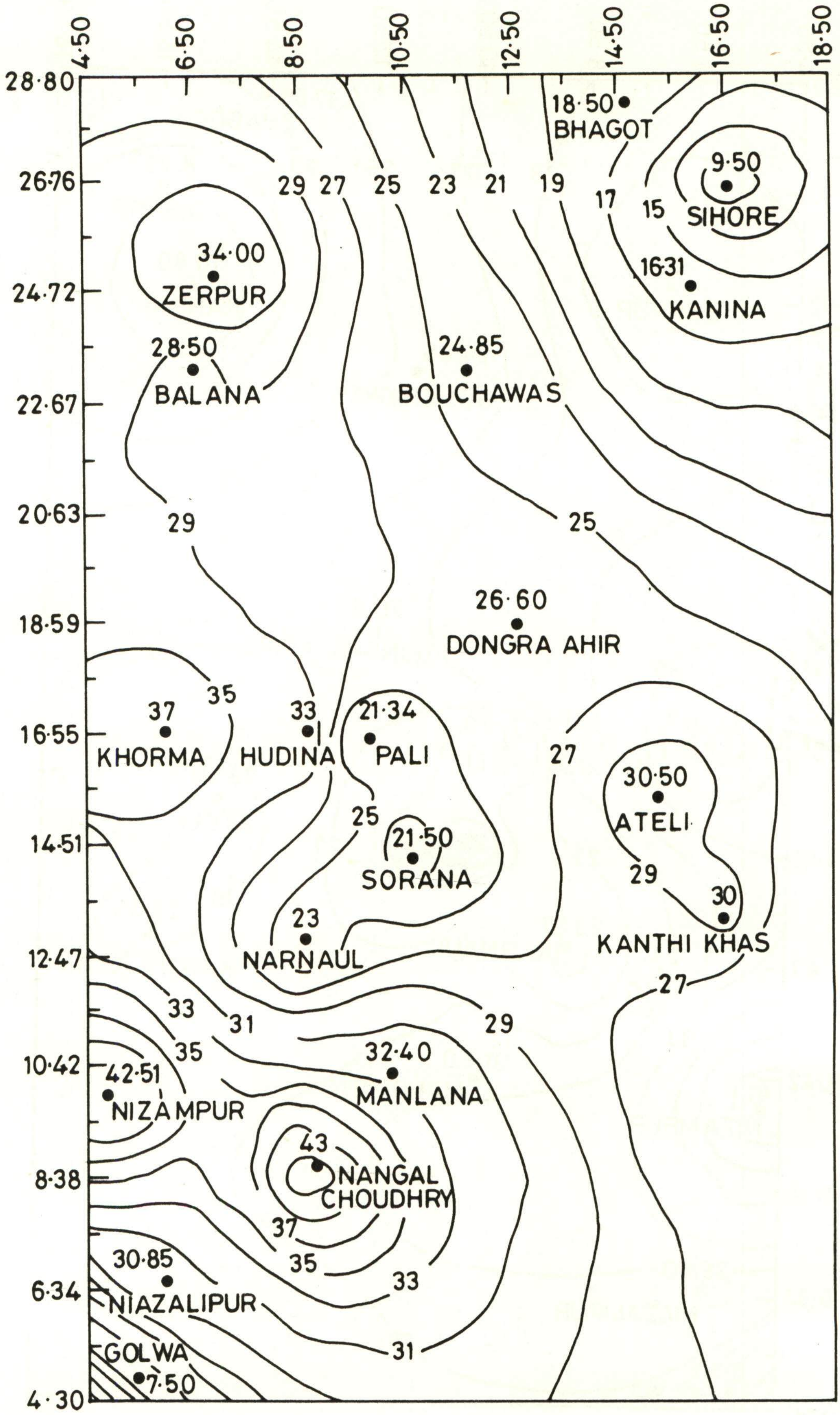


FIG. 4·29. DEPTH TO WATER TABLE CONTOUR MAP (POSTMONSOON, 1993)

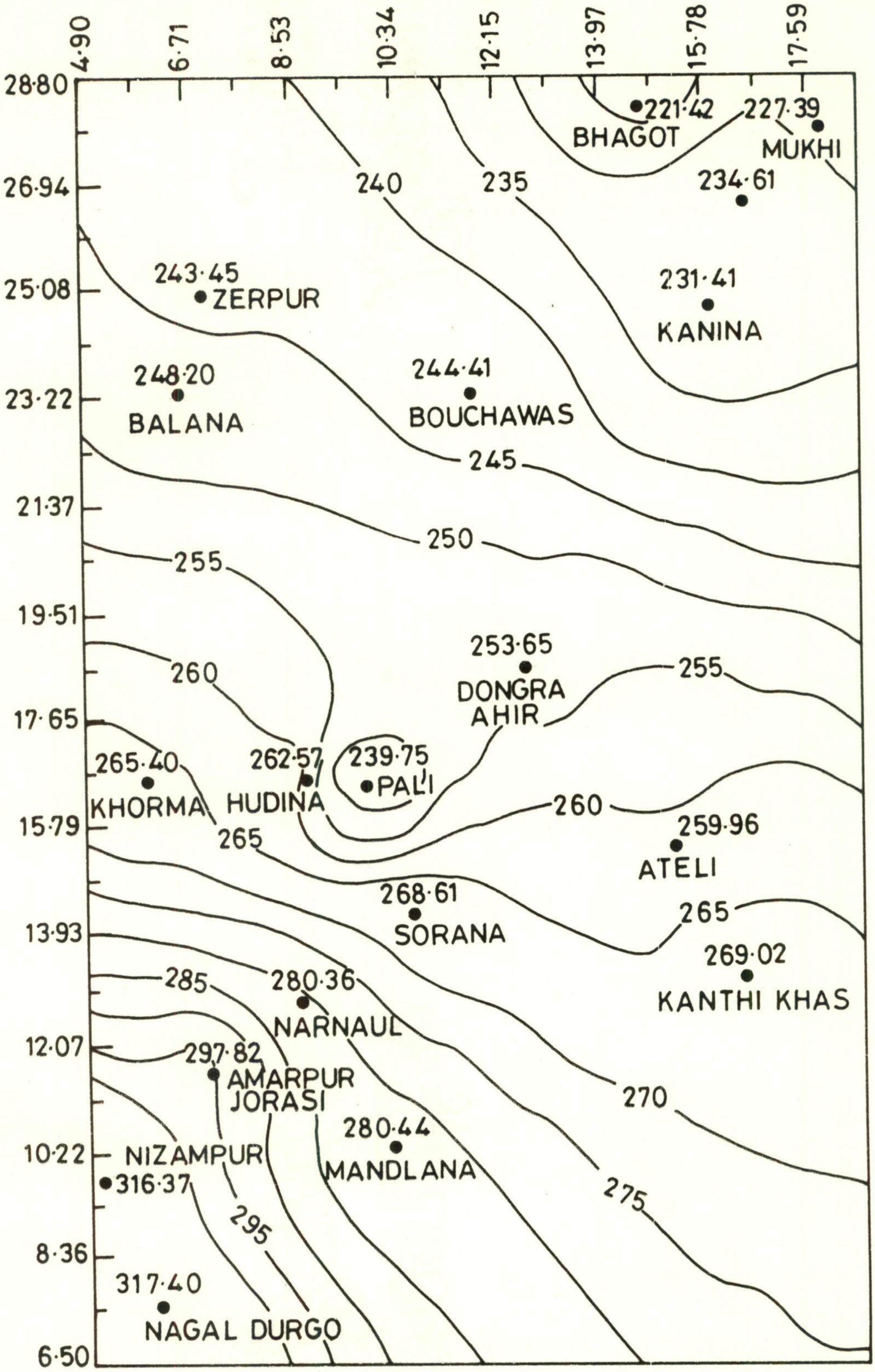


FIG.4·30. WATER TABLE ELEVATION CONTOUR MAP (PRE MONSOON, 1991) and northeast. Further, it can be observed that the watertable contours are quite closely spaced in the southern part, where the hard rocks with low permeability are exposed or occur at shallow depth. In contrast to this, in the central and northeastern parts, the spacing between consecutive watertable contours shows a relative increase indicating greater permeability of the aquifers. It is also corroborated from the figure that the permeability of the aquifer in the southern part (where hard rocks are exposed) is generally lower. In the postmonsoon period of the same year, the watertable continues to have slope towards north and NE (Fig.4.31). However, a groundwater trough is observed at Pali hydrograph station in all the watertable contour maps from 1990 to 1993. Further in the postmonsoon period, there is a slight depression of watertable at Kanina in the NE part (Fig.4.31). The water elevation contour maps of the year 1992 and 1993 (Fig.4.32-Fig. 4.35) indicate the similar direction of groundwater flow from south to southwest to north and northeast. The elevation of watertable varies from 221.82 AMSL in Kanina Block to 314.37 AMSL. However, in contrast to the watertable configration in year 1991, the number of maxima and minima has increased in the years 1992 than 1993 during premonsoon periods. Such a phenomenon can be explained in terms of greater watertable fluctuations, caused due to rainfall as well as increased groundwater withdrawals. To cite a few examples, one can identify the groundwater monds near Kanthikhas in premonsoon periods of 1992 and 1993 as well as at Narnaul and Dongra Ahir. But, these monds tends to disappear and become weakly developed during the postmonsoon period of the corresponding years. Manifestations of general overdraft conditions are quite evident in the configuration of water table contours.

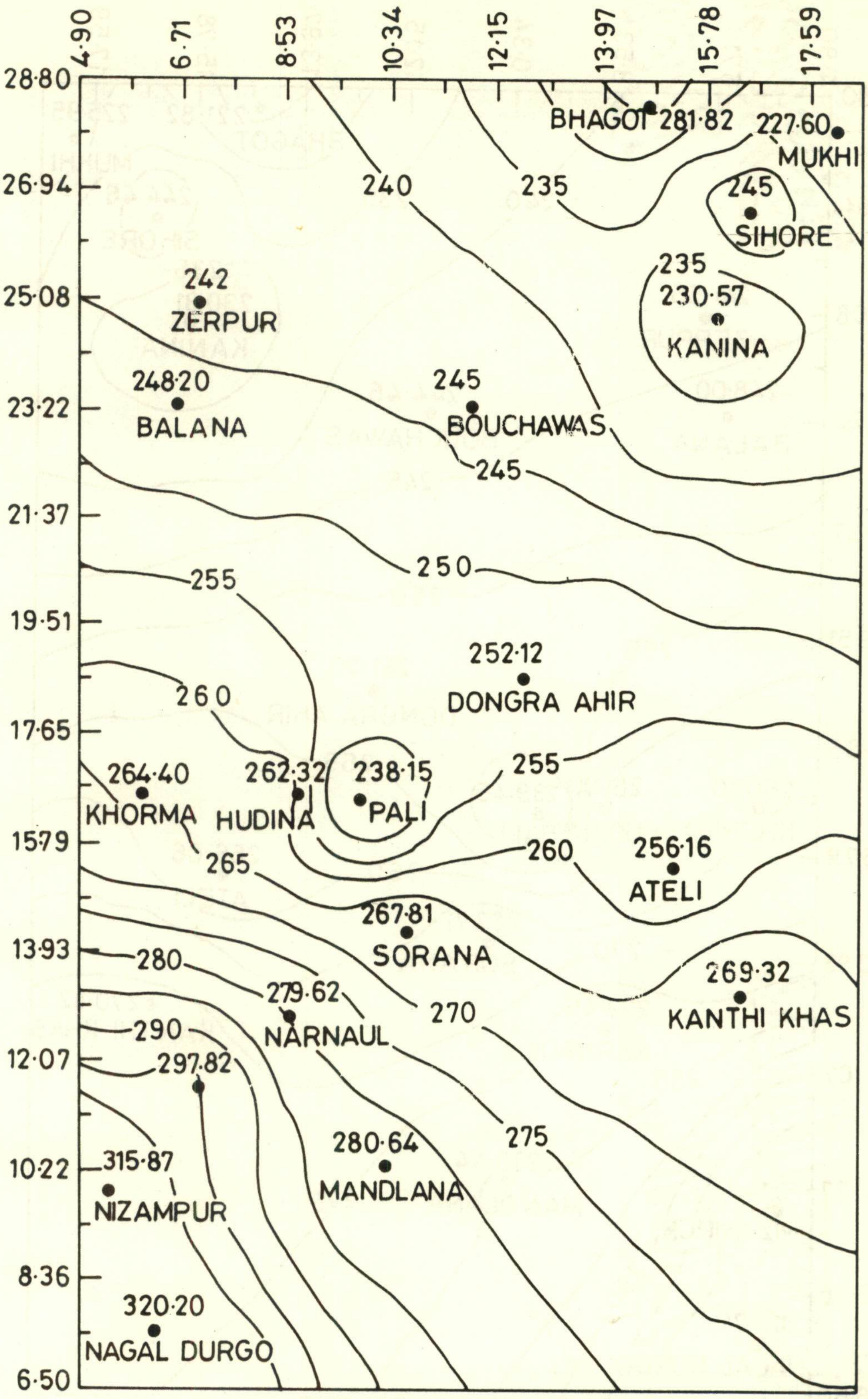


FIG. 4·31. WATER TABLE ELEVATION CONTOUR MAP (POST MONSOON, 1991)

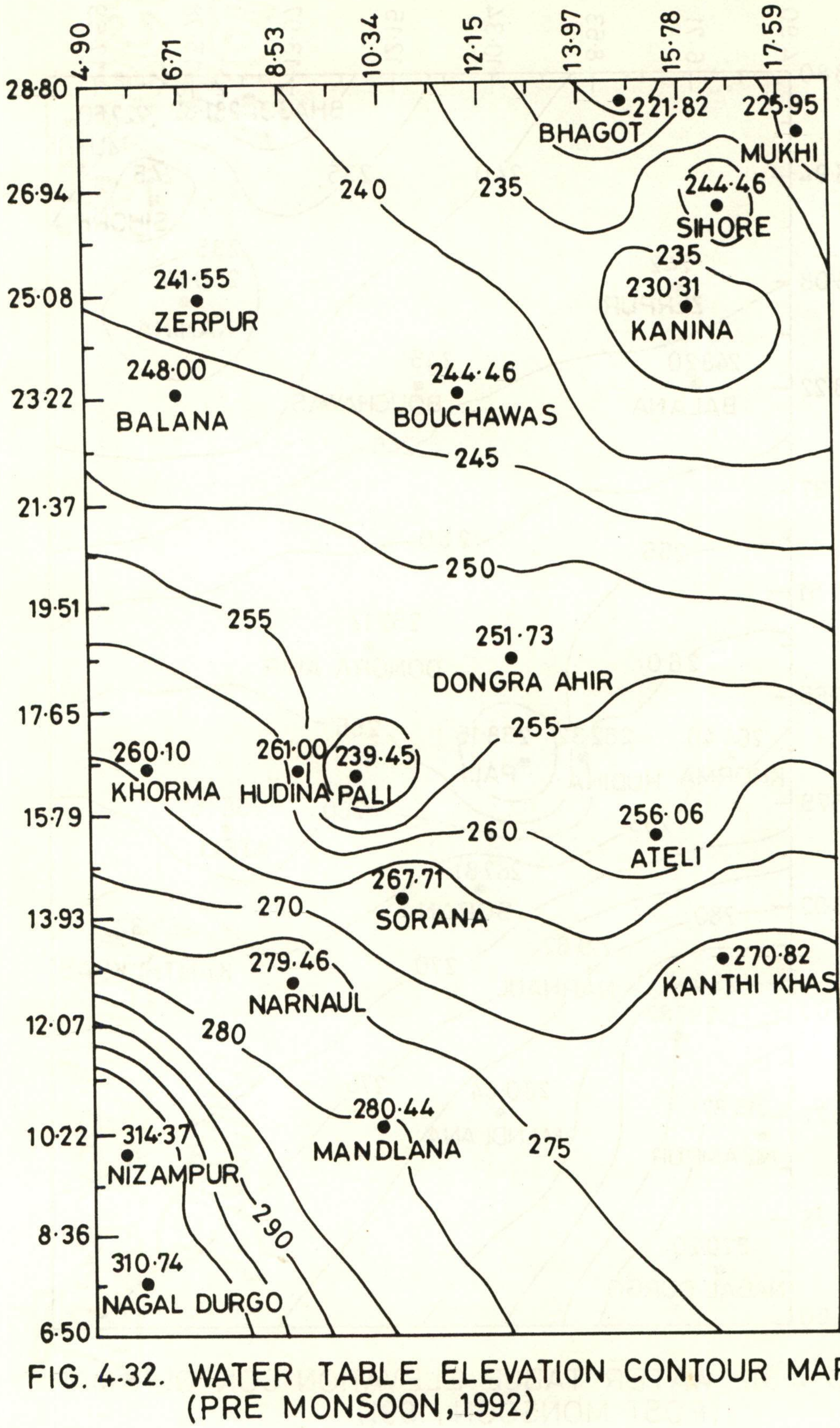


FIG. 4·32. WATER TABLE ELEVATION CONTOUR MAP (PRE MONSOON, 1992)

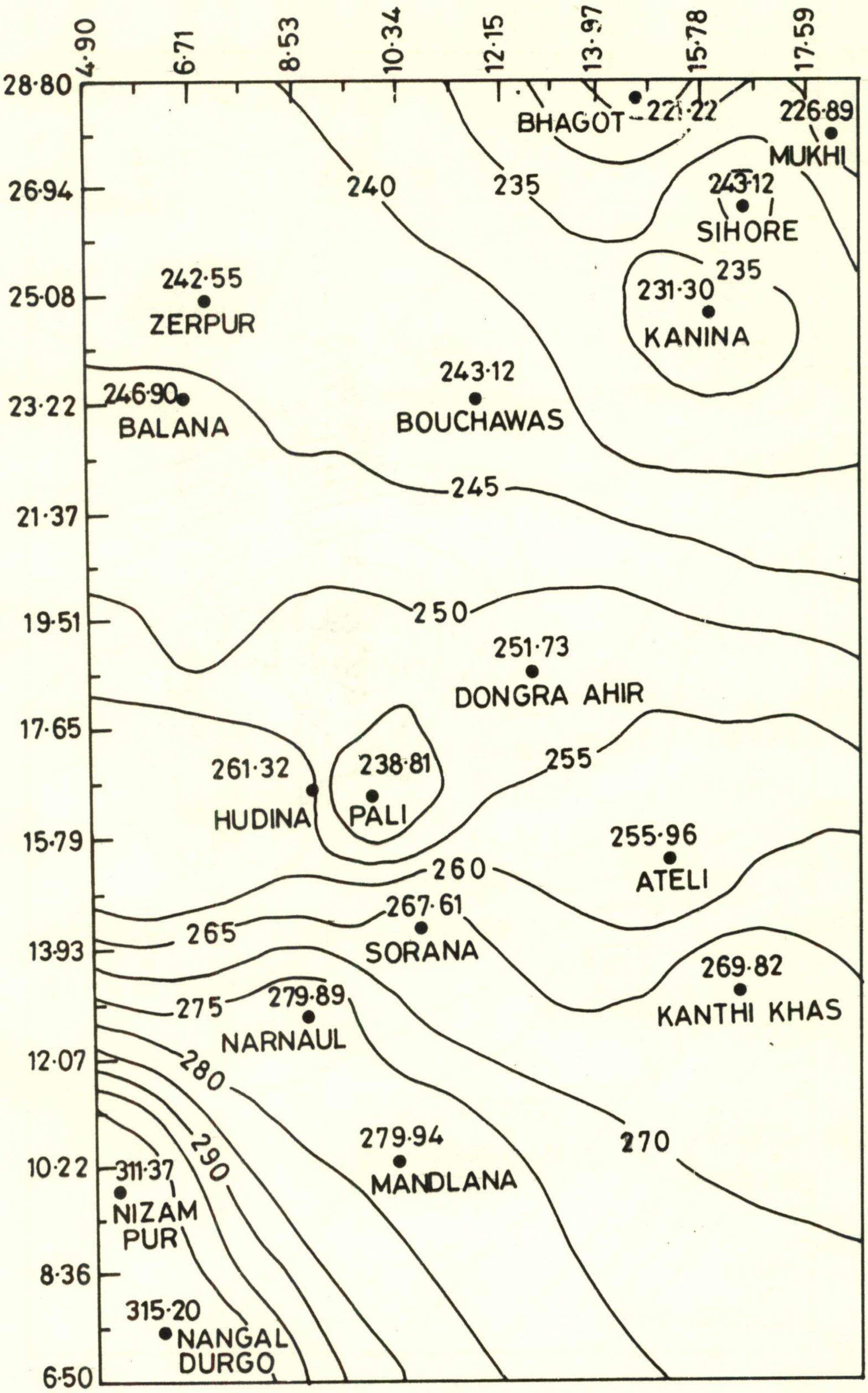


FIG.4·33. WATER TABLE ELEVATION CONTOUR MAP (POST MONSOON 1992)

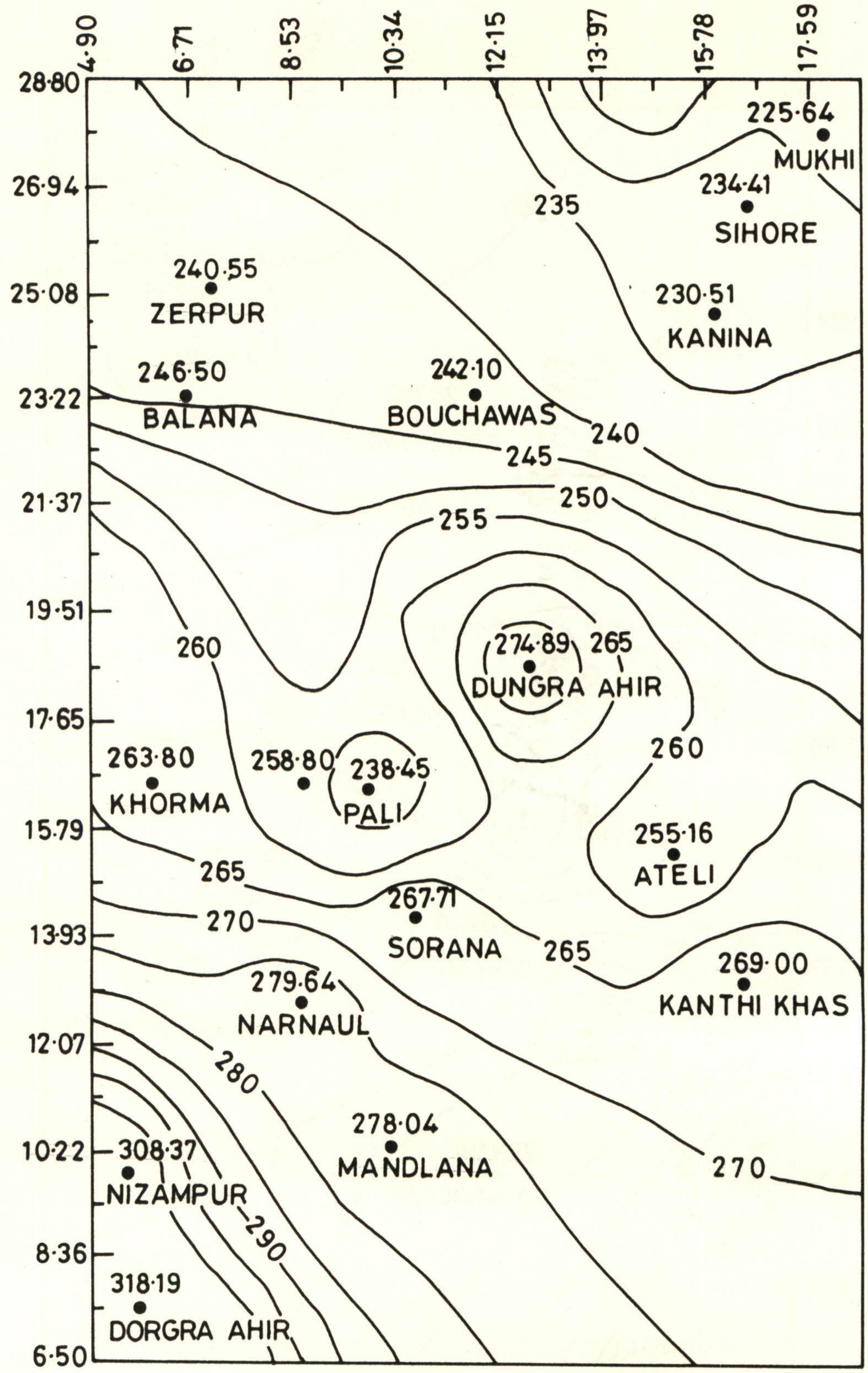


FIG.4·34. WATER TABLE ELEVATION CONTOUR MAP (PREMONSOON, 1993)

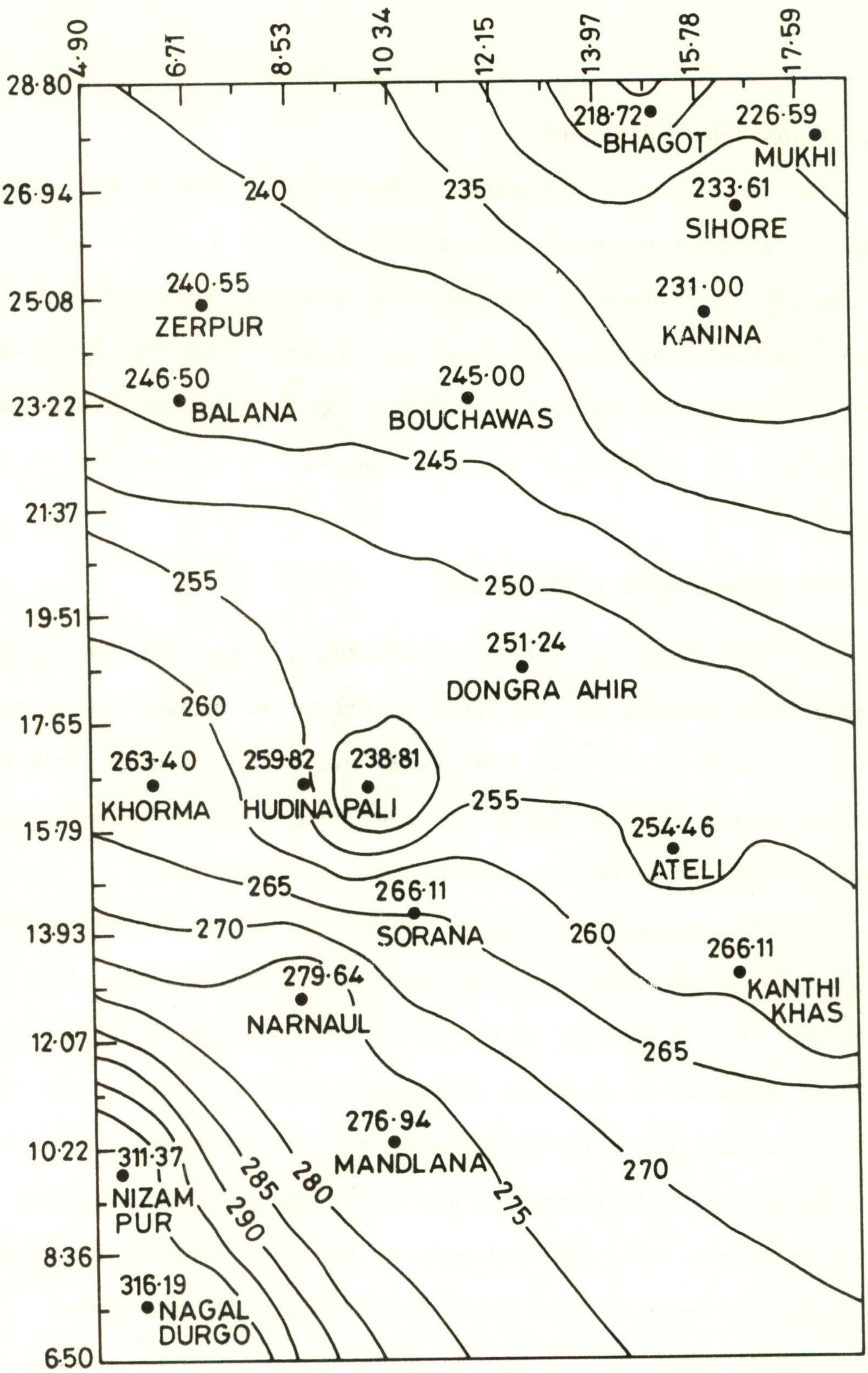


FIG.4·35. WATER TABLE ELEVATION CONTOUR MAP
(POSTMONSOON, 1993)

4.6.4.3 Watertable Fluctuations

Trend in watertable fluctuations monitored over long periods offer a viable technique to ascertain the extent of overdraft conditions if any, in a basin. Further, these can also be utilised to compute their preminial yields under the prevailing recharge conditions. On the other hand, the seasonal watertable fluctuations can be utilised to compute the available groundwater recharge and the groundwater balance. Both the types of variations in the watertable have been considered in the present study.

(i) Seasonal Fluctuations in Watertable

Table 4.5 present the seasonal fluctuations of watertable for the study area. It is seen from the table that the range of fluctuations between the premonsoon and postmonsoon season in the year 1990 varies from -11.1 to +1.8, with majority of hydrograph stations showing decline in watertable. Such a declining trend can be explained due to scanty rainfall combined with over exploitation of groundwater. In the year 1991, the range of pre and postmonsoon fluctuations in waterlevel varied from -3.0 to +1.2, whereas in the year 1992, the fluctuations varied from -1.30 to +0.22m, while number of wells went dry in this period. Further, a sizable number of open wells were either abandoned or converted into dug-cum-bored wells in the year 1993 due to declining watertable, where the fluctuation of pre and postmonsoon levels varied from -2 to +0.7 m. It is to be emphasized that most of the wells show declining waterlevels with the exceptions, being observed only in Pali (Mahendragarh Block), Kanina (in Kanina Block) and Sorana (in Ateli Block) in the northern and eastern parts.

(ii) Long Term Fluctuations in Watertable

Figure 4.36 shows water level fluctuation contour map for the period of premonsoon 1990 to premonsoon 1993. It is observed from the figure that the watertable

TABLE 4.5 SEASONAL FLUCTUATIONS OF WATER TABLE

S.No.	Location	Fluctuations (Pre & Post 1990)	Fluctuations (Pre & Post 1991)	Fluctuations (Pre & Post 1992)	Fluctuations (Pre & Post 1993)	Fluctuations (Pre & Post 1993)	W.L.Flactions (Pre.1977 to Pre. 1993)
BLOCK MAHENDRAGARH							
1.	SEROHI NGNAGAL	- 0.50	+ 1	-	-	- 2	-10.65
2.	ZERPUR	- 0.5	- 1	- 1	- 1	- 3	- 9.45
3.	PALI	- 0.8	- 1.6	- 0.64	+ 0.04	+ 0.3	- 2.91
4.	BALANA	-	-	- 1.10	+ 1.50	- 2	-
BLOCK KANINA							
5.	DONGRA AHIR	- 2.2	- 1.58	+ 0.22	0.0	- 1.03	-
6.	MANPUR	-10.40	-	-	-	-	-
7.	BOUCHAWAS	0.0	+ 1.02	- 1.34	-	0.55	-
8.	KANINA	- 0.25	+ 0.84	- 0.50	+ 0.49	+ 0.1	- 1.79
9.	SIHORE	- 0.5	- 0.1	- 1.30	0.75	- 0.25	-
10.	MUKHI	- 1	- 0.04	-	0.94	- 1.75	-
11.	BHAGOT	-	+ 0.40	- 1.0	-	- 4.4	-
BLOCK NARNAUL							
12.	NIZAMPUR	-	-0.5	- 1.1	- 3	-11	-21.38
13.	AMARPUR JORAGI	0.0	-	-	-	-	-
14.	NARNAUL	- 4.0	+ 0.47	- 0.43	+ 0.80	- 7.87	-
15.	HUDINA	- 0.32	0.25	- 1	- 2	- 4	- 8.66
16.	KHORMA	-0.40	1	-	- 0.8	- 3.30	- 3.3

Contd...

Table 4.5 continued

BLOCK ATELI							
17.	KANTIKHAS	- 0.5	+ 0.3	- 1	- 1.80	0.80	- 9.9
18.	ATELi	- 2.27	- 0.8	- 1.10	-1.0	- 1.6	- 9.27
19.	SORANA	+ 1.8	+ 0.5	+ 0.20	- 1.0	0.87	- 1.68
BLOCK NANGAL CHOUDHRY							
20.	GOLWA	- 0.4	-0.1	- 0.3	- 0.7	- 2.3	-
21.	NAGAL CHOUDHRY	- 0.5	-3.0	-	- 4	- 2.5	-30.5
22.	NANGAL DURGO	- 2.5	-	-	-	-	-33.11
23.	MANDLANA	0.0	- 0.20	- 1.30	- 1.1	- 3.2	-19.58
24.	NIAZALIPUR	- 11.1	- 2.0	- 1.1	- 1.05	- 5.85	-21.38

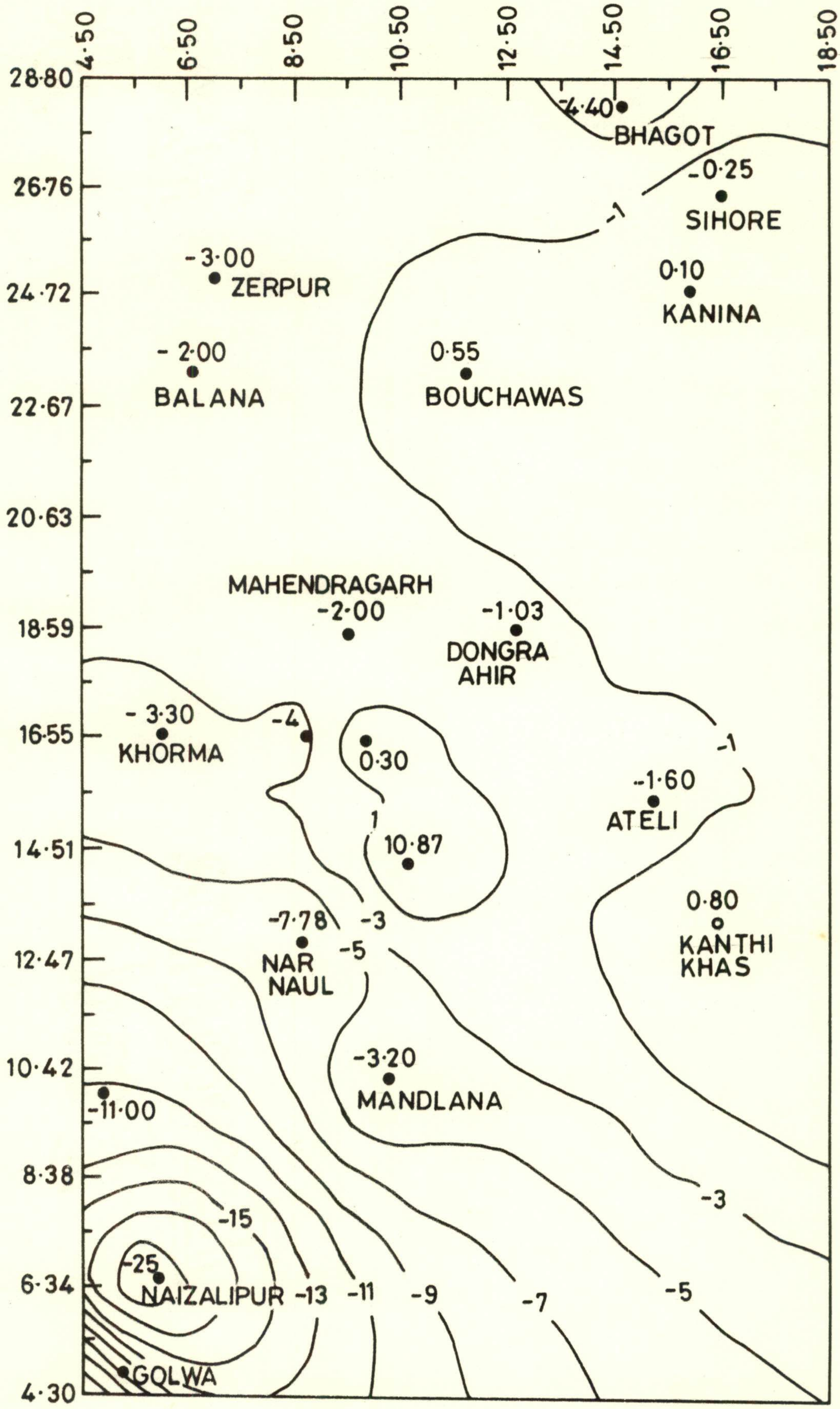


FIG. 4·36. FLUCTUATION CONTOUR MAP (PERIODS PRE-MONSOON, 1990 TO PREMONSOON, 1993) shows a declining trend at most of the localities mainly in the southern part, where large decline of watertable (upto 25 m) can be observed in the Nangal Choudhry station where a marked minima of water level fluctuation contours is obsrved at this station. Further, the data of water level fluctuation for the period premonsoon 1977 to premonsoon, 1993 has been considered for determining the long term fluctuations (Table 4.5). It indicate that all the hydrograph stations exhibit decline in groundwater levels. The maximum decline is in Nangal Choudhry station (30.5 m), Nangal Durgo (33.11 m) and Kanthikhas (28.1 m) villages.

(iii) Relation Between Rainfall and Depth to Water table

The relation between variation in rainfall and depth to water table for postmonsoon only for two hydrograph stations at Narnaul and Mahindragarh for the period between years 1974 to 1992 is shown in Figures 4.37 and 4.38 respectively.

From Figure 4.37 for Narnaul station, it can observed that there is rising trend in water table in the year 1976 and 1977 due to relatively increased recharge from rainfall. However a persistent decline in water level is observed during all the years except 1988 to 1990 due to lesser recharge. Similarly, in Mahindragarh hydrograph station, an overall decline in the watertable is observed continuously (Fig.4.38), except during 1975, 1977 and 1982-84 when slight flatting in the declining trend can be noted in response to above-average annual rainfall. Further, hydrograph totally went dry after the year 1989. In addition to the recharge, over-exploitation of groundwater also seems to be the reason for the decline of water-table in the area.

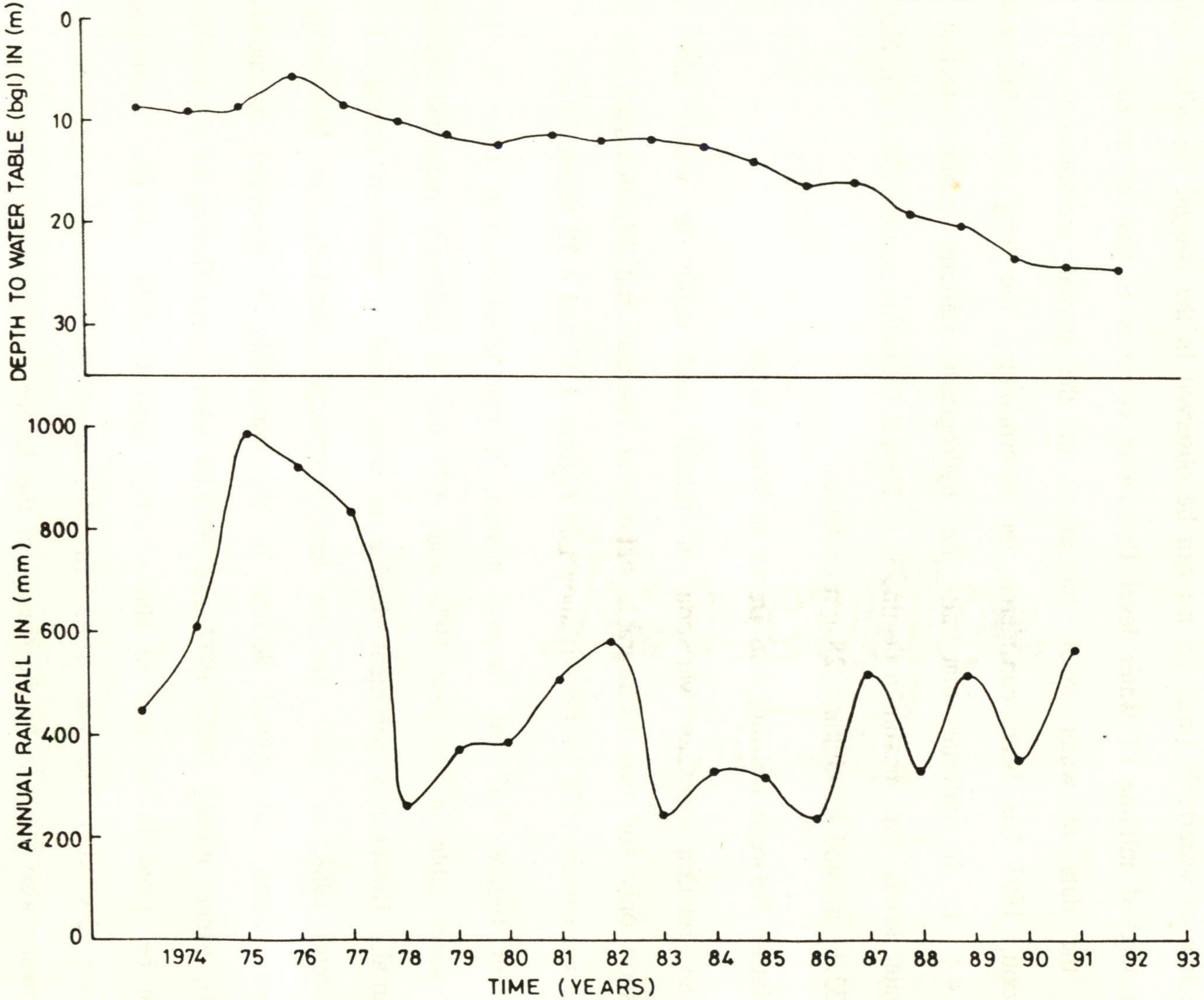


FIG. 4·37. RELATION BETWEEN YEARLY RAINFALL AND DEPTH TO WATER TABLE (POST MONSOON) AT NARNAUL HYDROGRAPH STATION

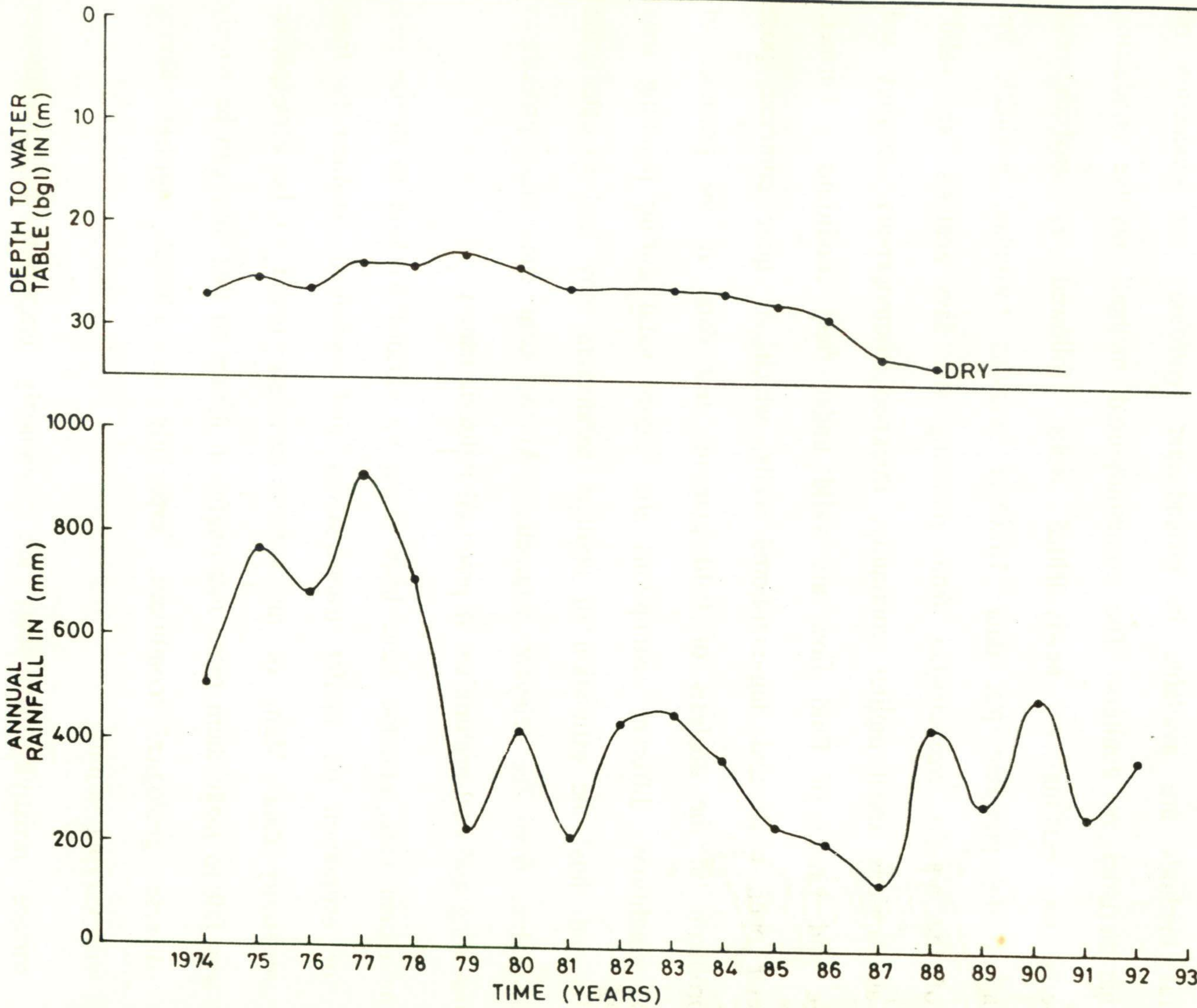


FIG. 4·38. RELATION BETWEEN YEARLY RAINFALL AND DEPTH TO WATER TABLE (POSTMONSOON) AT MAHENDRAGARH HYDROGRAPH STATION

4.6.5 Estimation of Transmissivity of Alluvial Aquifers from Geoelectrical Studies

Several methods are available in groundwater hydrology for evaluation of hydraulic characteristics of aquifers. The commonly-used methods involve conducting pumping tests on existing or newly-drilled wells, followed by analysis and interpretation of the pumping test data. However, various formulae, available for estimation of the aquifer charactristics from pumping test data analysis, are valid, if various assumptions about aquifer continuity, thickness, homogeneity, isotropy and well storage and nature of fluid flow are valid under field conditions . Further, large diameter open wells and dug-cum-bored wells, which are quite common, pose increased problems in the analysis of field pumping test data. In the presence of diverse field conditions, different assumptions are seldom valid during pumping tests on the wells and thus, the estimation of aquifers parameters may lead to calculation of erroneous values from the relevant parameters. At the same time these procedures are time consuming and cost-prohibitive, if practised indiscriminately.

In the recent yars, attempts have been made by various workers to devise new approaches for estimation of aquifer transmissivity and hydraulic conductivity from geophysical resistivity data. Many of the approaches were found to be area-specific and a need was felt to make them more meaningful in nature so that they can be widely applied in diverse geological conditions, especially in alluvial aqufiers having groundwater with varying salinity.

The surface resistivity soundings are commonly employed in groundwater investigations. The results, obtained after interpretations of resistivity data, yield details of depth/thickness and restivities of subsurface layers in terms of an earth model. From this data, Dar Zarrouk parameters i.e. transfer unit resistance (R) and longtitudinal unit conductance (C) (Maillet, 1947) can be calculated. The Dar Zarrouk parameters have been used for development of indirect resistivity interpretation by many workers (Ungemach et al., 1969; Steeples, 1970; Kelly, 1977 a, b; Schimshal, 1981; Kosinsky and Kelly, 1981). Kelly (1977, a, b) established an empirical relation aquifer electrical resistivity and aquifer hydraulic conductivity and a semi-empirical relation between the aquifer formation factor and hydraulic conductivity for glacial outwash materials of the upper Pawcatuck River Basin in southern Rhode Island, U.S.A.

Sri Niwas and Singhal (1981) established an analytical relationship between transverse unit resistance and aquifer transmissvity for homogeneous isotropic media and tested the applicability of the relation using published data for Rhode Island, U.S.A. Kosinski and Kelly (1981) attempted to establish a direct equivalence between a "normalized transverse resistence" and aquifer transmissivity. Kelly and Reiter (1984) and Mazac et al.(1985) have reviewed the existing relations between aquifer properties and resistivity-related parameters and confirmed that direct relations between these parameters between aquifer properties and resistivity-related parameter are more valid than inverse relation inspite of variation in hydraulic anisotropy. They also demonstrated the applicability of various available approaches by using different models under varying field conditions.

Singhal and Sri Niwas (1983) and Sri Niwas and Singhal (1985) widened the applicability of the relation between "modified transverse resistance" and aquifer transmissivity by considering variation in water quality for alluvial aquifers in Saharanpur, Varanasi and Banda districts.

In the present study, an attempt has been made to test the applicability of the modified relations as proposed by Singhal and Sriniwas (1983) and Sri Niwas and

Singhal (1985), for the alluvial aquifers of Mahendragarh district, where groundwater of widely varying quality occurs in the shallow aquifers.

4.7.5.1 Theoretical Background:

Sri Niwas and Singhal (1981) considered a prism of isotropic and homogenous aquifer material having unit cross-sectional area and thickness "h" for which the following relationships was proposed

$$T = K \sigma R \quad (4.1)$$

T = Aquifer transmissivity

K = Hydraulic conductivity

σ = Electrical conductivity ($\equiv 1/\rho$, the resistivity of the medium

R = Transverse unit resistance

Equation (4.1) assumes that change in aquifer resistivity is mainly due to the change in aquifer skeleton material (excluding rock matrix), and tortuosity of the interconnected pores. However, it was presumed that the gross chemical quality of groundwater remains relatively uniform. Equation (4.1) was further modified by Singhal and Sri Niwas (1983) taking into consideration "modified aquifer resistivity" instead of "aquifer resistivity". However, the modification factor is always the ratio of the average aquifer water resistivity ($\bar{\rho}w$) and the aquifer water resistivity (ρw) at a particular location. Thus, the equation (4.1) can be rewritten as:

$$T = (K \sigma')R' \quad (4.2)$$

Where,

$\sigma' = \sigma \cdot \rho w / \bar{\rho w}$ and $R' = R. \bar{\rho w} / \rho w$ are "Modified conductivity" and "Modified transverse resistance" of the aquifer respectively.

The product $K\sigma'$ is assumed to be constant in a groundwater basin and can be calculated if the hydraulic conductivity of the aquifer at a reference point is known. A natural corollary of equation (4.2) can thus, be written as:

$$K = \alpha \rho' \quad (4.3)$$

Where,

α is equal to the product $K \sigma'$ and ρ' is the "Modified aquifer resistivity".

Equations (4.2) and (4.3) are useful for computing transmissivity and hydraulic conductivity of the aquifers in porous, homogenous and isotropic media in cases when there is variation in quality of groundwater, which can influence the bulk resistivity of the aquifer.

4.6.5.2 The Application

In the present study, the aquisition of resistivity data was carried out by taking ten vertical electrical soundings (VES) in the vicinity of existing open well hydrograph stations. Due to distinct advantages of the Schlumberger method over Wenner sounding, (Bhattacharya and Patra, 1968; Zohdy et al., 1974), the former array electrode configuration was perferred. Out of the 10 soundings sites, of seven locations were selected for computation of transmissivity. These electrical soundings were taken at sites, where alluvial overburden is expected to have reasonable thickness, and the hydraulic anisotropy may not show marked variations. The available values of field transmissvity of the unconfined alluvial aquifers were used for comparison with the computed transmissivities. Table 4.6 summarises the interpreted results of VES, aquifer water resistivities, field hydraulic conductivities and

TABLE 4.6 : SUMMARY OF INTERPRETED DATA FOR VES, TRANSMISSIVITY AND OTHER COMPUTED PARAMETERS

S. No	Location	Sorana	Pirt-hipura	Katkai	Konthal Kurd	Sihore	Bouch-awas	Amarpur Jorasi	Remark
	VES No.	3	4	5	6	7	8	9	
1	Depth of Groundwater	18.30	35.44	29.45	22.10	10.20	23.90	25.35	
2	Lithology of Aquifer	Alluvium	Alluvium	Alluvium	Sand & Kankar	Sand	Sand-coarse	Alluvium	
3	Temp. of Groundwater at field	24°C	24.5°C	27.5°C	28°C	28.5°C	27.5°C	28°C	
4	E.C. of G.W. at field temp.	1110	2530	1480	5028	2160	4360	1300	
5	Resistivity of G.W. at								
	(a) field temp.	9.01	3.952	6.756	1.988	4.62	2.293	7.67	
	(b) ρw ,25°C	8.78	4.825	7.178	2.137	5.034	2.436	8.365	$\bar{\rho w}$ =6.54
6	Aquifer:								
	(a) Resistivity (ohm-m)	15	13	16	17	9	17	30	
	(b) Actual thickness	23	-	22	-	-	-	-	
	(c) Electircal thickness (m)(b)	15	15	17	23	13	33	15	

Contd....

Table 4.6 continued

S. No	Location	Sorana	Pirt-hipura	Katkai	Konthal Kurd	Sihore	Bouch-awas	Amarpur Jorasi	Remark
	VES No.	3	4	5	6	7	8	9	
7	Field Transmissivity m^2/day (After CGWB; HMITC)	151	150	118	360	-	-	250	
8	Transverse Resistance (R) ohm-m	225	195	272	391	117	561	450	
9	$R' = R.\bar{\rho w} / \rho w$	165.52	261.04	244.75	1151.8	150	1487	347.46	
10	k=(from field)	6.6*	10*	5.36*	15.65*	-	-	16.7*	
11	$\sigma' = \sigma.\rho w / \bar{\rho w}$	0.09062	0.05747	0.06945	0.01947	-	-	0.04317	
12	$k\sigma'$ computed Transmissivity	0.5980	0.5747	0.373	0.30470	-	-	0.7209	$k\bar{\sigma} = 0.5142$
13	$T = (k\sigma')R'$ M^2/day	85.120	134.24	125.9	607.8	77.139	764.70	178.68	
14	K=T/b	5.67	8.94	5.72	26.42	5.93	23.17	11.912	

* K values arrived at by using electrical thickness

transmissivities for seven selected locations of alluvial aquifers. With the help of aquifer water reistivity for different observation wells, an average value of aquifer water resistivity ($\bar{\rho w}$ = 6.4 ohm-m, at $25^{o}C$) may be calculated for the purpose of calculation of modified aquifer resistivity $\rho' = \rho . \bar{\rho}w / \rho w$ and modified transverse resistance $R' = R \bar{\rho} w / \rho w$.

Figure 4.39 shows a plot between field transmissivity and modified transverse resistance (R ') prepared from data of Table4.6. From the analysis of best fit line, the root mean square error (RMS) between field transmissivity (T) and "modified transverse resistance (R ') is found to be 36.74 m^2/day and seems to be within the resonable limits. From the above discussion, it may be concluded that the direct relation between aquifer transmissivity and modified transverse resistance of alluvial aquifers with varying water quality is quite meaningful and can be utilised for estimation of transmissivity from resistivity data for other areas. The hydraulic conductivity at a location may also be estimated from the relevant equation , if the α is known for a reference well in the area.

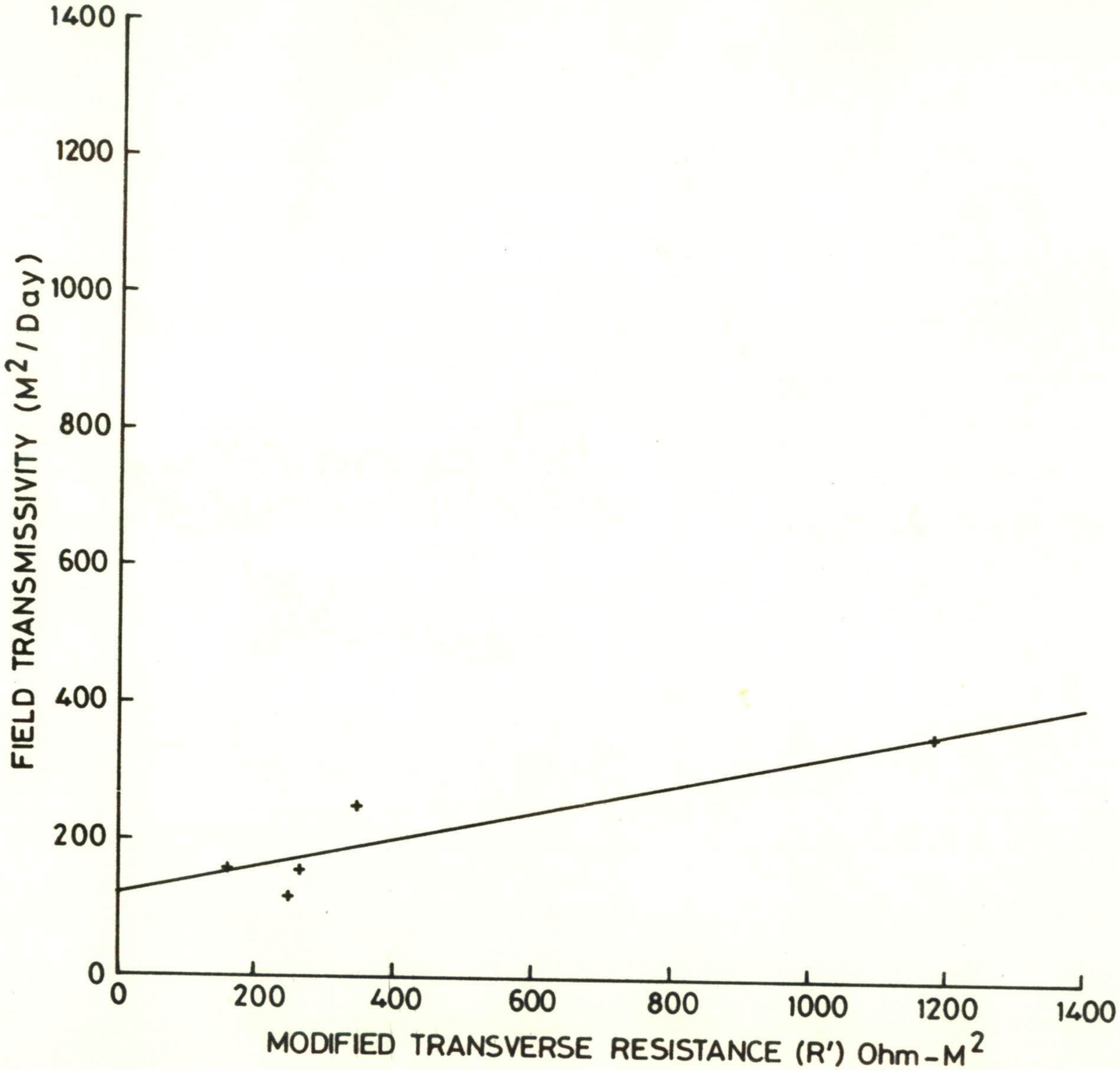


FIG.4.39. PLOT BETWEEN MODIFIED TRANSVERSE RESISTANCE AND FIELD TRANSMISSIVITY

CHAPTER - 5
GROUNDWATER QUALITY

5.1 INTRODUCTION

It is widely recognised that quality of groundwater is as important as its quantity. All natural waters lose their importance if the quality of the water does not meet the specifications laid down by the Regulatory agencies for different uses.

A groundwater, initially considered to be safe for drinking purposes, can become contaminated by man-made pollutants or natural processes, which may cause various disorders and other problems on consumption. The groundwater, originating from rain and snowmelt, infiltrates through soil into flow systems in the underlying geologic materials. The soil water zone has unique and powerful capabilities to alter the water chemistry as infiltration occurs through this biologically-active zone. In a recharge area, the soil zone undergoes a net loss of mineral matter to the flowing water.

As groundwater moves from a recharge to discharge area, its chemistry is further altered by the effect of geochemical processes. The desired quality of groundwater supply depends upon its purpose; thus quality-need for drinking water, industrial water, contact recreation and irrigation water vary widely. The water quality standard and criteria for different uses have been specified by different Regulatory Agencies (ICMR, 1975; ISI,1983, WHO; 1984).

5.2 CHEMICAL PROCESSES AFFECTING GROUNDWATER QUALITY

The geochemical properties of groundwater generally depend on those of recharged water viz.,atmospheric precipitation, inland surface waters and sea water and on subsurface geochemical processes. Temporal changes in origin and constitution of recharged water, hydrologic and human factors cause periodic changes in groundwater quality. The knowledge of geochemical processes, often leads to an understanding of groundwater quality and can occasionally aid in making useful predictions. The different geochemical processes which influence groundwater greatly, are given below (Todd,1980; Drever, 1982).

5.2.1 Reduction:

The most important constituents to be affected by this process are sulphates and nitrartes. The reduction of sulphate is generally due to organic matters (Schoeller, 1962) and is accompanied by their oxidation resulting in the production of CO_2, which in turn produces large quantities of HCO_3^-, H^+ and CO_3^- ions.

5.2.2 Ion Exchange:

The replacement of the structural or adsorbed ions of the geological materials by the ions present in solution has been termed as ion exchange (Garrels and Christ, 1965; Hem, 1985). However, there is not a single replaceability series for the inter-exchangeability of ions. The degree to which the ion exchange (both cation as well as anion exchange) occurs depends on **(a)** concentration of exchangeable ions in the solution, **(b)** the type of the solid material or sediments in contact with solution, **(c)** the state of ion in the soild-structural, adsorbed, and **(d)** degree of saturation of that ion in the solid (Holden, 1970). The exchangeablity of an adsorbed ion is far greater than that of the structural ion. The common exchange is, therefore, between the ions adsorbed by the solid, which is commonly seen in clay minerals, zeolites and organic substances. The adsorption capacity of some minerals is also influenced by other characteristics of adsorbed ions, besides its charge e.g. ion radius and degree of hydration.

Schoeller (1951,1962) has explained two types of base exchange-positive, when alkalis (Na^+, K^+) in water get exchanged for alkaline earths (Ca^{++}, Mg^{++}) in the aquifer material; and negative, when alkaline earths in the water get exhanged with alkalis in the rock. Former is generally the case, when sea water enters the coastal fresh water aquifers, and the latter takes place in coastal areas of inland saline water or in transition zone between the fresh water and the sea water.

5.2.3 Evaporation and Dissolution:

The process of evaporation and dissolution control the concentration of aqueous solutions to a greater extent, which in turn is influnced by the climatic factors.

Schoeller (1962) listed main factors influencing the process of mineralisation by dissolution and concluded that groundwaters are commonly highly mineralised due to large residence time in subsurface formations under relatively higher temperature gradients (resulting at considerable depths), thus allowing greater rock-water interaction.

5.2.4 Sea Water Encroachment of Coastal Aquifers:

Simple mixing of two waters of different composition can result in evolution of a new kind of water, which may not necessarily retain the qualities of the mixing waters. Sea water during encroachment into coastal aquifers, can modify the composition of the groundwater by base exchange, sulphate reduction and substitution of carbonic or other weak acid radicals and also by solution and precipitation.

Apart from the above-mentioned processes, certain type of bacteria especially those involved in nitrogen and sulphur cycles, modify the composition of soil and soil water, thereby, affecting the composition of natural water percolating through soil. Moreover, climatic changes also play an important role in changing the composition of groundwaters e.g., transfer of salts from sea to land by wind etc. (Holden, 1970).

5.3 GROUNDWATER QUALITY MONITORING NETWORK

Water quality monitoring is the effort to obtain quantitative information on the physical, chemical and biological characteristics of water via statistical sampling (Sanders et al.,1983). Water 'quality monitoring' refers to most type of water quality sampling (or measurement) and the 'network design' means determining action of the placement of sampling points. The sound network design for water quality monitoring can be formulated depending on the purposes of monitoring and monitoring activities. The monitoring activities can be broadly divided into data acquisition (operational) and data utilization (informational). Both major groups of activities are important for the effectiveness of a total monitoring system. The data acquisition consists of sample collection, and laboratory analysis. However, prior to sampling, the location and frequency of water quality variables measured must be determined through the network design.

Brown et al. (1972) have discussed the considerations in the location of observation wells for groundwater quality in different types of geological terrains and installation of observation and testing stations whereas Everett (1980) and

Kazman(1981) have discussed design aspects of groundwater monitoring network. Hem (1985) presented guidelines for sampling and preservation of water samples.Considerable effort has been put into the development of standard laboratory analysis procedures for estimation of various constiuents in natural waters(Environmental protection Agency, 1974; American Public Health Association, 1980). In the current study, the procedures described by Standard Methods (AWWA, 1989) for examination of water and waste water have been referred for estimation of the various constituents.

5.4 MONITORING AND HANDLING OF GROUNDWATER SAMPLES

To evaluate the groundwater quality characteristics of the present area, a programme of monitoring of groundwater quality was drawn in such a manner so as to bring out relevant parameters of water quality for the whole area with a network of optimally selected observation wells keeping in view the overall distribution of alluvium and the consolidated geological formations in the area. The selected sampling locations are evenly distributed in the area and are readily accessible. Figure 5.1 shows locations of sampling points in the study area. The frequency of the groundwater sampling was fixed, at least , once in a year/season. The possible variations in water quality with the depth and lithology were also considered in this study, and in order to represent water quality differences of shallow and deep[1] aguifers sampling was carried out from shallow and deep wells. The large diameter open and shallow,were chosen to procure water samples, as large diameter of the well facilitates a sampling device (bailer or the container) to be lowered into the well, if needed. Water samples were collected in polyethelene bottles of two-litre capacity from the selected wells. The sample bailers were cleaned prior to sampling using standard procedure to prevent

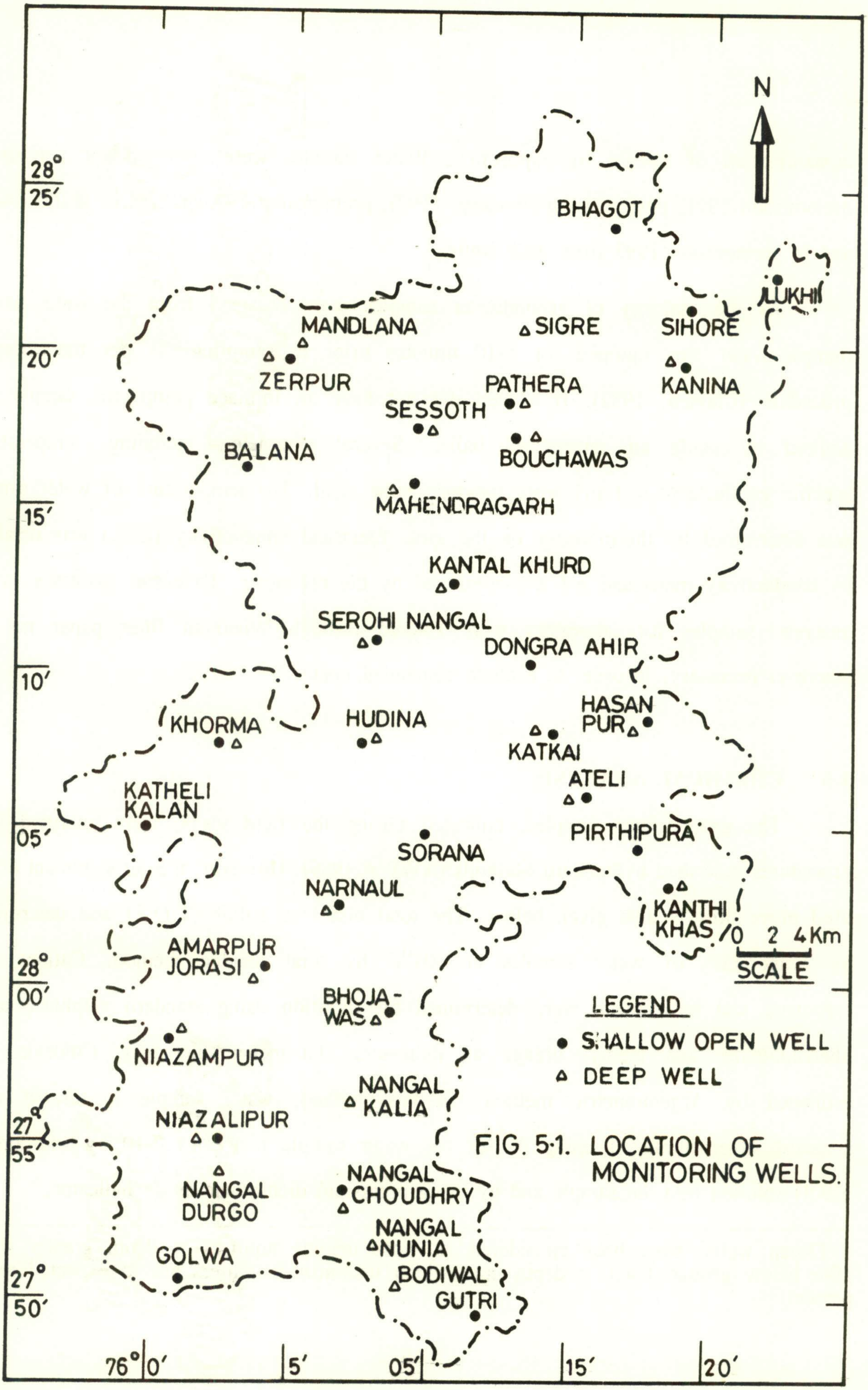


FIG. 5·1. LOCATION OF MONITORING WELLS.

contamination of sample by exposure . Water samples were collected for periods of premonsoon 1991, postmonsoon (January, 1992), premonsoon 1993 in case of shallow wells and in premonsoon 1993 from deep wells.

As the majority of groundwater samples were obtained from the wells having pumps, water was pumped for 5-10 minutes prior to sampling, as per the accepted procedure (Classen, 1982). If a well did not have an in-place pump, the sample was aquired by using an improvised bailer. Several parameters including, temperature, specific conductance,and pH were measure inthe field. The temperature of water sample was determined by thermometer on the spot. Electrical conductivity (E.C.) was obtained by conductivity meter,and pH was measured by the pH-meter. To ensure accuracy in the analysis, samples for laboratory were filtered through Whatman filter paper no. 42 wherever necessary, in order to exclude suspended matter.

5.5 CHEMICAL ANALYSIS

The groundwater samples, collected during the field visits, were analysed with procedures described byStandard Methods (AWWA,1989). However, a brief statement of the used procedures is also given below. The total dissolved solids (T.D.S) was determined by evaporation of water samples at $104^{o}C$ by total residue method. Cations like carbonate and bicarbonate were determined by filtration using standard sulphuric acid, phenolphthalin and methyl orange as indicators (Titrimetric methods). Chloride was estimated by Argentometric method. In this method, water sample is titrated with standard silver nitrate, keeping pH of the water sample between 7-10 by addition of NaOH solution into the sample and by using potassium dichromate as an indicator.

1.'Deeep wells' have been considered as those tapping aquifers at depth greater about 40m below ground level, a depth upto which unconfined aquifers are to expected to be present.

Sulfate was determined by gravimetric method with the ignition of residue. In this method, sulfate is precipitated as barium sulfate in a hydrochloric acid medium by addition of barium chloride. The precipitate comes out near the boiling point, and after a period of ignition, the precipitate is filtered and washed until it is free of chlorides, then it is ignited or dried and weighed as $BaSO_4$.

Anions like sodium and potassium were determined by using Flame Photometer in which the sample is sprayed into a gas flame for excitation and the desired spectral line is isolated by use of suitable slit. The intensity of light is then measured by photo tube potentiometer. Calcium and magnesium was determined by Atomic Absorption Spectrophotometer (AAS). In this method, a light beam is directed through the flame into a monochromator, and on to a detector that measures the amount of light absorbed by the atomized element in the flame. For accuracy of result, several samples were also analyzed by Induced Coupled Plasma (ICP) method. Fluoride, iodide and bromide were determined by Ion selective Electrode method (Orion model). For ensuring reliability, all the results were calibrated with the standard solutions, prepared for the individual ions.

A summary of analytical methods used for chemical analysis is given in Table 5.1. The accuracy of chemical analyses was verified by cation- anion balance method.

5.6 RESULTS OF CHEMICAL ANALYSIS: A GENERAL APPRAISAL

The data of values of chemical parameters of the groundwater for the three seasons,1991,1992, and 1993 are given in Tables 5.2-5.5. In the following paragraphs,a general appraisal of the ranges of the chemical parameters is made, followed by subsequent synoptic representation of their concentration on maps and Trilinear

Table 5.1 SUMMARY OF ANALYTICAL METHODS USED FOR CHEMICAL ANALYSIS OF WATER SAMPLES

Parameters	Analytical Methods
Temperature (^{o}c) T	Digital thermometer
Electrical conductance (E.C.) (Micro-Mhos/cm at 25^{o}C)	Conductivity meter
pH	Battery operated digital pH meter
Total dissolved solids (T.D.S)	Residue method
Carbonate and Bicarbonate	Titrimetric methods using standard sulphuric acid with phenolphthalin and methyl orange as indicators.
Chloride	Agrentometric method with potassium dichromate as indicator
Sulphate	Gravimetric method using barium chloride.
Fluoride	Ion selective electrode method
Bromide	Ion selective electrode method
Iodide	Ion selective electrode method

TABLE 5.2 CHEMICAL DATA OF GROUNDWATER ANALYSIS

SHALLOW GROUNDWATER APRIL,1991

Location	Na^{+}	K^{+}	Mg^{++}	Ca^{++}	Cl^{-}	SO_4^{--}	HCO_3^{-}	CO_3^{--}	pH	E.C	T.D.S	F^{-}	Br^{-}	I^{-}
Hudina	9.57	.269	5.96	9.34	16.13	1.93	5.40	.40	8.62	2061	1340	1.85	2.5	0.21
Khorma	2.88	.002	3.95	2.80	5.36	.85	2.85	.16	8.51	615	400	2.45	1.21	0.26
Sorana	7.83	.537	2.98	8.98	2.65	8.74	6.35	.66	8.76	1110	860	3.00	1.54	0.21
Pirthipura	4.78	.141	2.05	9.42	6.88	4.35	3.78	.10	8.22	2530	1390	0.38	1.83	0.01
Katkai	6.51	.072	9.38	9.88	18.90	2.85	4.55	.03	7.87	1480	1036	0.71	11.5	0.02
Sihore	1.39	.064	1.48	6.08	5.13	1.06	3.26	.00	8.61	2160	1512	0.89	1.12	0.13
Bouchwas	17.87	.064	18.51	9.68	38.81	1.77	5.17	.12	8.10	4360	3020	0.25	3.5	0.15
A.jorasi	11.35	.058	13.49	2.59	21.66	.66	4.78	.20	8.35	1300	845	1.21	2.3	0.13
Niazalipur	1.30	.070	6.17	4.24	5.36	.37	4.72	.29	8.51	798	670	0.85	1.5	0.04
Zerpur	8.26	.070	2.46	1.04	5.41	1.22	4.75	.29	8.3	2230	1886	1.32	2.02	0.00

TABLE 5.3 CHEMICAL DATA OF GROUNDWATER ANALYSIS

SHALLOW GROUNDWATER JANUARY,1992

Location	Na^{+}	K^{+}	Mg^{++}	Ca^{++}	Cl^{-}	SO_4^{--}	HCO_3^{-}	CO_3^{--}	pH	E.C	T.D.S	F^{-}	Br^{-}	I^{-}
N.Choudhry	4.35	0.26	0.86	1.62	2.82	1.54	3.15	0.20	8.60	4574	3350	0.67	0.82	0.13
Boucharia	13.38	0.61	3.26	3.25	11.56	3.37	6.48	0.40	8.59	1712	1125	0.26	1.94	0.14
Niazalipur	12.61	0.51	1.40	2.0	9.47	1.77	5.33	0.28	8.53	798	625	0.24	0.97	0.01
Hudina	16.9	2.03	3.20	3.24	15.51	3.99	4.25	0.35	8.70	2330	1900	1.14	4.86	0.02
Nizampur	34.8	1.11	9.26	5.48	32.15	8.74	8.13	0.28	8.32	4650	3525	0.37	10.0	0.04
Sorana	10.87	0.63	2.19	4.76	3.49	5.24	8.98	0.89	8.79	1110	750	1.68	3.28	0.01
Khorma	6.96	0.40	1.30	3.66	2.36	4.79	5.20	0.35	8.62	630	441	1.57	1.39	0.00
Bhojwas	21.72	0.43	1.60	1.76	14.21	1.04	9.84	1.38	8.94	2890	2187	3.89	3.87	0.01
Gotri	6.12	0.39	3.52	3.29	1.69	6.24	5.29	0.35	8.62	670	475	0.23	0.66	0.00
Ateli	47.85	1.79	9.62	11.14	37.80	21.23	9.55	0.48	8.50	4680	3800	0.32	7.37	0.06
Amarpur	12.39	0.56	42.9	4.27	8.72	4.62	7.2	0.50	8.64	1300	875	0.81	2.22	0.08
Kanthikhas	14.64	1.78	3.37	3.15	10.26	5.25	7.29	0.41	8.55	2240	1737	0.43	2.84	0.01
Faizabad	13.39	0.60	2.56	2.59	4.23	3.45	10.03	1.04	8.81	1190	833	3.14	1.05	0.01
Katkai	10.26	0.053	4.61	6.48	7.05	8.46	5.52	0.27	8.50	1480	950	0.36	1.98	0.02
Balana	18.27	0.63	2.89	0.84	9.05	2.63	10.11	1.18	8.86	1460	1050	3.02	1.14	0.02
Zerpur	62.52	4.47	3.93	4.23	59.52	5.74	9.52	0.24	8.20	7650	6900	0.16	20.1	0.05
Narnaul	32.62	3.57	1.61	5.23	27.53	6.86	8.68	0.28	8.30	5180	3676	0.25	9.01	0.04
Kanina	14.35	1.38	3.70	3.75	9.87	4.38	9.18	0.27	8.27	1540	1387	0.41	2.99	0.03
Zerpur-2	13.92	0.74	3.11	2.94	11.84	4.99	2.11	0.17	8.70	2210	1825	0.76	3.05	0.02
Pathera	41.32	1.91	9.10	12.47	36.67	21.22	6.56	0.55	8.72	3820	2455	0.84	10.4	0.08
Sihore	23.05	1.78	1.72	2.22	18.78	2.17	7.20	0.46	8.60	2160	1850	0.21	5.12	0.24
Nasibpur	6.52	0.75	1.60	1.24	1.57	3.24	4.60	0.28	8.59	430	322	0.41	0.77	0.002
M.garh	9.39	0.65	4.09	2.67	2.87	5.57	8.49	0.15	8.0	1480	1025	0.69	1.51	0.15
Bouchawas	27.49	3.49	12.02	15.72	25.95	24.49	7.78	0.19	8.21	4360	3850	0.22	5.97	0.03
Pirthipur	26.62	0.69	6.91	11.22	11.56	16.98	5.21	0.19	8.30	2530	2111	0.52	4.49	0.02

TABLE 5.4 CHEMICAL DATA OF GROUNDWATER ANALYSIS

SHALLOW GROUNDWATER MAY,1993

Location	Na^+	K^+	Mg^{++}	Ca^{++}	Cl^-	SO_4^{--}	HCO_3^-	CO_3^{--}	pH	E.C	T.D.S	F^-	Br^-	I^-
Faizabad	2.74	.56	4.83	4.94	2.11	4.53	4.99	.23	8.39	707	495	2.53	2.09	0.01
Bouchwas	18.48	3.83	11.70	17.76	22.42	18.11	7.30	.07	7.72	5553	4800	0.28	12.09	0.02
Sorana	6.52	1.66	1.39	1.27	3.38	2.18	4.85	.13	8.0	1549	1084	1.45	2.5	0.00
Niazalipur	3.04	1.27	3.12	7.83	3.52	6.76	3.37	.05	8.16	1320	925	1.02	2.61	0.002
Konthal Khurd	1.30	.23	9.05	5.98	1.97	4.60	8.50	.14	7.93	1500	960	1.51	1.16	0.00
Nangal Durgo	5.43	2.50	9.87	5.09	12.44	5.77	4.55	.04	7.95	3099	2205	0.88	7.65	0.00
Pathera	15.87	2.60	5.59	14.47	22.99	9.01	3.86	.10	7.75	4472	3900	1.10	13.0	0.16
Golwa	4.35	1.91	8.64	11.22	9.36	9.03	5.83	.13	8.15	2173	1800	0.92	5.43	0.00
Bodiwal	2.06	.64	5.34	3.50	1.97	3.71	4.80	.21	8.36	1133	788	1.15	1.86	0.01
Amarpur J.	6.52	1.27	9.05	8.73	5.36	11.45	5.83	.13	8.09	1549	1055	1.20	3.14	0.00
Bouchwas	13.48	1.91	10.87	10.50	10.86	14.99	6.83	.09	7.88	3109	2700	0.49	5.65	0.00

TABLE 5.5 CHEMICAL DATA OF GROUNDWATER ANALYSIS
DEEP GROUNDWATER MAY,1993

S.No	Location	Na^{+}	K^{+}	Mg^{++}	Ca^{++}	Cl^{-}	SO_4^{--}	HCO_3^{-}	CO_3^{--}	pH	E.C	T.D.S	F^{-}	Br^{-}	I^{-}
1-D	Narnaul	2.17	.51	4.26	3.49	3.38	3.10	3.90	.05	7.90	863	604	0.50	0.87	0.00
2-D	Hudina	9.57	1.40	4.93	2.24	12.69	1.62	4.35	.13	8.21	2475	1750	2.07	3.80	0.00
3-D	Bhojwas	19.57	3.83	2.73	2.59	15.93	2.54	8.71	.27	8.10	3868	3100	3.66	7.50	0.02
4-D	Nizampur	10.87	1.91	3.48	2.56	12.85	1.69	7.09	.23	8.51	2288	1372	2.02	4.27	0.02
5-D	Katkai	2.71	3.19	3.80	2.61	6.34	1.95	4.22	.38	8.68	1029	680	0.49	0.75	0.00
6-D	Ateli	11.96	5.75	5.34	4.76	20.73	2.37	3.23	.08	8.12	3452	2800	0.26	6.8	0.03
7-D	Sessoth	11.16	5.75	11.93	4.26	3.10	20.38	6.18	.09	7.92	5054	4500	0.71	16.2	0.00
8-D	Budwal	8.61	2.55	6.99	10.47	7.05	11.49	6.37	.04	7.52	1612	950	0.28	1.3	0.00
9-D	Serohinang	5.43	1.02	2.88	4.48	5.36	1.19	5.21	.33	8.53	1570	1020	2.35	1.25	0.02
10-D	N.choudhry	6.30	1.40	3.74	4.09	5.78	1.74	7.05	.72	8.73	1279	893	1.15	1.52	0.00
12-D	Kanthikas	15.22	1.91	2.34	1.87	10.72	3.13	5.29	.28	8.46	2600	2100	0.28	2.5	0.80
13-D	Bouchria	5.43	2.55	4.78	4.76	4.23	9.78	3.14	.28	8.67	1289	697	0.35	0.88	0.00
14-D	Konthal.K	2.17	.38	3.58	4.26	2.25	3.14	2.97	.62	8.5	759	493	1.24	0.65	0.00
15-D	Khorma	3.80	1.27	1.83	2.16	4.65	8.49	2.86	.17	8.50	748	486	2.46	0.30	0.00
16-D	Pathe	3.26	1.15	3.45	3.74	3.52	1.97	5.64	.24	8.36	894	496	9.5	1.60	0.00
17-D	Sigre	5.65	1.15	2.30	4.24	4.65	2.69	5.73	.33	8.49	1154	807	1.64	2.68	0.00
18-D	Nagal Kalia	7.17	2.30	2.46	3.74	7.47	3.12	3.16	.24	8.60	1331	931	1.19	2.48	0.01
19-D	A.jorasi	11.96	1.53	2.92	7.48	12.27	2.99	8.41	.21	8.13	2589	1812	1.89	9.04	0.02
20-D	N.durgo	7.06	2.52	4.55	6.14	10.86	2.09	5.47	.19	8.26	2860	2002	1.09	9.04	0.021
21-D	Bouchwas	4.78	1.27	6.78	7.79	4.23	8.74	4.21	.09	8.07	1164	1050	0.46	2.64	0.00
22-D	Lujata	10.65	2.68	9.87	15.46	.20	9.93	5.34	.05	7.76	4139	3400	0.36	17.8	0.00
23-D	Nangal.N	20.66	5.11	10.69	22.80	31.59	16.09	7.17	.07	7.73	5408	4900	1.86	19.8	0.00
24-D	Pirthipura	8.48	2.55	6.76	8.25	11.76	7.59	2.88	.13	8.20	2381	2100	0.36	5.64	0.02
25-D	Niyamatpur	5.65	1.91	3.96	5.10	6.00	2.19	6.45	.21	8.24	1944	1255	1.58	3.16	0.00
26-D	Mahendra	11.22	2.50	7.04	5.73	10.01	9.99	4.65	.13	8.19	2454	2100	4.64	1.31	0.00
27-D	Mandlana	9.24	2.12	6.17	8.48	9.25	6.66	8.40	.24	8.19	2538	2236	4.19	14.12	0.00
28-D	Kanina	11.22	4.60	6.41	9.63	4.79	15.24	6.46	.19	8.20	3016	2750	7.74	24.1	0.05
29-D	Parthal	4.35	1.91	5.43	3.73	4.79	3.95	4.52	.25	8.47	1133	788	0.68	5.35	0.004
30-D	Zerpur	14.79	2.68	5.20	4.24	9.87	8.59	5.76	.14	8.13	2680	2025	0.88	9.17	0.006
31-D	Niazalipur	2.39	1.27	6.13	5.09	3.16	6.45	3.32	.14	8.30	1040	710	0.97	3.62	0.002

diagram etc. The processing of these results by multivariate techniques is also attempted.

A persual of the results of the chemical analysis of gruondwater of the area (Table 5.2-5.5) shows a wide variation in different individual parameters as well as its electrical conductivity (EC) and Total dissolved solids (TDS). Though the overall pH (7-8.87) and temperature (24-27^{o}C) of water do not show any significant abnormalcy, the higher range of TDS indicates the groundwater to be generally saline with a few fresh water patches, as manifested by wide range of TDS (400 to 5000 mg/l) and EC (650 to 5500 micromhos/cm at 25^{o} C ́). The isolated villages with overall freshwater salinity, which can be readily picked up from the analysed results for shallow aquifers, are Khorma, Sorana, AmarpurJorasi, Niazalipur (May 1991) and Niazalipur, Sorana, Khorma, Gotri Amarpur Jorasi, Faizabad, Katkai and Nasibpur (January 1992). Further, for May 1993, the fresh water was found to be present in Faizabad ,Niazalipur, Konthal Khurd and Bodiwal villages only, though a good number of the open wells were found dry in this period due to persistent lowering of the water table. As such, some more wells had to be inventoried for monitoring of groundwater quality in May,1993.

For the deeper groundwater, the villages with acceptable salinity levels (< 1000 mg/l) are observed to be greater in number (12 out of 31) viz., Narnual (1-D), Katkai, Budiwal (8-D), Nangal choudhry (10-D), Boucharia (12-D), Konthal Khurd (13D), Khorma(14-D), Pathera (15-D), Sigre (16-D), Nangal Kalia (17-D), Parthal (28-D), Niazalipur (31-D). This indicates that the groundwater in the deeper aquifers is relatively fresh as compared to the shallow aquifers.

The hardness of the groundwater ranges from 200-1350 mg/l in shallow groundwater and 150-1400 mg/l in deep groundwater, thus it can be designated as hard to very hard as per criteria given by Sawyer and Mc Carty (1977).

In general, sulphate is in high concentration at most of the places, and ranges from 30 mg/l to 800 mg/l. Further, its concentration is found to increase at places of high salinity, except at few places like in Ateli and Bhojwas villages (Nangal Choudhry Block) in shallow groundwater (Tables 5.3,5.4). In the study area, chloride concentration also show an increasing trend with rise in salinity levels in the groundwater.

Further, magnesium concentration is varying from 25mg/l to 100 mg/l, except at few places where it is in higher concentration, e.g., Bouchawas, Amarpur Jorasi, Ateli, Sessoth, Nangal Nunina and Golwa. It may, however be noted that it is an essential nutrient for human body with an average adult requirement of 200-300 mg/day (W.H.O., 1984). Various regulatoy agencies viz., I.C.M.R., (1975) and I.S.I (1983) have suggeted permissible limits of calcium between 75 to 200 mg/l in drinking water. The calcium concentration in the groundwaters mostly varies within the tolerance limit and lies between 35 mg/l to 200 mg/l. In some wells, at Ateli, Pathera and Lujatait exceeds the maximum permissible limit of 200 mg/l. Sodium concentration is found to vary from 30 mg/l to 1500 mg/l. The reason for such a higher concentration at some locations needs to be looked into. In most natural waters, potassium is usually present in lower concentration than Na due to greater resistance of many potash-bearing minerals to dissolution. K^+ varies from 20 mg/l upto 115 mg/l, but at few places like Ateli and Sessoth, high K^+ concentration of upto 250 mg/l is observed. Such high level of K^+concentration may partly be due to use of potassium fertilizer for agricultural purposes, but data is not available to support this postulate. However, Handa (1983, 1994) explained that high potassium concentration in natural waters does not seem to have adverse physiological effects on users. The distribution of fluoride in the study area indicate high fluoride concentration at several places out of 72 samples from deep tube wells and dug wells (Tables 5.2-5.5).

F^-concentration in groundwater from 21 wells is higher than 1.5 mg/l. At 14 places, it is more than 2 mg/l. On the whole, there is a wide variation in F^-level in groundwater. Concentrations below as well as above the optimal range (0.6-1.5 mg/l), set by Regulatory Agencies, are encountered, especially in the deep wells.

Equilibrium concentration of fluoride in natural water may be influenced by concentration of Ca^{++}, HCO_3^- and pH of water & other related factors (Davis and Dewiest,1966). Hem (1985) also discussed the factors controling the occurence of fluoride in natural water. The presence of dissolved fluoride in natural waters is possible when conditions favour long residence time of F^- species in solution (Gaciri, S.J. & Davies, 1992). Low doses of F^-in water (below 0.6 mg/l) can cause dental caries and tooth decay, whereas its high levels (above 1.2mg/l) cause skeletal abnormalities, ostesclerosis and dental fluorosis (Shupe et al.,1979; Chaturvedi et al. 1988).

The higher concentration of fluoride in deeper aquifers may be explained due to presence of gelogical formations rich in fluorine minerals like apatite etc.

5.7 MULTIVARIATE ANALYSIS

The purpose of this techniques is to interprete the data structure within the variance-covariance matrix. The used techniques involve extraction of the eigen values and eigen vectors from the matirx of correlation or covariances. The techniques of factor analysis have been used by various workers in studying and interpretation of characteristics of natural water (Kalvan, 1966; Ashley and Llyod, 1978; Dalton and Upchurch, 1978). Davis (1986) has discussed the procedures of principal component and factor analysis and its applicatiaon in geological studies.

In the present study, principal component analysis and factor analysis have been attempted for assessing the chemical characteristics of groundwater of the area, using a computer programme given by (cf. Davis,1973). The epm ionic values have been utilized in these computations. Principal component analysis was carried out taking in account eight variables, namely Na^+, K^+, Mg^{++}, Ca^{++}, Cl^-, SO_4^{--}, HCO_3^- and CO_3^{--} for the shallow groundwaters for April 1991, January 1992 and May 1993 and deep groundwater of May,1993.

Among the eight factors mentioned above, four factors accounted for over 97% percent of the total variance for the shallow groundwater of 1991. The factors and their loadings are shown diagrammatically in Figure 5.2. The rectangular boxes represent the factors and the horizontal central line represents zero loading for the variable. Lines near the top of boxes represent high positive loading and the points near the bottom high negative loadings. The first eigen value (3.47) corresponds to largest factor, which accounts for 43.41% of total variance and is highly loaded with K^+, HCO_3^{-2}, SO_4^{-2}, CO_3^{-2} and Ca^{+2}. The second higher eigen value (3.023) corresponds to 37.79% and is highly loaded with Cl^-, Mg^{+2} followed with Na^+ ions. The third eigen value (1.04) corresponding to 13.02 % of trace, is loaded with Ca^{+2} only.

Similarly, among the eight factors in groundwater sample of Jan, 1992, four factors accounted for over 95% percent of total variance(Fig.5.3). From this figure, it is observed that the first eigen value (4.44) corresponds with 55.66 percentage of trace and is loaded with Cl^-, SO_4^{-2}, Ca^{-2}, Mg^{+2}, Na^+ and K^+. The second value (1.6673) corresponds to 20.84 percent of trace and is loaded with HCO_3^- only. The third eigen value (1.141) is accounted for 14.26% and is loaded with CO_3^{-2}.

Figure 5.4 shows the factor-loading for the shallow groundwater in 1993. The first eigen value (4.9793 , 62.24% of trace) is highly loaded with Cl^-, Na^+, Ca^{+2}, SO_4^{-2}, and K^+ and negatively loaded with CO_3^-. The second eigen value (1.5895 or 19.9%) is loaded with HCO_3^- and Mg^{+2}.

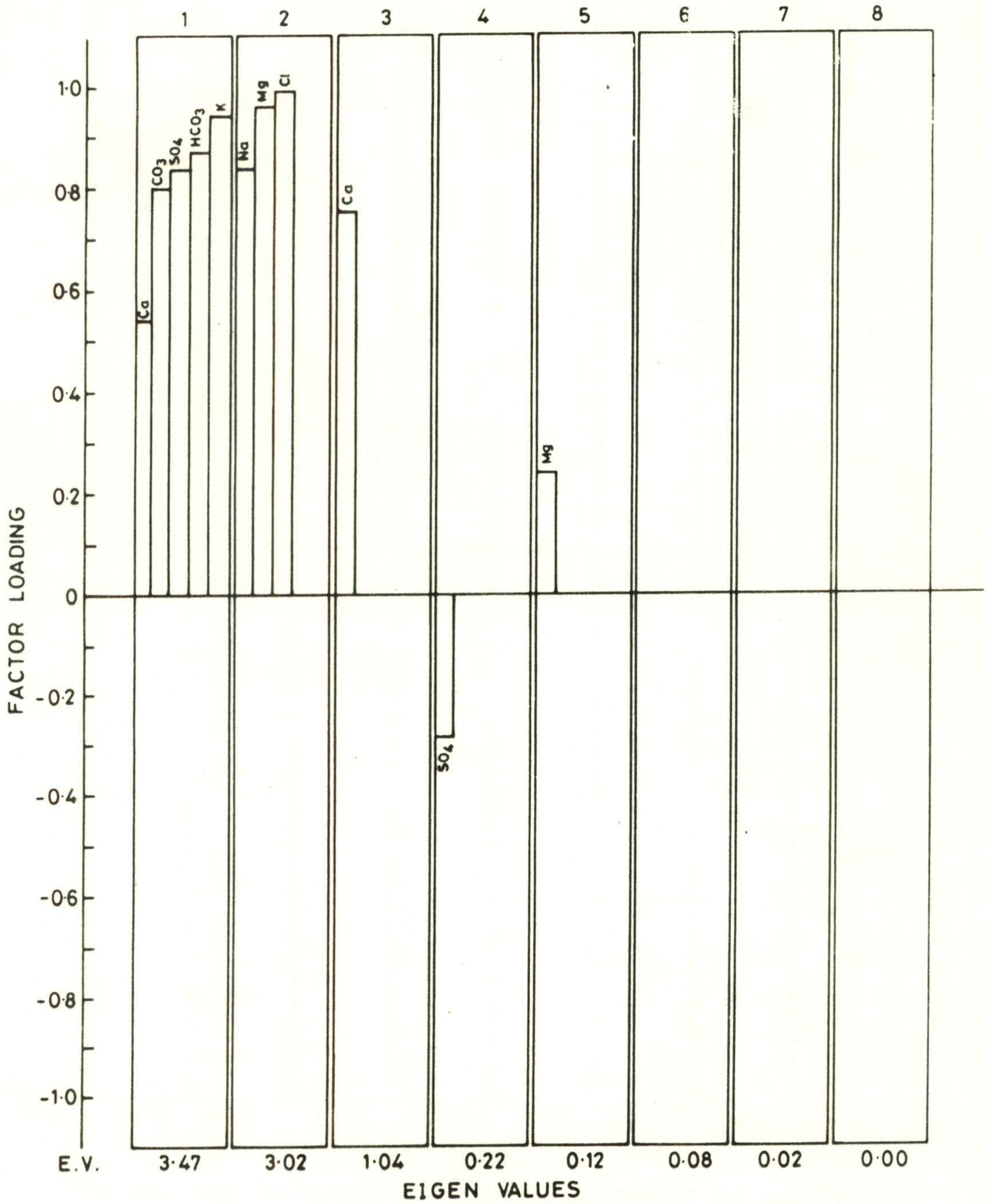


FIG.5·2. LOADING OF VARIABLES SHALLOW GROUNDWATER APRIL, 1991

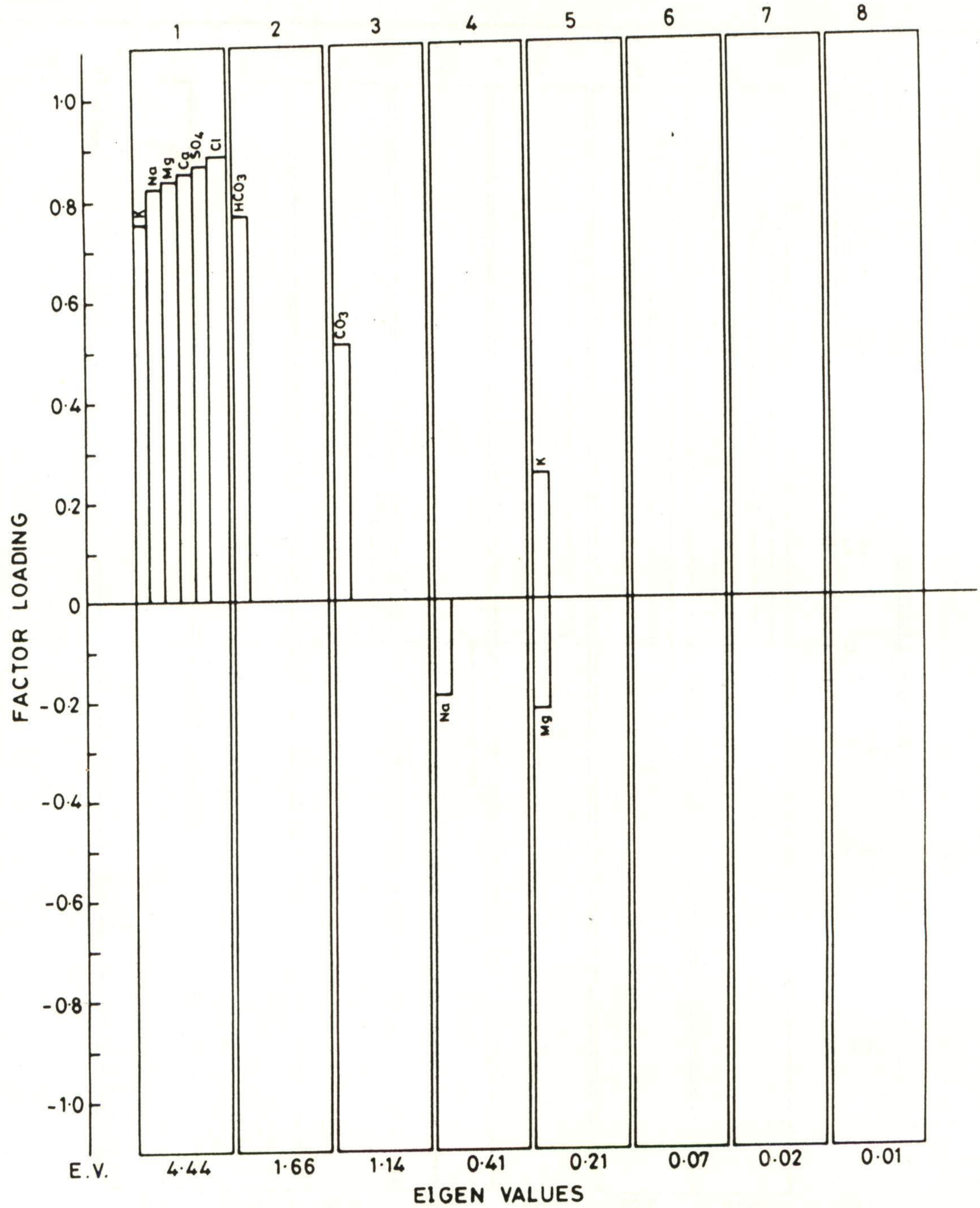


FIG.5·3. LOADING OF VARIABLES SHALLOW GROUNDWATER JAN.,1992

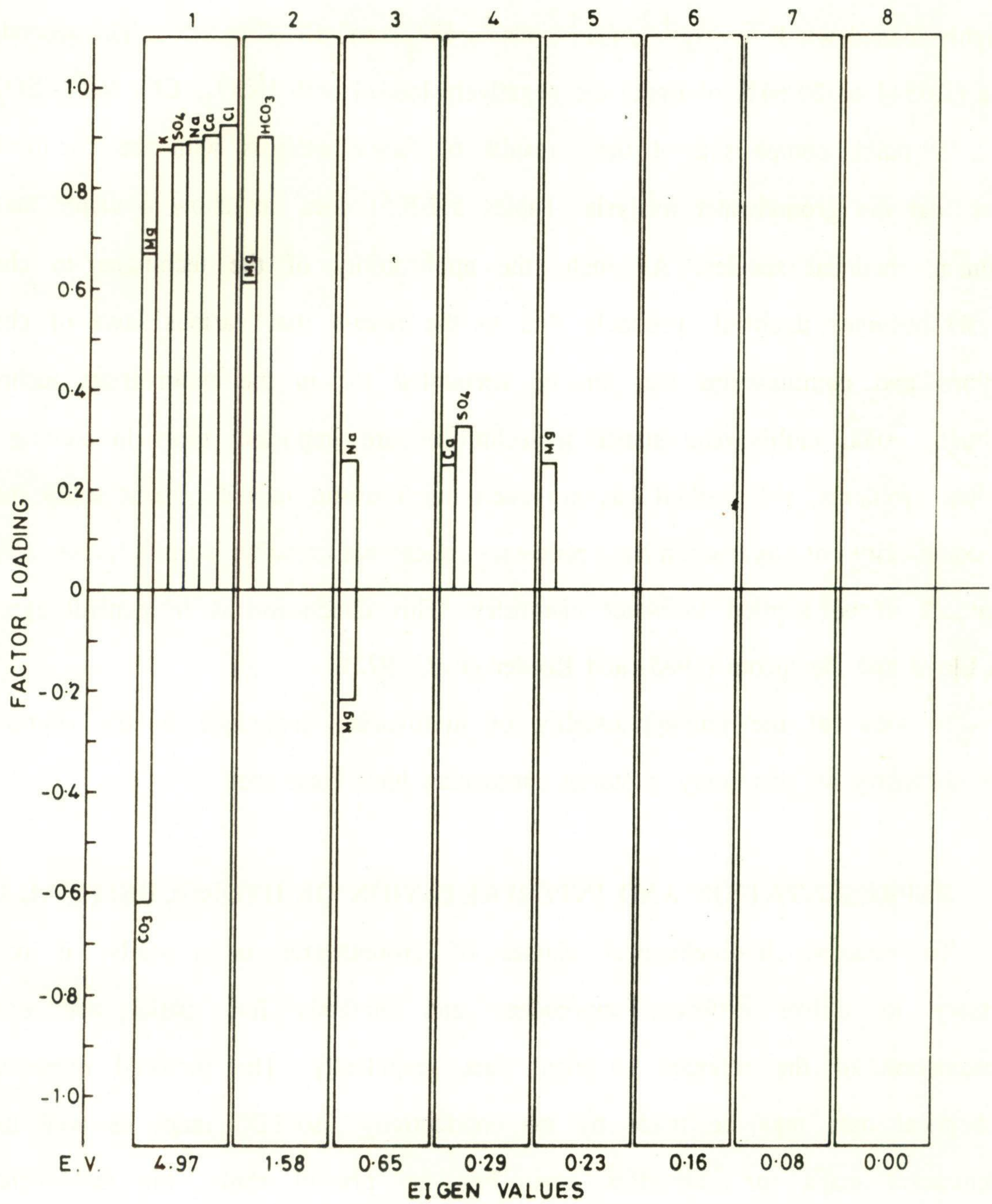


FIG. 5·4. LOADING OF VARIABLES SHALLOW GROUNDWATER, MAY, 1993

For deep groundwater of 1993, the first eigen value (3.81 or 47.72% of trace) is highly loaded wit K^+, Mg^{+2}, Ca^{+2} Na^+, SO_4^{-2} and Cl^- (Fig.5.5). The second eigen value (1.6544 or 20.64% of trace) are negatively loaded with HCO_3^-, Cl^-, Na^+, SO_4^{-2}.

A quick comparison of the results of factor analysis with the chemical data shows that the groundwater analysis (Tables 5.2-5.5) does not show a viable match of dominant chemical species. As such, the applicability of the technigue to chemical analysis becomes doubtful, probably due to the reason that various laws of chemical reactions and combinations can not be accounted for in the multivariate techniques. Although such multivariate statistical techniques are important tools in solving many complex problems, the method has not been much useful in the present study, because the complexity of hydrochemical processes does not readily permit these statistical techniques to be applied to water chemistry. This conclusion is in general agreement with Lloyd and Heathcote (1985) and Reeder et al. (972).

In view of the non-applicability of multivariate technique in the appraisal of water chemistry for this study, pictorial approaches have been tried.

5.8 REPRESENTATION AND INTERPRETATION OF HYDROCHEMICAL DATA

To establish hydrochemical classes of groundwater in a study, it is often necessary to utilize different approaches and methods for spatial and temporal representation of the relevant chemical data graphically. The pictorial representation of chemical data may be made by iso conductivity /iso-TDS maps as well as iso-concentration maps for individual ions. For the present study, the iso-conductivity for shallow groundwater maps for January, 1992 for deep groundwater for may ,1993 of the area have been prepared (Figs.5.6 and 5.7). The iso-conductivity map for shallow groundwater indicates presence of 3 E-W trending zones of high salinity (eletrical condutivity) and seperated from each other by narrow zones lower EC. The northernmost

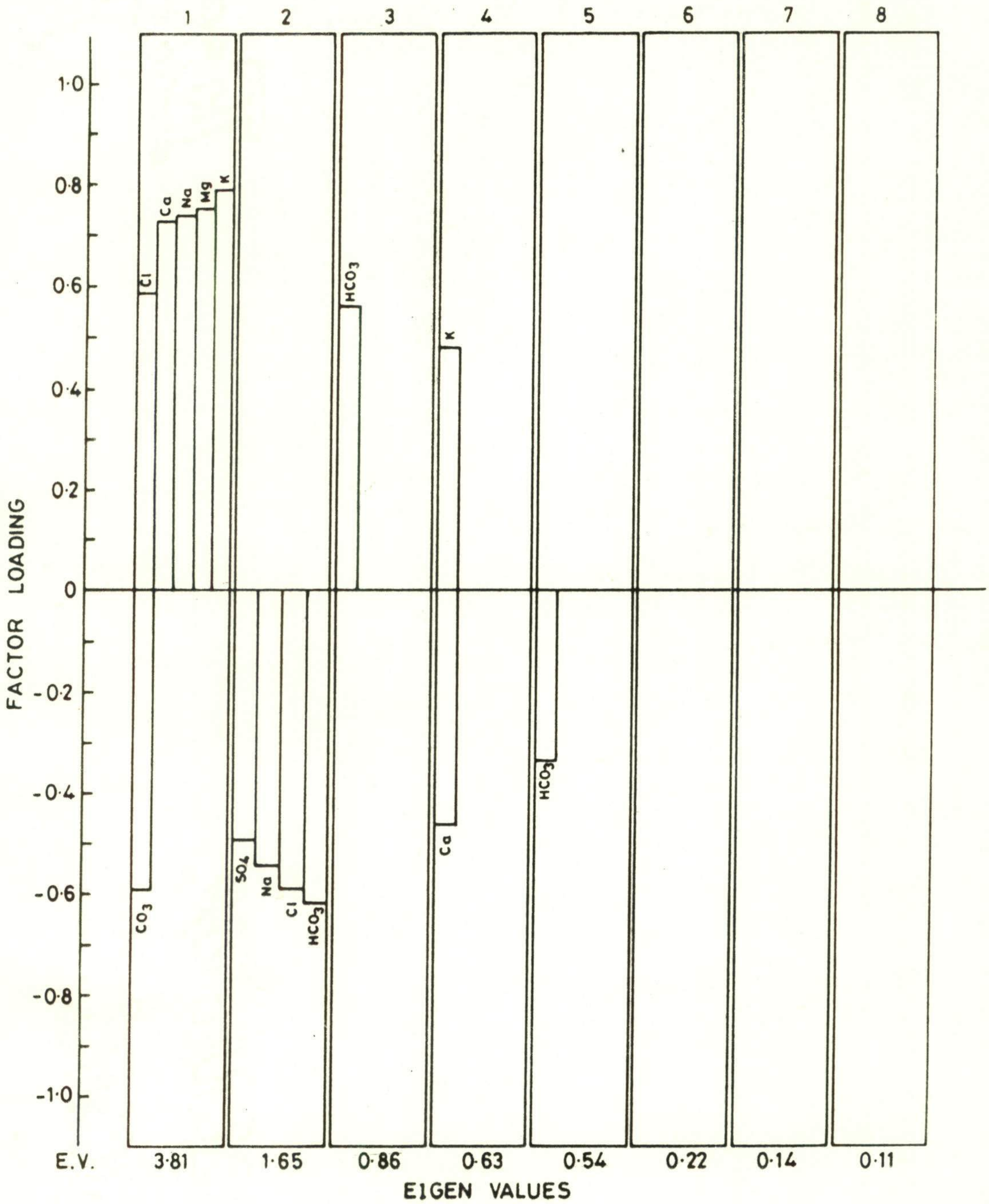


FIG. 5·5. LOADING OF VARIABLES, DEEP GROUNDWATER, MAY, 1993

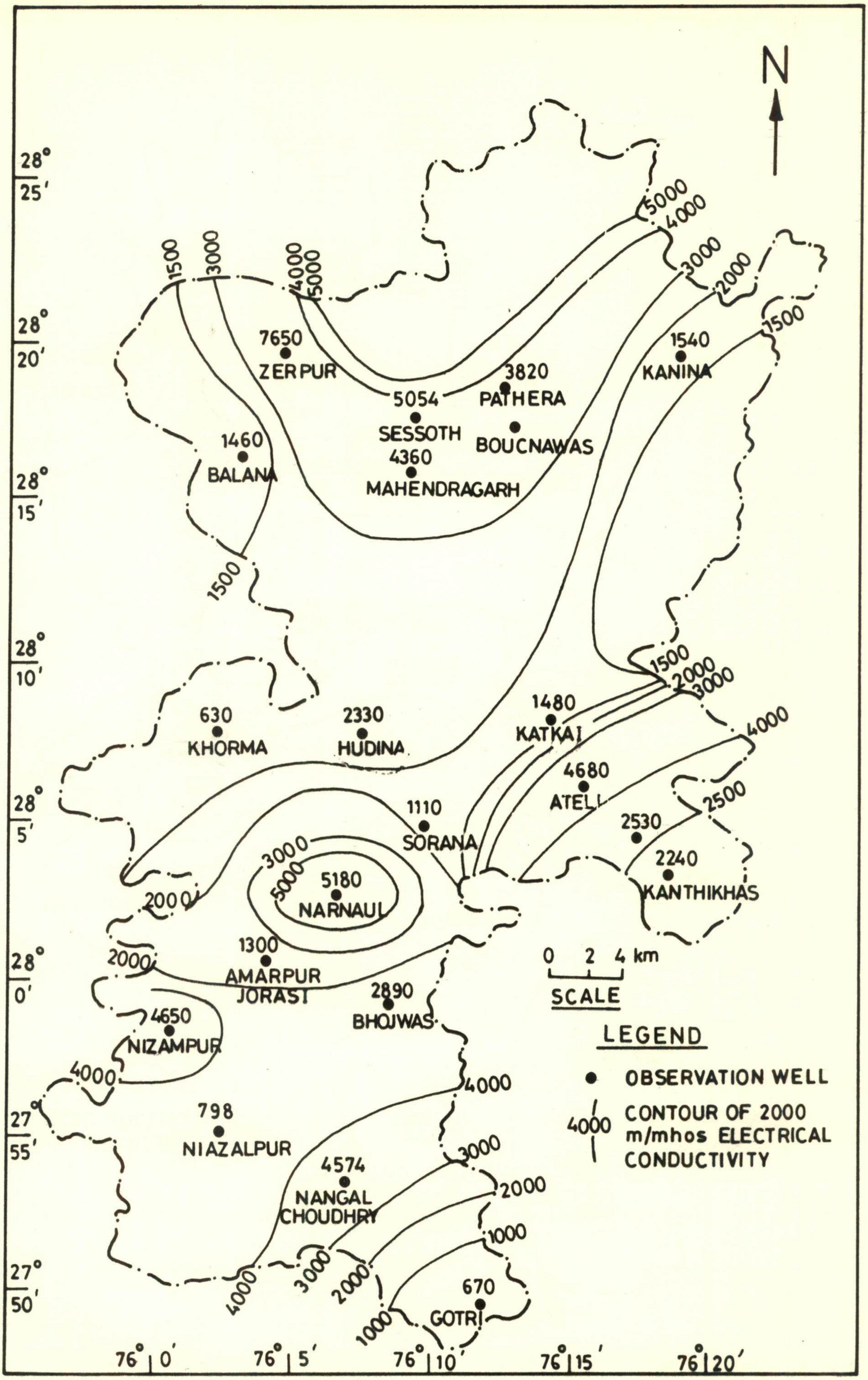


FIG. 5·6. MAP SHOWING VARIATION OF ELECTRICAL CONDUCTIVITY SHALLOW GROUNDWATER JAN., 1992

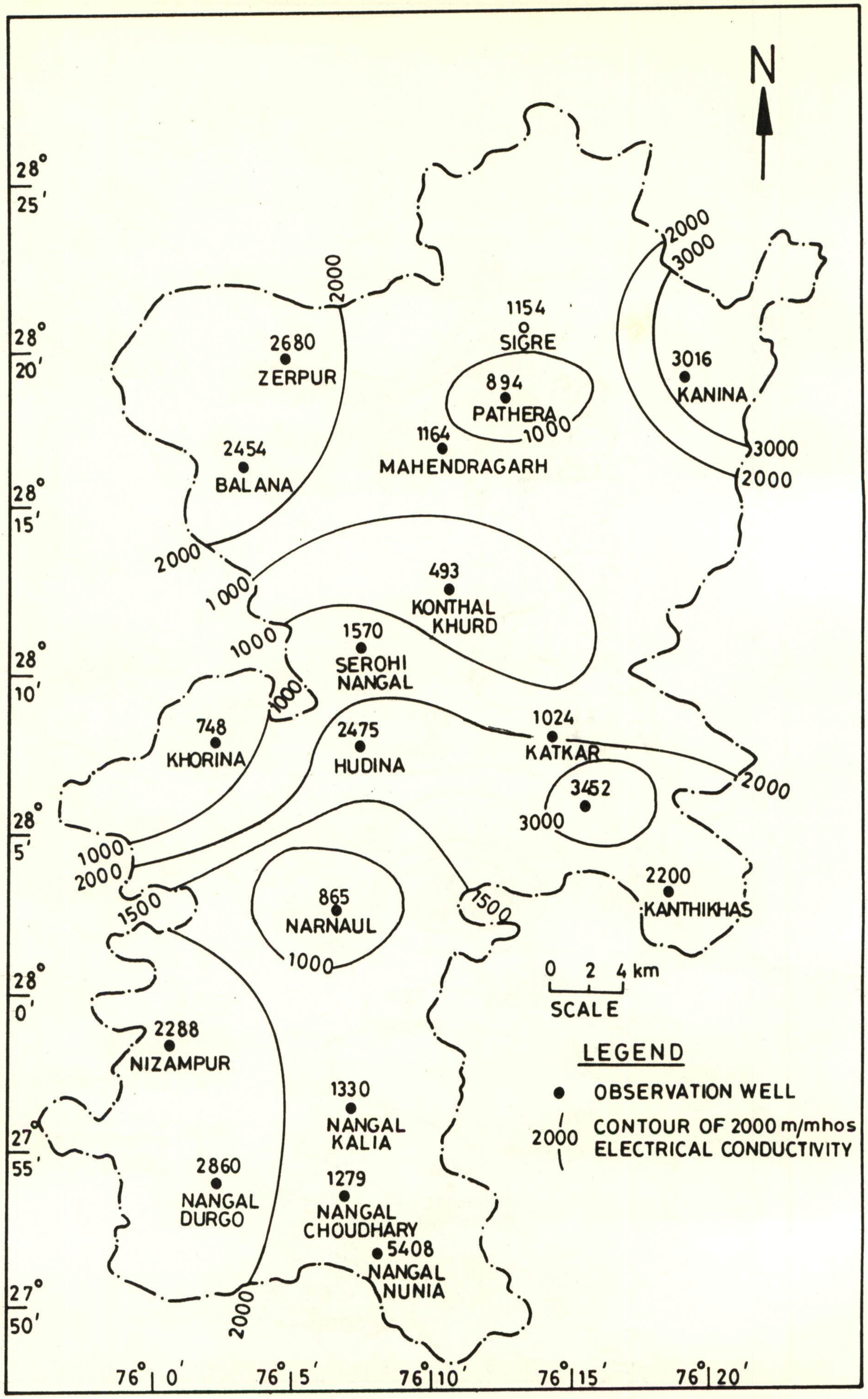


FIG. 5·7. MAP SHOWING ELECTRICAL CONDUCTIVITY VARIATION OF DEEP WELLS MAY, 1993 zone of high EC encompasses villages like Zerpur, Sessoth, Mahendragarh, Pathera, Bouchawas, Hudina and Kanina. The central tract of high salinity groundwater passes through Amarpur Jorasi, Narnaul Nizampur, Bhojwas, Ateli and Kanthi Khas. The Soutern zone covers a smaller area in the southeastern in the Nangal Choudhry block.

However, the EC map for the deeper aquifers for May 1993 shows retatively narrow and isolated areas of high EC, at Zerpur-Balana in NW, Kanina in northeast, Serohi Nangal and Hudina in the central part and Kanthi Khas in east. Towards south, Nizampur, Nangal Durg and Nangal Nunina villages are possess high EC.

The reasons for the irregular distribution of salinity in the Mahendragarh area can be brought out better from trilinear diagrams, iodide-chloride plots and chloride versus other ion plots.

5.8.1 Trilinear Diagram

The representation of hydrochemical data in Trilinear diagram was first attempted by Hill (1940) and was improved upon by Piper (1944). The diagram is useful for visually representing the differences in the major ion chemistry of groundwater. The central diamond-shaped area in this diagram (Fig.5.8) can be divided into several designated sub-areas, each of which is assigned on area number codes which represent waters of certain geochemical character (Davis and Dewiest,1966).

The chemical characteristics of shallow groundwater for the period, April 1991,January 1992, and May 1993, as well as for deep aquifers for the period May 1993, are plotted in the Piper Trilinear diagram (Figs.5.9-5.12). The subareas in which the water analyses plot are given in the Table 5.6. From the table, it is clear that majority of the groundwater samples from shallow wells in April 1991 fall in an area (9) pertaining to an intermediate type of water, with no definite chemical character, and a small fraction in another area (6) pertaining to water of dominant non-carbonate

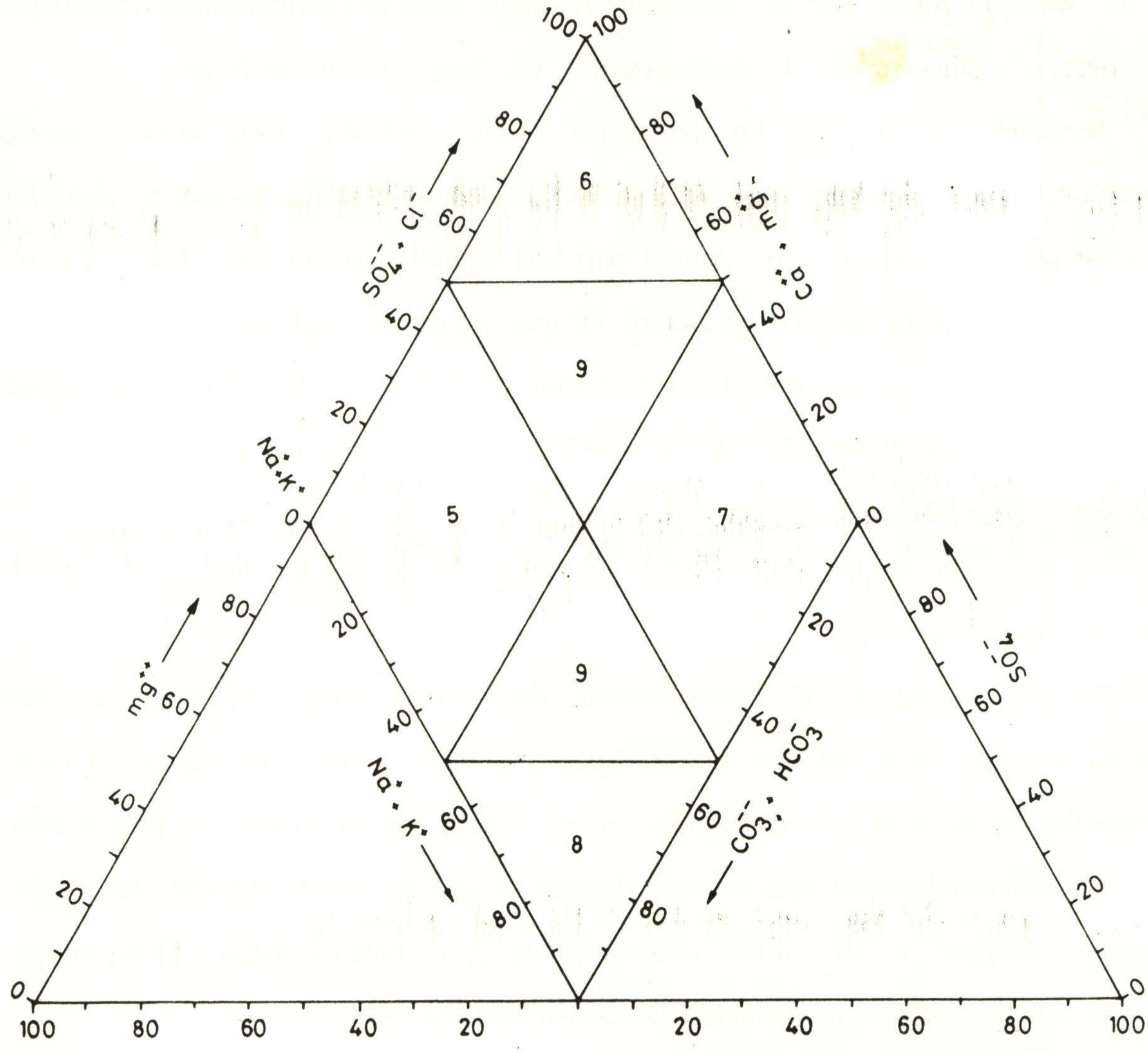


FIG. 5·8. TRILINEAR DIAGRAM (AFTER PIPER, 1944)

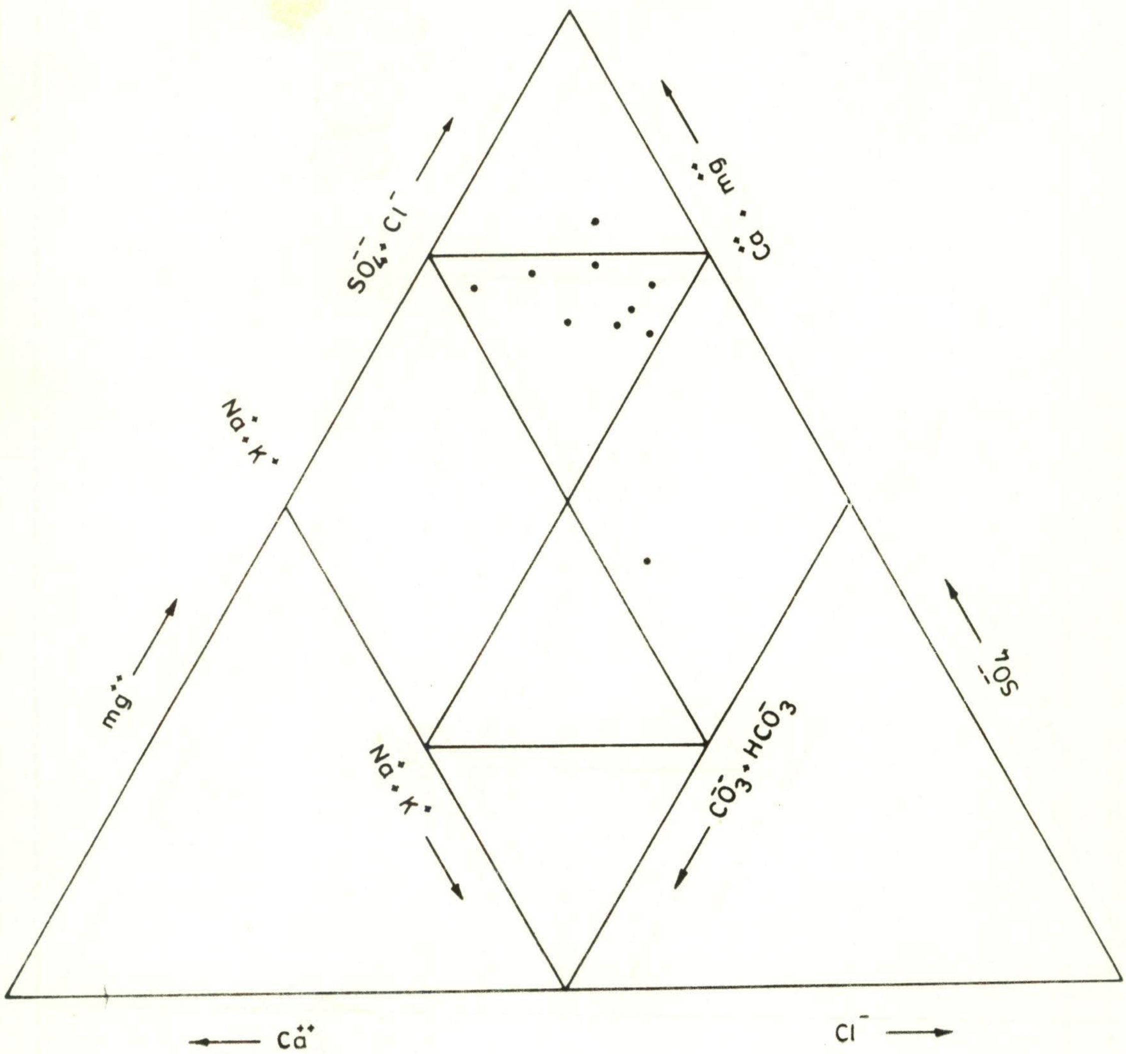


FIG.5·9. PIPER TRILINEAR PLOT OF SHALLOW GROUNDWATER; APRIL, 1991

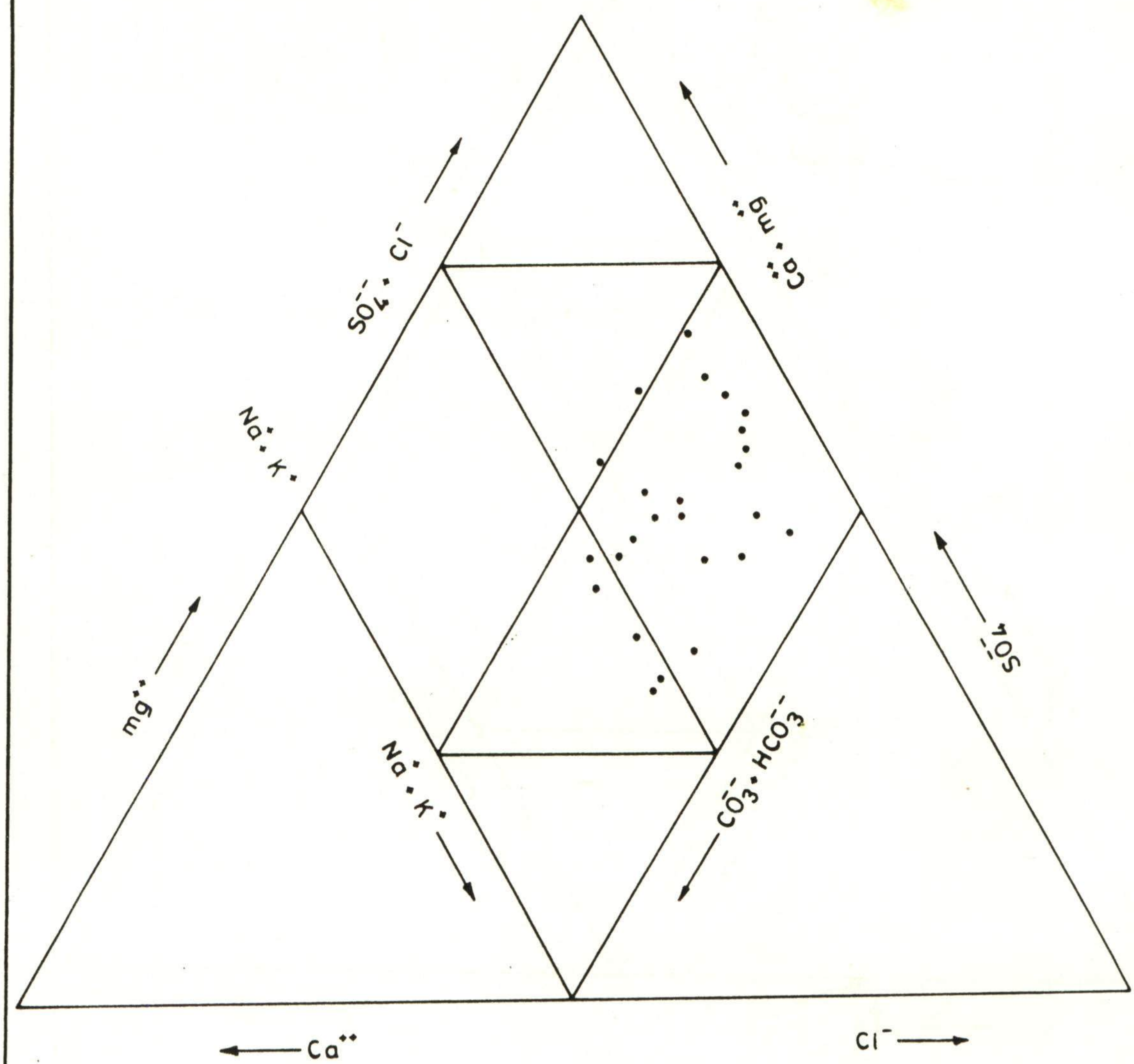


FIG.5·10. PIPER TRILINEAR PLOT OF SHALLOW GROUNDWATER; JAN., 1992

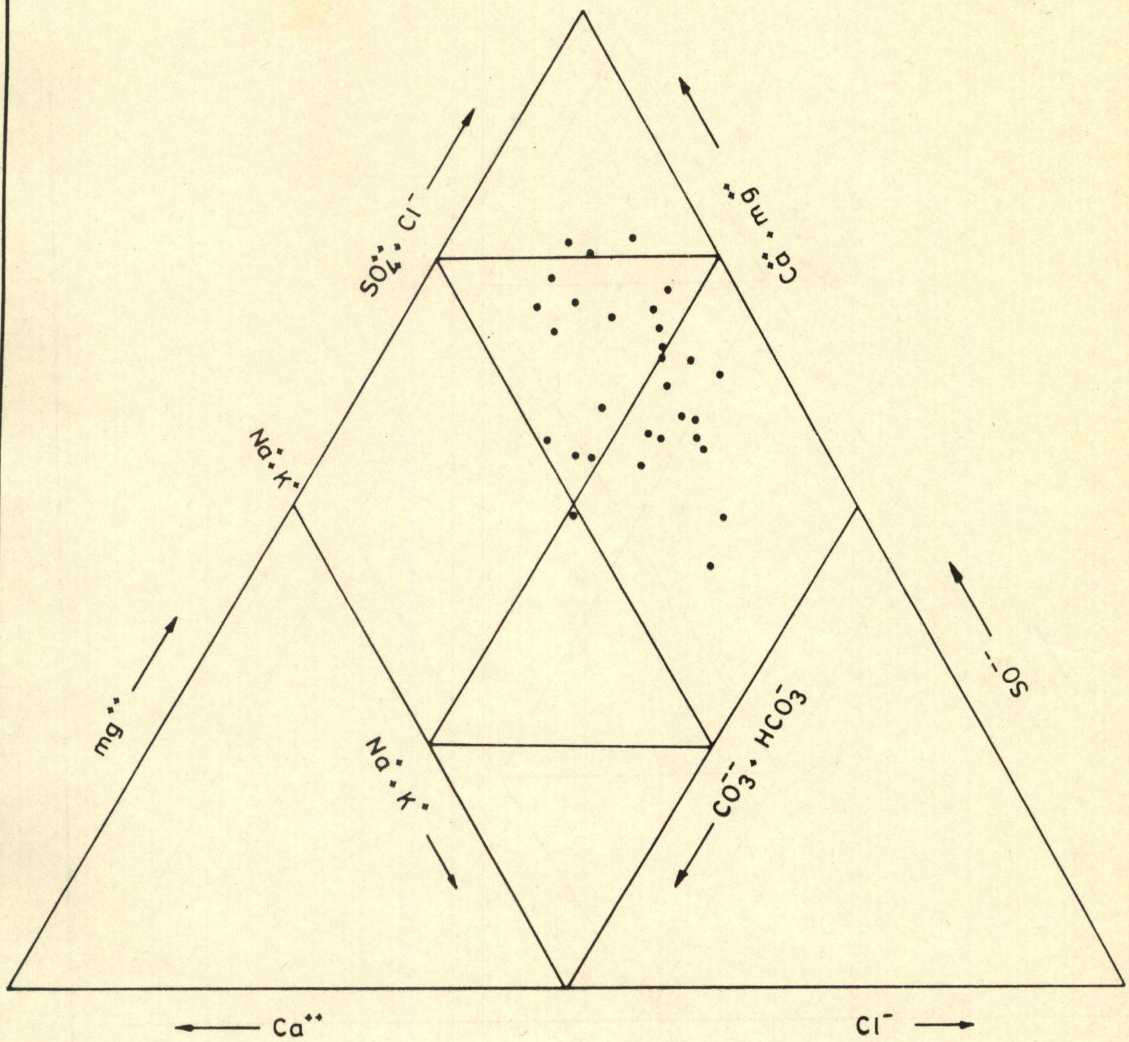


FIG. 5·11. PIPER TRILEAR PLOT DEEP GROUNDWATER; MAY, 1993

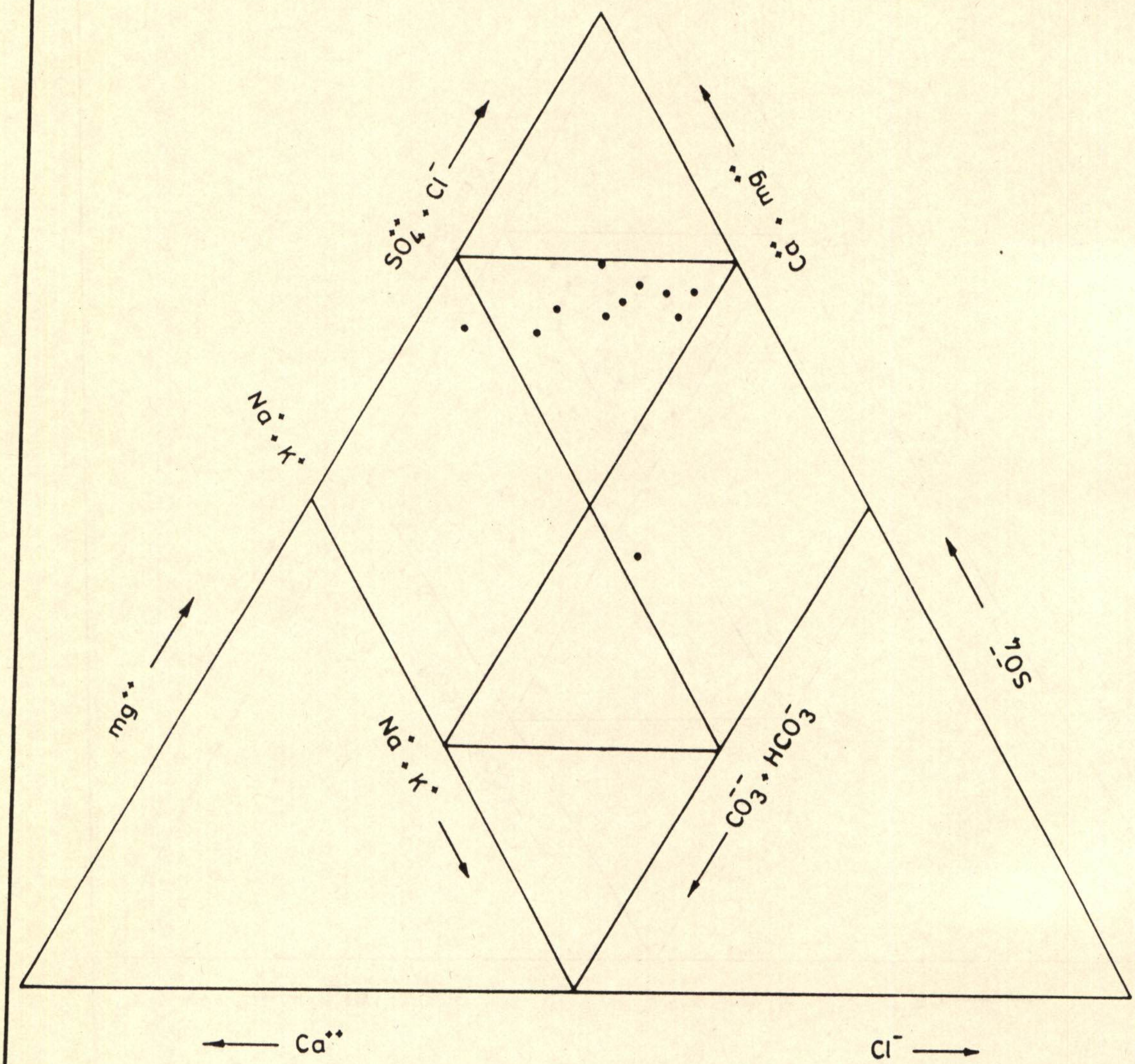


FIG.5·12. PIPER TRILINEAR PLOT OF SHALLOW GROUNDWATER; MAY, 1993

TABLE 5.6 CHEMICAL CHARACTERISTICS OF GROUNDWATER IN HILL PIPER DIAGRAMS.

SHALLOW WELLS APRIL 1991	SHALLOW WELLS JANUARY 1992	SHALLOW WELLS MAY 1993	DEEP WELLS MAY 1993	FALLING IN FIELD	EXPLANATIONS OF DIFFERENT AREAS IN DIAGRAMS
8	7	9	16	9	NØ One cation-anion pair exceed 50%
1	18	1	12	7	Non-carbonate alkali (primary salinity) dominated by alkalies and strong acid
1			2	6	Non-carbonate hardness (Cl^{-}+So_4^{--}) or secondary salinity
		1		5	Carbonate hardness (Secondary alkalinity) exceeds 50%.

hardness. However, in January 1992, the majority of groundwater samples were influenced by alkalies and strong acids (primary salinity of area 7). Further in May 1993, majority of the groundwater samples again fall in the area of intermediate chemical character (9), but still its chemical character was rich in alkaline earths (Ca^{++}, mg^{++}) whereas another fraction of samples showed primary salinity (Na^{+}, K^{+}). Thus, results generally indicate that these waters have affinity to either an intermediate type of water or have dominance of alkalies and strong acids. However, such a variation in chemical character in successive years is difficult to explain.

5.8.2 Romani's Modified Hill Piper Diagram

In the Romani modified Hill piper diagram (1981), right angled isosceles triangles are used for plotting concentration of cations and anions in epm for evaluating the hydrochemical classes of waters. Each triangle is further subdivided into 7 fields, each indicating different type of water (Fig.5.13). The cation triangle consists of calcium-type (C_1), magnesium-type(C_2), sodium-type(C_3), sodium-calcium-type(C_4) and calcium-magnesium type(C_5), sodium-magnesium type(C_6), calcium-magnesium-sodium-type(C_7). The anion triangle also consists of bicarbonate-type(A_1), sulphate-type(A_2), chloride type(A_3), chloride-bicarbonate-type(A_4), bicarbonate-sulphate-type(A_5), chloride-sulphate-type(A_6), and bicarbonate-sulphate-chloride type(A_7).

In the present study, classification and the types of the groundwater have been studied by plotting the chemical data of shallow groundwater for the periods of April 1991, January-1992, and May 1993 and deep groundwater for May 1993 (Figs.5.14-5.17 and Table 5.7). It is observed from the Figure 5.14 that the groundwater for the period April 1991 mostly falls in areas C_6, C_5 and C_1 and shows Na-Mg, Ca-Mg, and Ca-types of water for cations. For anions, it falls in the area of A_3 type. Therefore, groundwater for the period of April 1991 is mostly $Na^{+}-Ca^{+2}-Cl^{-}$ type and is considered to be a mixed-type of water.

Majority of the groundwater samples for January 1992 plot in the area C_3 (Na-type) in cation triangle, whereas in the anion triangle, they are distributed among areas A_1, A_4 and A_5 which imply bicarbonate-type, chloride-bicarbonate-type and bicarbonate-sulphate-type of water respectively. Thus, the water is generally of $Na^{+}-HCO_3-Cl$ types (Fig.5.15).

Shallow groundwater for the period May 1993 is distributed evenly among different areas in anion and cation triangles (Fig.5.17). Though the number of the samples in this period is less, these exhibit widely different types of water (viz., $Ca^{+2}-Mg^{+2}-Na^{+}-Cl^{-}-SO_4^{-2}-HCO_3^{-}$) type, showing a mixed character. On an overall basis, the shallow groundwater of the study area shows a mixed character during different periods. Through, it is difficult to assign any possible reason for the mixing of the cations ($Na^{+}$and Ca^{++}), the cation exchange phenomenon can not be ruled out.

Further, in the case of deep groundwater for the period May 1993, maximum samples fall in area C_3 (Na-type) and in area A_3 (Cl-type) and the remaining few samples are distributed among other areas (Fig.5.16).Thus, the deep groundwater shows high concentration of Na^{+} and Cl^{-}.

5.8.3 Expanded Durov Diagram

Expanded Durov diagram was developed by Burdon and Mazloum (1958) and Lloyd (1965). In this diagram, cations and anions triangles are separated into 25 percent along the axes, so that a single main sguare field is formed. The cations and anions are plotted in the appropriate triangle and are projected into the central field

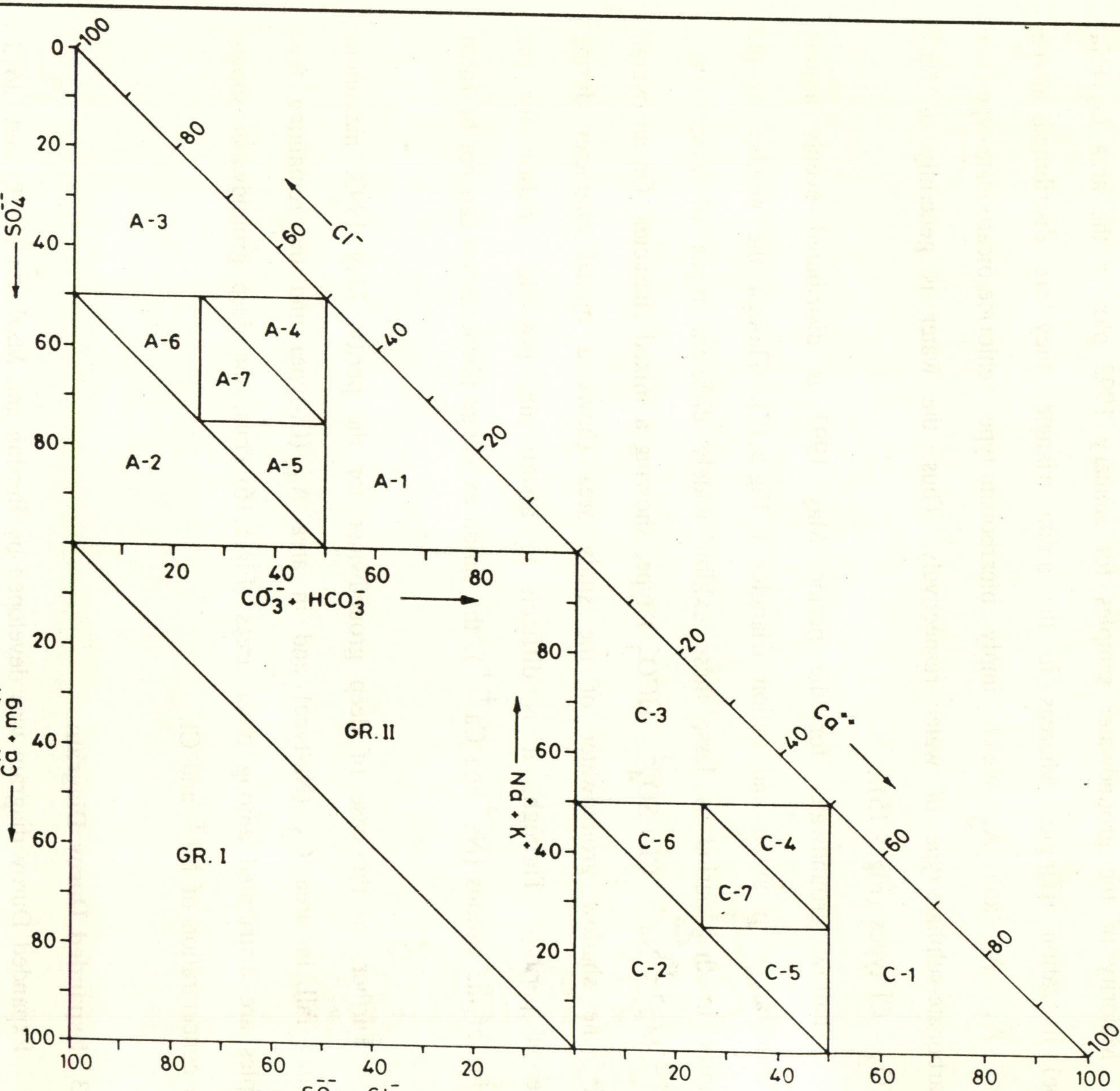


FIG.5.13. ROMANI MODIFIED HILL PIPER DIAGRAM, 1981

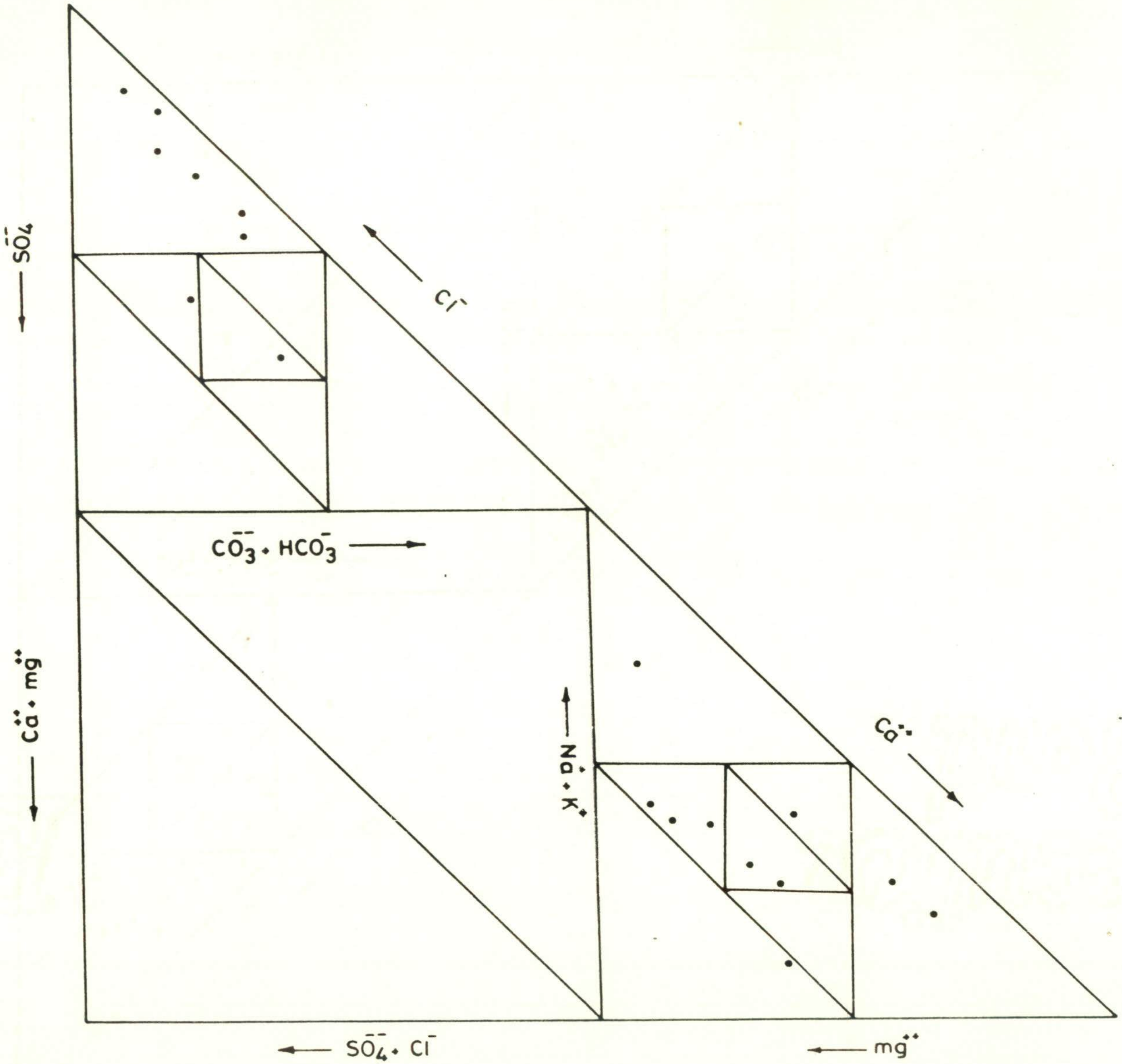


FIG.5·14.ROMANI MOFDIFIED TRILINEAR PLOT OF SHALLOW GROUNDWATER; APRIL, 1991

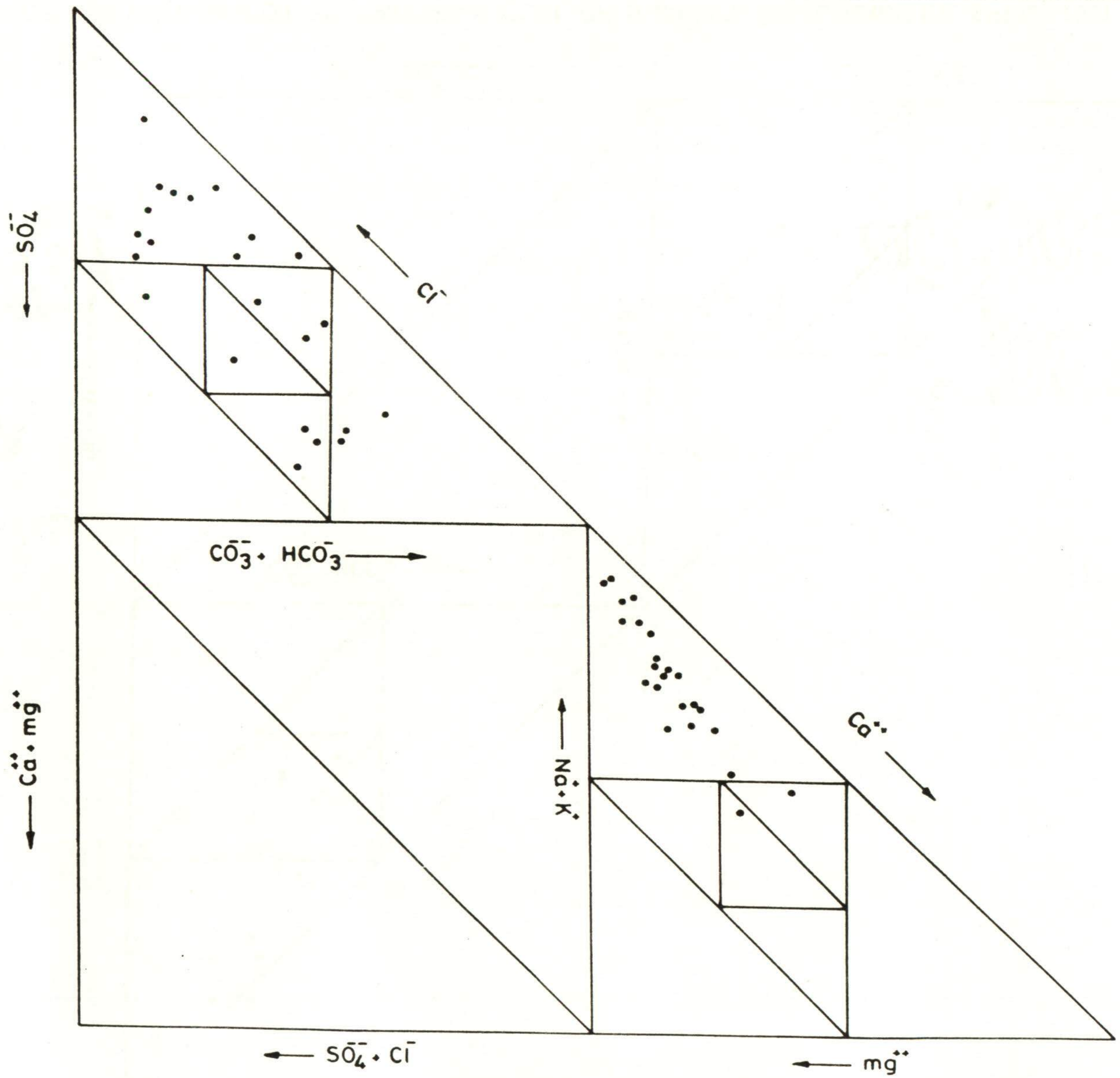


FIG. 5-15. ROMANI MODIFIED TRILINEAR PLOT OF SHALLOW GROUNDWATER; JAN., 1992

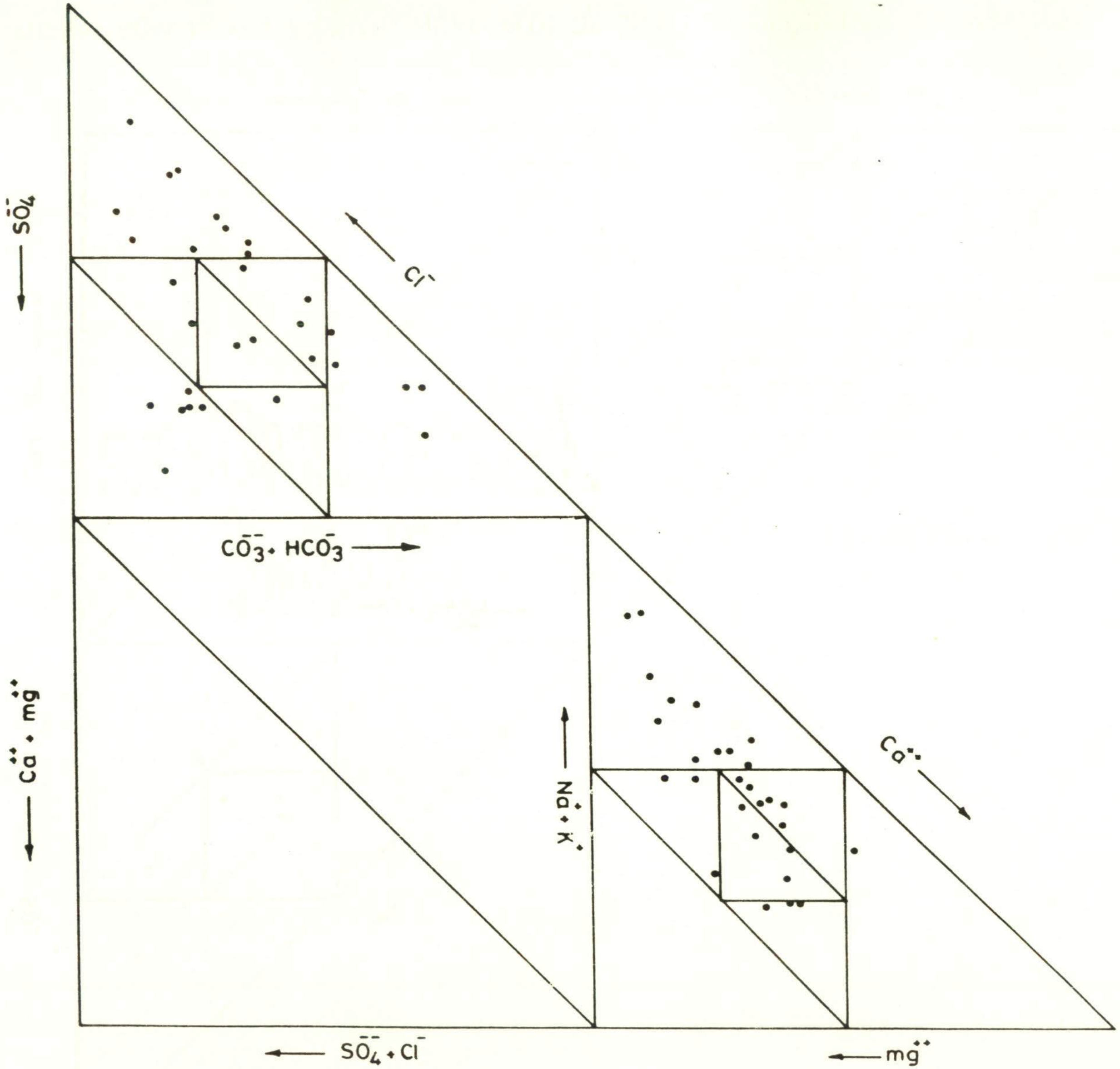


FIG.5·16. ROMANI MODIFIED TRILINEAR PLOT OF DEEP GROUNDWATER; MAY, 1993

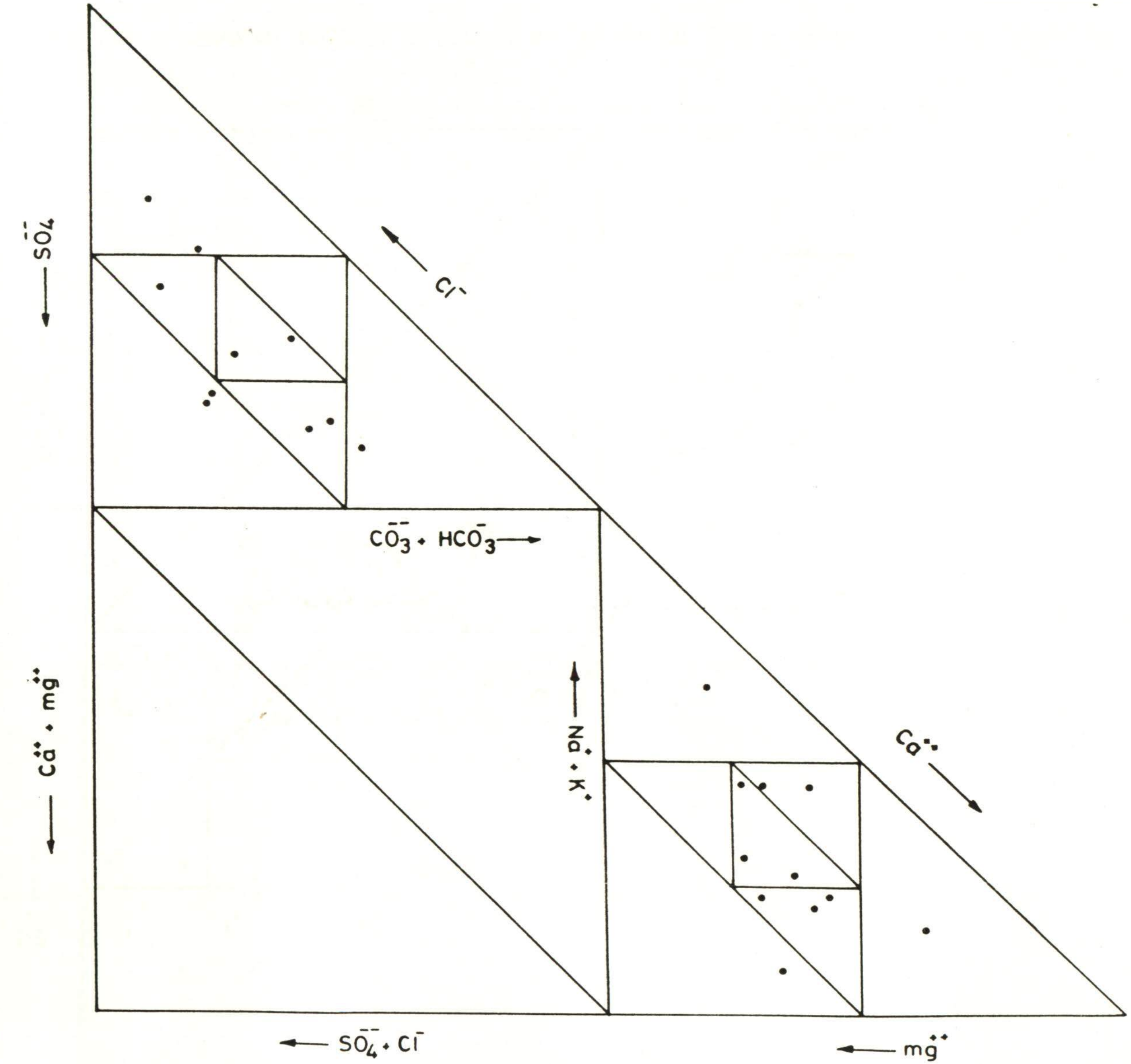


FIG.5·17. ROMANI MODIFIED TRILINEAR PLOT OF SHALLOW GROUNDWATER; MAY, 1993

TABLE 5.7 CHEMICAL CHARACTERISTICS IN ROMANI'S DIAGRAMS

SHALLOW WELLS APRIL 1991		SHALLOW WELLS JANUARY 1992		SHALLOW WELLS MAY 1993		DEEP WELLS MAY 1993		FALLING IN FIELD		EXPLANATIONS OF DIFFERENT AREAS IN DIAGRAMS	
CATIONS	ANIONS	CATIONS	ANIONS	CATIONS	ANIONS	CATIONS	ANDINS	CATIONS	ANIONS	CATION TRIANGLE	ANION TRIANGLE
2			4	1	1	1	5	C_1	A_1	Calcium-type	Bicarbonate -type
3				1	2		6	C_2	A_2	Magnesium-type	Sulphate-type
1	7	2	13	1	2	11	10	C_3	A_3	Sodium-type	Chloride-type
1		1	3	2		8	4	C_4	A_4	Sodium-calcium -type	Chlorid-bicar-bonate-type
			3	3	2		1	C_5	A_5	Calcium-magnesi-um-type	Bicarbonate-sulphate-type
3	1		1		1	3	2	C_6	A_6	Sodium-magnesi-um-type	Chlorid-sulph-ate-type
	2	1	1	3	2	7	2	C_7	A_7	Calcium-magnesi-um-Sodium-type	Bicarbonate - sulphate-chlo-ride type

square. The nine fields of the expanded Durov diagram have been classified as follows Fig.5.18: (Lloyd and Heathcote,1985).

Field 1: HCO_3^- and Ca^{++} dominant. Frequently indicates recharging waters in limestone, sandstone, and many other aquifers.

Field 2: HCO_3^- dominant and Mg^{++} dominant, or Ca^{++} and Mg^{++} dominant. Water often associated with dolomites; where Ca^{+2} and Na^+ are important partial ion exchange.

Field 3: HCO_3^- and Na^+ dominant; normally indicates ion-exchanged waters.

Field 4: SO_4^{-2} dominant or anions indiscriminant and Ca^{+2} dominant.It frequently indicates a recharge water in lavas and gypsiferous deposits. Otherwise, a mixed water or water exhibiting simple dissolution may be indicated.

Field 5: No dominant anion or cation indicates waters exhibiting simple dissolution or mixing.

Field 6: SO_4^{--} dominant or anions indiscriminant and Na^+ dominant is a water-type not frequently encountered and indicate probable mixing influence.

Field 7: Cl^- and Ca^{++} dominant, is infrequently encountered, unless cement pollution is present in a well; otherwise the water may result from reverse ion exchange of Na^+- Cl^- waters.

Field 8: Cl^- dominant and no dominant cation indicates that the groundwaters may be related to reverse ion exchange of Na^+-Cl^- waters.

Field 9: Cl^- and Na^+ dominant frequently indicates end-point waters. The Durov diagram does not permit much distinction between Na^+-Cl^- waters.

In an attempt to study chemical characteristics of the area rationally, the chemical output for the periods April 1991 January 1992, May 1993 and for the deep groundwater in May-1993 have been plotted in the expanded Durov diagram (Figs.5.19-

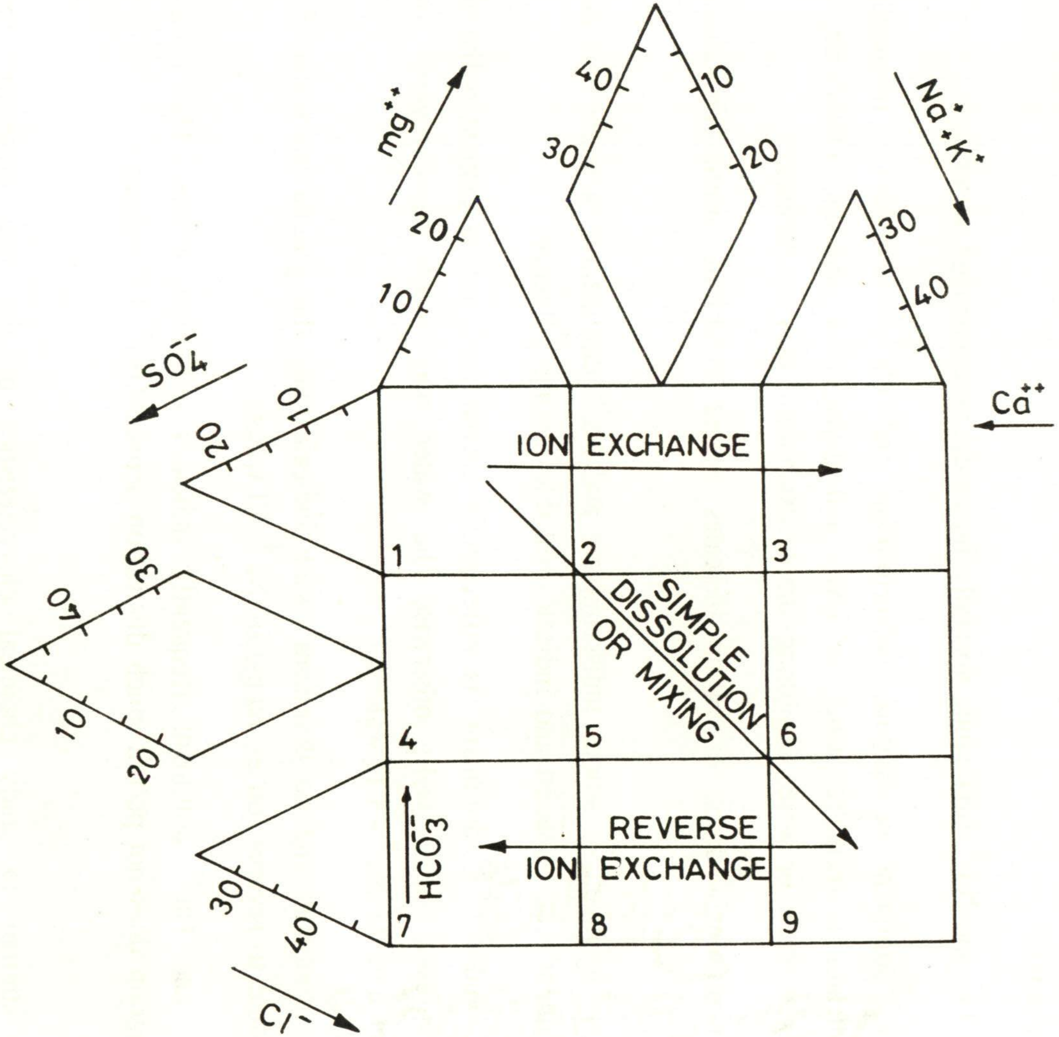


FIG. 5·18. EXPANDED DUROV DIAGRAM (AFTER BURDON & MAZLOUM, 1958 AND LLOYD, 1965)

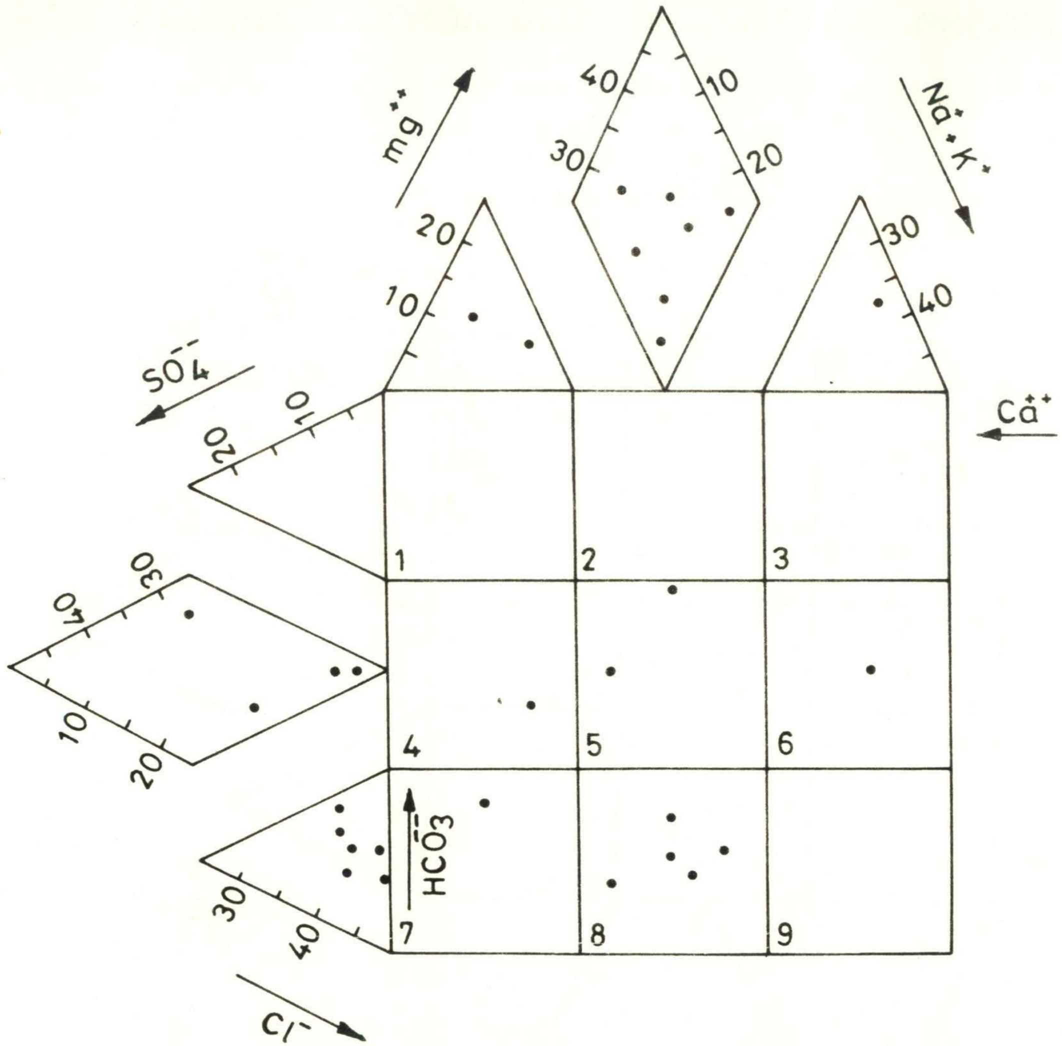


FIG. 5-19. EXPANDED DUROV PLOT OF SHALLOW GROUNDWATER, APRIL, 1991

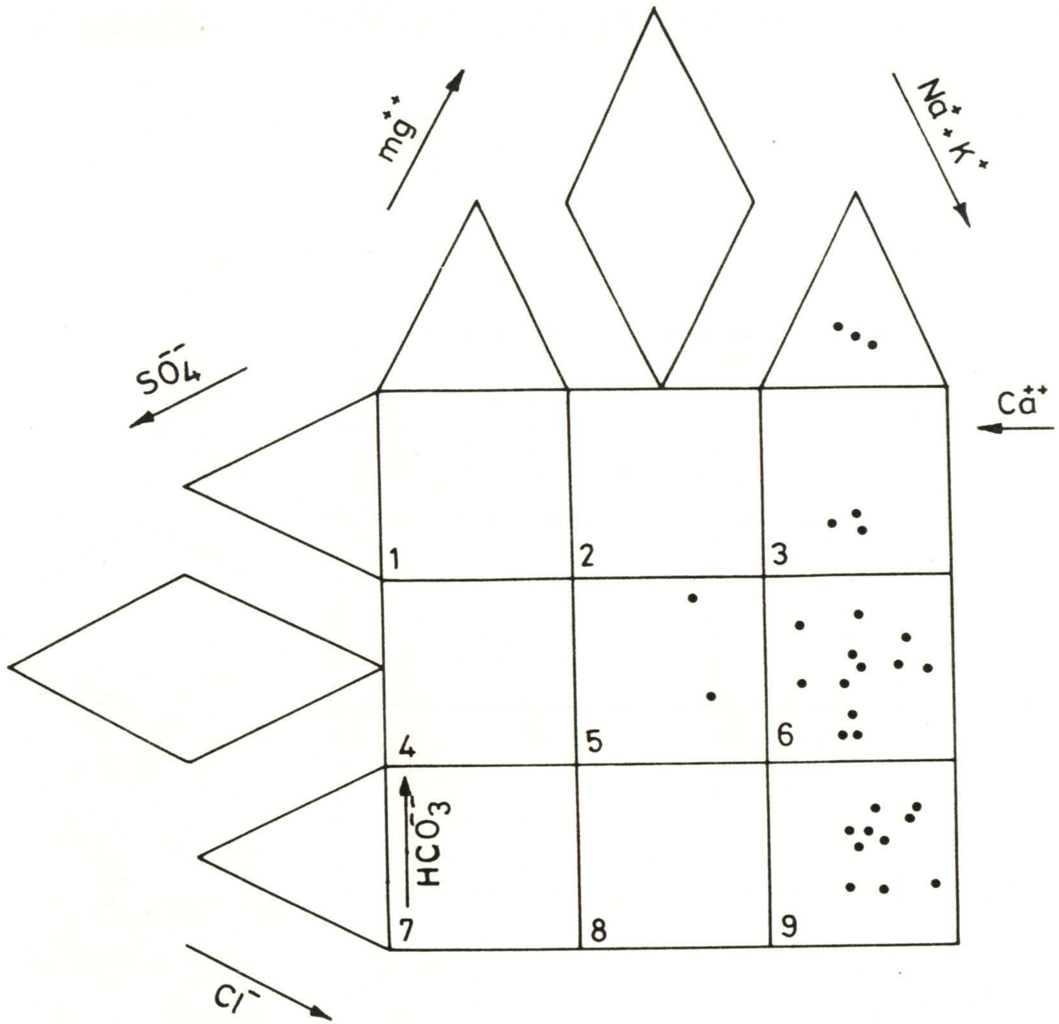


FIG.5·20. EXPANDED DUROV PLOT OF SHALLOW GROUNDWATER; JAN., 1992

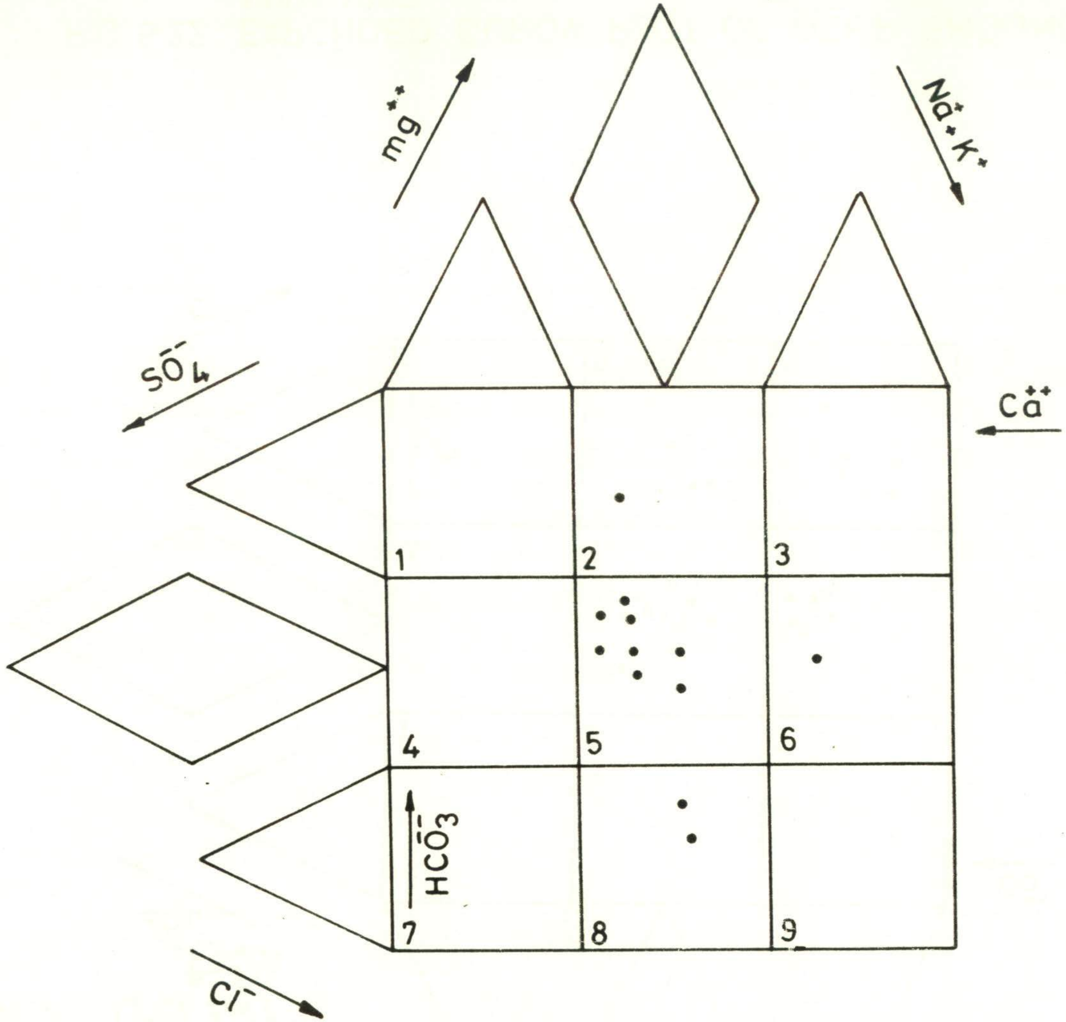


FIG.5·21· EXPANDED DUROV PLOT OF SHALLOW GROUNDWATER MAY, 1993

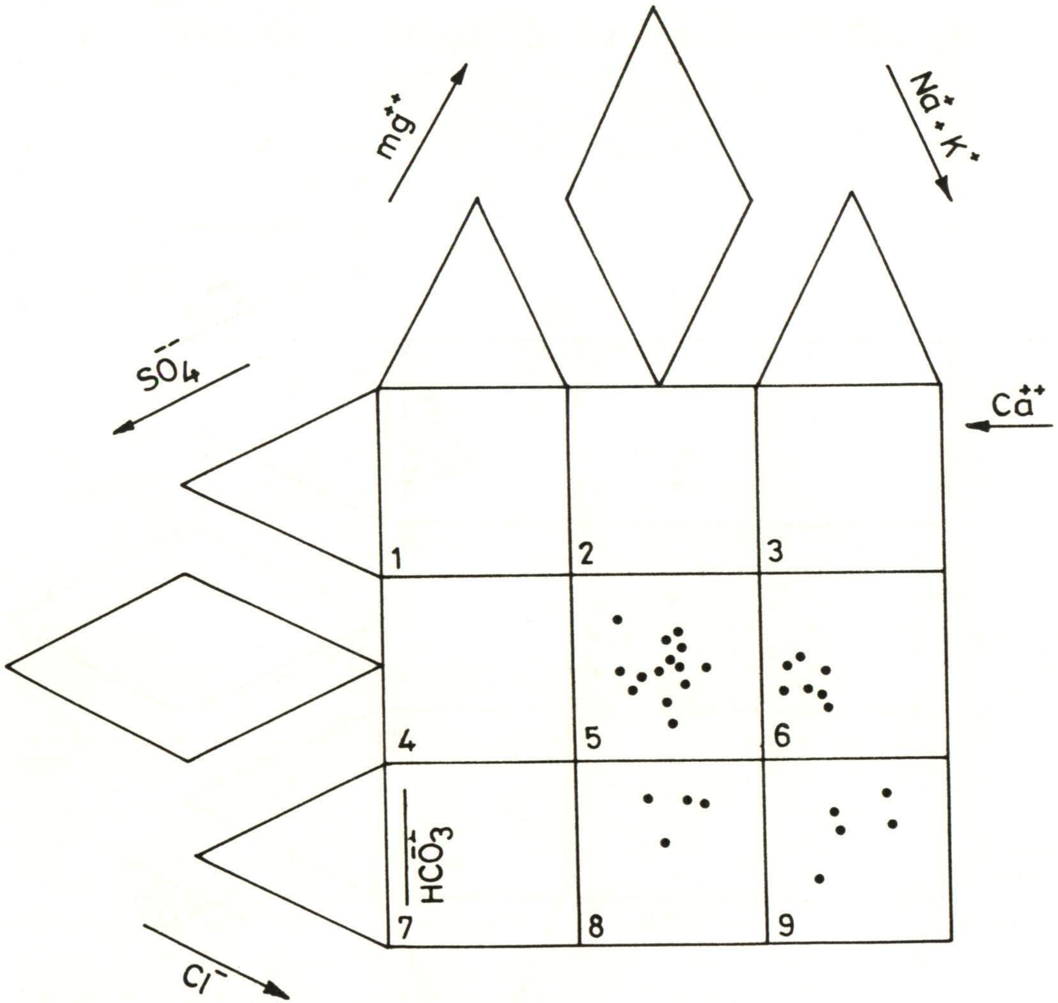


FIG. 5·22 EXPENDED DUROV PLOT OF DEEP GROUNDWATER
MAY, 1993

TABLE 5.8 CHEMICAL CHARACTERISTICS IN EXPANDED DUROV DIAGRAMS.

SHALLOW WELLS APRIL 1991	SHALLOW WELLS JANUARY 1992	SHALLOW WELLS MAY 1993	DEEP WELLS MAY 1993	FALLING IN FIELD	EXPLANATIONS OF DIFFERENT AREAS IN DIAGRAMS
1				7	Cl^{-} an Ca^{++}-dominant
1				4	So_4^{-2}- dominant
5		2	4	8	Cl^{-} - dominant groundwater (Related to reverse ion exchange) Na^{+}-Cl^{-} water
2	2	7	14	5	No dominant anion and cations (exhibiting dissulution or mixing)
1	12	1	7	6	So_4^{--}-dominant or Na^{+} dominant (probable mixing)
	9		5	9	Cl^{-} and Na^{+} dominant
	3			3	HCO_3^{-} and Na^{+} - dominant ion exchang water
				2	HCO_3^{-} dominant and Mg- dominant, Ca^{++}- , Mg^{++}- important ions

5.22). Table 5.8 shows the chemical characteristics of these water samples. From the table, it is observed that majority of the groundwater samples for the period April 1991 fall in field 8 and show the characteristics of end-point concentrations (Na^{+}-Cl^{-}) water, indicating occurrence of reverse ion exchange. However, in the period January 1992, majority of the samples show high concentration of $Na^{+}$and SO_4^{--} indicating a mixing influence, which is characteristic of field 6. The remaining samples fall in field 9, indicating end-point concentration of Na^{+} and Cl^{-}. However, the majority of groundwater samples (both shallow and deep aquifers) in May 1993 fall in field 5 and exhibit an intermediate character indicative of mixing (or dissolution) processes. The remaining samples are distributed among field 6, 8 and 9 showing dominance of SO_4^{--} ion and probably, the mixing trends. The plots of expaded Durov diagram confirm the earliar findings about the groundwater being of mixed-type but with an indication of processes like reverse ion exchange being active.

5.9 IODIDE-CHLORIDE RELATIONSHIP

Howard and Lloyd (1978) studied saline waters in Lincolnshire, England with the help of iodide-chloride relationship and differentiated the salinity in the aquifers into two types on the basis of their residence times. The aquifers showing high enrichment of iodide are considered to represent long residence within the aquifer system without the influence of sea water intrusion. This approach has also been tried in the present study by plotting and iodide-chloride relationships for the groundwater of the area (Fig. 5.23). From the figure, it is observed that the majority of samples fall above 10^{-5} mg/l of I^{-}/Cl^{-} ratio,which indicates enrichment of iodide with long residence, entrapment in rocks over prolonged periods due to poor subsurface drainage especially in the rocky aquifers having low permeability. Further, the groundwater in the deeper aquifers seems to be younger in origin.

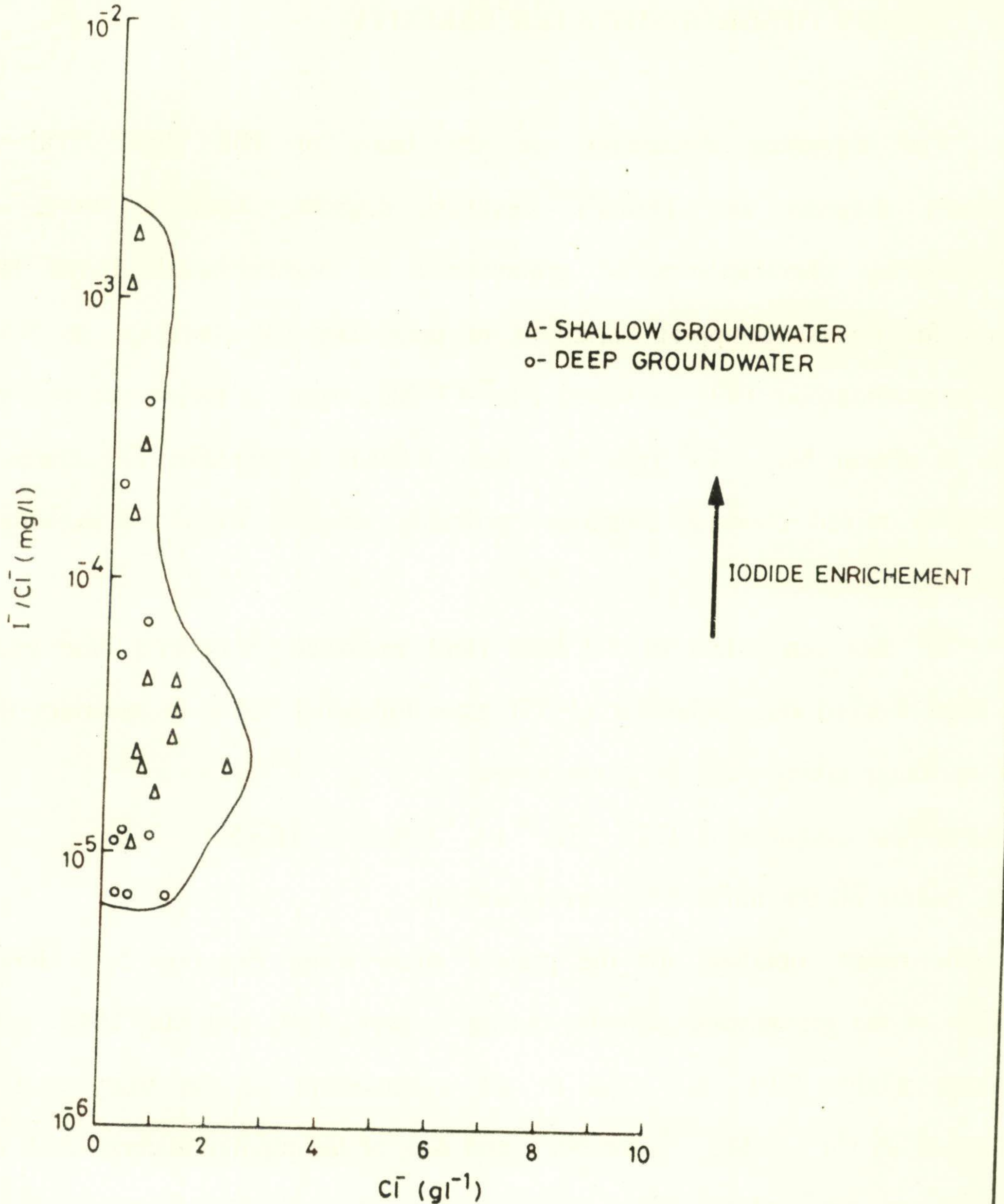


FIG.5·23. SHOWING IODIDE AND CHLORIDE RELATIONSHIPS FOR SALINE (SHALLOW, DEEP) GROUNDWATERS

5.10 ORIGIN OF GROUNDWATER SALINITY

The foregoing discussion, on the basis of Hill Piper Trilinear diagram, Romani's diagram and Durov's modified diagram, tend to bring out diffrent hydrochemical characteristics of groundwater of Mahendragarh Distt. However, the reason for diverse temporal variations in their chemical character, as from Na^{+}-Cl^{-}-type in premonsoon 1991 to mixed Na^{+}-Cl^{-}-SO_4^{--}-type in the winter of 1991-1992 and again to almost Na^{+}- Cl^{-} type have been difficult to explain. The Durov's plots also confirm a mixed chemical character, probably resulting from ion exchange or simple dissolution processes.

To ascertain extent of the base (ion) exchange, Shoeller's base exchange index has been worked out. Schoeller (1959) gave following index to ascertain the degree of base exchange taking place in groundwaters.

Positive base exchange = $\{Cl^{-} - (Na^{+}+K^{+})\}/Cl^{-}$, (Eq.5.1)

where all the ionic values are in meq/lit.

The results obtained for the present study using Equation 5.1, show that about 62-72% of the groundwater samples during January, 1992 and May,1993 exhibit -ve ion exchange (Table 5.9) i.e., most of the groundwater of the study area might have exchanged its Ca^{++} Mg^{++} for Na^{+} and K^{+} of the aquifer material and, thus, became enriched with $Na^{+}$and K^{+} ions.

5.11 GROUNDWATER GEOCHEMISTRY

For the present study, it must be recognised that the groundwater occurs in widely diverse type of alluvial and indurated aquifers, including the fractured and weathered calc-silicates, granites, quartzites, calc-gneisses and phyllites. Thus, the

TABLE 5.9 BASE EXCHANGE OF THE GROUNDWATERS IN DIFFERENT SEASONS (VALUES IN EPM)

April-May, 1993	Jan, 1992	May, 1993	Premonsoon, 1993 Shallow
0.40	-0.63	0.20	-0.56
0.45	-0.20	0.13	0.04
-2.21	-0.38	0.1	1.0
0.29	0.22	-0.16	-0.21
0.65	-1.10	0.069	0.22
0.71	-2.29	0.25	-0.36
0.52	-2.11	-4.6	-0.20
0.47	-0.55	-0.58	0.33
1.0	-0.41	0.98	-0.36
-0.53	-0.31	-0.33	-0.40
	0.48	-0.58	-0.41
	-0.62	-0.88	
	-2.0	-0.13	
	1.0	-0.09	
	-1.95	-0.25	
	-1.43	-0.46	
	-0.59	-0.26	
	-0.59	-0.09	
	-0.23	0.11	
	-0.18	0.42	
	1.00	-0.34	
	0.21	0.18	
	-2.49	-0.06	
	-0.19	-0.33	
	-0.21	0.23	
		-1.14	
		-0.30	
		0.36	
		-0.16	

geochemistry of groundwater would be influenced by the mobility of widely different elements and constituents present in the rocky aquifers, whereas the entire range of geochemical processes may not be reflected by the graphical methods like Hill-Piper and Durov's plots. Moreover, the phenomenon of recurrent droughts associated with the abundant evaporation is likely to have modified the chemical character of the groundwater. In the light of these observations, it seems relevant to consider the extent of ionic enrichment by evaporation processes, as manifested by plots of the more stable chloride versus other ions like HCO_3^-, Na^+ and SO_4^{--} as discussed by Jones et al. (1977) and Drever (1982).

Eugster (1970) and Jones et al. (1977) suggested that when evaporation is a major process in a region, a straight line relationship (45^o line) exists between Cl^-, and other ions present in the natural water. In the present work, figures 5.24 to 5.29 depict the plots between Cl^- vs. Na^+, Cl^- vs. SO_4^{--} and Cl^- vs. HCO_3^- ions for January 1992 and premonsoon, 1993. It is observed that for January 1992 and premonsoon 1993 Na^+ is relatively oversaturated or follows a 45^o straight line relationship compared to Cl^-. However, it is oversaturated in 1993. Likewise in 1992, SO_4^{--} is also undersaturated with respect to Cl^- in contrast to that in premonsoon 1993. Further, HCO_3^- is undersaturated with respect to Cl^- both in 1992 and 1993. Thus, a general abundance of Na^+ & Cl^- is brought out in the groundwater over most of the ions.

For the deep groundwater, 45^o straight line relationship between Na^+ and Cl^- premonsoon 1993 (Fig.5.25) reflects their mutual behavior and reflects enrichment due to evaporation. However, the 45^o straight line relationship between Cl^- and other ions is not clearly brought out by these plots for shallow groundwater; though an undersaturation of groundwater in SO_4^{--} in January 1992 with respect to Cl^- indicates ionic enrichment by evaporation. The overall deficiency of HCO_3^- in the groundwater

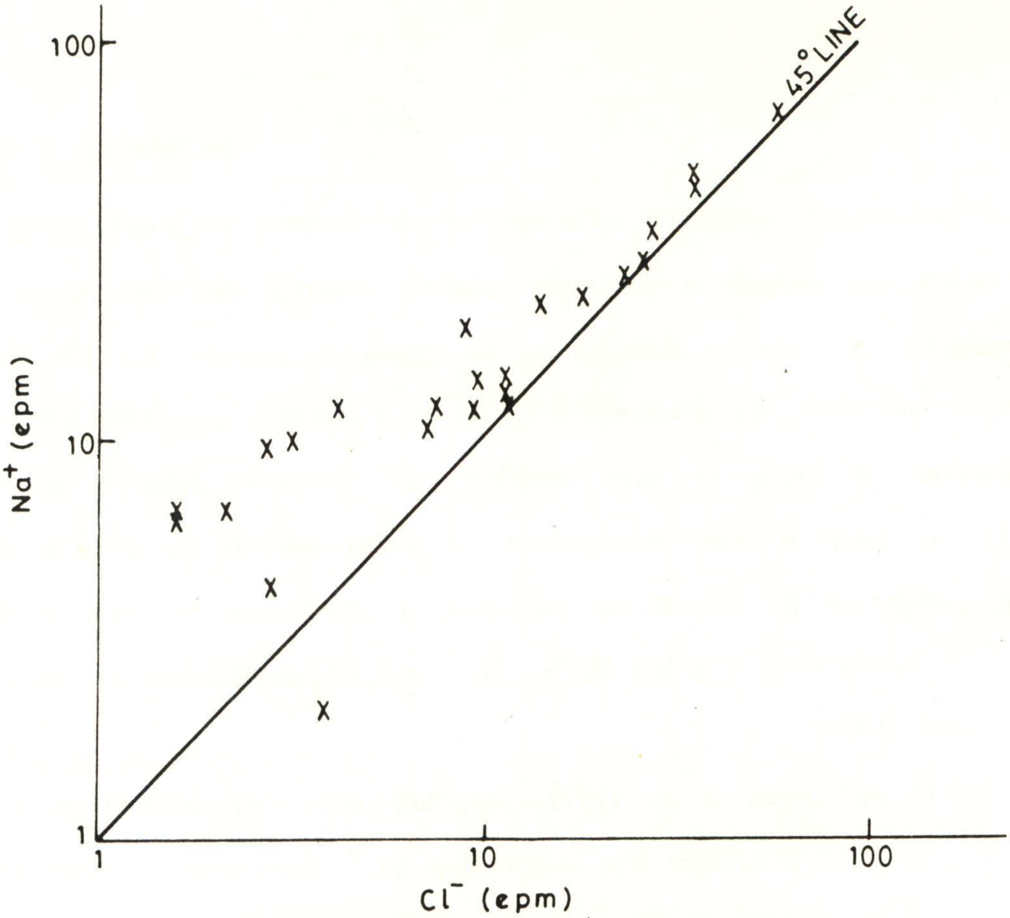


FIG.5·24. PLOT OF Cl^- Vs Na^+ JAN , 1992

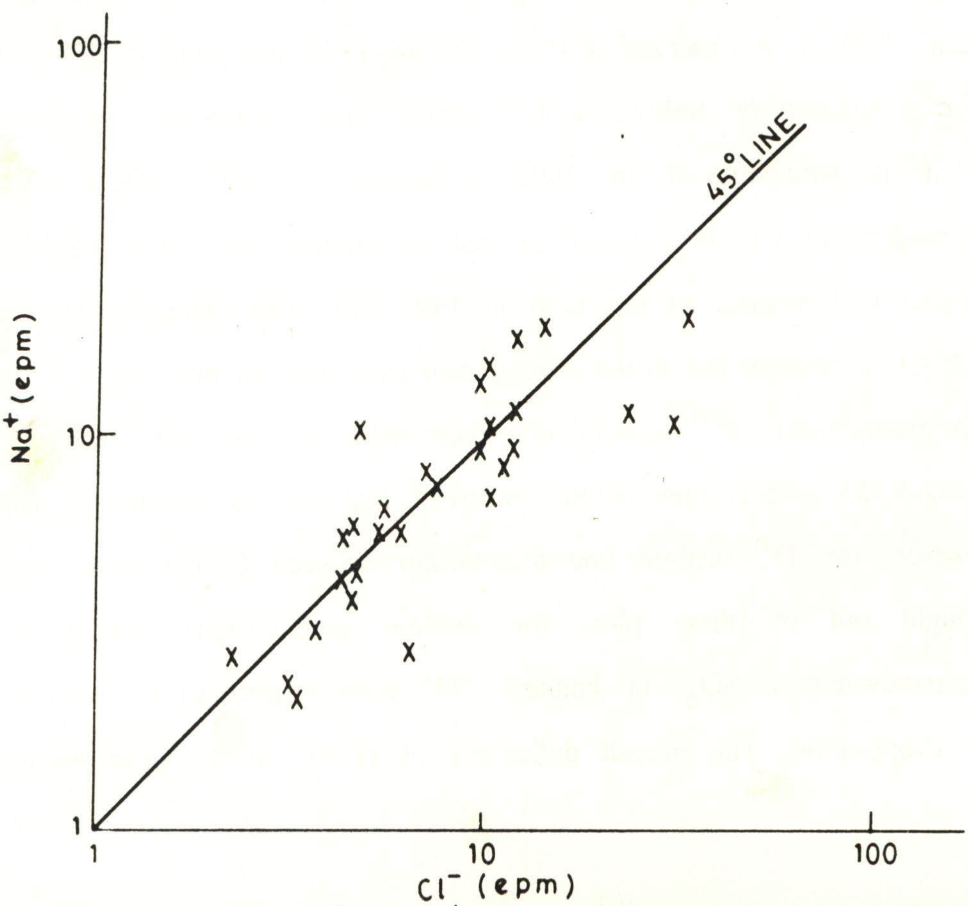


FIG.5·25. PLOT OF Cl^- Vs Na^+ FOR DEEP GROUNDWATER PREMONSOON, 1993

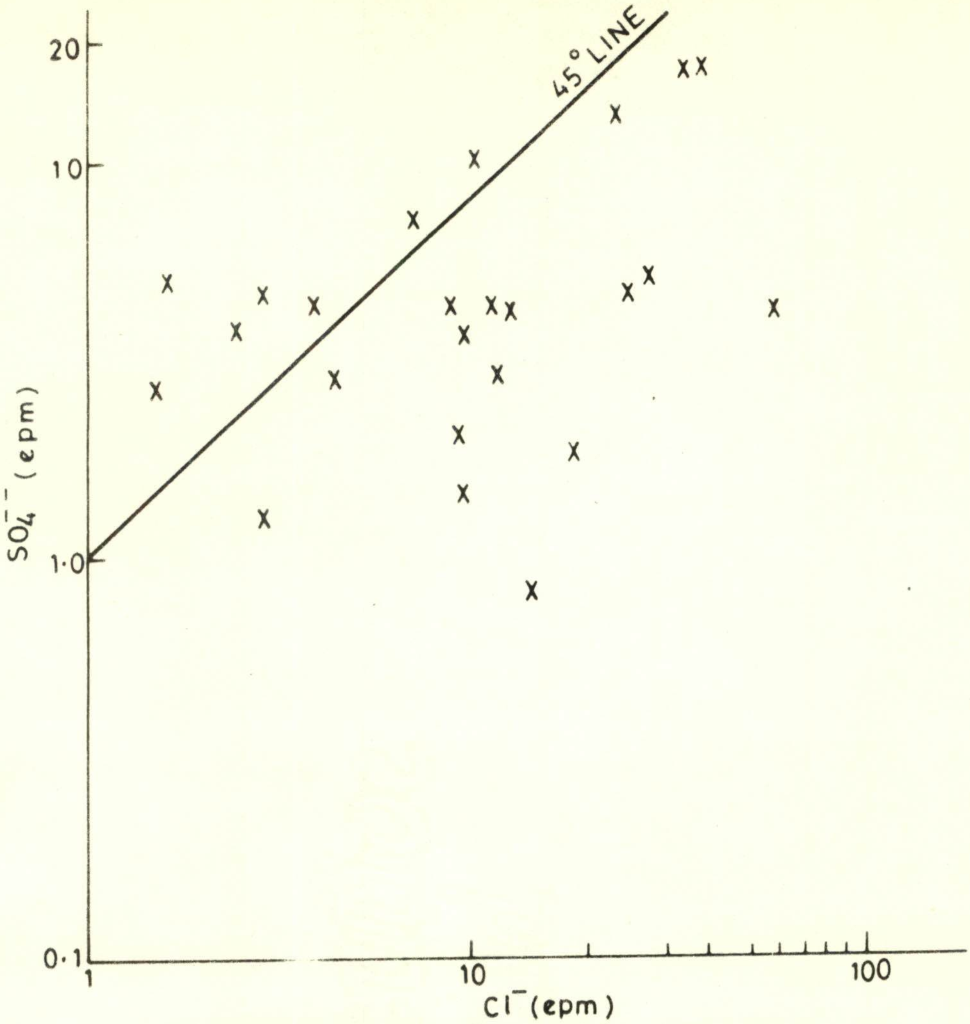


FIG.5·26. PLOT OF Cl^- Vs So_4^{--} JAN, 1992

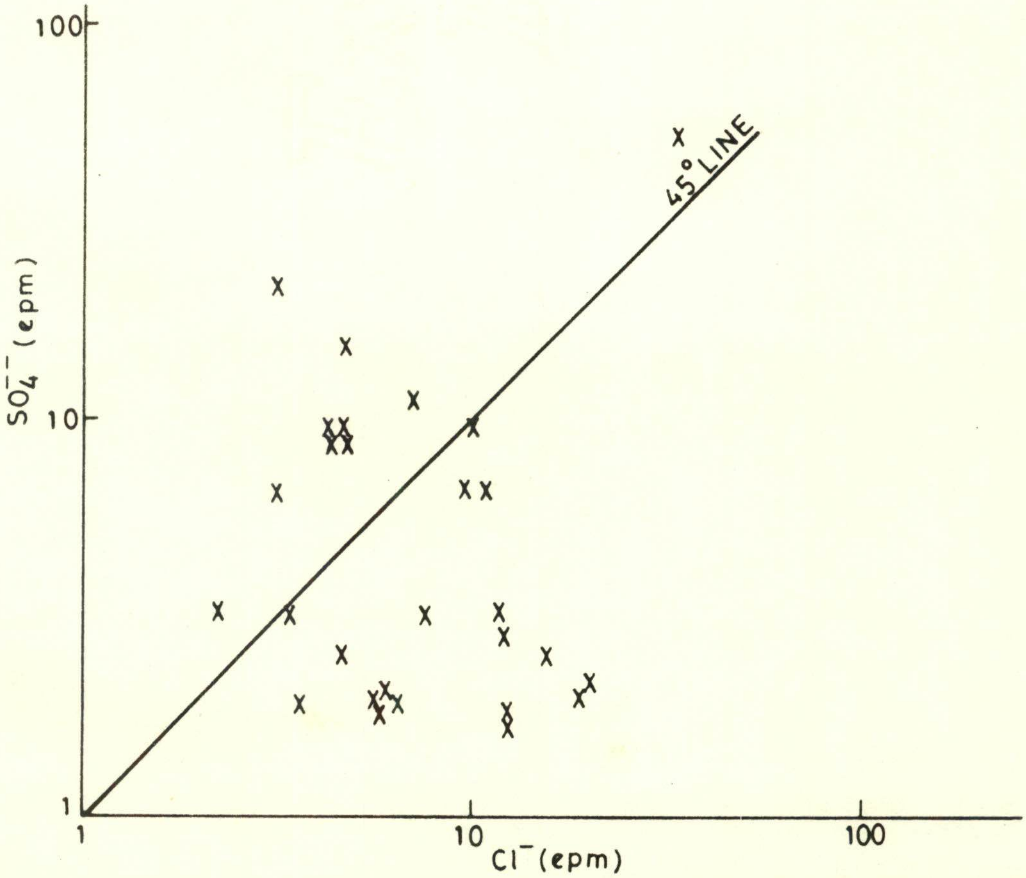


FIG. 5·27 PLOT OF Cl^- Vs So_4^{--} FOR DEEP GROUNDWATER PREMONSOON, 1993

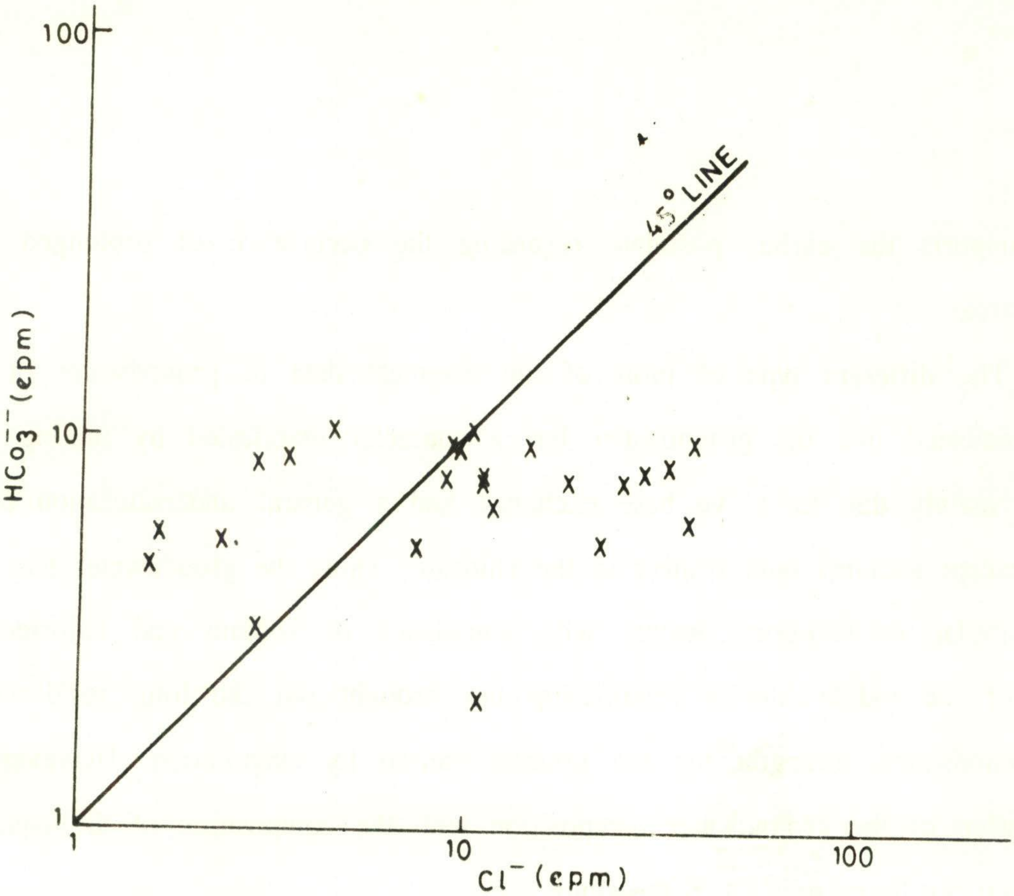


FIG. 5·28. PLOT OF Cl^- Vs HCO_3^- JAN, 1992

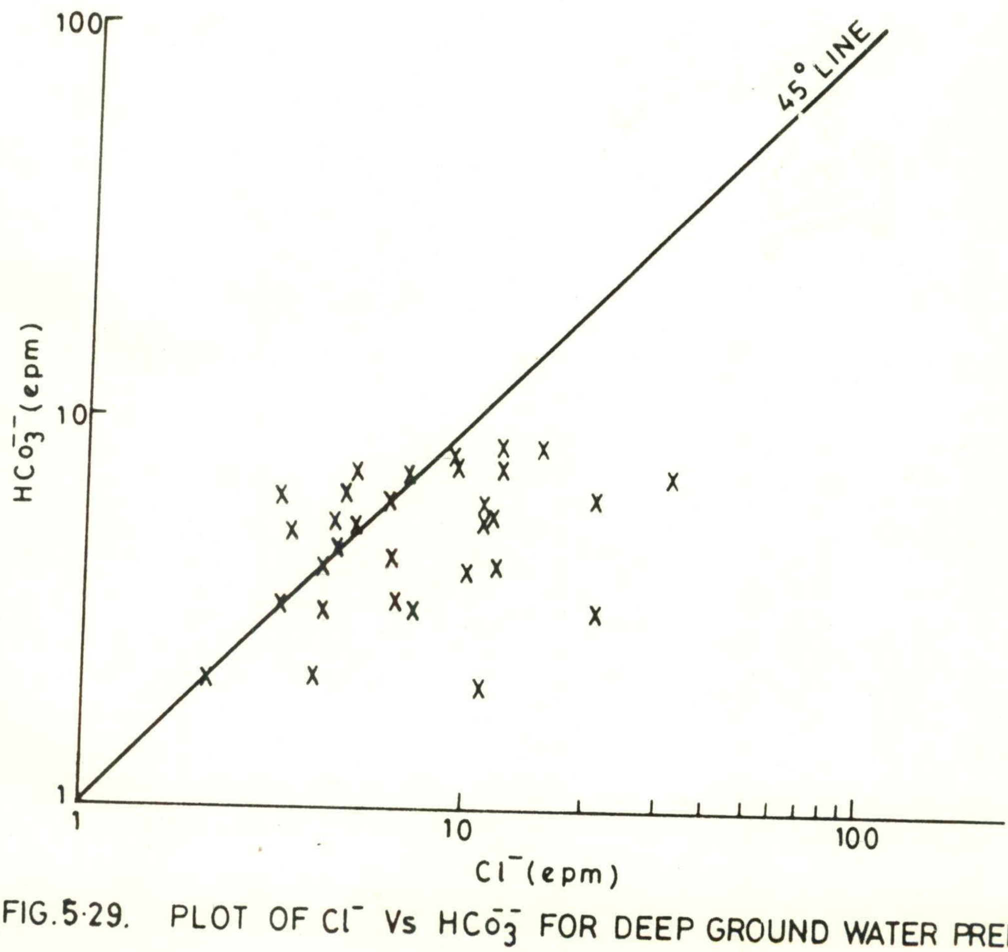


FIG. 5·29. PLOT OF Cl^- Vs HCO_3^- FOR DEEP GROUND WATER PREMONSOON, 1993 also supports the earlier postulate regarding the occurrence of prolonged dry spells in the area.

The different type of plots of the chemical data of groundwater in the study have indicated that the groundwater has a character manifested by mixing influences, caused mainly due to a -ve base exchange and a general undersaturation of different ions (except sodium) with respect to the chloride. Thus, the groundwater has a composition similar to end-point waters with abundance of sodium and chloride. Further, study of the iodide-chloride relationship has brought out the long residence time of the groundwater, strengthening the premise caused by evaporation. However, a direct relationship of the groundwater composition with the composition of the aquifer materials could not be established in the study.

CHAPTER - 6

SUMMARY AND CONCLUSIONS

Semi-arid region in Mahendragarh district of Haryana state exhibits general scarcity of surface and subsurface water resources. This situation has assumed alarming dimensions due to the persistent decline of water table, caused due to the over-exploitation of groundwater, associated with droughts and deterioration in quality.

The present research dissertation was taken up, with the following objectives:

(i) To bring out geological and structural features relevant to the hydrogeology.

(ii) Study of the hydrogeomorphological features of the area using satellite imageries, followed by field checks.

(iii) Evaluation of subsurface geology from the available data of tubewells and vertical Electrical Soundings (VES), and newly-recorded VES data, along with identification of aquifers.

(iv) To decipher hydrogeological conditions, including water-table configuration, fluctuation of watertable and estimation of selected hydraulic properties of. aquifers.

(v) To ascertain groundwater quality characteristics and probable source of salinity.

The study covers an area of about 1800 km^2 between latitudes $27^o48'$ and $28^o28'$N and longitudes $75^o54'$ and $76^o23'$E in the southwestern parts of Haryana.

The average yearly rainfall recorded for 40 years from two rain gauge stations at Mahendragarh and Narnaul, is 497 mm and 533 mm respectively. Geomorphologically, this region is almost a pediplain, having long and narrow ridges and with inselbergs of different sizes rock formations.

The rock formations belong to the the Delhi Supergroup of the Precambrian age (the Alwar and Ajabgarh Groups). Structurally, regions rock formations have been subjected to various tectonic forces, and, therefore, suffered extensive folding, faulting and igneous intrusions.

The study of metamorphic tectonites of the Delhi Supergroup reveals the presence of three sets of folds, designated as F_1, F_2, and F_3 in the chronological order, and associated structural elements. The earliest recognizable folds (F_1) are tight, and isoclinal with high amplitude/wave length ratio and are disposed in NNE-SSW direction. These folds have been formed due to WNW-ESE compressive forces. The F_2 folds are open, upright asymmetrical/symmetrical folds and have resulted in co-axial refolding of the F_1 folds. The third deformation structures are F_3 folds with WNW-ESE axial trend and high wavelength/amplitude ratios.

The rock formations exhibit characteristic jointing. The dominant joint directions are NE-SW (dipping 75^oNW), $N130^o$-310^o (dipping 50^oN) and $N75^o$-255^o (dipping N). The NW-SE trending fractures are open tensional joints, developed perpendicular to the NE-trending fold system and are of relevance in groundwater localization and movement. This has been verified by the occurrence of seepages of groundwater encountered during the field traverses.

Hydrogeomorphological studies from satellite imageries were carried out to demarcate geomorphic/landforms, fracture traces and lineaments. Various hydrogeomorphological features, such as **(i)** depositional features including alluvial plains, sand dunes, points bars, flood plains, **(ii)** moderate structural denudational hills and **(iii)** low-lying structural denudational features, e.g., inselbergs, pediplain, valley fills and vegetation anomalies, have been delineated from visual interpretation of False Color Composites (FCC) of the IRS satellite imageries. Frequency analysis of the joints in various rock formations, and of the fracture traces and lineaments delineated from the imageries, have revealed their close relation with each other in NNE-SSW, NW-SE, WNW-ESE directions. However, the development of fracture traces along a few azimuth groups like N320^{o}-360^{o}(SSE) is poorly correlated with joints. The reason for above variation in the frequency of the joints and fracture traces may be attributed to the disgrace nature of observation of joints in the field, which may have been somewhat subjectivity. Notwithstanding such as mismatch, fracture trace, and lineaments, picked up from the imageries, seem to offer important means to study and to interpret development of fractures and faults in rock formations of an area.

The present study, has revealed that majority of the fractures are oriented in NE-SW and WNW-ESE directions. However along the WNE-ESE trending joints, quartz and pegmatitic veins have also been observed. This trend coincides with the F_3 trend of fold axes and seems to represent direction of tensional forces in the 3rd stage of tectonic development in the area. Thus, the WNW-ESE trending fractures are the most important set, considered to remain open in depths.

In order to ascertain the practical viability of the interpretation of structural studies, the locations of existing production wells and of the fracture traces and lineaments have been plotted on the imageries of the area. For this purpose, the location of successful wells, drilled by the CGWB, were plotted on the hydrogeomorphological map from which it has been observed that most of the high-yielding wells are located either on fracture traces or fall in their vicinity. Thus, it is inferred that study of the fracture traces, and lineaments along with hydrogeomorphological features are important aids in targeting and localization of groundwater in a geologically and structurally complicated terrain.

Limited availability of the lithological data of wells make it difficult to study the subsurface geology and put severe constraints on compiling its holistic picture. These short-comings can, however, be overcome by the use of geophysical data inputs. Such an approach has been attempted using the available lithologs of existing wells and supplementing the information gaps with the geophysical data. A total of 54 vertical Electrical Soundings (VES) including 10 nos. of newly recorded VES data using Schlumberger electrode configuration has been utilized in this work. The data have been interpreted by a computerised (Direct) technique, combined with curve matching for calibration purposes. The field evidences and available hydrogeological and groundwater quality data have helped in assigning the resistively ranges for different subsurface geological formations.

The resistivity ranges, assigned to the different subsurface formations, are 18 to 110 ohm-m for sand, 5 to 100 ohm-m for clay -sand admixtures (depending on fraction of clay), 4 to 18 ohm-m for free of sand 9 to 153 ohm-m for kankar-clay admixture, 20 to 270 ohm-m for pegmatite, 40 to 200 ohm-m for quartzite (weathered and semi compact), 95 to 270 ohm-m for calc-silicate rock and 665 to 800 ohm-m slate. A judicious interpretation of the geophysical data in the light of available geological evidences is considered essential for achieving a realistic perception of the distribution of subsurface geological formations.

A set of geoelectrical sections along in different directions have been prepared to study the variation in lithology, as interpreted from resistivity values, and to demarcate and ascertain the nature of subsurface formations. The horizons in a few sections appear to be water-bearing in the northwestern parts. The occurrence of saline groundwater, as witnessed by the high EC values, is also indicated along a few sections.

The depth to bedrock is highly variable and slopes towards northeast and north in the area. As a consequence, thickness of alluvial deposits increases from south to north and from west to east. A sizable thickness of semi-compact and fractured rock is also indicated to be present beneath the alluvium with four isopachs, maxima of being above 80 m in southwestern parts and 45 m in the NW parts respectively.

In general, alluvial sands, often mixed with silt, gravel and kankar form the potential aquifers in the area. However, groundwater also occurs in the fractured rock. The depth to water table contour maps for the years 1991. 1992 and 1993 have indicated that depth to water table is highly variable in a wide range between 8m to 41m (bgl). It is shallow in NE parts and deepest in the NW and western parts. Further, there has been a significant decline of watertable (up to 25m) in the past few years. Such decline in water table can be explained due to the low recharge during years of lean rainfall along with over exploitation of groundwater.

The watertable elevation contours maps for the area for the years 1991, 1992 and 1993 indicate that elevation of watertable varies between 221.92 m (AMSL) to 314.37 (AMSL). The watertable slopes towards north and northeast. The permeability of the aquifer is greater in the northern parts, whereas steeper hydraulic gradient occurs towards south and northwestern parts indicating low permeability of the aquifers. Manifestations of general overdraft conditions are quite evident in the configuration of watertable contours.

An attempt has also been made to estimate transmissivity and hydraulic conductivity of unconfined alluvial aquifers from the resistivity soundings data, using earlier established of relations between aquifer transmissivity and transverse resistance. However, wide variations in salinity of groundwater tend to violate these relationships in the present study. Yet, keeping in view the varying salinity of the groundwater, the results of the study indicate that computed transmissivity of aquifer at seven places ranges from 77 to 764.6 m^2/day and compare reasonably well with the field transmisivities (118-360 m^2/day) for the corresponding locations. The RMS error in such estimates (36.74 m^2/day) seems to be within reasonable limits, in spite of the wide variation in groundwater salinity.

The chemical analysis of groundwater was carried out over three seasonal cycles of periods to establish quality characteristics of groundwater.

Ions like Na^+, K^+, Ca^{++}, Mg^{++}, HCO_3^-, CO_3^{-2}, SO_4^{-2}, Cl^- ; TDS, pH and electrical conductivity were analysed. The electrical conductivity contours indicated that the groundwater quality is generally marginal to saline in most places, especially in central, northern, southern, eastern and northwestern parts with Cl^- and Na^+ being the dominant ions. The fresh water zones are mainly located at places in the northwestern part of the area and in isolated patches elsewhere.

It has been observed that fluoride concentration in the groundwater from 21 wells is higher than optimal range, mainly in the NE, NW, SW and central parts. Further, fluoride concentration is greater in deeper aquifers, when compared to the shallow ones, probably because the deeper aquifers are in closer proximity of hard rocks, which contain fluorine-rich minerals. Thus, it is indicated that lithology of the geological formation is the major controlling-factor in causing high concentration of fluoride in the groundwater.

In order to classify the groundwater, the multivariate technique of factor analysis was also carried out. It is observed that results of factor analysis are inconsistent and do not show a good match of dominant chemical species. Thus, graphical approaches (Trilinear diagrams etc.) have been preferred, as the result of factor analysis, have to be ignored. The representation of hydrochemical data of groundwater on trilinear diagram was attempted .From this analysis, it has been inferred that the majority of samples indicate a general affinity to an intermediate range of non carbonate hardness, except in January, 1992, when it was rich in alkalis and strong acids.

The Romanis-modified-Hill-Piper diagram, reveal that, the groundwater quality for April, 1991 is mostly of Na^{+}-Ca^{++}-Cl^{-} type. However, the groundwater for the period January, 1992 show bicarbonate, chloride-bicarbonate and bicarbonate-sulphate types. Overall, shallow groundwater is generally of Na^{+}-HCO^{-}_{3}, Cl^{-}-types. It is also concluded that deep groundwater of May, 1993 has high concentration of Na^{+} and Cl^{-}.

The plotting of groundwater quality data on expanded Durov's Diagram has revealed a general Na^{+}-Cl^{-} type of groundwater, deeper aquifer shows high concentration of Ca^{+2} and SO_4^{-2} exhibiting dissolution or a mixing character.

The concentration of iodide in the groundwater generally indicates the residence time of the water. It is observed from the iodide-chloride relationship that, this area is enriched in saline groundwaters, and can be attributed to longer residence time, which may be caused by entrapment of groundwater within low-permeable aquifer materials receiving low recharge. However, a direct relationship of the groundwater composition with the composition of the aquifer materials could not be established.

The different type of plots of the chemical data of groundwater have indicated that the groundwater has a character, manifested by mixing influences, caused mainly due to a -ve base exchange and a general under saturation of different ions (except sodium) with respect to the chloride. Thus, the groundwater has a composition similar to end-point waters with abundance of sodium and chloride.

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