GROUNDWATER OCCURRENCE AND QUALITY IN SAHARANPUR TOWN, INDIA : IMPACT OF URBANIZATION

A THESIS

Submitted in fulfilment of the
requirements for the award of the degree
of

DOCTOR OF PHILOSOPHY
in
APPLIED GEOLOGY

By

VINAY KUMAR SHARMA

DEPARTMENT OF EARTH SCIENCES
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247 667 (INDIA)

JULY, 2007

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE ROORKEE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **GROUNDWATER OCCURRENCE AND QUALITY IN SAHARANPUR TOWN, INDIA : IMPACT OF URBANIZATION** in fulfilment of the requirement for the award of the degree of Doctor of Philosophy and submitted in the Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from July 2001 to July 2007 under the supervision of Dr. A.K. Awasthi, Professor, Department of Earth Sciences and Dr. D.C. Singhal, Professor, Department of Hydrology, Indian Institute of Technology Roorkee, Roorkee.

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

(VINAY KUMAR SHARMA)

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

(D.C. Singhal)
Professor
Supervisor

(A.K. Awasthi) 24/7/07
Professor
Supervisor

Date: 24/7/07

The Ph. D. Viva-Voce Examination of **Mr. Vinay Kumar Sharma**, Research Scholar, has been held on 10/11/07

Signature of Supervisors 10/11/07 Signature of H.O.D Signature of External Examiner 10/11/07

ABSTRACT

The storage and movement of ground water in alluvial aquifer systems depends on the physical character of the medium and the aquifer matrix. Because of its proximity to various sources of contamination, shallow aquifers in many urban areas get contaminated by unsaturated flow through overlying pervious zones in the alluvial sediments. Further, in urbanized areas, ground water within the shallow aquifer is commonly degraded by municipal and urban runoff, which may include sewage and industrial effluents. Thus, leakage from the shallow horizons can be potential source of pollutant transport to deeper levels. The deterioration in quality of ground water available for urban supplies worldwide is causing increasing concern to the communities as the water shortages go on increasing.

The Saharanpur town of Western Uttar Pradesh in India is a sizable urban complex growing at a steady rate as a result of increase in population accompanied by spurt in industrial activity. The present study seeks to examine the impact of urbanization and industrial development on the shallow ground water regime of Saharanpur town (U.P.) in North India where the major source of water supply to the urban populace is from shallow hand pumps and deeper tubewells. The available data about the growth of Saharanpur town indicates that its built up area increased from 1110 hectare in 1973 to 2340 hectare in 2003. Further, the population grew from 1,05,622 in 1941 to 4,68,074 in 2003 i.e. more than four times in the last 60 years or so.

Evaluation of ground water pollution from different sources have been attempted in past by several workers. Aller et al. [1987] suggested a seven parameter index called DRASTIC to evaluate ground water vulnerability of an area on the basis of hydrogeologic setting of the alluvial areas. The Drastic approach has been widely used with or without modifications for assessment of groundwater vulnerability for alluvial aquifers. In India, agencies like Central Ground Water Board (CGWB) and Central Pollution Control Board (CPCB) have so far been using methods to evaluate ground water pollution potential commonly from the data of depth to water table and rate of infiltration.

The area under study is a part of the Indo Gangetic plain and lies in the upper part of the Hindon Basin, bounded between latitude 29° 55' and 30° 0' North and longtidue 77° 30' and 77° 36' East. The area is located in Saharanpur district of Uttar Pradesh, India and is included in the Survey of India topographic sheet No. 53G/9 on the scale of 1:50,000. The investigated area is about 90 km^2 in area.

With a view to delineate the current land use in the study area, a land use map of Saharanpur city has been prepared from the sattelite image (LISS-III-Pan merged data)for year 2002 which shows that as much as 36% of the city area is urban land whereas 40% area is barren land.

Geomorphologically, the Saharanpur Distt. can be divided into Siwalik hill range (in the northeast) followed by Bhabhar zone (Upper piedmont), Tarai zone (Lower piedmont), younger alluvium and older alluvium of Recent age respectively towards south. Physiographically, the Saharanpur region falls in the drainage system of Hindon basin in its upper parts, Hindon being a tributary of river Yamuna. The notable drains (referred as nalas) in the city are Dhamola, Paondhoi and Kamela which merge together near the Clock Tower area in the central part. The regional hydrogeological fence diagram of the area indicates that there are three main sandy aquifer groups in the region separated by clay horizons. Regionally, the ground water flows in the area towards south with a steep slope in the Bhabar zone and mild slope in the Tarai zone. The depth of water table in the Bhabar zone is upto 36 m below ground level (bgl) whereas it is shallow (5-10 m bgl) in the Tarai zone where the study area is situated. The ground water generally flows towards southeast and south and is good in quality.

There are various notable industrial units in the area such as a large paper mill, a tobacco company, distilleries, electroplating, meat products and chemical units. These industrial units discharge waste effluents into the nearby drains, which finally meet the river Hindon. Further the municipal effluents carrying sewage of the town also meet the river system adding to the waste load of the river. The topographical map of the area prepared from recently surveyed data indicates the master slope of the ground surface towards south.

Lithologically, the water bearing formations in the study area are composed of fine to medium grained sands separated by clay horizons. Two types of aquifers have been delineated : the upper one is a shallow unconfined aquifer extending down to 18-20 m depth whereas the deeper aquifers are confined to semiconfined in nature. The ground water leveling monitoring was commenced in the area from 2001 initially on 17 shallow dug wells which was switched over to 51 hand pump well sites due to drying up of the open wells. A total of eight cycles of the ground water level monitoring have been carried out between 2001 to 2006. Further, upto to nineteen ground water samples were procured during each cycle (adding to a total of 136 samples) from shallow hand pumps in the city. For comparison, ground water from India Mark II hand pumps tapping deeper aquifer was also sampled at a few locations. The major physicochemical, bacteriological parameters along with the selected heavy metals were analyzed from the ground water samples. Besides, samples of raw sewage and effluents from point sources of pollution and from line sources of pollution (drains) and urban diffuse runoff were also collected for their chemical analysis. The chemical analysis of surface water in the area indicates high concentration of fecal coliforms and BOD at few localities, especially in the nalas and the sewage. Though the overall quality of ground water samples drawn from the unconfined aquifers has total dissolved solids (TDS) and other physicochemical parameters generally in acceptable ranges as per Bureau of Indian Standards for drinking (BIS:10500); some of these like TDS, nitrate, sulphate, $CaCO_3$ hardness, and alkalinity are found to exceed the BIS Limits at a number of localities namely Sheikhpura Qadim (in south), S.M. Inter College in central part of study area, localities in the vicinity of Dhamola nala especially towards south and in the west-central parts of the Saharanpur town in the vicinity of Kamela nala.. Besides, out of the heavy metals analysed, cadmium, chromium, copper and manganese have been observed to exceed the permissible limits at many of these places. The hazardous physicochemical and bacteriological parameters and heavy metals identified and detected in the ground water are fecal coliforms, cadmium, chromium, nitrates and sulphates. The possible line sources of pollution of the ground water have also been identified to be the Dhamola and Kamela nala(s) which seem to carry the sewage and industrial effluents of the town and its industries.

A total of thirty two geophysical resisitivity soundings and twelve Induced Polarization (IP) soundings were recorded at selected points in the area wherever space was available for laying down schlumberger sounding spread up to about 600 m (AB). The resistivity sounding data was interpreted using a software given by Zohdy (1989) and also compared with partial curve matching techniques. The IP sounding data was interpreted by using IX1D (Interpex) software. The characteristic resistivity and IP response ranges of the lithounits finally assigned are given as under

Table – Resistivity and IP Ranges of Litho-Units

Lithology	**Range of Resistivity (Ωm) (msec)**	**IP response**
Clay (or clay mixed with silt/sand)	<27	> 3
Sand	28-150	Uncertain
Gravel/Boulder	> 150	Uncertain

From the results of the geoelectrical and IP sounding interpretation and available lithologs for existing tubewells, geological fence diagram and geoelectrical sections have been prepared which show the occurrence of multi-layer aquifer system in the area. The interpretation of the sounding data is helpful in arriving better correlation of aquifer horizons but the presence of thin intervening clays/aquitard is not clearly indicated. Further, the depths indicated in geoelectrical sections are expected to be reduced by 30-35% in the actual lithologs.

The geoelectrical studies have helped in better delineation of aquifer-aquiclude system in the study area. Generally, the subsurface geological section is made up of sandy materials which tend to become more clayey towards the east, southeast and south. The intervening clay bands act as aquicludes and aquitards. At two localities viz. in the western part of the study area on Ambala road and in Pairagpur village towards south, indications are available from the geophysical sounding data about degraded quality of ground water. The studies indicate that such deterioration in ground water quality can be due to contamination from industrial sources and sewage in the vicinity of above locations.

Based on the hydrogeological setting of the study area, Drastic method of aquifer vulnerability assessment has been applied to find out its pollution potential in different parts. Calculation of the Drastic Index (DI) values indicates that very high pollution risk zone (DI>200) is not present in the study area. Yet, the assessment of ground water vulnerability has indicated that some central and southern localities of Saharanpur city are in medium risk (D.I. : 160-179) and high risk zones (D.I. >180).

Based on the chemical quality of groundwater vis-à-vis possible sources of surface pollution, it has been inferred that the main sources of pollution are indicated to be point sources (outfalls of sewage, Tobacco effluent and paper mill effluent) and line sources (viz. Dhamola and Kamela nalas). It is quite likely that the localities inferred to be hydrogeologically more vulnerable for ground water contamination are exposed to contamination by hazardous pollutants like fecal coliforms, cadmium, chromium and nitrate in ground water and thus stand greater risk of pollution than the areas with lower vulnerability. Such places need to be monitored for ground water quality more systematically and vigorously so that effective measures can be initiated for future protection of ground water at these localities on urgent basis.

Taking note of the possibility of ground water contamination in the Saharanpur town, an improved ground water quality monitoring network has been proposed in the present study, wherein eleven additional shallow tubewells have been proposed to be constructed near the line sourses and point sources of pollution for ground water quality monitoring in future. Such a network will be of considerable help in protection of the shallow ground water resources of the town where the majority of the population depends on the shallow ground water for drinking. In the absence of a national Ground Water Legislation, a series of other institutional steps have also been suggested for exercising greater restraints to be observed in day to day operation and management of the drinking water facilities in the town. In this context, the role of civic authorities and NGO's can be of considerable help.

The above studies have helped in delineating localities threatened with greater risk of ground water pollution by hazardous heavy metals and pathogenic bacteria. This will help in designing improved ground water quality monitoring networks for future protection of this valuable resource.

ACKNOWLEDGEMENTS

I feel privileged to express my deep sense of gratitude and sincere regards to **Dr. D.C. Singhal**, Professor of Hydrology Department and **Dr. A.K. Awasthi,** Professor of Earth Sciences Department, IIT, Roorkee for their keen interest, invaluable guidance and constant encouragement throughout the course of the present study.

I express my indebtedness and sincere thanks to **Dr. R.P. Gupta, Head, Earth Sciences Department and Dr. N.K. Goel Head, Department of Hydrology**, IIT, Roorkee for providing necessary facilities for my Ph.D. Work.

I thank, **A.K. Seth** from the bottom of my heart for illuminating, helping and educative discussions which helped in shaping this thesis. Without his help it was not possible to make this thesis a reality.

I express my sincere regards to **Er. Salek Chand, Institute Engineer, IIT, Roorkee, Er. D.K. Gupta, P.W.D. Saharanpur, Er. M.K. Agarwal Chief Engineer (Rtd.), Uttarakhand Jal Vidhut Nigam, Dehradun** and **Kameshwer Prasad (Audit Officer Dehradun, Uttarakhand)** for their help at the time of my study

I thankfully acknowledge valuable suggestion and help offered by **Dr. Kuldeep Kumar Garg, Dr. Rama Rao** and **Sri Ranjan Sinha.**

I wish to thank all faculty members of the Department of Hydrology for generously providing the research facilities for carrying out the work and for their cooperation extended throughout the course of this work viz. **Dr. B.S. Mathur**, **Dr. D.K. Srivastava, Dr. Ranvir Singh, Dr. M.D. Nautiyal, Dr. H Joshi, Dr. M. Perumal,** and **Dr. D.S. Arya.** The prompt assistance rendered by Mr. J.K. Sharma, Mr. D.P. Sharma, Mr. M.L. Gupta, Mr. A.K. Singhal, Mr. Jamshed Ali, Mr. Amarjeet Singh, Mrs. L. Thankamma, and Mr. Rajkumar, and other office staff of the Department of Hydrology is thankfully acknowledged.

I wish to acknowledge Scientists of National Institute of Hydrology **Dr. M.S. Rao** for his constant encouragement during my stay at Roorkee. I wish to acknowledge **Er. Ishwar Singh**, Municipal Corporation, Saharanpur for providing the lithological data of tube wells.

I express my gratitude to **Dr. R.G. Maheshwari** and his family for their constant encouragement since my graduation degree upto my present study.

I highly appreciate and express my sincere appreciation and heartfelt gratitude to **Dr. S.S. Srivastava** and **Dr. M. Israil** of Department of Earth Sciences, IIT, Roorkee for their invaluable guidance and constant encouragement throughout the course of this study. I also thank Mr. AR J. Nair of the department for extending all the coorperation.

I sincerely thank **Prof. G.C. Chowdhary, Prof B.B.S. Singhal, Prof. C.S.P. Ojha Dr. S.C. Bansal Dr. P.K. Sharma** for their encouragement during the course of study.

I express my sincere and special regards to my friend and companion **Mr. Ashish Srivastava, Deepak Agrawal, Nihar Ranjan Bhattacharjee, Rajeev Kumar Chauhan, Sri Krishna Yadav** and **Naveen Shukla** who had given moral and emotional support in my difficult time. All help and support gave me tremendous energy during my sullen times. I cherish the time I spent with him.

Dr. P. Kumar, Dr. Umesh Sharma, Dr. Dilbagh Singh and **Dr. Sukhveender Singh** are the few prominent names who helped me at various occasions during my present study.

I am also very thankful to my other friends viz., Sanjay Kumar, Lekraj, Naveen Shukla Sudipta Haldar, Rajendra Prasad, Kuntal Maiti, Rakesh Kumar Gautam, Pritam Chaudhari, Ritu Sharma and Suchismita for providing me great company during my stay in the IIT campus.

Last, but not the least, I would like to thank my **parents, brother** and **sister** who deserve an award for their patience, understanding and prayers during my study and the writing of this thesis. I appreciate their support without which, my six year stay in IIT would not have been possible. I thank them for their faith in my capability, for offering me a soothing relief while being rational and realistic, and finally for always having something encouraging to say even from thousands of miles away.

This thesis is dedicated to my grand father and maternal grand father.

(Vinay Kumar Sharma)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1
INTRODUCTION

1.1 General

Water is the elixir of all life on planet earth and constitutes an important component of hydrologic cycle. It occurs above the ground as 'surface water' and beneath the ground as 'subterranean water'. Groundwater reservoirs (aquifers) constitute widely distributed resources beneath the surface of the earth. Such resources form important source of water, which are exploited through wells, tanks or seeps and springs.

Though the global water availability through ground water constitutes only 0.67 percent component of the earth's total water, the total volume of readily usable ground water is greater than the fresh water stored in lakes, streams and rivers (Berner and Berner, 1996). About half of the groundwater occurs within 800 m of the earth's surface, and the remainder occurs between 800 m – 4000 m depth (Nace, 1969). Not all of it is usable; some, for example, is saline, and some can be regarded as inaccessible because of the great depth at which it occurs.

It is estimated that in developing countries like India, two out of five persons have no access to safe drinking water. Unfortunately, there are only limited resources to deal with these vital problems. In 1981, World Health Organization estimated that 80% of all sickness and disease caused by polluted water, non-availability of water and inadequate sanitation. The growth of urban settlements and growing industrial production, combined with rapidly increasing demand for water in the developing countries are causing water quality problems. In 1982 (http://www.infochangeindia.org, 2007), it was reported that 70% of all available water in India was polluted. The situation is much worse today.

The alluvial aquifer systems are the major source of groundwater for human needs as these can be recharged by precipitation in every year, mostly in monsoon (rainy) season. Because of its proximity to various sources of contamination, shallow alluvial aquifers in many urban areas can get contaminated through interstitial porosity and permeability. Over the years due to swelling population, increasing industrialization and expanding agriculture, the demand for water has multiplied. Simultaneously, the available per-capita water resources have been reduced due to the declining ground water table, combined with inefficient use of water. In the agricultural lands, groundwater commonly contains high concentration of dissolved solids (including nitrates) and pesticides. Further, in urban areas groundwater occurring within the shallow aquifer zone is commonly degraded by urban runoff, which includes municipal and industrial effluents. Sometimes, leakage from these shallow horizons can be potential source of pollutants transported to deeper levels. Protection and management of groundwater and its quality have become a high priority cardinal necessity in such a scenario. Evaluation of sources of contamination in alluvial groundwater systems is therefore, a challenging task for researchers and workers in this field.

Over- extraction of groundwater has reportedly resulted in problems of excessive Fluoride, Iron, Arsenic, and salinity in water affecting about 44 million people in India. Groundwater is facing an equally serious threat from contamination by industrial effluents and faecal matter, as well as pesticides and fertilizers from farm runoff. Water management is, therefore, a major issue of concern for town planners, builders and architects today, not just in terms of availability of required quantum of water but also of acceptable quality.

The initial step for a successful groundwater development in town areas is location of suitable aquifers and finding the best site for well(s) from a standpoint of quantity, quality, and depth of groundwater as well as absence of potential contamination by polluted effluents or other low quality degradable water.

As the modern practices of waste disposal by sanitary land fills etc. are yet to gain necessary momentum in countries like India, the leachates resulting from the solid waste dumps and the effluents can readily find their way into sub-surface formations, contaminating thereby the ground water. Further, seepages from various influent streams carrying industrial effluents might also result in the deterioration of the ground water quality available in the aquifers. The Saharanpur city of Uttar Pradesh (U.P.) in North India, is a sizeable urban complex growing at a steady pace as a result of increase in population (the present population being about 4,68,000) accompanied by spurt in industrial activity. The present study attempts to investigate the impact of disposal of industrial and municipal effluents on the ground water regime of Saharanpur town (U.P.) with a view to study the occurrence of groundwater and evaluate its vulnerability to pollution and the design guidelines for protection of groundwater resources.

1.2 RATIONALE

In the Saharanpur town of north India, a significant imbalance in the sustainable development of the groundwater resources in terms of quality and quantity is being noticed due to urban development and industrialization. However, the groundwater is also reportedly recharged here by deep percolation through relatively steep sloping "Bhabhar" (local term used for gravel/sand admixtures) sediments deposited at the base of the hill ranges (known as Siwaliks) which form foothills of Himalayas located towards northeast of Saharanpur.

The town has been witnessing a relatively fast development of industrial activity as a result of the presence of a number of medium and major industries. These industrial units include a notable paper mill along with related subsidiary cardboard factories, a sizable cigarette manufacturing unit, a slaughter house and several other industries related to chemicals. Most of these industrial units discharge waste effluents in to the nearby nalas (drains) with or without pre- treatment. Further, the municipal effluents carrying sewage of the whole population of the town is also discharged in the river systems adding to the organic waste loads in the area. The leachates generated from the solid waste dumped in the different part of the town also add to the pollutional loads in the nalas (drains) resulting in the emanation of foul odours in the vicinity of lotic waters. All these nalas finally join the river Hindon passing outside the municipal limit of Saharanpur Town. There is a strong likelihood that the waters infiltrating from these influent nalas will join the waste effluents infiltrating through the nala beds down to the groundwater regime of the area. This increases the pollution hazards of the shallow groundwater in this alluvial area considerably. Thus, realizing the need to identify areas vulnerable to pollute groundwater and workout guidelines for protection of groundwater quality, the present study has been taken up.

1.3 Study Area

The study area is located in Saharanpur district of Uttar Pradesh state in India (Fig. 1.1 and 1.2). The district is one of the populous districts in the state and is situated in the northwestern part of Upper Ganga-Yamuna interfluve in the upper Hindon river Basin. The study area is bounded between latitudes $29^{\circ}\ 54'$ and $30^{\circ}\ 0'$ North and between longitudes $77^{\circ}\ 30'$ and $77^{\circ}\ 37'$ East (Fig.1.2) and is included in the Survey of India topographic sheet No. 53G/9. Its ground elevation is around 270 meter above the mean sea level. Dhamola Nala, a tributary of river Hindon, divides the Saharanpur city in two parts. The part of the city which is located west of the Dhamola Nala is older than the eastern part which has developed in recent years.

1.3.1 Climate and Rainfall

The Saharanpur town experiences humid climate with three distinct seasons viz., summer, followed by rainy (also referred as monsoon) and winter seasons. The hydrometeorological observations for the town are being taken at the offices of the District Magistrate and Agriculture Department at Company Bagh. Table 1.1 gives the available values of air temperature, relative humidity and potential evaporation (at Roorkee station) monthly and yearly normal rainfall data (for Saharanpur taken for period between 1901 to 1950, after IMD, 1961). With a view to compare and gauge the change in pattern of such climatological data during the last fifty years, recent available meteorological data of the years 2004 and 2006 are presented in Table 1.2 (A) and 1.2 (B) respectively.

Table 1.1; Available average air temperature, monthly and yearly normal rainfall data taken for period 1901 to 1950 (after IMD, 1961)

Month	Air Temperature in °C		Rainfall in mm.	Relative Humidity in %	Potential Evaporation in mm.
	max.	min.			
January	20.1	6.6	37.6	84	42.8
February	22.9	8.7	36.1	78	62.4
March	28.7	13.1	23.4	62	110.4
April	35.2	18.2	11.2	41	152.7
May	39.4	23.6	14.2	37	198.9
June	38.5	25.9	95.8	55	192.0
July	33.3	25.5	261.4	80	135.3
August	32.3	25.0	248.9	84	123.8
September	32.4	23.4	164.6	80	121.6
October	30.9	17.2	22.3	73	99.4
November	26.5	10.1	5.1	74	55.5
December	22.0	6.8	15.5	81	38.5
	mean=30.2	mean=17.0	(annual) 936.1	mean=69	total=1333.8

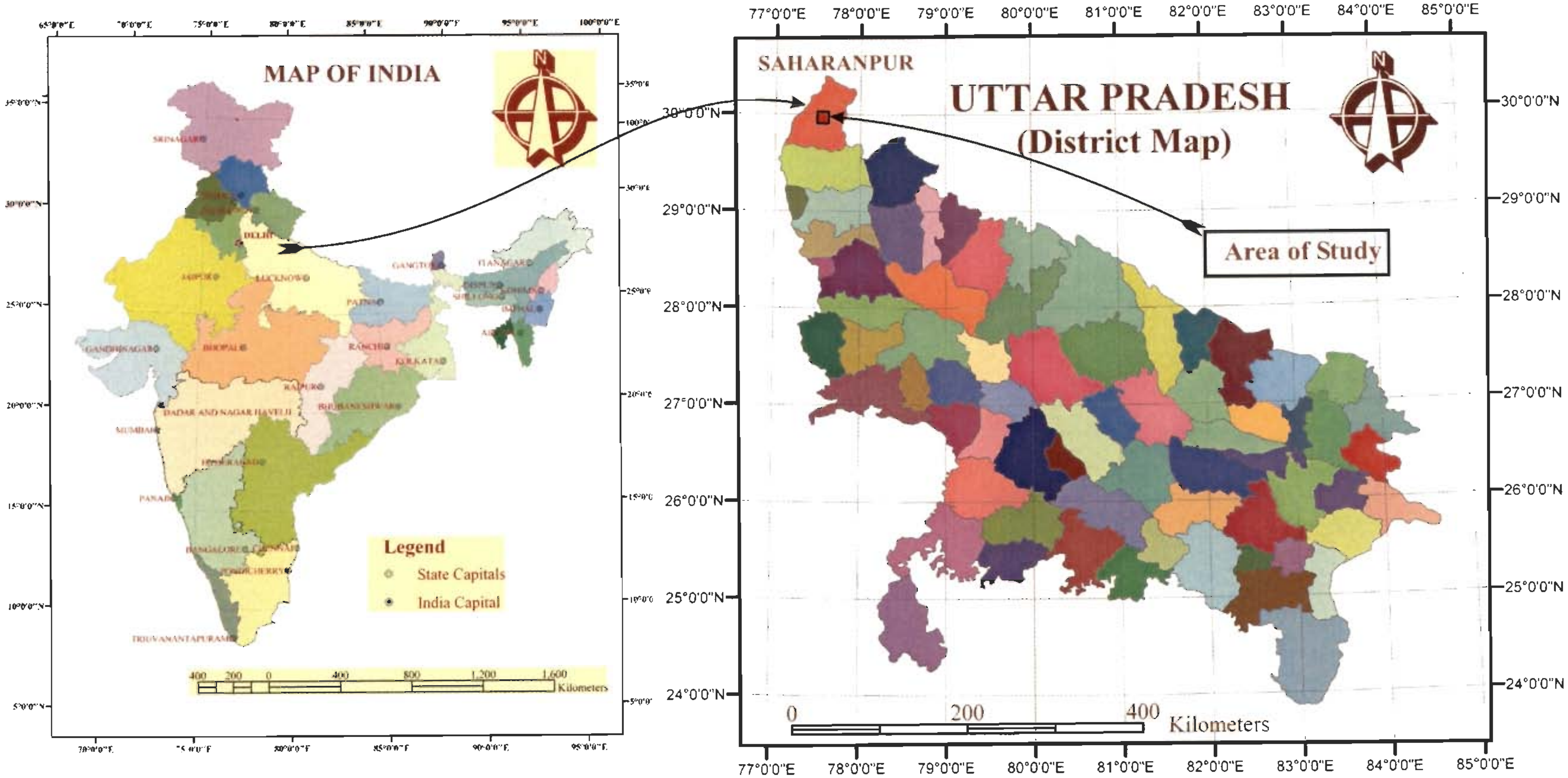


Fig. 1.1; Location of Saharanpur (Uttar Pradesh) in India

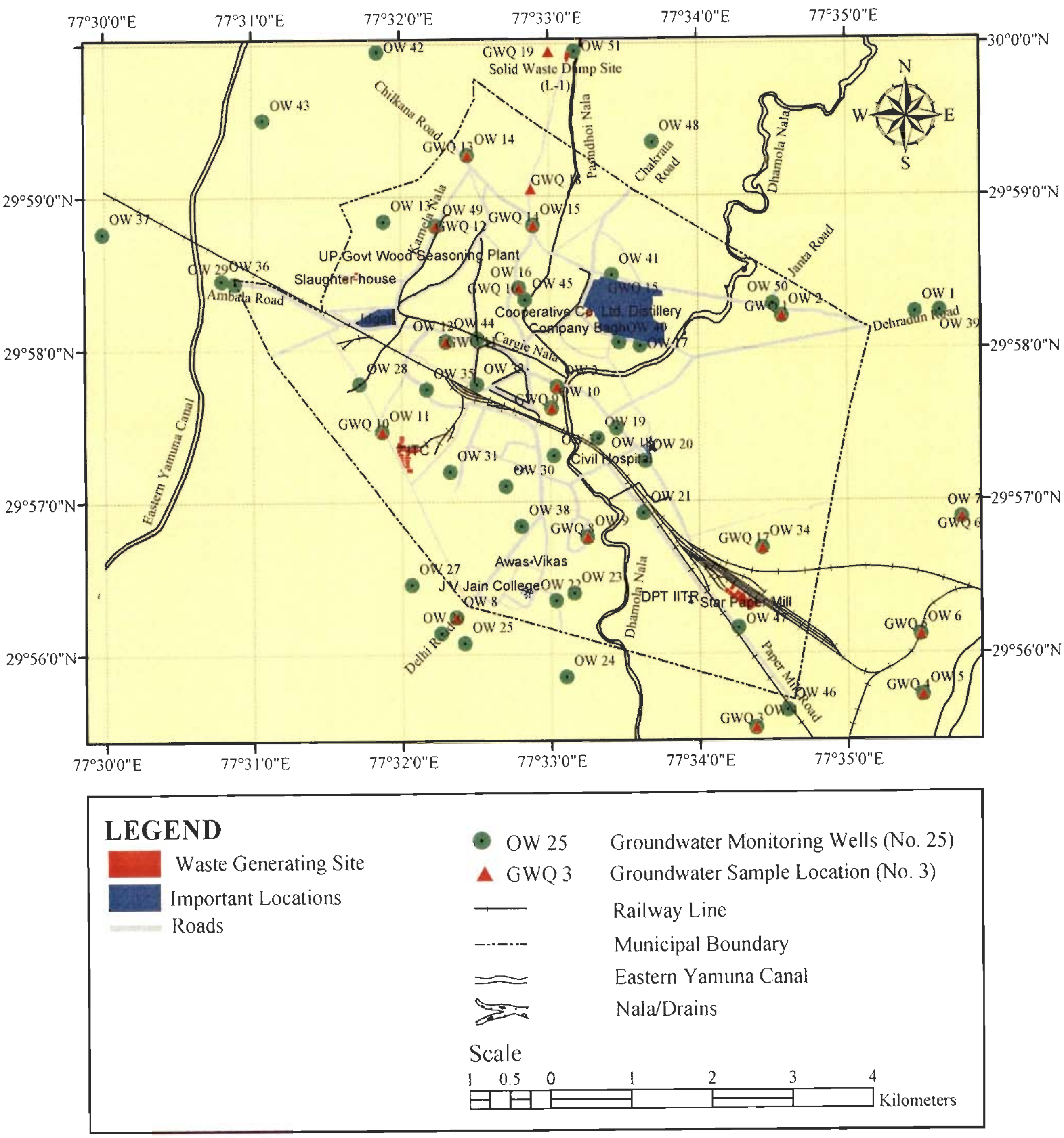


Fig. 1.2; Index Map of Saharanpur Town

Table 1.2(A) Climatic data of Saharanpur city for years 2004 (after Horticulture Exp. & Training Centre, Agriculture Deptt, U.P.2006)

Month	Average Air Temperature in °C		Rainfall in mm.	Average Relative Humidity in %	
	max.	min.		max.	min.
January	20.9	8.3	59.8	95.6	62.9
February	17.1	9.4	12.0	67.4	25.5
March	32.0	15.0	0.0	82.5	28.7
April	35.9	20.0	35.9	60.0	26.6
May	37.8	22.9	2.0	51.0	26.7
June	34.9	24.3	30.9	78.0	42.5
July	34.8	26.0	7.4	83.5	61.1
August	31.0	24.9	326.7	93.1	75.0
September	33.2	30.6	27.6	90.7	58.3
October	29.5	16.3	27.0	93.3	47.8
November	26.4	11.3	3.0	93.9	49.0
December	21.9	8.6	2.8	94.6	51.4
Average	29.6	18.1	(Annual) 535.1	82.0	46.3

Table 1.2(B) Climatic data of Saharanpur city for years 2006 (after Horticulture Exp. & Training Centre, Agriculture Deptt, U.P.2006)

Month	Average Air Temperature in °C		Rainfall in mm.	Average Relative Humidity in %	
	max.	min.		max.	min.
January	25.9	4.3	7.2	94.5	52.4
February	27.5	12.5	0.3	91.0	42.6
March	28.4	14.3	48.4	83.6	42.0
April	35.6	18.4	0.0	60.4	23.4
May	36.8	24.7	47.2	68.5	41.7
June	36.6	24.5	25.3	73.9	45.3
July	33.1	26.2	224.5	88.1	72.1
August	34.0	25.5	100.0	88.0	65.2
September	32.5	23.5	30.3	87.9	58.8
October	31.8	18.0	14.5	88.5	45.7
November	26.7	12.2	1.0	93.4	51.4
December	22.2	7.9	7.0	92.5	50.7
Average	30.9	17.7	(Annual)505.6	84.2	49.3

A review of hydrometeorological data (Tables 1.1 & 1.2(A) and 1.2(B)) indicates that during the last 50 years or so, there was a sharp decline in the annual rainfall from the average of 936 mm to about 535 mm in 2004 and 506 mm in 2006 and increase in mean relative humidity from about 69% to about 82% and 84% respectively. The temperature pattern, however , appears to have remained unchanged on an average basis.

A perusal of tables 1.1 & 1.2(A) & (B) shows that the mean air temperature begins to rise from around 4-6°C in January reaching a maximum of 37 – 39 °C during the months of May/ June. With the commencement of monsoon season (by the end of June) the temperature goes down. During the winter season (November to February) the temperature varies between 26° C to 6° C.

July – August are the months of maximum rainfall. The seasonal rainfall occurring in the area is due to onset of southwest monsoon. The total annual rainfall experienced in 2004 (Table 1.2(A)) was 535 mm out of which about 60 percent occurred during the month of August. The rest of the rainfall occured due to winter monsoon and due to local changes in the weather conditions.

The relative humidity recorded at Roorkee is highest during monsoon season. The lowest humidity is observed in the month of May and highest in the months of August & January, in general. However, the relative humidity has gone up by 12 – 14% during the last fifty years.

The mean monthly wind velocity is highest during the summer season when it goes upto 5.0 km/hour in the month of May and the minimum wind velocity (of the order of 1.0 km/hr) is observed during winters in the month of November. The potential evapotranspiration is maximum (around 200 mm) in the month of May and minimum (43 mm) in the month of January (Table 1.1).

1.3.2 Soils

The Saharanpur area is comprised of alluvial soils, which contain unconsolidated fluviatile sediments that are comprised of sandy loam to silty loam. Generally, silty to sandy loam is observed at surface in most parts of the town. In some parts of the area, clayey soil is also encountered.

1.3.3 Agriculture

The main agricultural crops in and around Saharanpur town are paddy in Kharif season (July-October) and wheat in Rabi season (winter). Further, sugarcane is grown in some areas during the whole year. The town and its environs are famous for its fruit-orchards and nurseries, the common fruits being mango, laukat, guava other seasonal fruits.

Near the city area of Saharanpur, Kharif-Rabi double crop farming is practiced by farmers, i.e. rice, maize, groundnuts, green vegetables, and fruits. Vegetables like brinjal, lemon, and cucumber are quite common crops.

1.3.4 Socio-economic and Demographic Aspects

Saharanpur city is a multi-functional city. It is primarily a commercial and industrial city, and is also the district headquarter. Its location in the fertile Ganga plain, high accessibility to Punjab, Haryana, and hilly districts of Uttaranchal determine the number and complexity of its functions, and have enlarged its regional character.

The salient demographic features of Saharanpur town area are presented in Tables 1.3 to 1.5. A perusal of Table 1.3 indicates that the total urban area of Saharanpur town increased at the rate of 3.53% per year during the period 1973 to 1983 and at the rate of 4.06% during the period 1993- 2003. Thus, the total area of the city became 2340 hectares during 2003. Further the population of the city increased from 238195 in 1973 to 468074 in 2003, indicating a 3.4% growth in the decade (1993 - 2003) (Table 1.4). Besides, the population density grew to 131 persons per hectare in 2003 (Table 1.5) from 100 per hectare in 1971.

Table 1.3; Urban growth of Saharanpur city from 1973 to 2003(after Garg, 2006)

Sl. No	Year	Data Source	Built-up area in hectares	Urban growth	% Growth	% Growth per annum
1	1973	Topographical map	1110.2	-	-	-
2	1983	Guide map	1502.0	391.8	35.3	3.53
3	1993	Aerial photograph	1685.0	183.0	12.2	2.44
4	1998	Field updating	1945.9	260.9	15.5	3.10
5	2003	IRS-IC (PAN)	2340.1	394.2	20.3	4.06

Table 1.4; Urban growth and population growth of Saharanpur city (after Garg, 2006)

Year	Urban population	Population growth	% Urban population growth year	Urban built-up area in hectare	Urban built-up growth	Population density (people /hectare)	Land in hectare per 1000 persons
1973	238195	-	-	1110.2	-	215	4.66
1983	309703	71508	3.00	1502.0	35.3	206	4.85
1993	348694	38991	1.268	1685.0	12.2	207	4.83
2003	468074	68594	3.40	2340.1	20.3	200	5.00

Table 1.5; Population density in Saharanpur city (after Garg, 2006)

Year	Area in hectare	Population	Population density / hectare
1941	1225.0	105622	86
1971	2266.0	225396	100
1981	2358.1	294391	125
1991	3000.2	373904	125
2001	3479.8	455754	131

1.3.5 Industrial Development

Saharanpur city is significant for agro-based and forest-based industries, which form an important ingredient of its economic structure. The city is highly industrialized, as it is evident from the fact that 15 percent workers of the city are industrial workers. Here, household industries also play an important role in its economic structure. The city has one large paper mill known as Star Paper Mill. It depends for its raw material on its own forests, situated in the nearby Siwalik area. It has one cigarette factory unit with the brand name of Indian Tobacco Company.

The commodities of the city can be grouped put into four main categories:-

(i) Agro-based products, (ii) Forest-based products, (iii) Industrial products, (iv) Animal based products.

(i) **Agro–based products -** Saharanpur city is the leading commercial centre for rice, maize, groundnuts, green vegetables, and fruits. Saharanpur city is very familiar for the trade of the famous brand of Basmati rice. It has a number of rice mills, scattered in the northern part of the city. It is the main collection centre of groundnuts. It has become an important centre of mangoes and vegetables like brinjal and lemon. Saharanpur city is the trade centre of sugar, jaggery (gur) and loaf-sugar (khandsari). It is also famous for cotton cloth, hosiery goods, and cigarettes.

(ii) **Forest-based products-** The city is popular for wooden handicraft items. It is also the trade centre for manufacturing various kinds of paper which is supplied to different parts of the country. Saharanpur city is also known for furniture goods.

(iv) **Industrial products-** Saharanpur deals in the wholesale trade of engineering goods, machines, wine and alcohol, ayurvedic and herbal medicines, stationery goods, hand pumps, plywood, plastic made goods, electrical equipment.

(iv) **Animal based products-** Saharanpur has gained recently its familiarity for leather goods. It is also known for the trade of meat. Milk products like- cheese, raw milk are sent from here to nearly and distant places.

The main industrial units functioning in Saharanpur town are listed in Table 1.5

Table 1.6; Nature of industrial units in Saharanpur town

Major and medium Industries	Paper, tobacco, textile, food processing, distillery and meat product.
Small Scale Industries	Electroplating, Paper and card board, steel rolling, rubber, and chemicals

1.4 Review of Previous work in the Area

Geological and geohydrological studies of Saharanpur area have been attempted in past by a few investigators. The systematic geological mapping of Saharanpur district was carried out by officers of Geological Survey of India viz. Shah (1965 – 66) and others. Raghav Rao (1965) described the geology and groundwater conditions of Saharanpur district in his Ph.D. dissertation. Pandey et al. (1968) in the description of groundwater resources of Tarai-Bhabhar belts and intermontane Doon valley of western Uttar Pradesh have described the regional hydrogeological frame-work of Saharanpur area. Further, Sastri et al. (1971) described the regional frame work of the area and indicated that Saharanpur is located on the northwestern periphery of Haridwar-Delhi ridge.

Water balance studies in some part of the district have also been included in the hydrogeological studies of upper Yamuna Project by Bhatnagar et al. (1977). Bhatnagar et al. (1983) carried out hydrogeological mapping of Bhabhar zone in Upper Yamuna Basin including areas of Saharanpur district. U.P. State Groundwater investigation organization (1983) made an extensive water balance study for Yamuna-Hindon Doab (interfluve) and estimated specific yield of aquifers in the western part of the Uttar Pradesh from various methods. They also calculated hydraulic characteristics of the aquifer by analyzing pumping test data and reported data of chemical analysis of shallow groundwater of the area.

Mathew (1983) estimated the transmissivity of the aquifers by using the surface resistivity sounding data and compared these values with the field transmissivity values computed from analysis of pumping test data of nearby tubewells. Murali (1984) studied the geomorphology and land use of upper Hindon basin around Saharanpur town. Sinha (1984) carried out Geoelectrical and hydrogeochemical studies of a part of upper Hindon basin Saharanpur district. Sriniwas and Singhal (1985) estimated transmissivity and hydraulic conductivity of aquifers of U.P. including parts of Saharanpur district, from the interpreted results of surface resistivity sounding data taken by Mathew (1983).

Khan (1987) calculated the aquifer parameters of alluvial sandy aquifers of Yamuna-Hindon Doab of Uttar Pradesh (India), using grain size parameters and compared the same with hydraulic conductivity values obtained from the analysis of pumping test data. He also evaluated the chemical character of the groundwater in the area using principal component analysis and factor analysis. Joshi (1987) presented hydrochemical studies of groundwater in

Saharanpur district. Kumar and Bhatia (1992) examined the groundwater quality variations of dug wells in Saharanpur district and concluded that shallow aquifers are rich in bicarbonates and alkaline earths metals. Barthwal (1996) in his report on "Hydrogeological framework and groundwater resource potential of Saharanpur district" has described the geohydrological conditions of the whole district. Shakeel (1997) studied the relationships amongst the grain size parameters and the aquifer parameters for shallow aquifers of western Uttar Pradesh including Saharanpur district. Verma et al (2000) of National institute of Hydrology, Roorkee have studied soil moisture movement and recharge to groundwater due to monsoon rains and irrigation using tritium tagging technique in Saharanpur district. Rao et al. (2000) have identified aquifer recharge sources and zones in parts of Ganga-Yamuna Doab using environmental isotopes. Kumar et al (2001) determined the saturated hydraulic conductivity in Upper parts of Hindon River catchment with the help of grain size parameters of soil. Hussain (2004) in his Ph.D. dissertation on "Assessment of groundwater vulnerability in an alluvial interfluve using GIS" has also dwelt upon the hydrogeological aspects of Saharanpur district and has suggested some modifications in the methodology of evaluating groundwater vulnerability of alluvial aquifers of Ganga-Yamuna interfluve in western Uttar Pradesh and Uttarakhand states.

Effects of industrial effluents on the water quality of river Hindon in District Saharanpur Uttar Pradesh have been studied by a number of research workers wherein quality of groundwater has also been examined (Patel et al., 1985; Patel, 1985; Reena et al., 1985; Singhal et al., 1987; Seth et al., 1990; Seth, 1993; Seth and Singhal, 1994). Saini et al. (2006) have reported findings of geochemical studies of groundwater in Saharanpur city based on their physicochemical parameters and concluded that chemical weathering is the dominant factor in the overall water chemistry of the area except for the presence of SO_4 which could be attributed to industrial effluents and atmospheric precipitation.

1.5 Scope of Present Work

A review of previous works clearly indicates that though various workers have done different types of studies in and around this industrial township, there are many gaps in our knowledge about the impact of population growth, urbanization and industrialization on the groundwater system. A holistic study in this regard with the following objectives in the present scenario is a cardinal need.

1. Study of Hydrogeological scenario and current land use in Saharanpur city
2. Mapping of areas with significant generation of industrial and municipal wastes
3. Impact of urban development and industrialization on groundwater regime
4. Assessment of groundwater pollution hazards and vulnerability
5. Planning of design guidelines for groundwater protection.

This thesis is, therefore, an attempt in this direction. The results of the study are presented in seven chapters.

After introducing the subject of study in Chapter I, Chapter II deals with the regional geology and geohydrological setup of the study area. In Chapter III, the details of geophysical investigations in the study area are described. These include the vertical electrical soundings and induced polarization studies. In Chapter IV, hydrogeology of the study area is explained using available information supplemented by results of geophysical investigations along with groundwater level monitoring. The Chapter V deals with the quality of surface water and groundwater in the study area based on a detailed inventory of polluting sources. Chapter VI presents the results of groundwater vulnerability studies based on the DRASTIC approach. It also attempts to integrate the vulnerable areas with the degraded quality of groundwater to evaluate the relative threat to future groundwater quality along with planning of design guidelines for groundwater protection. Finally, the conclusions and recommendations of the study area are given in Chapter VII.

Chapter 2
REGIONAL GEOLOGY AND GEOHYDROLOGICAL SETUP

2.1 Physiography

The Indo-Gangetic Plains forms a roughly east-west trending major physiographic unit lying just south of the great Himalayan Mountain belt and is bounded in the south by peninsular India. The Indo-Gangetic Plains consist of not only the Plains of Indus and Ganga river system but also of the Brahmaputra river system in the east. This entire tract of alluvium covers an area of about 4,00,000 sq. km. between the Peninsula and Extra-Peninsula of the Indian Subcontinent.

The present area of study is situated in the Ganga-Yamuna Doab Province which is the largest and most densely populated among other provinces of Indo-Gangetic Plains. Doab, a local term, is used for the portion of the land occupied by loose unconsolidated alluvium deposit bounded on its two sides by major rivers. The Ganga-Yamuna Doab Province is bounded by the Yamuna River in the west and the Ganga in the east.

2.2 Geological Setup of the Ganga Basin

The Ganga basin is a basin in which the river Ganga and its tributaries have deposited and continue to deposit sediments. The Ganga basin is a foreland basin which has been formed in the later stages of Himalayan orogeny on the under-thrusting Indian plate and Tibetan plate. In the early Miocene period, the basin was narrow and confined towards north of the present day Frontal Fault. It attained the present day configuration between the Himalayan and the Indian Peninsular shield during the Middle Pleistocene period (Shukla et al., 1994). As the northward drift of India continued, the more consolidated and metamorphosed older strata and the granitic magmas intrusive into them, slided southwards, impelled partly by gravity and partly by compressive forces. The basement surface under this basin is now known to slope down from south to north at an average angle of 1° to 3° but this surface is rather irregular and must locally contain hills and valleys. Both longitudinal and transverse faults are present in the basement and some of them are loci of the earthquakes occasionally felt in the region.

The basin owing its origin to the continent to continent collision has been deformed with a number of linear structural furrows and NE-SW trending ridges (Fig. 2.1). Subsurface geology, stratigraphy and structure of some parts of these plains have been furnished by Evans (1959) and Mathur and Evans (1964). The well-consolidated crust of the shield became engulfed under the light, soft and moist sediments. The salient geological features of this basin are presented below.

2.3 Sedimentary Fill

The neogene sediments encountered in the wells drilled by the Oil and Natural Gas Corporation, India, in the Foreland basin, varies in thickness from 620 to 4800 meters and are covered by the Ganga alluvium (Shukla et al., 1994). They are composed of gravels, sands and clays. The sands and gravels constitute aquifers. The thickness of the alluvium is maximum in the central part of the present day Ganga plain and diminishes both towards north as well as south. Estimates of the thickness of alluvium have ranged from about 15 km (Burrard, 1915) to about 4.5 km (Oldham, 1917). From the results of geophysical exploration and well data now available, it is now certain that the thickness of the alluvium is of the order of a thousand meters, and that it is the Siwalik sediments that constitute the bulk of sediments filling the depressions. These sediments were laid down in the Foreland basin over the floor of older rocks varying in age from Precambrian to Palaeogene. Aero-magnetic surveys of the Ganges basin indicate that the basement rocks lie at a depth of about 7,000 m (Sastri et al., 1971).

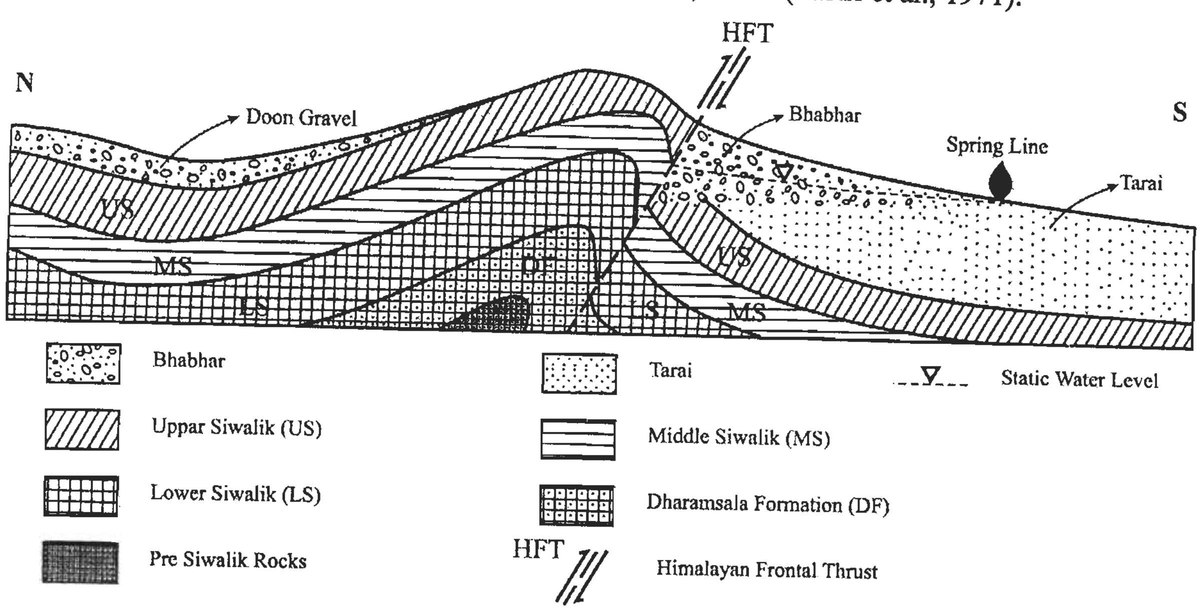


Fig. 2.1; Schematic Geologic Section (modified after Thakur and Pandey, 2004)

To the north, the sediments have a distinct tectonic boundary with the Siwalik Group in the form of Himalayan Frontal Thrust (Thakur and Pandey, 2004). This boundary is conspicuous by a sudden change in topographic relief, slope and surface elevation. Thus, the Ganga basin is characterized by two broad geomorphic units – hilly terrain of the Siwalik Group in the north which overlies the thrust (HFT) and the unconsolidated alluvial Plain forming gentle slope towards south (Fig. 2.1)

2.4 Regional Geological and Geomorphological Framework

Sastri et al. (1971) have mentioned that Saharanpur district is situated over the subsurface Delhi-Haridwar tectonic ridge passing below the Ganga Plain towards its west. The regional geology of the Saharanpur district is broadly shown in Fig. 2.2 and the geological succession is given in Table 2.1 It is observed from the Fig 2.2 that rock formations of Siwalik Supergroup are present in northeastern part of the district whereas the remaining part of the district is covered by alluvial sediments of Ganga plain. The Siwalik Supergroup has been classified into Lower, Middle and Upper Siwaliks. The Siwaliks are differentiated from the early Tertiaries by a pronounced unconformity. These sediments in the fore-deep were subjected to the upheavals during the Upper Pleistocene period due to continued subduction of the Indian plate. The Siwaliks in the northern part were uplifted, deformed and thrust faulted, forming the Frontal Fault and the Himalayan foot hills, whereas, the Siwaliks occurring south of the Frontal Fault, underlying the Ganga alluvium, are gently dipping and thickening towards the north..

In the hilly parts of Saharanpur district towards the northeast (Fig. 2.1), only formations belonging to Upper Siwalik and Middle Siwalik are present with the Lower Siwalik being absent. The Siwalik sedimentary units generally dip towards south with dips of 20° to 60°. The Middle Siwaliks are traversed by a number of major and minor faults resulting in anticlinal structures. As mentioned earlier, the parts of the Saharanpur district, south of the Siwalik foothills, are covered by alluvial sediments containing alluvial fans composed of assorted gravels, boulders, cobbles, pebbles.

Table 2.1; Geological succession in Saharanpur district (modified after Taylor. 1950)

Statigraphic Units		Age	Lithological Constituents
Younger alluvium		Holocene	Sands and clays
Older alluvial Plain		Middle to Pleistocene	Boulders, pebbles, gravel, sands, silt and clay.
Siwalik Supergroup	Upper Siwaliks	Upper Pliocene to Lower Pleistocene	Sandstone with boulders cobbles, conglomerates and assorted clays.
	Middle Siwaliks	Upper Miocene to Lower Pliocene	Sandstone with associated clays and pebbles beds.
	Lower Siwaliks	Upper Miocene to Lower Pliocene	Absent
PreSiwalik Rocks			

Physiographically, Taylor (1950) has divided the Indo-Gangetic Plain into three belts which are named as Bhabhar, Tarai and the Alluvial Plain from north to south in the northern fringes of the Ganga –Brahmaputra Alluvial Province which was designated by him as one of the groundwater provinces of India. The Saharanpur can be divided into four parts viz., Siwalik Hills, the Upper Piedmont (or Bhabhar), the Lower Piedmont (or Tarai) and the Alluvial Plain (Axial Belt) (Fig.2.2).

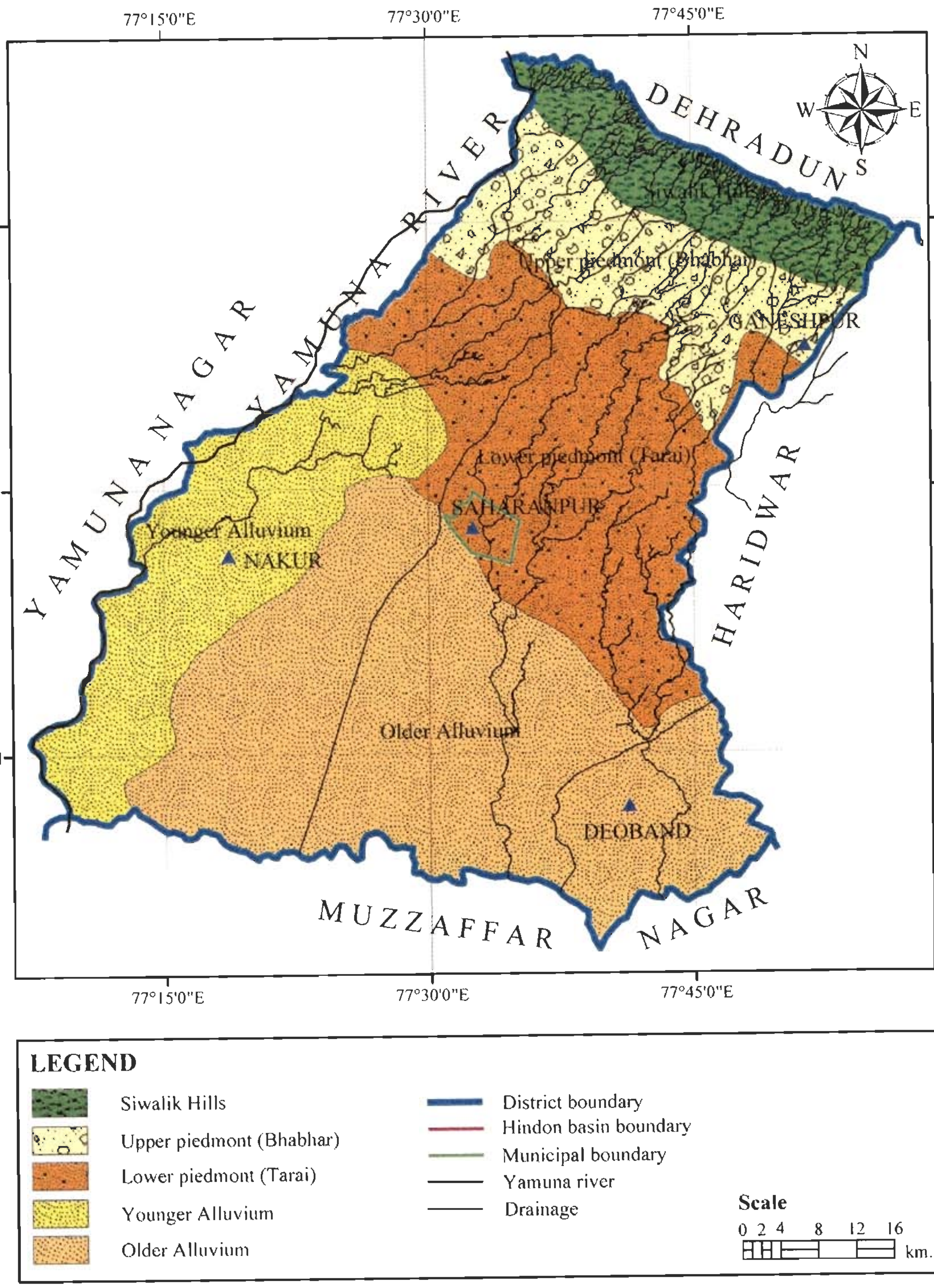


Fig. 2.2; Geomorphological Units of Saharanpur District

2.4.1 Siwalik Hills

The Saharanpur region is bounded in the north by foothills forming southern fringe of roughly east-west trending Himalayas. This unit shows high relief and the deep incised drainage with steep and sharp hill slopes. These hills are characterized by rugged topography and varied lithology, mainly comprising sandstones, claystones, conglomerates, sands, clays and silts. These hills are affected by many major and minor faults (Barthwal, 1996).The Himalayan Frontal Fault – a thrust - separates granular sediments from relatively older rocks of Siwaliks at their south margin

2.4.2 Upper Piedmont (Bhabhar)

This geomorphologic unit lies just south of the Siwalik hills and is locally called as 'Bhabhar'. The Bhabhar is characterized by presence of coarse gravels (boulders, pebble and cobbles etc.) which are relatively dry sedimentary deposits fringing the Siwaliks foot hills towards southwest. Geologically, the term Bhabhar is employed to describe the deposits formed along the foot hill zone by coalescence of series of alluvial cones and fans. This zone is found to be absent in the present study area but due to its southern steep gradient ($\approx$ 5m/km.), its high permeability, acts as a recharging area for the deep aquifers of Saharanpur city (Kumar et al., 2001). The water table in this belt is generally at deeper levels of 30-35 m.bgl. The Bhabar zone is mostly encountered in the Muzaffarabad and Sadauli Qadim blocks of the District.

2.4.3 Lower Piedmont (Tarai Zone)

The Lower Piedmont, locally known as 'Tarai' is characterized by sedimentary deposits consisting of mixture of sand and clay along with the occasional gravels. This zone has shallow water table (with its depth around 3-5 m. bgl). This zone has a plain surface mildly sloping towards south with a gradient of around 1.2 m/km. The boundary between the Tarai and the Bhabhar zone is demarcated by presence of springs forming a linear pattern, commonly known as 'spring line'. The Tarai zone shows flat to gently undulating plains with mild gradients towards south-west and is also characterized by the coalescing alluvial fans.

The Saharanpur town is occupied by the Tarai Zone as manifested by generally shallow water table.

2.4.4 Alluvial Plain

This unit, also called as Axial Belt, is demarcated in northeast by the termination of alluvial fans which grade further down slope into vast alluvial plains. The Alluvial Plain is generally absent in the present study area of Saharanpur town. This Plain is composed of alternations of sand, silt and clays, occasionally containing gravels. The sediments deposited in the plains can be divided into Older alluvial plain and the Younger alluvial plain.

The Older alluvium shows flat undulating topography and was deposited by river Hindon and its tributaries and is found to be present in southern part of the district covering Deoband town etc.

The Younger alluvial plain is found along the beds of river channels and is comprised of coarse grained alluvial deposits of varying lithology (medium to coarse sands) and is characterized by presence of fluvial land forms like point bars, palaeochannels and meanders. This is mainly encountered in the western part of the district mainly around Nakur town (Fig. 2.2)

2.5 Regional Drainage and Hydrogeology

Saharanpur region is a part of the Hindon river basin of Yamuna river system in the Ganga –Yamuna Doab (Fig.2.3) and contains streams originating from the Siwalik Hills which flow downwards in parallel to near parallel courses towards southwest.

Hindon River has two main tributaries in the upper part of the basin viz., Nagdeo and Dhamola. The Nagdev joins the Hindon River nearly in the middle of the Upper Hindon basin and Dhamola joins it near village Sadauli Hariya. Thus, the study area falls in the Dhamola subbasin of the Hindon system. The flow of streams gives rise to dendritic type of a drainage pattern (Fig. 2.3). Murali (1984) has calculated drainage density of Upper Hindin River watershed basin which varies from 0.35 $km.^{-1}$ to 1.8418 $km.^{-1}$. As per the classification proposed by Strahler (1957), the drainage of Upper Hindon River watershed is classified as coarse textured drainage.

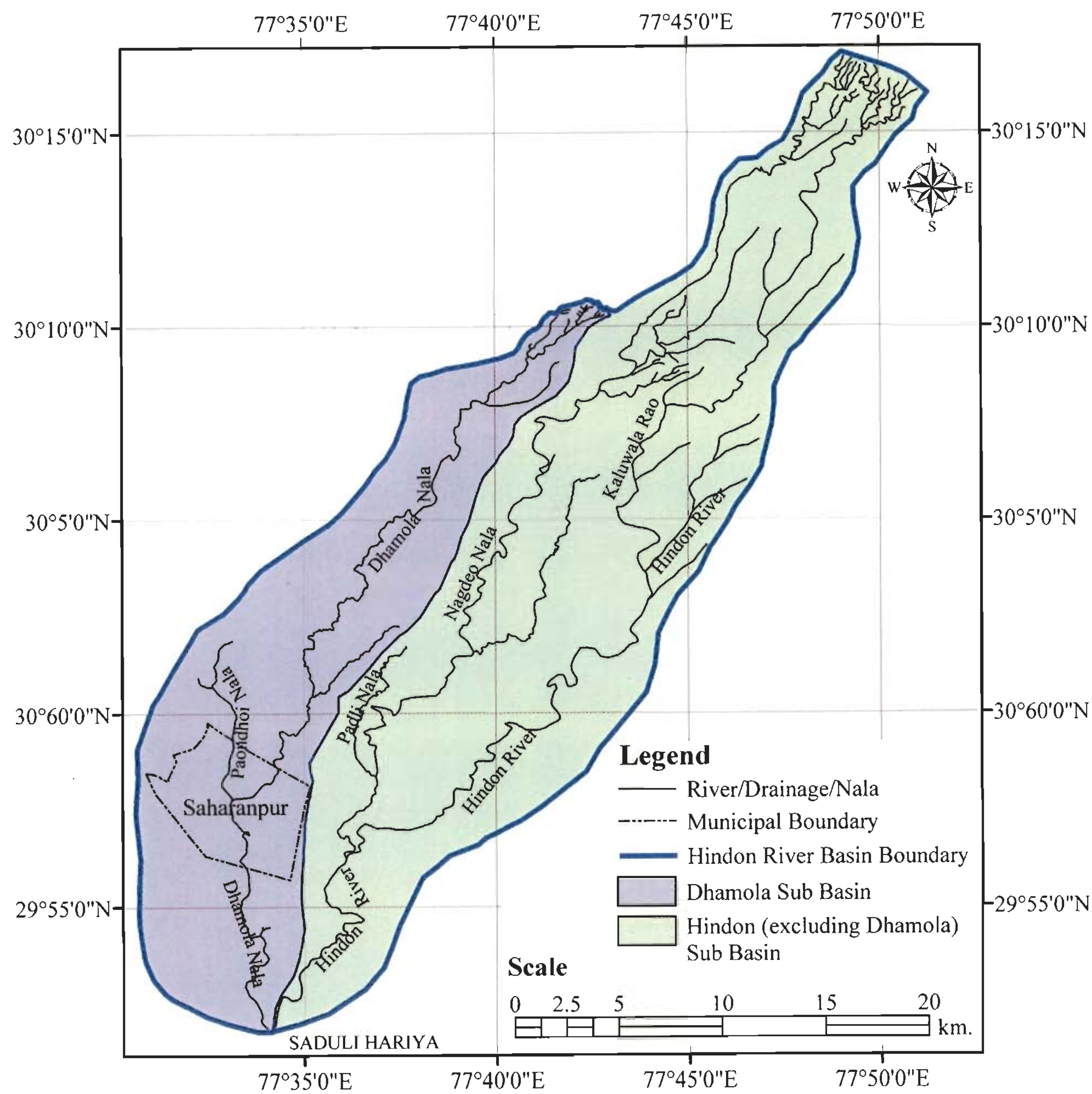


Fig. 2.3; Drainage in Upper Hindon Basin (after Murali, 1984)

2.6 Hydrogeological Conditions

Hydrogeologically, Saharanpur Region, a part of Ganga–Yamuna interfluve, is comprised of alluvial aquifers which overly the rocks of subsurface Siwalik Supergroup. These rocks are also water bearing. In the northeastern parts where Siwaliks rock formations are exposed, the ground water occurs as springs and seepages mainly because of presence of confining clay-stone intercallations within the sandstones of middle Siwaliks. South of the Siwalik rock formations, the Bhabhar zone comprised of assorted gravel along with occasional clay beds allows deep recharge of ground water due to which depth of ground water table deepens upto 36 m below ground level (m bgl). However, some wells located just below the foothills of Siwaliks show shallow water table at depths between 4-9 m bgl which may be due to perched conditions.

The regional water table lies at a depth range 10 to 36 m bgl in the Bhabhar zone indicating thereby high recharging capacity of the gravels present in the Bhabhar zone. Close to the southwestern boundary of the Bhabhar zone, water table shows a sudden shallowing up with its depth varying between 3 m to 12 m bgl. The occurrence of spring line marks the beginning of Tarai zone. This shallow water table continues to occur with in the Saharanpur city in the northern parts. The boundary between Bhabhar zone and Tarai zone seems to pass through Biharigarh area where a number of shallow tubewells yield adequate amount of water for irrigation without installation of any pumping devices. In the northeastern part of Saharanpur town, the depth of water table ranges between 7-10 m bgl where as it is shallower near Yamuna river (between 3-5 m bgl). In Nakur and Gangoh blocks towards southwest, water table is found to occur at deeper levels upto 30 m bgl. In fact, in the area adjoining the Eastern Yamuna canal the water table is found occur at shallow depth of 3-5 m bgl probably because of return flow from canal irrigation.

The water table elevation contour map (Fig. 2.4) available for the Saharanpur district shows a steep water table gradient (2.5 m to 10 m/km in the north) in the Bhabhar zone towards north becoming gentler 0.5 m-1.5 m/km) towards south. The general ground water flow direction is from northeast to southwest and north to south.

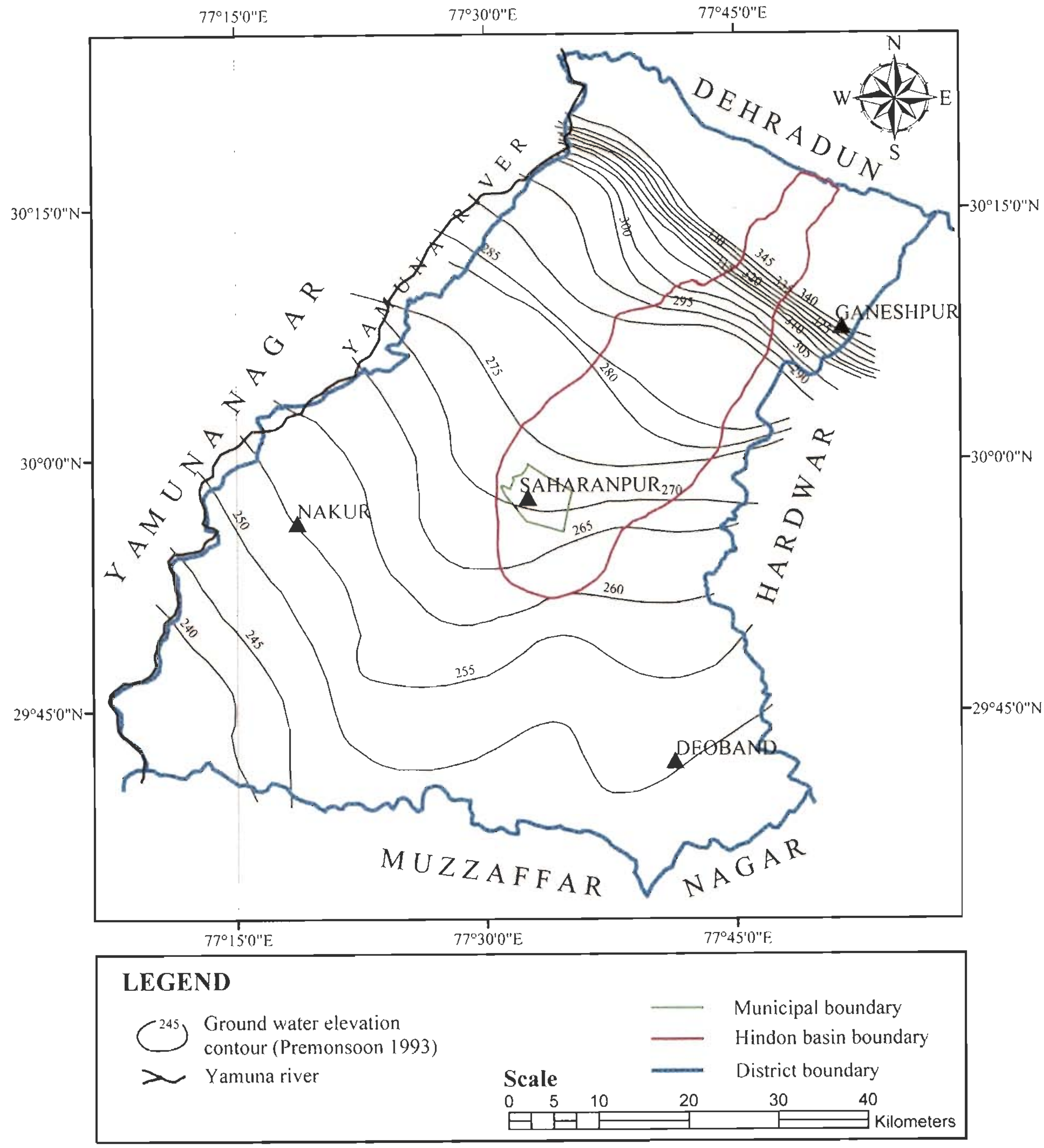


Fig. 2.4; Water Table Elevation Contour Map of Saharanpur District (after Barthwal, 1996)

The water table fluctuation data for the region shows that seasonal fluctuation of water table ranges from 0.10 to 2.5 m for the entire district. The trend of water table fluctuation data over the years shows an overall, yet inconsistent, decline of water table between the period 1988-2004. The decline is especially noticeable in the observation well- hydrographs in the - Baliakheri (Station-Saharanpur), - Nagal (Station-Lakhnauta) and Muzaffarabad blocks (Station - Behat and Khujnawar Majri) in Fig. 2.5 to 2.8. However, in few locations of Muzaffarabad block (Station - Sarsawa and Sunderpur) rising water level trend is also observed in Fig. 2.9 and 2.10.

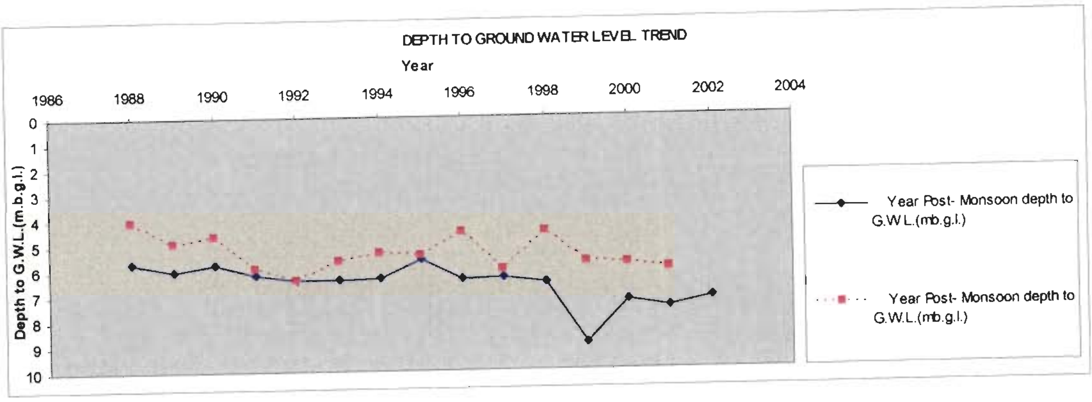


Fig. 2.5; Long Term Depth to Water Level Trend (m bgl) of Monitoring Station – Lakhnauta (Block- Nagal)

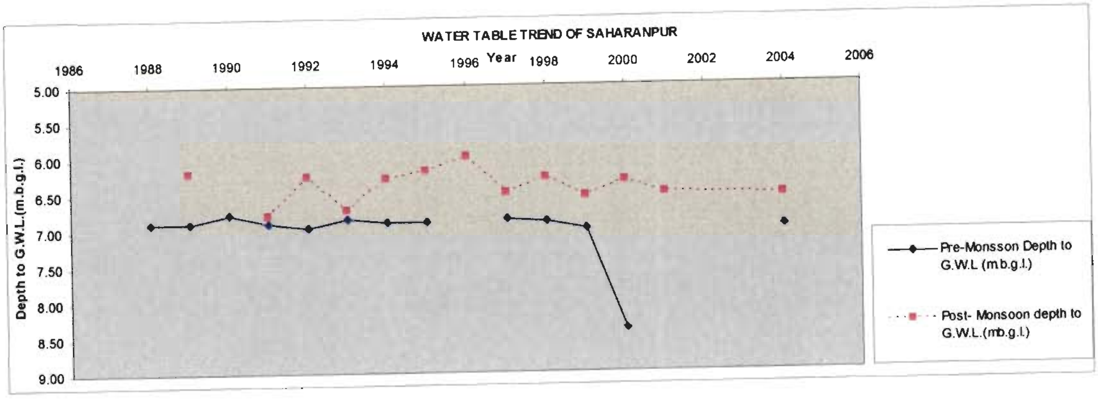


Fig. 2.6; Long Term Depth to Water Level Trend (m bgl) of Monitoring Station – Saharanpur (Block- Baliakheri)

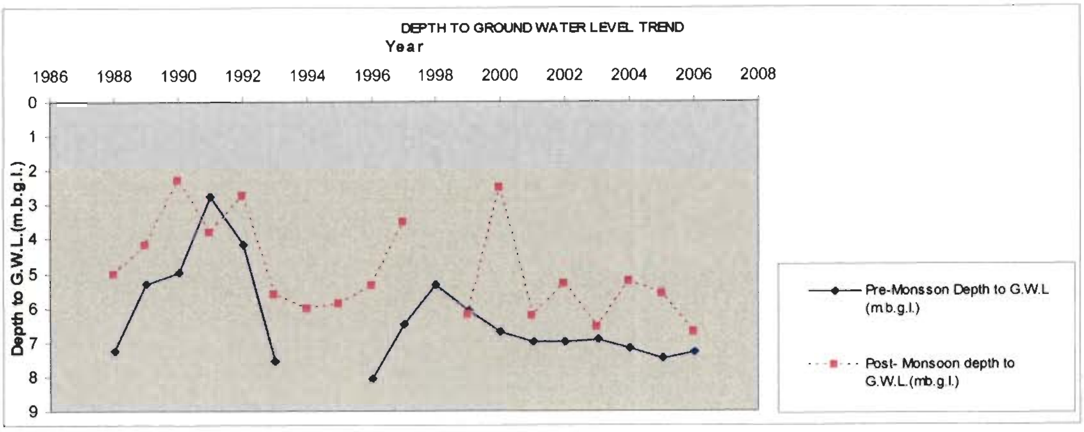


Fig. 2.7; **Long Term Depth to Water Level Trend (m bgl) of Monitoring Station – Behat (Block- Muzaffarabad)**

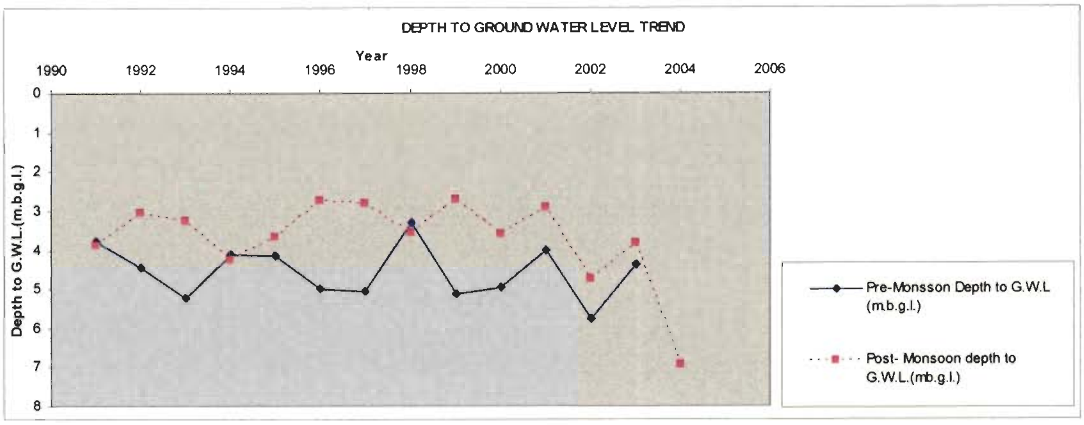


Fig. 2.8; **Long Term Depth to Water Level Trend (m bgl) of Monitoring Station – Khujnawar Majri (Block- Muzaffarabad)**

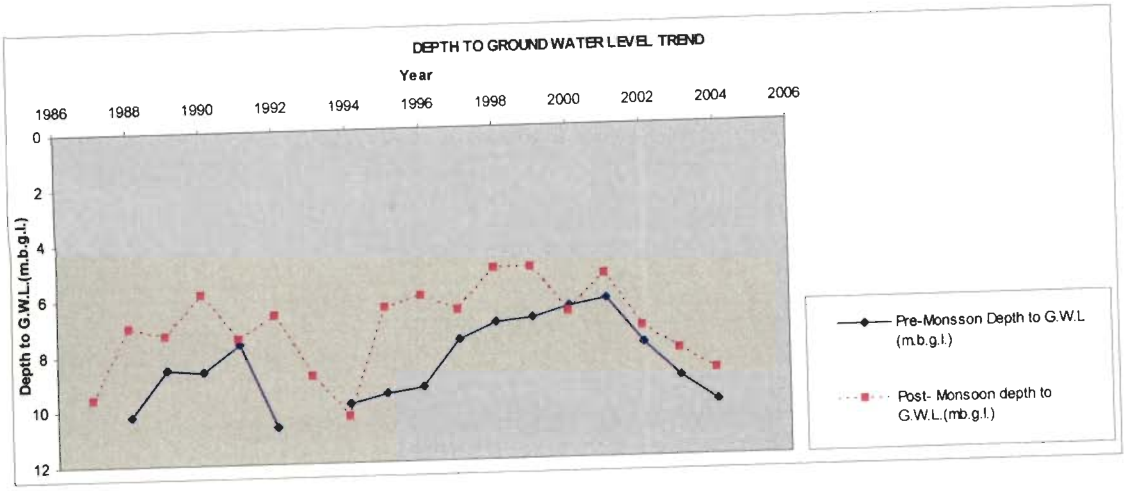


Fig. 2.9; **Long Term Depth to Water Level Trend (m bgl) of Monitoring Station – Sarsawa (Block- Muzaffarabad)**

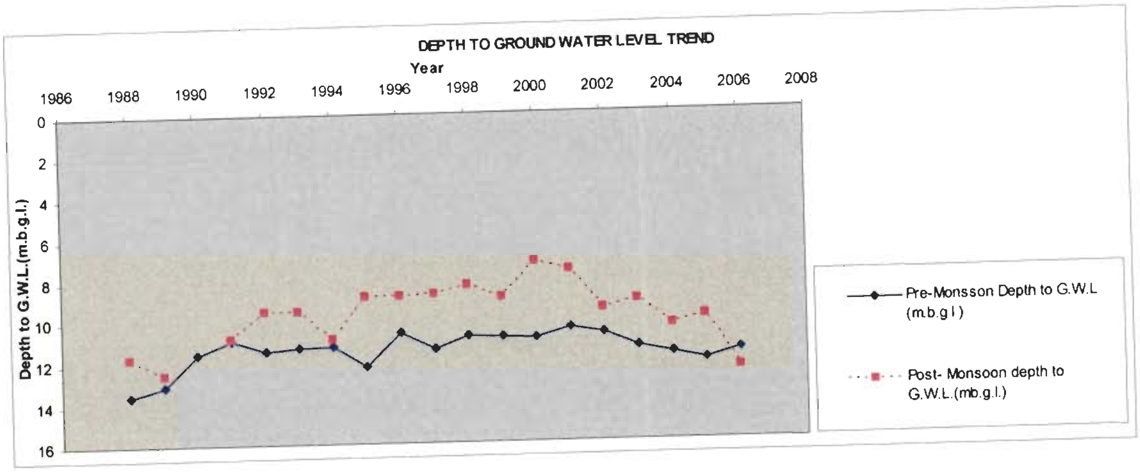


Fig. 2.10; **Long Term Depth to Water Level Trend (m bgl) of Monitoring Station – Sunderpur (Block- Muzaffarabad)**

Available literature for the region indicates that the groundwater recharge to the water table aquifers is mostly from rainfall in the area. However, The recharge to the deeper deeper aquifers takes place both by lateral subsurface percolation from the north and also due to vertical leakage from the overlying aquifers due to heavy pumping (Rao et al., 2000).

The data of exploratory wells and piezometer constructed under the upper Yamuna project indicate that there is a three tier aquifer system in Saharanpur district (Fig 2.11). The first aquifer group is encountered above a depth of 147 m bgl. The second aquifer group starts from 167 into 267 m bgl whereas the third group occurs below 290 m bgl. All the three aquifer groups are separated by thick horizons of clay acting as aquicludes in the Bhabhar zone towards the north of Saharanpur city.

Ganeshpur well drilled by CGWB down shows a water table at a depth of 36.8 m bgl (Fig. 2.4). This tubewell gave a discharge of 1610 lpm at a drawdown of 6.60 meter and the transmissivity of the Ist aquifer in this well was calculated to be 542.6 m^2. per day with permeability of 15.4 meter per day. The middle aquifer system has transmissivity ranges from 775-1050 m^2 per day. The third aquifer group has transmissivity of 1000 m^2 per day with yield of 2400 lpm in the Salempur tubewell.

The groundwater resource potential of the district indicates a safe level of ground water development with the total amount utilizable ground water resource being of the order of 1506 MCM (million cubic meter) with the annual ground water drafts being around 957 MCM (UP GWD, PersonalCommunication). However, these data pertain to year 2001 - 2002 and as such the ground water development scenario may be significantly different under present conditions.

The overall quality of ground water in Saharanpur district is reported to be good to very good with the electrical conductivity around 563µs/cm with the Saharanpur deep tubewell (EC 620µs/cm) indicating good quality of ground water.

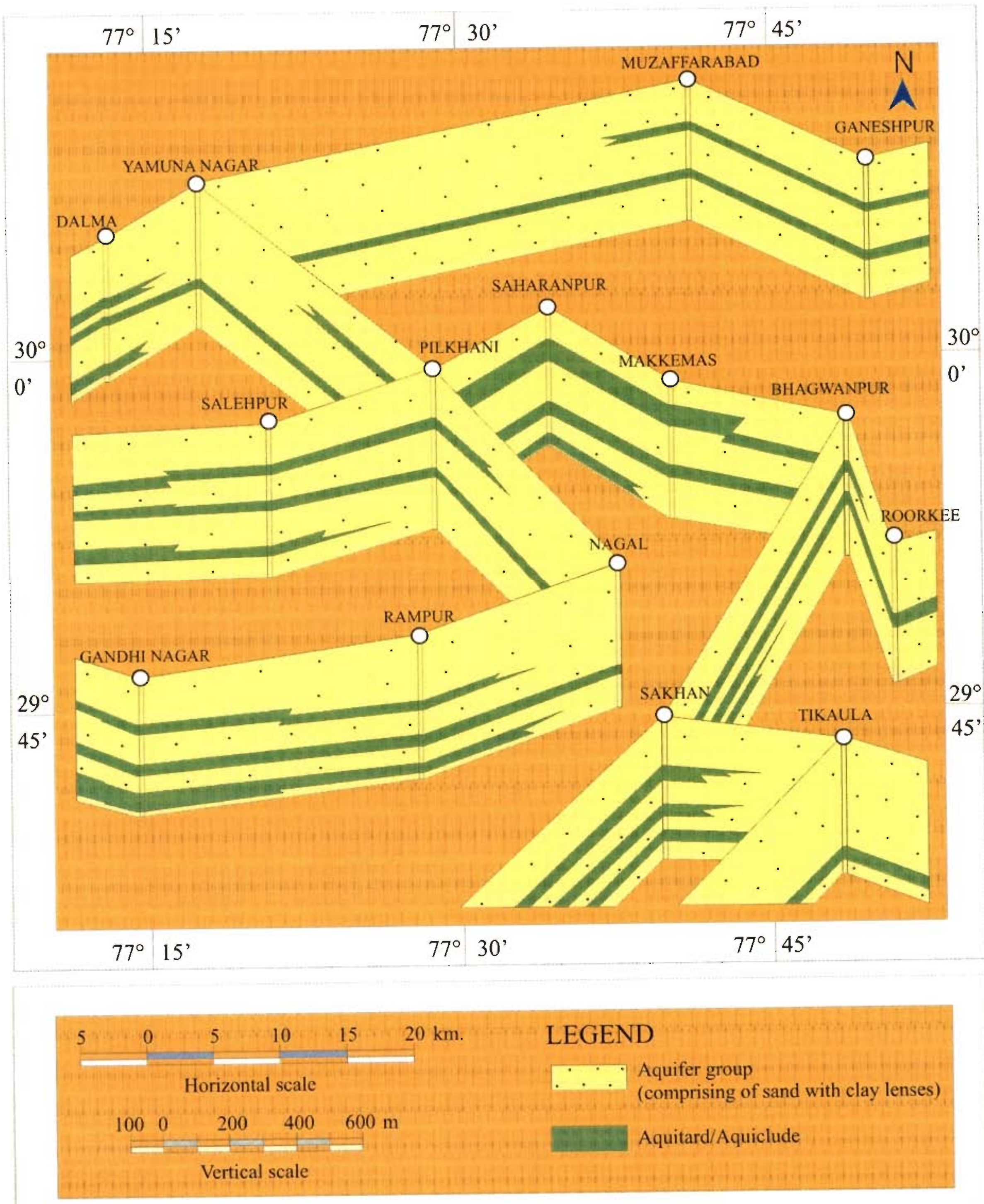


Fig. 2.11: Regional Hydrogeological Fence Diagram(modified after Bhatnagar et al.,1977)

Chapter 3

GEOPHYSICAL STUDIES

3.1 General

The exploration and development of ground water in areas characterized by a variable thickness of unconsolidated alluvium is one of the more difficult tasks faced by hydrogeologists. The problem becomes more acute when there are variations of lithology like clay-sand alternations, often impregnated by kankar. The search for new supplies of ground water in many alluvial areas usually starts with hydrogeological surveys followed by geophysical investigation and ultimate spurt in drilling activity within the prospective areas.

Geophysical methods have been found to be highly useful in ground water exploration. The geoelectrical, seismic, magnetic and gravity prospecting methods can be used to reduce substantially the amount of test drilling and also help in selection of sites for future exploitation of groundwater. The common use of resistivity methods is for determining the thickness of sand and gravel deposits and the depth of bedrock in hard rock terrains. 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 is slight or gradational, the measurements cannot be interpreted with the desired accuracy. This problem is more acute in alluvial areas having deposition of sand-clay alternations.

In regions covered with this veneer of soil, alluvium and/or vegetation, geophysical studies have been found to be very useful in delineating hidden features. The commonly employed geophysical methods in ground water exploration have been electrical resistivity and seismic (refraction) techniques. These methods mainly help in ascertaining, the thickness of unconsolidated overburden and the weathered bedrock. However, the seismic refraction method has a severe limitation that no information can be obtained about a low velocity layer below a dense hard material. Besides, inspite of large amount of specialized equipment and personnel involved in the seismic work, the technique remains an indirect means of locating favourable areas for ground water, in as much as it does not furnish any information about the water quality. On the other hand, the electrical resistivity method provides a fairly good idea about the nature of aquifer, the quality of groundwater, in addition to the depth to bedrock. The low resistivity zones, if any, below a compact bedrock like basalt, can also be detected by this method (Kailasam, 1971; Singhal et al., 1988). Besides, cost of resistivity prospecting is considerably less than that of seismic refraction method. Thus, the electrical resistivity method may even be regarded as more or less a direct means of locating water bearing formations.

3.2 Electrical Resistivity Prospecting

In resistivity prospecting, the electrical resistivity is studied, which is (numerically) equal to the resistance between opposite face of a unit cube of the material and its unit is ohm-m. Electrical resistivity of earth materials varies considerably and has a wide range. The resistivity for certain native metals is as low as 10^{-8} ohm-m while the same for some crystalline rocks is of the order of 10^{4}-10^{8} ohm-m.

The aim of resistivity prospecting with reference to groundwater exploration is to delineate the subsurface layers based on resistivity variation with depth. For this purpose a four point electrode system is employed, where electrodes are placed symmetrically about a central point in a straight line. Direct current (or a low ferequency alternating current ≤ 1 cps) is used to energise the ground galvanically through two outer electrodes and the potential difference is measured between two inner electrodes.

Two most commonly used four electrode systems are Wenner and Schlumberger, named after the distinguished workers in electrical prospecting. The relative accounts of these two systems were discussed by Deepermann (1954) and Kunetz (1966). To obtain information from deeper horizons progressively, the current electrodes are expanded outwardly with respect to the central point. The method is popularly known as vertical electrical sounding (VES) or electrical drilling.

Wenner and Schlumberger arrays are respectively the potential difference and potential gradient measuring devices. In Wenner arrangement, the separation between all the electrodes are always kept equal, whereas in Schlumberger arrangement, the potential electrodes (or measuring electrodes) are kept close to each other in comparison to the current electrode separation. It may be mentioned here that the field procedure is easier with Schlumberger method and the surface inhomogeneities affect the measurement to a lesser degree than with the Wenner arrangement.

It is possible to determine the maximum separation between the measuring (potential) electrodes, which may be used in the Schlumberger arrangement, so that the apparent resistivity will be within a given error limit (= 5 percent). Ordinarily, it is desirable that the current electrode separation should always be more than 4.47 times the spacing between potential electrodes.

In resistivity sounding the potential difference (ΔV) and current strength (I) are observed at each separation and their ratio (= resistance) when multiplied with a suitable geometrical factor (defined for particular electrode system) determines a function called 'apparent resistivity' (ρ_a). Thus

$$\rho_a = K_g.\Delta V/I \quad .. \quad (3.1)$$

where,

K_g is geometrical factor

For Wenner configuration, the geometrical factor

$$K_{gw} = 2\pi a \quad .. \quad (3.2)$$

Where is a interelectrode separation

and for Schlumberger configuration, the geometrical factor

$$K_{gs} = [\pi(L^2 - b^2)]/2b \quad .. \quad (3.3)$$

Where, L is half current electrode separation and

b is half potential electrode separation

The apparent resistivity function is plotted on a log-log graph versus 'L' in Schlumberger and 'a' in Wenner arrangement, respectively.

The interpretation of geoelectric sounding data in terms of geology requires considerable experience with the method of interpretation and a sound knowledge of the geological conditions of the area under consideration. The interpretation, quite often, is based on the pattern of a group of resistivity curves, rather than the shape of a single curve (Kunetz, 1966). The correct interpretation of geoelectric sounding data also requires geological information; both surface and subsurface. Availability of lithological logs of existing boreholes, at selected points, are particularly useful for providing controls and for confirming the results of the geophysical investigation (Sri Niwas and Singhal, 1983). A prior knowledge of the preliminary geology in the surveyed area is also an important prerequisite. For horizontally stratified earth, there is no problem in the choice of the profile for sounding. However, in dipping formations the profile should be kept parallel to their strike. The trends of rivers and stream valleys are occasionally of help in deciding the profile for the geoelectric sounding.

There are wide variations in the resistivity values of different geological material. These values are merely indicative of the order of variations normally met in electrical prospecting and accordingly, should be employed only as a guide.

Table 3.1 ; Electrical Resistivities of Geological Materials and Waters (after Rao, 1975).

Material	**Resistivity (ohm-m)**
Crystalline rocks: Granites, gneisses, and crystalline schists.	200 to 10,000
Consolidated sedimentary rocks: Slates, shales, sandstones, limestones.	100 to 1000
Unconsolidated sedimentary formations: Marls, clays, sands, alluvium and surface soils (other than those in arid regions)	0.5 to 100
Water:	
1. Surface water (in fresh water lakes, rivers etc.)	300 to 500
2. Potable ground water	10 to 100
3. Saline water	0.08 to 0.75

3.2.1 Interpretation of Resistivity Data

The objective of interpretation of resistivity sounding data is to determine the true resistivities and thickness of different layers on theoretical considerations. These results are subsequently used to obtain a realistic picture of the subsurface within the known geological frame work. The former is referred to as quantitative interpretation, while the later is known as geological interpretation. The success of geoelectrical methods depends much on the geological interpretation. There are broadly two different approaches for resistivity data interpretation namely, (1) Manual Approach, and (2) Automatic Approach.

Manual Approach

The quantitative methods are classified as indirect and direct, depending on the manner in which the layer parameters are deduced from field apparent resistivity curves. The quantitative interpretation starts with the numerical evaluation of Stefanescu's equation (1930) or some of its transformed form to give the potential at the surface of earth, the evaluation of which enables the preparation of master curves. In the indirect method of interpretation, the field curve is matched with the standard master curves to obtain layer parameters. However, for the computation of master curves, one has to evaluate the Stefanescu's integral which does not render itself to integration analytically thus posing a basic problem. The success of resistivity interpretation is intimately linked with the successive improvement in the method of efficient numerical integration of Stefanescu's equation. Kunetz (1966) has given a brief account of the various procedures attempted for the solution of the equation. Zohdy (1965), Keller & Frischknecht (1966), Bhattacharya & Patra (1968), and Koefoed (1979) have elegantly described the techniques used in indirect interpretation. The indirect method basically amounts to finding a solution of inverse resistivity problem using trial and error process.

Automatic Approach

Numerically evaluation of the Stefanescu's integral has become feasible with the advent of digital computers. Since 1973, a number of methods of automatic resistivity interpretation have appeared in literature, where decision making regarding the adjustment of layer parameters is made by the software. Koefoed (1979) has given a comprehensive account of various approaches of automatic interpretation of the resistivity data. Koefoed has mentioned two streams of automatic iterative interpretation. The interpretation can be done in the apparent resistivity domain (r-domain) or in the resistivity transform domain (λ-domain). In the r-domain interpretation, comparison is made between the observed apparent resistivity and the theoretically computed apparent resistivity data for trial models, whereas in the λ-domain interpretation, first the resistivity transform function is estimated from the observed apparent resistivity function and then a comparison is made between observed and the computered resistivity transform for trial models (Inman et al., 1973; Zohdy et al., 1974; Bichara & Lakshmanan, 1976; Johnson, 1977; SriNiwas et al., 1982; Zohdy, 1989).

3.2.2 Geological Interpretation

Different terrains offer widely ranging problems in geological interpretation of geoelectric sounding data. In alluvial formations, sand and gravel beds which form good aquifers, are indicated by relatively high resistivity. In case the salinity of the formation water is appreciable, the problem may become complicated, as both clays and sands would show low resistivity values. In such cases, methods of induced polarization (IP) are often found useful as relatively high values of IP are often indicative of presence of increased clay fractions within sandy horizons and vice versa (Roy and Elliot, 1980).

3.3 Combined Induced Polarization (IP) and Resistivity Soundings

The polarization of earth media due to external current either in DC mode (or low frequency mode) when the current is switched off is studied in the IP method (Telford et al., 1976; Parasnis, 1979). The phenomenon is purely transitory in close analogy to induced magnetization phenomenon in magnetic remnance behaviour of rocks and minerals. Earth materials too exhibit remnance in electrical polarization. The main sources of IP can be electrode polarization, membrane polarization, electrofiltration (or electrokinetic) polarization involving electrochemical interactions between nonmetallic mineral grains and the electrolytes. The study of the decaying potential difference as a function of time is known as study of IP in the 'Time Domain'. The ground water studies have often been carried out with the 'time domain IP'.

The main parameters studied in IP studies are the chargeability (Seigel, 1959) and polarizability (Kumarov et al., 1966). The current usage of IP methods favours use of Apparent Chargeability ($\overline{\eta}$) along with Apparent resistivity (ρ_{app}). These two parameters are related as under :

$$\overline{\eta} = \sum_{i=1}^{n} \eta_i \frac{\partial \log \rho_{app}}{\partial \log \rho_i}$$

where, η_i and ρ_i are chargeability and resistivity of the ith material. The final formula used is as under

$$\frac{\overline{\eta}}{\eta_1} = 1 + \sum_{i=2}^{n} \frac{\partial \log \rho_{app}}{\partial \log \rho_i} \left(\frac{\eta_i^{`}}{\eta_1} - 1 \right)$$

If the theoretical expression for ρ_{app} is known, then the corresponding chargeability $(\overline{\eta}/\eta_1)$ can be derived easily.

The techniques of sounding and profiling used in resistivity measurements are also used in the IP method. The IP soundings can be recorded using the Schlumberger (or Wenner) array of electrodes in time domain measurements, and the field data $(\bar{\eta})$ is plotted versus the electrode spacing (AB/2) on log coordinates. The IP sounding curves can be interpreted by curve matching procedures (using IP sounding curves given by Seigel, 1959) or available softwares (like IX1D Interpex Version 3.36). The IP sounding plots can be of significance in complementating a resistivity sounding curve, especially in identifying thin clay layers occurring within sandy horizons.

Roy & Elliot (1980) have described useful application of combined resistivity and IP surveys for delineating saline water and fresh water zones in areas of Canada having sand shale alternations. They have suggested following applications of combined IP and resistivity studies:

1. As simultaneous decrease of apparent resistivity and apparent chargeability indicates salt water presence, integrated IP and Resistivity sounding can be of much help in isolating salt water bearing horizons.
2. Clean sand is marked by resistivity increase and a decrease in chargeability (Electrofiltration) and combined soundings can be diagnostic tool in differentiating different lithologies.
3. As IP method is very sensitive to moisture content in comparison to its counterpart, it can distinguish salt water sands, shales and clays where as they appear as a single medium in resistivity sounding curve. So, IP method is a better resolution tool for lithological demarcation. Cutoff values of 100 Ωm and 3 m sec (or more) have been suggested by Roy & Elliot (Op cit) for New Brunswick area (Canada) for resistivity and chargeability thresholds to distinguish fresh water aquifers (from saline water bearing rocks).
4. As resistivity results from VES alone are not reliable for precision work due to lack of resolution for higher resistivity contrasts, thin beds, great depths, dips etc., combined IP and resistivity sounding is an optimal combination to resolve many of these ambiguities while attempting any hydrogeological or engineering geophysical site investigations.

Field Procedure for IP Surveys

In time domain, a square pulse of current is passed and decaying voltage is measured at preset time intervals during the switch off period. The output voltage is integrated over an interval and divided by the voltage applied to the current electrodes. The amplitudes and duration of pulses are selected in such a way that decay of voltage is over a second before the reverse pulse is transmitted. The standard cycle time is 6 seconds with each on-off period as 2 seconds.

3.4 Geoelectrical Investigations in the Study area

In the present study, it was decided to carry out geoelectrical survey comprised of electrical resistivity and induced polarization soundings so as to achieve following objectives :

(i) To distinguish sandy horizons from the clay-silt layers for delineating the aquifer-aquiclude system in the area.

(ii) In some areas of suspected ground water pollution, it became necessary to delineate zones of contaminated ground water. It was expected that it may be possible to delineate some aquifer(s) contaminated by sewage or industrial effluents.

Keeping in view the above objectives, a total of 32 vertical electrical soundings (VES) were recorded in Saharanpur town with the help of DC resistivity meter (ABEM SAS 300B model) at selected sites shown in Fig. 3.1. Out of these, IP soundings were carried out at 12 VES sites using SAS 1000 model with the VES also being repeated. This also included two VES measurements with orientation perpendicular to the earlier VES recordings in Company bagh (VES No. 1 & 21) and at Pairagpur village (VES 6 & 30). The maximum current electrode separation (AB) was kept at 600 m.

3.4.1 Quantitative Interpretation of Resistivity & I.P. Sounding Data

Preliminary quantitative interpretation of Vertical Electrical Sounding (VES) curves was attempted to interprete true resistivity and thickness manually by conventional curve matching technique using master curves and its auxiliary charts given by Orellana and Moony (1966). For some sounding curves, the curve matching did not yield realistic interpretation. The results were then modified by using IX1D Interpex software (Version 3.36) and the software given by Zohdy (1989). In case the computed curve did not match with the field curve, the initial layer parameters were modified. A gain, the theoretical curve was computed with modified layer

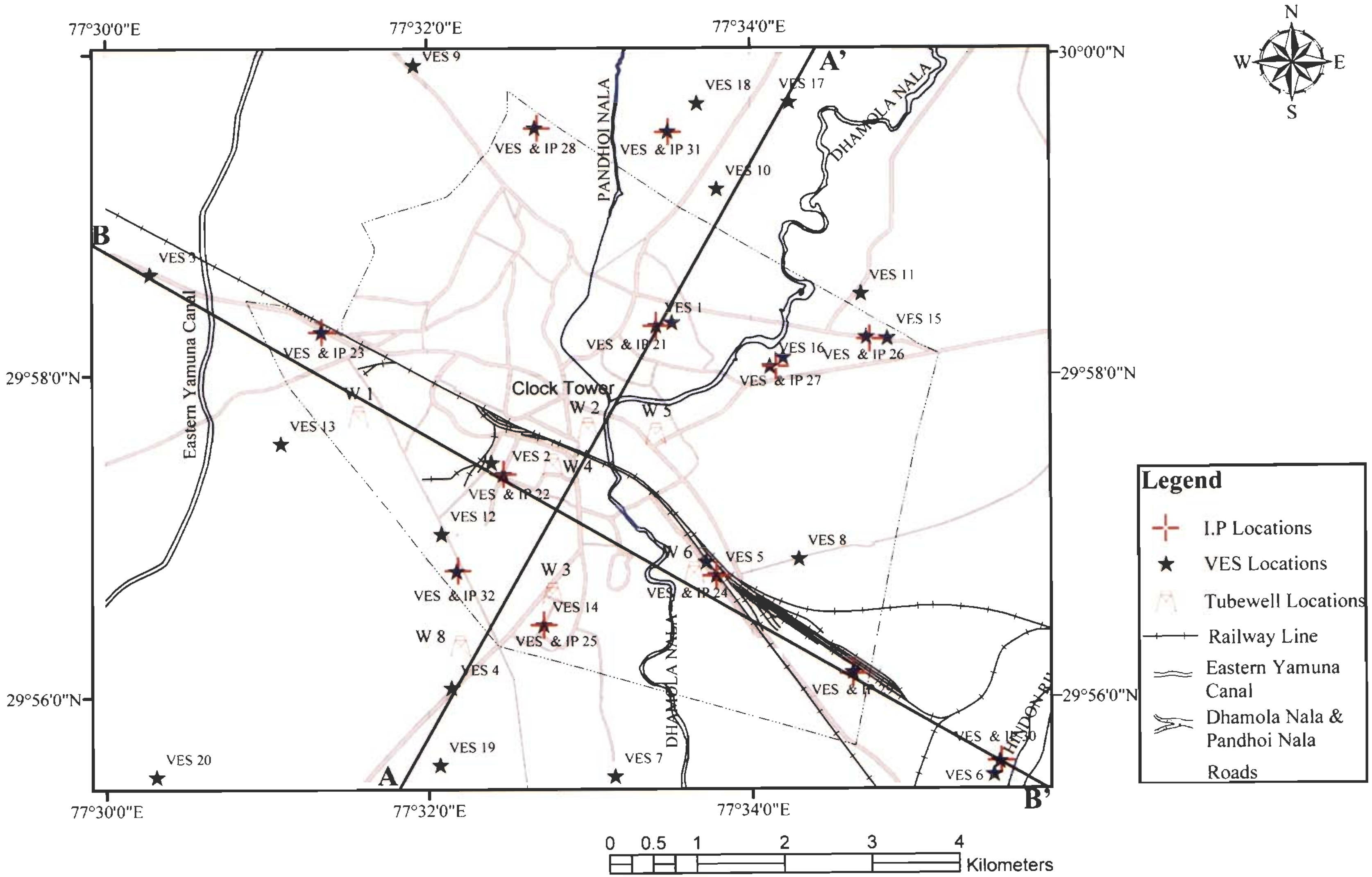


Fig. 3.1; Location Map of VES and IP Soundings

parameters and compared with the field curve. At first the resistivity module of the software is used, and then the interpreted model is taken into account along with the IP data to identify the conductive clayey zones i.e. to separate the unidentified layer, if any, present in case of resistivity. Again the resistivity module is used to further improve the model, so as to match with the known lithology. The process was repeated till a good match was obtained. During the process, the available lithological information was also utilized to arrive at a realistic model.

IX1D software first carries out automatic estimation of a layered model using field data and then the apparent resistivity calculated by manual approach is used to calculate the synthetic curve to minimize the error. The curve is then analyzed to determine the number of layers present and the resistivity and thicknesses in the model. Then, forward modeling is used to calculate the synthetic curve from the estimated model for comparison with the original data.

For Schlumberger data, the offsets between different segments are not removed from the data, but are instead introduced into the synthetics. These offsets occur for overlapping segments where several data points are taken with the same AB/2 values but different MN values. The offsets can be partially due to phenomena related to layered media responses but are in many cases more likely caused by variations in the electrical properties of the ground in the near surface where the potential electrodes are planted.

Masked points are not used in the calculation of the fitting error. The fitting error is displayed on the window status bar as a percent error. Similar logic is followed in case of Induced polarization.

The interpreted geoelectrical data of the area was compared with the lithology of nearby wells and tubewells to fix the range of resistivity and IP for different geological materials, as under (Table 3.2).

Table 3.2 : Resistivity ranges for geological formations in the study area.

Lithology	Resistivity range (Ohm-m)	IP (msec0
Clay	≤ 27	> 3 msec
Clay (sandy)	28-32	
Clayey sand	30-45	
Sand (fine grained)	37-49	uncertain
Sand (medium grained)	49-77	
Sand (coarse)	71-150	
Gravel	> 150	

3.4.2 Geological Interpretation of Resistivity and IP Data

The final results of layered earth model arrived after quantitative interpretation of resistivity and IP data are given in Annexure 3.1(A) to Annexure 3.1(K) and Annexures 3.2(A) to

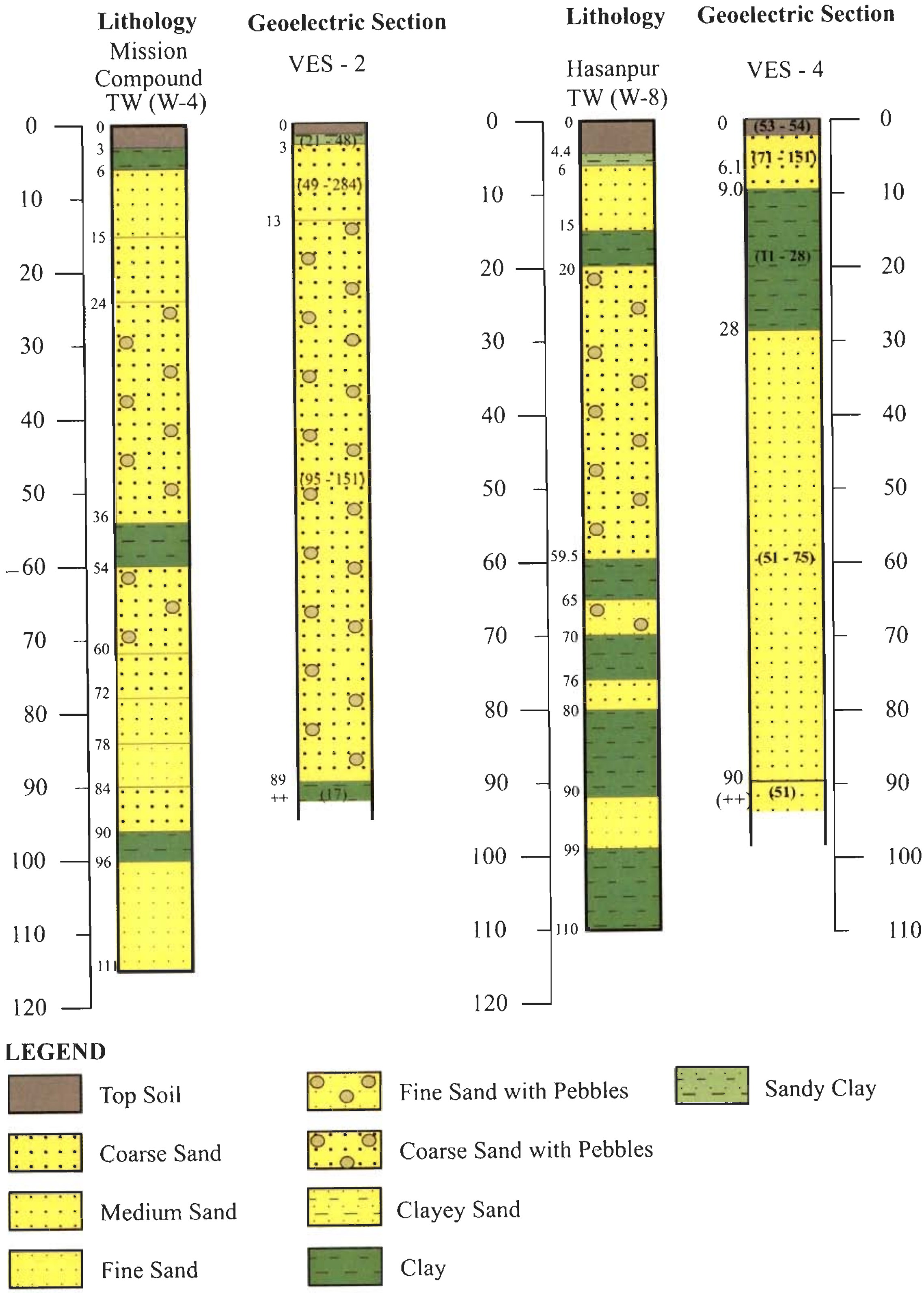
3.2(F) respectively. A perusal of the results has indicated that results of few repeat soundings (VES) are inconsistent with the information available from earlier sounding data due to which two of the data sets had to be ignored (e.g. VES-IP-22 near railway yard and VES-6 at Pairagpur).

Further, examination of the VES data (alongwith IP sounding data) was first carried out at those sites where the lithologs of existing tubewells are available. For comparison, the lithologs of the tubewells alongwith the interpreted VES-IP results are given in Fig. 3.2 (A) to 3.2 (C). It is observed that in general, there is a fairly good match of the observed depth of water table (in the shallow observation wells) vis-à-vis the layered earth model arrived at by quantitative interpretation. However, for arriving at the correlation of individual layers of sands and clays, use of IP sounding interpretation along with resistivity model has been of considerable help. Yet, it is observed that it has been difficult to detect thin clay beds (aquitards) having thickness upto 3 m or so in the interpreted geoelectrical data. Further, wherever, thicker clay beds are present in the lithologs, or amount of clay-silt is increased within the sandy zones, their presence can be ascertained with considerable accuracy. But, at places like VES-4 taken at about 1 km from Hassanpur tubewell (W 8), a notable near surface clay indicated in VES-4 interpretation from 9 m to 28 m depth (19 m thick) was actually found to occur from a depth of 15 to 20 m bgl. (having 5 m thickness) whereas a few other clay layers were reported from the depth of 59 m onwards. The range of error in depth of such detection of such layers is of the order of 30-35%. Accordingly, the depths indicated in the geoelectrical sections would be expected to decrease by 30-35% in the actual litholog. Similarly, the thickness of clayey layers may have to be modified and adjusted in the interpretation.

Based on the overall interpretation of resistivity and IP data, two geoelectrical sections have been prepared along NE-SW and WNW-ESE directions (AA' and BB' profiles respectively, shown in Fig.3.1). The geoelectrical sections (AA') along SSW-NNE direction (Fig. 3.3(A)) has indicated that in general, sandy formations dominate in the section. Further, one sandy horizon with medium to coarse grained sand (resistivity: 53 to 266) is present beneath the water table from the depth of around 13 m to 19 m below which a sandy clay zone (with varying amount of clay) occurs from 19 m onwards. However, in VES-21, this sandy layer has a thickness of 15 m whereas in VES-4 a sizable clay layer appears in the interval 9 to 28 m bgl.

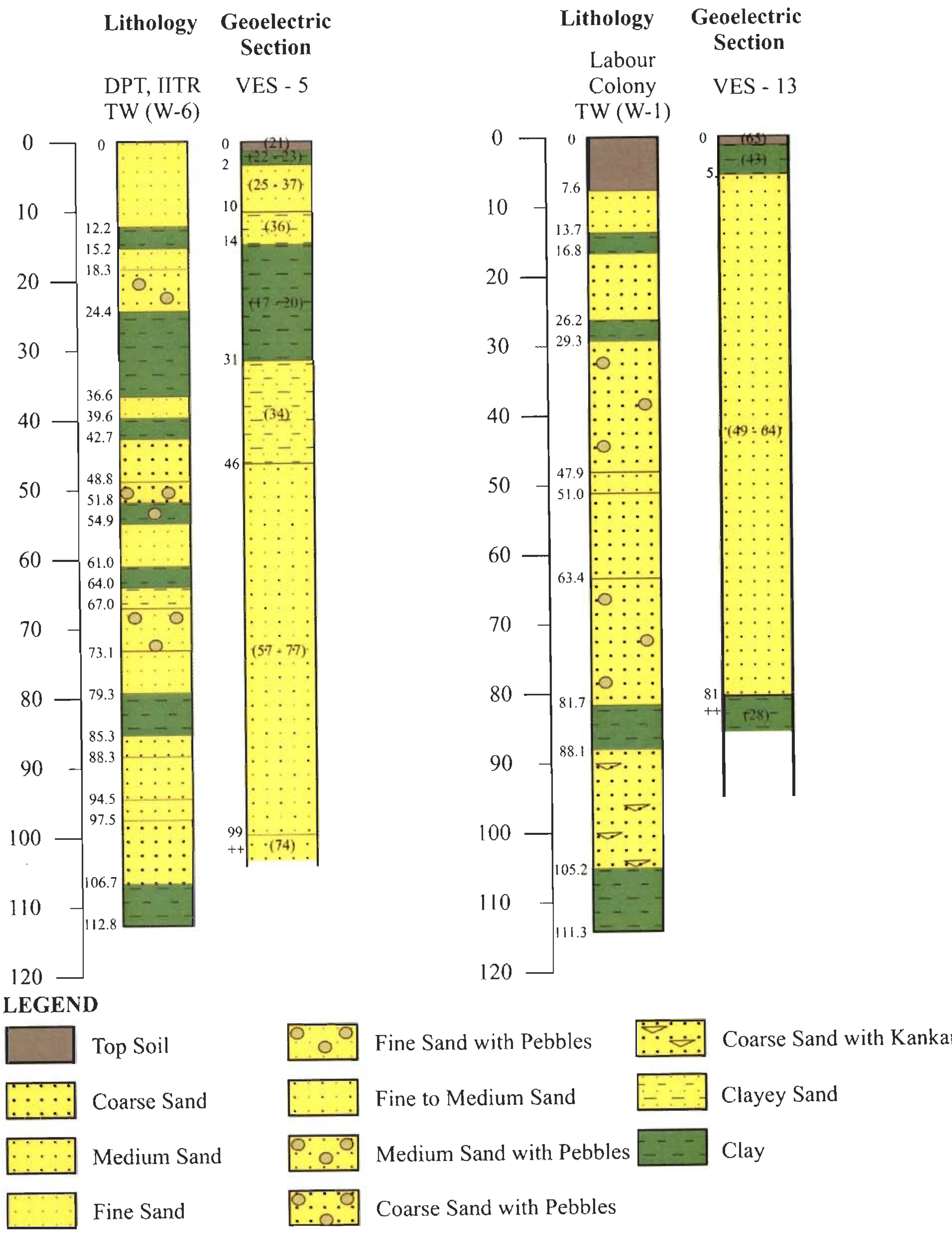
An almost similar situation prevails in geoelectrical section (BB') along NW-SE (Fig. 3.3(B)) with a shallow clay layer indicated towards southeast. The clay layer of about 17-22 m thickness (resistivity: 17-30 Ωm) is indicated to occur in VES-5, 29 & 30 below the depth of about 13 m bgl.

Keeping in view the general trends of lithological variation, the detailed interpretation of the various VES and IP soundings is given in the following paragraphs.



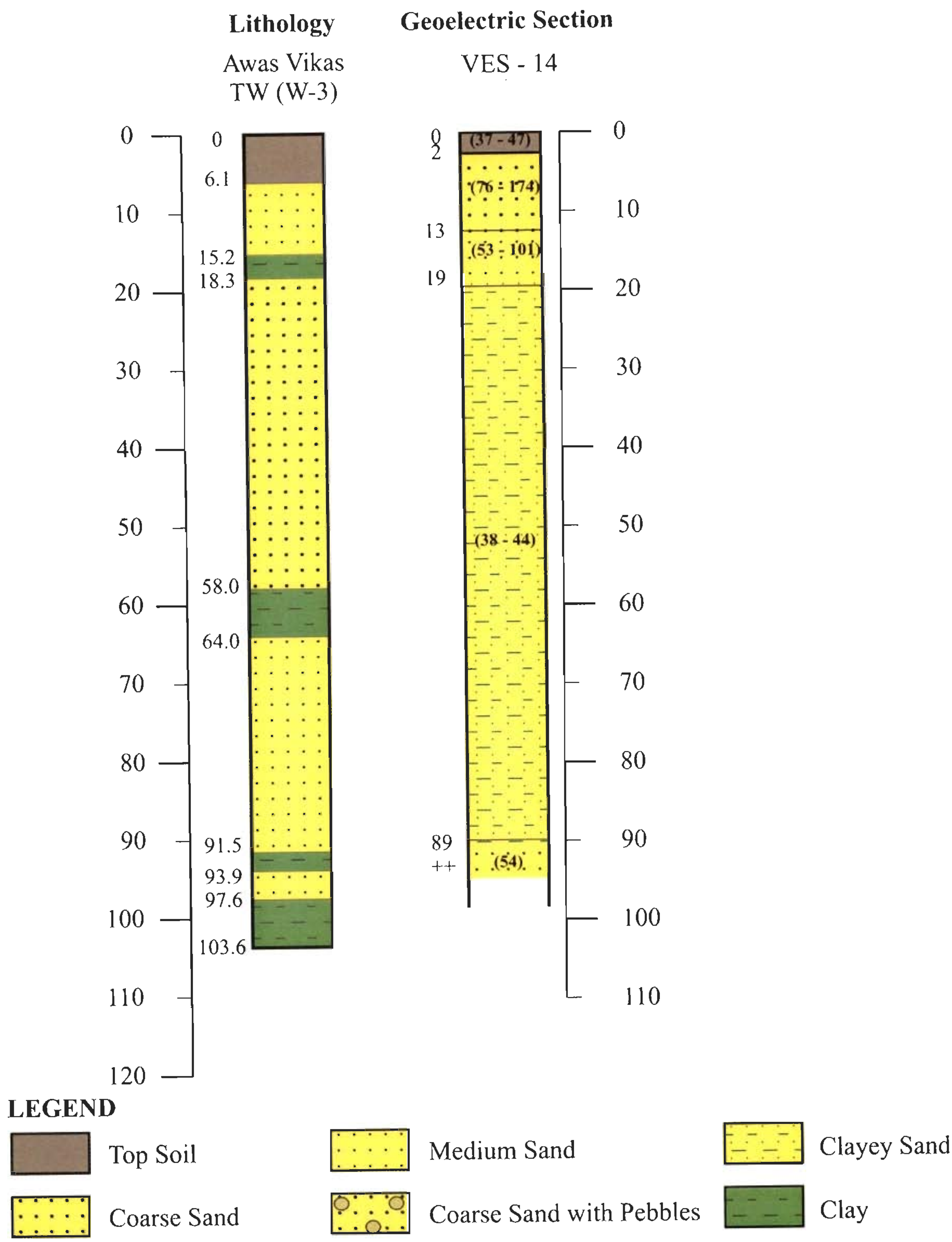
Note : Values in parenthesis in geoelectric sections indicate resistivity range(s) in ohm -m

Fig. 3.2 (A); Comparison of Tubewell Lithologs (TW) with nearby Interpreted Geoelectric Litho-sections (VES)



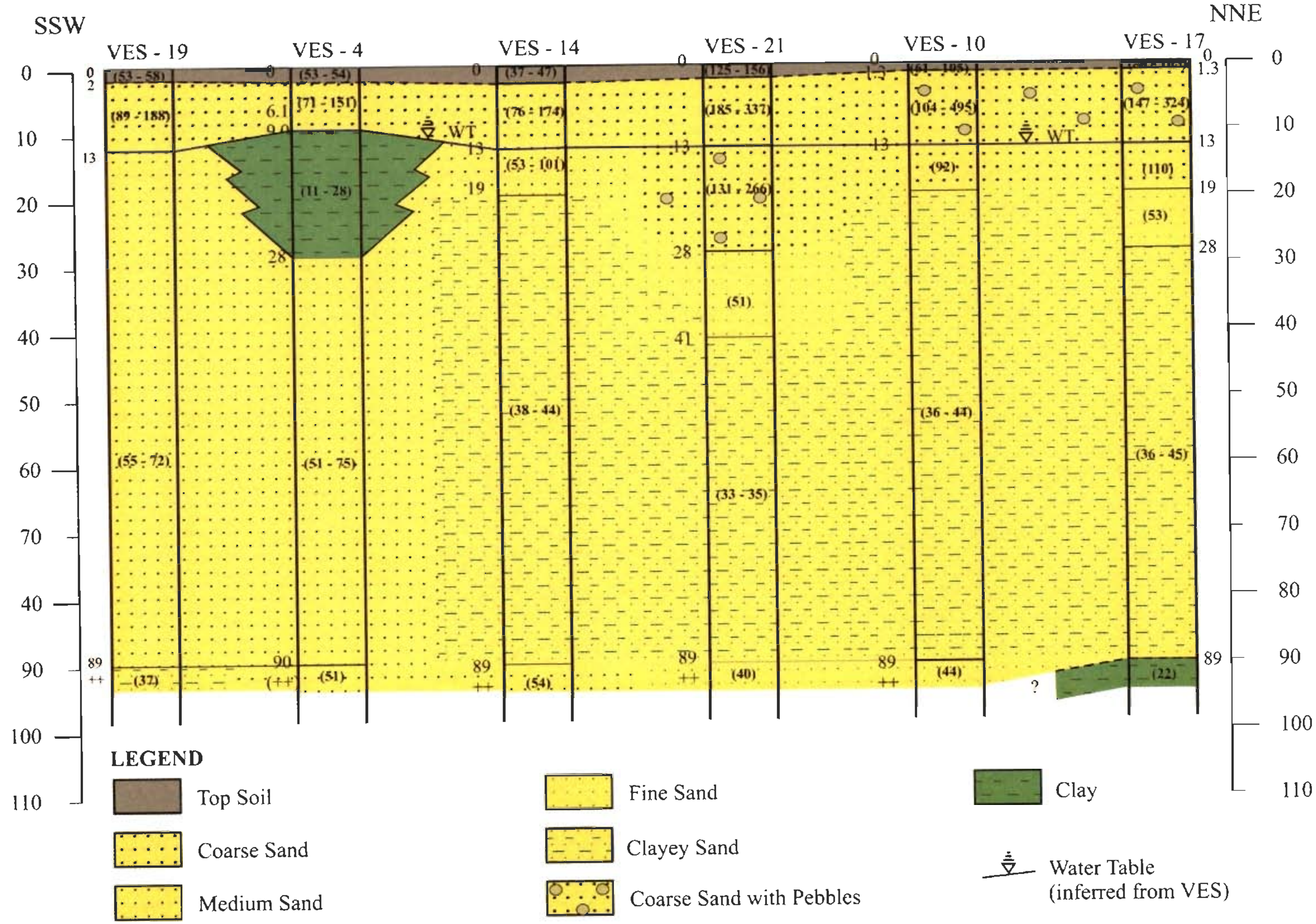
Note : Values in parenthesis in geoelectric section indicate resistivity range(s) in ohm -m

Fig. 3.2 (B); Comparison of Tubewell Lithologs (TW) with nearby Interpreted Geoelectric Litho-sections (VES)



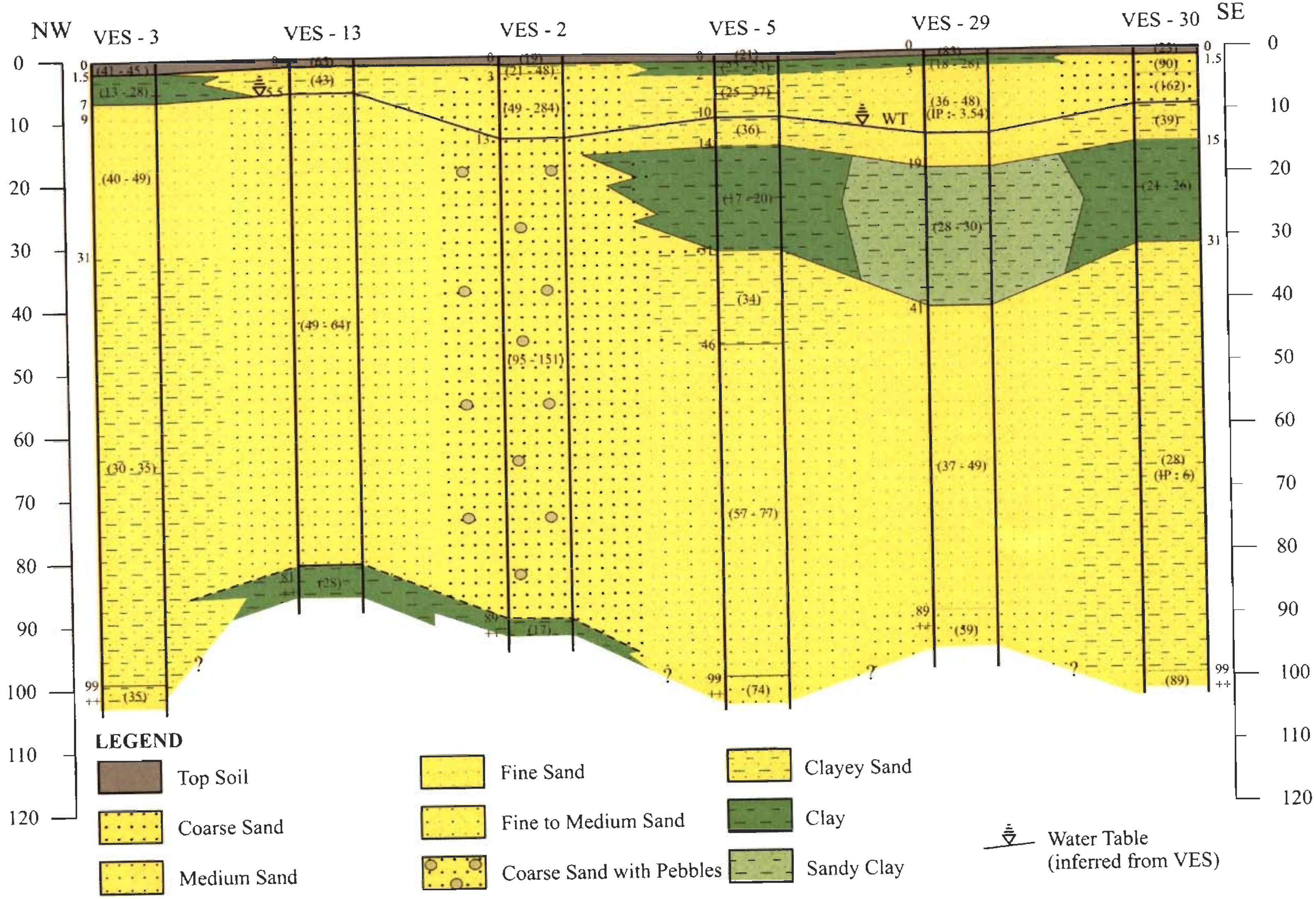
Note : Values in parenthesis in geoelectric section indicate resistivity range(s) in ohm -m

Fig. 3.2 (C); Comparison of Tubewell Litholog (TW) with nearby Interpreted Geoelectric Litho-section (VES)



Note: (1) Values in parentheses indicate resistivity range(s) in ohm-m
(2) Section Line shown in Fig. 3.1 (A)

Fig. 3.3 (A); Geoelectrical Section A-A' (Not to Scale)



Note: (1) Values in parentheses indicate resistivity ranges(s) in ohm-m
(2) Section line shown in Fig. 3.1(B)

Fig. 3.3 (B) Geoelectric Section B-B' (Not to Scale)

3.5 Detailed Interpretation of VES/IP Soundings

VES-IP/21 and VES -1 (Company Bagh)

The interpretation of VES-1 recorded in Company Bagh during summer 2004 indicates presence of dry sand with pebbles (resistivity 100 to 360 Ωm) below the top soil upto a depth of 11.8 meters. Beneath this the KH type of resisting curve shows a decreasing trend with resisting stabilizing around 23 Ωm between the depth interval of 37-55 m. The water table is indicated to occur around a depth of 11.8 m bgl (against actual WT depth of 6 m bgl). The unconfined aquifer occurs between 12 to 25 meters depth (res. 70-212 Ωm) indicating presence of medium to coarse sand with some pebbles. Beneath 55 m depth, a layer of fine sand is indicated upto a depth 80 m which shows a transition into medium sand beneath 80 meters. Near the location of VES-1, another VES/IP 21 sounding was recorded in the month of June 2006 which shows that the resistivity of the unsaturated dry sand is indicated to vary between 185-337 Ωm upto a depth 13 m bgl which seems to pertain to water table. Below the water table, coarse sand with pebble is indicated with resistivity of 131-266 Ωm. This appears to be a good aquifer. Between 28 m and 41 m another layer of fine sand with resistivity of 51 Ωm is present. However, from 41 to 89 m presence of clayey sand (resistivity: 33-35 Ωm) is indicated upto 89 meter depth below which there is a sandy layer of uncertain thickness with resistivity of 40 Ωm.

The data of computed induced polarization model has given negative values of (-42 to 45 m.sec) and has not been used in the interpretation.

VES-2 and VES IP-22 (Railway Yard)

This sounding was recorded near Saharanpur Railway Station in the railway colony premises (Fig. 3.1). The automatic interpretation of VES-2 using Zohdy software indicated presence of a dry sandy layer (49-284 Ωm) upto the depth of 13 m bgl. beneath the top soil which is about 2.8 m thick. Below the dry sand, water table is indicated to be present as shown by steadily decreasing resistivities upto 95 Ωm. The unconfined aquifer is made up of coarse sand with pebble having resistivity between 91-163 Ωm upto a depth of 89 m bgl. Below this sand, a clayey zone having (resistivity: 17 Ωm) is indicated with uncertain thickness.

The observation of VES-IP sounding No. 22 recorded near VES-2 location appeared to be fictitious indicating presence of a highly conductive zone of resistivity 4 -21 Ωm from depth of 7.5 m upto 51 m. This may pertain to a conductor like some type of metallic pipe etc. Accordingly, data of this sounding has not been taken into consideration.

VES-3 (Ambala Road near Post & Telegraph Training Office)

This sounding was recorded near Post & Telegraph Training Office (PTO) along the Saharanpur-Ambala highway (Fig. 3.1). The interpretations of the sounding shows presence of top soil of thickness 1.5 m (resistivity: 41-45 Ωm). This is underlain by a clay of resistivity 13-28 Ωm upto a depth of 7 meters below which a layer of fine sand is present with resistivity of 42 to 49 Ωm upto a depth of 31 m bgl. The presence of water level is indicated around the depth of 7 m bgl. From 31 to 99 m depth and further downwards, clayey sand with resistivity of 32-35 Ωm is present.

VES-4 (ITI)

This sounding was recorded near Vikas Bhawan on Delhi Road. Its location falls close to the Hasanpur tubewell. A 2 meter thick top soil in this sounding is underlain by coarse sand with resistivity of 71-151 Ωm upto a depth of 9 m bgl. which may pertain to water table. The actual depth of water table in the vicinity is around 5 m.bgl. This is underlain by a clay horizon of over 18 m thickness with a resistivity of 11-28 Ωm. However, this clay horizon is reported to be only 5 m in thickness in the nearby Hasanpur tubewell between the depth interval of 10-15 m.bgl. This clay zone is underlain by a sandy horizon of resistivity 51-75 Ωm upto a depth 89 m and more.

VES-5/VES-IP 24 (Himmat Nagar)

This sounding was recorded in Himmat Nagar area in the southeastern part of the study area (Fig.3.1). The nearest tubewell from this sounding is the DPT tubewell in IIT Campus at a distance of about 300 meters. The interpretation of the sounding data indicate presence of a 2 m thick top clay (resistivity 22-23 Ωm) underlain by a sandy clay (resistivity 25-37 Ωm) upto the depth of 10 m bgl. The presence of this clay is confirmed by IP values of 4.6 m sec. in VES-IP 24 (The depth of water table in a nearby well in Brahampuri is about 7.5 m bgl). Beneath the sandy clay, a zone of clay is indicated upto 31 m depth, which is again underlain by a clayey sand of resisting 34 Ωm upto 46 m depth. Below this layer, a thick sandy horizon (57-77 Ωm) is indicated to be present upto the depth of 99 meter and beyond.

The observation of repeat sounding VES 24 do not seem to match with the findings from VES-5 but the IP values at the depth of 7 m bgl and between 40-130 m depth interval seems to confirm presence prolific clayey fractions at this location upto the depth of 99 m and below. This is however, not in agreement with the high resistivity indicated in the VES interpretation. Yet, the available litholog of DPT tubewell drilled in IIT Campus has indicated presence of a number of clay beds upto a depth of 113 m or so. The high values of IP (9.65 m sec) along with low resistivity of 9 Ωm in the depth interval of 40-130 m seem to confirm the occurrence of several clay horizons in this location.

VES-6/VES-IP-30 (Pairagpur)

The field data of this VES (6) has not been considered in the interpretation due to negative resistance value observed after half current electrode separation of 120 m. Instead, data of VES IP-30 recorded in July 2006 has been considered in the interpretation. The interpretation of this sounding data (VES-IP 30) has indicated presence of a thin top soil of 1.5 m thickness underlain by relatively high values of resistivities (90-162 Ωm) upto a depth of 10 meters where water table is indicated to be present (actual it is at 7 m bgl in a nearby well). The unconfined aquifer is indicated to occur between the depth of 10-15 m in clayey sand horizon (resistivity: 30 Ωm). Between the depth of 15-31 m, there is a low resistivity zone (21-26 Ωm) which may pertain to presence of clay or a layer with poor quality ground water. From 31 m downwards, sandy clay is indicated to be present upto 99 m and below with resistivity of 28 Ωm and IP value of 6.0 m.sec indicated in the interpretation model of VES IP-30.

VES-7 (Ram Nagar)

This sounding was recorded in southern part of the study area towards west of Dhamola Nala and shows a K type of field resistivity curve. Its interpretation indicates presence of dry sand (resistivity: 119-391 Ωm) upto a depth of 13 meters after which a sudden decrease in resistivity is noted indicating presence of saturated zone below the depth of 13 meters. The unconfined aquifer seems to occur between the depth interval of 13-41 meters with resistivity between 72-242 Ωm indicating presence of coarse sand with pebbles. Beneath the depth of 41 meters, fine sand with clay is indicated to be present upto 89 m depth. Below this depth, the resistivity values show a sharp decline indicating presence of clay.

VES-8 (Dabki Junardar)

This sounding was recorded in the south-eastern part of the study area (Fig. 3.1) and shows presence of a thin top soil layer of resistivity 76 Ωm underlain by dry unsaturated sand (resistivity: 96-417 Ωm) upto 13 m depth (Actual depth of water table in a well is about 10 m.bgl). Below this depth, saturated zone is indicated with smaller resistivity range of 165-339 Ωm upto 28 m level. Beneath this unconfined aquifer, another layer of fine to medium sand (57 Ωm) is present upto 41 m depth which is underlain by clayey sand (resistivity: 33 Ωm) upto 61 m depth followed by another sandy layer of res. 64 Ωm upto 89 m depth. The bottom layer has a higher resistivity of 147 Ωm indicating presence of coarse sandy horizon.

VES-9 (Halalpur)

This sounding was recorded beyond the northern periphery of study area on Chilkana road (Fig. 4.1). Its interpretation has indicated presence of low resistivity clayey horizons (resistivity: 11-17 Ωm) right from surface downwards upto 14.6 m. with the WT occurring at around 4 m bgl. Further, below this zone a layer of resistivity: 23 Ωm is expected to be present upto 21 m depth, after which the resistivity shows a rise upto 76 Ωm indicating coarsening of the sequence upto 99 m depth and beyond. However, it is difficult to detect the presence of water table in the field resistivity curve due to its mild 'A' type shape.

VES-10 (Arya Nagar)

Recorded in the northern part of the study area (Fig. 3.1), this sounding shows a K-type field resistivity curve and relatively deep water table at about 13 m.bgl, with the unsaturated sandy zone having a resistivity in the range of 105 to 475 Ωm. The top (unconfined) aquifer having 6 m thickness shows a resistivity of 92 Ωm which is underlain by a thick clayey sand (res 36-44 Ωm) upto a depth of 89 m and beyond.

VES-11 (Balmiki Colony)

This sounding was taken in the eastern part of the study area near Mahipura (Fig. 3.1) and shows a mildly rising A-type field resistivity curve. The top soil layer having a low resistivity of 22-35 Ωm is underlain by unsaturated fine sand (54-71 Ωm) and a sandy clay (24-30 Ωm) upto 10 m depth which may pertain to water table. This is underlain by apparently saturated sandy horizon (resistivity: 39-43 Ωm) upto 46 m depth below which the resistivity declines to 34 Ωm down to a depth of about 68 m.bgl. Beneath this depth, the resistivity shows slight increase to 44 Ωm implying increase in sandy fraction upto 99 m depth. However, the bottom layer has indicated a resistivity of 78 Ωm further beneath.

VES-12 (ITC)

This sounding was recorded on the main road passing near ITC factory (Fig. 4.1) in the southwestern part. The VES field curve is mild K-type in nature and indicates presence of sandy material (resistivity: 42-138 Ωm) upto a depth of 13 m.bgl which seems to pertain to water table. The layer just below this depth has a resistivity of 87 Ωm upto 28 m indicating presence of medium to coarse sand. This is underlain by a clayey sand horizon (res. 35-41 Ωm) upto 41 m depth. The layers beneath this depth have resistivity between 73 to 109 Ωm upto 89 m, below which a sandy clay (res. 32 Ωm) seems to be present.

VES-13 (Manikmau)

This sounding was taken in the western part of the town near tubewell (W1) at labour colony (Fig. 3.1). The interpretation of the VES data indicates presence of a thick clayey sand (resistivity: 36-43 Ωm) below top soil upto a depth of 5.5 m. Beneath the clayey sand, there is a thick sandy horizon (res. 49-64 Ωm) upto a depth of 81 m.bgl. However, around 81 m depth, a clayey layer of resistivity 28 Ωm is indicated upto uncertain depth. The two thin clay beds encountered in the nearby tubewell (W1) between 15-30 m depth have not been confirmed in the VES data (Fig. 3.3 B).

VES-14 / VES-IP-25 (Awas Vikas)

This sounding was taken in the southern part of the study area along Delhi road near Awas Vikas tubewell (W-3) (Fig. 3.1). The field resistivity curve is K-type in nature and shows presence of a sandy layer (resistivity: 76-174 Ωm) upto 13 m depth below the top soil. The water table in a nearby well occurs at a depth of about 7 m.bgl. The top aquifer is also sandy in nature with lower range of resistivity (53-101) upto 19 m depth below which a thick clayey sand (res. 38-44 Ωm) is indicated upto 89 m depth. Thus, the clay layer reported in the litholog of the nearby tubewell (W-3) is not inferred in this location Fig. 3.2 (C) and 3.3 (A) as well.

The combined VES-IP-25 shows an almost identical resistivity sequence with the resistivities of unsaturated zone slightly in higher range (58-210 Ωm) than in VES-14. The upper aquifer has a resistivity of 148 Ωm upto the depth of 19 meters which is underlain by a sandy horizon upto the depth of 41 meter, with resistivity of 42-81 Ωm. Resistivity of the deeper layers upto 61 m is however, showing a lower resistivity of 28 Ωm indicating presence of sandy clay. Below this depth, fine to medium sand is indicated with resistivity of 38-80 Ωm (60 Ωm in IP model).

VES-15 and VES-IP-26 (Mahipura)

Recorded towards southeast of VES-11 (Fig. 3.1), these soundings show mild K-type field curves, almost similar to VES-11. The top layer (resistivity: 36-38 Ωm) of 4-5 m thickness is underlain by a fine sand (resistivity : 41-53 Ωm) between depth of 4.5-99 m.bgl which indicates presence of almost uniform type of fine sand (The actual water table occurs at 8 m.bgl). However, in the VES-IP-26, the geoelectrical section shows increased resistivity upto 96 Ωm indicating presence of increasing sandy fractions. This is also confirmed by resistivity of 50 Ωm and IP of 6.28 msec in the 3rd layer of IP interpretation from 33 m depth downwards.

VES-16 and VES-IP-27 (Remount Depot)

These soundings are localized in the eastern part of study area (Fig. 3.1). Both these soundings curves are of KH type and have high resistivity layers (145-1029 Ωm) right from surface (in VES-16) upto a depth of 9 m below which resistivity starts decreasing upto 105 Ωm in the depth interval 13-19 m. The actual water table is indicated to occur at a depth of 10 m bgl. The first aquifer seems to occur between the depth of 9-19 m (with resistivity of 105-330 Ωm) in a sandy gravel horizon. Between 28-41 m depth fine sand is indicated to occur with resistivity of 51-53 Ωm below which a sandy clay having resistivity 22-26 Ωm is present upto the depth of 89 m. Beneath this layer, a sandy horizon of 51 Ωm resistivity is present.

The data of VES-IP-27 indicates high resistivity zone upto 9 m depth with resistivity of 253-675 Ωm. However, in this sounding, the clay zone indicated beneath 41 m depth in VES-16 is missing. However, the clay is confirmed in the interpretation of IP data by the occurrence of thick zone occurring from the depth of 32 m having a resistivity of 15 Ωm and IP of 6.28 m sec.

VES-17 (Ganpati Vihar)

This sounding is recorded in northern part of the study area between Behat Road and Dhamola nala (Fig. 3.1). In this sounding, the top soil layer is underlain by high resistivity layer composed of sand and pebble (resistivity 212-324 Ωm) upto the depth of 13 m. Below this, an aquifer zone of resistivity 54-110 Ωm is present upto a depth of 28 m which is underlain by a fine sand upto 89 m depth. Further, downward, a clayey layer (22 Ωm) is indicated to be present upto uncertain depth.

VES-18 (Refinery Colony)

This sounding is located on the western side of Saharanpur-Behat road and its location is about 1 km west of VES-17 (Fig. 3.1). The field curve in this location is similar to VES-17 (K-type) in nature generally confirming the strata available in location VES-17. However, the resistivity of unsaturated zone is slightly in a higher range (upto 727 Ωm) down to about 13 m below surface. However, the resistivity of the bottom layer in this sounding location is in the order of 121 Ωm indicating a rise in the resistivity.

VES-19 (Prem Nagar)

This sounding is located in the southern part of the study area towards east of Delhi road (Fig. 3.1). The top soil in this location, is underlain by the unsaturated layer having resistivity 89-188 Ωm upto the depth of 9 m below ground surface. Below this a sandy layer is indicated with resistivity in the order of 55-113 Ωm upto the depth of 89 m. The bottom layer occurring below 89 m has a resistivity of 37 Ωm indicating increase of clay fraction in the sand.

VES-20 (Navada Aquiduct)

This sounding is located in the south-western corner of the study area (Fig. 3.1). Interpretation of the VES curve has indicated presence of clayey sand (resistivity 31-47 Ωm) below the thin top soil upto a depth of 9 m where water table may occur. The upper aquifer starting from the depth of 9 m upto 89 m shows resistivity of 53-70 Ωm indicating presence of medium to coarse sand. The bottom most layer below the depth of 89 m has a resistivity of 31 Ωm indicating presence of increased clayey nature of sand.

VES-IP-23 (Ambala Road)

This sounding was taken on Ambala road near the municipal limit of Saharanpur just west of road bridge over the railway line. The top layer is made up of clayey soil which is underlain by overall low resistivity zone (13-19 Ωm) between the depth of 2 to 68 meters. This zone seems to be comprised of clay material. Alternatively, it may pertain to a sandy horizon having poor quality ground water. There is no indication of presence of water table as the resistivity values seem to show only slight variation. Yet, the actual depth to water table is about 4-5 m.bgl. Below the depth of 68 m, the resistivity of 28-47 Ωm is indicated which may pertain to fine sand.

The results of IP interpretation also seem to confirm the presence of saline water bearing layers in the top aquifer starting from a depth of about 2.4 m bgl, where an IP of 50.21 msec has been recorded, against resistivity of 19.61 ohm-m upto 42 m depth.

VES-IP-28 (Khata Khedi)

This sounding was recorded in the northern part of the area between Paondhoi nala and Chilkana road. The top soil layer at this location is underlain by coarse sand having resistivity of 144 Ωm in a sandy layer upto the depth of 19 meter. Below this depth, the resistivity shows a further decline upto 51 Ωm till the depth of 89 m indicating presence of sand.

The IP interpretation of this sounding appears to confirm the absence of clayey fractions at deeper level showing a resistivity of 50 Ωm.

VES-IP-29 (Khan Alampur yard)

This combined VES-IP sounding was recorded along railway line in the south-eastern part of the study area (Fig. 3.1). The geoelectrical section shows presence of low to medium resistivity (28-48 Ωm) materials upto a depth of about 13 m. This is underlain by clayey sand horizons with variable fraction of clays upto depth of 89 meter with resistivity varying between 29 to 49 Ωm. The presence of water table is not indicated in this section although water is available in this area from the depth of less than 9 m.bgl. The interpreted IP model generally corroborates the absence of clay fraction below 3 m depth with the resistivity being of the order of 44 Ωm.

VES-IP-31 (Chowdhary Vihar)

This combined sounding was recorded east of Paondhoi nala in the northern part of study area. The field resistivity curve is K-type in shape with increasing resistivity (82-385 Ωm) upto depth of 12 meters which might pertain to water table. Beneath the water table, the resistivity shows persistent decline upto 25 m depth (resistivity116-249 Ωm).

The underlying layer from depth of 25 m upto 80 meter and beyond shows the resistivity varying in the range 47-59 Ωm indicating presence of fine to medium grained sand. However, interpreted IP model shows presence of clayey fractions beneath the depth of 2 m onwards as indicated resistivity of 20-26 Ωm and IP response of 52-63 msec. However, presence of clay could not be confirmed due to nonavailability of lithological information in this part of the study area.

VES-IP-32 (Wazir Vihar)

This sounding location is in Wazir Vihar area (Fig. 3.1) where the ground water observation well shows the depth of water table to be about 7 m bgl. This location is about half km towards SSE of VES-12. The geoelectrical section shows presence of top clayey sand (resistivity 25-46 Ωm) upto 3 m below which medium to coarse grained sand is present upto 10 m depth presumed to pertain to water table. The top aquifer has a resistivity of 42 to 109 Ωm upto 68 m depth. This lithology is continued by sandy layer of resistivity 60 Ωm upto 99 m depth and beyond.

The interpreted IP model confirms the presence of sandy horizons in this soundings only upto the depth of 14 m beneath which the interpretation is not available.

3.6 Salient Conclusions:

The above results of the VES & IP soundings have revealed that generally it is possible to delineate the thick aquifer (sandy and gravel) zones from aquicludes (i.e. clays) in the study area. Yet, it was found difficult to detect and confirm presence of thin clay-layers which may constitute aquitards between the aquifers. Further, the subsurface geoelectric section indicates overall sandy nature of geological formations which tend to become more clayey towards south, southeast and east with development of clay bands.

Further, generally it is been difficult to detect the areas with contaminated ground water except at a few locations where some polluted zones are likely to occur e.g. VES-IP 30 (Pairagpur) and VES-IP-23 (Ambala road). However, this needs to be confirmed from the actual water quality data.

Chapter 4
Hydrogeological Conditions

Subsurface hydrogeological picturisation of the study area has been attempted integrating the results of the geoelectrical studies with the available subsurface hydrogeological data.

The topographical features together with the landuse pattern play important roles in shaping and modifying subsurface occurrence of groundwater and its quality these aspects are therefore discuss below.

4.1 Land Use Pattern

The land use map of the study area has been prepared from merged satellite imagery data of LISS-III and Pan for 2002 using ERDAS Imagine 8.6. Fig. 4.1 shows the land use map of Saharanpur city in which the urban area is the order of 1232 hectare i.e. about 36% of the total area, whereas barren area is comprised of 1387 hectare (about 40% of the total area). The plantations occupy about 400 hectare, constituting about 13% of the municipal area. The remaining area is occupied by crops and water bodies, the last one being mainly comprised of city drains (Table 4.1). This distribution of land use pattern indicates a considerable increase in the built up area in the city from 1110 hectare to 2340 hectare during last three decades (Table 4.1). The area is expanding outward in the north-western direction (beyond the eastern Yamuna canal), in the south-western direction (towards Delhi road) and along eastern direction (along the Dehradun road). It may be noted that the area covered by plantations and vegetation is mainly occupied by the presence of fruit-orchards and nurseries flourishing since long time.

Table 4.1: Land use class distribution in Saharanpur city

Class	Area in hectare	%
Water bodies	172	5
Barren land	1387	40
Crops	210	6
Urban land	1232	36
Plantations	440	13

4.2 Topographic Features

The area of study forms part of the great Indo-Gangetic Plain. However, with a view to work out variation in elevation of the Saharanpur town area, a surface elevation contour map (Fig. 4.2) has been prepared (with 0.5 m contour interval) after conducting detailed ground elevation survey of 51 well locations where handpump installations are available on existing shallow borings. It is observed from the Reduced Level (R.L.) data (Table 4.2) and the contour map (Fig. 4.2) that the ground configuration in Saharanpur area is governed by master slope of the ground surface which is towards south. The ground slope varies between 1: 260 to 1: 850. However, the surface gradient often shows local variations in the form of minor high-lands and depressions (Fig. 4.2). Accordingly, topographically high spots in the area are in northern part of the city where ground elevation varies around 277 m above mean sea level (AMSL). The spots with lowest elevation are situated towards south at a minimum elevation of about 269 m (AMSL). The Dhamola nala flows from an elevation of about 278 m (AMSL) down to less than 269 m level. A perusal of the Table 4.2 shows that the highest R.L. (reduced level) within the municipal limits pertains to observation well no. 48 at Vishnu Dham (276.805 m AMSL).

The topographical survey thus, indicates that the ground surface in the study area largely forms a southerly sloping plain with variations in the elevations between 269-277 m AMSL.

4.3 Hydrogeological Conditions – Earlier Studies

Available data indicates that the water bearing formations in the Saharanpur town are generally sandy horizons separated by imperious clays occasionally impregnated by kankar (a nodular formation rich in $CaCO_3$) nodules. Based on lithological logs of seven tubewells and available water level data, two types of aquifer have been delineated in a geological fence diagram (Fig. 4.3). The upper one is a shallow unconfined aquifer which generally extends upto depth of about 15 m bgl. The deeper aquifers, are confined to semi confined aquifers, located at depth around 15 to 115 meters below ground level separated by three to four aquitards at average depths of 15-36, 54-60, 80-90 and 95-120 meters. Four to five aquifer zones have been tapped in a tubewell drilled recently in the southeastern part of the town in the premises of Department of Paper Technology of IIT Roorkee in the Saharanpur campus upto a depth of 106 meters (Fig. 4.3).

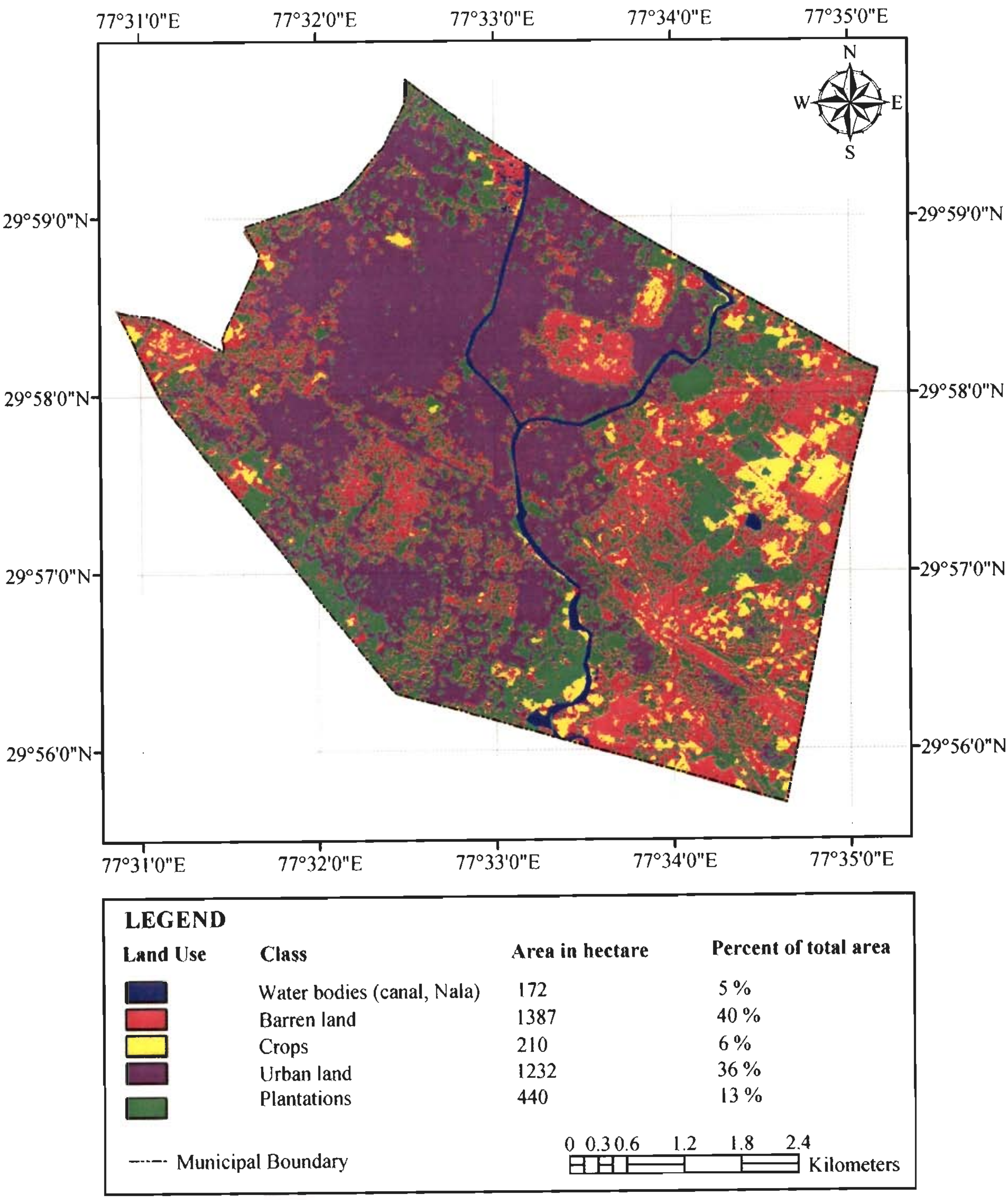


Fig. 4.1; Land Use Map

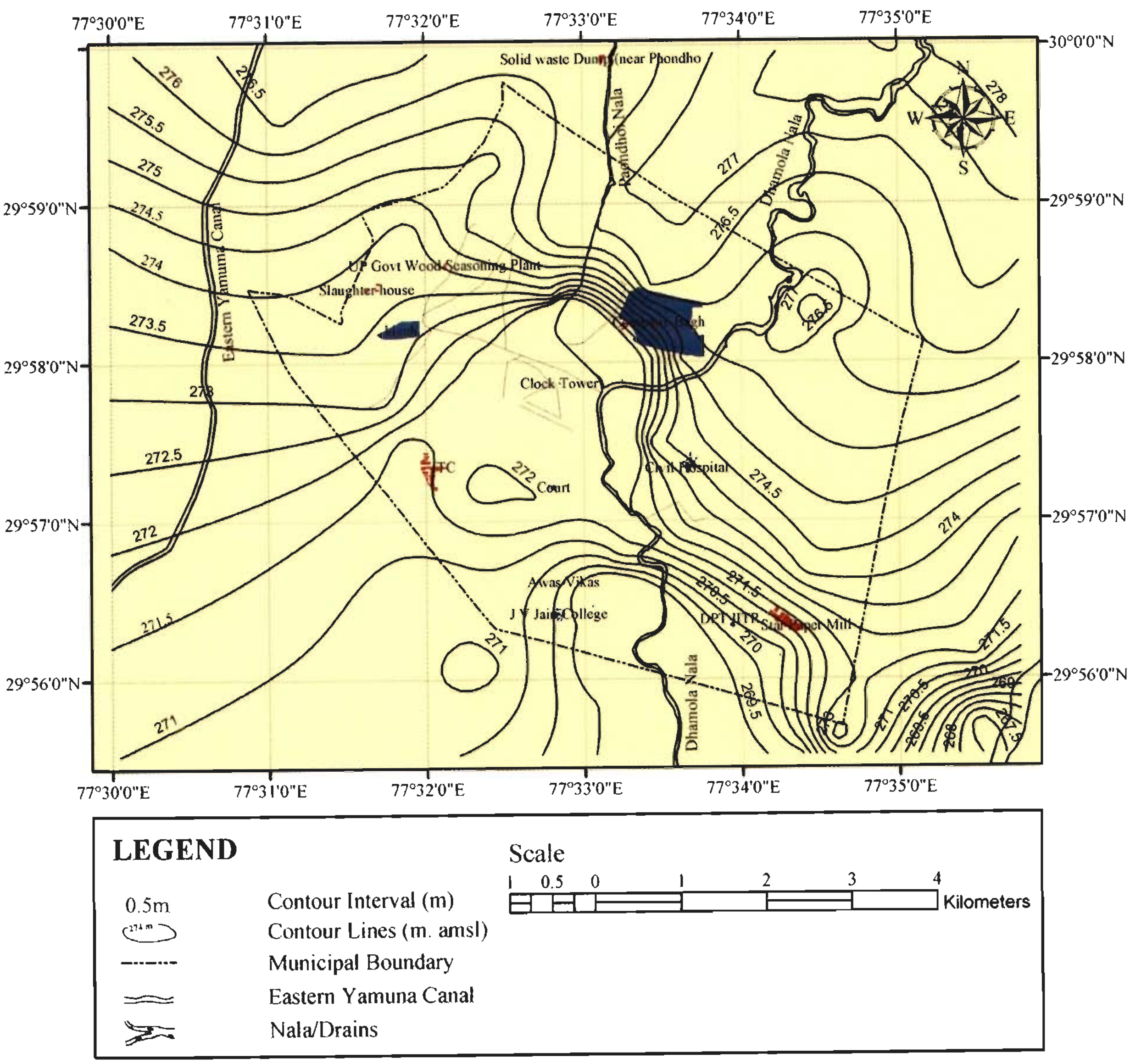


Fig. 4.2; Topographical Contour Map of Saharanpur Town

Table 4.2 Reduced levels of ground surface of monitoring wells

Name of Hydrograph Station	Obs. Well nos.	Long X	Lat Y	RL (m amsl)
Dudhli Sarak	OW 1	77.591030	29.9705833	276.940
Mahipura	OW 2	77.576000	29.9702000	275.980
S M Inter College	OW 3	77.550800	29.9625000	268.195
Shekhpura Qadim	OW 4	77.572930	29.9252833	269.870
Pairagpur	OW 5	77.591700	29.9288000	267.690
Dudhali Bhukara	OW 6	77.591467	29.9353833	272.515
Ghogreki	OW 7	77.596183	29.9481333	272.970
Hasanpur	OW 8	77.539400	29.9374000	270.900
Hakiquat Nagar	OW 9	77.554100	29.9461000	271.060
Govind Nagar	OW 10	77.550200	29.9602000	270.315
Wazir Vihar	OW 11	77.531200	29.9577000	271.205
Patel Nagar	OW 12	77.538400	29.9675000	271.965
Sabarika Bagh	OW 13	77.531500	29.9806000	273.815
Munnalal Girl's Degree College	OW 14	77.540900	29.9878000	274.870
Arabi Madrisa	OW 15	77.548200	29.9801000	276.535
Shahid Ganj	OW 16	77.546600	29.9733000	273.480
Company Bagh	OW 17	77.560100	29.9670000	274.970
Janakpur 1	OW 18	77.557400	29.9580000	273.890
Janakpur 2	OW 19	77.555300	29.9569000	271.120
Govt. Hospital	OW 20	77.560600	29.9544000	273.465
Bharampuri	OW 21	77.560400	29.9487000	272.865
Awas Vikas Colony 1	OW 22	77.550600	29.9392000	269.145
Awas Vikas Colony 2	OW 23	77.552600	29.9400000	265.275
Awas Vikas Colony 3	OW 24	77.551700	29.9309000	269.455
Lakha Colony	OW 25	77.540333	29.9346000	271.095
Vikas Bhawan	OW 26	77.537700	29.9357000	271.235
Pant Vihar	OW 27	77.534450	29.9410000	270.440
Wazir Vihar 2	OW 28	77.528700	29.9629000	273.325
Thana qutubsher 1	OW 29	77.514800	29.9739000	274.015
Chandar Nagar	OW 30	77.545050	29.9516833	272.010
Bhattiyari Bagh	OW 31	77.538800	29.9533000	272.190
Gill Colony	OW 32	77.550400	29.9550000	271.880
SRE Railway Station	OW 33	77.541817	29.9627778	271.925
Dabki Junardar	OW 34	77.573700	29.9449000	274.260
Khalasi Line	OW 35	77.536200	29.9623000	271.690
Qutubsher 2	OW 36	77.513300	29.9742000	274.017
Qutubsher 3	OW 37	77.499900	29.9794000	274.019
Ahamad Bagh	OW 38	77.546750	29.9473056	270.925
Dudhali Sarak 2	OW 39	77.593800	29.9707000	276.665
Beri Bagh 2	OW 40	77.557778	29.9673889	272.740
M S College	OW 41	77.557000	29.9747000	276.525
Halalpur	OW 42	77.530800	29.9991000	276.720
Ramgarh	OW 43	77.518000	29.9917000	276.540
Luhani Sarai	OW 44	77.541900	29.9678000	271.605
Shahid Ganj 2	OW 45	77.547278	29.9720278	269.000
Shekhpura Qadim 2	OW 46	77.576472	29.9271944	273.385
Shekhpura Qadim 3	OW 47	77.571000	29.9362000	270.470
Visnu Dham	OW 48	77.561583	29.9891389	276.805
Sabrika Bagh n	OW 49	77.537300	29.9801000	274.965
New Mahipura	OW 50	77.575000	29.9715000	274.530
Khata Khedi	OW 51	77.552900	29.9991000	276.156

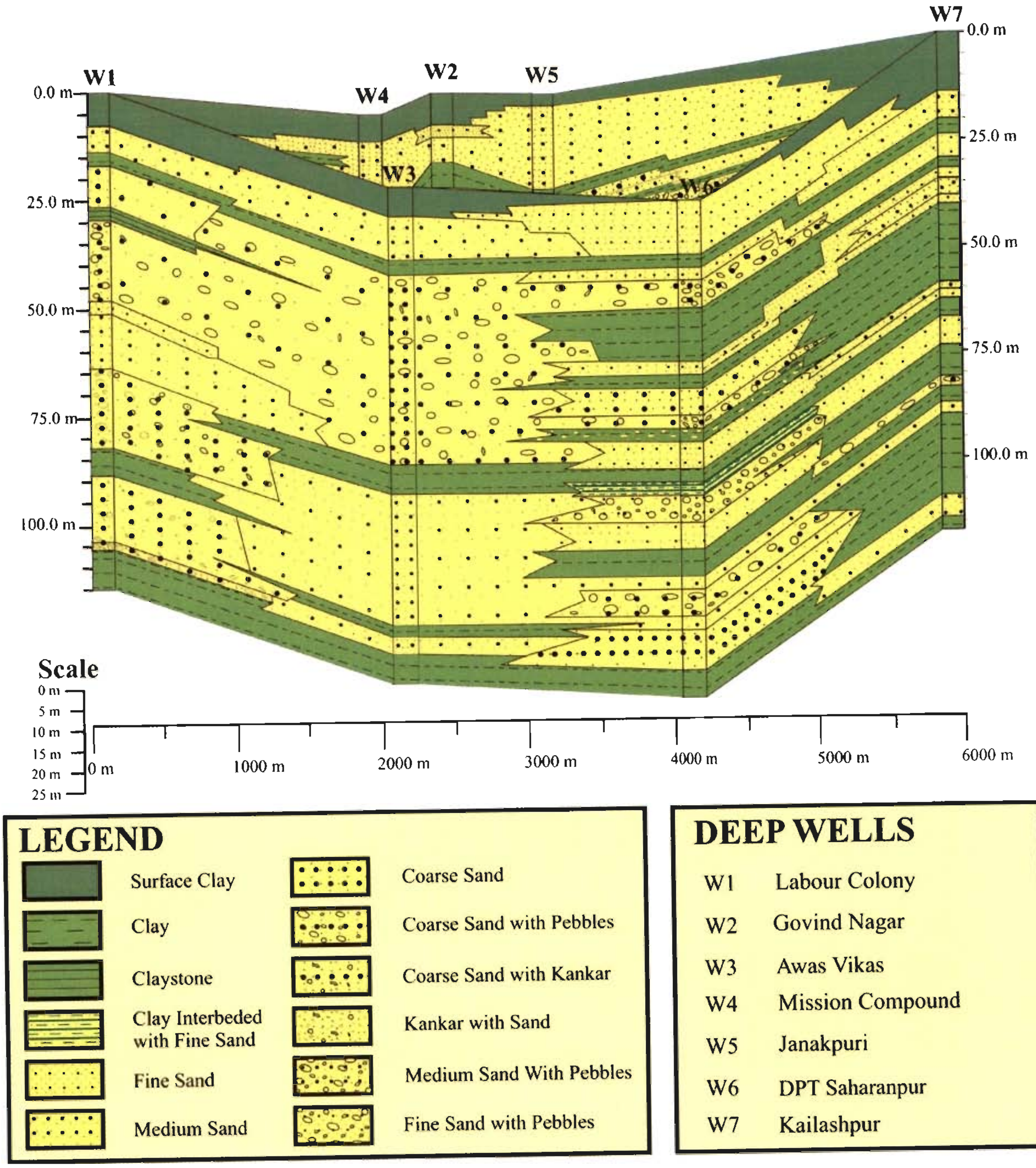


Fig. 4.3; Geological Fence Diagram Based on Well Data

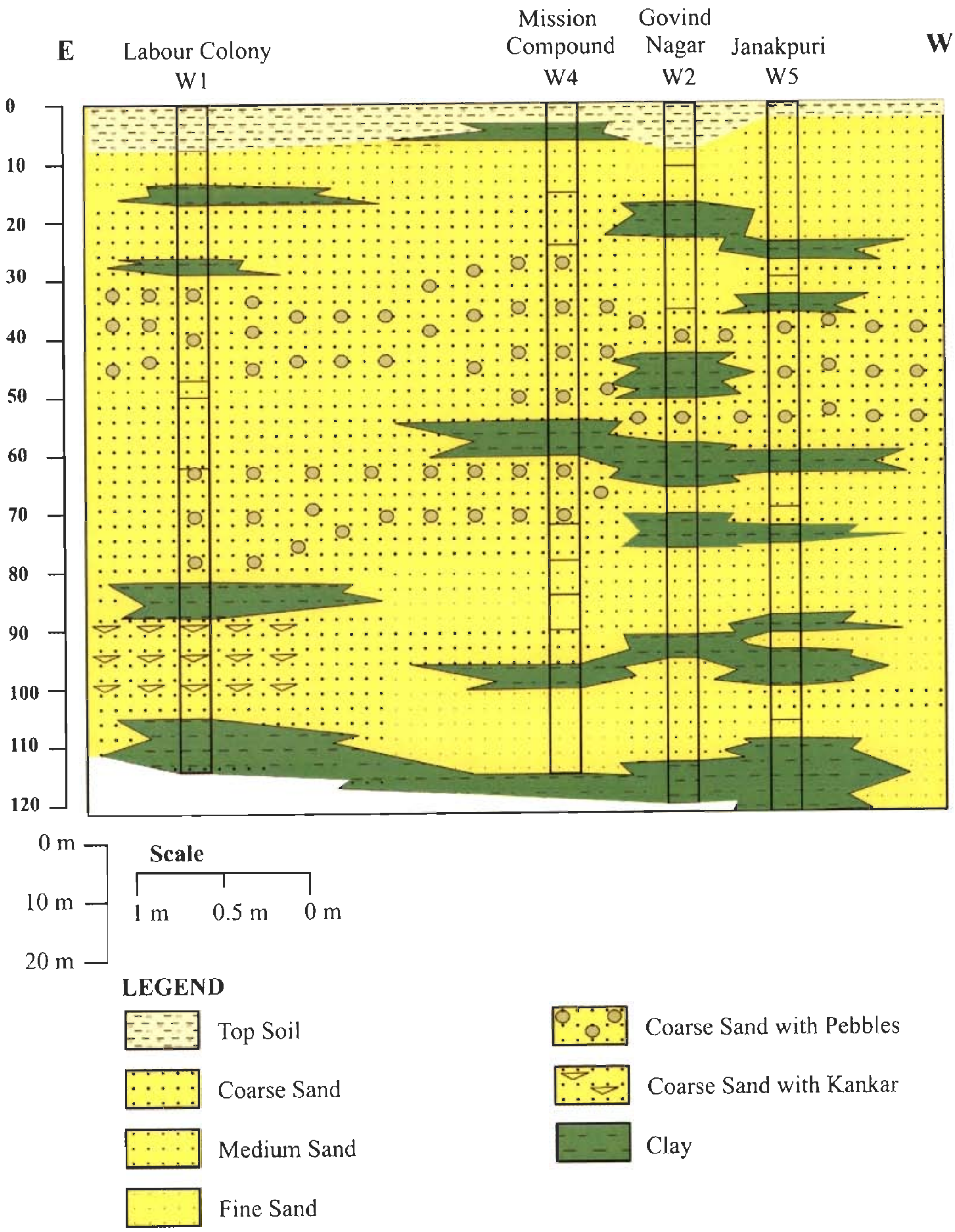


Fig. 4.4; Geological Section along E – W Direction

The relative thickness of aquifers gradually increases towards west due to pinchout of clayey zones. The geological data of a deep tubewell drilled at Hassanpur on Saharanpur Delhi Road at about 2.5 km from Saharanpur city is also available from CGWB sources. The drilling was carried down to 453 m depth for installation of piezometer(s) where shallow, medium and deep piezometers were installed upto 446 m depth. The drilling data shows presence of a series of nine confined aquifer horizons. The depth intervals of confined sandy horizons met in the tubewell are given in Annexure-2.1. It is also observed that the unconfined aquifer in the tubewell occurs in the depth interval of 6 to 15 m bgl and is composed of fine to medium grained sand with in the underlying clay of 5 m thickness (from 15 m depth) which is aquiclude. Fig. 4.4 shows the geological section prepared along east-west direction in the central part of the study area based on available lithologs of tubewells. This section shows presence of relatively larger number of clayey zones in a sandy section. The clays seem to be localized in nature, each having thickness of 3-8 m or so. However, the bottom most clay layer occurring at a depth of 106 to 112 m in the W1 tubewell (at labour colony) seems to be regional in character and is present in all tubewells.

Present Studies :

The electrical resistivity soundings supplemented by induced polarization studies have provided additional data about nature of subsurface geological formations in the study area. It is clear from the two geoelectric sections (see Fig 3.3 A and 3.3 B in chapter three) that there is a general increase in sand content of the formation towards north whereas the clay fractions tend to increase in the southern and south-eastern directions. However, as mentioned earlier (chapter 3), the depth ranges observed in the geoelectrical section(s) need to be adjusted suitably keeping in view the electrical anisotropy and equivalence. Correlation of lithologs and depth of water levels of drilled wells with the interpretated lithologs from geoelectrical measurements indicate that the depth(s) of expected water table and their other horizons need be reduced to about 65-70% of those obtained in the geoelectrical interpretation. Thus, the common reported depth of water table around 13 m would be reduced to about 8-9 m bgl.

The above sequence may be modified by occurrence and pinchouts of clay lenses, as in Hassanpur tubewell (W-8).

An almost similar section with local variations is observed in the geoelectric section BB' (Fig. 3.3(B)) with an additional clayey zone being present in the southeastern part of the study area between Himmatnagar (VES-5) to Pairagpur (VES-IP-30). Further, the unconfined aquifer in VES 3 & VES 13 tends to merge with the lower sandy horizon.

Besides the geological fence diagram (Fig. 4.3), and the geological section, and geoelectrical sections, the geological interpretation of the other sounding data has also indicated presence of generally sandy sections interrupted by localized occurrence of clay bands (occasionally with kankar). These clay layers seem to act as aquicludes/aquitards in the study area. As mentioned earlier, the occurrence of clays appear to increase towards south and southeast which may lead to poor subsurface drainage in these parts of the study area. Further, in two sounding locations e.g. VES-IP 23 (Ambala road) and VES-IP 30 (Pairagpur) abnormal lowering of resistivities in the unconfined aquifer seems to point out towards some sort of ground water contamination resulting in the presence of poor quality ground water. Though this needs to be confirmed from the examination of ground water quality data of the nearby shallow wells/hand pumps, prima-facie, it seems to be a result of contamination arising from local industrial activities (viz. slaughter house waste effluents flowing in Kamela drain passing close to VES-IP 23 and Dhamola nala loaded with paper mill effluents near VES-IP 30).

4.4 Ground Water Level Monitoring

The groundwater monitoring in the study area was commenced in year 2001 in open dug wells which however dried up gradually making it difficult to continue the monitoring. Thus, the groundwater level monitoring had to be suspended after 2002. Later, it was resumed in the year 2004 in manually operated hand pumps at 51 sites of shallow borings where pumping installations were also available. These hand pumps tapped the unconfined aquifer in the study area. Thus, the shallow borings having hand pump installations had to be used as observation wells because no functioning open wells could be found and some of the existing open wells had already been closed down due to one or the other reason.

For measurement of depth to water table in the shallow borings with hand pump, an innovative procedure was devised by opening the manual pumping machine from the top by removing the inner valve in order to facilitate lowering of the electrical water level indicator/measuring tape as shown in photograph (Plate 4.1). The method of measurement of the depth to water table in the borings included use of an electrical water level indicator often supplemented by a measuring tape coated with white chalk. Four cycles of depth to water table monitoring were carried out during the years 2004 and 2006, during premonsoon (i.e. before rainy season) and postmonsoon (i.e. after rainy season) periods as given in Table 4.3. The reduced water table elevation map for premonsoon and postmonsoon, 2004 as well as 2006 are given in Figure 4.5 (A&B) and 4.6 (A&B) respectively. These maps clearly show –

- The ground water flow is southerly
- The water table elevations vary between 256 to ≥272 m amsl.
- The water table elevation decreases southwardly
- The increase in water table elevation due to monsoon recharge is almost 2 m.

Depth to Water Table :

The depth to water table maps based on the premonsoon and postmonsoon levels in shallow hand pumps are shown in figures 4.7 (A) and.7 (B) respectively. A perusal of these figures shows that the range of depth of water table below surface in the study area shows a wide variation between 2.5 to over 10 m bgl during 2006 being maximum in the southeast (OW 20 and OW 34) in the area between civil hospital and Dabki Junardar. However, the water table is found to be shallow (2.5 – 5 m bgl) towards west and north west. During the postmonsoon period, the water table shows slight rise as is clear in the OW 29 and OW 36 towards north west. The water table elevation contour maps for year 2004 and 2006 indicate the general ground water flow direction toward northwest to southeast and north to south. The slope of the water table shows a variation in the range of 1:500 to 1:1000, the slope being more steep in the vicinity of the Paondhoi nala and less steep along the Dhamola nala. The highest water table in the area is generally found to occur near Khatakhedi (OW 51) and OW42 (Khalapar) as seen in Figure 4.5 (A&B). Further, the water table elevation is observed to be small near OW22, and OW 23, (Avas Vikas Colony, Fig. 4.6 A&B). The relatively larger spacing of adjacent water table elevation contours as in western, south west and north eastern parts of the study area generally indicates that aquifer transmissivity in these parts is greater than that in the east.

The seasonal water table fluctuation contour map (Fig. 4.8) prepared from premonsoon and postmonsoon water level data of the shallow hand pumps for year 2006, shows that the net recharge to the unconfined aquifer during the monsoon season (of 2006) was of the order of 0.1 to 1.5 m, being maximum (>1.5 m) near OW 13 in the north-western part of the city. However, the general order of fluctuation in most parts of the city is very nominal, ranging upto 1.0 m. This indicates good to high specific yield of the unconfined aquifer. The hydraulic conductivity of the confined aquifer is found to vary between 10-12 m/day near the water supply tubewell in IIT Campus.

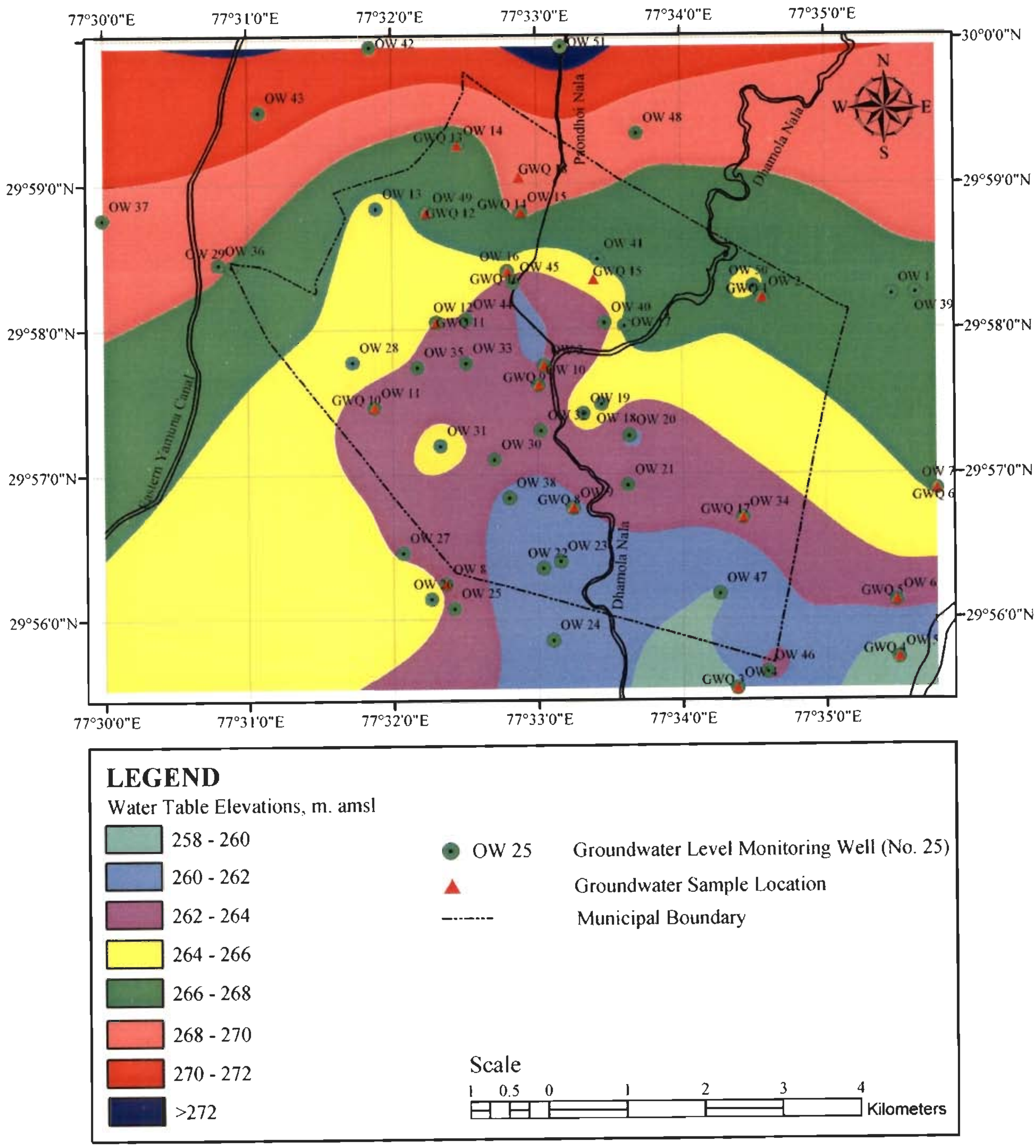


Fig. 4.5 (A); Water Table Elevation Contour Map (Premonsoon 2004)

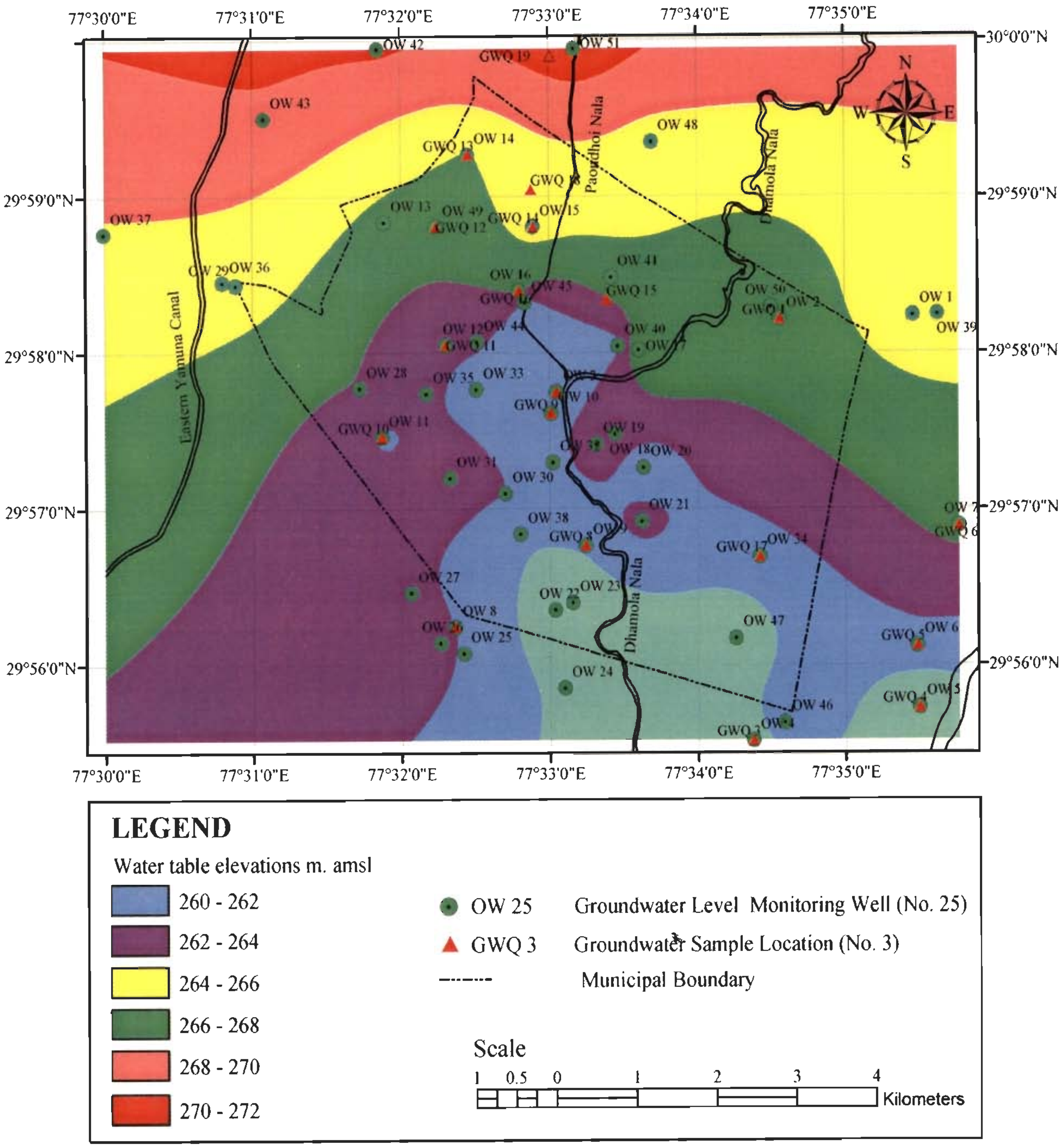


Fig. 4.5 (B); Water Table Elevation Contour Map (Postmonsoon 2004)

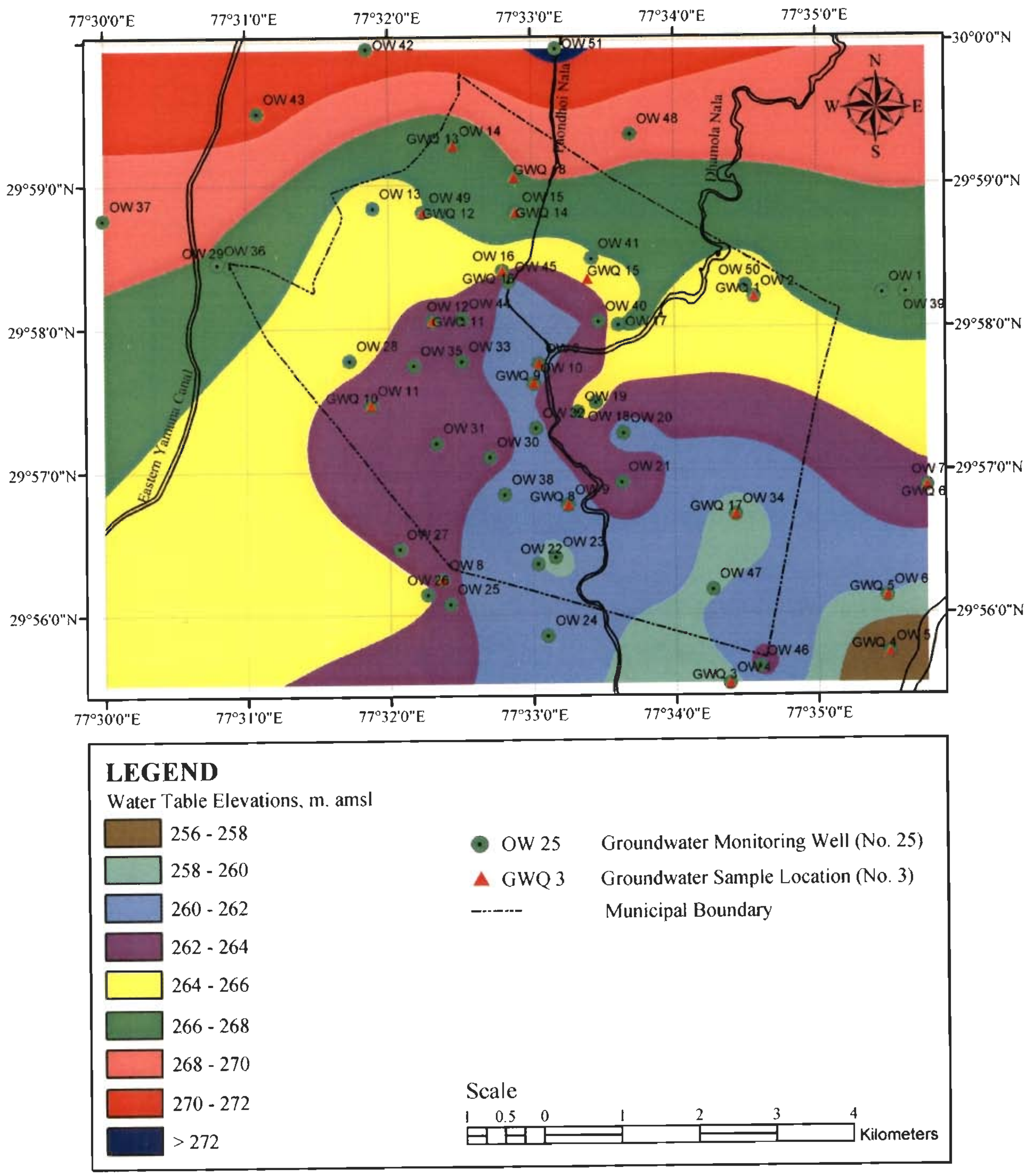


Fig. 4.6 (A); Water Table Elevation Contour Map (Premonsoon 2006)

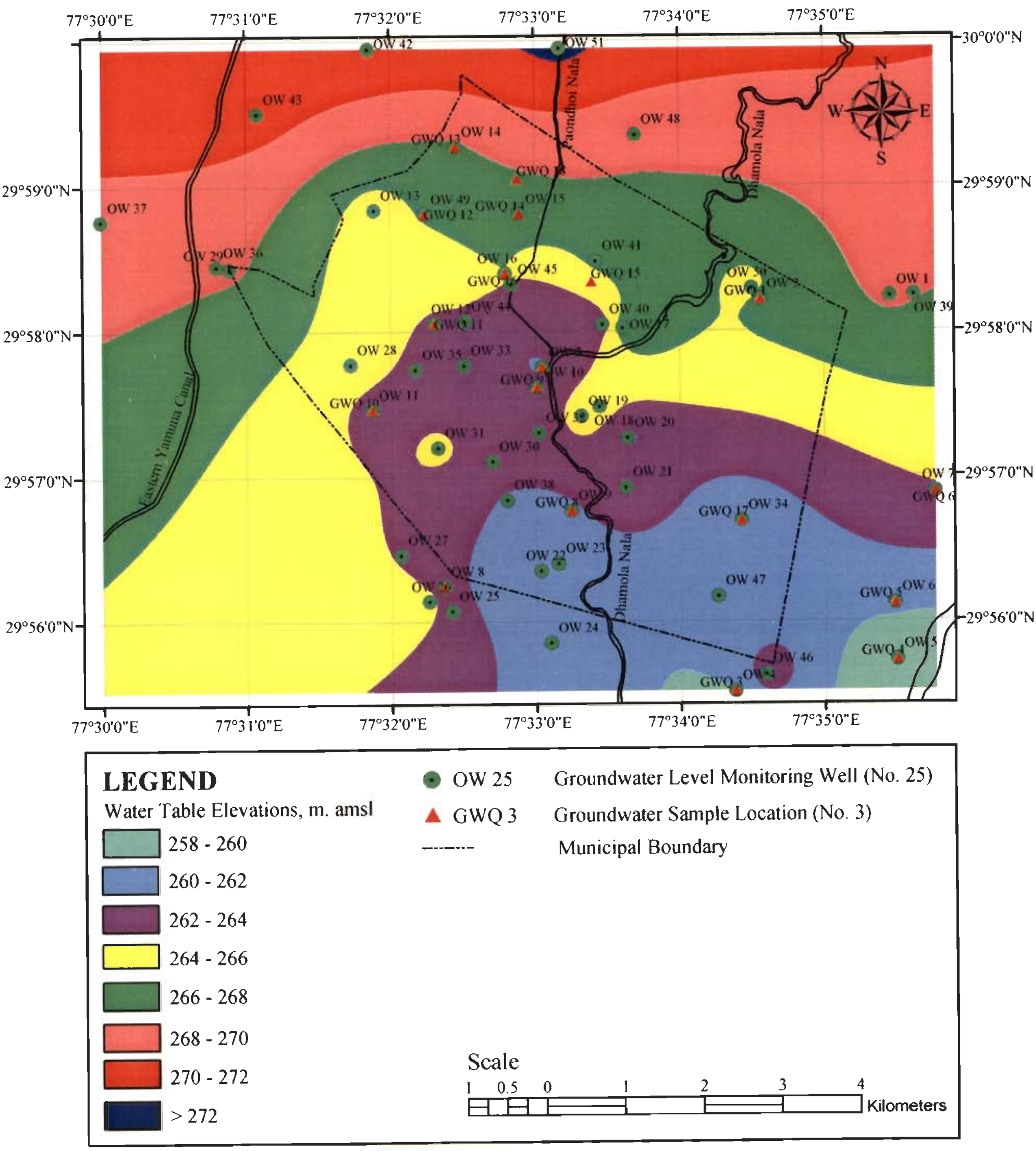


Fig. 4.6 (B); Water Table Elevation Contour Map (Postmonsoon 2006)

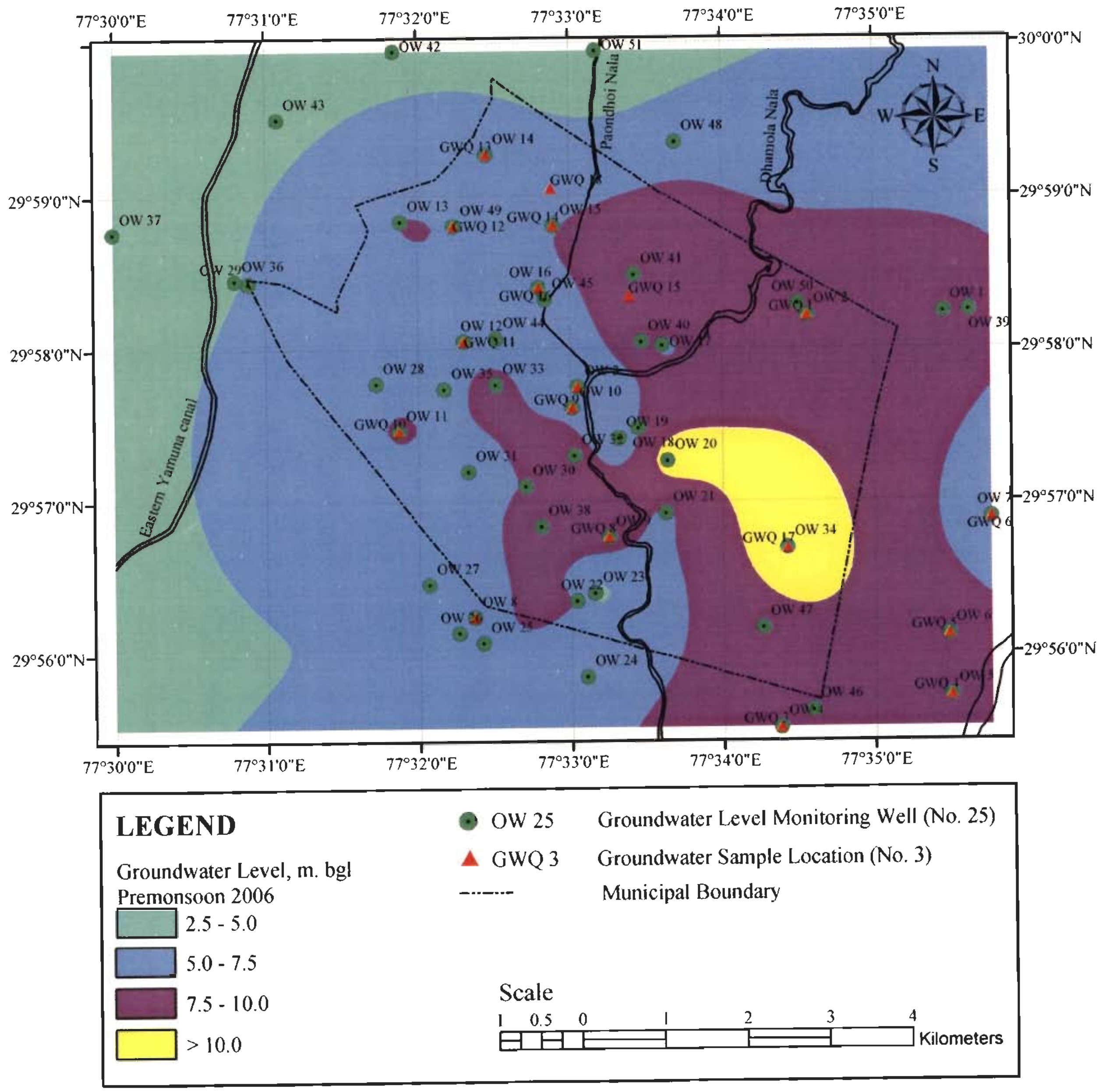


Fig. 4.7 (A); Depth to Water Table Contour Map (Premonsoon 2006, m bgl)

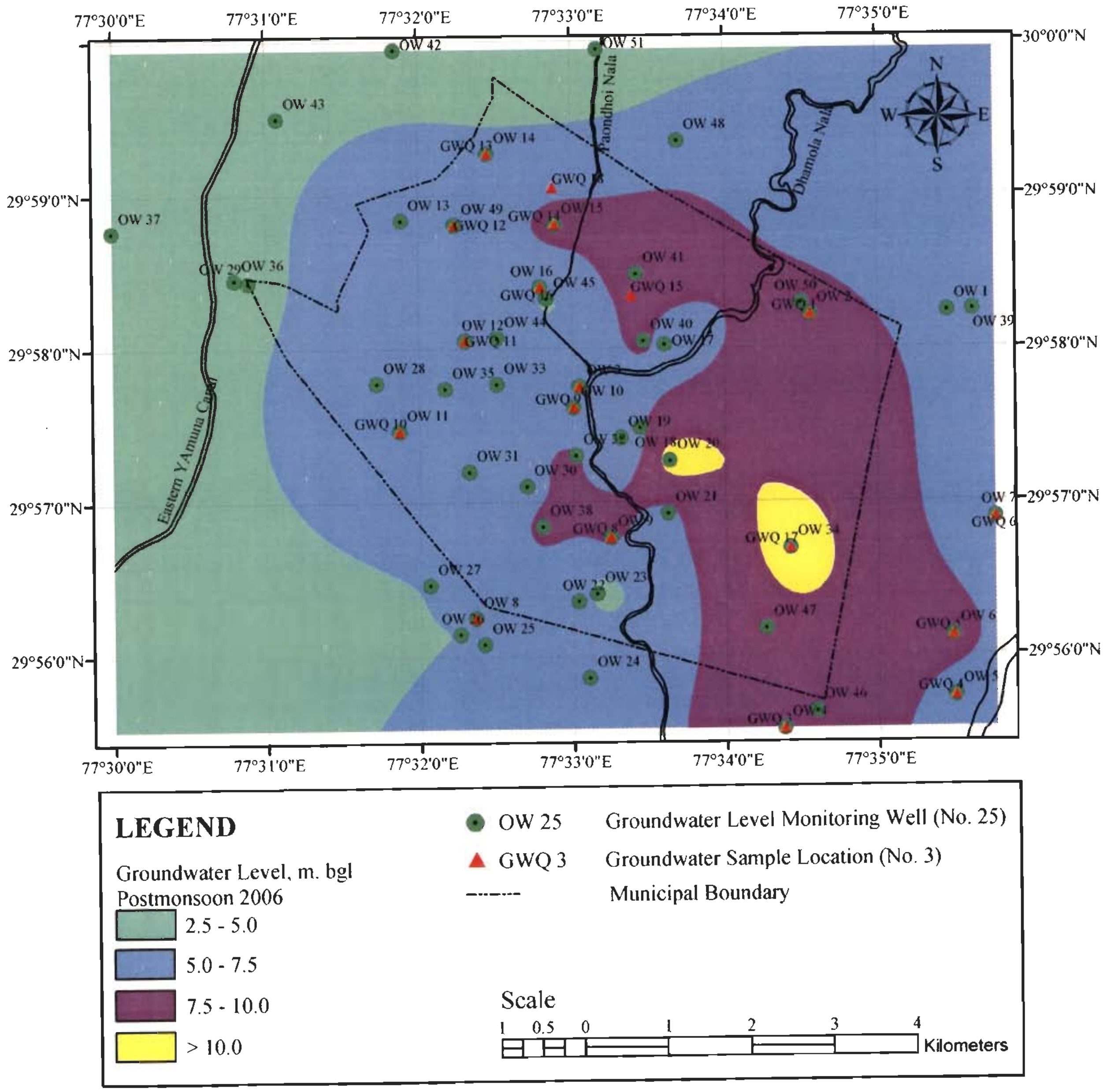


Fig. 4.7 (B); Depth to Water Table Contour Map (Postmonsoon 2006, m bgl)

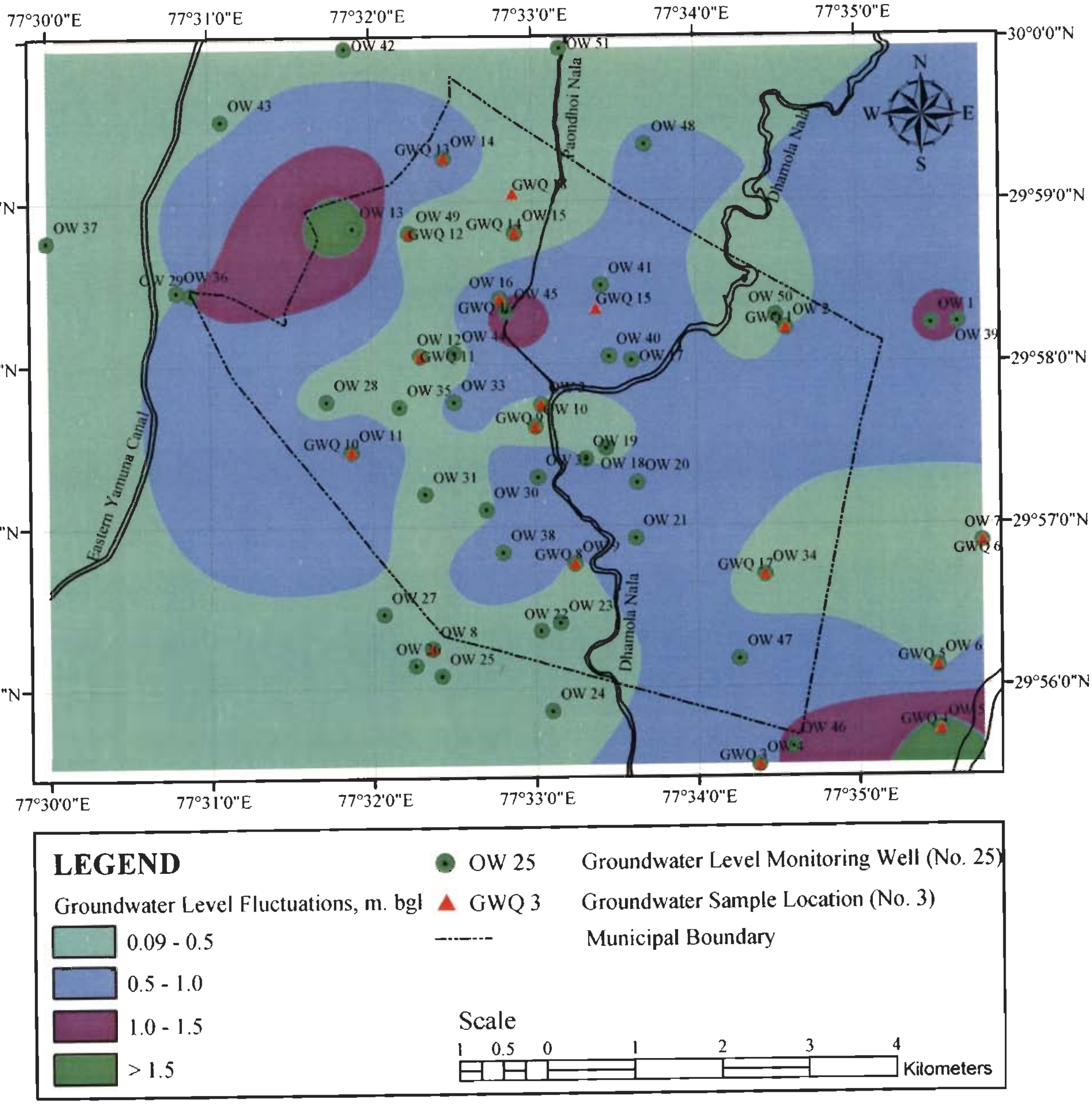


Fig. 4.8; Seasonal Water Table Fluctuation Contour Map, Year 2006

Table 4.3 Depth to Water Table for Years 2004 and 2006

Name of Hydrograph Station	Obs. Well No.	Premonsoon 2004(m bgl)	Postmonsoon 2004(m bgl)	Premonsoon 2006(m bgl)	Postmonsoon 2006(m bgl)
Dudhli Sarak	OW 1	8.69	7.49	8.85	7.51
Mahipura	OW 2	8.88	8.26	9.15	8.32
S M Inter College	OW 3	5.68	5.14	5.80	5.24
Shekhpura Qadim	OW 4	9.94	9.01	10.27	9.08
Pairagpur	OW 5	9.05	7.21	9.68	7.28
Dudhali Bhukara	OW 6	9.13	8.63	9.34	8.75
Ghogreki	OW 7	6.27	5.94	6.23	6.04
Hasanpur	OW 8	6.98	6.55	7.28	7.32
Hakiquat Nagar	OW 9	8.88	8.33	9.16	8.41
Govind Nagar	OW 10	7.32	6.98	7.54	7.06
Wazir Vihar	OW 11	8.08	6.91	8.26	6.98
Patel Nagar	OW 12	7.53	7.16	7.67	7.28
Sabarika Bagh	OW 13	7.97	5.96	8.06	7.86
Munnalal College	OW 14	7.45	6.52	7.55	6.12
Arabi Madrisa	OW 15	7.75	7.43	7.96	8.58
Shahid Ganj	OW 16	7.39	6.43	7.52	6.51
Company Bagh	OW 17	7.33	6.42	7.61	6.50
Janakpur 1	OW 18	8.14	7.83	8.24	7.88
Janakpur 2	OW 19	5.49	4.88	5.68	4.92
Govt. Hospital	OW 20	11.64	10.62	11.73	10.88
Bharampuri	OW 21	8.34	7.48	7.63	7.59
Awas Vikas Calony 1	OW 22	7.98	7.58	8.06	7.60
Awas Vikas Calony 2	OW 23	4.54	4.02	4.68	4.12
Awas Vikas Calony 3	OW 24	7.72	7.23	7.36	7.28
Lakha Colony	OW 25	7.57	7.12	7.62	7.27
Vikas Bhawan	OW 26	5.64	5.47	5.78	5.51
Pant Vihar	OW 27	6.12	5.58	5.69	5.63
Wazir Vihar 2	OW 28	7.33	6.96	7.45	7.11
Thana qutubsher 1	OW 29	5.77	4.58	5.84	4.64
Chandar Nagar	OW 30	7.96	7.45	8.06	7.56
Bhattiyari Bagh	OW 31	7.06	6.71	7.28	6.87
Gill Colony	OW 32	9.21	8.13	9.34	8.26
SRE Railway Station	OW 33	8.54	7.84	8.66	7.91
Dabki Junardar	OW 34	11.10	10.60	12.05	10.65
Khalasi Line	OW 35	7.38	6.98	7.48	7.02
Qutubsher 2	OW 36	5.17	4.68	5.27	4.74
Qutubsher 3	OW 37	4.02	3.69	4.11	3.72
Ahamad Bagh	OW 38	9.05	8.13	9.17	8.25
Dudhali Sarak 2	OW 39	8.60	7.49	8.73	7.58
Beri Bagh 2	OW 40	9.57	8.85	9.68	8.98
M S College	OW 41	9.59	8.87	9.68	9.03
Halalpur	OW 42	4.34	3.96	4.44	4.05
Ramgarh	OW 43	4.90	4.41	4.76	4.50
Luhani Sarai	OW 44	7.21	6.83	6.94	6.95
Shahid Ganj 2	OW 45	6.67	5.02	6.82	5.10
Shekhpura Qadim 2	OW 46	10.25	9.01	9.24	9.12
Shekhpura Qadim 3	OW 47	10.14	9.44	9.58	9.50
Visnu Dham	OW 48	7.88	7.17	7.34	7.26
Sabrika Bagh n	OW 49	7.84	7.62	7.95	7.70
New Mahipura	OW 50	8.49	8.20	8.57	8.24
Khata Khedi	OW 51	2.41	2.52	2.43	2.56

Chapter 5
Quality of Surface Water & Ground Water

5.1 General

Quality of natural waters, both above and beneath the ground are as important as quantity, in as much as the usability of available water resources is determined by their physical, chemical and bacteriological attributes. In the present chapter, the quality aspects of both surface water and ground water have been considered in terms of procedures, standards and criteria laid down by various workers and natural regulatory agencies like Bureau of Indian Standards (BIS).

Hem (1985) has presented guidelines for sampling and preservation of water samples. Considerable effort has been put into the development of standard analytical procedures for estimation of various constituents in natural waters (American Public Health Association, APHA, 1998). In the current study, the procedures described by Standard Methods (APHA, 1998) for examination of water and waste water has been referred for determination of the various constituents. The BIS standards (10,500) and (2490) have been referred for comparing the quality of groundwater for drinking and surface water for direct disposal into runoff waters. Tables 5.1 & 5.2 show the ranges of concentrations of various physico-chemical parameters, heavy metals and bacteriological parameters as laid down for drinking (BIS:10,500) and for direct disposal of surface water effluents into surface runoff (BIS:2490).

In the present study a total of 146 nos. of water samples (Table 5.0) were collected in polyethelene bottles of two litre capacity from the selected localities. The sample bottles were cleaned prior to sampling using standard procedures to prevent contamination during handling.

Table 5.0 Details of Groundwater and Surface water samples procured during different years

Years	Groundwater		Surface Water	
	Periods		Periods	
	Premonsoon	Postmonsoon	Premonsoon	Postmonsoon
2001	17	17	Nil	Nil
2002	17	17	Nil	Nil
2004	17	17	Nil	Nil
2006	13	19 + 2 (deep well)	Nil	10
Total	**64**	**72**	**Nil**	**10**

Pretreatment and Chemical Analysis

It was planned in the present study to carry out most of the chemical analysis in laboratory except few parameters viz. pH, temperature, and electrical conductivity which were determined on the spot in the field. Accordingly, it became necessary to pretreat water samples with suitable chemical reagents for the purpose of fixation of Dissolved Oxygen (DO) in the field. For such a fixation, reagents (viz. Sodium Azide and Manganous Sulphate), as recommended in APHA (1998), were utilized.

For the determination of toxic metals, the collected water samples were acidified with concentrated HNO_3 (5 ml per litre of water) to reduce the pH of the sample below 2.0. Subsequently, each 100 ml of water samples was concentrated by evaporation and digested with concentrated HNO_3. After cooling, it was filtered through 0.45 μm filter paper into 50 ml volumetric flask and the volume was made up by adding double distilled water. It was again transferred to 50 ml. polyethylene bottle and utilized for the determination of heavy metals by Atomic Absorption Spectrophotometer (Model GBC Avanta) and Inductively Coupled Plasma (ICP), Model Perkin Elmer SCIEX.

The quality parameters estimated from the analyses of ground water and surface water are listed in Table 5.3

Table 5.1 : Indian Standards for Drinking Water (BIS:10500, 1991)

S.No.	Substance or characteristic	Desirable limits	Undesirable effects outside the desirable limit.	Desirable/ essential	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
1.	Colour, Hazen units,Max	10	Above 10, consumer acceptance decreases.	Essential	May be extended to 50 only if toxic substances are not suspected in absence of alternate sources.
2.	O'dour	Unobjectionable	-	Essential	(a)Test cold and when heated. (b)Test at several dilutions.
3.	Taste	Agreeable	-	Essential	Test to be conducted only after safety has been established.
4.	Turbidity, NTU, Max	10	Above 10, consumer acceptance decreases.	Essential	May be extended upto 25, in absence of alternate sources.
5.	Dissolved solids, mg/l, Max	500	Beyond this palatability decreases and may cause gastro intestinal irritation.	Desirable	May be extended upto 3000, in the absence of alternate sources.
6.	pH value	6.5-8.5	Beyond this range the water will affect the mucous membrane and/or water supply.	Essential	May be relaxed upto 9.2, in absence of alternate sources.
7.	Total hardness as $CaCO_3$ (mg/l), Max	300	Encrustation in water supply structure and adverse effects on domestic use.	Essential	May be extended upto 600, in the absence of other sources.
8.	Calcium (as Ca) mg/l, Max	75	Encrustation in water supply structure and adverse effects on domestic use.	Desirable	May be extended upto 200, in the absence of other sources.
9.	Magnesium (as Mg) mg/l, Max	30	Encrustation in water supply structure and adverse effects on domestic use.	Desirable	May be extended upto 100, in the absence of other sources.
10.	Copper (as Cu) mg/l, Max	0.05	Astringent taste, discoloration and corrosion at pipes, fittings and untensils will be cause beyond this.	Desirable	May be relaxed upto 1.5
11.	Iron (as Fe) mg/l, Max.	0.3	Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures, and promote iron bacteria.	Essential	May be extended upto 1.0, in absence of alternate sources.
12.	Manganese (as Mn) mg/l, Max	0.1	Beyond this limit taste/appearance are effected, has adverse effect on domestic uses and water supply structures.	Desirable	May be extended upto 0.5, where alternate source is not available.
13.	Chloride (as Cl) mg/l, Max	250	Beyond this limit, taste, corrosion and palatability are affected.	Essential	May be extended upto 1000, in the absence of other alternate sources.
14.	Sulphate (asSO_4) mg/l, Max	200	Beyond this causes gastro intenstinal irritation when magnesium or sodium are present.	Desirable	May be extended upto 400 provided magnesium (as Mg) does not exceed 30.
15.	Nitrate (as NO_3) mg/l, Max	45	Beyond this methemoglobinemia takes place.	Desirable	No relaxation.
16.	Cadmium (as Cd) mg/l, Max	0.01	Beyond this, the water becomes toxic	Desirable	No relaxation of this limit is allowed. To be tested, when pollution is suspected.
17.	Lead (as Pb), mg/l, Max	0.1	Beyond this limit, the water becomes toxic.	Desirable	No relaxation being a health parameter. To be tested when pollution/plumbo-solvency is suspected.
18.	Zinc (as Zn) mg/l, Max	5	Beyond this limit it can cause astringent taste and an opalescene in waters.	Desirable	May be relaxed upto 15. To be tested when the pollution is suepended.
19.	Chromium (as Cr^{6+}) mg/l, Max	0.05	May be carcinogenic above this limit.	Desirable	No relaxation. To be tested when pollution is suspected.

Table 5.2: Tolerance Limits for Industrial Effluent Discharged [BIS:2490 (Part I), 1981]

Sl.No.	Characteristics	Into inland surface water	Into public sewer	On land for irrigation	Into marine coastal areas for process waste water
1.	Dissolved solids (mg/l)	2100	2100	2100	-
2.	pH value	5.9-9.0	5.5-9.0	5.5-9.0	5.5-9.0
3.	Amm. Nitrogen as (N)) (mg/l)	50	50	-	50
4.	BOD 3 days at 27°C (mg/l)	30	350	100	100
5.	COD (mg/l)	250	-	-	250
6.	Lead (Pb) (mg/l)	0.1	1.0	-	0.01
7.	Cadmium (Cd) (mg/l)	2.0	1.0	-	2.0
8.	Total Chromium (Cr) (mg./l)	2.0	2.0	-	2.0
9.	Zinc (Zn) (mg./l)	5.0	15	-	15
10.	Chloride (mg/l)	1000	1000	600	-
11.	Sulphate (mg/l)	1000	1000	1000	-
12.	Sulphide (mg/l)	2.0	-	-	5.0
13.	Dissolved phosphate as(P) (mg/l)	5.0	-	-	-
14.	Free Ammonia	5.0	-	-	5.0

Surface Drainage

A detailed account of different drains with their feeding channels is quite relevant before discussing the inventory of polluting sources. As such, it was observed during field visits that following drains (locally called nalas) constitute the feeding channels to the two major drains - Dhamola and Paondhoi nalas in the study area (Fig. 5.1) :

i. Kamela Nala: The 'Kamela Nala' originating from Pratap Nagar and passing through Kamela colony carries the effluents from the slaughter house (located on Kamela road), Government wood seasoning plant and several lime kilns. This nala passes through the city and ends up near Ramnagar-Pathanpura area to meet the Dhamola nala (Plate 5.1).

ii. Baroon Jat Nala : This Nala originates near Sharda Nagar and joins the Kamela nala near Anand Nagar.

iii. Cargie Nala: This nala meets the Kamela nala near Lohani Sarai.

iv. Androom Nala: Androon nala has its origin near Rani Bazar and meets the Kamela nala near Sarai Gariban.

v. Islamia Nala: Islamia nala also originates near Rani Bazar and joins Kamela nala towards southwest of Islamia Inter College.

vi. Chakrata Road Nala: Chakrata road nala originates in north of M.S. College near Madhav Nagar and meets the Paondhoi nala near Keshav Nagar.

vii. D M Residence Nala : D.M. residence nala originates close to Bajoria road and meets the Dhamola near Kapil Vihar.

viii. Railway Road-Clock Tower-G.P.O. Road Nala : This is also a small drain carrying the urban runoff of the central part of Saharanpur city. Finally they joins to Dhamola Nala.

A majority of the above cited drains (nalas) also carry urban and industrial runoff along with the storm water runoff.

TABLE 5.3 : Quality Parameters Monitored for Ground Water and Surface Water.

Parameters	Unit
Physical :	
Temperature (water)	°C
pH	-
Conductivity	Micromhos/cm
Total dissolved solids	mg/l
Total suspended solids	mg/l
Chemical :	
Dissolved oxygen*	mg/l
Biochemical oxygen demand(3 days at 27°C)*	mg/l
Chemical oxygen demand*	mg/l
Total Hardness (as $CaCO_3$)	mg/l
Calcium (Ca^{++})	mg/l
Magnesium (Mg^{++})	mg/l
Sodium (Na^+)	mg/l
Potassium (K^+)	mg/l
Nitrate (as N)	mg/l
Chloride (as Cl^-)	mg/l
Sulphate (As SO_4^{--})	mg/l
Total Alkalinity (as $CaCO_3$)	mg/l
Bicarbonate (as $CaCO_3$)	mg/l
Carbonate (as $CaCO_3$)	mg/l
Ammonia – N(as N)	mg/l
Total Kjeldahl Nitrogen (as N)	mg/l
Oil & Grease	mg/l
Total Iron (as Fe)	mg/l
Cadmium (as Cd)	mg/l
Lead (as Pb)	mg/l
Nickel (as Ni)	,g/l
Copper (Cu)	mg/l
Total Chromium (as Cr)	mg/l
Manganese (Mn)	mg/l
Total Phosphate (as P)	mg/l
Ortho Phosphate (as P)	mg/l
Poly Phosphate (as P)	mg/l
Biological	
Total Coliforms	No./100 ml
Fecal Coliforms	No./100 ml

* for surface water only

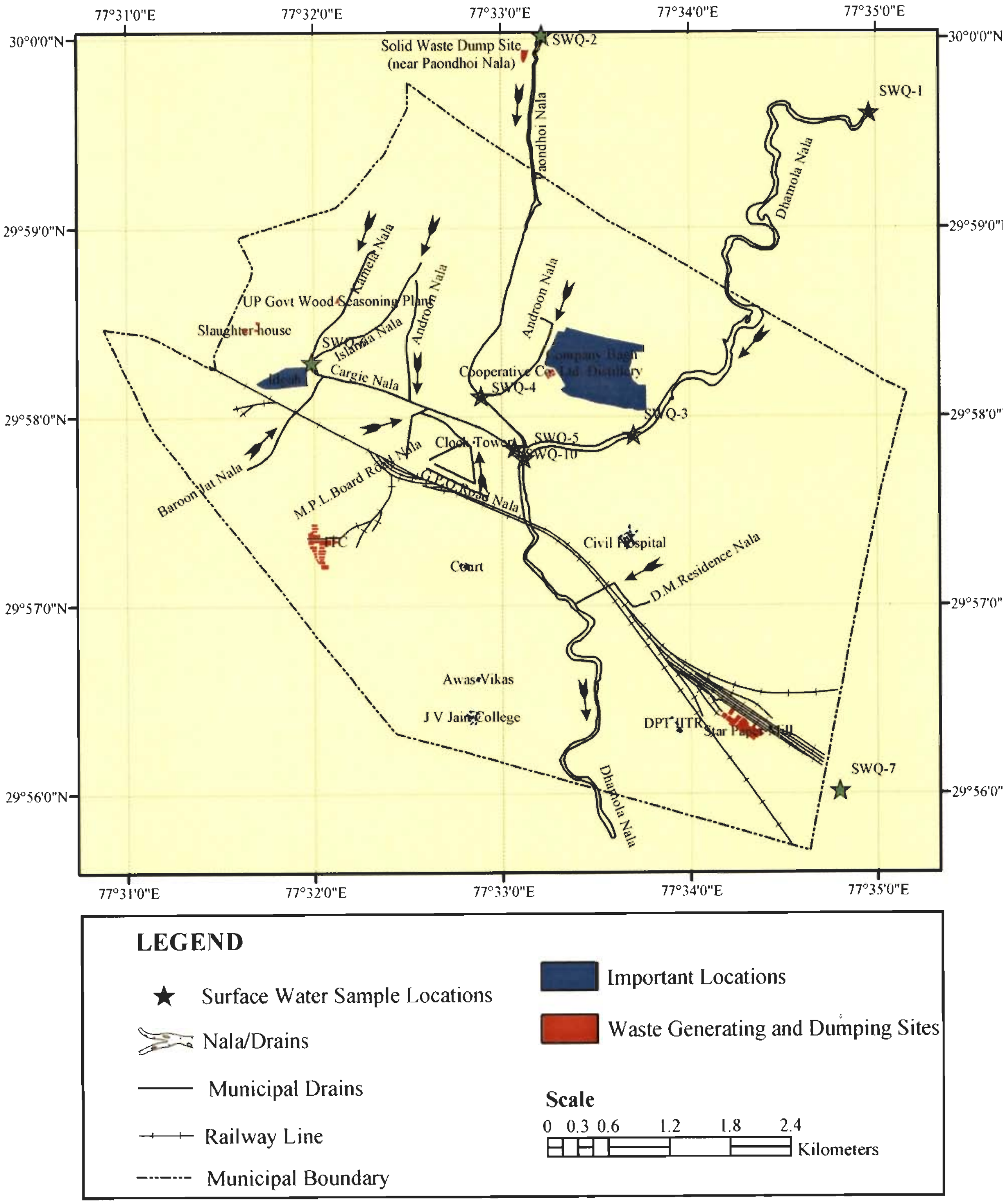


Fig. 5.1; **Location Map of Surface Water Samples, Solid Waste and Spread out Nonpoint Samples (SWQ 8 for Residential Area and SWQ 9 for Commercial Area)**

5.2 Inventory of Polluting Sources

As the goal of present work is to frame guide lines for designing the groundwater quality monitoring network to protect groundwater resource in the Saharanpur city from pollution by different sources, three types of the pollution sources have been inventoried in this study :

(i) Point sources

(ii) Line sources

(iii) Non point sources of pollution

(i) **Point sources** : Outfalls of waste effluent from individual industrial units, Star Paper Mill, Indian Tobacco Company, sewage pumping station and other units dealing with chemicals, rubber and electroplating etc. are included in point sources.

(ii) **Line sources** : e.g. Dhamola, Paondhoi and Kamela drains etc.

(iii) **Non point sources of pollution** : These include the urban storm water runoff and normally consist of the runoff which may originate from natural processes such as rainfall affected by human activity such as crop and lawn irrigation, human washings etc. Such sources of pollution are usually spread out over large areas. It is often difficult to trace the exact origin of the nonpoint pollution because they result from a wide variety of human activities carried out under influence of varying natural characteristics of soil, climate, and topography. Keeping these factors in view, the urban nonpoint sources of pollution in present study area have been divided into residential and commercial types of urban storm water runoff. The samples from residential runoff were obtained by combining a number of grab samples taken from drains traversing the residential areas in the city. On the other hand, the sampling of commercial (urban) runoff was accomplished by combining several samples of urban runoff taken in the commercial/market areas of the city.

A total of ten samples of surface water were collected from the point sources, from the principal drains in the city and from the urban storm water runoff (residential and commercial) during December 2006 at locations shown in figure 5.1. The drains included the Dhamola (SWQ-1 & SWQ-3), Paondhoi (SWQ-2 & SWQ-4) and Kamela nala (SWQ-6) and areas downstream of the confluence of Paondhoi and Dhamola (SWQ-5) (Fig. 5.1). The industrial effluent from point sources covered in this study included the wastes from Star Paper Mill (SWQ-7). Besides, the raw sewage was also sampled from the sewage pumping station (SWQ-10) in the central part of city. However, it may be mentioned that as the storm water runoff for residential and commercial areas was sampled (SWQ-8 and SWQ-9) by mixing several grab samples from the spread out areas, it is not possible to pinpoint their locations.

5.3 Waste Generation

As mentioned earlier, there are three principal sources of waste generation in Saharanpur city.

1. Sewage generated by the human population and pumped to the sewage treatment plant.
2. Industrial waste effluents from Star Paper Mill, Indian Tobacco company (ITC) and slaughter house.
3. Solid wastes derived from daily disposals by the populace and industries.

(1) Sewage Generation :

As per the data supplied by U.P. Jal Nigam, a Govt. Department, an agency operating under Yamuna Action Plan, a total of 32.64 MLD/day (Million Litre/Day) of sewage is being treated currently by a UASB type treatment plant which has a capacity of treating 38 MLD of Municipal waste/day.

As per the said source, the raw influent sewage fed into the treatment plant has following characteristics:

S.N.	Sample type	TSS (mg/l)	BOD (mg/l)	Remarks
1.	Influent sewage	276	180	Monthly average
2.	Effluent sewage	43	25	Monthly average

Details of Total Coliform and Fecal Coliform present in the sewage are as under :

S.N	Sample type	Total MPN/100 ml	Fecal Coliform/100 ml	Remarks
1.	Inlet sewage (raw)	7.8×10^5	6.9×10^5	Monthly average
2.	Polishing Pond	5.9×10^4	5.6×10^4	Monthly average
3.	Outlet sewage (effluent)	9.5×10^3	9.2×10^3	Monthly average

As per Saharanpur Municipal Corporation (personal communication), all the sewage is carried through underground pipes buried 12-13 ft. beneath the ground surface and discharged directly into the Dhamola drain.

(2) Industrial Wastes :

The effluents generated from the main industries are of the following type :

(i) Paper Mill Waste : This waste is mainly generated from the Star Paper Mill. The total effluent discharged from paper mill is of the order of 32814 m^3/day with the paper production capacity of the mill being of the order of 250 metric ton/day of writing and printing paper (the maximum capacity being 300 metric ton/day). The waste effluent from the paper mill is reported to be provided a secondary level treatment employing ASP Technique.

(ii) Indian Tobacco Company (ITC), Saharanpur : This Tobacco industry produces branded cigrattes upto 50 million cigrattes per day. The process involves consumption of considerable amounts of water as under :

Water used in Industrial cooling	7133 m^3/month
Factory use	5022 m^3/month
Worker colony	8308 m^3/month
Processing	1244 m^3/month
Total water consumed	21710 m^3/month

The treatment of the waste effluent is carried out by using compressed air for aeration. The details of the quality characteristics and quantity of waste effluent generated from the Tobacco factory are not available.

(iii) Animal-Slaughter house effluent : The effluent from this unit has a direct outfall into the Kamela drain severely affecting its water physically and chemically. However,the chemical characteristics of this effluent are not available except its apparent blood red color as visible after its outfall into the Kamela drain which carries the distinct colored liquor, with foul odours apparently due to low D.O. and high organic loads.

Besides these, there are several small scale industrial units like electroplating, fabricating, painting and dyeing operating from home or small sheds in commercial areas, which also discharge their liquid wastes in the existing drains/sewage system.

(3) Solid Wastes :

As per the sources of Municipal Corporation, Saharanpur a total of 280 tons/day of dry solid waste is generated in the city out of which 230 tons/day is comprised of Municipal waste and 50 tons/day of wastes of miscellaneous nature contributed by a variety of sources including scattered small scale industrial units.

Table 5.4 (A); Physico-chemical Analysis of Surface Water Samples, Saharanpur City (Dec. 2006)

PARAMETERS	CITY DRAINS UP-STREAM PART		DRAINS IN CENTRAL CITY				INDUSTRIAL EFFLUENTS	URBAN STORM WATER		RAW SEWAGE	LEACHATE	BIS : 2490
	Dhamola U/S (SWQ-1)	Paondhoi U/S (SWQ-2)	Dhamola D/S (SWQ-3)	Paondhoi D/S (SWQ-4)	Confluence(SWQ-5)	Kamela Drain (SWQ-6)	Star Paper effluent (SWQ-7)	Residential (SWQ-8)	Commercial (SWQ-9)	Raw Sewage (SWQ-10)	Solid Waste (L1)	
Temp^{0}C	16.800	17.800	19.70	19.90	18.50	18.40	26.200	19.200	19.100	18.300	NA	
pH	8.050	8.000	7.56	7.52	7.26	7.13	7.620	7.350	7.600	7.420	7.70	5.5-9.0
EC(umhos/cm)	580.000	300.000	783.00	603.00	983.00	3530.00	2063.000	890.000	1056.000	1060.000	1861.00	
TDS(mg/l)	348.000	180.000	470.00	362.00	590.00	2118.00	1238.000	534.000	634.000	636.000	1210.00	2100
TSS(mg/l)	6.000	26.000	18.00	78.00	212.00	554.00	402.000	52.000	110.000	92.000	38.00	
DO(mg/l)	5.500	7.800	0.80	2.00	0.90	NIL	NIL	1.100	0.700	1.000	NA	
BOD(mg/l)	31.420	10.000	60.00	32.00	96.66	510.00	70.000	96.000	147.000	110.000	NA	30
COD(mg/l)	110.000	60.000	320.00	240.00	300.00	1540.00	300.000	110.000	240.000	160.000	NA	250
Total Alkalinity(mg/l)	180.000	388.000	260.00	228.00	262.00	552.00	288.000	214.000	316.000	304.000	48.00	
HCO_3(mg/l)	177.890	386.550	259.23	227.32	261.51	551.34	286.920	213.490	314.820	303.280	47.77	
CO_3(mg/l)	0.110	1.450	0.77	0.68	.0.49	0.66	1.080	0.510	1.180	0.720	0.23	
SO_4(mg/l)	125.090	176.120	182.70	213.98	215.62	279.82	262.530	194.220	231.260	154.720	631.24	1000
Cl(mg/l)	15.000	10.000	57.00	40.00	72.00	360.00	274.000	79.000	97.000	68.000	596.00	1000
Total Hardness(mg/l)	276.000	204.000	350.00	266.00	312.00	456.00	504.000	294.000	366.000	306.000	656.00	
Ca(mg/l)	71.280	23.790	79.29	64.07	61.67	163.39	113.730	56.060	85.700	71.280	64.07	
Mg(mg/l)	55.260	16.020	12.62	25.74	38.36	11.66	53.420	37.390	36.910	31.080	120.44	
Na(mg/l)	12.500	10.400	56.30	65.40	68.80	101.80	120.400	89.200	102.600	49.800	235.00	
K(mg/l)	ND	ND	9.30	5.20	6.80	4.20	12.900	9.800	12.600	2.100	107.00	
Amm-N(mg/l)	0.560	0.560	13.72	19.88	36.96	33.04	0.560	38.640	52.920	45.360	11.20	50
TKN(mg/l)	1.960	1.680	15.12	22.12	39.48	35.00	1.960	41.440	56.000	46.480	16.80	
NO_3(mg/l)	2.010	1.890	3.68	7.62	5.62	20.34	31.260	6.310	8.930	7.790	74.00	
Total-P(mg/l)	3.105	2.131	43.70	45.63	68.16	138.63	42.260	55.360	58.640	65.210	54.28	
Ortho-P(mg/l)	1.992	1.208	38.73	40.22	61.92	134.84	38.040	51.420	53.850	62.310	51.76	
Poly-P(mg/l)	1.113	0.923	4.97	5.41	6.20	3.79	4.220	3.940	4.790	2.900	2.52	
Oil &Grease(mg/l)	0.028	0.017	0.0176	0.012	0.0116	0.036	0.0756	0.0116	0.0304	0.039	NA	
MPN/100ml	$12x10^2$	$17x10^2$	$50x10^3$	$30x10^3$	$110x10^2$	NA	NA	$23x10^2$	$90x10^3$	$170x10^3$	NA	
FecalColiform/100ml	Nil	Nil	$9x10^3$	$8x10^3$	$14x10^2$	NA	NA	$7x10^2$	$6x10^3$	$30x10^3$	NA	

Note: **NA= Not Available**

5.4 Quality of Surface Water

The results of chemical analysis of the surface water samples procured from the three main city drains, industrial effluents from the Star Paper Mill and the raw sewage alongwith urban storm water runoff are presented in Table 5.4(A) and 5.4(B).

Table 5.4 (B); Heavy Metals Analysis of Surface Water Samples, Saharanpur City (Dec. 2006)

PARAMETERS	CITY DRAINS UP-STREAM PART		DRAINS IN CENTRAL CITY				INDUSTRIAL EFFLUENTS	URBAN STORM WATER		RAW SEWAGE	LEACHATE	BIS: 2490
	Dhamola U/S (SWQ-1)	Pandhoi U/S (SWQ-2)	Dhamola D/S (SWQ-3)	Pandhoi D/S (SWQ-4)	Confluence (SWQ-5)	Kamela Drain (SWQ-6)	Star Paper effluent (SWQ-7)	Residential (SWQ-8)	Commercial (SWQ-9)	Raw Sewage (SWQ-10)	Solid Waste (L1)	
Cd(mg/l)	0.004	0.011	0.025	0.015	0.027	0.023	ND	0.006	0.001	0.030	0.025	2
Fe(mg/l)	ND	ND	0.016	0.002	0.057	0.661	0.954	1.014	0.184	0.235	1.140	
Cu(mg/l)	ND	ND	ND	ND	ND	0.007	ND	ND	ND	ND	0.950	
Zn(mg/l)	ND	ND	ND	ND	ND	0.111	0.054	ND	0.034	ND	0.093	5
Cr(mg/l)	0.027	0.031	ND	0.023	0.023	0.030	0.039	0.034	0.051	ND	ND	2
Ni(mg/l)	0.011	0.044	ND	ND	ND	ND	0.073	ND	ND	ND	0.033	
Mn(mg/l)	0.002	ND	0.004	ND	ND	0.329	0.009	0.178	0.166	0.201	0.013	
Pb(mg/l)	0.002	0.007	0.032	0.024	0.033	0.026	0.037	0.031	0.030	0.030	0.008	0.1

Note: **NA= Not Available**

Dhamola-Paondhoi Nala(s) :

The Tables 5.4(A) and 5.4(B) show that the quality of surface water in the two main city drains generally exhibits high BOD in most of the stretches, namely in the Dhamola and Paondhoi nala(s) in the central parts of the city (SWQ-3 & SWQ-4, Fig. 5.1) as the BOD is higher (60 and 32 mg/l) than the permissible limit (30 mg/l) laid down by BIS (Bureau of Indian Standards 2490) for surface discharge of effluents into surface drainage. However, in case of upstream stretch of Paondhoi nala near Khatakheri locality (SWQ2), the BOD of surface water in the Paondhoi stream is 10 mg/l, being well within the permissible BIS limit of 30 mg/l. Even in SWQ-1, in upstream part of Dhamola, it is only marginally high. As against this, in the stretches downstream of the confluence of Dhamola and Paondhoi (SWQ-5), the surface waters show high concentration of BOD of the order of 96.7 mg/l which is very high in comparison to the permissible standards. The total chemical oxygen demand (COD) generated due to the waste effluents in these streams is also in a very high range varying from 60 to 110 mg/l in the upstream parts of the nalas and in the range of 300 mg/l in the downstream part of the confluence of Dhamola and Paondhoi nalas (SWQ-5). The high values of BOD in the Dhamola and Paondhoi nalas are a combined effect of organic waste effluent loads released into these nalas through underground hidden drains. However, the cumulative effect of the waste outfalls in the Dhamola nala is best reflected in the stretch downstream of the confluence of the sewage outfall into it. The presence of total coliforms and Fecal coliforms have also been found to range quite high in the order of 9,000/100 ml to 14000/100 ml indicating high degree of pollution. This indicates direct contamination of the surface water in the city drains from the sewage. Amongst the toxic metals analysed, most of these are observed to be within the permissible BIS 2490 limits.The high ranges of BOD, COD and fecal coliforms in the surface water of the city drains highlight the integrated effects of organic waste loads generated both due to the sewage outfall and the hidden underground drains bringing industrial effluents. A very clear feature emerges that the level of contamination goes on increasing as these drains/streams traverse through the town. The magnitude of difference between the values of several water quality parameters mentioned in upstream of the town, in the midst and at the downstream has been observed to be substantial. Yet, it is difficult to apportion the relative impact of the municipal sewage and industrial units on the quality of the water in these drains as the demarcation between these is not clear.

Kamela/Cargie Nala(s) :

The chemical analysis of the effluents from the Kamela nala containing slaughter house wastes (Fig. 5.1) shows high concentration of organic waste load with the BOD and COD of the order of 510 and 540 mg/l respective in sample SWQ-6. The untreated nature of these waste effluents is also corroborated by the presence of high concentration of fecal coliforms, ammonical nitrogen and total phosphorous. The total dissolved solids and other physico-chemical constituents in the waste are also high of the order of 2010 mg/l (TDS), 456 mg/l (hardness), 138.6 mg/l (Total-P) respectively. The total suspended solids in the Kamela nala effluent are in the high range of the order of 554 mg/l and the oil and grease are found to be high above the BIS standard (0.01 mg/l). Out of the toxic metals, cadmium is observed to be in high concentration in this drain.

Raw Sewage

The quality of the raw sewage (SWQ-10) entering from the sewage pumping plant of Upper Yamuna Action Plan shows high values of BOD (110 mg/l) and low value of DO (1 mg/l) with the oil and grease in the range of .04 mg/l, high concentration of ammonical nitrogen (43.4 mg/l) and TKN as 46.48 mg/l. On the basis of the analysis, the sewage appears to be of moderate strength.

Paper Mill Effluent :

Although the waste effluent from the Star Paper Mill (SWQ-7) shows high concentration of organic loads both in terms of BOD (70 mg/l) and COD (300 mg/l), yet its effect on the quality of surface water within the city area may be considered as marginal as the drains from the paper Mill are falling in the southern downstream parts of the city. It may be seen that the dissolved oxygen in the paper Mill waste is nil implying the presence of oxygen deficient condition in the drain. Due to this reason, very foul odours are found to be emanating in the vicinity of the drain carrying the paper Mill waste. Similarly, the total suspended solids in the paper Mill effluent are found to be also high of the order of 400 mg/l.

Urban Storm Water Runoff

The urban storm water runoff of the residential (SWQ-8) and commercial area (SWQ-9) shows a high concentration of BOD in the range of 96 to 146 mg/l (in Dec. 2006) and COD in the range of 110 to 240 mg/l in Dec. 2006. The dissolved oxygen in the storm water runoff (0.7 to 1.1 mg/lit) is also very low. Further, trace metals like chromium and manganese are found in marginally high concentrations in the urban commercial runoff reflecting the influence of local industrial units.

It is worth noting that the concentrations of heavy metals like Pb, Cd, Ni, Cr, Cu, Mn, Fe, Zn in the surface waters of city drains and the storm water runoff are found to be generally within the permissible limits of BIS 2490 [Table 5.4(B)].

5.5 Quality of Ground Water

As mentioned earlier, the monitoring of ground water quality has been carried out in Saharanpur city at 19 sites where installed hand pumps were available at the borings tapping shallow unconfined aquifers (Fig. 5.2). The ground water pumped from deeper aquifers (>30m depth) for water supply through existing development tubewells has been analyzed only from two locations as it is reported to be generally of good quality. The sampling sites for shallow ground water are located throughout the study area in the vicinity of sources of suspected surface water pollution viz. point sources (near industrial units), line sources (near city-drains) and the nonpoint sources like residential-urban and commercial-urban areas. However, no new borings were planned and only existing borings installed with handpumps were picked up. Therefore, it has not been possible to cover all possible localities where pollution was suspected. The innovative procedure of sampling the ground water from such borings and their chemical analysis has been shown in a photograph (Plate 5.1).

The results of physico-chemical and heavy metal analyses of ground water for the years 2001-2002, 2004 and 2006 are given in Annexures 5.1(i) to 5.1(viii) and 5.2(i) to 5.2(viii) for the premonsoon and postmonsoon periods respectively. The data of Total Coliforms and Fecal Coliforms for the period 2006 for the selected analyzed samples is also included in these tables.

It is worth mentioning that the criteria for considering a parameter in higher concentration (than permissible BIS limits) has been considered in this study to be relevant only if more than 10% samples show excessive concentration of that parameter. In the present groundwater study, the number of such samples has been considered to be two or more as the total number of ground water samples was 19. Further, the quality parameters considered relevant for assessing the acceptability of water for a specified use like drinking are taken as fecal coliforms, cadmium, chromium, nitrate, sulphate, chloride and TDS in the decreasing order. Only these parameters are considered significant as heavy metals like lead, nickel, copper, manganese etc. are present within permissible BIS limits, or have only marginal or cosmetic adverse effects on users. Further, high TDS, hardness and alkalinity may not cause adverse effects on the health of users and their high concentration is related to their natural origin. Besides, separate discussion of Electrical Conductivity (EC) and cations like Ca^{++}, Mg^{++}, Na^{+} & K^{+}, HCO^{-}_{3} and CO^{-}_{3} has not been attempted here as other related parameters have been considered in the discussion. Further, some of these are not listed in the BIS guidelines laid down for ground water for drinking purposes.

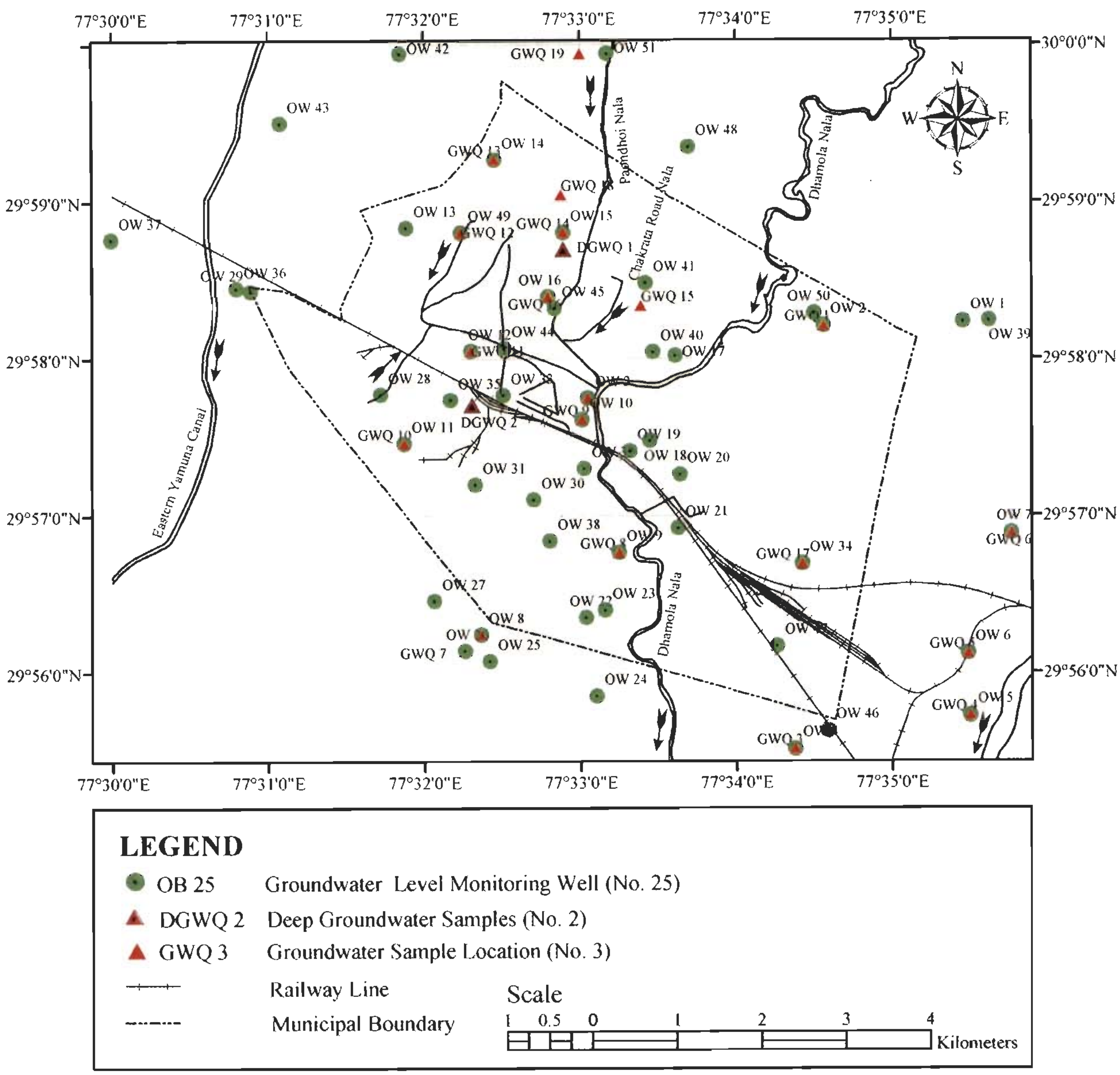


Fig. 5.2; Location Map of Groundwater Samples

For effective representation of quality parameters, various pictorial diagrams have been prepared by plotting the epm concentrations of the anions and cations after their accuracy checks by ion balancing method. Those analyses which showed excessive difference between cations and anions in the ground water samples have not been considered in the interpretation of quality data. The maximum percentage difference in the sum of cations and anions which has been allowed in the analytical data is of the order of 10-15% of the sum of ions.

The methods of pictorial representation of ground water quality data used in the present study are the Bar diagrams and Piper Trilinear diagrams. These methods have been chosen as they are able to provide a synoptic and temporal idea of the groundwater quality characterization as well as nature of salinity present therein.

Trilinear Plots :

The Pipe Trilinear diagrams for years (2001 to 2006) are given in Fig. 5.3(A)&(B) to Fig. 5.6(A)&(B). It is seen from these figures that the majority of the ground water samples (35 Nos) for premonsoon periods fall in Area 9 of the diamond shaped field of Piper diagram for all the four years indicating that they have intermediate composition with no dominant cation-anion pair (Mathess, 1982). However, ground water samples have dominant 'Secondary Salinity' (falling in Area 6 of the diamond shaped field) indicating thereby that non-carbonate hardness exceeds fifty percent in ground water. The remaining ground water samples (12 Nos.) have dominant carbonate hardness (implying presence of secondary alkalinity) as they belong to Area 5 of the diagrams. However, during postmonsoon period, the character of ground water is changed drastically. It is seen from the Fig. 5.3(B) to 5.6(B) that majority of samples (24 Nos) fall in Area 5 of the diamond shaped field implying dominating secondary alkalinity (i.e. carbonate hardness). Further, 22 samples lie in Area 9 indicating intermediate character of the ground water whereas 19 samples still lie in Area 6 indicating dominant noncarbonate hardness. The overall chemical character of the ground water is given in Table 5.5.

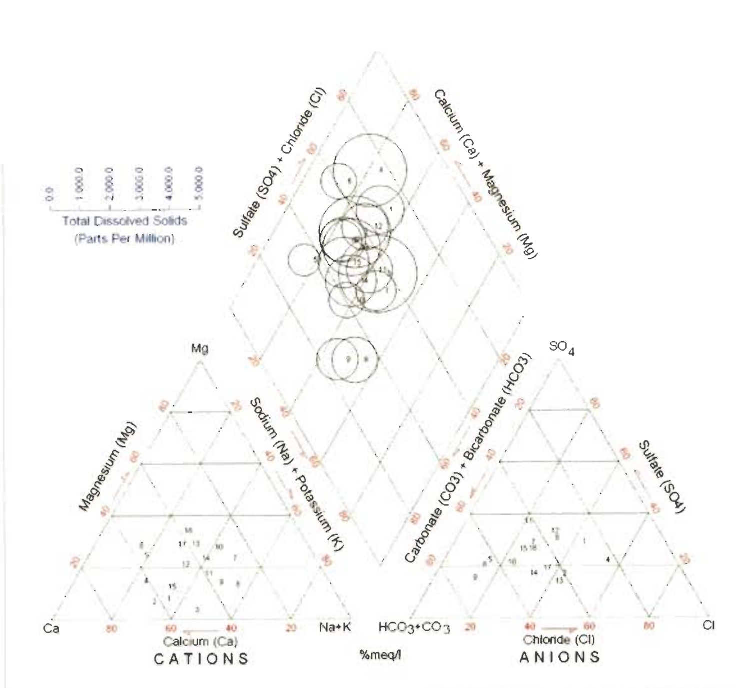


Fig. 5.3 (A); Piper Trilinear Diagram (Premonsoon 2001)

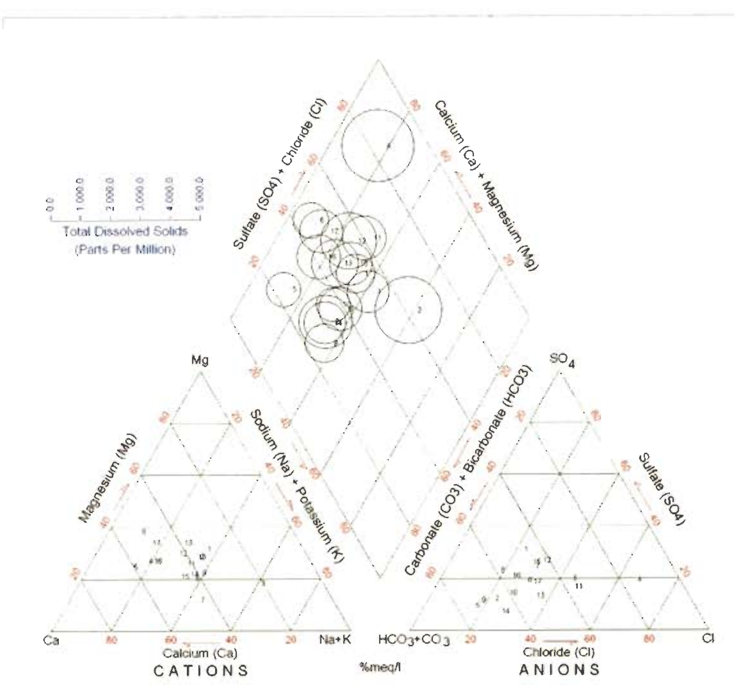


Fig. 5.3 (B); Piper Trilinear Diagram (Postmonsoon 2001)

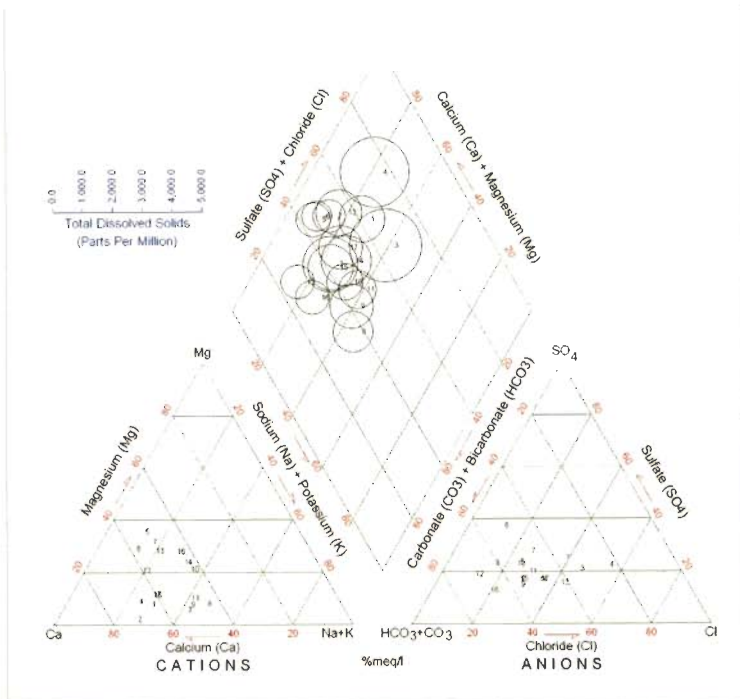


Fig. 5.4 (A); Piper Trilinear Diagram (Premonsoon 2002)

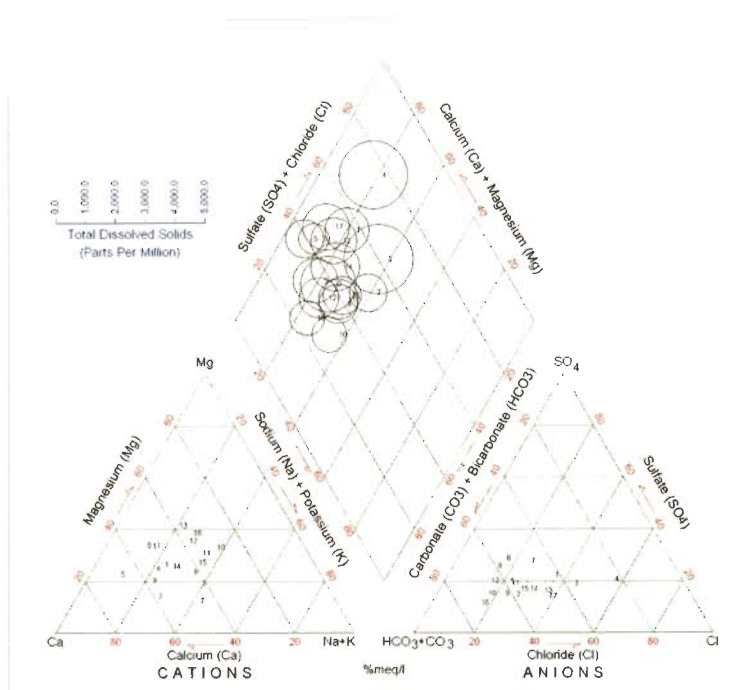


Fig. 5.4 (B); Piper Trilinear Diagram (Postmonsoon 2002)

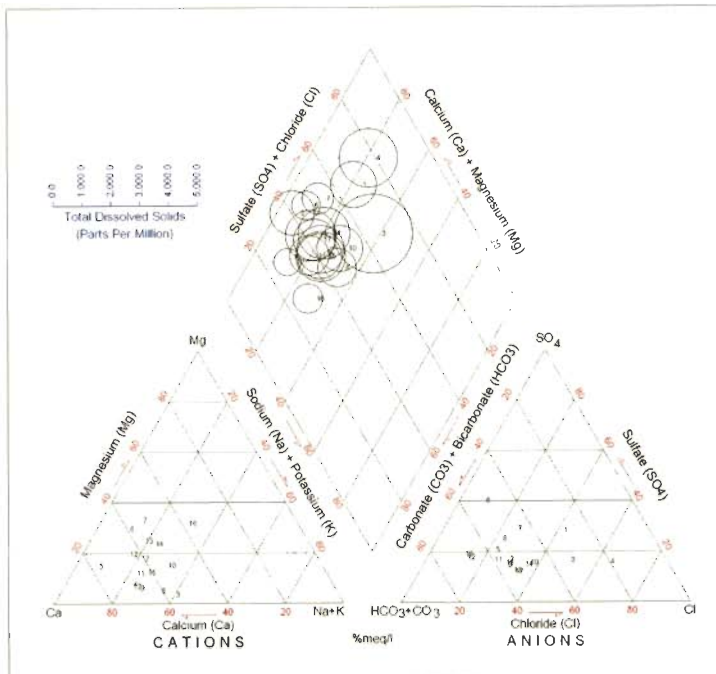


Fig. 5.5 (A); Piper Trilinear Diagram (Premonsoon 2004)

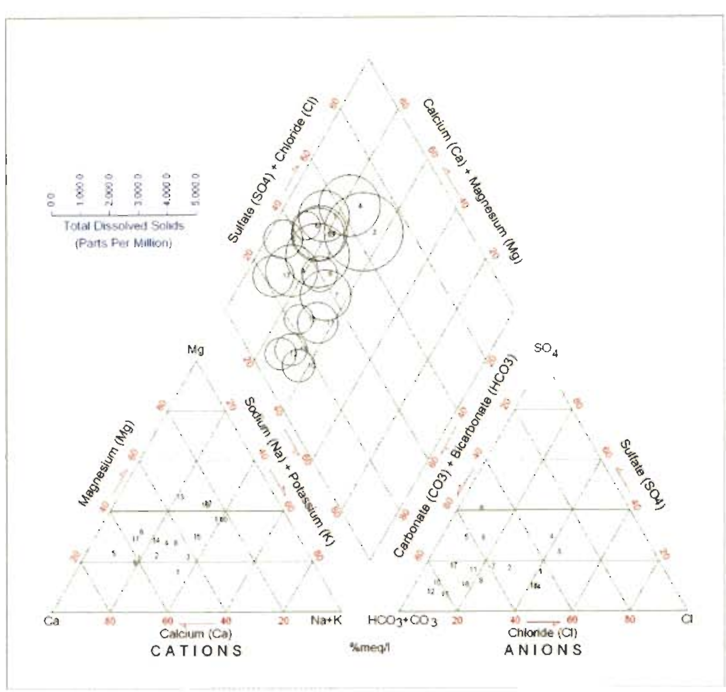


Fig. 5.5 (B); Piper Trilinear Diagram (Postmonsoon 2004)

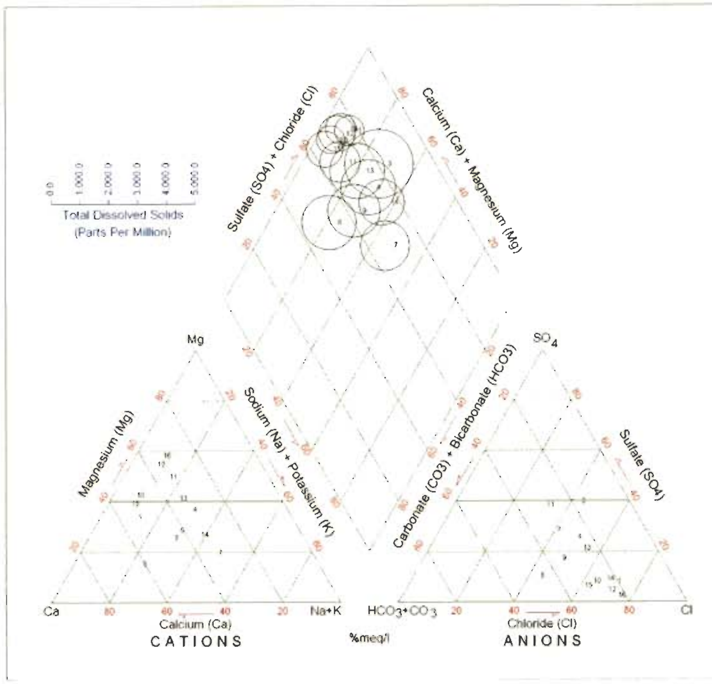


Fig. 5.6 (A); Piper Trilinear Diagram (Premonsoon 2006)

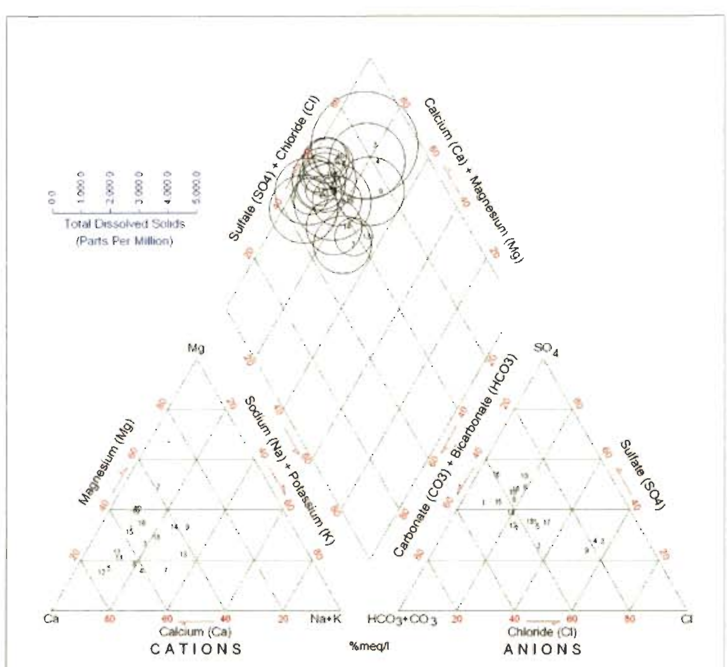


Fig. 5.6 (B); Piper Trilinear Diagram (Postmonsoon 2006)

Table 5.5: Chemical Character of Ground Water

Years	Premonsoon period				Postmonsoon periods			
	Area	5	6	9	Area	5	6	9
2001		4	3	10		5	2	9
2002		3	2	10		9	3	5
2004		3	3	10		10	2	4
2006		2	9	5		-	12	4
Total (all years)		**12**	**17**	**35**		**24**	**19**	**22**

Area 5 = Secondary alkalinity (Carbonate hardness exceeds 50%)

Area 6 = Secondary salinity (Non-carbonate hardness exceeds 50%)

Area 9 = Intermediate composition.

A. Physico-chemical Analysis

The physico-chemical analysis of the ground water samples mainly includes the total dissolved solids TDS and EC, cations (Ca^{++}, Mg^{++}, Na^{+} & K^{+}) and anions (Cl^{-}, HCO_3^{-}, CO_3^{--} SO_4^{--}) nutrients like NO_3^{-}, total phosphate, besides the physical attributes like pH. It may be mentioned that the major physicochemical parameters of ground water samples have been compared for years 2004 and 2006, and accordingly their variations have been shown by bar diagrams in Fig. 5.7 and 5.8.

Total Dissolved Solids (TDS)

Generally, it is observed that the total dissolved solids (TDS) of the groundwater vary in the ranges 234-1514 mg/l [Annexure 5.1(i) to 5.1(viii)]. The majority of the samples show higher TDS in terms of Bureau of Indian Standards (BIS:10500) in premonsoon also as well as during postmonsoon periods as the TDS ranges between 320-1600 mg/l. Especially, during year 2004, the ground water samples show high overall salinity at 15 locations barring GWQ 12 & 16 during premonsoon period (Fig. 5.7). Likewise, during postmonsoon 2004, high TDS is observed at 11 locations. However, the general range by which the TDS exceeds the BIS limit during both the periods is not indeed very large in terms of national and international guidelines and its effect can be considered cosmetic only as the populace of the town has virtually adjusted to these ranges of TDS in drinking water without experiencing visible harmful effects. Similarly, during 2006, five (out of thirteen) samples show TDS exceeding its limit in premonsoon period and thirteen (out of eighteen) samples have high TDS during postmonsoon period (Fig. 5.8). Further, the salinity in the postmonsoon period shows a general increase over that in premonsoon season which is difficult to explain. One of the reasons could be the higher concentration of salts (like Calcium and Magnesium) in recharged waters percolating through the Bhabhar zone in the north (Rao et al., 2000). Such incoherencies not withstanding, the overall impact of such marginally high salinity is to impart saline taste to the drinking water, but marginally high TDS may not warrant rejection of the ground water merely on basis of this single parameter and TDS values upto extended limit of 3000 mg/l in ground water may be recommended for drinking in the absence of alternate sources (BIS:10,500).

Hardness (as $CaCO_3$) :

Among the physico-chemical parameters, 'hardness' seems to be a significant factor for acceptance of ground water for drinking. Use of hard water in drinking may cause problem of indigestion to users besides formation of encrustations in the water supply pipes. However, in the absence of alternate sources, the BIS limit (of 300 mg/l) may be extended upto 600 mg/l. The hardness is contributed by 'Ca' and 'Mg' which seem to be high at almost all the places in the city in the premonsoon (and postmonsoon) samples during all the years of study. The range of $CaCO_3$ hardness found in the ground water of the town varies from 228 to 760 mg/l in premonsoon and 258 to 1212 mg/l in postmonsoon period. It is seen that $CaCO_3$ hardness is found to be higher than BIS limit (300 mg/l) almost in all localities during the 4 years of sampling [Annexure 5.1(i) to 5.1(viii)]. The probable cause for excessive hardness appears to be the source rocks in the Himalayan foot hills towards north from where ground water is recharged through the Bhabar zone. This is corroborated by the general increase of hardness of the ground water in postmonsoon samples. Such sources of recharge for deep ground waters have been proposed and confirmed by Rao et al. (Op cit). As the sequence of rock formations found in Siwalik hills is rich in carbonate rocks, it may not be far fetched to imagine that Ca^{++} and Mg^{++} ions may get leached and removed in the recharged ground waters towards the Bhabhar and Tarai zones, more so in the postmonsoon period(s).

Nitrates (NO_3^-):

Nitrate (NO_3) is another sensitive parameter for ground water quality in case of drinking waters. Its presence in drinking water consumed by females in high concentrates may cause 'Blue baby syndrome' or methemoglobinemia disease in their newly born infants. Its maximum limit permissible as per BIS (10500) is 45 mg/l as NO_3 [Annexures 5.1(i) to 5.1(viii)]. The range of nitrate concentration observed in the ground water of the area varies between 1.7 to 80.0 mg/lit in premoonsoon period and between 11.1 to 89.5 mg/lit in postmonsoon season for years 2004 & 2006. The values of nitrates during 2001 & 2002 have not been considered due to inconsistencies. This parameter is found to be in concentrations higher than BIS limits in a number of samples in both the years (Fig. 5.7 & 5.8).

Sulphate (SO_4^{--}) :

Sulphate is a sensitive physico-chemical parameter for ground water used for drinking purposes. The highest permissible limit as per BIS:10500 standards is 200 mg/l. If the concentration is higher beyond the permissible limits, it may cause the gastrointestinal problem in users especially when Mg^{++} and Na^{+} are also present in water. It is observed that the value of sulphate observed in premonsoon periods varies in the range of 50.6-297.1 mg/l and 44.8-409.0 mg/l in postmonsoon periods [Annexures 5.1(i) to 5.1(viii)]. During 2004, the sulphate concentration in ground water is observed to be higher than BIS limit only at two localities viz. GWQ-3 (Sheikhpura Qadim) and GWQ-4 (Pairagpur) in the postmonsoon period. However, in premonsoon period of 2006, the ground water at Mahipura (GWQ-1), Sheikhpura Qadim (GWQ-3), Pairagpur (GWQ-4), Govind Nagar (GWQ-9), Sabari ka Bagh (GWQ-12), Muna Lal Degree College (GWQ-13), Arabi Madarsa (GWQ-14), Company Bagh (GWQ-15) and Shahid Ganj (GWQ-16) is found with higher concentration of sulphate than permissible limits (Fig. 5.8). Further, in the postmonsoon season samples also, it is found in higher concentration at most of the above localities as well as at Haqiquat Nagar (GWQ-8), Wazir Vihar (GWQ-10), Patel Nagar (GWQ-11) and HAV Inter College (GWQ-18).

Chloride (Cl^-) :

The permissible limit of chloride is 250 mg/l and may cause bad taste and may effect palatability among the users if taken in higher concentration. Besides, its high values also indicate possible fecal contamination. The ranges of chloride for premonsoon periods of different years is found in the range of 16.0-360.0 mg/l and between 6.0 to 434.9 mg/l in the postmonsoon period as given in Annexure 5.1(i) to 5.1(viii) and shown in Fig.5.7 & 5.8. It is found to be generally within the limits permitted by BIS Standards except at few localities in the southern parts of the city near Sheikhpura Qadim (GWQ-3) Pairagpur (GWQ-4) and Govind Nagar (GWQ-9) especially in the samples of year 2006.

Total Alkalinity :

The permissible limits of Alkalinity is 200 mg/l as per Indian standards. It is observed from the Annexure 5.1(i) to 5.2.(viii) and Fig. 5.7 & 5.8 that concentration of total alkalinity is found high at most of the places in all the years. The alkalinity varies in the ranges of 128-500 mg/l and 190-520 mg/l in premonsoon and postmonsoon periods respectively in the four years mentioned earlier. However, high concentration of alkalinity in drinking water is not known to cause any direct noticeable effects on the human health.

Total phosphorous:

This is a nutrient but its tolerance limits have not been laid down in the BIS guidelines. Its concentration in the ground water lies in the range 0.008-1.913 mg/l in premonsoon and 0.017-0.494 mg/l during postmonsoon periods [Annexure 5.1(i) to 5.1(viii)].

pH and Temperature:

The pH of the shallow ground water is within the desirable limits and its range is between 6.79-8.3 which is well with in the recommended range. Similarly, the temperature of ground water in field conditions ranged between 23 to 27°C which is considered acceptable range.

B. Heavy Metals

The temporal variation of selected heavy metal concentration (viz. Cd, Cr, Cu, Mn, Pb, Ni, Zn and Fe) in ground water samples during 2004 and 2006 is given in Annexures 5.2(i) to 5.2(viii) and is shown in Fig. 5.9 to 5.11. Their description is given in the following paragraphs:

Cadmium (Cd^{++}) :

The higher concentration of Cadmium is more toxic for human health and causes disorder of kidney and lungs. As seen from the Annexures [(5.2(i) to 5.2(viii)], the concentration of the cadmium in ground water is higher than the safe prescribed limits (0.01 mg/l) for drinking water (BIS:10500) at a number of places namely Mahipura (GWQ-1), Sheikhpura Qadim (GWQ-3), Pairagpur (GWQ-4), Ghogreki (GWQ-6), Hasanpur (GWQ-7), Hakiqat Nagar (GWQ-8), Wazir Vihar (GWQ-10) and Patel Nagar (GWQ-11). Fig. 5.9 shows that relatively higher concentrations are found at 7 sample locations in year 2004 and 8 locations in year 2006. The concentration of cadmium for premonsoon and postmonsoon periods (years 2004 and 2006) are in the range of 0.0-0.056 mg/l and 0.0-0.029 mg/l. The reason of higher concentration at these places appears to be due to the discharge of waste

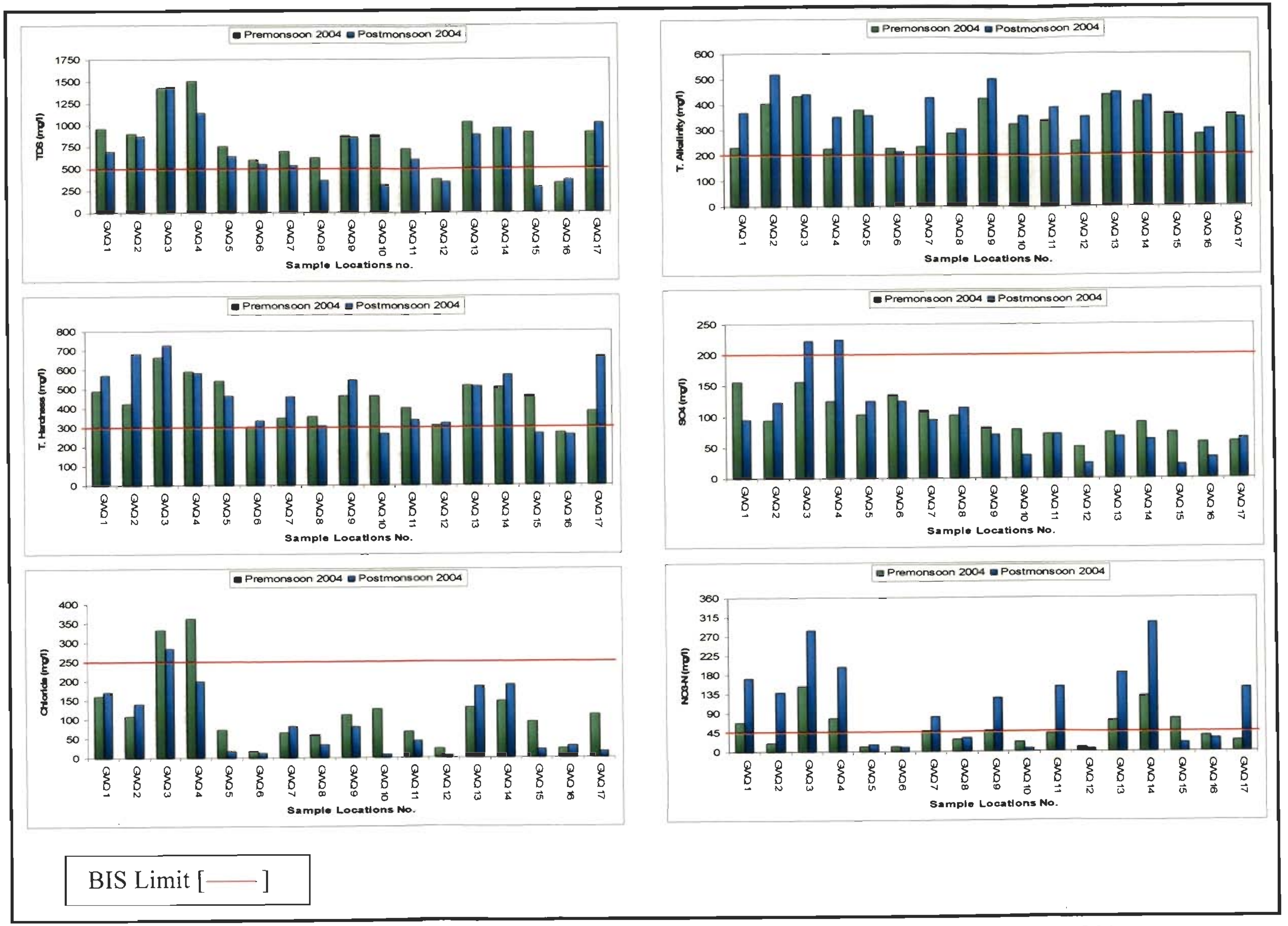


Fig. 5.7; Bar Diagram Showing variation of Physico-chemical Parameters of Groundwater (Year 2004)

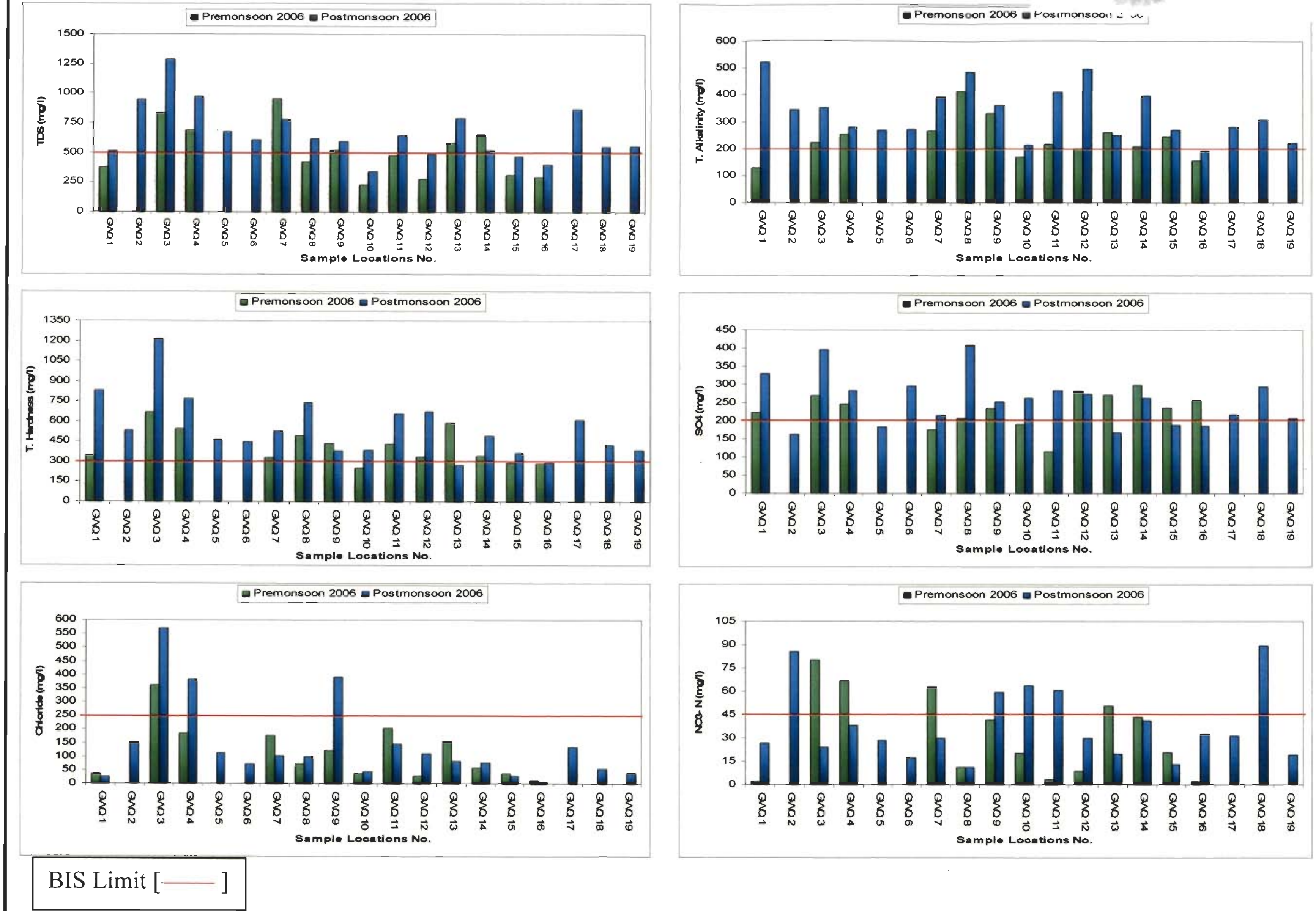


Fig. 5.8; Bar Diagram Showing variation of Physico-chemical Parameters of Groundwater (Year 2006)

effluents from various scattered industrial units directly into the nearby drains. Especially at locations like Sheikhpura Qadim (GWQ-3), Pairagpur (GWQ-4), the high Cd concentration may be explained due to the proximity of these locations to discharging areas of paper mill effluent. Another place of higher concentration of Cd is found in the Haqiquat Nagar (GWQ-8) which is close to the Dhamola drain. Similarly, Patel Nagar (GWQ-11) is near the Kamela drain which carries waste from the slaughter house and other units.

Total Chromium (Cr) :

The high concentration of Cr may cause carcinogenic effect amongst the users. The waste effluents generated by the electroplating units in the town are disposed directly into the nearby drains. The concentration of chromium for periods 2004 (premonsoon and postmonsoon) is observed to be under permissible limit (0.05 mg/l) prescribed by BIS: 10500 almost at all the locations as given in Fig.5.10. However, its high concentration is found at one location viz. Wazir Vihar (GWQ-10) in premonsoon 2006 out of two measurements. On the other hand, during postmonsoon period (2006) higher values of chromium have been observed at eight locations namely Mahipura (GWQ-1), Pairagpur (GWQ-4), Dudhali Bhukara (GWQ-8), Hakiquat Nagar (GWQ-8), Govind Nagar (GWQ-9), Wazir Vihar (GWQ-10), Sabri Ka Bagh (GWQ-12), Munnalal College (GWQ-13) and Shahid Ganj (GWQ-16) as shown in Fig.5.10. The main source of contamination of ground water due to chromium can be direct dumping of the industrial effluents into the nearby drains in the city area where electroplating units are common.

Copper (Cu^{++}) :

The higher concentration of Cu in drinking water may cause astringent taste in water, discoloration and corrosion of water supply pipe fitting etc. It is seen from the Annexure 5.2(viii) that Cu is found in higher concentration than the permissible limits (0.05 mg/l) laid down by BIS:10500 at a number of localities though the analysis is available for year 2006 only. However, the BIS limit can be relaxed upto 1.5mg/l. The higher concentration of Cu have been observed in premonsoon and postmonsoon periods at Haqiquat Nagar (GWQ-8) which is close to the Dhamola drain. As indicated in Annexure 5.2 (viii) the higher values of Cu are also found at Mahipura (GWQ-1), Pairagpur (GWQ-4), Dudhali Bhukara (GWQ-5), Ghogreki (GWQ-6), Wazir Vihar (GWQ-10) and Company Bagh (GWQ-15). The main reason of the high concentration of copper in ground water can be due to the direct discharge of waste effluents in the nearby drains within the crowded urban complex. Another important factor can be disposal of solid wastes from which leachates are generated.

Manganese (Mn^{++}) :

High concentration of Mn can cause the change in taste/appearance and has the adverse effect on domestic uses and the water supply infrastructure.The concentration of Mn is found in the range of 0.001-0.395mg/l and 0.026-1.011mg/l in premonsoon and postmonsoon period during different years as given in (Annexures 5.2(v)to5.2(viii) and shown in Fig.5.11. From the present study, the values of manganese are observed to be higher than the safe limit of 0.1 mg/l (extendable upto 0.5mg/l) at 11 locations. The high values (1.011 mg/l) found at Mahipura (GWQ-1) and other locations may be due to the dumping of solid and liquid wastes which may cause generation of leachates with high concentration of manganese. Yet, manganese is not considered a hazardous pollutant due to its extendable safe limit.

Lead (Pb^{++})

The concentration of lead was determined by analyzing the ground water samples during postmonsoon, 2004 and 2006 (both premonsoon and postmonsoon periods). However, its concentration was found well within the BIS limit (less than 0.1 mg/l) except in GWQ-19 [Annexure 5.2(vi) to 5.2(viii)]. The values of lead estimated in the samples from AAS instrument before postmonsoon 2004 are not considered.

Nickel (Ni^{++})

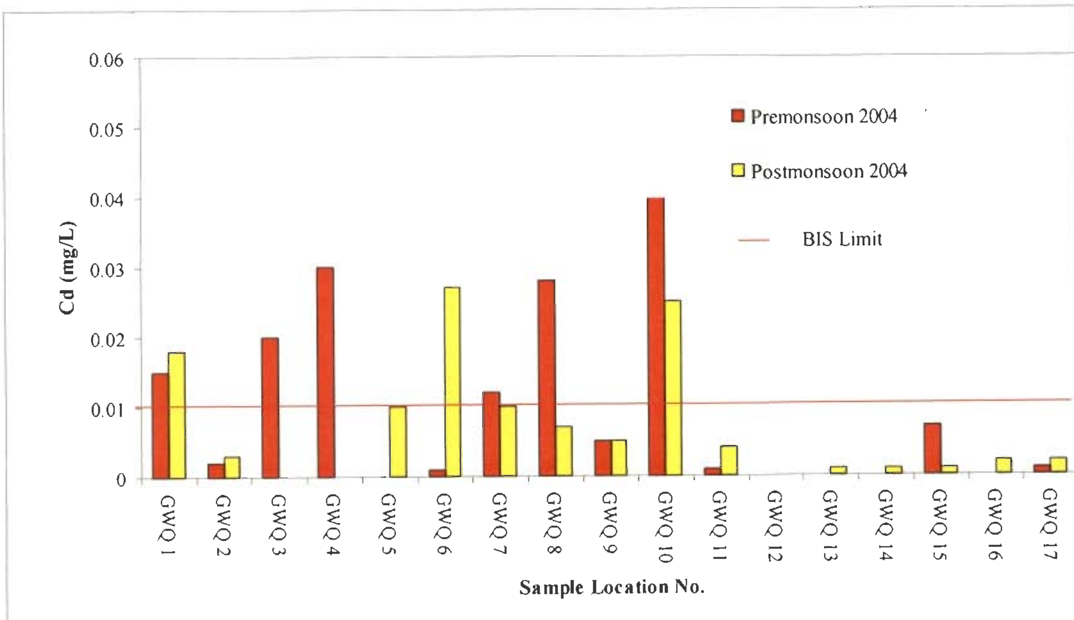
This heavy metal was also found well below the BIS limit (less than 0.2 mg/l) in all the tested samples [Annexure 5.2(i) to 5.2(viii)].

Zinc (Zn^{++})

The concentration of zinc in the ground water samples of year 2006 was found to be well below the BIS limit of 5 mg/l [Annexure 5.2(vii) to 5.2(viii)].

Total Iron (Fe)

The BIS limit of iron in drinking water is 0.3 mg/l (extendable to 1.0 mg/l) in the absence of alternate sources). In the present study its concentration varied in the acceptable ranges [Annexure 5.2(i) to 5.2(viii)] barring GWQ-3 (Sheikhpura Qadim), where it is found to be exceptionally high (2.272 mg/l) during December, 2006.



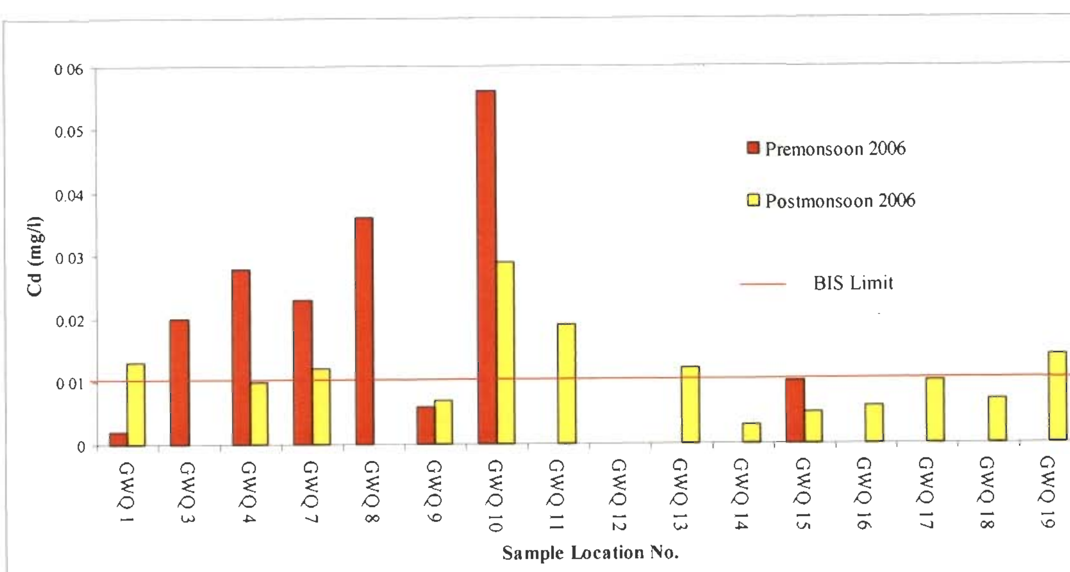


Fig. 5.9; Plot of Temporal variation of Cadmium Concentration in Ground Water (Years 2004 and 2006)

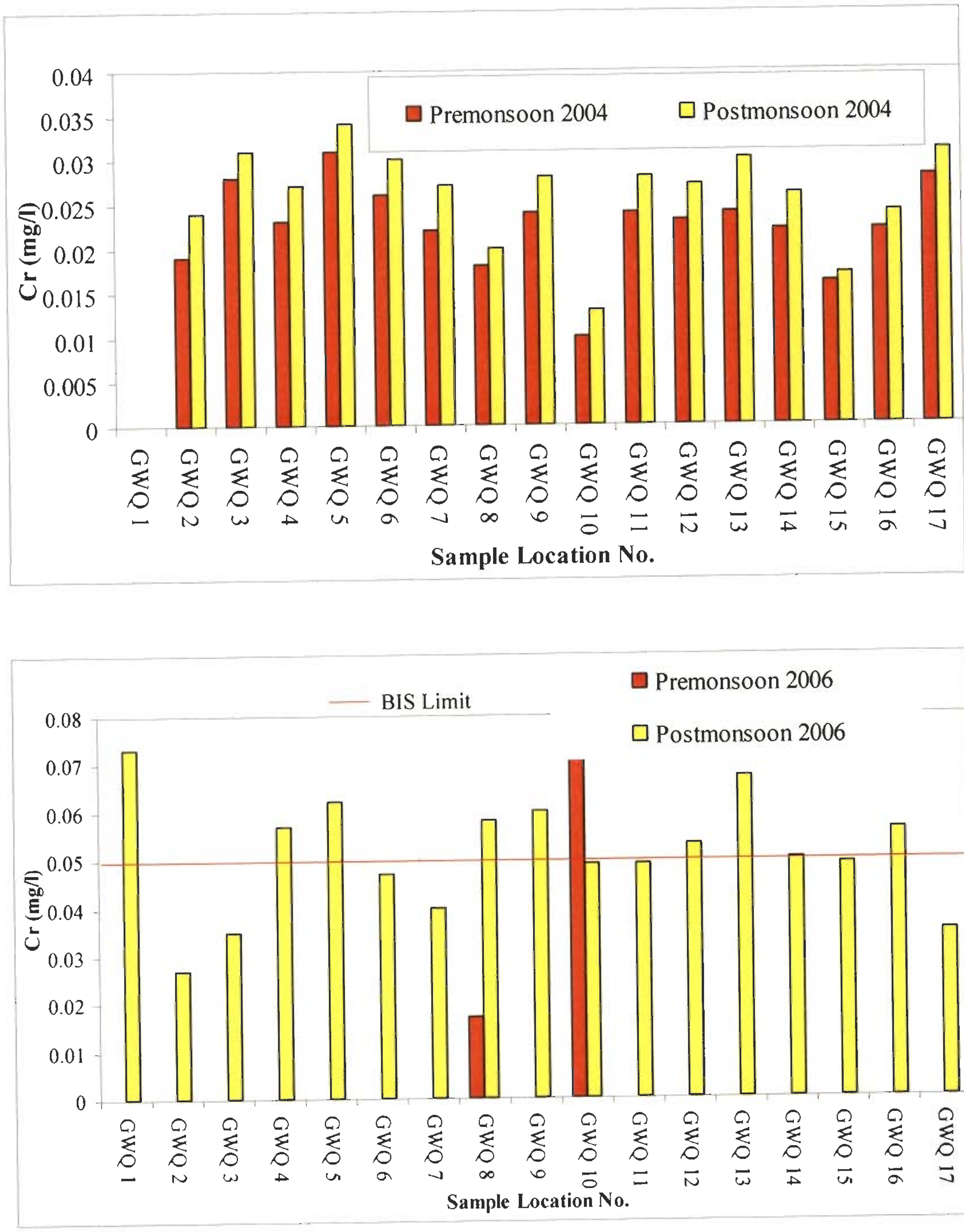
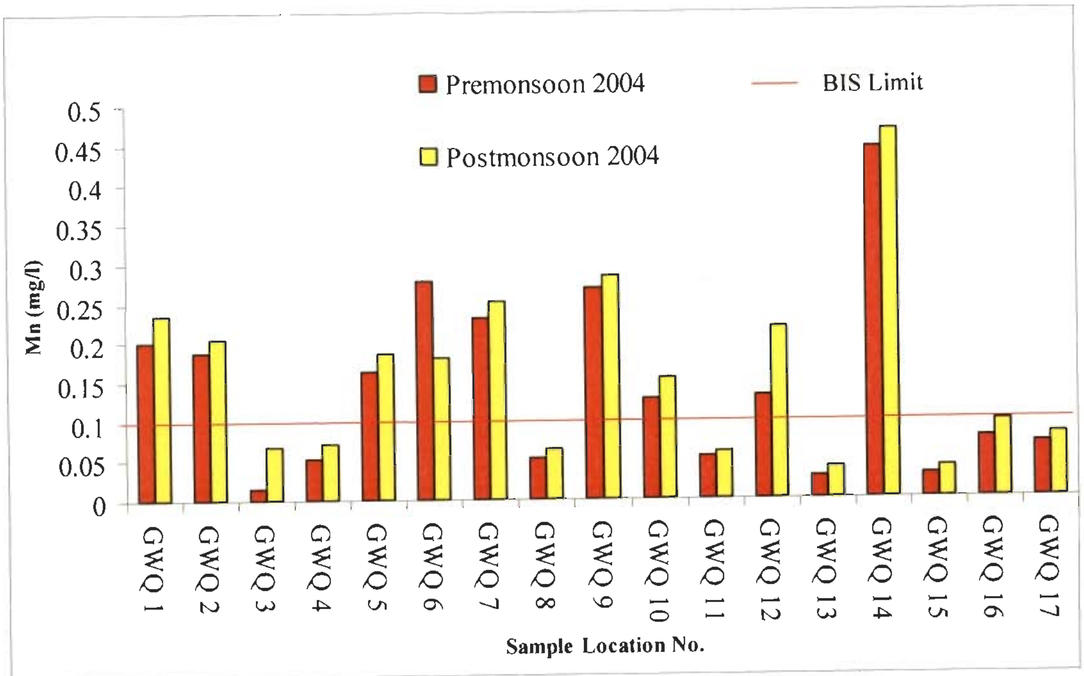


Fig. 5.10; Plot of Temporal variation of Chromium Concentration in Ground Water (Years 2004 and 2006)



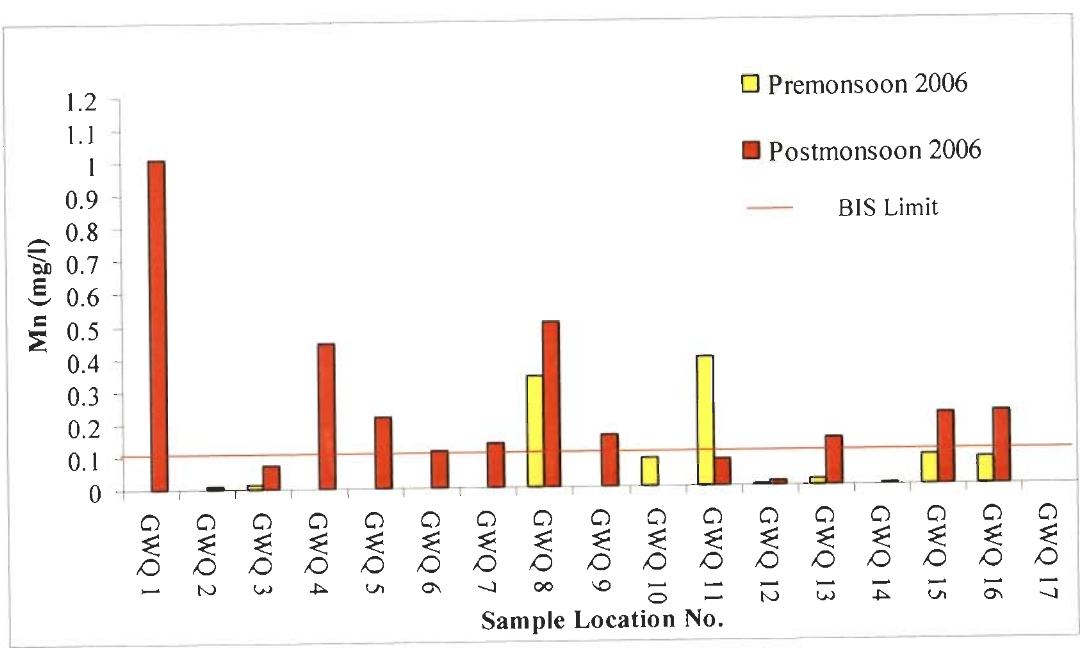


Fig. 5.11; Plot of Temporal variation of Manganese Concentration in Ground Water (Years 2004 and 2006)

C. Bacteriological Parameters :

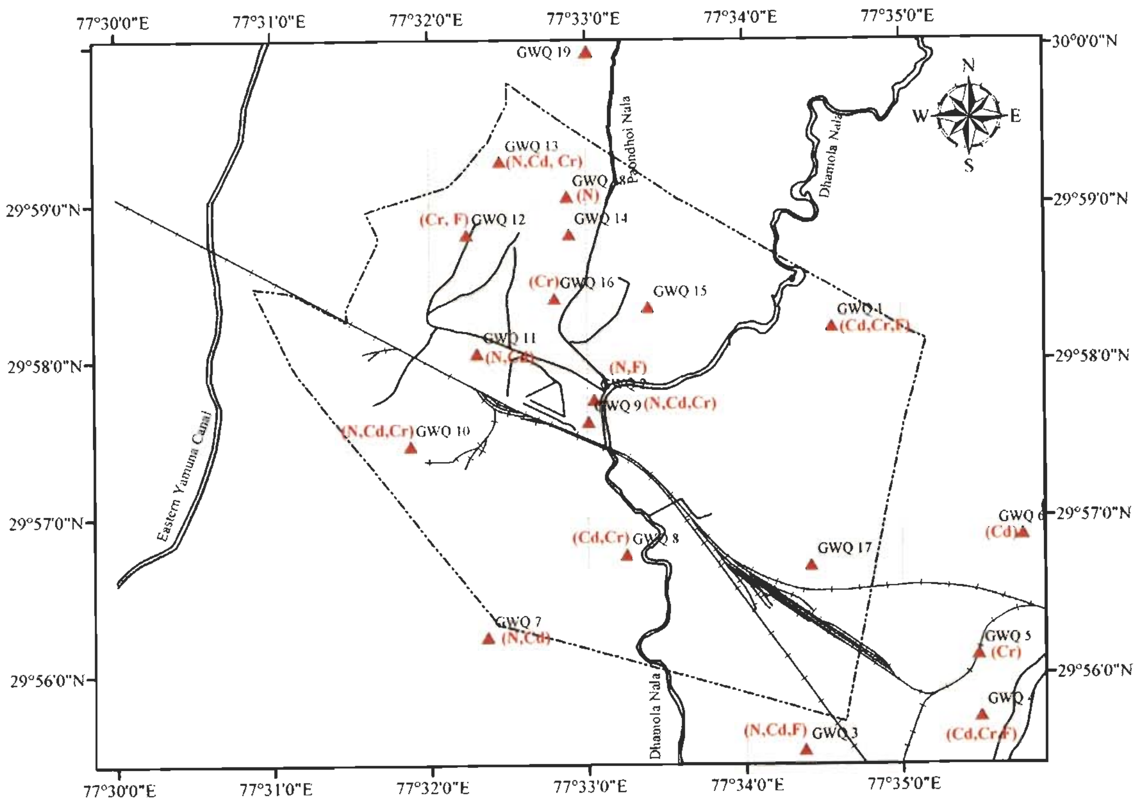
Amongst these, total coliforms and fecal coliforms have been analyzed and appear to be present in large quantity in most of the ground water samples. However, the fecal coliforms have been considered in details as some of the total coliforms in drinking water may not be harmful to users.

Fecal Coliform :

Presence of the fecal coliforms which indicate direct contamination of water from sewage have been detected during 2006 at few locations as indicated in Annexures 5.2(vii)&5.2(viii) namely Mahipura (GWQ-1) on the northern periphery of city, S.M. Inter College (GWQ-2) and Sabari ka Bagh (GWQ-12) being close to the Kamela nala in interior parts and Shekhpura Qadim (GWQ-3), Pairagpur (GWQ-4) in the southern parts . The high counts of fecal coliform observed at location S.M. Inter College (GWQ-2) in premonsoon period indicate pollution from sewage in Dhamola drain. Similarly, the high count of fecal coliform observed at Pairagpur (GWQ-4) in the southern periphery of city in postmonsoon period (2006) may be due to its location being close to the effluent drain of Star Paper mill respectively. The presence of fecal coliforms in ground water indicates the possibility of presence of pathogenic bacteria which can cause killer diseases like cholera, jaundice and typhoid. The fecal coliforms were not estimated for period(s) prior to 2006.

5.6 Conclusion

The deeper aquifers (> 30 meter depth) are not polluted and the water is of good quality for drinking as per BIS: 10500 Standards. However, the surface water and groundwater of shallow aquifers are at places polluted (Fig 5.12). The bar diagrams have provided idea of the temporal variations in the composition of ground water with the $CaCO_3$ hardness, sulphate, alkalinity and nitrate showing high values with respect to the quality criteria laid down by Bureau of Indian Standards for drinking (BIS:10500) especially in the postmonsoon samples. The Piper trilinear plots of chemical data indicate generally intermediate to hard nature of ground water with its character changing to dominating carbonate hardness in the postmonsoon samples. The analysis of ground water at some places indicates excessive concentrations of heavy metals like cadmium, chromium, copper, manganese and fecal coliforms when compared to the quality criteria for drinking water (BIS:10500). The reasons for high concentration of these heavy metals can be attributed to the direct disposal of industrial effluents to nearby drains. Similarly, the origin of high fecal coliforms can be traced to the presence of sewage in the nalas specially downstream of the sewage pumping station in the central part of the study area.



LEGEND

▲ GWQ 3 (N,Cd, Cr,F) — Groundwater Sample Location (No. 3)(Letters in Parentheses Denote Location with Concentration by Nitratre, Cadmium,Chromium and Fecal coliform Respectively

Railway Line

Municipal Boundary

Scale

1 0.5 0 1 2 3 4 Kilometers

Fig. 5.12; Area Showing Chemical constituents and Fecal Coliforms in the Groundwater (2006) higher than Permissible Limits (BIS : 10500)

Chapter 6

Ground Water Vulnerability and Protection

6.1 General

The ground water utilization has increased dramatically in developing cities of the world over the last few decades. With the increasing utilization, the need to protect ground water resources from contamination has also been realized. The potential for ground water pollution depends on the physical and geological characteristics of the area, chemical nature of the pollutants and the rate of their generation alongwith the physiographical situation of places of their origin in relation to the aquifers. Aller et al. (1987) proposed a standardized system to evaluate ground water pollution potential using hydrogeologic setting especially in alluvial areas. For this, they developed a relative ranking system called DRASTIC and incorporated seven factors viz. depth (D) of water, net recharge (R), aquifer (A) media, soil(S) media, topography (T), impact (I) of vadose zone and hydraulic conductivity (C) of the aquifer. The relative ranking system uses a combination of weights and ratings to produce a numerical value, called the DRASTIC Index which is helpful in evaluating priority areas with respect to ground water pollution potential. Higher values of DI indicate relatively higher degree of vulnerability for groundwater pollution. The Drastic index (DI) can be integrated with the data of pollution sources and ground water quality to arrive at the degree of contamination. Fig 6.1 shows the schematic diagram showing the seven raster layers in GIS mode for computation of Drastic index.

6.2 DRASTIC Analysis

In the present study, the Drastic method (Aller et al., 1987) has been employed to evaluate the ground water pollution potential and finally, to ascertain the degree of ground water pollution hazard considering the spatial proximity of sampling locations to the polluting sources.

6.2.1 DRASTIC Weightages

The parameter weighting and rating method of (Aller et al., (1987) employing the above mentioned seven Drastic parameters has been used (Table 6.1) for the evaluation of groundwater vulnerability for pollution in the Saharanpur town, the area of study from the set of field data collected in the year 2004. In view of deficient annual rainfall pattern during 2006 , the field water table data collected in the 2004 was used for the Drastic analysis.

(1) Depth (D) to water table for post monsoon season (year 2004) in the area on the basis of ground water monitoring at 51 observation well points. This is given a weightage of 5 in the DRASTIC scheme.

(2) Evaluation of net ground water recharge (R) during the monsoon period of year 2004 on the basis of premonsoon and postmonsoon depth of water table in 51 observation wells. This is assigned a weightage of 4.

(3) Nature of aquifer (A) media evaluated from available lithologs of existing exploratory wells drilled in the past. This carries a weightage of 3 in the Drastic scheme.

(4) Nature of soil(s) inferred after comparative examination of lithologs and vertical electrical sounding (V.E.S.) data interpretation at 25 locations. The soil media has been given a weightage of 2, as per Aller et al. (Op cit).

(5) The topographic (T) slope zonations in which the individual ground water level monitoring wells are located. The topography is given a weightage of 1 only.

(6) The impact (I) of unsaturated zone (i.e. clayey, silty, sandy etc.) as inferred from the examination of lithological logs of existing tubewells and interpretation of resistivity data. This factor is given a weightage of 5.

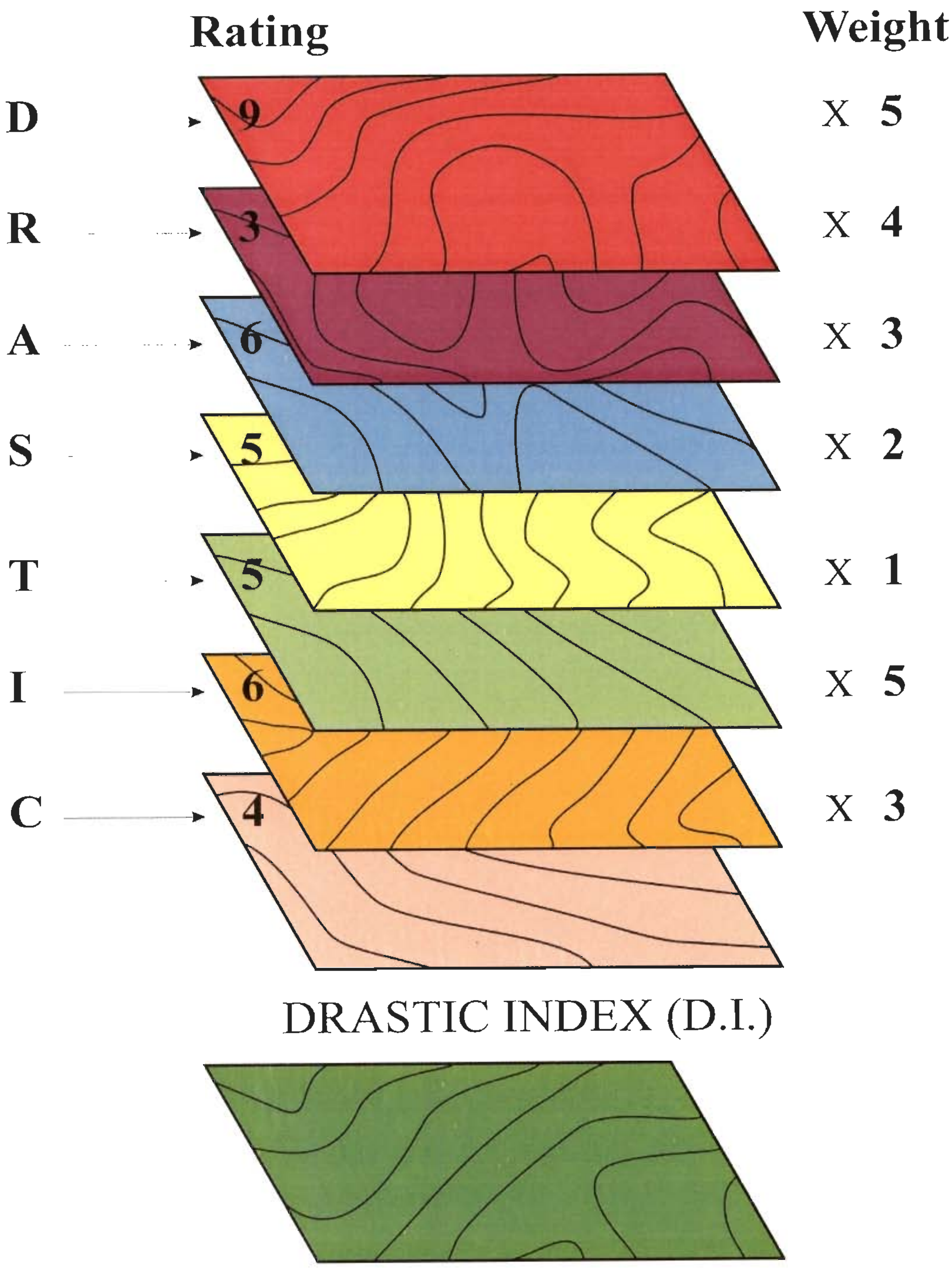
(7) The hydraulic conductivity (C) of the aquifer material was taken from the available figures from the results of interpreted pumping test data for selected tubewells. The hydraulic conductivity is given a weightage of 3 (Table 6.1).

6.2.2 Evaluation of Drastic ratings:

Rating for various ranges of drastic parameters as given by Aller et al.(1987) are given in the table 6.2 to 6.8.

Depth to ground water (D) :

For considering this parameter, available postmonsoon data of depth to water table during year 2004 has been considered. It is seen from the Annexure 6.1 and Fig. 6.2 that the depth to water table in the wells after the rainy season (post monsoon) period of year 2004 varies between 2.32 m below ground level (bgl) in the northern part (Khatakheri observation well No. 51) to 10.6 m bgl near Government (Bajoria) hospital. As such, the rating of this parameter is assigned a value of 5 for areas with depth of water table between 9-15 m bgl, value of 7 for areas with water table depth from 4.5-9.1 m bgl and value of 9 for areas with depth of water table between 1.5 to 4.5 m bgl (Table 6.2).



$$D.I. = (9x5) + (3x4) + (6x3) + (5x2) + (5x1) + (6x5) + (4x3) = 132$$

Fig. 6.1; Conceptual illustration of the DRASTIC method of aquifer vulnerability assessment

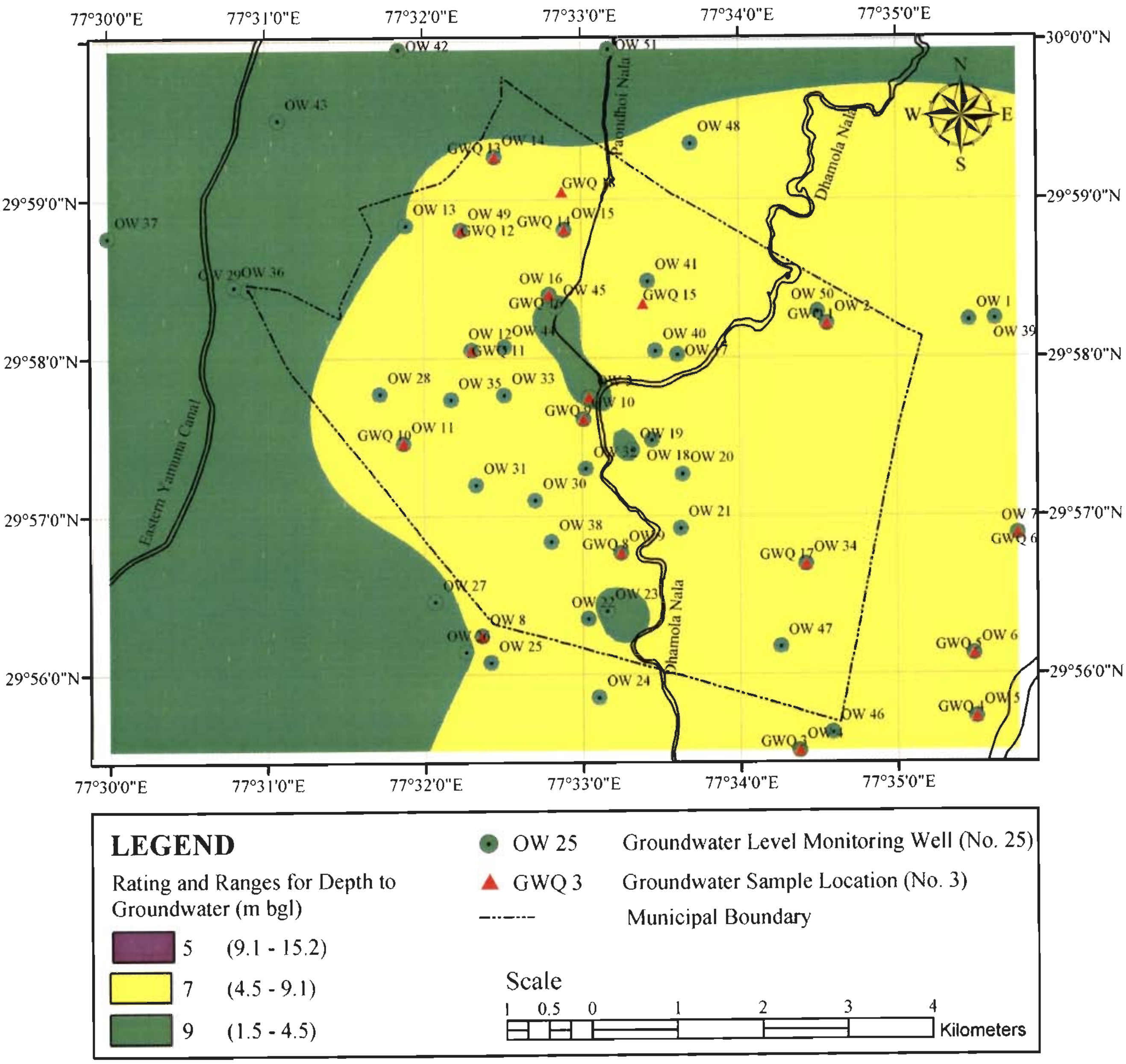


Fig. 6.2; Depth to Water Table, Postmonsoon 2004

Table 6.1; Assigned weights for DRASTIC parameters

Parameter	Weight Scale
Depth to water table	5
Net Recharge of aquifer	4
Aquifer media	3
Soil media	2
Topography	1
Impact of Vadose zone	5
Hydraulic Conductivity	3

(Source: Aller et al; 1987)

Table 6.2; Ranges and Ratings for Depth to groundwater

Depth to Groundwater	
Range (m bgl)	**Rating**
0 - 1.5	10
1.5 - 4.5	9
4.5 - 9.1	7
9.1 - 15.2	5
15.2 - 22.9	3
22.9 -30.9	2
> 30.5	1

(Source: Aller et al; 1987)

Table 6.3; Ranges and Ratings for net Recharge

Net Recharge	
Range (mm)	**Rating**
0 - 50.8	1
50.8 - 101.6	3
101.6 - 177.8	6
177.8 – 254	8
> 254	9

(Source: Aller et al; 1987)

Table 6.4; Ranges and Ratings for Aquifer media

Aquifer Media		
Range	**Rating**	**Typical Rating**
Massive Shale	1 – 5	2
Metamorphic /Igneous	2 – 5	3
Weathered metamorphic /Igneous	3 – 5	4
Thin Bedded Sandstone , Limestone, Shale sequence	5 – 9	6
Massive Sandstone	4 – 9	6
Massive Limestone	4 – 9	6
Sand and Gravel	4 – 9	8
Basalt	2 – 10	9
Karst Limestone	9 – 10	10

(Source: Aller et al; 1987)

Table 6.5; Ranges and Ratings for Soil Media

Soil Media	
Range	**Rating**
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and / or Aggregated clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck	2
Non shrinking and non aggregated clay	1

(Source: Aller et al; 1987)

Table 6.6; Ranges and Ratings for Topography

Topography (Slope %)	
Range (%)	**Rating**
0 – 2	10
2 – 6	9
6 -12	5
12 – 8	3
> 18	1

(Source: Aller et al; 1987)

Table 6.7; Ranges and Ratings for Impact of Vadose zone

Impact of Vadose zone media		
Range	**Rating**	**Typical Rating**
Silt/ clay	1 – 2	1
Shale	2 – 5	3
Limestone	2 – 7	6
Sandstone	4 – 8	6
Bedded sandstone, limestone, shale	4 – 8	6
Sand and gravel with significant silt and clay	4 – 8	6
Metamorphic/ igneous	2 – 8	4
Sand and gravel	6 – 9	8
Basalt	2 - 10	9
Karst limestone	8 - 10	10

(Source: Aller et al; 1987)

Table 6.8; Ranges and Ratings for Hydraulic Conductivity

Hydraulic Conductivity (m/day)	
Range	**Rating**
0.005 – 0.5	1
0.5 – 1.5	2
1.5 – 3.5	4
3.5 – 5.0	6
5 - 10.0	8
> 10.0	10

(Source: Aller et al; 1987)

Net Recharge (R) :

It is seen from data of net recharge of ground water recorded during year 2004 that the seasonal recharge varies between 90 mm to 1840 mm at different observation wells. So it is given ratings of 3 to 9 as shown in Table 6.3. The data of the net recharge are given in Annexure 6.2 and shown in figure 6.3.

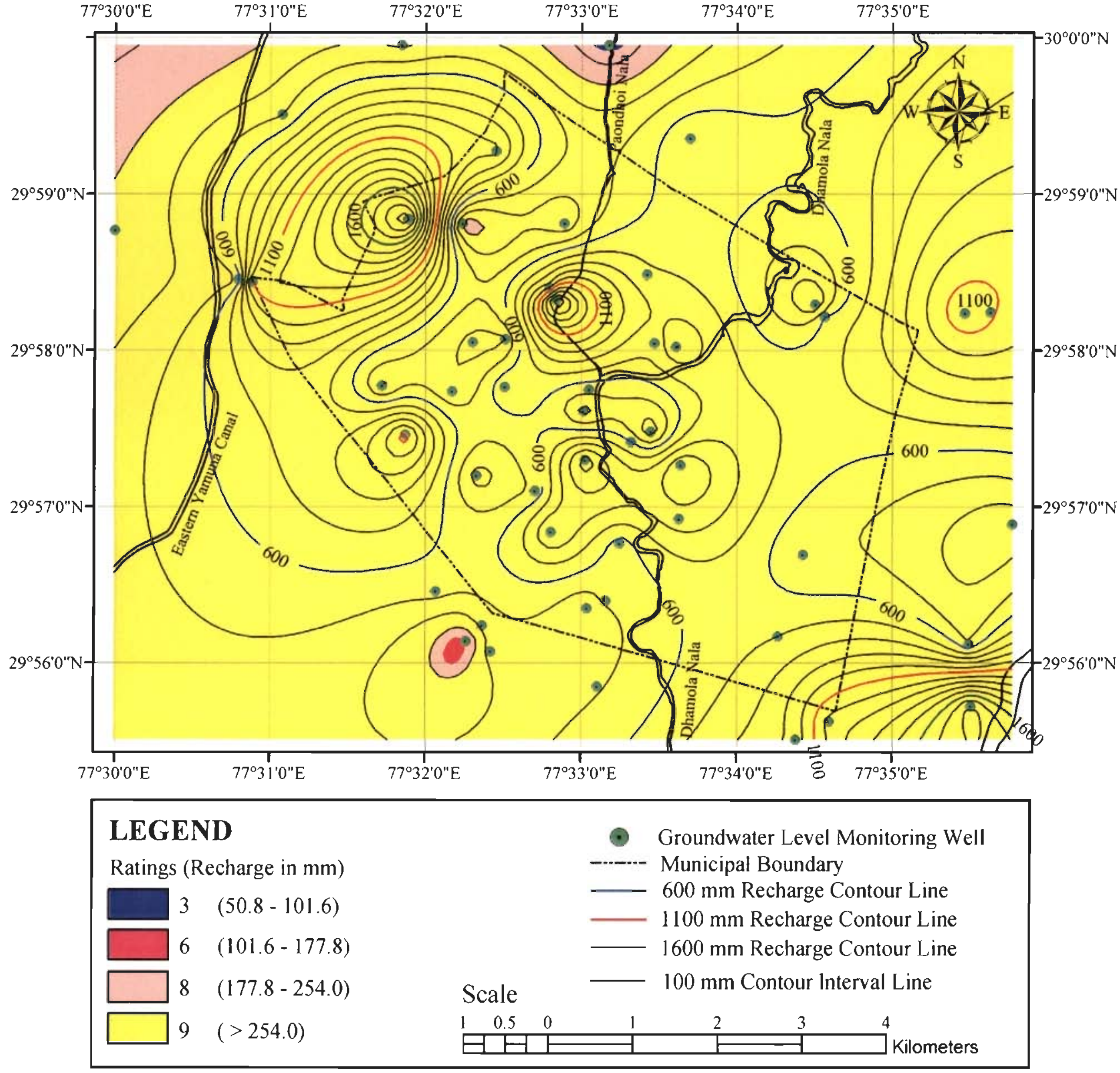


Fig. 6.3; Net Recharge (2004)

Aquifer Media (A) :

From the geological fence diagram of the study area (Fig 4.3) it is seen that the lithology of shallow aquifer in the tubewells varies from fine to medium sand occasionally having kankar (Annexure 6.3). So it is assigned a rating of 8 as per Table 6.4 as shown in Fig 6.4.

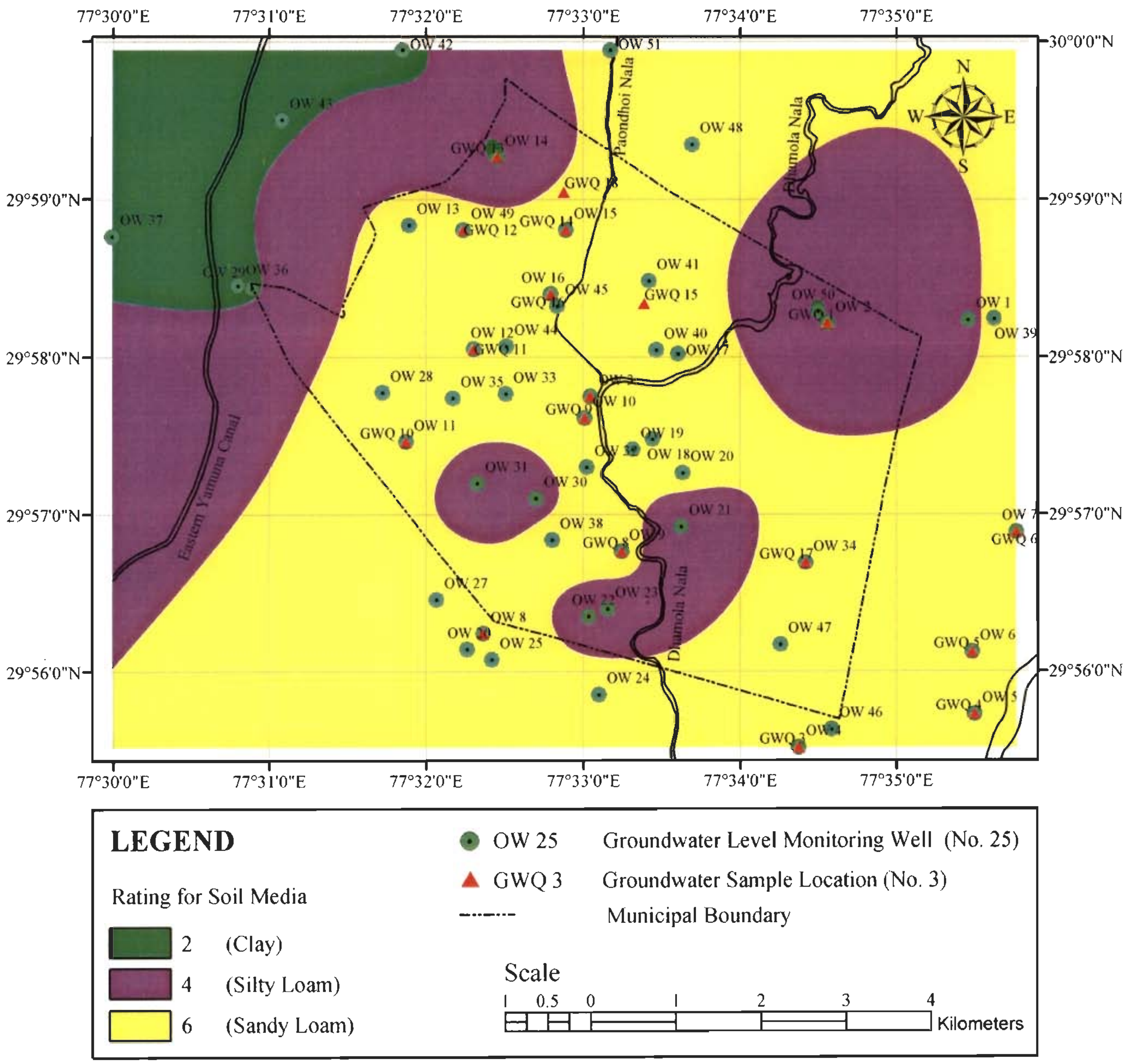


Fig. 6.5; Soil Media

Topography (T):

The general topography of the ground in the study area is that of a plain area with slopes being less than 2% (Fig. 6.6) and annexure 6.5 except at few points. So it is assigned a rating between 9 to 10 as per scheme of Aller et al. (Op cit, Table 6.6).

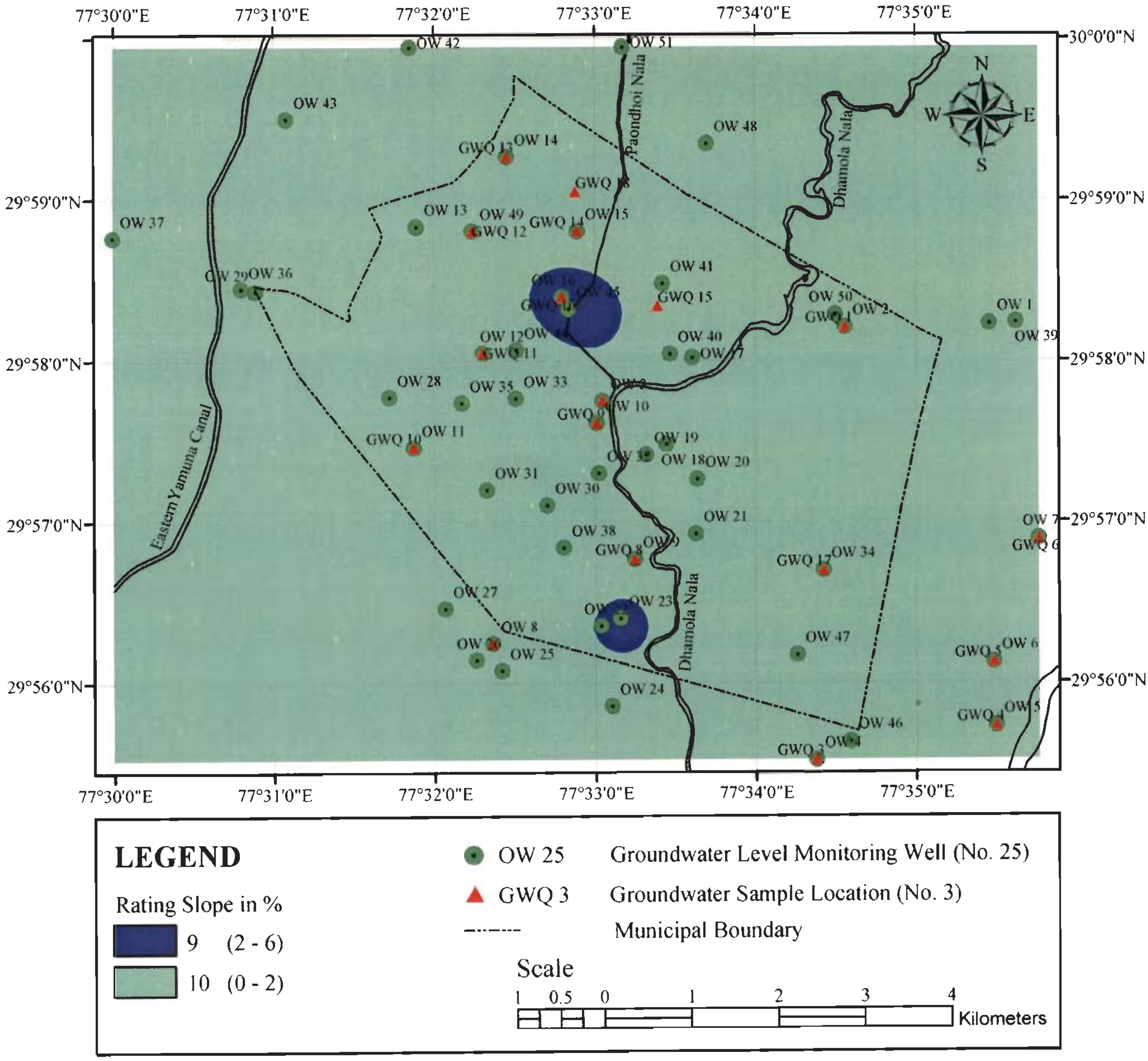


Fig. 6.6; Topographic (Percent Slope) Map

Impact of Vadose Zone (I):

The nature of vadose zone in the area when compared with resistivity values in the resistivity sounding data indicates a general presence of clay to fine sand with occasional kankar (Annexure 6.6). So it has been given ratings varying from 1 to 6 (Table 6.7) and is shown in Fig 6.7.

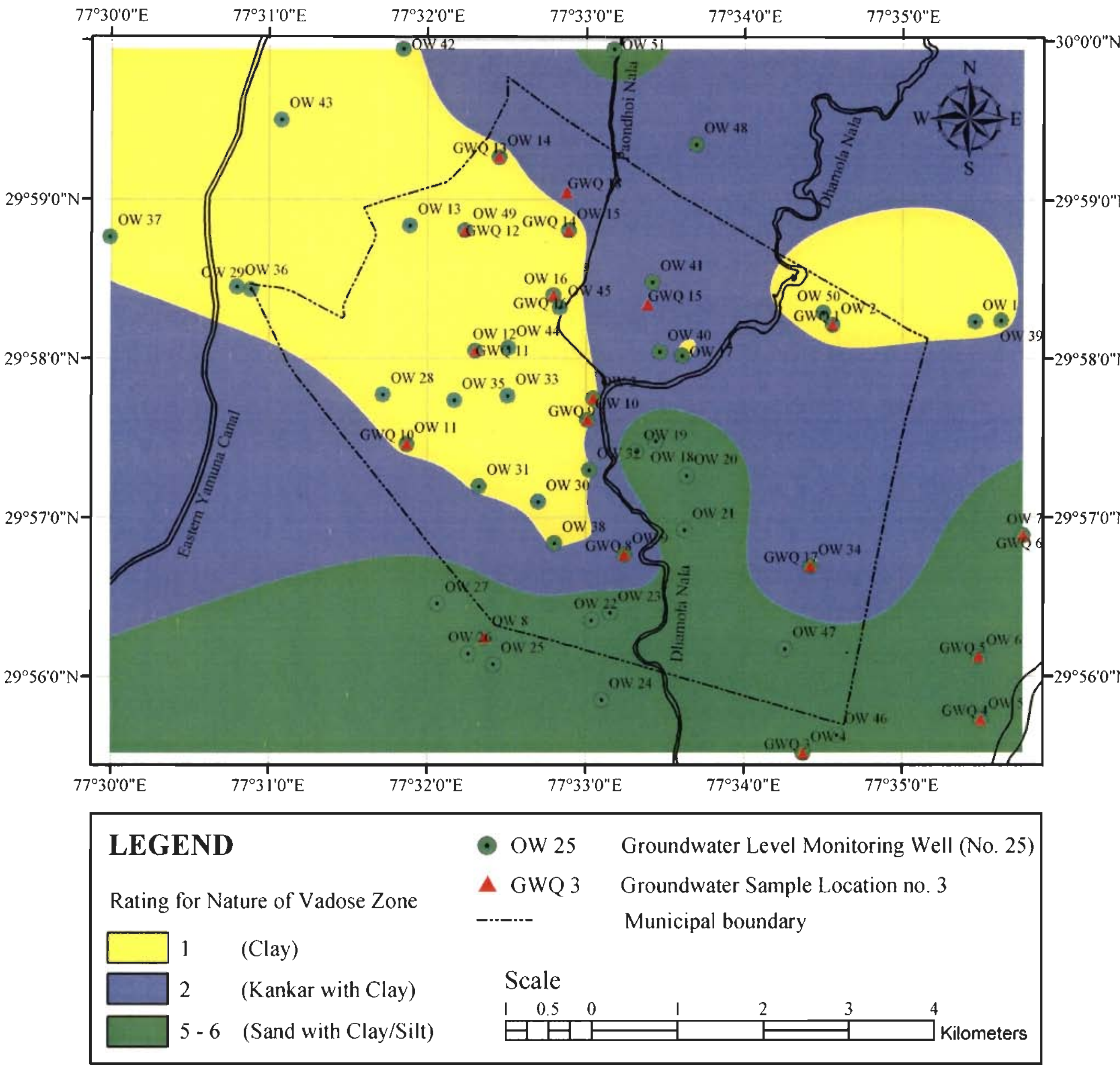


Fig. 6.7; Impact of Vadose Zone

Hydraulic Conductivity (C):

The available data of hydraulic conductivity for two sites in the study area indicate the hydraulic conductivity of unconfined aquifer to vary between 10-12 m/day (Annexure 6.7) and thus it is given a uniform rating of 10 from the given Table 6.8 and is shown in Fig 6.8.

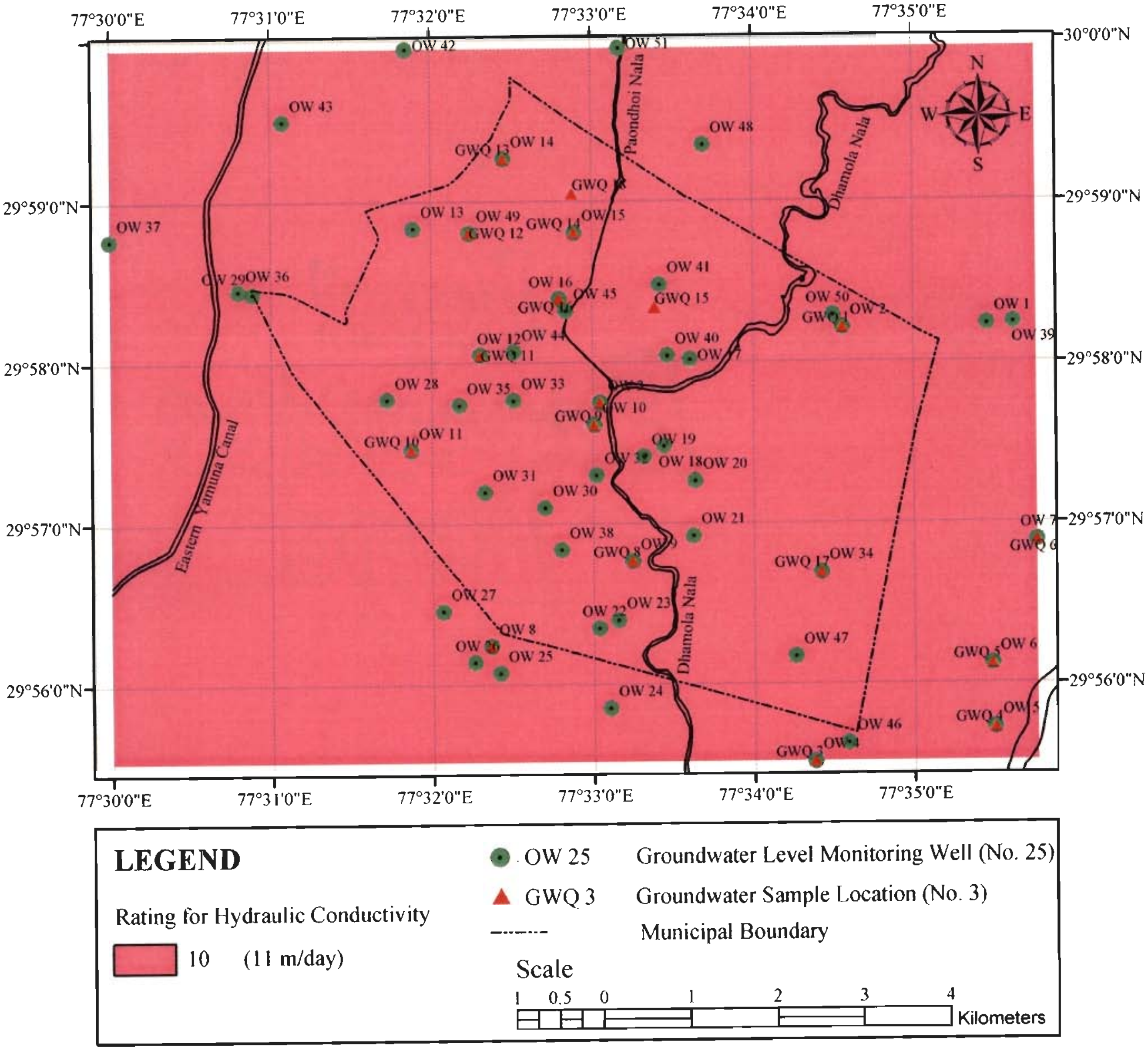


Fig. 6.8; Hydraulic Conductivity

6.2.3 Drastic Indices (D.I.)

The Drastic method allows the user to determine a numerical value for any hydrological setting by using an additive model. The equation for determining the DRASTIC Index (DI) is as under :

$D_rD_w + R_rR_w + A_rA_w + SrS_w + T_rT_w + I_rI_W + C_rC_w$ = Pollution Potential

where, r = rating and w = weight

The DRASTIC index map (Fig. 6.9) prepared from the superimposed seven layers indicates that the DRASTIC index has values ranging from 144 to 182 in the study area (Annexure 6.7, last column). The DRASTIC index in the northern part of the area is minimum and its value increases towards south attaining maximum values near Pant Vihar (ground water sampling station OW 27), Avas Vikas colony on Delhi Road (OW 24) and Shekhpura Qadim (OW 4).

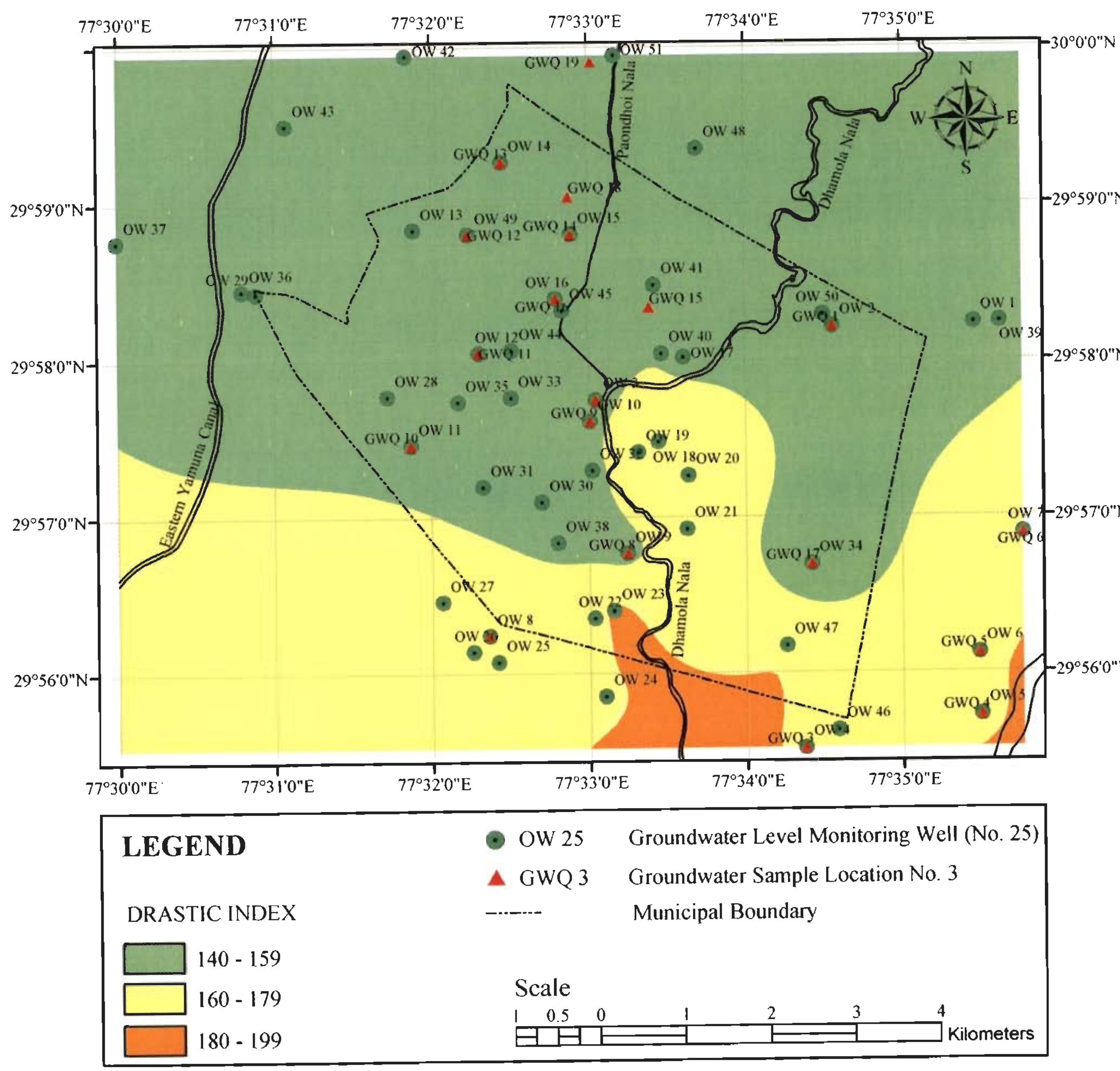


Fig. 6.9; DRASTIC Index Map

Table 6.9; Color codes DRASTIC indices

Classes	Index ranges	Color codes
1	< 79	Violet
2	80 – 99	Indigo
3	100 – 119	Blue
4	120 – 139	Dark green
5	140 – 159	Light green
6	160 – 179	Yellow
7	180 – 199	Orange
8	200 and above	Red

(Source: Aller et al; 1987)

As per the classification and color codes given by Aller et al. (1987), and given in Table 6.9 a value of D.I. higher than 179 (orange color) has been taken to indicate highly vulnerable area for ground water pollution. Accordingly, a small portion in the southern part of the city (covering Awas Vikas colony on Delhi Road) falls in the high pollution risk zone. Further, the central part of the area around observation well 21 (Bhrahmpuri) and OW 32 (Gill colony) are included in the moderate risk zone (DI=160-179, yellow color). On the other hand, areas in the northern, north-western and eastern part of the area seem to fall in the low risk zone having D.I. values less than 160 (green color). There are no localities with very high ground water pollution potential in the study area (DI > 200, red color).

6.3 Design of Ground Water Pollution Monitoring Network

To arrive at the degree of pollution hazard for the ground water in the unconfined aquifer, the data of excessive chemical concentrations of related physicochemical and bacteriological parameters and heavy metal parameters have been compared and correlated with the possible sources of pollution [Tables 6.10 (i) to 6.10 (vii)]. It is found from a perusal of these tables that the probable sources of groundwater pollution include the point locations (near the waste effluent outfalls of major industries viz. ITC, Slaughter House, the Cooperative Distilleries and the Star Paper Mill etc), the line sources (viz. Dhamola, Kamela and Paondhoi drains etc.) and the residential/commercial areas from where the nonpoint storm water runoff is generated. It is observed from these tables that quality parameters like fecal coliforms, cadmium, chromium and nitrate are the hazardous constituents (in decreasing order) found to be present in excessive concentrations mainly in the central southwestern and southern parts of the city where as less hazardous pollutants like copper, manganese and sulphate are also found in high concentrations at some places. The sample locations having groundwater with high concentration of hazardous parameters have been compared with the localities having high groundwater vulnerability in terms of Drastic Index (DI) for the respective nearby observation wells. This integration has resulted in evaluation of relative threat perception to the shallow groundwater quality at different sampling locations as indicated in tables 6.10(i) to table 6.10(viii). It is observed from these tables that the localities having high threat of contamination with respect to the above mentioned hazardous parameters are Mahipura (GWQ-1), S.M Inter College (GWQ-2), Sheikhpura Qadim (GWQ-3), Pairagpur (GWQ-4), Hassanpur (GWQ-7), Hakiqat Nagar (GWQ-8), Govindnagar (GWQ-9), Wazir Vihar (GWQ-10), Patel Nagar (GWQ-11), Sabri Ka Bagh (GWQ-12), Munnalal College (GWQ-13) and H.A.V. Inter College (GWQ-18). Thus such areas need to be monitored more intensively for ground water quality monitoring. For accomplishing this objective, a total of eleven (11) additional water quality monitoring wells/hand pump sites are required to be construted and installed as given in Table 6.11 and shown in Fig. 6.10 as per the guidelines given by Vrba & Zoporozec (1994) and Foster et al. (2002). For ready reference, the groundwater quality monitoring wells with existing contamination by more hazardous subsurfaces [viz. Nitrate (N), Cadmium (Cd), Cromium (Cr) and Fecal Coliforms (F)] in December 2006 have also been shown in Fig 6.10.

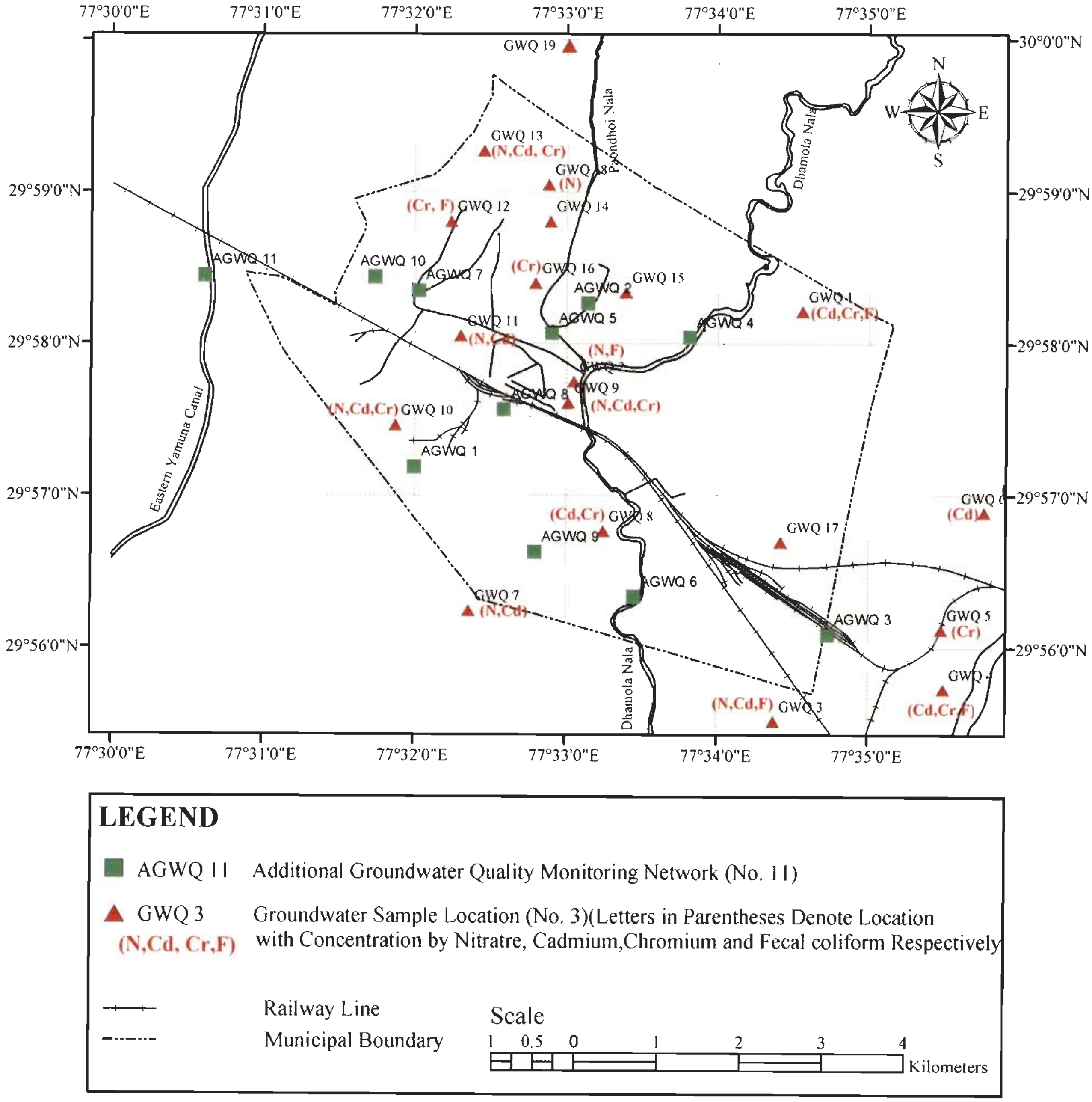


Fig. 6.10; Location Map of Additional Groundwater Quality Monitoring Network

Table 6.10(i) : Localities showing high Nitrates in ground water, 2006 (BIS Standard : 45 mg/l)

Sample No.	Locality	NO_3 Concentration (mg/l)		Possible source	Drastic Index	Remarks
		Premonsoon-06	Postmonsoon-06			
GWQ2	S.M. Inter College	-	85.6	Near confluence of Dhamola and Paondhoi drain	152	Moderate pollution risk
GWQ3	Sheikhpura Qadim	80.3	-	Near Dhamola drains and d/s of waste sites	177	High pollution risk
GWQ7	Hasanpur	62.7	-	D/S of ITC effluent drain	177	High pollution risk
GWQ9	Govind Nagar	-	59.3	Near confluence of Paondhoi and Dhamola drain	152	Moderate pollution risk
GWQ10	Wazir Vihar	-	63.8	D/S of ITC effluent drain	152	Moderate pollution risk
GWQ11	Patel Nagar	-	61.1	Close to Kamela drain	152	Moderate pollution risk
GWQ13	Muna Lal College	50.8	-	Close to Hosiery factory effluent drain.	146	Moderate pollution risk
GWQ18	H.A.V. Inter College	-	89.5	Close to Paondhoi drain.	158	Moderate pollution risk

Table 6.10 (ii) : Localities showing high Sulphate in ground water, 2006 (BIS Standard : 200 mg/l)

Sample No.	Locality	SO_4 Concentration (mg/i)		Possible source	Drastic Index	Remarks
		Premonsoon-06	Postmonsoon-06			
GWQ1	Mahipura	-	330.00	D/S of solid waste dump	148	Moderate pollution risk
GWQ3	Sheikhpura Qadim	269.53	396.68	D/S of Dhamola drain and waste sites.	177	High pollution risk
GWQ4	Pairagpur	-	282.88	Paper (mill) effluent drain	177	High pollution risk
GWQ6	Ghogreki	-	295.95	Outside study area	177	High pollution risk
GWQ8	Hakiquat Nagar	-	409.03	Near Dhamola drain	152	Moderate pollution risk
GWQ9	Govind Nagar	-	252.66	Near confluence of Paondhoi and Dhamola drain	152	Moderate pollution risk
GWQ10	Wazir Vihar	-	261.71	D/S of ITC effluent drain	152	Moderate pollution risk
GWQ11	Patel Nagar	-	283.11	Close to Kamela drain	152	Moderate pollution risk
GWQ12	Sabarika Bagh	282.28	273.23	Close to Kamela drain	152	Moderate pollution risk
GWQ13	Muna Lal College	270.76	-	Close to Hosiery factory effluent drain	146	Moderate pollution risk
GWQ14	Arabi Madarsa	297.10	262.53	Near Paondhoi drain	152	Moderate pollution risk
GWQ16	Shahid Ganj	256.36	-	Near Paondhoi drain	151	Moderate pollution risk
GWQ17	Dabki Junandar	-	216.44	Near Dhamola drain	142	Moderate pollution risk
GWQ18	H.A.V. Inter College	-	293.81	Close to Paondhoi drain	158	Moderate pollution risk

Table 6.10(iii) : Localities showing high Cadmium in ground water, 2006 (BIS Standard : 0.01 mg/l)

Sample No.	Locality	Cd Concentration (mg/l)		Possible source	Drastic Index	Remarks
		Premonsoon-06	Postmonsoon-06			
GWQ1	Mahipura	-	0.013	D/S of solid waste dump	148	Moderate pollution risk
GWQ3	Sheikhpura Qadim	0.020	-	Near Dhamola drain and d/s of waste sites.	177	High pollution risk
GWQ4	Pairagpur	0.028	-	Proximity to Paper (mill) effluent drain.	177	High pollution risk
GWQ5	Dudhali Bhukara	-	0.019	Outside study area	177	High pollution risk
GWQ6	Ghogreki	-	0.030	Outside study area	177	High pollution risk
GWQ7	Hasanpur	0.023	0.012	D/S of ITC effluent drain	177	High pollution risk
GWQ8	Hakiquat Nagar	0.036	-	Near Dhamola drain	152	Moderate pollution risk
GWQ10	Wazir Vihar	0.056	0.029	D/S of ITC effluent drain	152	Moderate pollution risk
GWQ11	Patel Nagar	-	0.019	D/S of Kamela drain	152	Moderate pollution risk
GWQ13	Munalal College.	-	0.012	Close to Hosiery factory effluent	146	Moderate pollution risk

Table 6.10(iv) : Localities showing high Chromium in ground water, 2006 (BIS Standard : 0.05 mg/l)

Sample No.	Locality	Cr Concentration (mg/l)		Possible source	Drastic Index	Remarks
		Premonsoon-06	Postmonsoon-06			
GWQ1	Mahipura	-	0.073	D/S of solid waste dump	148	Moderate pollution risk
GWQ4	Pairagpur	-	0.057	Proximity to Paper (mill) effluent drain.	177	High pollution risk
GWQ5	Dudhali Bhukara	-	0.062	Outside study area	177	High pollution risk
GWQ8	Hakiquat Nagar	-	0.058	Near Dhamola drain	152	Moderate pollution risk
GWQ9	Govind Nagar	-	0.060	Near confluence of Paondhoi and Dhamola drain	152	Moderate pollution risk
GWQ10	Wazir Vihar	0.072	-	D/S of ITC effluent drain	152	Moderate pollution risk
GWQ12	Sabari Ka Bagh	-	0.053	Close to Kamela drain	152	Moderate pollution risk
GWQ13	Muna Lal Girl's Degree College	-	0.067	Close to Hosiery factory effluent drain.	146	Moderate pollution risk
GWQ16	Shahid Ganj	-	0.056	Close to Paondhoi drain.	151	Moderate pollution risk

Table 6.10(v) : Localities showing high Copper in ground water, 2006 (BIS Standard : 0.05 mg/l)

Sample No.	Locality	Cu Concentration (mg/l)		Possible source	Drastic Index	Remarks
		Premonsoon-06	Postmonsoon-06			
GWQ1	Mahipura	-	0.055	D/S of solid waste dump	148	Moderate pollution risk
GWQ4	Pairagpur	-	0.247	Proximity to Paper (mill) effluent drain.	177	High pollution risk
GWQ5	Dudhali Bhukara	-	0.169	Outside study area	177	High pollution risk
GWQ6	Ghogreki	-	0.289	Outside study area	177	High pollution risk
GWQ8	Hakiquat Nagar	0.313	0.310	Near Dhamola drain	152	Moderate pollution risk
GWQ10	Wazir Vihar	0.169	-	D/S of ITC effluent drain	152	Moderate pollution risk
GWQ15	Company Bagh	0.100	-	Within croweded urban complex, close to Dhamola drain	152	Moderate pollution risk

Table 6.10(vi) : **Localities showing high Manganese in ground water, 2006 (BIS Standard : 0.1 mg/l)**

Sample No.	Locality	Mn Concentration (mg/l)		Possible source	Drastic Index	Remarks
		Premonsoon-06	Postmonsoon-06			
GWQ1	Mahipura	-	1.011	D/S of solid waste dump	148	Moderate pollution risk
GWQ4	Pairagpur	-	0.444	Proximity to Paper (mill) effluent drain	177	High pollution risk
GWQ5	Dudhali Bhukara	-	0.217	Outside study area	177	High pollution risk
GWQ6	Ghogreki	-	0.114	Outside study area	177	High pollution risk
GWQ7	Hasanput	-	0.137	D/S of ITC effluent drain.	152	Moderate pollution risk
GWQ8	Hakiquat Nagar	0.338	0.501	Near Dhamola drain	152	Moderate pollution risk
GWQ9	Govind Nagar	-	0.157	Near confouence of Paondhoi and Dhamola drain.	152	Moderate pollution risk
GWQ11	Patel Nagar	0.395	-	Close to Kamela drain.	152	Moderate pollution risk
GWQ13	Munalal College.	-	0.147	Close to Hosiery factory effluent	146	Moderate pollution risk
GWQ15	Company Bagh	-	0.218	Within crowded urban complex close to Dhamola drain	152	Moderate pollution risk
GWQ16	Shahid Ganj	-	0.223	Near Paondhoi drain	151	Moderate pollution risk

Table 6.10(vii) : Localities showing high number of Fecal Coliforms in ground water, 2006 (BIS Standard : Nil)

Sample No.	Locality	Fecal Coliform/100 ml		Possible source	Drastic Index	Remarks
		Premonsoon-06	Postmonsoon-06			
GWQ1	Mahipura	-	2	D/S of solid waste dump	148	Moderate pollution risk
GWQ2	S.M.Inter College	4	2	Near Confluence of Dhamola and Paondhoi drains	152	Moderate pollution risk
GWQ3	Shekhpura Qadim	-	2	Near Dhamola drains and d/s of waste sites	177	High pollution risk
GWQ4	Pairagpur	-	6	Proximity to Paper (mill) effluent drain	177	High pollution risk
GWQ12	Sabarika Bagh	2	-	Close to Kamela drain	152	Moderate pollution risk

Table 6.11 : Ground Water Pollution Monitoring Network Design (Saharanpur)

	Data/info	Methods/Criteria	Recommendations
Monitor point source pollution	Pollution sources map vulnerability map	One well for one point source of high risk, not protected, very large quantity, located at vulnerable area.	New sample location one well each near ITC outfalls Cooperative Distillery & Star Paper Mill (Fig. 6.5)
Monitoring line source	Pollution sources map, ground water flow map.		One well each in the vicinity of Dhamola, Paondhoi and Kamela drains and one well downstream of their confluence.
Monitor diffusive pollution	Vulnerability map, land use map, recharge map	Locate monitoring well in high pollution risk area (=high pollution load + high vulnerability)	No additional well required.
Monitor water supply sources.	Capture zone of water supply well, pollution risk map.		One sample site each as under (Fig.6.5) : 1.Near Govind Nagar Tubewell, 2.Near Railway Station (Mission Compound Tubewell, 3.Near Avas Vikas Tubewell 4.Near HAV Inter College.
Set-up an integrated monitoring network.		Monitoring network map locations of all pollution monitoring wells; indicating existing wells and newly designed wells.	Figure 6.5

Table 6.12 : Guidelines for ground water protection (Saharanpur)

Ground water protection strategy.	Contents	Recommendations
Prevention of ground water pollution	Reduction of pollution sources, mitigation of pollution risk, protection of wellhead and water supply sources.	1.Construct concrete platform near well head water supply. 2.At hand pump sites giving polluted water, install warning sign posts. 3.Discourage public from using drinking water from shallow hand pumps. 4.Better modality of solid waste collection and disposal. 5Renovation/Upgradation of sewerage and storm water drainage system. 6.Improvement of water distribution infrastructure.
Institutional frame work	National, Provincial, municipal, NGOs	Municipal and Govt. Agencies to disseminate water use information to people through media etc.
Legislation	Water law, pollution prevention law.	1.Promulgate Ground water legislation in the State after incorporating relevant provisions and utilization guidelines for ground water.
Public awareness	Workshop of stakeholders, Public information campaigning.	1.More workshops of stakeholders may be organized at regular time intervals. 2.Local media News Paper(s) may punlicise the deliberations. 3.Empowerment of NGO's.

6.4 Guide Lines for Ground Water Protection :

The design of the ground water monitoring network in an area has to be followed by suitable actions to be undertaken relating to the ground water protection strategies. These include the following actions (Table 6.12) :

(i) - Prevention of ground water pollution by reducton of pollution sources, by abiding to the prevailing law of the land relating to the functioning of industrial units
- mitigation of pollution risk.
- protection of well head and water supply sources by construction of concrete platform near the well heads of water supply wells. The role of NGO's in implementation of above actions can be vital.
- Improvement in solid waste collection and disposal strategies
- Renovating and upgrading the sewerage and storm water system
- Improving the infrastructure related to supply of drinking water.

(ii) Institutional framework and ground water legislation.

The relevant national agencies (e.g. Central Ground Water Board, Govt. of India), Provincial Government Departments (like State Ground Water Department and U.P. Jal Nigam) and Municipal authorities have to be mobilized to initiate suitable action relating to promulgation of ground water legislation, not yet enacted in India. Further, there is a need for dissemination of water use information to people through media and implementation of the decisions for strict enforcement of prevalent legal provisions for ground water utilization. In this context, the local municipal authority should come forward to discourage use of local hand pump wells for tapping shallow unfit ground water for drinking. A public campaign is required to be launched in respect of poor quality of shallow ground water in the affected areas of the city where suitable warning sign posts/banners can be installed announcing (to the common citizens) not to consume polluted water for drinking. However, such advisories can only be followed by the people if alternative sources of hygienic water supply, say through India Mark II hand pumps (which tap deeper aquifers) and deep tubewells yielding quality water are provided. The case of a recently constructed tubewell in IIT Campus of the city is a live example of such an alternative. This tubewell was installed in addition to the municipal water supplies from other deep tubewells of the city. Such augmentation of the water supply tubewells in the city is highly recommended.

It is imperative that in towns of India like Saharanpur, where no ground water legislation is presently in force, the ground water protection strategy needs implementation of a series of measures to mitigate pollution as well as expeditious institutional decision making to enforce the augmentation arrangements for water supply so as to obtain desired optimum supply of drinking water. In such scenarios, role of the Municipal authorities supported by empowerment of NGO's can be crucial.

Chapter 7

Summary and Conclusions

The deterioration in the quality of ground water available for urban supplies worldwide has been causing serious concern amongst the user communities as quality water becomes less accessible and the shortages go on increasing. In urban and industrialized areas, the ground water in shallow aquifer can get easily degraded by municipal and urban run off which often includes industrial effluents and sewage. The problem can become more acute in alluvial areas characterized by presence of shallow water table where typical hydrogeological settings render aquifer more vulnerable to ground water contamination. An attempt has been made in the present work to study the occurrence of ground water and assess influence of urban development in Saharanpur town of western Uttar Pradesh, India on the quality of ground water for pollution in terms of its vulnerability and propose design guide lines for future ground water protection.

The study area is a part of Indo Gangetic alluvial plain situated in the upper part of the Hindon basin in the Saharanpur District of Uttar Pradesh. The Hindon is a tributary of the river Yamuna whereas its feeding drains (locally called nalas) in the study area are Dhamola, Paondhoi and Kamela. Geomorphologically, the Saharanpur town is situated in the Tarai zone south of the Himalayan foothills. The hydrogeological set up of the area indicates that there are three main sandy aquifer groups separated by clay horizons. The ground water flows in the area towards south and the general depth of water table is found to vary between 2.5 to 12 m below ground level (bgl). Examination of past data of water table variations in the well hydrographs for last two decades has revealed that it is generally showing a declining trend during last few years. The quality of the ground water in the region is generally potable.

The available data about the growth of Saharanpur urban sprawl indicates that during the last three decades the built up area has more than doubled whereas the population has increased fourfold during the last six decades. The land use map prepared from the merged satellite imagery of LISS-III and Pan using ERDAS Imagine (8.6) for the year 2002 shows that over 36% of the city area is urbanized whereas 40% has become barren. There are various industries in the area such as Star Paper Mill, one Unit of Indian Tobacco Company and industrial units relating to distillery, electroplating, meat products and chemicals. Most of these industrial units discharge waste effluents into the surface drains of the city which finally meet the river Hindon towards south. Besides, the municipal effluents carrying sewage generated by the populace of the town also join the surface drainage system adding to its waste loads.

There are two types of aquifers in the study area. The upper aquifer is of unconfined type extending up to about 20 m in depth below which a series of confined and semiconfined aquifers are present. The aquifers are mainly comprised of fine to medium grained sand separated by disconnected discrete clay layers which are often intercalated with kankar nodules. The ground water level monitoring in the study area was started in the year 2001 in open dug wells which however, dried up soon making it difficult to continue the monitoring. As a result, an innovative method of measurement of water table was devised and monitoring was continued in the 51 hand pumps fitted wells tapping shallow aquifers distributed in the town. The ground water monitoring data for the hand pump wells was carried out for the period before rainy season (premonsoon) and after rainy season (postmonsoon) for four years between 2001 and 2006. This data has brought out the wide variation in the depth of water table occurring between 3 m to 12 m bgl. A total of 8 cycles of ground water sampling has also been carried out from upto 19 handpump-wells for analyzing the major physicochemical and bacteriological parameters and selected heavy metals in a total of 136 ground water samples. Ground water from two nos. India Mark II hand pump wells tapping deeper aquifers (> 30 m.bgl) was also sampled for comparison purpose. Besides, 10 nos. surface water samples from possible point sources of industrial and sewage pollution and along the city drains were also collected for chemical analysis.

Quality of Water :

Chemical analysis of surface water from drains as well as sewage indicates high concentration of fecal coliforms and BOD. The data of physicochemical analyses of ground water have been plotted on bar diagrams and Piper trilinear diagrams. The bar diagrams have provided idea of the temporal variations in the composition of ground water with the $CaCO_3$ hardness, sulphate, alkalinity and nitrate showing high values with respect to the quality criteria laid down by Bureau of Indian standards for drinking (BIS:10500) especially in the postmonsoon samples. The Piper trilinear plots of chemical data indicate generally intermediate to hard nature of ground water with its character changing to dominating carbonate hardness in the postmonsoon samples. The analysis of ground water at some places indicates excessive concentrations of heavy metals like cadmium, chromium, copper, manganese and fecal coliforms when compared to the quality criteria for drinking water. The reasons for high concentration of these heavy metals can be attributed to the direct disposal of industrial effluents to nearby drains. Similarly, the origin of high fecal coliforms can be traced to the presence of sewage in the nalas especially downstream of the sewage pumping station in the central part of the study area.

Aquifer Delineation-Geolectric Approach :

With a view to delineate the aquifer system in the study area, a total of 32 Vertical Electrical Soundings (VES) have been carried out in the study area using Schlumberger configuration of electrodes at selected locations. In addition, 12 Induced polarization (IP) soundings were also recorded at places where it was necessary to detect clay layers within sandy alluvium. The field data of VES was interpreted using Zohdy (1989) software whereas the IP sounding data was interpreted using IX1D (Interpex version 3.36) software. The quantitative interpretation of geophysical data was modified using available lithological information about the nearby tubewells in the study area. The interpretation of geophysical data has indicated that the subsurface geology of the area is mainly comprised of sandy formations occasionally mixed with gravels. The sandy horizons are separated by clay bands to give rise to a multiple aquifer system. Generally, the clay layers tend to increase towards south, southeastern and eastern part of the study area. However, thin clay layers could not be detected by geophysical investigations. Further, the geoelectrical depths have to be reduced by approx. 30 to 35% to get the actual depth of the water table and layer boundaries in the actual lithological sections. At two places on Saharanpur-Ambala road (in the western part of the area) and at Pairagpur village (in the southern part of the study area), there are indications of contamination of ground water due to ongoing industrial activities in the vicinity of the sounding locations. The degradation of ground water quality has been generally confirmed from the data of chemical analysis of ground water samples in these two localities where there was a noticeable increase in the overall salinity of ground water alongwith high concentration of cadmium and chromium, nitrates, sulphates and alkalinity etc..

Vulnerability to Pollution of Ground Water :

Based on the hydrogeological setting of the study area, localities having vulnerable ground water have been delineated. For this purpose, ground water vulnerability has been worked out by employing the widely used method of DRASTIC. The method involved calculation of the seven hydrogeological parameters namely depth of water table, net ground water recharge, aquifer media, soil media, topography, impact of vadoze zone, and hydraulic conductivity of the shallow aquifers. The values of Drastic indices (DI) indicate that some central and southern localities of Saharanpur city are exposed to medium to high risk of ground water pollution (DI=160-199) in case of degraded ground water being present in their vicinity. The ground water in such high risk localities may get polluted by fecal coliform, cadmium, chromium and nitrate which are hazardous pollutants for the ground water. These places are also prone to pollution from less hazardous pollutants like copper, manganese and sulphate. In view of the potential threat of ground water pollution in these high risk localities, effective measures have to be initiated for more intensive ground water quality monitoring on regular basis.

In the light of the above revealing facts about high risk of ground water contamination in Saharanpur town, it is essential that the existing ground water quality monitoring network be strengthened in order to ensure protection of ground water resources in future. For this purpose, eleven additional shallow monitoring tubewells have been proposed to be constructed near the line sources (nalas) and point sources of pollution (waste outfalls from industries units and sewage pumping station). Such strengthened quality monitoring networks will be of considerable help in future protection of ground water in the town where majority of the population depends on shallow ground water for drinking. As there is no State Ground Water Legislation inforce in India, a series of institutional measures are essential for exercising rigorous watch on the day to day operation and management of the drinking water supply facilities. In such endeavours, role of municipal authorities and Non Govt. Organizations (NGOs) can be very effective.

Limitations of the study and suggestions for future research :

The limitations of the above studies are as under :

(i) The geoelectrical studies in the study area have not yielded the results with desired accuracy about the occurrence of thin clay beds even with combined VES-IP method of geophysical investigations being used in field. Further, the depth of occurrence of thick clay layers is not reflected with adequate precision.

(ii) As the open wells are not available in the study area, one has to resort to recording of depth to water table in hand pumps only which are generally owned by private entrepreneurs. Many a times, they objected to the mechanical opening of their pumping devices for measurement of depths. For this, new monitoring wells need to be constructed.

(iii) It became difficult to isolate the nonpoint runoff in residential and commercial areas so that it was difficult to procure truly representative water samples of storm water runoff in the town.

(iv) The application of DRASTIC approach of evaluating ground water vulnerability in alluvial areas is generally applicable in large areas on regional basis so that there is adequate variation of individual parameters of the index. In the present study, parameter(s) like aquifer media and hydraulic conductivity did not show much variation in their values. This may need to be rectified by applying a modified approach which may ensure enough variation in the important attributes. Further, a method suitably incorporating temporal changes of landuse may also be required to accommodate temporal dynamics of landuse.

The above study, has highlighted the nature of occurrence and quality of shallow ground water in the study area, and its pollution hazards in the context of its vulnerability. Further, there is a need to augment the ground water quality monitoring network for protection of the shallow ground water resources of towns like Saharanpur where majority of its population survive by consuming drinking water from large number of installed hand pumps.

REFERENCES

Aller, L., Lehr, J.H., Petty, R.J and Bennett, T., 1987. DRASTIC : A Standardized System for Evaluation of Ground water Pollution Potential using Hydrogeologic Setting, Journal, Geological Society of India, Vol. 29 ,23-27

APHA, 1998. Standard Methods for Examination of Waters and Waste water 20th Edition, AWWA- WEF, Washington, DC- 20005- 2605

Barthwal, G.D., 1996. Hydrogeological Framework and Ground water Resources Potential, Saharanpur District, Uttar Pradesh (Unpublished report), Government of India, Ministry of Water Resources, Central Ground Water Board. 99 p.

Berner, E.U., and Berner, R.A., 1996. Global Environment Water, Air and Geochemical Cycles. Uppersaddle River, N.J., USA. Prentice Hall.

Bhatnagar, N.C., Agashe, R.M., and Nautiyal, M. D., 1983. Hydrogeology Mapping of Bhabhar Zone in Upper Yamuna Basin, Technical Report No. 3, Studies in Upper Yamuna Basin, Government of India, Ministry of Irrigation, Central Ground Water Board, North Western Region Chandigarh.16 p.

Bhatnagar, N.C., Agashe, R.M., and Sikka, V.M., 1977. Water Balance Studies in Upper Yamuna River Basin, Technical Report No. 9, Upper Yamuna Project, Chandigarh, Government of India, Ministry of Irrigation, Central Ground Water Board. 138 p.

Bhattacharya, P.K. and Patra, H.P., 1968. Direct Current Geo-Electrical Sounding. Elsevier, Amsterdam.

Bichara, M. and Lakshmanan, K., 1976. Fast Automatic Processing of Resistivity Soundings. Geophys. Prospect., Vol.24, pp. 354-370.

Burarrd, S.G., 1915. Origin of Gangetic trough, commonly called the Himalayan Foredeep. Proc. Royal Soc. London, Vol. 91-A, pp. 220-238.

Bureau of Indian standard, 1981. Tolerance limits for industrial effluent, BIS 2490 (part 1), New Delhi

Bureau of Indian Standard, 1991. Characteristics for drinking water, BIS 10500, New Delhi

Central Ground Water Board, Ministry of Water Resources, 1995. Ground Water Resources of India, (Published Report), Government of India, 147 p.

Deepermann,K., 1954. Die Abhangigkeit des Scheinboren Wider standes vom Sondenabstand bei der Vierpunkt Methode. Geophys. Prospect ., Vol. 2, pp. 262-273.

ERDAS., 1997. Erdas Imagine, Tour guides, Erdas, Inc., Atlanta, USA, 454p.

Evans, P., 1959. Stratigraphy and Tectonics of the Assam Oilfield Region. E.C.A.F.E. Symposium (United Nations, Bangkok), 1958, New Delhi, p. 170.

Foster, S., Hirata, R., Gomes, D., E'Elia, M., and Paris M. 2002. Ground water Quality Protection Guide for Water Utilities Municipal Authorities and Environmental Agency, The World Bank, Washington DC, 103 p.

Garg, K.K., 2006. Slums and Their Management in Saharanpur City – A study in geographical perspective, U. P., Ph.D. Thesis (Unpublished), J.V. Jain College, Saharanpur, 540 p.

Hem, J.D., 1985. Study and Interpretation of the Chemical Characteristics of Natural water, 3rd ed., U.S. Geological Survey Water Supply, Paper No. 2254, Washington, D.C.

Hussain, H.M., 2004. Assessment of Ground water Vulnerability in an Alluvial Interfluve using GIS, Ph.D. Thesis (Unpublished), Department of Hydrology, Indian Institute of Technology Roorkee, Roorkee, 257 p.

Information for change. Info change News and Features, 2007. http://www.infochangeindia.org

Inman, J.R., Ryu, J. And Ward, S.H., 1973. Resistivity Inversion Geophysics, Vol.30, pp. 1088-1108.

Johanson, H.K., 1977. A Man/Computer Interpretation System for Resistivity Soundings over a Horizontally Stratified Earth. Geophys. Propect. Vol.25, pp. 667-691

Joshi, S.B., Singhal, D.C., Seth, A.K., Mathur, R.P. and Singhal, B.B.S., 1987. Hydrochemical studies of natural waters of Upper Hindon basin, U.P. National Symposium on Hydrology, N.I.H., Roorkee, pp. III-37-48.

Kailasham, L.N., 1971. Geophysics in geological mapping and structural studies. Rec. Geol. Surv. Ind., Vol.103 (2) pp 14-30

Keller,G.V.and Frischknecht, F.C., 1966. Electrical Methods in Geophysical Prospecting. Pergamon Press. New York, N .Y. 519 p.

Khan, S.P. 1987. Hydrological Studies of Yamuna-Hindon Doab, U.P., M.E. Dissertation (Unpublished), University of Roorkee, Roorkee, 170 p.

Koefoed, O., 1979. Geo-Sounding Principles, 1, Resistivity Sounding Measurements. Elsevier, Amsterdam.

Komarov,V.A., Pishpareva, H. N., Semenov, M. B., and Khloponina, L. S., 1966, (Sheinmanna, S. M., editor), Theoretical Fundamentals for Interpretation of Survey Data Obtained with the Induced Polarization Method: Leningrad, Isdatel'stov "Nedra," 203 p.

Kumar, C.P., Digamber Singh and Mittal, Sanjay, 2001. Determination of Saturated Hydraulic Conductivity in Upper part of Hindon River Catchment. Hydrology Journal, Vol. 24 (2) , pp. 55-62

Kumar, Sudhir and Bhatia, K.K.S., 1992. Ground water Quality Variations in Saharanpur District (U.P.). NIH Seminar on Ground Water Hydrology, New Delhi, Vol. 1, pp. 195-213.

Kunetz,G., 1966. Principles of Direct Current Resistivity Prospecting. Geoexploration Monograph Series 1, No. 1, Gebruder Borntraeger Stuttgart.

Mathew, Jyothi Jacob, 1983. Transmissivity Estimation from Resistivity Sounding Data, M.Tech. Dissertation (Unpublished), Department of Earth Sciences, University of Roorkee, Roorkee. 82p.

Mathur, L. P., and Evans, P., 1964. Oil in India. (A Review), Proc. International Geological Congress (Twenty-Second Session), New Delhi. 85p

Matthess, G., 1982. The Properties of Groundwater, John Wiley and Sons, New York, 405p.

Murali, G, 1984. Geomorphological Studies and Ground water Assessment of Upper Hindon Basin, Saharanpur District, Uttar Pradesh, M. Tech. Dissertation (Unpublished), Department of Earth Sciences, University of Roorkee, Roorkee, 120p.

Nace, R.L., 1969. World Water Inventory and Control, Water, Earth and Man. Richard J. Chorley (ed). Methuen, London, pp. 31- 42.

Oldham, R.D, 1917. The Structure of Himalayas and Gangetic Plain as Elucidated by Geophysical Observation in India. Mem. Geol. Suv. Ind., 42 : 1 – 153.

Orellana,E., and Moony, A.M., 1966. Master Tables and Curves for Vertical Electrical Sounding over Layered Structures, Infraction Madrid, Spain.

Pandey, M.P., Raghava Rao, K.V., and Raju, T.S., 1968. Groundwater Resources of Tarai-Bhabar Belts and Intermontane Doon Valley of western Uttar Pradesh (Published Report No.1) Bulletins of the Exploratory Tubewells Organization, Ministry of Food and

Agriculture, Series A – Exploratory Drilling and Groundwater, GIPN – SI – 1 Tubewell (N.D.)/ 63 – 30-5-67 -300, 253 p.

Parasnis, D.S., 1962. Principles of Applied Geophysics, Methuen, London, 275p

Patel, Nilanchal, 1985. Hydrochemical Studies of Natural Waters with Reference to the Waste Effluents Disposal in Upper Hindon Basin, Saharanpur area, U.P. M. Tech. Dissertation (Unpublished), Department of Earth Sciences, University of Roorkee.197 p.

Patel, Nilanchal, Singhal, D.C., and Singhal, B.B.S., 1985. Development of Dissolved Oxygen SAG Model for Hindon River Downstream of a Paper Mill near Saharanpur Town, U.P., India. International Seminar on 'Environmental Impact Assesment of Roorkee, India 12-14 December, pp. 811-819

Raghava Rao, K.V., 1965. Hydrogeological Studies of Alluvial Area in the Parts of Saharanpur District, U.P., Ph.D. Thesis (Unpublished), University of Roorkee, Roorkee, 313 p.

Rao, M.B.R., 1975. Outlines of Geophysical Prospecting- A Manual for Geologists. Prasaranga, Mysore.

Rao, M.S., Kumar, Bhishm, Nachiappan, Rm.P., and Jagmohan, 2000. Identification of Aquifer Recharge Sources and Zones in Parts of Ganga-Yamuna Doab Using Environmental Isotopes. Proc. International Conference on Integrated Water Resources Management for Sustainable Development, New Delhi, India. pp. 271-281.

Reena, Mathur, R.P., Seth, A.K., Sinha, S.K., 1985. Impact of industrial activity on the quality of water in Hindon basin, District Saharanpur (U.P.), International seminar on 'Environmental Impact Assesment of Roorkee, India, 12-14 December, pp. 785-800.

Roy, K.K. and Elliott, H.M., 1980. Resistivity and IP Survey for Delineating Saline Water and Fresh Water Zones., Geoexploration, Vol.18. pp. 145-162

Saini, Ravi K., Chakrapani, G.J., and Sen, A.K., 2006. Geochemical studies of ground water in Saharanpur, Uttar Pradesh, Journal Geological Society of India, Vol. 68, July 2006, pp. 50-58.

Sastri, V.V., Bhandari, L.L., Raju, A.T.R., and Datta, A.K., 1971. Tectonic framework and subsurface stratigraphy of the Ganga basin, Journal, Geological Society of India, Vol. 12, No. 3, pp. 222-233.

Saxena, V.N., Singh, Rajpal, Amga, R.N., Tyagi, K., 1983. Water balance study of Hindon-Yamuna Doab (un-published report) U.P. Ground Water Investigation Organization, Roorkee Division, Roorkee, 73 p.

Seigel, H. 1959. Mathematical formulation and type curves for induced polarization, Geophysics, Vol. 24, N3 pp. 547-565.

Seth, A.K, 1993. Hydrochemical studies in Upper Hindon Basin, District Saharanpur, U.P., India, Ph.D. Thesis (Unpublished), Department of Earth Sciences, University of Roorkee, Roorkee, 235 p.

Seth, A.K., and Singhal, D.C., 1994. Status of ground water quality in Upper Hindon Basin, Saharanpur area (Uttar Pradesh) in Proc. Regional Workshop on Environmental Aspects of Ground water development, Kurukshetra, India, Theme 1, pp. 114-122.

Seth, A.K., Singhal, D.C., and Singhal, B.B.S., 1990. Water quality modeling of river Hindon, District Saharanpur, U.P., Hydrology Journal of IAH, Roorkee, Vol. XIII, No. 4, pp. 213-227.

Shah, D.L., 1965-66. Report on Hydrogeological survey in part of Saharanpur and Bijnor districts, Uttar Pradesh (Unpublished report) Geological Survey of India, Government of India.

Shakeel, M., 1997. An integrated approach for evaluation of hydraulic properties of alluvial aquifers, Ph.D. Thesis (Unpublished), Department of Hydrology, University of Roorkee, Roorkee, 217 p.

Shukla, S.N., Nudiar, B. and Misra, M.M. 1994. Lithostratigraphy of Ganga basin, India. Indian Journal, Petroleum Geol., Vol. 3(2), pp69-90.

Singhal D.C., Sri Niwas and Singhal B.B.S., (1988). Integrated Approach to Aquifer Delineation in Hard rock Terrains-A case study from the Banda District India. Journal of Hydrology, 98 pp-163-183

Singhal, B.B.S., Mathur, R.P., Singhal, D.C., Mathur, B.S., Minocha, V.K., Seth, A.K. and Sinha, S.K., 1987. Effects of Industrial Effluents on the Water Quality of River Hindon, District Saharanpur, U.P., Journal, Geological Society of India, Vol. 30, No. 5, pp. 356-368.

Singhal, D.C., Niwas, S., Shakeel, M., and Adam, E.M., 1998. Estimation of Hydraulic Characteristics of Alluvial Aquifers from Electrical Resistivity Data, Journal Geological Society of India, Vol. 51, pp. 461-470.

Sinha, S. K., 1984. Geoelectrical and Hydrogeochemical Studies of a Part of Upper Hindon Basin, Saharanpur District, Uttar Pradesh, M. Tech. Dissertation (Unpublished), University of Roorkee. 197 p.

Sri Niwas and Singhal D.C., 1983. An Automatic Technique of Interpreting Field Resistivity Data, Proc. Central Groundwater Board Semin. Assess. Dev. Manage. Ground water Resources, New Delhi, Vol-3., pp 3-164 - 3-176.

Sri Niwas and Singhal, D.C., 1985. Aquifer Transmissivity of Porous Media from Resistivity Data, Journal of Hydrology, 82, pp. 143-153.

Sri Niwas, Pawan Kumar and Wason, H.R., 1982. First Automatic Solution of the Inverse resistivity problem. Proc. Ind. Acad. Sc., (Earth planet. Sci), Vol.91, pp. 29-41

Strahler, A.N., 1957. Quantitative Analysis of Watershed Geometry, Trans. American Geophysical Union, Vol 38, pp. 913-920.

Taylor, G.C., 1950. Ground water Provinces of India, Economic Geology, Vol 54, pp. 683-697.

Telford,W.M., L.P. Geldart. Sheriff. R.E. and Keys, D.A., 1976. Applied Geophysics, Oxford and IBM Publ. Co.Pvt.Ltd. 860 p.

Thakur, V.C. & Pandey, A.K., 2004. Active Deformation of Himalayan Frontal Thrust and Piedmont Zone South of Dehradun in Respect of Seismotectonics of Garhwal Himalaya. Him. Geol., 25(1), 25-31.

Verma, S. K., and Kumar, Bhishm, 2000. Study of Soil Moisture Movement and Recharge to Groundwater Due to Monsoon Rains and Irrigation Using Tritium Tagging Technique in Saharanpur District, CS/AR-23/1999-2000, National Institute of Hydrology, Jal Vigyan Bhawan, Roorkee. 47p.

Vrba, J. and Zoporozec, A. (Eds) 1994. Guide Book on Mapping Ground water Vulnerability Intl. Association of Hydrogeologists,131 p.

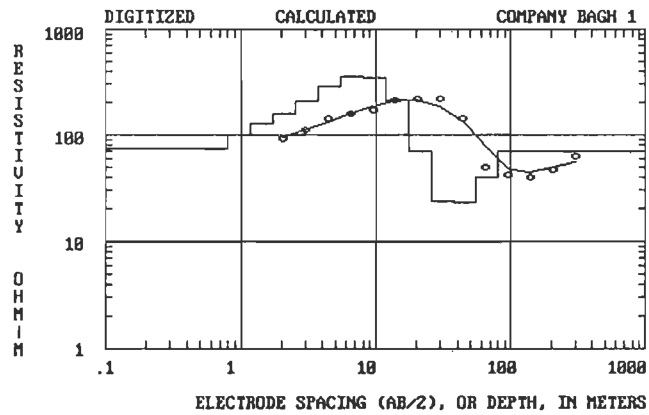
Zohdy, A.A.R. 1965. Geoelectrical and Seismic Refraction Investigation near San Jose California. Groundwater, Vol.3, No.3, pp 41-48.

Zohdy, A.A.R., 1974. A computer Programme for the Calculation of Schlumberger Sounding Curves by Convolute NPIS Pub., PB-247 265. 11p

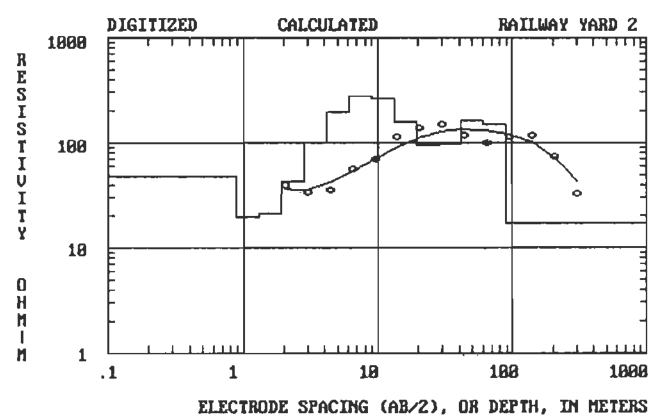
Zohdy. A.A.R. 1989. A New Method for Interpretation of Schlumberger Sounding Curves. Geophysics. Vol.2, pp. 245-253.

Annexure – 3.1(A)

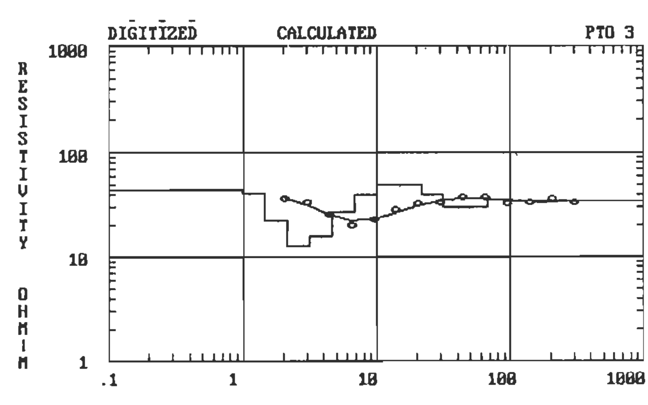
COMPANY BAGH	VES-1
Depth in meters	**Resistivity in Ohm-m**
0.80	73.52
1.18	100.26
1.73	127.65
2.54	158.96
3.74	208.36
5.48	284.12
8.05	360.05
11.81	351.53
17.33	212.10
25.44	70.69
37.35	23.70
54.82	23.29
80.46	40.34
++++	70.35



RAILWAY YARD	VES-2
Depth in meters	**Resistivity in Ohm-m**
0.89	48.20
1.31	19.60
1.92	21.11
2.82	43.34
4.14	99.08
6.09	196.80
8.93	283.64
13.12	262.08
19.26	160.59
28.27	95.27
41.49	97.82
60.90	162.92
89.40	151.75
++++	17.00

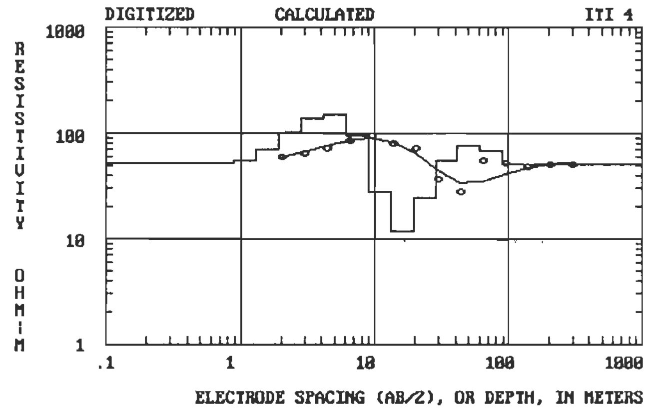


PTO	VES-3
Depth in meters	**Resistivity in Ohm-m**
0.99	44.68
1.46	41.25
2.14	22.57
3.14	12.66
4.61	15.87
6.77	27.57
9.93	40.33
14.58	48.81
21.40	48.95
31.41	39.55
46.11	30.40
67.67	30.13
99.33	35.34
++++	34.76

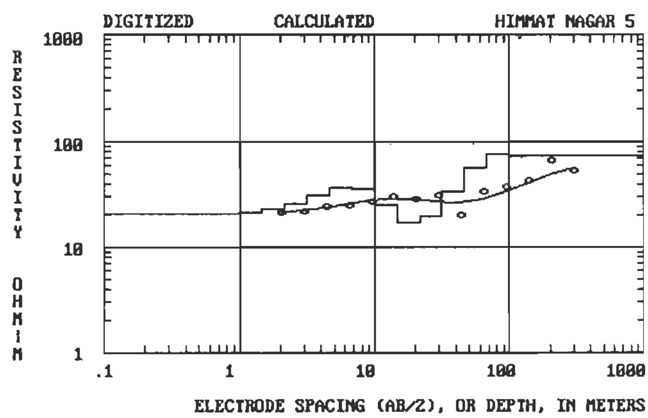


Annexure – 3.1 (B)

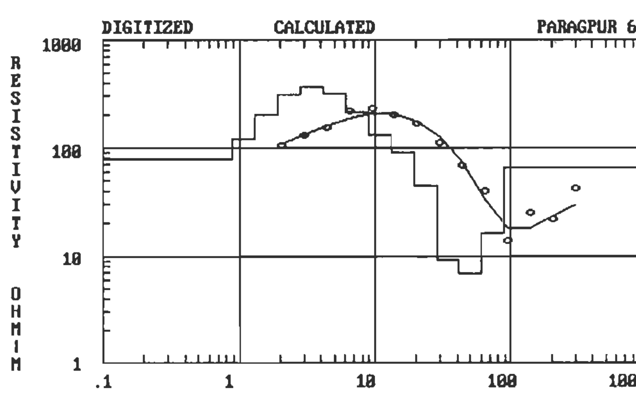
ITI	VES-4
Depth in meters	**Resistivity in Ohm-m**
0.89	52.52
1.31	54.37
1.93	71.09
2.83	103.21
4.15	139.96
6.10	151.57
8.94	95.23
13.12	27.84
19.26	11.77
28.27	24.18
41.50	55.64
60.91	75.26
89.40	69.01
++++	50.91



HIMMAT NAGAR	VES-5
Depth in meters	**Resistivity in Ohm-m**
0.99	20.54
1.46	21.42
2.14	22.95
3.14	25.63
4.61	30.83
6.77	36.73
9.93	35.98
14.58	25.37
21.40	17.24
31.41	19.83
46.11	33.80
67.67	56.68
99.33	76.73
++++	74.32



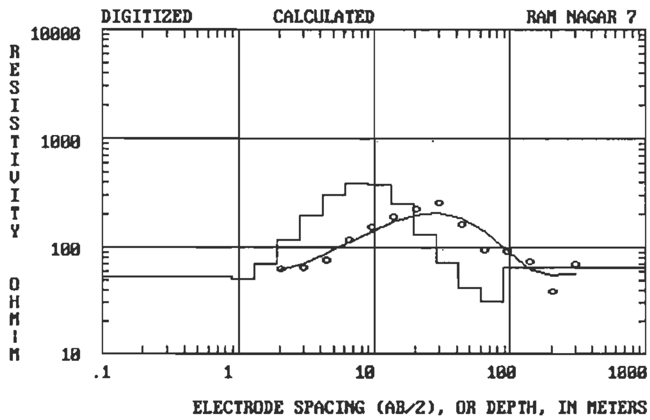
PARAGPUR	VES-6
Depth in meters	**Resistivity in Ohm-m**
0.89	77.43
1.31	119.40
1.936	202.99
2.83	311.81
4.15	368.11
6.09	317.73
8.94	211.49
13.12	131.36
19.26	90.90
28.27	44.75
41.50	9.29
60.91	6.80
89.40	16.49
++++	64.49



Annexure – 3.1 (C)

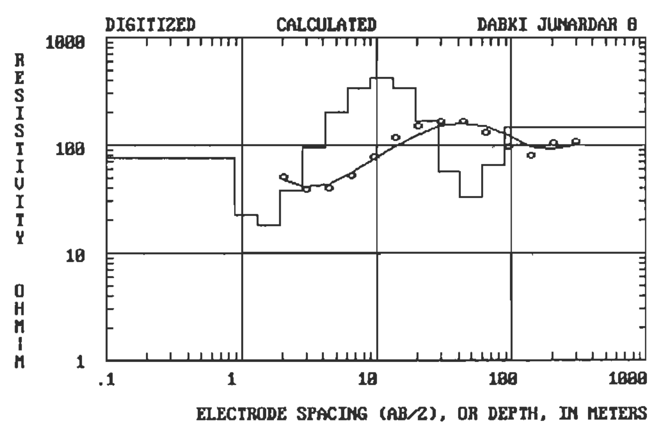
RAM NAGAR **VES-7**

Depth in meters	Resistivity in Ohm-m
0.89	53.17
1.31	50.82
1.92	71.07
2.82	118.86
4.14	197.32
6.09	302.37
8.93	390.96
13.12	374.59
19.26	248.32
28.27	129.67
41.49	72.03
60.90	41.85
89.39	30.93
++++	5.24



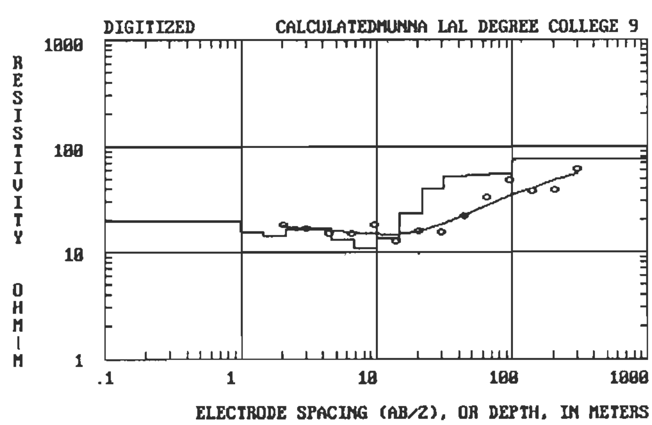
DABKI JUNARDAR **VES-8**

Depth in meters	Resistivity in Ohm-m
0.89	75.95
1.31	22.79
1.926	18.18
2.82	38.18
4.14	95.83
6.09	203.85
8.93	340.09
13.12	417.58
19.26	338.96
28.27	165.09
41.49	56.72
60.90	32.95
89.39	64.04
++++	147.55



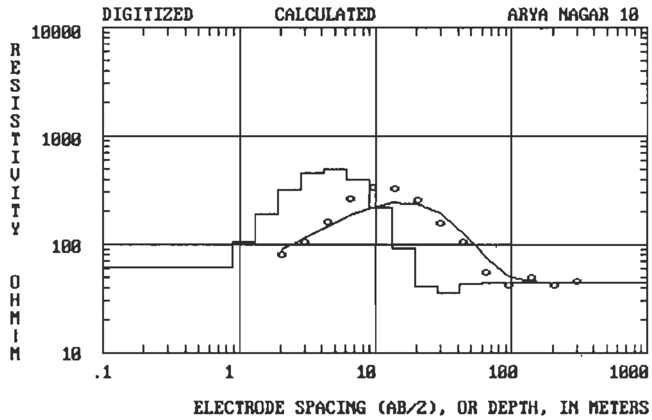
MUNNA LAL DEGREE COLLEGE **VES-9**

Depth in meters	Resistivity in Ohm-m
0.99	19.68
1.45	15.51
2.14	14.33
3.14	16.30
4.61	16.56
6.76	13.02
9.93	10.83
14.58	13.30
21.40	23.19
31.41	40.08
46.10	52.58
67.67	53.68
99.33	55.62
++++	76.06

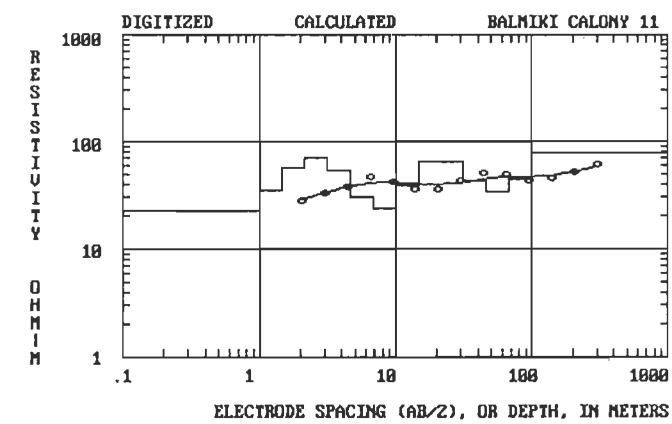


Annexure – 3.1 (D)

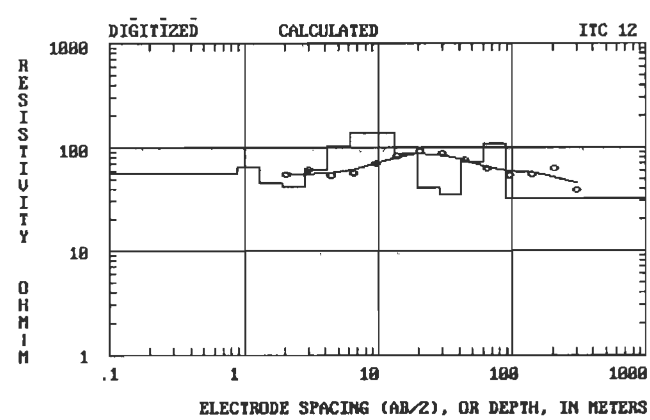
ARYA NAGAR	VES-10
Depth in meters	Resistivity in Ohm-m
0.89	61.14
1.31	104.58
1.92	191.47
2.82	323.01
4.14	453.67
6.09	494.74
8.93	395.09
13.12	222.11
19.26	91.92
28.27	40.72
41.49	36.04
60.90	42.73
89.39	43.85
++++	44.50



BALMIKI CALONY	VES-11
Depth in meters	Resistivity in Ohm-m
0.99	22.30
1.45	34.73
2.14	56.60
3.14	70.72
4.61	54.02
6.76	29.97
9.93	23.97
14.58	38.88
21.40	64.79
31.41	64.11
46.10	42.87
67.67	33.48
99.33	44.03
++++	77.88

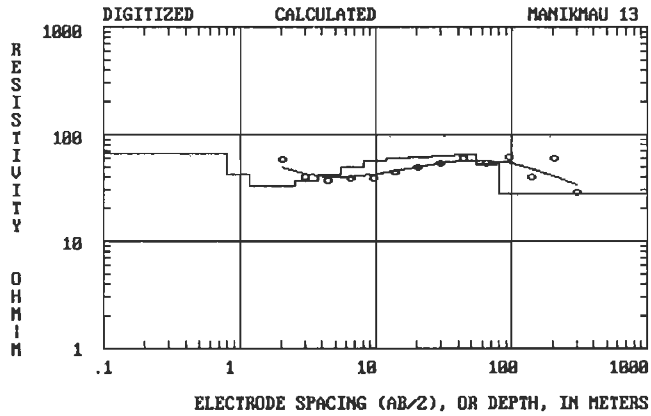


ITC	VES-12
Depth in meters	Resistivity in Ohm-m
0.89	56.68
1.31	64.05
1.92	45.54
2.82	41.60
4.14	61.73
6.09	101.42
8.93	138.35
13.12	136.59
19.26	87.00
28.27	41.36
41.49	34.58
60.90	73.16
89.39	109.01
++++	31.82



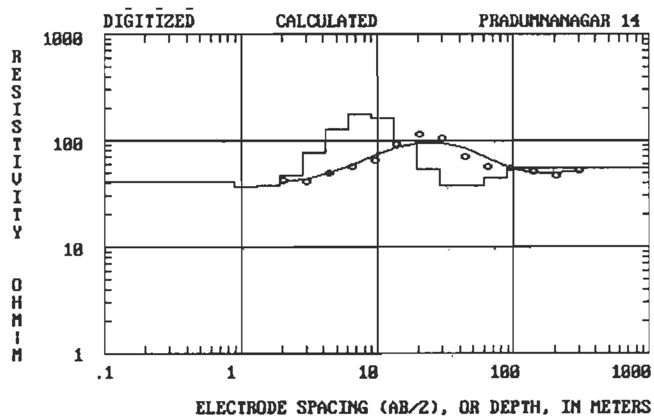
MANIKMAU **VES-13**

Depth in meters	Resistivity in Ohm-m
0.80	65.83
1.18	41.50
1.73	33.21
2.54	32.87
3.73	36.49
5.48	42.59
8.04	49.89
11.80	56.50
17.33	60.53
25.44	61.99
37.34	63.65
54.81	64.92
80.45	51.96
++++	27.75



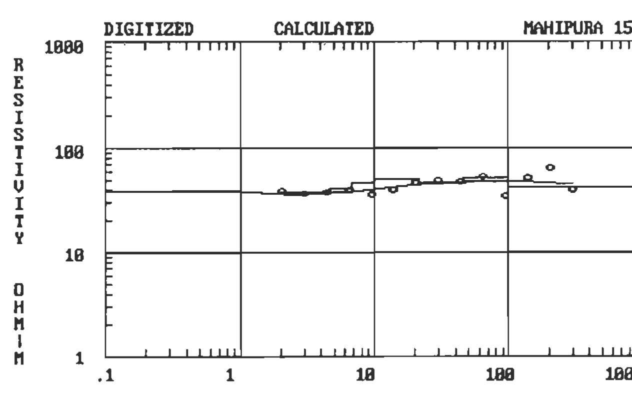
PRADUMNA NAGAR **VES-14**

Depth in meters	Resistivity in Ohm-m
0.89	40.48
1.31	36.41
1.92	37.35
2.82	47.28
4.14	76.36
6.09	128.72
8.93	174.28
13.12	161.48
19.26	100.58
28.27	53.38
41.49	37.76
60.90	38.21
89.39	43.92
++++	54.47



MAHIPURA **VES-15**

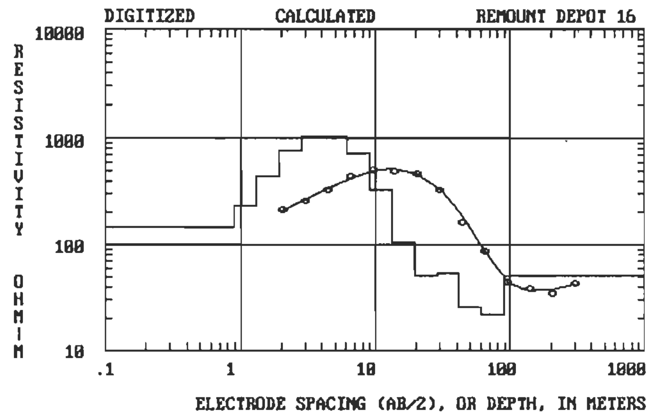
Depth in meters	Resistivity in Ohm-m
0.99	38.41
1.45	37.22
2.14	36.46
3.14	35.95
4.61	36.97
6.76	41.11
9.93	47.11
14.58	51.40
21.40	51.00
31.41	47.06
46.10	46.25
67.67	51.51
99.33	52.90
++++	41.97



Annexure – 3.1 (F)

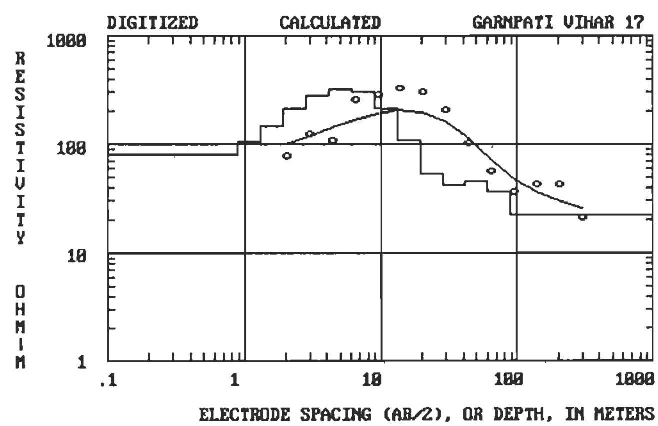
REMOUNT DEPOT **VES-16**

Depth in meters	Resistivity in Ohm-m
0.89	145.56
1.31	231.25
1.92	444.77
2.82	768.33
4.14	1026.91
6.09	1029.35
8.93	728.93
13.12	329.89
19.26	105.54
28.27	50.71
41.49	52.93
60.90	25.94
89.39	21.80
++++	51.41



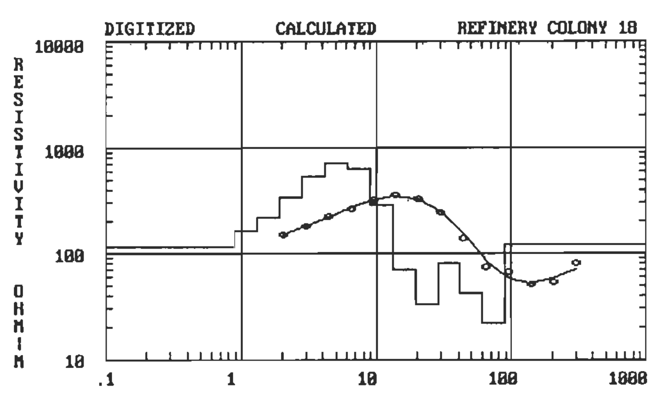
GARNPATI VIHAR **VES-17**

Depth in meters	Resistivity in Ohm-m
0.89	79.61
1.31	104.57
1.92	147.58
2.82	211.37
4.14	280.94
6.09	324.09
8.93	302.45
13.12	211.76
19.26	109.69
28.27	53.58
41.49	41.58
60.90	45.06
89.39	36.27
++++	22.46

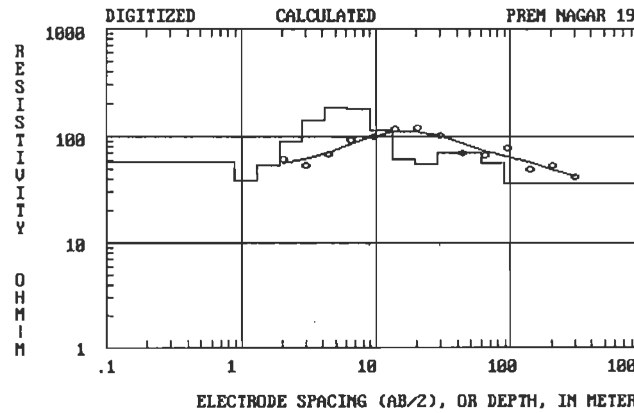


REFINERY COLONY **VES-18**

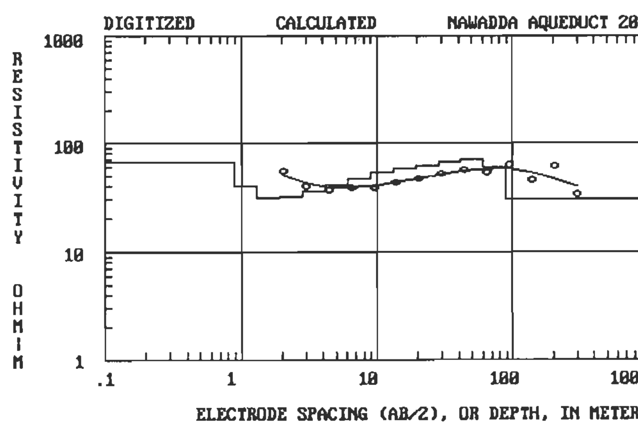
Depth in meters	Resistivity in Ohm-m
0.89	113.65
1.31	163.54
1.92	220.58
2.82	333.88
4.14	540.29
6.09	726.58
8.93	634.45
13.12	290.78
19.26	71.21
28.27	33.20
41.49	80.73
60.90	42.35
89.39	22.02
++++	120.95



PREN NAGAR Depth in meters	VES-19 Resistivity in Ohm-m
0.89	58.49
1.31	39.13
1.92	53.51
2.82	89.47
4.14	140.56
6.09	188.06
8.93	181.07
13.12	113.60
19.26	62.15
28.27	55.14
41.49	69.99
60.90	71.19
89.39	57.28
++++	36.85

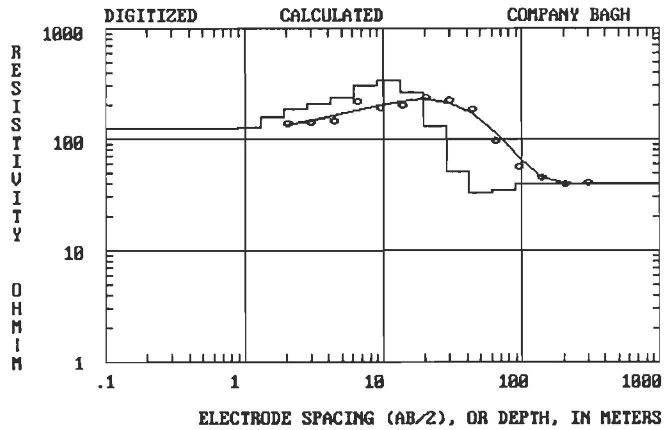


NAWDDA AQUEDUCT Depth in meters	VES-20 Resistivity in Ohm-m
0.89	67.07
1.31	40.04
1.92	31.56
2.82	32.02
4.14	35.63
6.09	41.00
8.93	47.44
13.12	53.58
19.26	58.34
28.27	62.13
41.49	66.24
60.90	69.88
89.39	59.11
++++	30.73

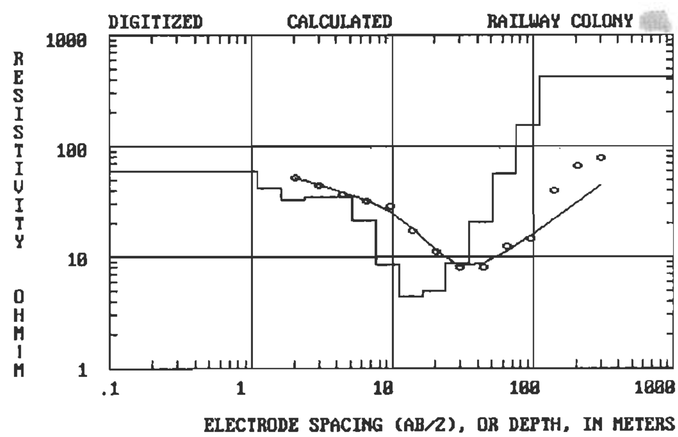


Annexure – 3.1 (H)

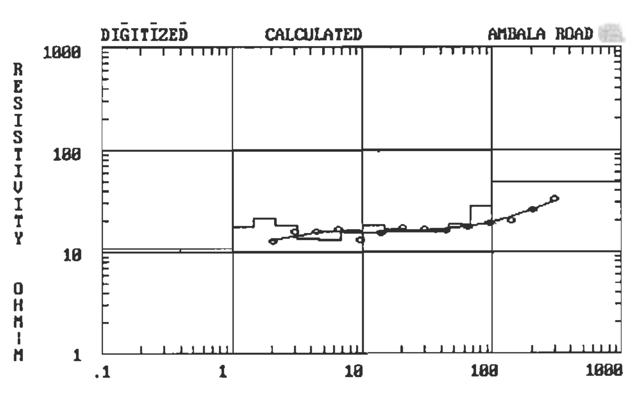
COMPANY BAGH	VES-21
Depth in meters	**Resistivity in Ohm-m**
0.89	125.54
1.31	129.28
1.93	156.70
2.83	185.81
4.15	205.16
6.09	240.95
8.94	302.71
13.12	337.42
19.26	266.21
28.27	130.96
41.50	51.08
60.91	32.61
89.40	35.10
++++	40.17



RAILWAY COLONY	VES -22
Depth in meters	**Resistivity in Ohm.m**
1.10	60.26
1.62	41.73
2.38	33.00
3.49	34.81
5.12	35.03
7.52	21.18
11.04	8.42
16.20	4.40
23.78	4.88
34.90	8.69
51.23	20.70
75.19	56.78
110.37	153.86
++++	423.30

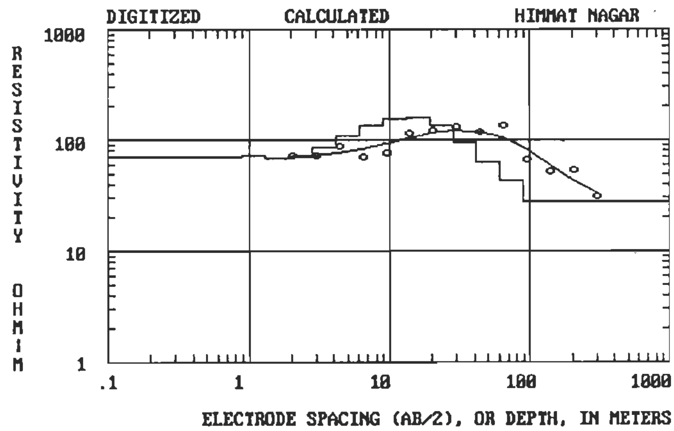


AMBALA ROAD	VES-23
Depth in meters	**Resistivity in Ohm-m**
0.99	10.89
1.46	17.71
2.14	21.29
3.14	17.95
4.61	13.36
6.77	13.12
9.93	16.30
14.58	17.94
21.40	16.95
31.41	15.89
46.11	15.84
67.67	18.79
99.33	28.22
++++	47.54



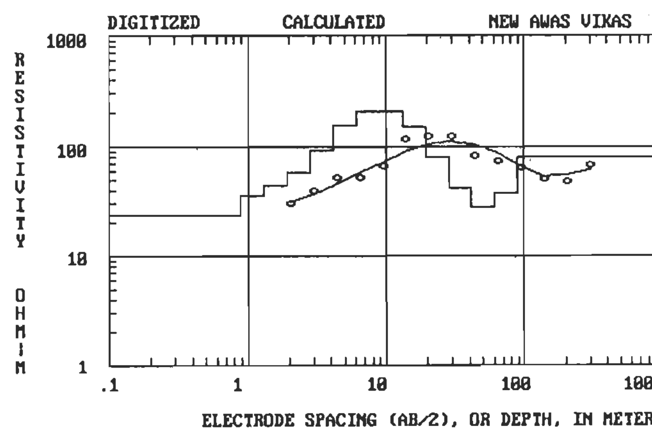
HIMMAT NAGAR — VES-24

Depth in meters	Resistivity in Ohm-m
0.89	70.67
1.31	71.47
1.93	69.12
2.83	70.60
4.15	83.89
6.09	107.56
8.94	133.44
13.12	153.49
19.26	157.15
28.27	133.44
41.50	94.23
60.91	63.83
89.40	43.72
++++	28.27



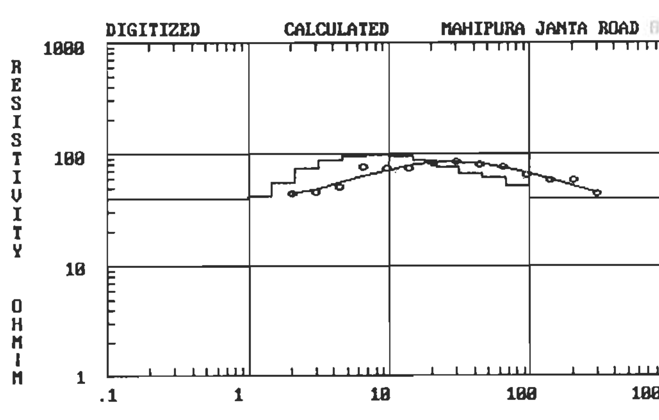
NEW AWAS VIKAS — VES-25

Depth in meters	Resistivity in Ohm-m
0.89	24.07
1.31	35.74
1.93	44.39
2.83	58.01
4.15	92.73
6.09	154.01
8.94	210.23
13.12	208.97
19.26	148.25
28.27	81.46
41.50	41.89
60.91	28.25
89.40	37.59
++++	80.00



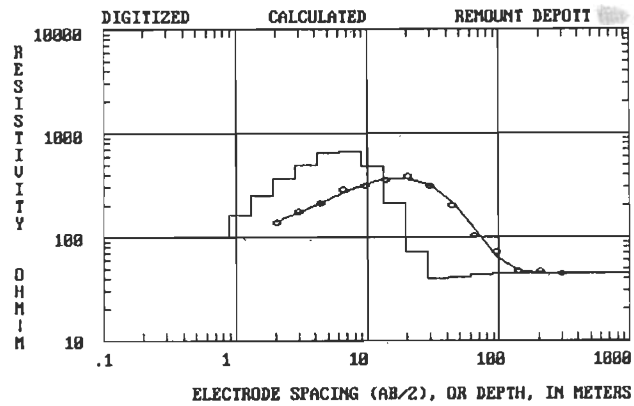
MAHIPURA JANTA ROAD — VES-26

Depth in meters	Resistivity in Ohm-m
0.99	39.74
1.46	42.53
2.14	55.16
3.14	73.64
4.61	87.54
6.77	93.82
9.93	96.09
14.58	95.03
21.40	88.30
31.41	76.73
46.11	66.38
67.67	60.63
99.33	52.85
++++	39.38

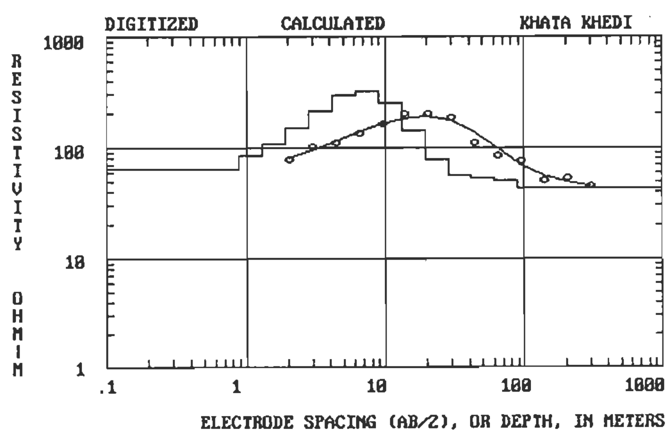


Annexure – 3.1 (J)

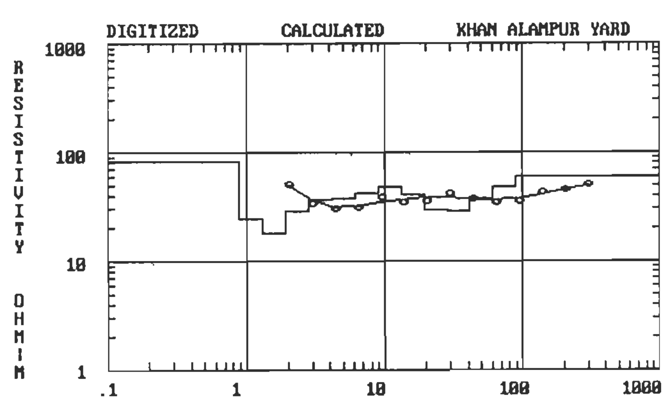
REMOUNT DEPOTT	VES-27
Depth in meters	Resistivity in Ohm.m
0.89	100.80
1.31	163.11
1.93	253.71
2.83	365.74
4.15	499.65
6.09	640.04
8.94	674.77
13.12	486.60
19.26	214.63
28.27	71.80
41.50	40.21
60.91	41.43
89.40	43.23
++++	44.78



KHATA KHEDI	VES-28
Depth in meters	Resistivity in Ohm-m
0.89	65.43
1.31	85.38
1.93	108.91
2.83	149.03
4.15	215.44
6.09	291.77
8.94	319.83
13.12	251.86
19.26	143.58
28.27	77.69
41.50	57.00
60.91	54.14
89.40	51.10
++++	42.74

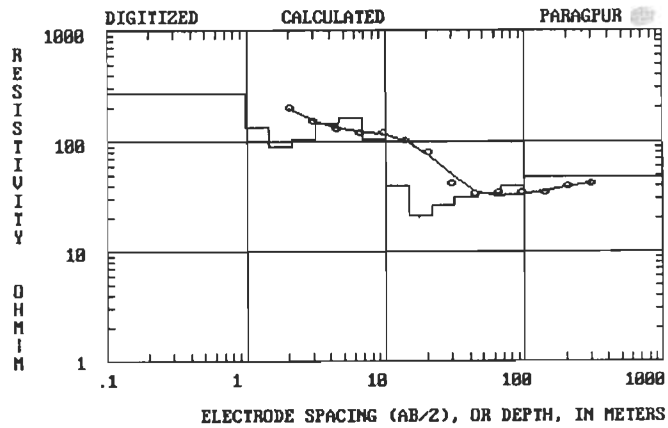


KHAN ALAMPUR YARD	VES-29
Depth in meters	Resistivity in Ohm-m
0.89	83.72
1.31	24.45
1.93	18.12
2.83	28.53
4.15	36.50
6.09	37.44
8.94	42.44
13.12	48.09
19.26	40.63
28.27	29.52
41.50	28.71
60.91	37.35
89.40	48.76
++++	58.99

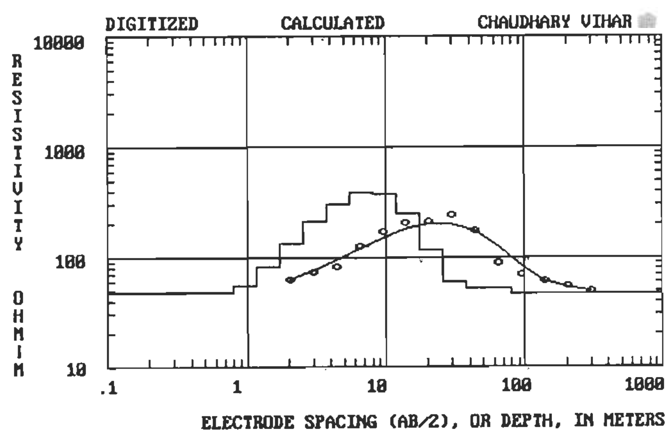


Annexure – 3.1 (K)

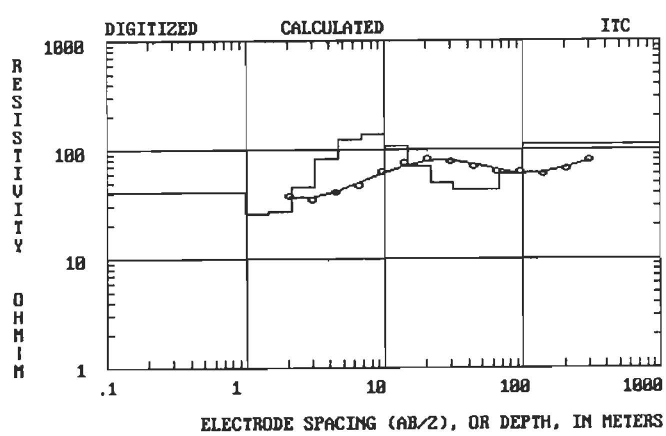
PAIRAGPUR	VES- 30
Depth in meters	Resistivity in Ohm.m
0.99	269.87
1.46	134.56
2.14	90.27
3.14	104.57
4.61	146.28
6.77	162.20
9.93	104.69
14.58	39.34
21.40	21.50
31.41	26.38
46.11	31.29
67.67	34.08
99.33	39.88
++++	47.70



CHOWDHARY VIHAR	VES-31
Depth in meters	Resistivity in Ohm-m
0.80	48.43
1.18	55.15
1.73	81.99
2.54	134.58
3.73	211.34
5.48	305.04
8.05	385.10
11.81	375.84
17.33	248.79
25.44	116.15
37.35	59.45
54.82	52.42
80.46	52.87
++++	47.10

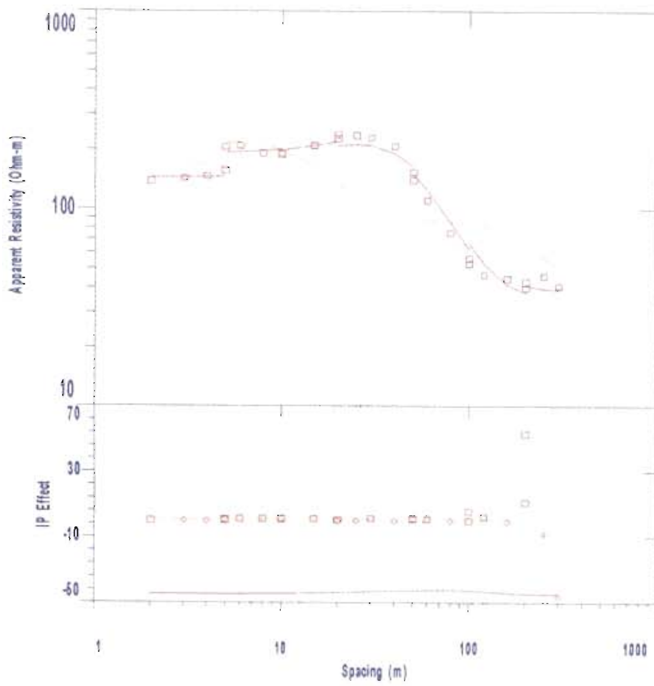


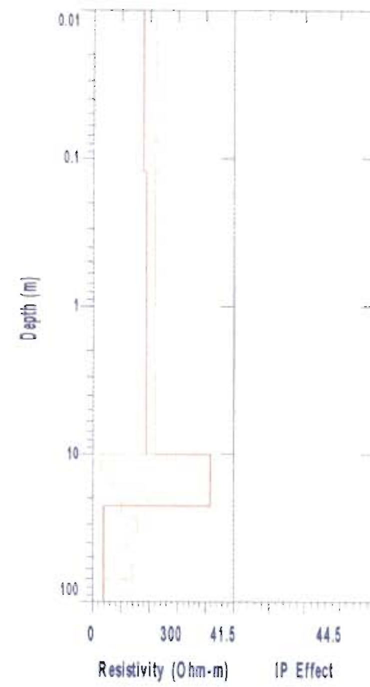
ITC	ITC-32
Depth in meters	Resistivity in Ohm-m
0.99	40.45
1.46	25.47
2.14	27.33
3.14	45.81
4.61	82.95
6.77	124.69
9.93	137.76
14.58	108.93
21.40	70.12
31.41	49.12
46.11	42.97
67.67	43.62
99.33	60.49
++++	111.93



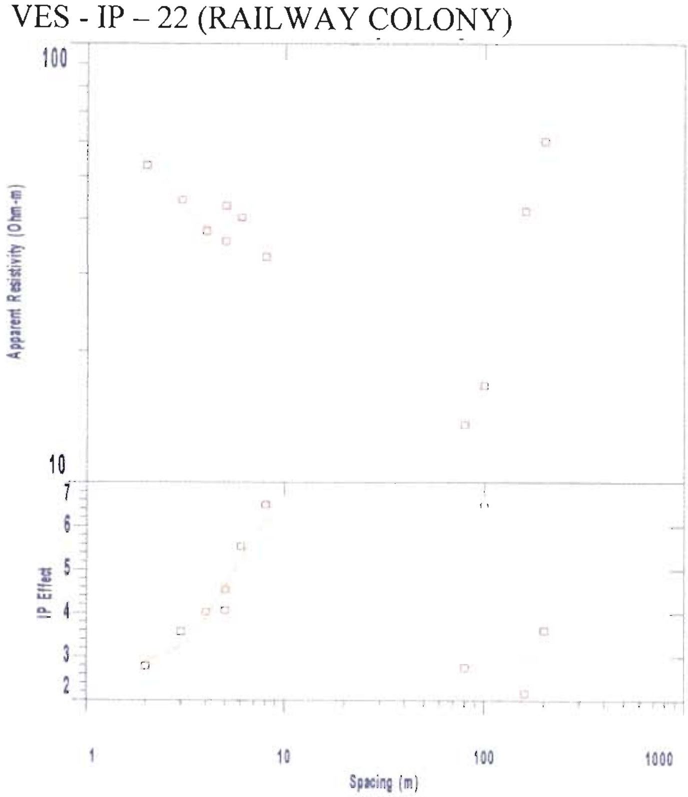
Annexure – 3.2 (A)

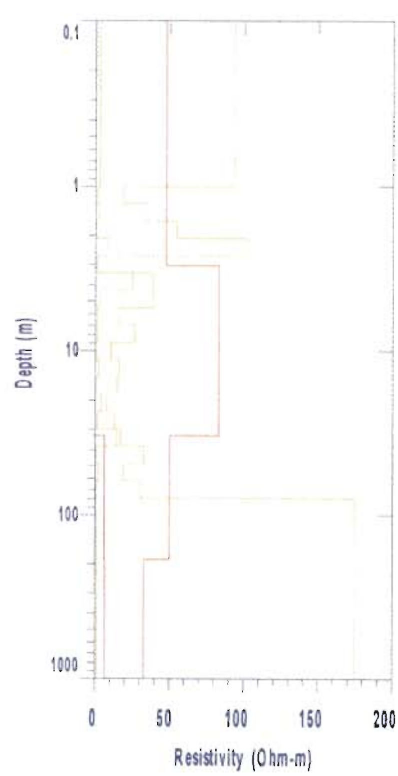
VES - IP – 21 (COMPANY BAGH)





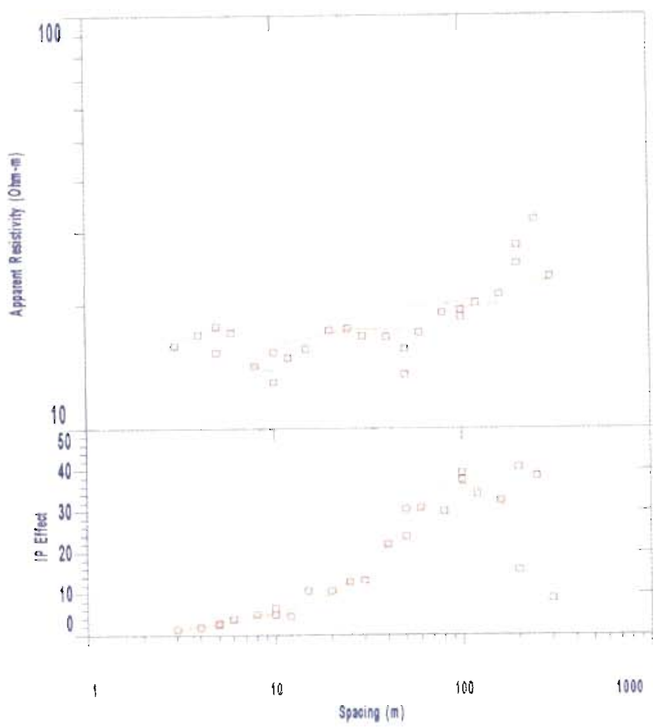
VES - IP – 22 (RAILWAY COLONY)

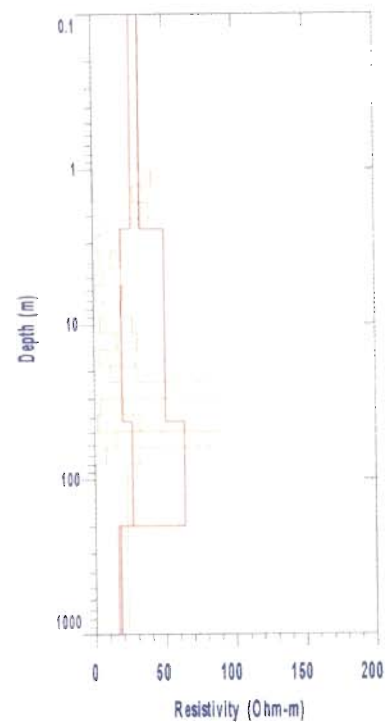




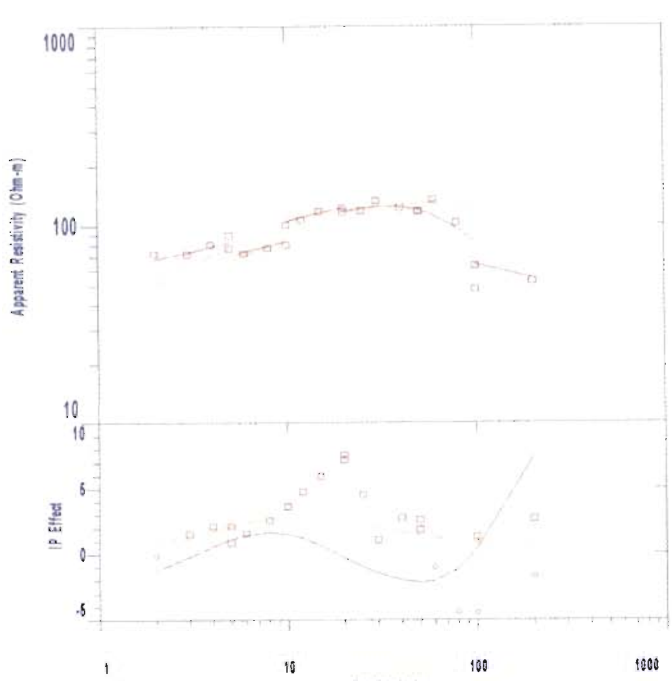
Annexure – 3.2 (B)

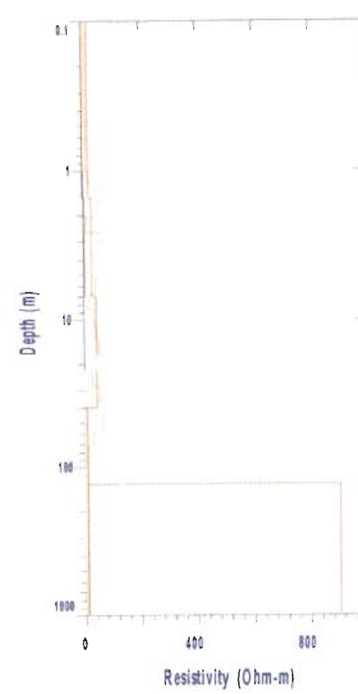
VES - IP – 23 (AMBALA ROAD)



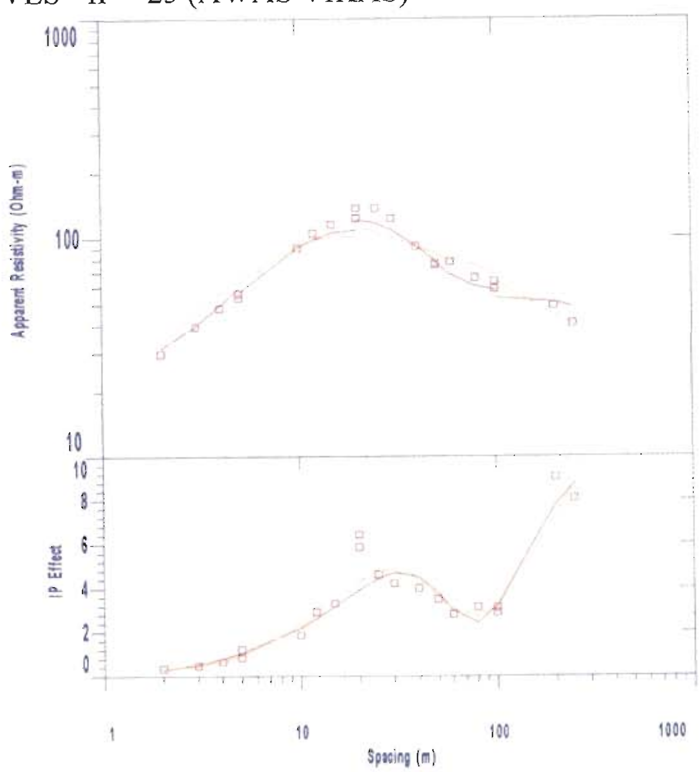


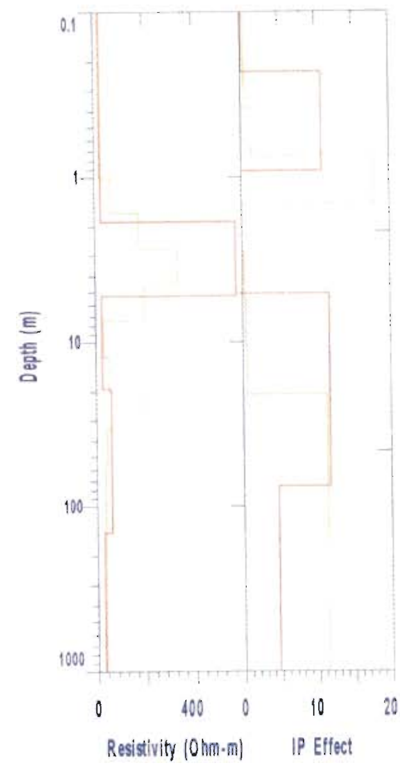
IP – 24 (HIMMAT NAGAR)



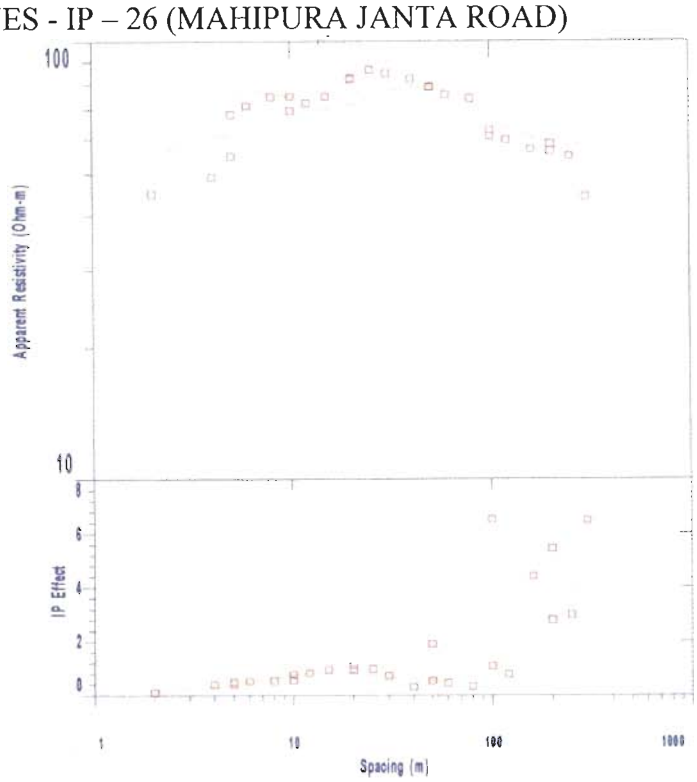


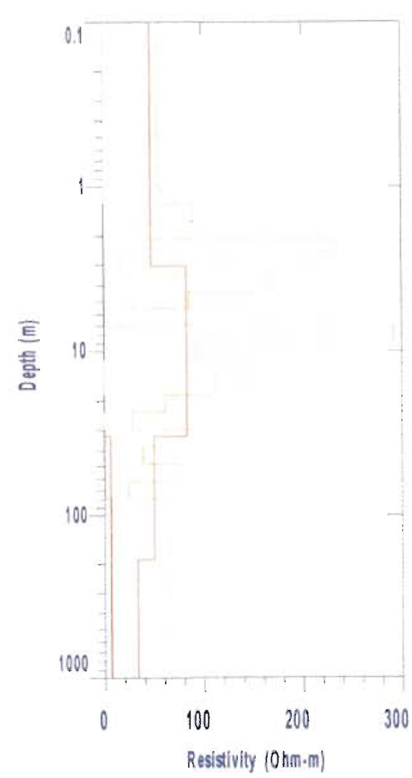
VES - IP – 25 (AWAS VIKAS)





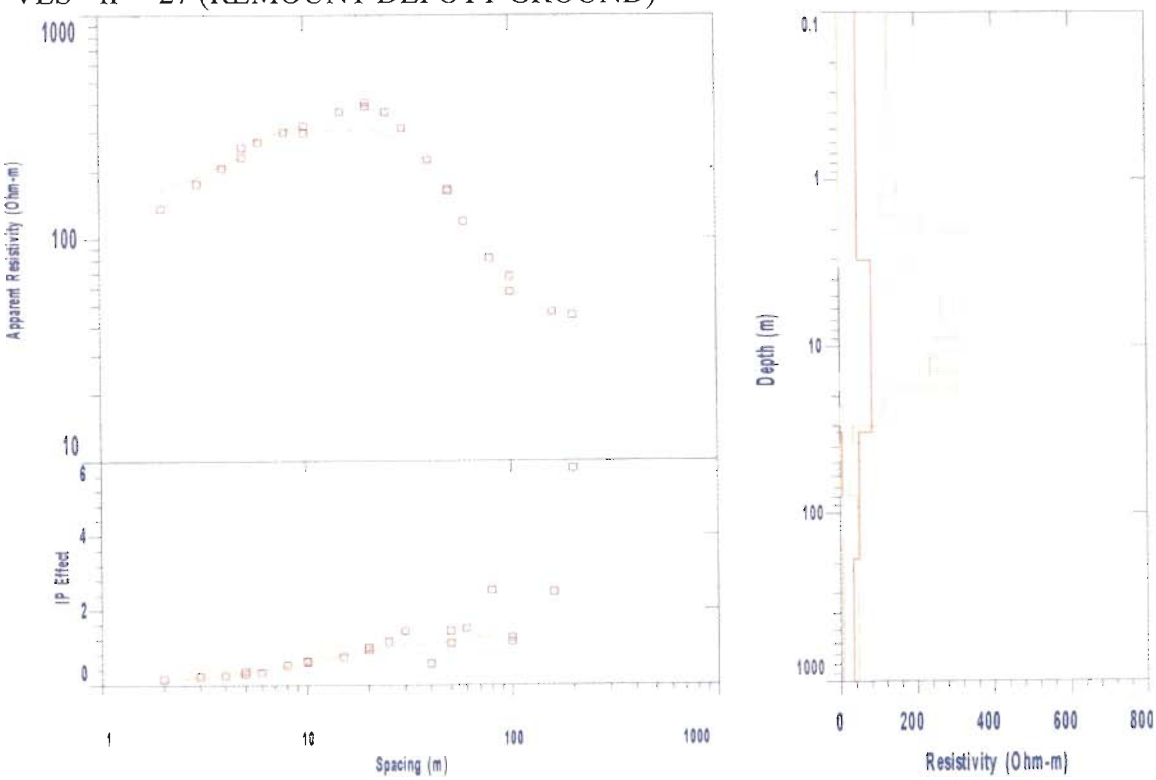
VES - IP – 26 (MAHIPURA JANTA ROAD)



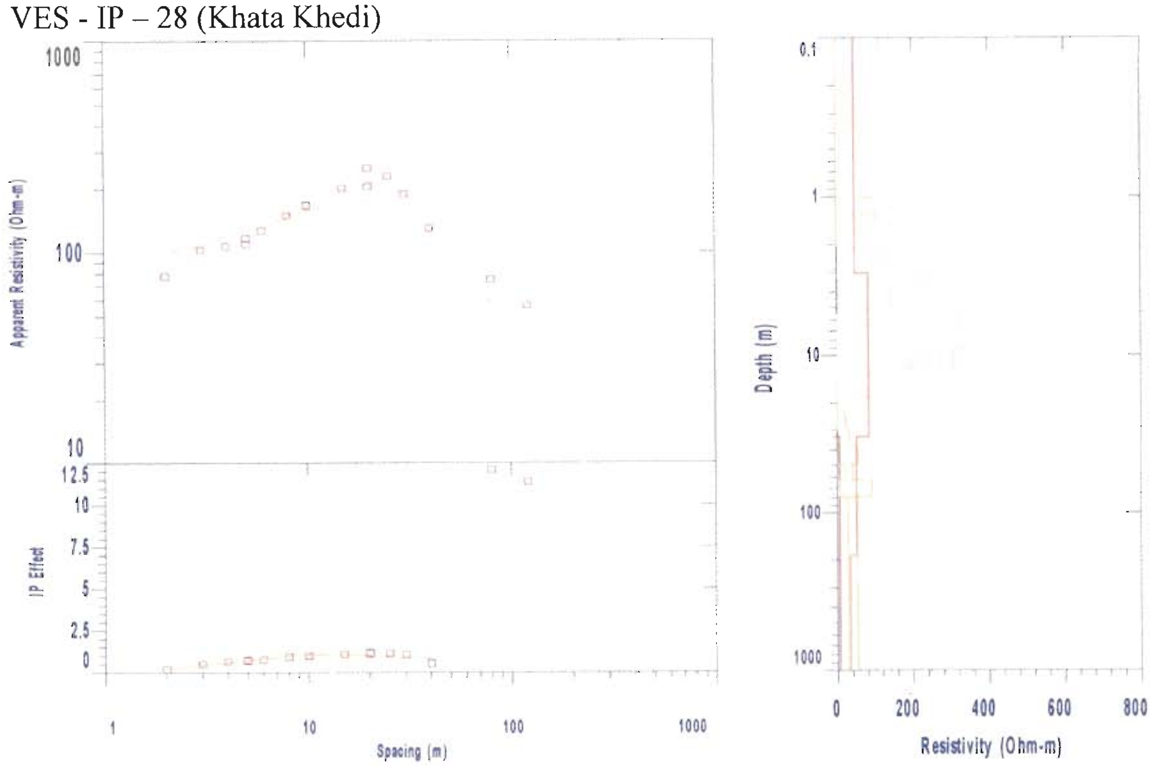


Annexure – 3.2 (D)

VES - IP – 27 (REMOUNT DEPOTT GROUND)

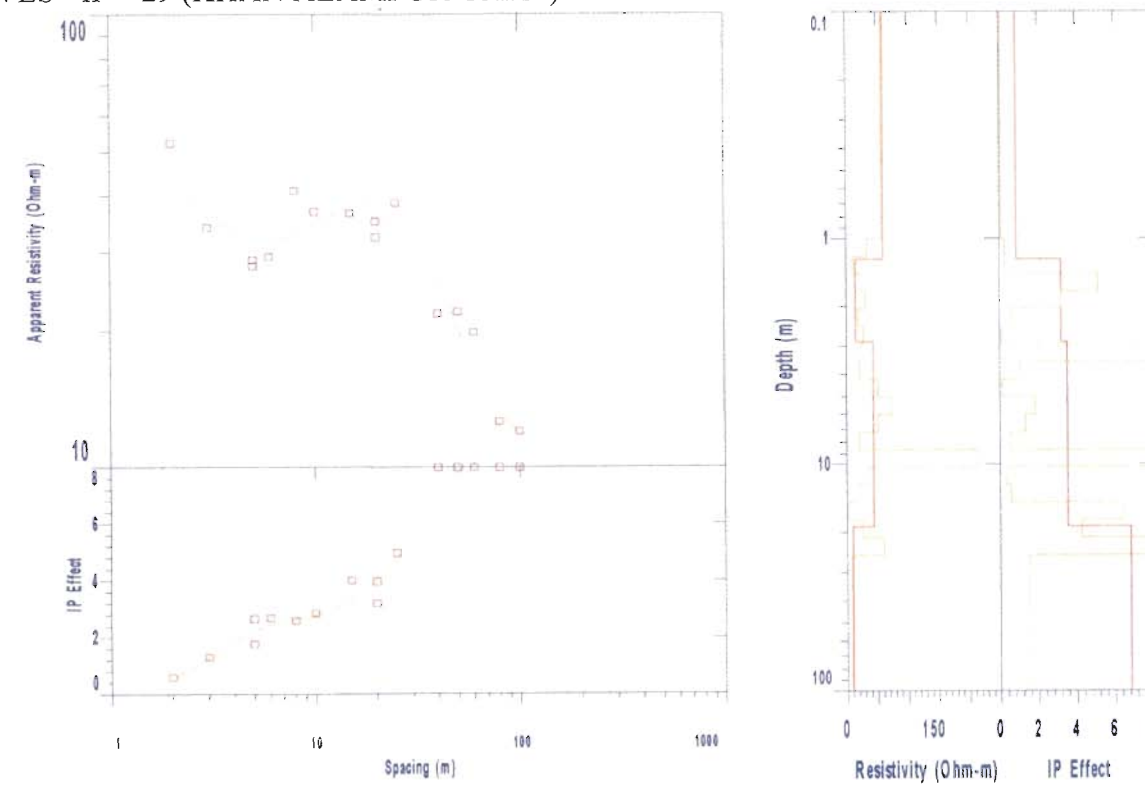


VES - IP – 28 (Khata Khedi)

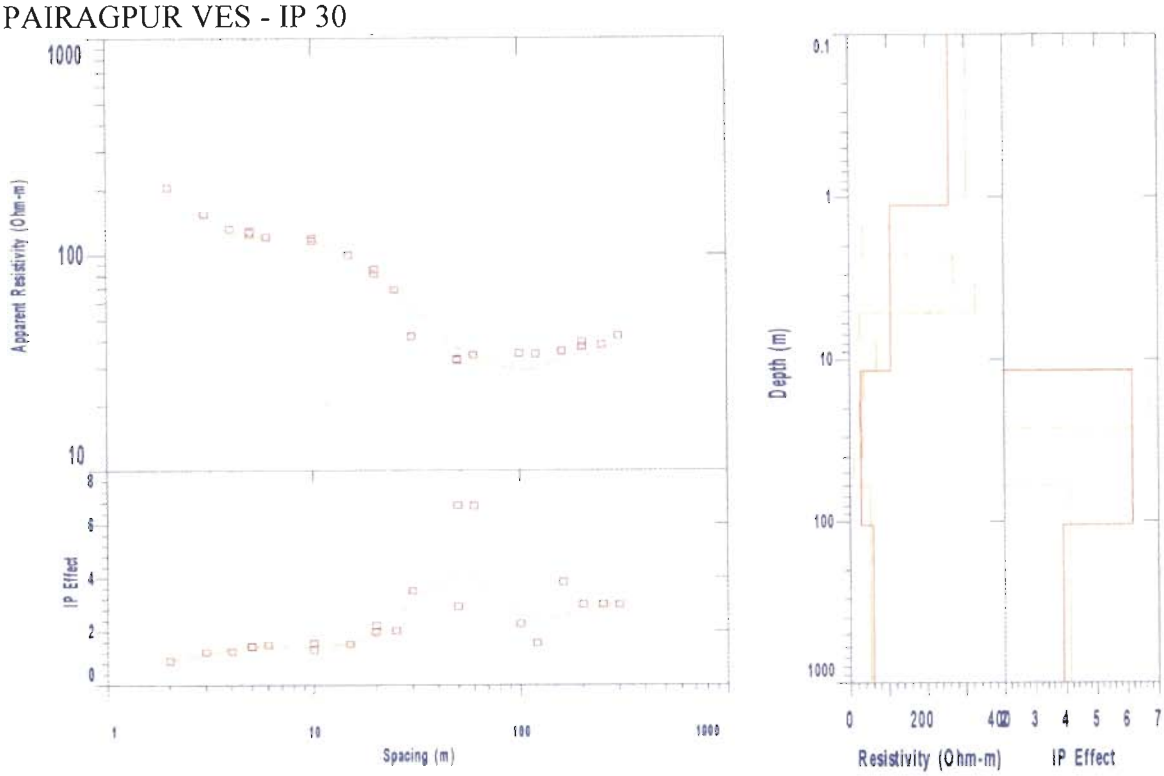


Annexure – 3.2 (E)

VES - IP – 29 (KHAN ALAMPUR YARD)

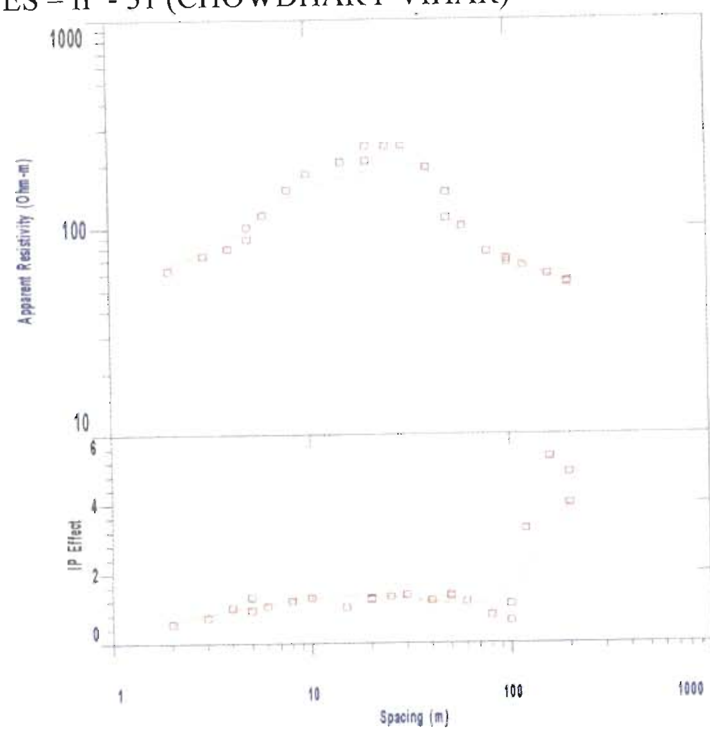


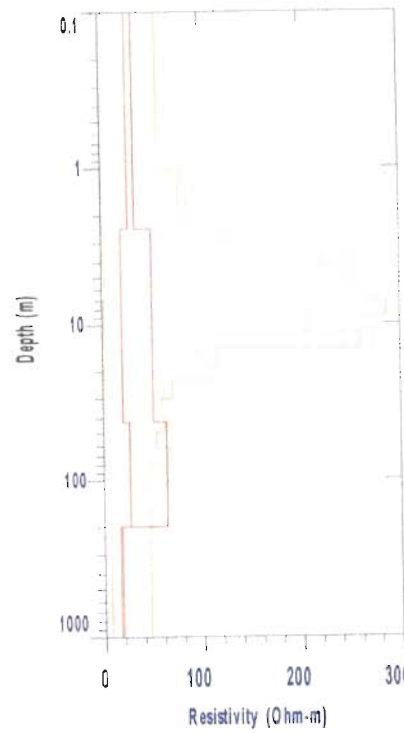
PAIRAGPUR VES - IP 30



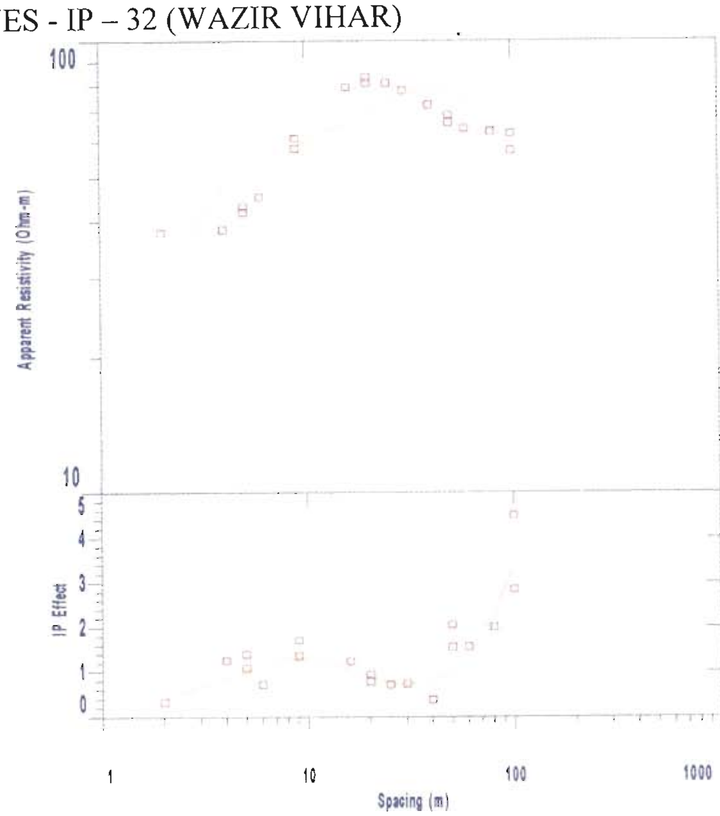
Annexure – 3.2 (F)

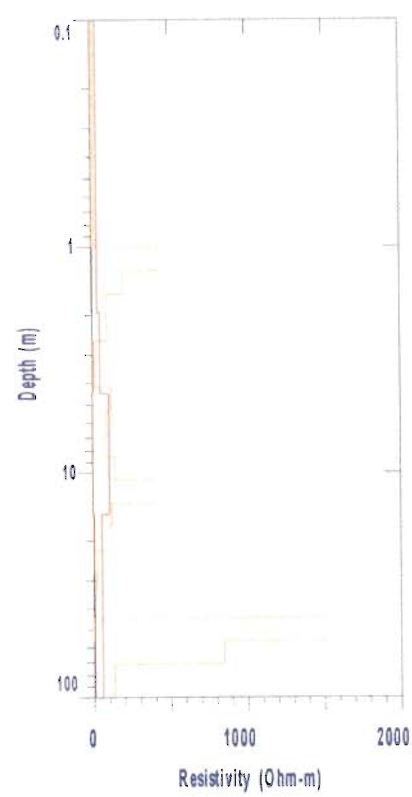
VES – IP - 31 (CHOWDHARY VIHAR)





VES - IP – 32 (WAZIR VIHAR)





Annexure – 4.1

Details of confined sand horizons encountered during the drilling of the piezometer at Hassanpur (Saharanpur).

1.	20-59.5 m (39.5 m thick)	Sand, coarse to medium and fine grained, with some gravel.
2.	126-150 m (24 m thick)	Sand, medium to fine grained, micaceous, gravel, subrounded to subangular.
3.	170-210 m (40 m thick)	Gravel (subangular to subrounded), sand (medium to fine grained).
4.	213-235 m (22 m thick)	Sand (fine to medium grained) micaceous with some gravel.
5.	275-285 m (10 m thick)	Sand, medium to fine grained, micaceous with little gravel subrounded.
6.	328-340 m (12 m thick)	Sand, very fine to medium grained, micaceous.
7.	385-39 m (10 m thick)	Sand, medium to fine grained, micaceous with little gravel subangular to subrounded.
8.	398-407 m (9 m thick)	Sand, medium to fine grained, micaceous with little gravel subangular to subrounded.
9.	420-430 m	Sand, medium to fine grained, micaceous with little some gravel.

Annexure 5.1 (i)

Physico-chemical analysis of Groundwater Samples (Premonsoon 2001), Saharanpur

Name of Groundwater Sampling	Groundwater Stations	Temp 0C	pH	EC (mhos/cm)	TDS (mg/l)	T.Alk. (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K (mg/l)	Total-P(mg/l)
Mahipura	GWQ 1	24.5	7.1	1341	832	214	213.7	0.3	162.3	160.3	450	159.2	12.63	27.8	87.4	14.2	0.031
S M Inter College	GWQ 2	25.1	7.7	1493	955	500	497.7	2.3	266	153.9	500	181.6	11.17	15.1	78.5	14.7	0.03
Shekhpura Qadim	GWQ 3	25.5	7.9	1792	1385	440	436.7	3.3	207	164.5	666	249.6	10.2	205	224	15.5	0.021
Pairagpur	GWQ 4	24.5	7.3	2000	1500	300	299.4	0.6	342	198.3	760	247.2	34.49	238	65.6	44.2	0.01
Dudhali Bhukara	GWQ 5	24	7.9	593	330	312	309.7	2.3	33	83.95	232	65.6	16.51	10.4	11.8	14.4	0.015
Ghogreki	GWQ 6	23.5	6.8	972	600	210	209.9	0.1	95	130.4	396	107.2	31.09	10.7	24.6	1.6	0.014
Hasanpur	GWQ 7	28	7.4	1222	914	260	259.4	0.6	73	124.3	276	62.4	29.14	81.2	95.48	21.2	0.013
Hakiquat Nagar	GWQ 8	24	6.9	938	625	412	411.7	0.3	38	98.76	230	66.4	15.54	12.4	88.5	44.8	0.008
Govind Nagar	GWQ 9	25	7.2	674	390	410	409.4	0.6	33	68.4	228	67.2	14.57	13.72	81.1	14.2	0.012
Wazir Vihar	GWQ 10	23	7.5	752	450	290	289.1	0.9	54	82.3	264	58.4	28.66	57.3	64.8	15.4	0.012
Patel Nagar	GWQ 11	23	7.7	1088	730	286	284.7	1.3	61	182.7	352	100	24.77	39.3	94.6	20.1	0.016
Sabarika Bagh	GWQ 12	23	7.6	1185	825	244	243.1	0.9	100	165	464	129.6	34	41.1	78.88	20.2	0.024
Munnalal Girl's Degree College	GWQ 13	24	7.4	1455	1010	412	411.0	1.0	194	96.7	456	107.2	45.66	58.3	76.4	18.2	0.02
Arabi Madrisa	GWQ 14	24	7.8	1488	940	410	407.6	2.4	126	102.5	346	88	30.6	110.2	74.6	22.8	0.025
Company Bagh	GWQ 15	25	7.3	1172	790	360	359.3	0.7	80	142	452	148.8	19.43	88.5	78.4	15.8	0.015
Shahid Ganj	GWQ 16	26	7.8	1352	860	284	282.3	1.7	78	121	430	94.4	47.12	81.9	55.3	14.6	0.52
Dabki Junardar	GWQ 17	25	7.1	1200	892	320	319.6	0.4	122	98.36	402	99.2	37.4	12.4	52.8	15.2	0.028
BIS: 10500		-	6.5-8.5	-	500	200	-	-	250	200	300	75	30	45	-	-	-

Annexure 5.1 (ii)

Physico-chemical analysis of Groundwater Samples (Postmonsoon 2001), Saharanpur

Name of Groundwater Sampling	Groundwater Stations	Temp 0C	pH	EC (mhos/cm)	TDS (mg/l)	T.Alk. (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K (mg/l)	Total-P(mg/l)
Mahipura	GWQ 1	24	7.1	1154	790	250	249.7	0.295	57.98	124.6	380	80	43.72	130	80.1	13.2	0.11
S M Inter College	GWQ 2	24.5	7.8	1400	710	504	501	2.965	82.97	71.19	410	94.4	42.26	137.8	78.5	22.3	0.113
Shekhpura Qadim	GWQ 3	24.5	7.2	1820	1400	334	333.5	0.496	208.9	136.4	390	88	41.29	290	162	148.9	0.114
Pairagpur	GWQ 4	24	6.8	1952	1600	198	197.9	0.117	434.9	178.2	884	240	68.97	208	65.6	24.4	0.115
Dudhali Bhukara	GWQ 5	23	7.7	534	400	366	364.3	1.713	39.99	35.8	308	88.8	20.89	15.8	11.6	14.4	0.112
Ghogreki	GWQ 6	23	7.2	816	550	290	289.6	0.43	83.97	82.15	370	86.4	37.4	12.5	12.8	4.6	0.016
Hasanpur	GWQ 7	24.5	7.3	996	690	264	263.5	0.493	84.97	105.8	336	107.2	16.51	84.5	95.48	21.2	0.115
Hakiquat Nagar	GWQ 8	24.5	7.6	748	550	344	342.7	1.28	51.98	102.4	354	97.6	26.72	36.4	78.2	16.8	0.115
Govind Nagar	GWQ 9	24.5	7.8	684	560	354	351.9	2.083	42.99	44.85	320	83.2	27.2	68.1	75.9	14.3	0.117
Wazir Vihar	GWQ 10	24	7.1	690	505	268	267.7	0.316	56.98	48.56	336	78.4	34	25.2	64.8	13.2	0.115
Patel Nagar	GWQ 11	24	7.3	1296	1000	232	231.6	0.433	150	77.77	480	121.6	42.74	98.2	82.6	17.2	0.131
Sabarika Bagh	GWQ 12	24	7.6	1123	900	346	344.7	1.287	124.8	163.4	580	140	55.86	14.5	78.88	16.8	0.119
Munnalal Girl's Degree College	GWQ 13	24.5	7.4	1069	810	324	323.2	0.762	114	63.37	570	125.6	62.17	198.1	76.4	15.7	0.118
Arabi Madrisa	GWQ 14	25	7.5	991	710	364	362.9	1.076	73.98	29.63	382	103.2	30.12	168.1	74.6	18.5	0.125
Company Bagh	GWQ 15	23	7.6	996	800	260	259	0.967	77.4	110.3	448	125.6	32.54	153	78.4	16.7	0.115
Shahid Ganj	GWQ 16	25	7.3	1197	850	320	319.4	0.598	66.2	90.53	532	143.2	42.26	147	44.9	14.5	0.293
Dabki Junardar	GWQ 17	24	7.1	1100	834	306	305.6	0.361	98.2	85.16	524	127.2	50.03	12.8	30.2	15.1	0.112
BIS: 10500		-	6.5-8.5	-	500	200	-	-	250	200	300	75	30	45	-	-	-

Note: **ND = Not Detected**

Annexure 5.1 (iii)

Physico-chemical analysis of Groundwater Samples (Premonsoon 2002), Saharanpur

Name of Groundwater Sampling	Groundwater Stations	Temp 0C	pH	EC (mhos/cm)	TDS (mg/l)	T.Alk. (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K (mg/l)	Total-P(mg/l)
Mahipura	GWQ 1	24.5	7.1	1368	900	254	253.70	0.30	135.9	130.4	460	164.8	11.66	35.4	66.1	13.8	0.033
S M Inter College	GWQ 2	25.2	7.9	1354	932	458	454.61	3.39	114.7	106.3	436	169.6	2.914	15.1	54.9	14.6	0.031
Shekhpura Qadim	GWQ 3	25.6	7.9	1970	1130	352	349.40	2.60	245.5	162.4	660	239.2	15.06	195	184.6	15.4	0.022
Pairagpur	GWQ 4	25.7	7.3	1960	1516	288	287.46	0.54	342.2	198.3	640	227.2	17.49	58	65.7	24.1	0.01
Dudhali Bhukara	GWQ 5	24.6	7.9	720	345	288	285.87	2.13	65.2	96.9	310	75.2	29.63	10.1	10.8	8.2	0.015
Ghogreki	GWQ 6	23.8	6.8	885	612	224	223.87	0.13	22.5	123.7	316	85.6	24.77	10.3	16.1	1.3	0.016
Hasanpur	GWQ 7	26	7.4	1127	714	240	239.44	0.56	65.65	106.1	304	76.8	27.2	78	17.4	10.8	0.014
Hakiquat Nagar	GWQ 8	25	6.9	917	622	346	345.74	0.26	42.57	98.76	238	81.6	8.257	12.44	78.2	16.5	0.008
Govind Nagar	GWQ 9	25	7.2	900	390	384	383.43	0.57	98.42	76.42	244	85.6	7.286	14.5	63.8	14.8	0.013
Wazir Vihar	GWQ 10	24	7.5	1100	458	254	253.25	0.75	54.21	80.29	358	98.4	27.2	61.3	69.9	14.9	0.013
Patel Nagar	GWQ 11	24	7.7	1060	752	274	272.72	1.28	77.53	80.44	282	94.4	11.17	39.3	72.1	12.4	0.017
Sabarika Bagh	GWQ 12	24	7.6	900	836	316	314.82	1.18	21.92	65.14	324	97.6	19.43	34.3	22.7	11.3	0.024
Munnalal Girl's Degree College	GWQ 13	25.3	7.4	1360	1024	308	307.28	0.72	154.2	84.56	464	122.4	38.37	68.3	34.8	15.7	0.02
Arabi Madrisa	GWQ 14	24	7.8	1425	948	388	385.72	2.28	135.5	98.25	388	103.2	31.57	36.34	65.1	11.7	0.025
Company Bagh	GWQ 15	25	7.3	1142	836	340	339.36	0.64	82.26	78.4	456	155.2	16.51	88.5	62.9	10.6	0.015
Shahid Ganj	GWQ 16	25.4	7.8	1327	867	298	296.25	1.75	41.21	42.61	342	86.4	30.6	81.9	42.3	14.1	0.052
Dabki Junardar	GWQ 17	25	7.1	1240	898	326	325.62	0.38	116	85.43	356	120.8	13.11	11.5	45.1	12.8	0.03
BIS: 10500		-	6.5-8.5	-	**500**	**200**	-	-	**250**	**200**	**300**	**75**	**30**	**45**	-	-	-

Note: **ND = Not Detected**

Annexure 5.1 (iv)

Physico-chemical analysis of Groundwater Samples (Postmonsoon 2002), Saharanpur

Name of Groundwater Sampling	Groundwater Stations	Temp 0C	pH	EC (mhos/cm)	TDS (mg/l)	T.Alk. (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K (mg/l)	Total-P(mg/l)
Mahipura	GWQ 1	24.3	7.1	1000	744	288	287.7	0.34	123.8	113.7	468	124.8	37.89	154	48.7	10.1	0.11
S M Inter College	GWQ 2	24.6	7.8	1300	753	456	453.3	2.683	103.8	86.42	548	178.4	24.77	127.7	68.2	22.1	0.114
Shekhpura Qadim	GWQ 3	24.8	7.2	1900	1422	388	387.4	0.576	235.4	145.5	634	177.6	46.14	195	158.3	14.4	0.114
Pairagpur	GWQ 4	24.6	7.1	1900	1568	274	273.7	0.323	342.2	178.5	746	207.2	55.37	173	63.8	23.7	0.115
Dudhali Bhukara	GWQ 5	24.1	7.5	748	412	322	321	0.952	60.05	83.9	424	128	25.26	14.5	10.2	10.4	0.112
Ghogreki	GWQ 6	24	7.2	765	584	248	247.6	0.368	34.5	98.26	326	80.8	30.12	11.7	13.5	8.3	0.116
Hasanpur	GWQ 7	24.5	7.2	831	633	232	231.7	0.344	60.54	102.5	346	110.4	17	90.4	91.3	20.6	0.115
Hakiquat Nagar	GWQ 8	24.7	7.4	700	485	326	325.2	0.766	37.57	107.3	312	81.6	26.23	28.5	58.1	13.2	0.115
Govind Nagar	GWQ 9	24.8	7.4	886	664	380	379.1	0.893	68.35	68.48	468	140	28.66	34.2	43.2	14.7	0.117
Wazir Vihar	GWQ 10	24	7.3	700	423	316	315.4	0.59	37.29	52.41	298	59.2	36.43	57.3	63.8	14.1	0.115
Patel Nagar	GWQ 11	24	7.2	1000	755	306	305.5	0.454	58.15	75.37	404	89.6	43.72	39.3	72.3	16.8	0.132
Sabarika Bagh	GWQ 12	24.8	7.6	864	812	330	328.8	1.228	36.3	78.21	436	92.8	49.54	54.7	53.5	16.2	0.12
Munnalal Girl's Degree College	GWQ 13	24.6	7.1	1084	844	334	333.6	0.394	123.5	83.75	520	103.2	63.63	76.2	42.9	15.3	118
Arabi Madrisa	GWQ 14	25	7.1	1000	878	392	391.5	0.462	112.3	93.26	410	108.8	33.52	36.34	46.8	18.5	0.126
Company Bagh	GWQ 15	24	7.5	900	824	314	313.1	0.929	75.2	70.14	302	72.8	29.14	88.5	53.4	16.3	0.116
Shahid Ganj	GWQ 16	24.7	7.2	1000	847	324	323.5	0.481	33.8	39.42	352	69.6	43.23	66.8	42.6	13.8	0.298
Dabki Junardar	GWQ 17	24	7.1	1000	913	336	335.6	0.396	134.4	72.48	540	132.8	50.52	13.7	27.9	13.9	0.113
BIS: 10500		-	6.5-8.5	-	500	200	-	-	250	200	300	75	30	45	-	-	-

Note: ND = Not Detected

Annexure 5.1 (v)

Physico-chemical analysis of Groundwater Samples (Premonsoon 2004), Saharanpur

Name of Groundwater Sampling	Groundwater Stations	Temp 0C	pH	EC (mhos/cm)	TDS (mg/l)	T.Alk. (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K (mg/l)	Total-P(mg/l)
Mahipura	GWQ 1	24.6	7.1	1400	960	230	229.7	0.271	160	156	490	180	9.715	68.6	52.62	13	0.033
S M Inter College	GWQ 2	25.3	7.7	1200	902	404	402.1	1.89	108	93.26	424	155.2	8.743	20.6	48.2	14.4	0.032
Shekhpura Qadim	GWQ 3	25.9	6.9	1900	1420	430	429.7	0.32	331.2	155.9	664	251.2	8.743	154	175.2	13.3	0.023
Pairagpur	GWQ 4	26	6.8	1900	1500	226	225.9	0.134	361.9	125.3	588	212.8	13.6	78.1	66.9	7.4	0.01
Dudhali Bhukara	GWQ 5	25.4	7.2	900	750	378	377.4	0.561	71.98	103.3	542	183.2	20.4	11.5	11.4	4.8	0.016
Ghogreki	GWQ 6	24.1	7.4	700	600	228	227.5	0.536	15.99	135	304	82.4	23.8	11	12.6	1.1	0.017
Hasanpur	GWQ 7	25.8	7.1	1000	700	232	231.7	0.274	64.98	110.3	348	87.2	31.57	49	18.8	3.2	0.016
Hakiquat Nagar	GWQ 8	25.3	7.4	900	625	286	285.3	0.672	60	101.6	356	132	6.315	28.2	68.3	13.4	0.009
Govind Nagar	GWQ 9	25.5	7.2	1200	875	422	421.4	0.626	112	82.71	464	171.2	8.743	49	58.7	13.7	0.014
Wazir Vihar	GWQ 10	25.7	7.1	1200	880	322	321.6	0.38	126	78.6	464	146.4	23.8	21.8	78.8	13.14	0.013
Patel Nagar	GWQ 11	24.2	7.1	900	730	338	337.6	0.399	65.98	72.01	400	136.8	14.09	40.9	39.1	10.7	0.018
Sabarika Bagh	GWQ 12	24.9	7.5	500	380	256	255.2	0.757	22.99	50.61	310	96	17	10.8	19.1	5.2	0.025
Munnalal Girl's Degree College	GWQ 13	26.2	6.9	1300	1032	436	435.7	0.324	130	74.48	516	145.6	36.92	72.9	40.1	10.4	0.02
Arabi Madrisa	GWQ 14	24.9	6.9	1500	955	408	407.7	0.304	146	90.12	508	143.2	36.43	130	54.5	9.6	0.026
Company Bagh	GWQ 15	26.1	7.1	1200	904	364	363.6	0.429	91.97	74.48	462	155.2	17.97	76.7	60.4	7.2	0.015
Shahid Ganj	GWQ 16	24.8	7.2	600	334	280	279.6	0.416	21.99	58.25	270	60.8	28.66	36.3	38.8	15.4	0.53
Dabki Junardar	GWQ 17	24.9	7.1	1210	910	360	359.6	0.425	112	58.84	380	119.2	19.91	24.8	33.58	10.6	0.031
BIS: 10500		-	6.5-8.5	-	**500**	**200**	-	-	**250**	**200**	**300**	**75**	**30**	**45**	-	-	-

Note: **ND = Not Detected**

Physico-chemical analysis of Groundwater Samples (Postmonsoon 2004), Saharanpur

Annexure 5.1 (vi)

Name of Groundwater Sampling	Groundwater Stations	Temp 0C	pH	EC (mhos/cm)	TDS (mg/l)	T.Alk. (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K (mg/l)	Total-P(mg/l)
Mahipura	GWQ 1	25.1	7.1	900	696	366	365.6	0.432	171	95.47	570	170.4	34.97	171	44.24	8.2	0.12
S M Inter College	GWQ 2	24.8	7.8	1200	870	518	515	3.048	138	123	680	195.2	46.63	138	72.2	21.8	0.116
Shekhpura Qadim	GWQ 3	25.2	7.1	2000	1435	440	439.5	0.519	284	222.6	726	196.8	56.83	284	154.6	12.6	0.114
Pairagpur	GWQ 4	25.8	7.2	1600	1138	350	349.5	0.519	198	224.3	582	151.2	49.54	198	63.6	24.6	0.116
Dudhali Bhukara	GWQ 5	24.3	7.4	800	643	356	355.2	0.837	16.35	125.5	462	139.2	27.69	16.35	11.4	4.6	0.113
Ghogreki	GWQ 6	24.4	7.2	680	550	214	213.7	0.318	10.4	125	332	85.6	28.66	10.4	12.6	12.5	0.017
Hasanpur	GWQ 7	24.7	7.1	800	538	426	425.5	0.502	80.85	95.06	460	142.4	25.26	80.85	85.5	24.8	0.116
Hakiquat Nagar	GWQ 8	25	7.2	700	368	302	301.6	0.448	32.66	114.4	308	78.4	27.2	32.27	42.2	11.7	0.115
Govind Nagar	GWQ 9	24.9	7.2	1000	859	500	499.3	0.742	78.9	70.37	546	168.8	30.12	125	36.5	15.9	0.117
Wazir Vihar	GWQ 10	24.2	7.4	400	320	356	355.2	0.837	7.45	37.04	268	45.6	37.4	7.45	62.4	15.3	0.116
Patel Nagar	GWQ 11	24.7	7.1	900	605	390	389.5	0.46	42.31	71.6	336	59.2	45.66	152.5	73.1	16.3	0.134
Sabarika Bagh	GWQ 12	25.4	7.6	400	350	350	348.7	1.302	6.01	24.28	322	52	46.63	6.01	48.8	15.7	0.12
Munnalal College	GWQ 13	24.9	7.1	1100	886	448	447.5	0.528	184.5	67.49	510	92	68	184.5	39.8	15.8	0.119
Arabi Madrisa	GWQ 14	24.8	6.9	1100	956	432	431.7	0.322	188	62.96	572	150.4	47.6	301.5	44.6	20.2	0.127
Company Bagh	GWQ 15	25.5	7.7	400	284	356	354.3	1.666	20.5	21.81	266	60.8	27.69	20.5	44.8	17.3	0.117
Shahid Ganj	GWQ 16	24.6	7.2	800	365	302	301.6	0.448	30.25	33.29	258	43.2	36.43	30.25	36.6	14.7	0.303
Dabki Junardar	GWQ 17	23.9	6.9	1100	1011	348	347.7	0.259	14.6	65.02	668	181.6	51.97	149	26.4	14.25	0.114
BIS: 10500		-	6.5-8.5	-	500	200	-	-	250	200	300	75	30	45	-	-	-

Note: **ND = Not Detected**

Annexure 5.1 (vii)

Physico-chemical analysis of Groundwater Samples (Premonsoon 2006), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Temp°C	pH	EC (μmhos/cm)	TDS (mg/l)	T.Alk. (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K (mg/l)	Total-P (mg/l)	MPN/100ml	F.Coli/100ml
Mahipura	GWQ 1	26.7	7.5	615	371	128	127.62	0.38	35	223.85	346	86.4	31.56	1.75	17.8	ND	0.026	2	nil
Shekhpura Qadim	GWQ 3	25.6	7.4	1382	829	220	219.48	0.52	360	269.53	668	173.6	56.82	80.30	112.4	ND	1.913	14	4
Pairagpur	GWQ 4	25.8	7.4	1150	690	252	251.40	0.60	184	245.66	544	106.4	67.50	67.00	96.0	ND	0.293		
Hasanpur	GWQ 7	25.5	7.4	1448	954	266	265.37	0.63	177	174.06	326	84.0	28.16	62.70	122.8	ND	0.316		
Hakiquat Nagar	GWQ 8	25.1	7.5	715	421	416	414.76	1.24	71	206.16	490	158.4	22.82	11.20	56.3	6.7	0.012	2	nil
Govind Nagar	GWQ 9	26.1	7.8	843	514	330	328.05	1.95	121	232.49	434	105.6	41.28	41.80	71.6	6.1	0.126	2	nil
Wazir Vihar	GWQ 10	24.8	7.2	359	224	168	167.80	0.20	35	188.87	250	55.2	27.19	20.30	6.4	ND	0.436		
Patel Nagar	GWQ 11	26.5	8.0	815	473	216	213.99	2.01	203	113.57	430	73.6	59.73	3.59	29.5	ND	0.895		
Sabarika Bagh	GWQ 12	28.2	8.2	437	273	198	195.00	3.00	27	282.28	336	56.0	47.59	8.65	10.4	ND	1.130	11	2
Munnalal Girl's Degree College	GWQ 13	26.4	7.5	963	579	260	259.30	0.70	154	270.76	588	112.8	74.30	50.80	69.3	2.3	0.067		
Arabi Madrisa	GWQ 14	26.8	7.8	651	432	206	204.78	1.22	57	297.10	340	80.0	33.99	43.50	48.3	6.3	0.998		
Company Bagh	GWQ 15	25.4	7.9	488	307	242	240.20	1.80	35	234.55	290	68.0	29.14	20.70	6.8	0.6	0.093		
Shahid Ganj	GWQ 16	25.9	8.3	475	293	154	151.60	2.40	22	256.36	280	42.4	42.25	1.73	9.2	ND	0.109		
BIS: 10500		-	6.5-8.5	-	**500**	**200**	-	-	**250**	**200**	**300**	**75**	**30**	**45**	-	-	-	**Nil**	**Nil**

Note: **ND = Not Detected**

Annexure 5.1 (viii)

Physico-chemical analysis of Groundwater Samples (Postmonsoon 2006), Saharanpur

Name of Groundwater Sampling	Groundwater Stations	Temp0C	pH	EC (umhos/cm)	TDS (mg/l)	T.Alk (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	NO_3 (mg/l)	Na (mg/l)	K(mg/l)	Total-P(mg/l)	Ortho-P(mg/l)	Poly-(mg/l)	Total MPN /100ml	Total F.Coli /100ml
Mahipura	GWQ 1	26.5	6.79	838	510	520	520	0.01	24	330.0	828	214.7	70.90	26.5	29.6	1.1	0.921	0.835	0.086	8	2
S M Inter College	GWQ 2	23.9	7.78	1433	944	342	340	2.02	152	162.1	532	96.9	67.99	85.6	22.6	ND	2.013	1.913	0.118	23	2
Shekhpura Qadim	GWQ 3	23.8	7.03	1980	1288	352	351.6	0.42	570	396.7	1212	334.8	91.30	24.3	102.5	2.3	1.673	1.522	0.151	23	2
Pairagpur	GWQ 4	25.6	7.27	1480	968	280	279.5	0.53	383	282.9	768	248.3	35.93	38.2	87.0	ND	0.893	0.757	0.136	30	6
Dudhali Bhukara	GWQ 5	23.8	8.11	1023	676	268	264.9	3.13	114	182.7	466	153.0	20.39	28.7	17.6	1.2	1.312	1.208	0.104		
Ghogreki	GWQ 6	24.2	8.16	922	604	270	266	4.00	71	296.0	446	103.3	45.65	17.2	11.6	ND	0.965	0.867	0.098		
Hasanpur	GWQ 7	24.7	7.22	1174	774	394	393.4	0.59	103	214.8	526	165.0	27.68	29.8	93.7	ND	0.621	0.412	0.209		
Hakiquat Nagar	GWQ 8	24.1	7.98	953	620	486	481.5	4.52	99	409.0	740	232.3	38.85	11.1	60.8	6.1	0.051	0.047	0.004	4	Nil
Govind Nagar	GWQ 9	24.2	7.59	916	595	360	358.7	1.34	392	252.7	380	83.3	41.76	59.3	63.8	ND	0.731	0.651	0.080		
Wazir Vihar	GWQ 10	23.7	7.47	540	338	214	213.4	0.64	45	261.7	384	88.1	39.82	63.8	9.3	ND	0.678	0.316	0.362		
Patel Nagar	GWQ 11	23.8	7.2	1029	645	410	409.4	0.61	147	283.1	658	203.4	36.42	61.1	28.6	ND	1.123	0.993	0.130		
Sabarika Bagh	GWQ 12	25.3	7.15	783	486	496	495.3	0.74	111	273.2	670	225.9	25.74	29.8	16.8	1.2	1.575	1.429	0.146	Nil	Nil
Munnalal Girl's Degree College	GWQ 13	24.8	7.34	1198	789	248	247.5	0.47	82	167.2	272	74.5	20.88	19.8	51.8	3.8	0.088	0.031	0.057		
Arabi Madrisa	GWQ 14	24.5	7.23	856	518	396	395.4	0.59	76	262.5	494	114.5	50.50	41.1	56.3	9.8	1.421	1.389	0.032		
Company Bagh	GWQ 15	22.9	7.71	712	466	268	266.7	1.36	28	188.5	360	96.1	29.14	13.3	12.4	ND	0.188	0.134	0.054	2	Nil
Shahid Ganj	GWQ 16	24.6	7.87	635	398	190	188.6	1.41	6	186.0	288	71.3	26.71	32.5	13.8	ND	0.278	0.161	0.117		
Dabki Junardar	GWQ 17	23.9	7.8	1313	862	278	276.4	1.64	135	216.4	610	184.2	36.42	31.3	20.6	ND	1.287	1.131	0.156		
H.A.V Inter College	GWQ 18	24.5	7.55	835	550	308	306.9	1.15	54	293.8	422	109.7	35.93	89.5	39.3	2.4	1.426	1.365	0.061		
GW U/S of Paondhoi	GWQ 19	24.8	7.46	842	555	220	229.3	0.69	38	205.8	384	90.5	38.36	19.3	9.6	ND	0.881	0.387	0.494	-	-
Deep Well Railway station	DGW 1	23.7	8.15	614	403	224	222.7	1.32	26	132.5	300	58.4	37.31	2.1	4.8	ND	0.318	0.228	0.090		
Deep Well Municipal Tank	DGW2	22.9	7.62	622	408	264	262.5	3.56	23	169.5	340	109.7	16.02	3.3	6.2	ND	0.276	0.196	0.080		
BIS: 10500		-	6.5-8.5	-	**500**	**200**	-	-	**250**	**200**	**300**	**75**	**30**	**45**	-	-	-	-	-	**Nil**	**Nil**

Note: **ND = Not Detected**

Annexure 5.2 (i)

Heavy Metal Analysis of Groundwater Samples (Premonsoon 2001), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd(mg/l)	Fe(mg/l)	Cr(mg/l)	Ni(mg/l)	Mn(mg/l)
Mahipura	GWQ 1	0.003	0.168	ND	0.009	0.168
S M Inter College	GWQ 2	0.001	0.425	0.012	0.001	0.102
Shekhpura Qadim	GWQ 3	0.02	0.038	0.022	ND	0.019
Pairagpur	GWQ 4	0.03	ND	0.015	ND	0.029
Dudhali Bhukara	GWQ 5	ND	0.035	0.025	ND	0.011
Ghogreki	GWQ 6	0.001	ND	0.022	ND	0.204
Hasanpur	GWQ 7	0.007	0.106	0.019	ND	0.106
Hakiquat Nagar	GWQ 8	0.021	0.236	0.012	ND	0.038
Govind Nagar	GWQ 9	0.004	0.008	0.018	ND	0.234
Wazir Vihar	GWQ 10	0.044	ND	0.01	ND	0.221
Patel Nagar	GWQ 11	ND	0.029	0.02	ND	0.043
Sabarika Bagh	GWQ 12	ND	0.04	0.02	ND	0.176
Munnalal College	GWQ 13	ND	ND	0.019	ND	0.019
Arabi Madrisa	GWQ 14	0.001	0.05	0.018	ND	0.246
Company Bagh	GWQ 15	0.008	ND	0.013	ND	0.002
Shahid Ganj	GWQ 16	ND	0.023	0.02	ND	0.058
Dabki Junardar	GWQ 17	0.001	ND	0.024	ND	0.058
BIS: 10500		**0.01**	**0.3**	**0.05**	**0.20**	**0.10**

Note: **ND = Not Detected**

Annexure 5.2 (ii)

Heavy Metal Analysis of Groundwater Samples (Postmonsoon 2001), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd(mg/l)	Fe(mg/l)	Cr(mg/l)	Ni(mg/l)	Mn(mg/l)
Mahipura	GWQ 1	0.007	70	ND	0.01	0.188
S M Inter College	GWQ 2	0.001	0.425	0.014	0.001	0.154
Shekhpura Qadim	GWQ 3	ND	0.038	0.022	ND	0.038
Pairagpur	GWQ 4	0.01	ND	0.02	ND	0.043
Dudhali Bhukara	GWQ 5	0.007	0.035	0.03	ND	0.153
Ghogreki	GWQ 6	0.02	ND	0.023	ND	0.157
Hasanpur	GWQ 7	0.01	0.106	0.02	ND	0.189
Hakiquat Nagar	GWQ 8	0.002	0.236	0.013	0.002	0.045
Govind Nagar	GWQ 9	0.004	0.008	0.02	ND	0.258
Wazir Vihar	GWQ 10	0.02	ND	0.004	ND	0.287
Patel Nagar	GWQ 11	0.001	0.029	0.02	0.001	0.048
Sabarika Bagh	GWQ 12	ND	0.04	0.02	ND	0.186
Munnalal College	GWQ 13	0.001	ND	0.02	ND	0.026
Arabi Madrisa	GWQ 14	0.001	0.05	0.02	ND	0.387
Company Bagh	GWQ 15	0.003	ND	0.013	ND	0.028
Shahid Ganj	GWQ 16	0.003	0.023	0.02	ND	0.065
Dabki Junardar	GWQ 17	0.001	ND	0.025	ND	0.06
BIS: 10500		**0.01**	**0.3**	**0.05**	**0.20**	**0.10**

Note: **ND = Not Detected**

Annexure 5.2 (iii)

Heavy Metal Analysis of Groundwater Samples (Premonsoon 2002), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd(mg/l)	Fe(mg/l)	Cr(mg/l)	Ni(mg/l)	Mn(mg/l)
Mahipura	GWQ 1	0.014	0.017	ND	0.01	0.185
S M Inter College	GWQ 2	0.002	0.426	0.012	0.001	0.113
Shekhpura Qadim	GWQ 3	ND	0.036	0.022	ND	0.018
Pairagpur	GWQ 4	0.01	ND	0.015	ND	0.032
Dudhali Bhukara	GWQ 5	0.008	0.035	0.025	ND	0.012
Ghogreki	GWQ 6	0.022	ND	0.022	ND	0.223
Hasanpur	GWQ 7	0.016	0.015	0.019	ND	0.117
Hakiquat Nagar	GWQ 8	0.003	0.237	0.012	0.002	0.041
Govind Nagar	GWQ 9	0.004	0.008	0.018	ND	0.225
Wazir Vihar	GWQ 10	0.022	ND	0.01	ND	0.185
Patel Nagar	GWQ 11	0.002	0.027	0.02	0.001	0.048
Sabarika Bagh	GWQ 12	ND	0.039	0.02	ND	0.144
Munnalal College	GWQ 13	ND	ND	0.019	ND	0.022
Arabi Madrisa	GWQ 14	ND	0.052	0.018	ND	0.296
Company Bagh	GWQ 15	ND	ND	0.013	ND	0.03
Shahid Ganj	GWQ 16	ND	0.024	0.02	ND	0.064
Dabki Junardar	GWQ 17	0.001	ND	0.024	ND	0.06
BIS: 10500		**0.01**	**0.3**	**0.05**	**0.20**	**0.10**

Note: **ND = Not Detected**

Annexure 5.2 (iv)

Heavy Metal Analysis of Groundwater Samples (Postmonsoon 2002), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd(mg/l)	Fe(mg/l)	Cr(mg/l)	Ni(mg/l)	Mn(mg/l)
Mahipura	GWQ 1	0.014	0.185	ND	0.012	0.214
S M Inter College	GWQ 2	0.002	0.455	0.017	0.001	0.165
Shekhpura Qadim	GWQ 3	ND	0.04	0.026	ND	0.044
Pairagpur	GWQ 4	0.01	ND	0.022	ND	0.051
Dudhali Bhukara	GWQ 5	ND	0.042	0.03	ND	0.161
Ghogreki	GWQ 6	0.001	ND	0.025	ND	0.166
Hasanpur	GWQ 7	ND	0.117	0.021	ND	0.218
Hakiquat Nagar	GWQ 8	0.003	0.244	0.016	0.003	0.049
Govind Nagar	GWQ 9	ND	0.01	0.022	ND	0.265
Wazir Vihar	GWQ 10	0.021	ND	0.006	ND	0.286
Patel Nagar	GWQ 11	0.002	0.03	0.022	0.002	0.05
Sabarika Bagh	GWQ 12	ND	0.043	0.022	ND	0.194
Munnalal College	GWQ 13	ND	ND	0.022	ND	0.028
Arabi Madrisa	GWQ 14	ND	0.058	0.022	ND	0.411
Company Bagh	GWQ 15	ND	ND	0.013	ND	0.032
Shahid Ganj	GWQ 16	ND	0.026	0.021	ND	0.074
Dabki Junardar	GWQ 17	0.001	ND	0.027	ND	0.064
BIS: 10500		**0.01**	**0.3**	**0.05**	**0.20**	**0.10**

Note: **ND = Not Detected**

Annexure 5.2 (v)

Heavy Metal Analysis of Groundwater Samples (Premonsoon 2004), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd(mg/l)	Fe(mg/l)	Cr(mg/l)	Ni(mg/l)	Mn(mg/l)
Mahipura	GWQ 1	0.015	0.02	ND	0.012	0.201
S M Inter College	GWQ 2	0.002	0.521	0.019	0.002	0.188
Sheikhpura Qadim	GWQ 3	0.02	0.045	0.028	ND	0.015
Pairagpur	GWQ 4	0.03	ND	0.023	ND	0.053
Dudhali Bhukara	GWQ 5	ND	0.046	0.031	ND	0.162
Ghogreki	GWQ 6	0.001	0.002	0.026	0.001	0.278
Hasanpur	GWQ 7	0.012	0.022	0.022	ND	0.231
Hakiquat Nagar	GWQ 8	0.028	0.264	0.018	0.005	0.053
Govind Nagar	GWQ 9	0.005	0.01	0.024	ND	0.267
Wazir Vihar	GWQ 10	0.05	ND	0.01	ND	0.127
Patel Nagar	GWQ 11	0.001	0.03	0.024	0.003	0.054
Sabarika Bagh	GWQ 12	ND	0.048	0.023	ND	0.131
Munnalal College	GWQ 13	ND	ND	0.024	ND	0.028
Arabi Madrisa	GWQ 14	ND	0.065	0.022	ND	0.444
Company Bagh	GWQ 15	0.007	ND	0.016	0.001	0.03
Shahid Ganj	GWQ 16	ND	0.027	0.022	ND	0.077
Dabki Junardar	GWQ 17	0.001	0.002	0.028	0.002	0.07
BIS: 10500		**0.01**	**0.3**	**0.05**	**0.20**	**0.10**

Note: **ND = Not Detected**

Annexure 5.2 (vi)

Heavy Metal Analysis of Groundwater Samples (Postmonsoon 2004), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd(mg/l)	Fe(mg/l)	Cr(mg/l)	Ni(mg/l)	Mn(mg/l)	Pb(mg/I)
Mahipura	GWQ 1	0.018	0.03	ND	0.018	0.234	0.0217
S M Inter College	GWQ 2	0.003	0.544	0.024	0.003	0.204	0.0057
Sheikhpura Qadim	GWQ 3	ND	0.051	0.031	ND	0.067	0.0061
Pairagpur	GWQ 4	ND	ND	0.027	ND	0.072	0.0032
Dudhali Bhukara	GWQ 5	0.01	0.054	0.034	ND	0.186	0.0048
Ghogreki	GWQ 6	0.027	0.003	0.03	0.002	0.18	0.0048
Hasanpur	GWQ 7	0.01	0.028	0.027	ND	0.251	0.0028
Hakiquat Nagar	GWQ 8	0.007	0.271	0.02	0.007	0.064	0.1487
Govind Nagar	GWQ 9	0.005	0.014	0.028	ND	0.283	0.0090
Wazir Vihar	GWQ 10	0.025	ND	0.013	0.001	0.153	0.0062
Patel Nagar	GWQ 11	0.004	0.036	0.028	0.004	0.06	0.0025
Sabari Ka Bagh	GWQ 12	ND	0.052	0.027	ND	0.218	0.0086
Munnalal College	GWQ 13	0.001	ND	0.03	ND	0.039	0.0015
Arabi Madrisa	GWQ 14	0.001	0.07	0.026	ND	0.466	0.0025
Company Bagh	GWQ 15	0.001	ND	0.017	0.001	0.04	0.0056
Shahid Ganj	GWQ 16	0.002	0.031	0.024	ND	0.098	0.0022
Dabki Junardar	GWQ 17	0.002	0.003	0.031	0.002	0.08	0.0048
BIS: 10500		**0.01**	**0.3**	**0.05**	**0.20**	**0.10**	**0.10**

Note: **ND = Not Detected**

Annexure 5.2 (vii)

Heavy Metal Analysis of Groundwater Samples (Premonsoon 2006), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd (mg/l)	Fe (mg/l)	Cu (mg/l)	Zn (mg/l)	Cr (mg/l)	Ni (mg/l)	Mn (mg/l)	Pb (mg/l)
Mahipura	GWQ 1	0.002	ND	ND	0.078	ND	ND	ND	0.03
Sheikhpura Qadim	GWQ 3	0.02	0.114	0.043	0.088	ND	ND	0.012	0.035
Pairagpur	GWQ 4	0.028	0.124	0.029	0.412	ND	ND	0.001	0.034
Hasanpur	GWQ 7	0.023	0.004	ND	0.078	ND	ND	ND	0.034
Hakiquat Nagar	GWQ 8	0.036	0.157	0.313	1.21	0.017	0.077	0.338	0.027
Govind Nagar	GWQ 9	0.006	ND	ND	0.088	ND	ND	0.002	0.035
Wazir Vihar	GWQ 10	0.056	0.248	0.169	0.744	0.072	0.003	0.088	0.033
Patel Nagar	GWQ 11	ND	0.029	ND	0.887	ND	ND	0.395	0.033
Sabari Ka Bagh	GWQ 12	ND	0.058	ND	0.102	ND	ND	0.003	0.035
Munnalal College	GWQ 13	ND	0.058	ND	0.554	ND	ND	0.018	0.035
Arabi Madrisa	GWQ 14	ND	ND	ND	0.122	ND	ND	ND	0.034
Company Bagh	GWQ 15	0.01	0.005	0.1	0.419	ND	ND	0.09	0.034
Shahid Ganj	GWQ 16	ND	ND	ND	0.351	ND	ND	0.08	0.01
BIS: 10500		**0.01**	**0.3**	**0.05**	**5.00**	**0.05**	**0.20**	**0.10**	**0.10**

Note: **ND = Not Detected**

Annexure 5.2 (viii)

Heavy Metal Analysis of Groundwater Samples (Postmonsoon 2006), Saharanpur

Name of Groundwater Sampling	Groundwater Sampling Station no.	Cd (mg/l)	Fe (mg/l)	Cu (mg/l)	Zn (mg/l)	Cr (mg/l)	Ni (mg/l)	Mn (mg/l)	Pb (mg/l)
Mahipura	GWQ 1	0.013	0.542	0.055	3.394	0.073	0.057	1.011	0.001
S M Inter College	GWQ 2	ND	0.060	ND	ND	0.027	ND	0.010	0.032
Sheikhpura Qadim	GWQ 3	ND	2.272	ND	1.672	0.035	0.155	0.073	0.009
Pairagpur	GWQ 4	0.010	0.162	0.247	1.036	0.057	0.029	0.444	0.007
Dudhali Bhukara	GWQ 5	0.019	ND	0.169	0.158	0.062	ND	0.217	0.024
Ghogreki	GWQ 6	0.030	ND	0.289	0.864	0.047	0.025	0.114	0.020
Hasanpur	GWQ 7	0.012	0.048	ND	ND	0.040	ND	0.137	0.024
Hakiquat Nagar	GWQ 8	ND	0.035	0.310	3.077	0.058	ND	0.501	0.035
Govind Nagar	GWQ 9	0.007	0.058	ND	0.387	0.060	ND	0.157	0.020
Wazir Vihar	GWQ 10	0.029	ND	ND	1.968	0.049	0.040	ND	0.021
Patel Nagar	GWQ 11	0.019	0.022	ND	ND	0.049	ND	0.082	0.028
Sabari Ka Bagh	GWQ 12	ND	0.059	ND	0.009	0.053	0.079	0.015	0.022
Munnalal College	GWQ 13	0.012	0.039	0.004	0.140	0.067	0.077	0.147	0.024
Arabi Madrisa	GWQ 14	0.003	ND	ND	ND	0.050	ND	0.004	0.028
Company Bagh	GWQ 15	0.005	0.058	ND	1.750	0.049	ND	0.218	0.033
Shahid Ganj	GWQ 16	0.006	0.178	ND	0.355	0.056	ND	0.223	0.017
Dabki Junardar	GWQ 17	0.010	ND	ND	ND	0.035	ND	ND	0.024
H.A.V Inter College	GWQ 18	0.007	0.113	ND	0.035	0.049	ND	0.089	0.032
GW U/S of Paondhoi	GWQ 19	0.014	ND	ND	ND	0.046	0.950	0.107	0.270
Deep Well Railway station	DGW 1	0.007	ND	ND	ND	0.043	ND	ND	0.015
Deep Well Municipal Tank	DGW2	0.004	ND	ND	ND	0.034	ND	ND	ND
BIS: 10500		**0.01**	**0.3**	**0.05**	**5.00**	**0.05**	**0.20**	**0.10**	**0.10**

Note: **ND = Not Detected**

Annexure 6.1

Depth to Water Table

Obs. Well nos.	Name of Hydrograph Station	Depth to water level (Postmonsoon 2004 m bgl)	Rating	Weight	Number
OW 1	Dudhli Sarak	7.49	7	5	35
OW 2	Mahipura	8.26	7	5	35
OW 3	S M Inter College	5.14	7	5	35
OW 4	Sheikhpura Qadim	9.01	7	5	35
OW 5	Pairagpur	7.21	7	5	35
OW 6	Dudhali Bhukara	8.63	7	5	35
OW 7	Ghogreki	5.94	7	5	35
OW 8	Hasanpur	6.55	7	5	35
OW 9	Hakiquat Nagar	8.33	7	5	35
OW 10	Govind Nagar	6.98	7	5	35
OW 11	Wazir Vihar	6.91	7	5	35
OW 12	Patel Nagar	7.16	7	5	35
OW 13	Sabari Ka Bagh	5.96	7	5	35
OW 14	Munnalal College	6.52	7	5	35
OW 15	Arabi Madrisa	7.43	7	5	35
OW 16	Shahid Ganj	6.43	7	5	35
OW 17	Company Bagh	6.42	7	5	35
OW 18	Janakpur 1	7.83	7	5	35
OW 19	Janakpur 2	4.88	7	5	35
OW 20	Govt. Hospital	10.62	7	5	35
OW 21	Bharampuri	7.48	7	5	35
OW 22	Awas Vikas Colony 1	7.58	7	5	35
OW 23	Awas Vikas Colony 2	4.02	9	5	45
OW 24	Awas Vikas Calony 3	7.23	7	5	35
OW 25	Lakha Colony	7.12	7	5	35
OW 26	Vikas Bhawan	5.47	7	5	35
OW 27	Pant Vihar	5.58	7	5	35
OW 28	Wazir Vihar 2	6.96	7	5	35
OW 29	Thana qutubsher 1	4.58	7	5	35
OW 30	Chandar Nagar	7.45	7	5	35
OW 31	Bhattiyari Bagh	6.71	7	5	35
OW 32	Gill Colony	8.13	7	5	35
OW 33	SRE Railway Station	7.84	7	5	35
OW 34	Dabki Junardar	10.6	5	5	25
OW 35	Khalasi Line	6.98	7	5	35
OW 36	Qutubsher 2	4.68	7	5	35
OW 37	Qutubsher 3	3.69	9	5	45
OW 38	Ahamad Bagh	8.13	7	5	35
OW 39	Dudhali Sarak 2	7.49	7	5	35
OW 40	Beri Bagh 2	8.85	7	5	35
OW 41	M S College	8.87	7	5	35
OW 42	Halalpur	3.96	9	5	45
OW 43	Ramgarh	4.41	7	5	35
OW 44	Lohani Sarai	6.83	7	5	35
OW 45	Shahid Ganj 2	5.02	7	5	35
OW 46	Sheikhpura Qadim 2	9.01	7	5	35
OW 47	Sheikhpura Qadim 3	9.44	7	5	35
OW 48	Visnu Dham	7.17	7	5	35
OW 49	Sabari Ka Bagh 2	7.62	7	5	35
OW 50	New Mahipura	8.2	7	5	35
OW 51	Khata Khedi	2.32	9	5	45

Annexure 6.2

Net Recharge

Obs. Well nos.	Name of Hydrograph Station	Net Recharge (mm)	Rating	Weight	Number
OW 1	Dudhli Sarak	1200	9	4	36
OW 2	Mahipura	620	9	4	36
OW 3	S M Inter College	540	9	4	36
OW 4	Sheikhpura Qadim	930	9	4	36
OW 5	Pairagpur	1840	9	4	36
OW 6	Dudhali Bhukara	500	9	4	36
OW 7	Ghogreki	330	9	4	36
OW 8	Hasanpur	430	9	4	36
OW 9	Hakiquat Nagar	550	9	4	36
OW 10	Govind Nagar	340	9	4	36
OW 11	Wazir Vihar	1170	9	4	36
OW 12	Patel Nagar	370	9	4	36
OW 13	Sabari Ka Bagh	2010	9	4	36
OW 14	Munnalal College	930	9	4	36
OW 15	Arabi Madrisa	320	9	4	36
OW 16	Shahid Ganj	960	9	4	36
OW 17	Company Bagh	910	9	4	36
OW 18	Janakpur 1	310	9	4	36
OW 19	Janakpur 2	610	9	4	36
OW 20	Govt. Hospital	1020	9	4	36
OW 21	Bharampuri	860	9	4	36
OW 22	Awas Vikas Colony 1	400	9	4	36
OW 23	Awas Vikas Colony 2	520	9	4	36
OW 24	Awas Vikas Calony 3	490	9	4	36
OW 25	Lakha Colony	450	9	4	36
OW 26	Vikas Bhawan	170	6	4	24
OW 27	Pant Vihar	540	9	4	36
OW 28	Wazir Vihar 2	370	9	4	36
OW 29	Thana qutubsher 1	1190	9	4	36
OW 30	Chandar Nagar	510	9	4	36
OW 31	Bhattiyari Bagh	350	9	4	36
OW 32	Gill Colony	1080	9	4	36
OW 33	SRE Railway Station	700	9	4	36
OW 34	Dabki Junardar	500	9	4	36
OW 35	Khalasi Line	400	9	4	36
OW 36	Qutubsher 2	490	9	4	36
OW 37	Qutubsher 3	330	9	4	36
OW 38	Ahamad Bagh	920	9	4	36
OW 39	Dudhali Sarak 2	1110	9	4	36
OW 40	Beri Bagh 2	720	9	4	36
OW 41	M S College	720	9	4	36
OW 42	Halalpur	380	9	4	36
OW 43	Ramgarh	490	9	4	36
OW 44	Lohani Sarai	380	9	4	36
OW 45	Shahid Ganj 2	1650	9	4	36
OW 46	Sheikhpura Qadim 2	1240	9	4	36
OW 47	Sheikhpura Qadim 3	700	9	4	36
OW 48	Visnu Dham	710	9	4	36
OW 49	Sabari Ka Bagh 2	220	8	4	32
OW 50	New Mahipura	290	9	4	36
OW 51	Khata Khedi	90	3	4	12

Annexure 6.3

Aquifer Media

Obs. Well nos.	Name of Hydrograph Station	Aquifer media	Rating	Weight	Number
OW 1	Dudhli Sarak	Medium sand	8	3	24
OW 2	Mahipura	Medium sand	8	3	24
OW 3	S M Inter College	. Fine to medium sand	8	3	24
OW 4	Sheikhpura Qadim	Fine to medium sand	8	3	24
OW 5	Pairagpur	Fine to medium sand	8	3	24
OW 6	Dudhali Bhukara	Medium sand	8	3	24
OW 7	Ghogreki	Medium sand	8	3	24
OW 8	Hasanpur	Medium sand	8	3	24
OW 9	Hakiquat Nagar	Fine to medium sand with pebbles	8	3	24
OW 10	Govind Nagar	Fine to medium sand	8	3	24
OW 11	Wazir Vihar	Medium sand	8	3	24
OW 12	Patel Nagar	Fine to medium sand with pebbles	8	3	24
OW 13	Sabari Ka Bagh	Medium sand	8	3	24
OW 14	Munnalal College	Medium sand	8	3	24
OW 15	Arabi Madrisa	Fine to medium sand	8	3	24
OW 16	Shahid Ganj	Fine to medium sand	8	3	24
OW 17	Company Bagh	Fine to medium sand	8	3	24
OW 18	Janakpur 1	Medium sand	8	3	24
OW 19	Janakpur 2	Medium sand	8	3	24
OW 20	Govt. Hospital	Medium sand	8	3	24
OW 21	Bharampuri	Fine to medium sand with pebbles	8	3	24
OW 22	Awas Vikas Colony 1	Medium sand	8	3	24
OW 23	Awas Vikas Colony 2	Medium sand	8	3	24
OW 24	Awas Vikas Calony 3	Medium sand	8	3	24
OW 25	Lakha Colony	Medium sand	8	3	24
OW 26	Vikas Bhawan	Medium sand	8	3	24
OW 27	Pant Vihar	Medium sand	8	3	24
OW 28	Wazir Vihar 2	Medium sand	8	3	24
OW 29	Thana qutubsher 1	Medium sand	8	3	24
OW 30	Chandar Nagar	Medium sand	8	3	24
OW 31	Bhattiyari Bagh	Medium sand	8	3	24
OW 32	Gill Colony	Fine to medium sand	8	3	24
OW 33	SRE Railway Station	Medium sand	8	3	24
OW 34	Dabki Junardar	Medium sand	8	3	24
OW 35	Khalasi Line	Medium sand	8	3	24
OW 36	Qutubsher 2	Medium sand	8	3	24
OW 37	Qutubsher 3	Medium sand	8	3	24
OW 38	Ahamad Bagh	Medium sand	8	3	24
OW 39	Dudhali Sarak 2	Medium sand	8	3	24
OW 40	Beri Bagh 2	Medium sand	8	3	24
OW 41	M S College	Fine to medium sand with pebbles	8	3	24
OW 42	Halalpur	Medium sand	8	3	24
OW 43	Ramgarh	Medium sand	8	3	24
OW 44	Lohani Sarai	Medium sand	8	3	24
OW 45	Shahid Ganj 2	Fine to medium sand	8	3	24
OW 46	Sheikhpura Qadim 2	Fine to medium sand with pebbles	8	3	24
OW 47	Sheikhpura Qadim 3	Fine to medium sand	8	3	24
OW 48	Visnu Dham	Fine to medium sand with pebbles	8	3	24
OW 49	Sabari Ka Bagh 2	Medium sand	8	3	24
OW 50	New Mahipura	Medium sand	8	3	24
OW 51	Khata Khedi	Fine to medium sand	8	3	24

Annexure 6.4

Soil Media

Obs. Well nos.	Name of Hydrograph Station	Soil media	Rating	Weight	Num
OW 1	Dudhli Sarak	Silty Loam	4	2	8
OW 2	Mahipura	Silty Loam	4	2	8
OW 3	S M Inter College	Sandy	6	2	12
OW 4	Sheikhpura Qadim	Sandy	6	2	12
OW 5	Pairagpur	Dry Sand	6	2	12
OW 6	Dudhali Bhukara	Sandy	6	2	12
OW 7	Ghogreki	Sandy	6	2	12
OW 8	Hasanpur	Sandy	6	2	12
OW 9	Hakiquat Nagar	Sandy	6	2	12
OW 10	Govind Nagar	Sandy	6	2	12
OW 11	Wazir Vihar	Sandy	6	2	12
OW 12	Patel Nagar	Sandy	6	2	12
OW 13	Sabari Ka Bagh	Sandy	6	2	12
OW 14	Munnalal College	Clay	3	2	6
OW 15	Arabi Madrisa	Sandy	6	2	12
OW 16	Shahid Ganj	Sandy	6	2	12
OW 17	Company Bagh	Sandy	6	2	12
OW 18	Janakpur 1	Sandy	6	2	12
OW 19	Janakpur 2	Sandy	6	2	12
OW 20	Govt. Hospital	Sandy	6	2	12
OW 21	Bharampuri	Clay	3	2	6
OW 22	Awas Vikas Colony 1	Silty Loam	4	2	8
OW 23	Awas Vikas Colony 2	Silty Loam	4	2	8
OW 24	Awas Vikas Calony 3	Sandy	6	2	12
OW 25	Lakha Colony	Sandy	6	2	12
OW 26	Vikas Bhawan	Sandy	6	2	12
OW 27	Pant Vihar	Sandy	6	2	12
OW 28	Wazir Vihar 2	Sandy	6	2	12
OW 29	Thana qutubsher 1	Clay	3	2	6
OW 30	Chandar Nagar	Silty Loam	4	2	8
OW 31	Bhattiyari Bagh	Silty Loam	4	2	8
OW 32	Gill Colony	Sandy	6	2	12
OW 33	SRE Railway Station	Sandy	6	2	12
OW 34	Dabki Junardar	Sandy	6	2	12
OW 35	Khalasi Line	Sandy	6	2	12
OW 36	Qutubsher 2	Clay	3	2	6
OW 37	Qutubsher 3	Clay	3	2	6
OW 38	Ahamad Bagh	Sandy	6	2	12
OW 39	Dudhali Sarak 2	Sandy	6	2	12
OW 40	Beri Bagh 2	Sandy	6	2	12
OW 41	M S College	Sandy	6	2	12
OW 42	Halalpur	Clay	3	2	6
OW 43	Ramgarh	Clay	3	2	6
OW 44	Lohani Sarai	Sandy	6	2	12
OW 45	Shahid Ganj 2	Sandy	6	2	12
OW 46	Sheikhpura Qadim 2	Sandy	6	2	12
OW 47	Sheikhpura Qadim 3	Sandy	6	2	12
OW 48	Visnu Dham	Sandy	6	2	12
OW 49	Sabari Ka Bagh 2	Sandy	6	2	12
OW 50	New Mahipura	Silty Loam	4	2	8
OW 51	Khata Khedi	Sandy	6	2	12

Annexure 6.5

Topography

Obs. Well nos.	Name of Hydrograph Station	Topography (slope %)	Rating	Weight	Number
OW 1	Dudhli Sarak	0.5	10	1	10
OW 2	Mahipura	1.0	10	1	10
OW 3	S M Inter College	1.5	10	1	10
OW 4	Sheikhpura Qadim	1.0	10	1	10
OW 5	Pairagpur	1.5	10	1	10
OW 6	Dudhali Bhukara	1.0	10	1	10
OW 7	Ghogreki	0.5	10	1	10
OW 8	Hasanpur	0.5	10	1	10
OW 9	Hakiquat Nagar	1.5	10	1	10
OW 10	Govind Nagar	1.0	10	1	10
OW 11	Wazir Vihar	0.5	10	1	10
OW 12	Patel Nagar	1.0	10	1	10
OW 13	Sabari Ka Bagh	0.5	10	1	10
OW 14	Munnalal College	0.5	10	1	10
OW 15	Arabi Madrisa	1.0	10	1	10
OW 16	Shahid Ganj	3.0	9	1	9
OW 17	Company Bagh	1.0	10	1	10
OW 18	Janakpur 1	1.5	10	1	10
OW 19	Janakpur 2	1.5	10	1	10
OW 20	Govt. Hospital	1.0	10	1	10
OW 21	Bharampuri	0.5	10	1	10
OW 22	Awas Vikas Colony 1	2.3	9	1	9
OW 23	Awas Vikas Colony 2	2.5	9	1	9
OW 24	Awas Vikas Calony 3	1.5	10	1	10
OW 25	Lakha Colony	0.5	10	1	10
OW 26	Vikas Bhawan	0.5	10	1	10
OW 27	Pant Vihar	0.5	10	1	10
OW 28	Wazir Vihar 2	0.5	10	1	10
OW 29	Thana Qutubsher 1	0.5	10	1	10
OW 30	Chandar Nagar	0.5	10	1	10
OW 31	Bhattiyari Bagh	0.5	10	1	10
OW 32	Gill Colony	1.0	10	1	10
OW 33	SRE Railway Station	0.5	10	1	10
OW 34	Dabki Junardar	0.5	10	1	10
OW 35	Khalasi Line	0.5	10	1	10
OW 36	Qutubsher 2	0.5	10	1	10
OW 37	Qutubsher 3	0.5	10	1	10
OW 38	Ahamad Bagh	0.5	10	1	10
OW 39	Dudhali Sarak 2	0.5	10	1	10
OW 40	Beri Bagh 2	1.5	10	1	10
OW 41	M S College	1.5	10	1	10
OW 42	Halalpur	0.5	10	1	10
OW 43	Ramgarh	0.5	10	1	10
OW 44	Lohani Sarai	1.0	10	1	10
OW 45	Shahid Ganj 2	3.0	9	1	9
OW 46	Sheikhpura Qadim 2	1.0	10	1	10
OW 47	Sheikhpura Qadim 3	1.0	10	1	10
OW 48	Visnu Dham	1.0	10	1	10
OW 49	Sabari Ka Bagh 2	1.0	10	1	10
OW 50	New Mahipura	1.0	10	1	10
OW 51	Khata Khedi	0.5	10	1	10

Annexure 6.6

Impact of Vadose Zone

Obs. Well nos.	Name of Hydrograph Station	Nature of Vadose Zone	Rating	Weight	Number
OW 1	Dudhli Sarak	Clay	1	5	5
OW 2	Mahipura	Clay	1	5	5
OW 3	S M Inter College	Clay	1	5	5
OW 4	Sheikhpura Qadim	Fine sand	6	5	30
OW 5	Pairagpur	Fine sand	6	5	30
OW 6	Dudhali Bhukara	Fine sand	6	5	30
OW 7	Ghogreki	Fine sand	6	5	30
OW 8	Hasanpur	Fine sand	6	5	30
OW 9	Hakiquat Nagar	Clay	1	5	5
OW 10	Govind Nagar	Clay	1	5	5
OW 11	Wazir Vihar	Clay	1	5	5
OW 12	Patel Nagar	Clay	1	5	5
OW 13	Sabari Ka Bagh	Clay	1	5	5
OW 14	Munnalal College	Clay	1	5	5
OW 15	Arabi Madrisa	Clay	1	5	5
OW 16	Shahid Ganj	Clay	1	5	5
OW 17	Company Bagh	Kankar with clay	2	5	10
OW 18	Janakpur 1	Fine sand	6	5	30
OW 19	Janakpur 2	Fine sand	6	5	30
OW 20	Govt. Hospital	Fine sand	6	5	30
OW 21	Bharampuri	Fine sand	6	5	30
OW 22	Awas Vikas Colony 1	Fine sand	6	5	30
OW 23	Awas Vikas Colony 2	Fine sand	6	5	30
OW 24	Awas Vikas Calony 3	Fine sand	6	5	30
OW 25	Lakha Colony	Fine sand	6	5	30
OW 26	Vikas Bhawan	Fine sand	6	5	30
OW 27	Pant Vihar	Fine sand	6	5	30
OW 28	Wazir Vihar 2	Clay	1	5	5
OW 29	Thana Qutubsher 1	Clay	1	5	5
OW 30	Chandar Nagar	Clay	1	5	5
OW 31	Bhattiyari Bagh	Clay	1	5	5
OW 32	Gill Colony	Clay	1	5	5
OW 33	SRE Railway Station	Clay	1	5	5
OW 34	Dabki Junardar	Clay	1	5	5
OW 35	Khalasi Line	Clay	1	5	5
OW 36	Qutubsher 2	Clay	1	5	5
OW 37	Qutubsher 3	Clay	1	5	5
OW 38	Ahamad Bagh	Clay	1	5	5
OW 39	Dudhali Sarak 2	Clay	1	5	5
OW 40	Beri Bagh 2	Kankar with clay	2	5	10
OW 41	M S College	kankar with clay	2	5	10
OW 42	Halalpur	Clay	1	5	5
OW 43	Ramgarh	Clay	1	5	5
OW 44	Lohani Sarai	Clay	1	5	5
OW 45	Shahid Ganj 2	Clay	1	5	5
OW 46	Sheikhpura Qadim 2	Fine sand	6	5	30
OW 47	Sheikhpura Qadim 3	Fine sand	6	5	30
OW 48	Visnu Dham	Kankar with clay	2	5	10
OW 49	Sabari Ka Bagh 2	Clay	1	5	5
OW 50	New Mahipura	Clay	1	5	5
OW 51	Khata Khedi	Sand	6	5	30

Annexure 6.7

Hydraulic Conductivity and DRASTIC Index

Obs. Well nos.	Name of Hydrograph Station	Hydraulic Conductivity	Rating	Weight	Number	Drastic Index
OW 1	Dudhli Sarak	11	10	3	30	148
OW 2	Mahipura	11	10	3	30	148
OW 3	S M Inter College	11	10	3	30	152
OW 4	Sheikhpura Qadim	11	10	3	30	177
OW 5	Pairagpur	11	10	3	30	177
OW 6	Dudhali Bhukara	11	10	3	30	177
OW 7	Ghogreki	11	10	3	30	177
OW 8	Hasanpur	11	10	3	30	177
OW 9	Hakiquat Nagar	11	10	3	30	152
OW 10	Govind Nagar	11	10	3	30	152
OW 11	Wazir Vihar	11	10	3	30	152
OW 12	Patel Nagar	11	10	3	30	152
OW 13	Sabari Ka Bagh	11	10	3	30	152
OW 14	Munnalal College	11	10	3	30	146
OW 15	Arabi Madrisa	11	10	3	30	152
OW 16	Shahid Ganj	11	10	3	30	151
OW 17	Company Bagh	11	10	3	30	152
OW 18	Janakpur 1	11	10	3	30	177
OW 19	Janakpur 2	11	10	3	30	177
OW 20	Govt. Hospital	11	10	3	30	177
OW 21	Bharampuri	11	10	3	30	171
OW 22	Awas Vikas Colony 1	11	10	3	30	172
OW 23	Awas Vikas Colony 2	11	10	3	30	182
OW 24	Awas Vikas Calony 3	11	10	3	30	177
OW 25	Lakha Colony	11	10	3	30	177
OW 26	Vikas Bhawan	11	10	3	30	165
OW 27	Pant Vihar	11	10	3	30	177
OW 28	Wazir Vihar 2	11	10	3	30	152
OW 29	Thana Qutubsher 1	11	10	3	30	146
OW 30	Chandar Nagar	11	10	3	30	148
OW 31	Bhattiyari Bagh	11	10	3	30	148
OW 32	Gill Colony	11	10	3	30	152
OW 33	SRE Railway Station	11	10	3	30	152
OW 34	Dabki Junardar	11	10	3	30	142
OW 35	Khalasi Line	11	10	3	30	152
OW 36	Qutubsher 2	11	10	3	30	146
OW 37	Qutubsher 3	11	10	3	30	156
OW 38	Ahamad Bagh	11	10	3	30	152
OW 39	Dudhali Sarak 2	11	10	3	30	152
OW 40	Beri Bagh 2	11	10	3	30	157
OW 41	M S College	11	10	3	30	157
OW 42	Halalpur	11	10	3	30	156
OW 43	Ramgarh	11	10	3	30	146
OW 44	Lohani Sarai	11	10	3	30	152
OW 45	Shahid Ganj 2	11	10	3	30	151
OW 46	Sheikhpura Qadim 2	11	10	3	30	177
OW 47	Sheikhpura Qadim 3	11	10	3	30	177
OW 48	Visnu Dham	11	10	3	30	157
OW 49	Sabari Ka Bagh 2	11	10	3	30	148
OW 50	New Mahipura	11	10	3	30	148
OW 51	Khata Khedi	11	10	3	30	158

Plate 4.1

Plate 4.2

Plate 5.1

Plate 5.2