केंद्रीय भूमि जल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण मंत्रालय

भारत सरकार

Central Ground Water Board

Ministry of Water Resources, River Development and Ganga Rejuvenation

Government of India

Report
on

AQUIFER MAPPING AND GROUND WATER MANAGEMENT PLAN

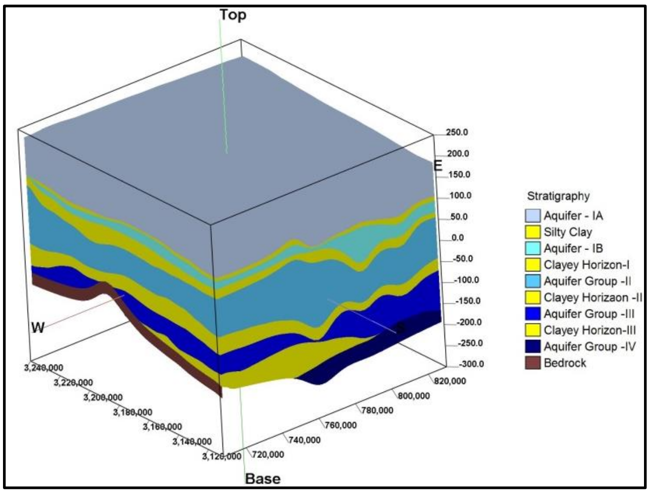
Parts of NCR, Uttar Pradesh

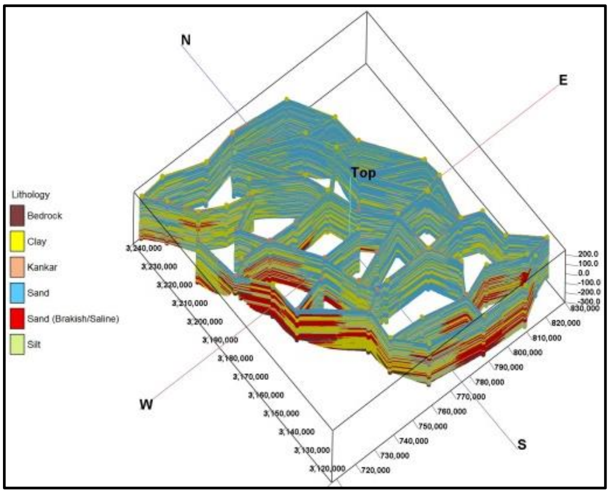
उत्तरी क्षेत्र, लखनऊ

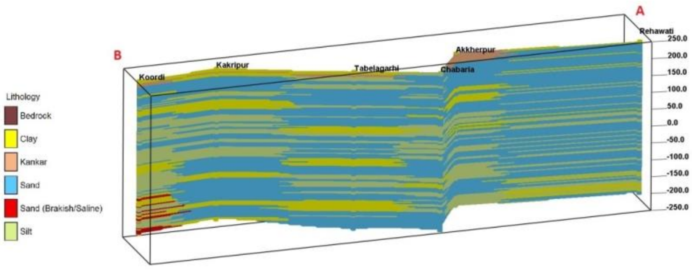
Northern Region, Lucknow

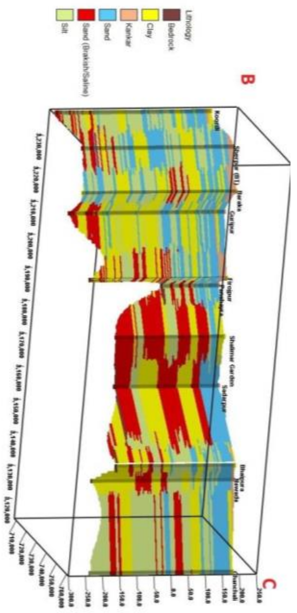
Draft Report

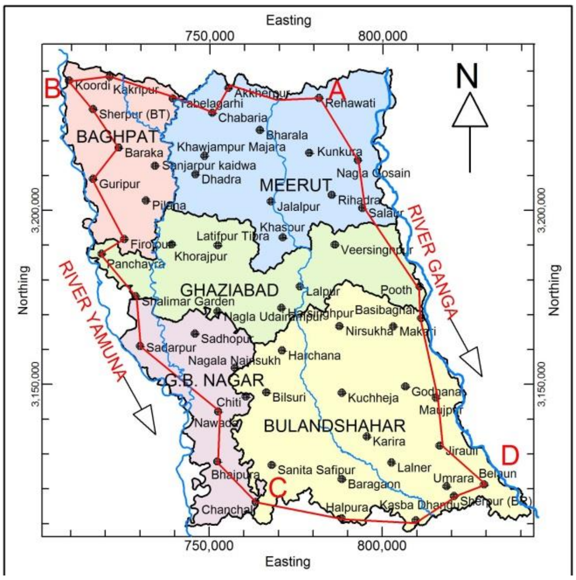
Report on Aquifer Mapping and Formulation of Aquifer Management plan in NCR, Uttar Pradesh

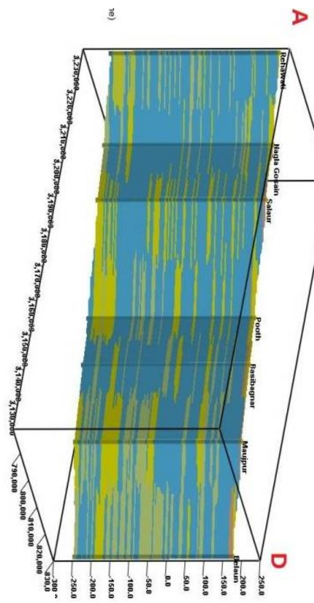


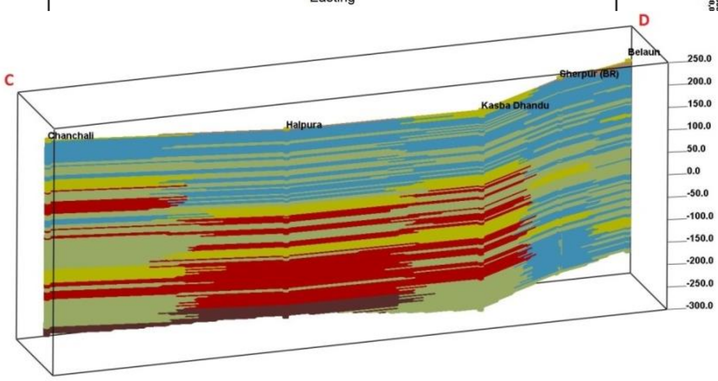












EXECUTIVE SUMMARY

National Capital Region (**NCR**) had a total area of 34,144 km^2 spanning over 15 districts in the states of Uttar Pradesh, Haryana, and Rajasthan, together with the National Capital Territory of Delhi, with the Nation Capital as its core **(www.ncrpb.nic.in**).NCR, Uttar Pradesh (**UP**) comprises of 5 districts, namely - Baghpat, Meerut, Ghaziabad, Gautam Buddh Nagar and Bulandshahar, covering nearly 11,275 sq km. There are 46 blocks and 3156 villages in these districts. Blessed with immense natural and human resource potential, it is one of the few zones poised to become front-runner in the country. Collectively, NCR, UP has seen decadal population growth by 26.01%, with maximum growth of 49.11% observed in G B Nagar district and minimum 11.95% in Baghpat district.

Rapid pace of development in NCR, UP has resulted in increasing dependence on ground water. Demand of ground water has seen steep escalation over past few years, putting stress on its aquifers. Though NCR, UP as a whole has sufficient ground water for further development, the symptoms of stress on ground water resource are surfacing at places, particularly in urban areas. Latest estimation of dynamic ground water resource (as on 31.3.2011) has put 13 blocks under 'Over-exploited',12 under 'Critical' and 6 under 'Semi-critical' category . Comparison of water levels measured in CGWB monitoring stations during 2013 with decadal mean (2004-13) shows departure towards negative side in almost all the districts. Long term water level trend of these stations for the period 2004-2013 shows declining trend in major part of the area, with maximum declines observed in Baghapt and G.B. Nagar districts (more than 1.0 m/year). Water levels measured during 2013 range from 3.73 mbgl (Dhaulana, Ghaziabad) to 26.75mbgl (Pilana, Baghpat) during pre-monsoon and from 1.65mbgl (Dhaulana, Ghaziabad) district Ghaziabad to 25.30 mbgl (Pilana, Baghpat) at (Pilana) during post-monsoon.

For NCR, UP to become a front-runner in the country warrants that its growth does not get hampered due to deteriorating ground water scenario. It, therefore, becomes imperative that the development of the area is bolstered with a sustainable ground water management plan, enabling it to grow in a desired and planned manner. This can only be achieved by having proper knowledge of the underlying aquifer systems and their characteristics through various data generation activities in order to develop a robust simulation model serving as Decision Support System for planning of developmental activities.

With this view, the NCR, UP was taken up for aquifer mapping on 1:50000 scale under National Aquifer Management (NAQUIM) project. For this purpose, all the available data from CGWB and other agencies was collected and integrated to work out the data gap in order to plan data generation. Exploratory drilling coupled with geophysical logging was carried out to understand sub-surface disposition of various aquifer systems and their lithological characteristics. Geophysical surveys, such as Vertical Electrical Soundings, 2D Imaging etc. in conjunction with lithological data generated from exploratory drilling helped to demarcate aquifer geometry through inferred lithological variations across the area, both laterally, as well as vertically. Pumping tests were carried out in the wells constructed tapping different aquifers to determine hydraulic properties of individual aquifer systems. Ground water sampling was done to ascertain quality of water in the area. In addition, other data generation activities were also undertaken to supplement the information gathered through principal activities. Based on the data generated, flow model was developed to simulate different stress scenarios.

Land use and land cover map of the study area as per remote sensing data of year 2012 shows that major part (82%) is under agriculture and 10% area under rural habitation. Area under Urban Residential is 5%. The forest cover is only 0.53% whereas area of water bodies is 2.14%. Mean annual rainfall is about 900 mm, nearly 86% of which takes place during south-west monsoon from June to September.

General slope of the area is northwest to southeast, with elevation of land surface varying from 240 mamsl in the north to 170mamsl in the southeast. Major part of the land occupies the upland surface between valleys of the rivers Ganga and Yamuna, dissected by minor N-S drainages, namely Kali Nadi and Hindon in Meerut and Baghapt districts, flowing parallel to each other. Geomorphologically, the area can be divided into 2 broad units – a) Older Alluvial Plain (OAP) or Varanasi Alluvial Plain and b) Younger Alluvial Plains (YOP) occupying low-lying areas along major rivers.

Broadly, two distinct geological units can be seen in the area – a) Older Alluvium or Varanasi Alluvium underlying Older Alluvial Plain or upland area, and b) Younger Alluvium underlying Younger Alluvial Plain, i.e the flood plains of rivers. Bed rock composed of Delhi quartzite has been encountered at different depths in Yamuna-Hindon doab.

The alluvium comprises very fine to coarse grained sands, sandy clay, silt, clay and kankar (calcareous concretion). In the western part (towards Yamuna), alluvium is predominated by clay inter-beds, whereas in the eastern part (towards Ganga) thick sand beds are encountered. It is about 300 m thick in the western part and thickens beyond 450m in the eastern part. Sand horizons form the aquifers. Aquifers separated by prominent and regionally extensive thick clay beds have been identified and grouped as Aquifer Group 1 (A1), Group 2 (A2), Group 3 (A3) and Group 4 (A4). The first aquifer, further sub-divided into IA and IB, occurs down to maximum 176m. Aquifer Group II starts from 76 mbgl and extends down to maximum 316 mbgl. The third aquifer group starts from 180 mbgl and extends down to maximum 417 mbgl. The fourth aquifer starts from 300 mbgl and continues down to maximum drilled depth of 450 mbgl. Isopach maps of different aquifer groups reveal that aquifer groups are relatively thicker in Meerut, Ghziabad and parts of Bulandsahar district and in small parts of G.B.Nagar district. Hydraulic conductivities in phreatic aquifer are relatively higher in comparison deeper aquifers.

In terms of drinking water standards, quality of water in phreatic aquifer is, in general fresh, with brackish water also found at some places. Maximum TDS of 4563 mg/l observed at Mursudpur in G.B. Nagar district. Sporadic occurrence of high fluoride concentrations has been reported from all the districts. Generally, high values are up to 4.35 mg/l, with solitary instance of 6.64mg/l in G B Nagar district. Iron content is high in majority of the samples. Presence of high iron and fluoride appear geogenic in nature. Nitrate content above permissible limit has been found in a considerable number of samples from phreatic aquifer. For irrigation use, suitability of water indicates medium to high salinity and low and medium alkali water. The water can be used for plants with good salt tolerance. Nitrate and fluoride are also within permissible limit. Based on electrical logging and VES, formation water quality has been inferred as brackish to saline in deeper aquifers in western part of Baghpat and at shallow depths in G.B.Nagar district. In southern part of Bulandsahar district brackish zone starts below Aquifer-I.

Analysis of samples collected for bacteriological reveal presence of total coliform. and faecal coliform at some places. Residual pesticide analysis shows presence total Endosulfan and Dieldrin above permissible limit in some samples. Barring a single instance of high concentration, total DDT is otherwise found below permissible limit.

The area is under intensive irrigated agriculture since decades. Almost all the tube wells are tapping ground water from Aquifer I, which is highly prolific aquifer.

Simulation through aquifer response model with different stress conditions has generated following scenarios for **Aquifer-I** (Pumping for all purposes from Aquifer II is insignificant hence the piezometeric head of aquifer II remains the same throughout the model run).

Scenario 1. With current rate of pumping (2015) from Aquifer I and same recharge rate upto 2025, the model predicts continued declining trend of water levels in most of the piezometers, with declining trend ranging from 0.2 m to 0.3m annually.

Scenario 2. Considering annual increase in pumping by 1% (in view of the area under agriculture intense irrigation) upto 2025, the model predicts annual lowering of water levels by 0.2 to 0.4m. Extrapolating this trend linearly for next 20 years, i.e. till 2045, the saturated aquifer thickness would reduce to 50 to 60% of the total aquifer thickness.

Scenario 3. A number of urban agglomerations already exist in the area and conversion of land use from agriculture to urban area is taking place at a rapid pace. There is ever-increasing demand for ground water in urban areas. Considering increase in pumping rate by 5% annually for the next 10 years and keeping the recharge rate same the model was run upto 2025. Model prediction shows that at Loni and Bisrikh, ground water level would be lowered by 0.2m at Loni and 0.80m at Bisrikh. The lowering of water level by 0.2 to 0.8 m in 10 years may be considered as insignificant when compared to the total saturated thickness of the aquifer I.

Scenario 4. Considering occurrence of drought once in four years, with increase in pumping by 6% during drought year and keeping the recharge rate almost same lowering of water levels by just 0.2m is predicted, which may be termed insignificant. However consecutive drought would create larger impact in the model area.

DRAFT REPORT

AQUIFER MAPPING AND FORMULATION OF AQUIFER MANAGEMENT PLAN IN NCR, UTTAR PRADESH

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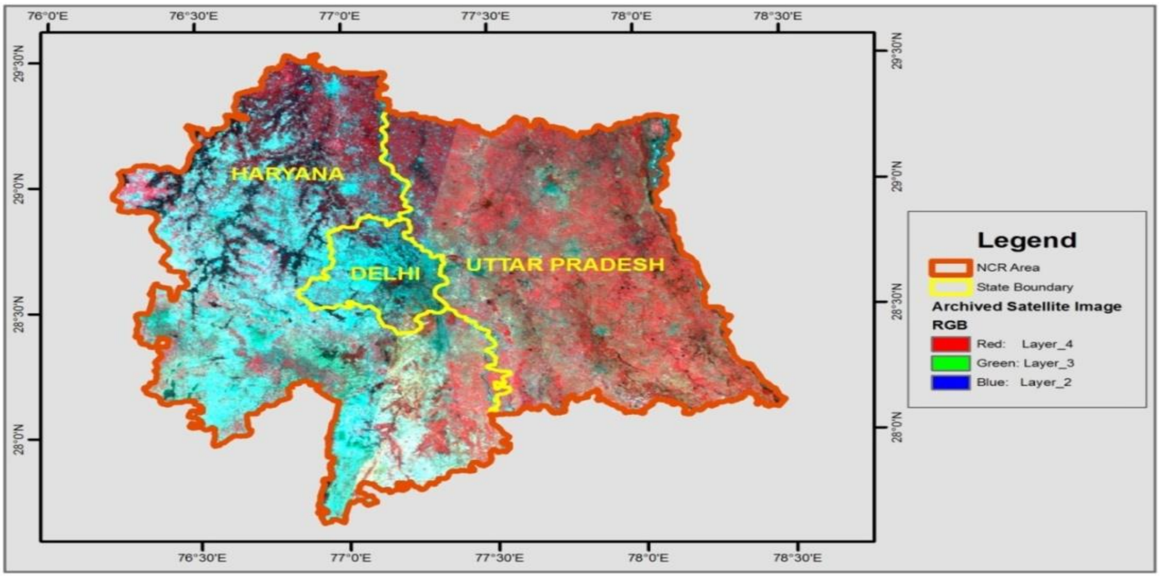
CHAPTER-1

INTRODUCTION

There has been a paradigm shift from “groundwater development” to “Groundwater management” in the past two decades in the country. An accurate and comprehensive micro-level picture of groundwater through aquifer mapping in different hydrogeological settings would enable robust groundwater management plans in an appropriate scale. Aquifer mapping is a process wherein a combination of geologic, geophysical, hydrologic and chemical field and laboratory analyses are applied to characterize the quantity, quality and sustainability of ground water in aquifers. This would help achieving drinking water security, improved irrigation facility and sustainability in water resources development in large parts of rural India, and many parts of urban India.

Central Ground Water Board (CGWB) has implemented the Aquifer Mapping Programme/Project in the National Capital Region (NCR) of Delhi, Haryana and Uttar Pradesh (**Fig. 1**) with the broad objective of preparing an aquifer-wise management plan for the region. Various multi–disciplinary geo-scientific activities were undertaken in the study through in-house capacity of CGWB and partly through outsourcing by the WAPCOS Ltd., New Delhi for generation of micro-level hydrogeological data. This report primarily deals with the U.P. part of National Capital Region adjoining Delhi **Fig.1.1**.

Fig. 1.1 National Capital Region (NCR) under Aquifer Mapping Programme.



1.1 Objective

The broad objective of the study is to establish the geometry of the underlying aquifer systems in horizontal and vertical domain and characterize them, so as to work out the development potential and prepare aquifer-wise management plan using ground water simulation model.

1.2 Scope of Study

The scope of the present study is broadly within the framework of National Aquifer Mapping and Management Programme (NAQUIM) being implemented by CGWB. There are four major activity components viz.: (i) data collection / compilation (ii) Data gap analysis (iii) Data generation and (vi) Preparation of aquifer maps and management plan to achieve the objectives. Data compilation included collection, and wherever required procurement, of all maps from concerned agencies, such as the Survey of India, Geological Survey of India, State Governments departments etc., computerization and analyses of all acquired data, and preparation of a knowledge base. Identification of Data Gap included to ascertain requirement for further data generation in respect of hydrogeological, geophysical, chemical, hydrological, hydrometeorological studies, etc. Data generation included those of hydrometeorology, soil infiltration, sub-surface geophysics, chemical quality of ground water, litho logs and aquifer parameters. Generation of ground water chemical quality data was accomplished by collection of water samples and their laboratory analyses for all major parameters, heavy metals, pesticides and bacteria. Sub-surface geophysical studies incorporated vertical electrical sounding, two-dimensional image profiling, and borehole logging. Additional data pertaining to sub-surface lithology and aquifer parameters were obtained through drilling of additional exploratory wells and slim holes, pumping tests at the drilling sites and slug tests in a number of sites and their analyses.

1.3 Approach and Methodology

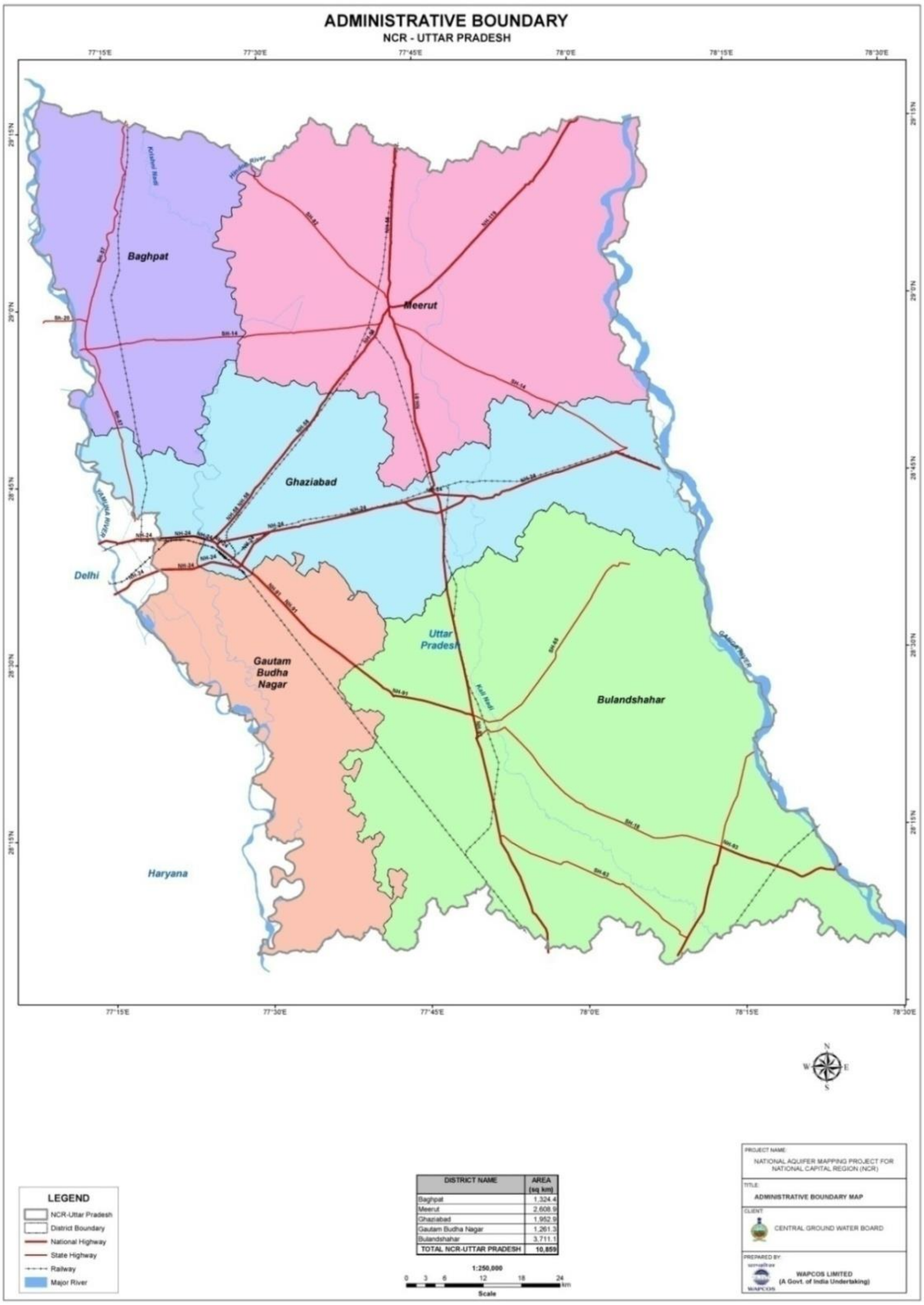
The approach and methodology adopted to achieve the major objective has been shown in the form of a flow chart given below-

Flow Chart of Activities	
Compilation of existing data by CGWB and WAPCOS	Identification of data gaps by CGWB
Additional data generation By WAPCOS	
Preparation of GIS layers by WAPCOS / CGWB	
Preparation of thematic maps on GIS platform by WAPCOS / CGWB	
Preparation of Aquifer maps and management plan by CGWB	

1.4 Study Area

National Capital Region (NCR), Uttar Pradesh comprises of five districts, namely, Baghpat, Bulandshahar, G.B. Nagar, Meerut and Ghaziabad districts (including the recently carved out Hapur from Ghaziabad district with total of forty-six administrative blocks covering an area of 11274 sq km approx. (including urban and rural area). The study area lies between Longitude $77^0$10’ to $78^0$29’ and Latitude $28^0$08’ to $29^0$07’, (Fig. 1.2).falling in Survey of India Toposheet Nos.53G, 53H & 53L The study area forms part of Upper Ganga Alluvial Plains in the inter-fluvial belt of Ganga-Yamuna doab.

Fig.-1.2 Administrative Map of study Area NCR, UP



As per 2011 census, the total population of these districts is 1,45,61,224 persons. Total number of villages is 3156. Collectively, these districts have seen decadal growth in population by 26.01%, with maximum growth of 49.11% observed in G B Nagar district and minimum 11.95% in Baghpat district. District-wise salient figures details are given in Table-1.1

Table-1.1 District-wise area and population, NCR, Utter Pradesh

District	Geographical Area (Sq Km)			Population			Decadal Growth in % (2001-2011)			Blocks	Village
	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural		
Baghpat	1321	60	1261	1303048	275025	1028023	11.95	19.90	10.00	6	315
Meerut	2590	245	2345	3443689	1759182	1684507	15.80	21.20	10.70	12	667
Hapur*	660	54	606	1323867						4	350
Ghaziabad	910	126	784	3343334	3162547	1519098	41.27	74.10	1.40	4	205
G.B. Nagar	1441	150	1291	1648115	974309	673806	49.11	120.30	1.60	4	373
Buland-shahar	4352	72	4280	3499171	867429	2631742	16.26	28.30	13.00	16	1246
Total	11274	707	10567	14561224	7038492	7522732	26.01			46	3156

*Recently carved out of Ghaziabad district;

1.5 Data Availability & Data Gap Analysis

The data pertaining to various attributes of ground water were collected from available literatures of Central Ground Water Board, State Departments and other agencies. The compiled data were plottedon 1:50,000 scale map and analysis of Data Gap was carried out for ascertaining additional requirement of Hydrogeological, Hydrological, Hydro chemical, and Geophysical Studies. Data Requirement, Data Availability and Data Gap Analysis is summarized in Table-1.2 and presented in Fig.-1.3.

Table 1.2: Data Availability and Data Gap Analysis for Aquifer Mapping in NCR, UP

Sl No	Study Aspect	Data Requirement	Data Availability	Data Gap
1	Rainfall and Other Climatic data	4 IMD Meteorological Satiation in the area	Not Data Partially Available	Rainfall data Study area
2	Soil	Soil Map and Soil infiltration rate	Soil Map	Soil Infiltration rate across the area
3	Land Use	latest land use Pattern in GIS Platform	Land Use as in CGWB Report	Latest data in GIS platform required
4	Geomorphology	Digitized Geomorphological Map	Not Available	Digitized Geomorphological Map
5	Geophysics	Geophysical Survey in all toposheets	Not Available	432 VES Required & 2D Line Imaging
6	Exploration	Exploratory well along with aquifer parameters	Exploratory well exist but theses tap multiple aquifer group	40 EW, 40 OW & 15 SH Required tapping different aquifer Groups/ Aquifer Parameters
7	Recharge Parameters	recharge parameters of different soil and aquifer types based on field stuidies	Recharge parameters are given in Ground Water resource estimation	Entire Study area
8	Discharge Parameters	Discharge parameters for different GW abstraction structure	Discharge parameters are given in Ground Water resource estimation	Entire Study area

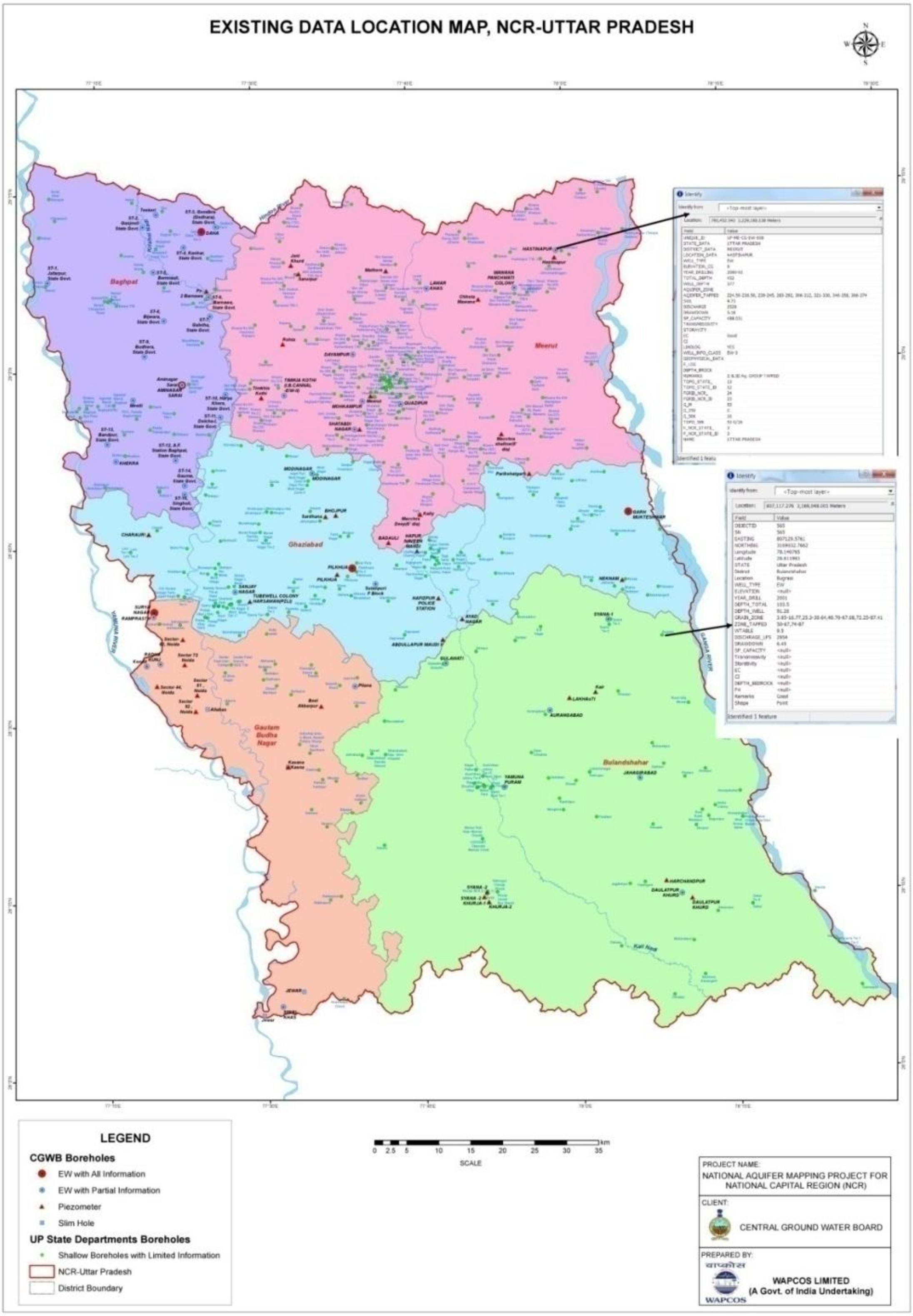


Fig.-1.3: Existing Data Location Map NCR, UP

CHAPTER 2

CLIMATE AND RAINFALL

The development of hydrometeorology as a science is closely linked with increasing use of meteorology to the problem of hydrology, agriculture and groundwater studies. Rainfall data are mainly used for groundwater recharge study as well design and construction of water resources projects. During planning and designing of dams, long term rainfall data are used for the estimation of water flowing in a stream. All forms of precipitation are measured as vertical depth of water that would accumulate on a level surface if the entire precipitation remained where it fell.

In the present study statistical analysis of last thirty years daily normal rainfall, collected from IMD have been carried out District wise, which have been briefed in following paragraph

2.1Baghpat District

The Climate of Bhagpat district is Sub humid to subtropical climate with maximum and minimum temperature 43^0C and 3^0C respectively. Annual normal rainfall is about 639 mm where 86% of the rainfall takes place in the month of June to September due to South - West monsoon shown in figure 2.1. Due to the effect of climate change the maximum deviation of monsoonal rain fall from normal is found to be -68.7% and -25.6% for the month of June and September respectively. Details Statistical analysis of monthly and seasonal rainfall data of last 30 years daily normal rain fall is given in table 2.1.

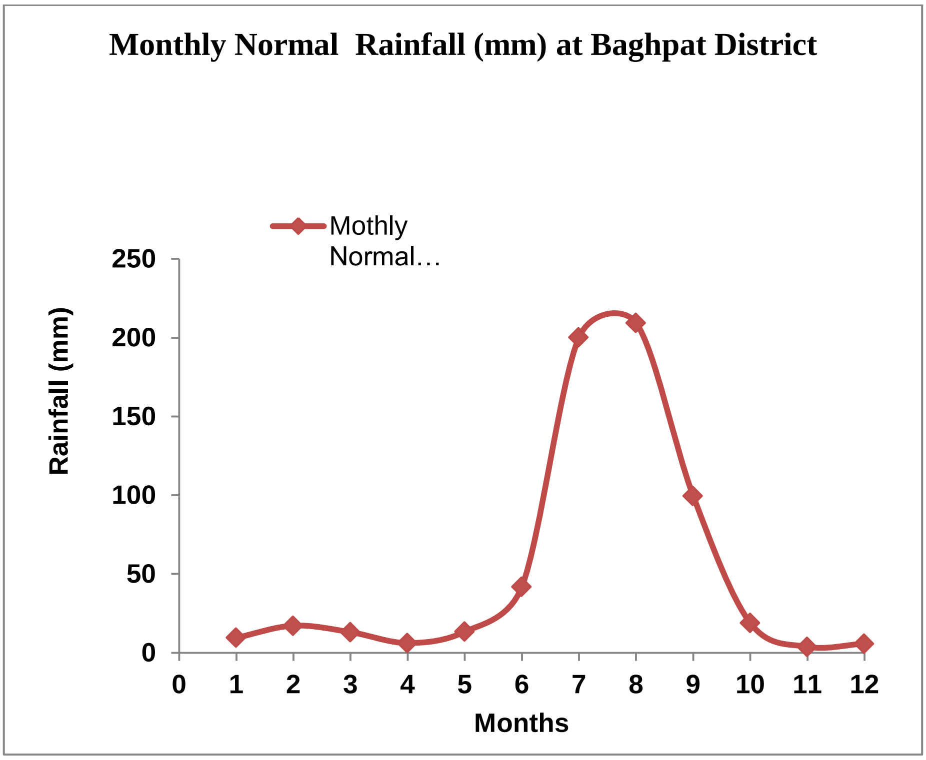


Figure 2.1: Monthly Normal Rainfall (in mm) at Baghpat District

Station : Baghpat					
Season	**Month**	**Rainfall**	**Deviation**	**Caraterized**	**Rainy Days**
Winter Season (January to February)	January	9.5	-28.8	Deficit	1.8
	February	17.2	28.8	Excess	1.4
	Total	26.7			3.2
	Mean/Average	13.4			1.6
	SD	5.4			0.3
	CV	40.8			17.7
Hot or Summer Monsoon (March to May)	March	13.1	20.2	Excess	1.5
	April	6.2	-43.1	Deficit	0.6
	May	13.4	22.9	Excess	1.3
	Total	32.7			3.4
	Mean/Average	10.9			1.1
	SD	4.1			0.5
	CV	37.4			41.7
South West Monsoon (June to September)	June	41.9	-68.7	Deficit	2.5
	July	200.2	49.6	Excess	8.9
	August	209.4	56.5	Excess	9.3
	September	99.6	-25.6	Deficit	5
	Total	551.1			25.7
	Mean/Average	137.8			6.4
	SD	81.0			3.3
	CV	58.8			50.7
NE (October to December)	October	18.9	98.9	Excess	1.1
	November	3.8	-60.0	Deficit	0.4
	December	5.8	-38.9	Deficit	0.5
	Total	28.5			2.0
	Mean/Average	9.5			0.7
	SD	8.2			0.4
	CV	86.3			56.8
	Annual Mean	54.1			2.9
	Annual Total	639.0			34.3
	Annual SD	75.1			3.2
	Annual CV	138.8			110.6

Table2.1: Statistical Analysis of Baghpat District – Monthly and Seasonal Rainfall data based on 30 years normal daily rainfall (mm)

SD: Standard Deviation, CV: Coefficient of Variation. Dev: Deviation,

According to IMD: Characterized: Normal, Excess and Deficit

(Above+19: Excess, +19 to -19: Normal, < -19: Deficit (Drought))

2.2 Ghaziabad District

The Climate of Ghaziabad is similar to Baghpat district which is Sub humid to subtropical climate with maximum and minimum temperature is 42^0C and 4.5^0C respectively. The normal annual rainfall of the district is 750.3 mm shown in figure 2.2. The maximum deviation occurs during south west monsoon which is 72% for the month of June. Detailed Statistical analysis of monthly and seasonal rainfall data of last 30 years daily normal rain fall is given in Table: 2.2.

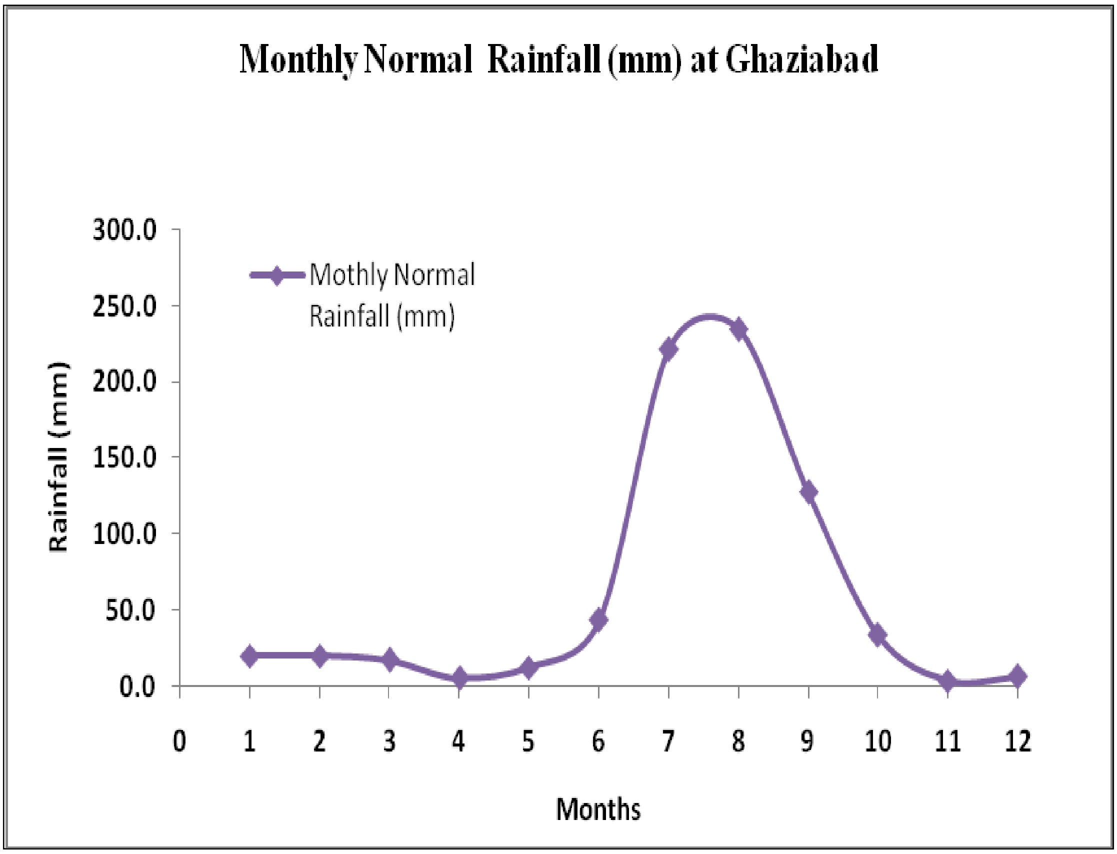


Figure 2.2: Monthly Normal Rainfall (mm) at Ghaziabad District

Table 2.2: Statistical Analysis of Ghaziabad District – Monthly and Seasonal Rainfall data based on 30 years normal daily rainfall (mm)

Station : Ghaziabad	**Month**	**Rainfall (mm)**	**Deviation (%)**	**Characterized**	**Rainy Days**
Season	January	20.5	-0.5	Normal	1.5
Winter Season (January to February)	February	20.6	0.0	Normal	1.3
	Total	41.1			2.8
	Mean/Average	20.6			1.4
	SD	0.1			0.1
	CV	0.3			10.1
Hot or Summer Monsoon (March to May)	March	18.5	44.6	Excess	1.1
	April	5.8	-52.1	Deficit	0.6
	May	13.0	8.4	Normal	1.1
	Total	36.3			2.8
	Mean/Average	12.1			0.9
	SD	5.9			0.3
	CV	48.8			30.9

South West Monsoon (June to September)	June	43.8	-72.1	Deficit	2.6
	July	221.6	41.2	Excess	9.4
	August	234.7	49.6	Excess	9.8
	September	128.6	-18.7	Normal	5.3
	Total	628.7			28.1
	Mean/Average	156.9			6.8
	SD	89.2			3.4
	CV	56.9			50.9
NE (October to December)	October	33.9	124.5	Excess	1.3
	November	4.3	-71.5	Deficit	0.3
	December	8.0	-53.6	Deficit	0.7
	Total	45.2			2.3
	Mean/Average	15.1			0.8
	SD	16.4			0.5
	CV	108.6			65.7
	Annual Mean	62.5			2.9
	Annual Total	750.3			35.0
	Annual SD	84.2			3.4
	Annual CV	134.7			116.1

2.3 Meerut District

The Climate of Meerut is Sub humid to subtropical climate with maximum and minimum temperature is 43^0C and 1.5^0C respectively. The normal annual rainfall of the district is 904.7 mm shown in figure 2.3. The maximum rainfall occurs in the month of June to September due to south west monsoon. The statistical analysis of annual rainfall from 1995 – 2011 has been carried out and found that the no. of rainy days is significantly declining as shown in figure 2.4. The maximum deviation of 88% has occurred in the year 2003 resulted into the drought like situation shown in table 2.3. Rainfall analysis is also carried out from 30 years normal of daily rainfall data and found that 68.7% maximum deviation occurred in the month of June during south west monsoon shown in table 2.4. The mean annual maximum and minimum temperature 34.7 ^{0}C and 13.2 ^{0}C respectively and the mean annual rainfall 75.4(mm) shown in figure 2.5.

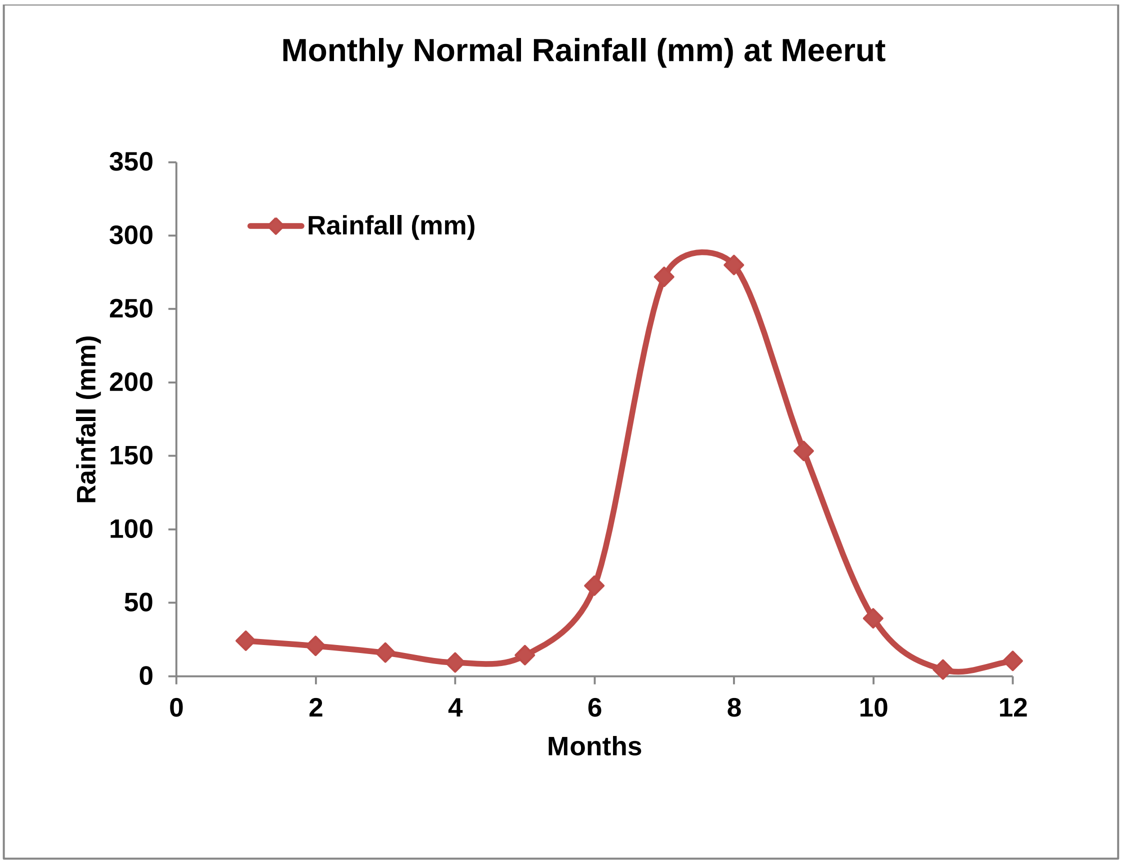


Figure 2.3: Monthly Normal Rainfall (mm) at Meerut District

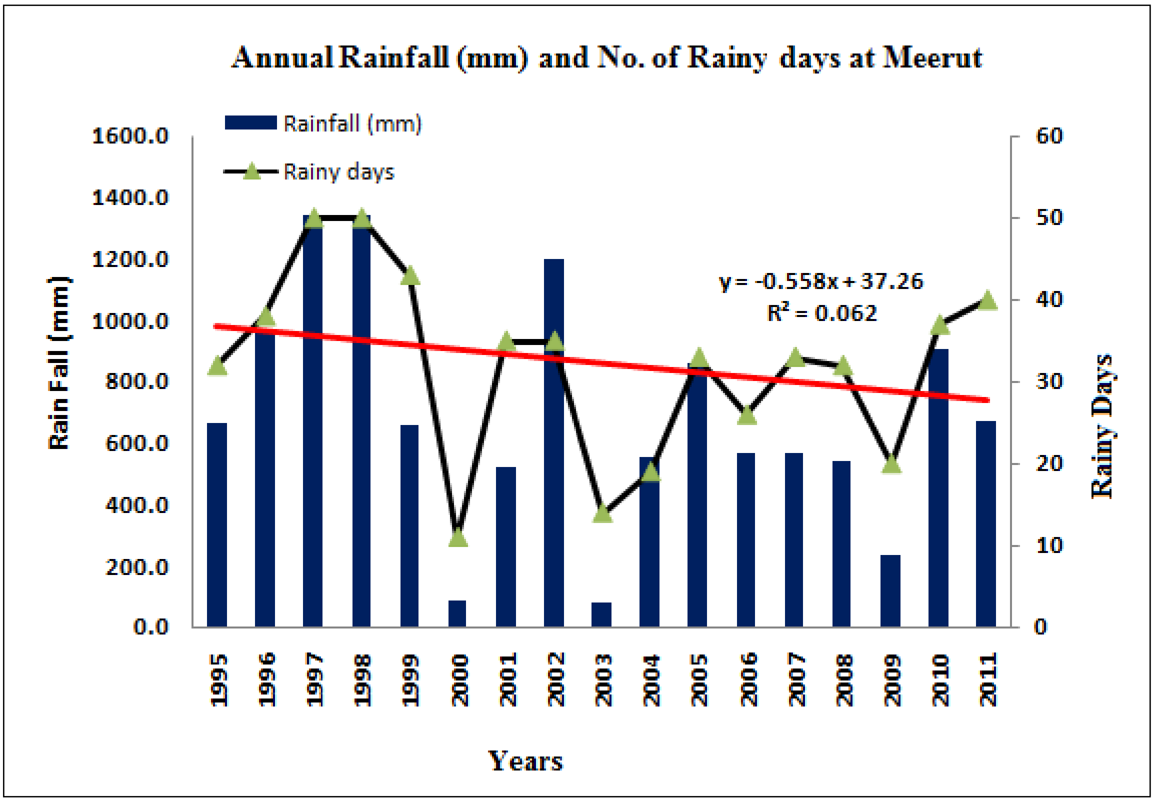


Figure 2.4: Annual Rainfall (mm) and No. of Rainy days at Meerut District

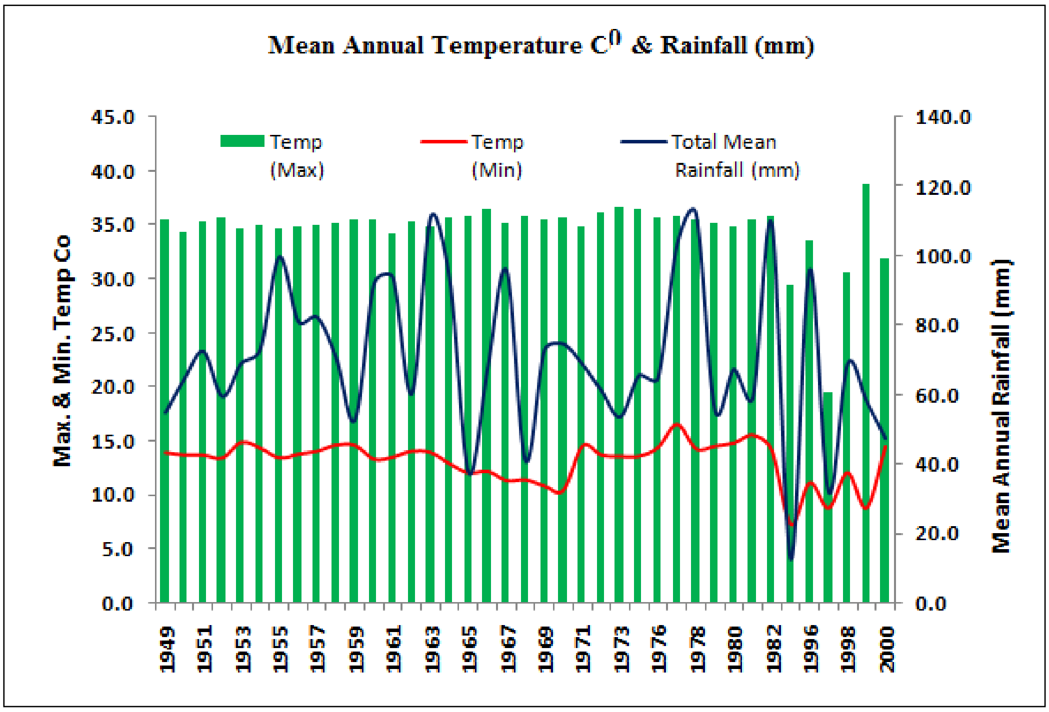


Figure 2.5: Mean Annual Temperature C^0 (Max. & Min.) and Rainfall (mm) at Meerut District

Table 2.3: Annual Rainfall using Statistical Analysis at Meerut (1995-2011)

Year	Rainfall (mm)	Rainy days	Deviation (%)	Characterization
1995	665.2	32.0	-4.8	Normal
1996	964.2	38.0	38.1	Excess
1997	1338.4	50.0	91.5	Excess
1998	1338.4	50.0	91.5	Excess
1999	654.4	43.0	-6.3	Normal
2000	83.7	11.0	-88.0	Deficit
2001	519.7	35.0	-25.6	Deficit
2002	1199.5	35.0	71.7	Excess
2003	81.3	14.0	-88.4	Deficit
2004	554.4	19.0	-20.6	Deficit
2005	859.7	33.0	23.1	Excess
2006	565.9	26.0	-19.0	Normal
2007	566.0	33.0	-19.0	Normal
2008	540.2	32.0	-22.7	Deficit
2009	231.0	20.0	-66.9	Deficit
2010	904.6	38.0	29.5	Excess
2011	668.3	40.0	-4.5	Normal

Table 2.4: Statistical Analysis of Meerut District – Monthly and Seasonal Rainfall data based on 30 years normal daily rainfall (mm)

Station : Meerut	Month	Rainfall (mm)	Deviation (%)	Characterized	Rainy Days
Season	January	24.1	8.6	Normal	2
Winter Season (January to February)	February	20.6	-8.0	Normal	1.6
	Total	44.7			3.6
	Mean/Average	22.4			1.8
	SD	2.5			0.3
	CV	11.1			15.7
Hot or Summer Monsoon (March to May)	March	15.9	21.4	Excess	1.4
	April	9.3	-29.0	Deficit	0.6
	May	14.2	8.4	Normal	1.3
	Total	39.4			3.3
	Mean/Average	13.1			1.1
	SD	3.4			0.4
	CV	26.1			39.6
South West Monsoon (June to September)	June	61.6	-68.8	Deficit	3.3
	July	271.8	41.9	Excess	10.4
	August	279.8	46.0	Excess	10.9
	September	153.2	-20.0	Deficit	5.4
	Total	766.4			30.0
	Mean/Average	191.6			8.5
	SD	104.2			3.7
	CV	54.4			49.9
NE (October to December)	October	39.3	118.1	Excess	1.3
	November	4.5	-75.1	Deficit	0.3
	December	10.4	-42.5	Deficit	0.7
	Total	54.2			2.3
	Mean/Average	18.1			0.8
	SD	18.6			0.5
	CV	103.1			65.7

2.4 Bulandshahar District

The Climate of Bulandshahar is Sub humid to subtropical climate with mean maximum and minimum temperature is 35.6 0C and 14.1 0C respectively. The normal annual rainfall of the district is 784.5 mm shown in figure 2.6. The maximum rainfall occurs in the month of June to September due to south west monsoon but the statistical analysis of 30 years daily normal rain fall suggest that the maximum deviation of 71.8% from the normal occurred in the month of June, indicating about the climate change shown in table 2.5.

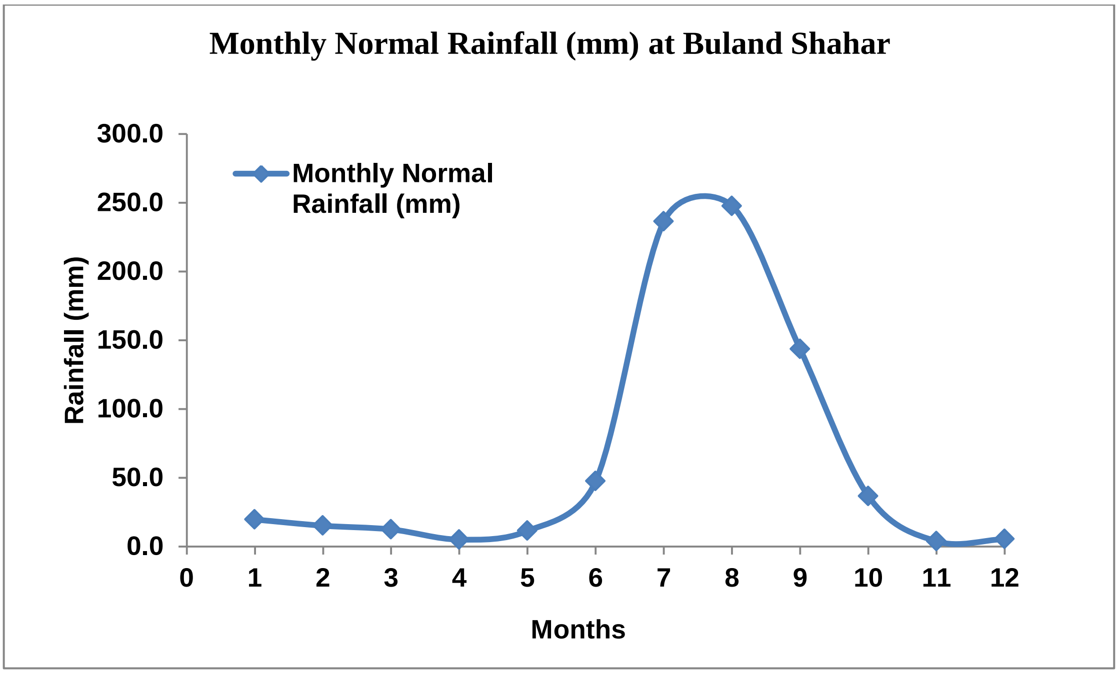


Figure 2.6: Monthly Normal Rainfall (mm) at BulandShahar District

Table 2.5: Statistical Analysis of Bulandshahar District – Monthly and Seasonal Rainfall data based on 30 years normal daily rainfall (mm)

Station- : Bulandshahar	Month	Rainfall (mm)	Deviation (%)	Characterized	Rainy Days
Season	January	19.6	12.6	Normal	1.6
Winter Season (January to February)	February	15.1	-13.2	Normal	1.3
	Total	34.7			2.9
	Mean/Average	18.4			1.5
	SD	3.2			0.2
	CV	18.3			14.6
Hot or Summer Monsoon (March to May)	March	12.4	29.2	Excess	1.2
	April	5.0	-48.9	Deficit	0.4
	May	11.4	18.8	Normal	1.0

	Total	28.8			2.6
	Mean/Average	9.6			0.9
	SD	4.0			0.4
	CV	41.8			48.0
South West Monsoon (June to September)	June	48.5	-71.8	Deficit	2.8
	July	236.5	40.4	Excess	10.1
	August	248.7	48.1	Excess	10.5
	September	143.5	-14.8	Normal	5.4
	Total	675.2			28.8
	Mean/Average	168.8			8.2
	SD	93.4			3.7
	CV	55.3			51.9
NE (October to December)	October	36.6	139.2	Excess	1.4
	November	3.8	-75.2	Deficit	0.3
	December	5.4	-64.7	Deficit	0.5
	Total	45.8			2.2
	Mean/Average	15.3			0.7
	SD	18.5			0.6
	CV	121.1			79.9

CHAPTER-3

PHYSIOGRAPHIC SETUP

3.1Physiography

The Study area forming a part of Ganga-Yamuna Doab lies in the Northwestern part of UP. The area is flanked in the east by Ganga river and in the west by Yamuna river. The area is almost a monotonous plain with sporadic occurrences of sand dunes, and sandy ridges, ravine tracts and depressions close to river Ganga. At places, minor sandy mounds can be seen in the vicinity of other minor rivers also. In some parts, close to river system, badland topography has developed due to differential erosion. In such areas, exposed kankar-lenses and beds form mounds. The fertile and cultivated soil expanses are sometimes broken by barren expanses of flat lands with Usar lands having alkaline soils spread as white sheet on the surface, as well as kankar at shallow depths. Elevation of land surface varies from 240 m amsl in the north to 170 m amsl in the south east, thus exhibiting an elevation difference of 70m. The general slope of the area is northwest to southeast. Major part of the land occupies the upland surface between valleys of the rivers Ganga and Yamuna. This upland surface is dissected by minor drainages, namely Kali Nadi and Hindon in Meerut and Baghapt districts, flowing parallel to each other in N-S direction. Regionally, the area can be divided into following tracts/units based on physiographic consideration.

a. Khadar b. Uplands

(a) Ganga Khadar

The eastern most part of the district following and adjacent to Ganga river is a low flood plain of Ganga. The width of the tract is variable and the development of Khadar is most prominent on the eastern bank of Ganga. On the western bank, the development of Khadar is restricted and its boundary with the upland is made up of bluffs and scarps as seen close to Anupshahar and Rajghat Narora.

(b) Uplands

East of Yamuna lies the upland plain which extends eastward as far as the Khadar of Ganga and consists of a wide and level plain broken only by various drainage lines and streams. The rise from low land to upland is seldom abrupt.

3.2 Geomorphology

The geomorphologic map of NCR on 1:250000 scale (Fig.-3.1) has been prepared on the basis of data generated through georeferenced Resourcesat-2 and Cartosat-1 satellite imageries having 5.6m and 2.5m spatial resolution respectively, with value addition through limited field checks.

Perusal of the map shows that the area can be divided into 2 broad units – a) Older Alluvial Plain (OAP) or Varanasi Alluvial Plain and b) Younger Alluvial Plains (YOP) along major rivers. A few distinctive geomorphological sub divisions of the above units are also present.

(a)Older Alluvial Flood Plain

The Older Alluvial Plain, occupying about ~84% area forms the upland. Central part of the area exhibit slightly higher region which acts as water divide between rivers Ganga and Yamuna. The area along Yamuna, Hindon and Krishni rivers is marked by development of ravines and badland at places. Flood plains of Ganga and Yamuna, locally known as Khadar, constitute older floods plains. It is characterized by presence of fluvial land forms such as mender scares, cut and meanders and palaeo channels (Figure 3.1). The zone is separated by from uplands/ OAP by the occurrence of sharp break at places, discontinuous natural levees, occurrence of stabilized sand dunes and abrupt change in slope (Figure 3.1).

b) Active Flood Plain

Younger Alluvial Plains exist along Ganga, Yamuna, Hindon & Kali rivers. Abandoned channels and sand bars can be seen in the flood plain of these rivers. Whereas YOP along Ganga river is 5-10 kms wide, it attains width up to 20 kms along Yamuna in the central part. These plains can be further sub-divided into two district units.River channel and adjacent terraces form this geomorphological feature, consisting of sand, silt and silty clay with clay pockets It is subjected to periodic flooding. Active channel width is narrower in case of Yamuna in comparison to Ganga. Belts of erosion terraces occupy either side Kali Nadi. Northern segment of Hindon river has only erosion terrace, while in southern part, just before merger with Yamuna, it has only depositional terrace (Figure 3.1).The other features common in this unit are Point Bars, Meander scrolls (Figure 3.1)

3.3 Land Use

Land-use and land cover map showing rural and urban areas, commercial, residential, recreational, defence etc. area is presented as Figure:3.2.The land use and land cover map of the study area as per remote sensing data of year 2012 shows that major part (82%) is under agriculture and 10% area in rural habitation. Area under Urban Residential is 5%. The forest cover is only 0.53% whereas area of water bodies is 2.14% (Table 3.3, Fig.3.2& Fig 3.3).

Table 3.3: Land use and land cover in NCR, UP (as per remote sensing data 2012)

Total Area (sq km)	Agri- cultural	Circulatio	Commerci al	Defence	Forest	Industrial	Public&Se mi Public	Recreatio nal	Rural	Utilization	waste Land	water	Urban Residentia
11360	9410	4.65	14.3	10.6	53.4	65.4	28.5	33.9	1004	8.5	11.4	214	501.8
(%)	82.83	0.05	0.14	0.11	0.53	0.65	0.29	0.34	10.04	0.08	0.11	2.14	5.02

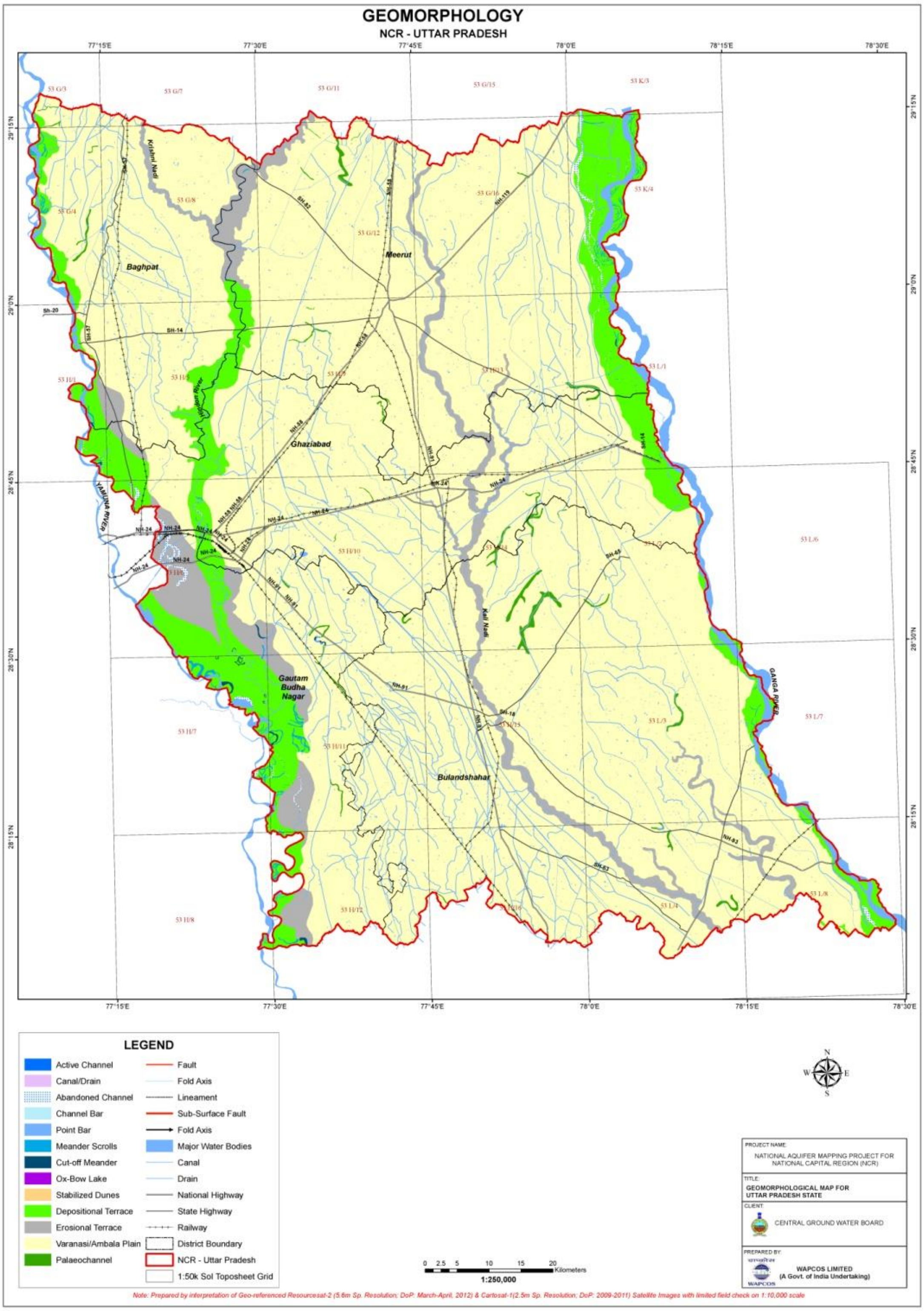


Figure 3.1: Geomorphological Map NCR, Uttar Pradesh

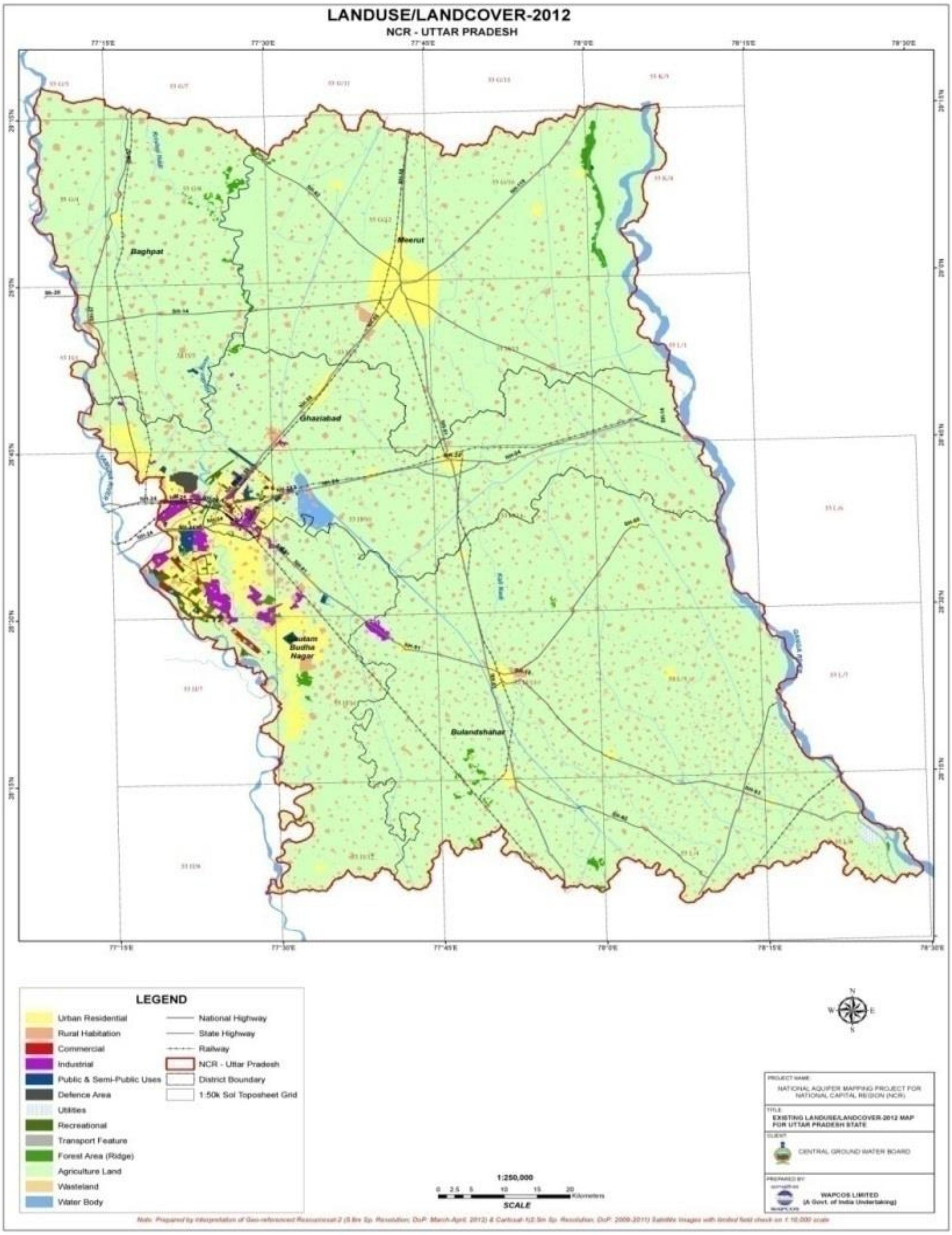
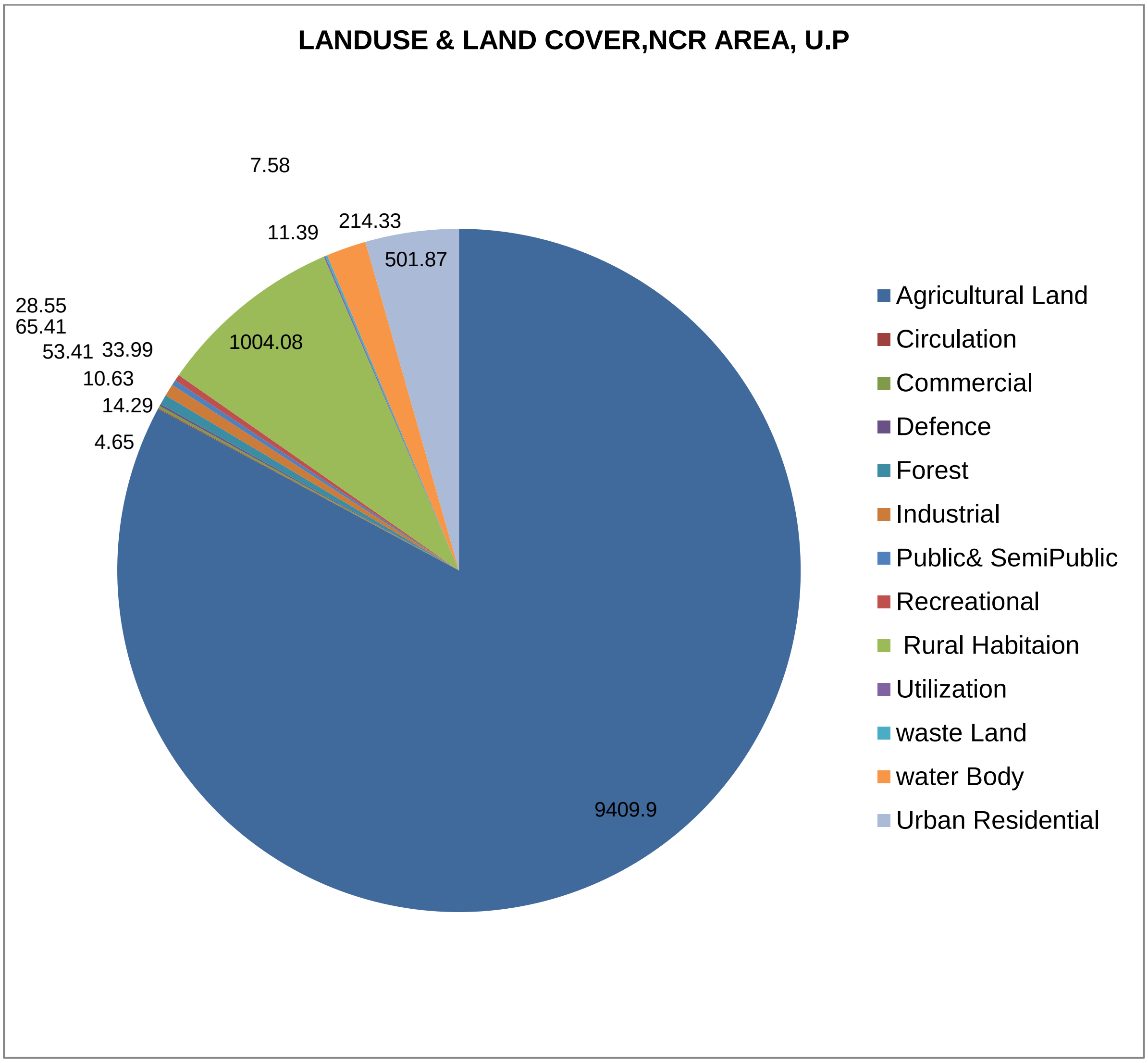


Figure 3.2 Land-use and Land Cover Map**,** NCR, U.P

Figure 3.3 Different Land-use, NCR,



3.4 Soil:

Soil Map of Uttar Pradesh published by National Bureau of soil Survey & Land Use Planning (ICAR) (NBSS &LUP, 2004) shows that in major part of NCR, UP the soilsoccur on nearly level to level plains, are deep and well drained and have loamy surface. Generally, the soils are fine or coarse loamy, with both varieties occurring together and one or the other being predominant component at different places. A number of variants of above soil type also exist in the area due to slight departure from general characteristics. In very small patches in Ganga – Kali Doab to the north, this type of soil is associated with fine silty type i,e, the silt occurs as minor component along with general type of soil.

In some part the soils exhibit calcareous nature. This type of soil is present particularly in Bulandsahar district, both in Ganga –Kali and Kali-Yamuna Doabs. Towards Ganga River in this part, soils are moderately well drained. In about half of Kali-Yamuna Doab to the west of Kali, this type of soil occurs on very gentle slope, shows signs of slight erosion and is also slightly sodic and saline. To the north in Meerut district, soil with calcareous nature in Ganga-Kali Doab is present only in minor proportions.

In the immediate vicinity of Ganga and Yamuna channels, the soils generally occur on very gentle slopes. These soils have sandy surface, are excessively drained and experience moderate to slight flooding. The soils have minor amount of coarse loamy type or coarse loamy over sandy type. In a narrow belt along Ganga, soil occurs on gentle slope with slight erosion and is also slightly saline. Along Yamuna, the soil is calcareous whereas along Ganga the calcareous component is present only in minor amount.In narrow belts on either side of Hindon and Kali, soils occur on very gentle slope. These soils are coarse loamy over sandy and calcareous. Non- calcareous and coarse loamy variant is also associated in minor amount in the southernmost part. However, soils are non-calcareous along Kali and exhibit signs of slight erosion.

3.4.1: Soil Infiltration Test:

Soil infiltration is the process by which water on the ground surface enters in to the soil. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation water. Infiltration rate defined the volume flux of water flowing into the soil profile per unit of soil surface area and measured in inches per hour or millimeters per hour. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. The infiltration rate decreases as the soil becomes saturated. Infiltration rates decline to a steady or quasi-steady state as soil becomes increasingly moist over the period of a storm or experimental wetting. Infiltration rate usually shows a sharp decline with time from the start of the application of water. The constant rate approached after a sufficiently large time is referred as the steady-infiltration rate. In dry soil, water infiltrates rapidly in initial phases and called as the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches at steady state rate. This is called the basic infiltration rate or steady state infiltration rate.

Determination of infiltration rates is essential for reliable prediction of surface runoff, saturated hydraulic conductivity of the surface layer and groundwater recharge, and in developing or selecting the most efficient irrigation methods. Quantifying the soil infiltration capacity is of great importance to understanding and describing the hydrologic analysis and modeling. The use of efficient irrigation methods with reduced water losses is critical in most part of water scare regions of Indian sub-continent. This makes studies on determination of infiltration rates of utmost importance. The measure of infiltration of water into the soil is an important parameter which helps in planning recharge interventions.

The classification of infiltration rate is given in Table 3.4 (a)

Table-3.4(a) : Classification of Soil Infiltration Rate

Class	**Rate of infiltration (mm/hour)**	**Remarks**
Very Slow	<2.5	Soil in this group has very high percentage of clay.

Low	2.5 – 12.5	Most of these soils are shallow, high in clay and low in organic matter contents
Medium	12.5 – 25.0	Soils in this group are loams and silts
High	>25	These soils are deep sands, deep well aggregated silt loams and some tropical soils with porosity.

Soils with low infiltration can be responsible for runoff and flooding and can become saturated during rain events. This, in turn, decreases soil strength and increases erosion potential. It can also cause nutrient deficiencies in plants and generate anaerobic conditions. Soils that have reduced infiltration have an increase in the overall amount of runoff water. In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile or into tile lines need proper chemical management to ensure the protection of groundwater and surface water resources. Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases detachment of particles, and enhances the erosion potential. In some areas that have a steep slope, surface material lying above a compacted layer may move in a mass, sliding down the slope because of saturated soil conditions. Decreases in infiltration or increases in saturation above a compacted layer can also cause nutrient deficiencies in crops. Either condition can result in anaerobic conditions which reduce biological activity and fertilizer use efficiencies. The numbers of infiltration test conducted in each district are as given in Table 3.4(b)

Table 3.4(b) Details of Infiltration Test Conducted in NCR,U.P.

Sl No	District	No. of Soil Infiltration Test
1.	Baghpat	54
2.	Meerut	117
3	Ghaziabad	61
4.	Gautam Budh Nagar	52
5.	Bulandshahar	151
Total Uttar Pradesh		435

3.4.2 Baghpat District:

Soil infiltration tests in the Baghpat district shows variation in the infiltration rate which were observed in the entire district. The initial infiltration rate in Baghpat district varies between 30 mm/hr to 450 mm/hr and the final infiltration rate varies between 3 mm/hr to 90 mm/hr. The average initial and final infiltration rate for the district is found to be 169.7 mm/hr and 13.3 mm/hr respectively. The average infiltration rate for the Baghpat district is estimated as 91.5 mm/hr. The higher infiltration rates are observed at sites Asara, Kashampur Kheri, Makara, Osika and Pura indicating sandy nature of local soils. Sandy loam soil is known to have high infiltration rates while clay loam and sandy clay soils are known to have very low infiltration rates.

3.4.3 Meerut District:

Wide variation in the infiltration rate has been observed in the entire district. The initial infiltration rate in Meerut district varies between 30 mm/hr to 960 mm/hr and the final infiltration rate varies between 3 mm/hr to 102 mm/hr. The average initial and final infiltration rate for the district is found to be 208.4 mm/hr and 20.9 mm/hr respectively. The average infiltration rate for the Meerut district is estimated as 114.1 mm/hr. The higher infiltration rates at many sites indicate sandy nature of local soils. Sandy loam soil is known to have high infiltration rates while clay loam and sandy clay soils are known to have very low infiltration rates

3.4.5 Ghaziabad District :

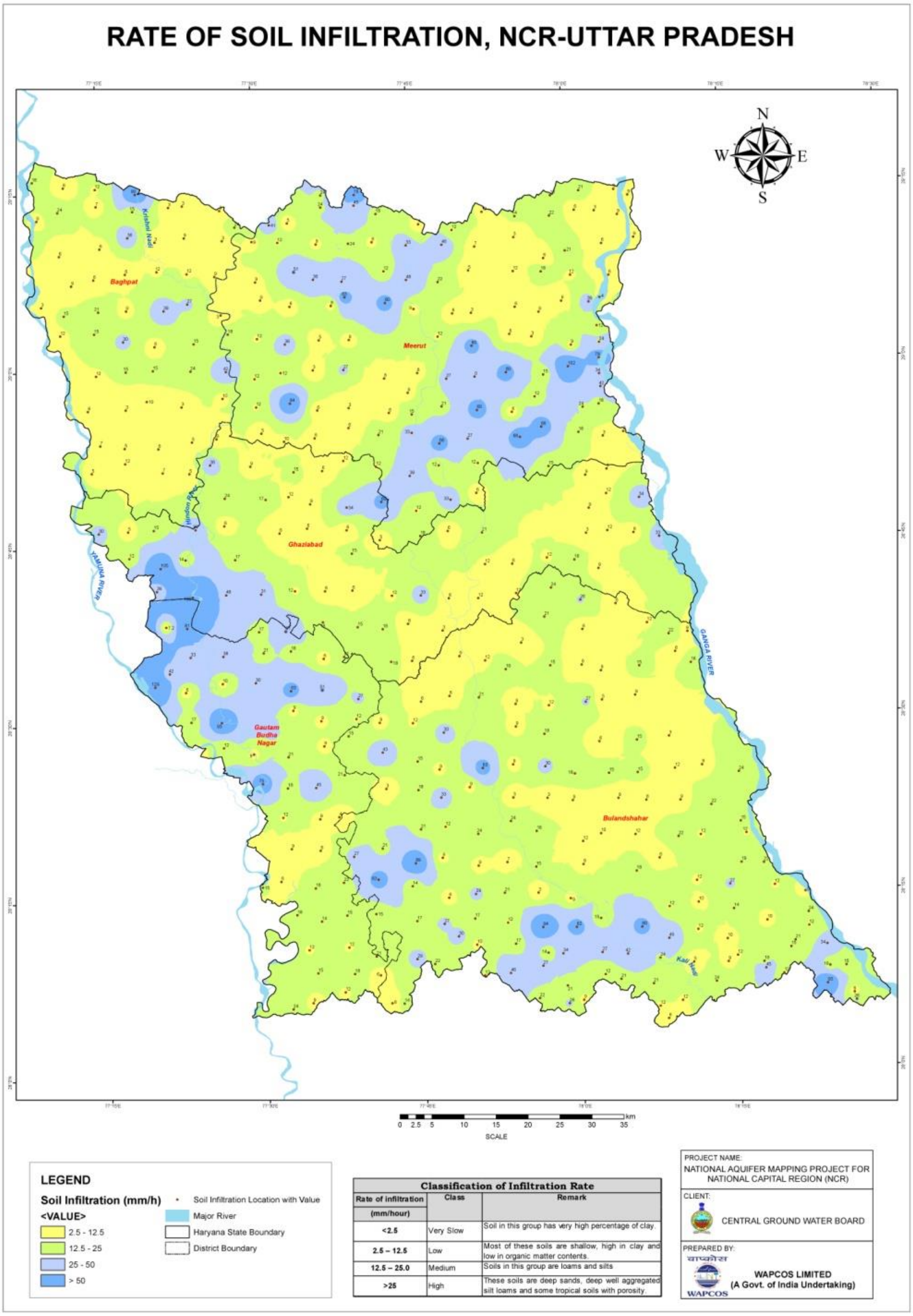
The initial infiltration rate in Ghaziabad district varies between 30 mm/hr to 450 mm/hr and the final infiltration rate varies between 3 mm/hr to 108 mm/hr. The average initial and final infiltration rate for the district is found to be 198 mm/hr and 19 mm/hr respectively. The average infiltration rate for the Ghaziabad district is estimated as 108 mm/hr.

3.4.6 :Gautam Budh Nagar District

Soil infiltration tests in the Gautam Budh Nagar district also shows wide variation in the infiltration rate.The initial infiltration rate in Gautam Budh Nagar district varies between 30 mm/hr to 390 mm/hr and the final infiltration rate varies between 4 mm/hr to 129 mm/hr. The average initial and final infiltration rate for the district is found to be 203.1 mm/hr and 24.6 mm/hr respectively. The average infiltration rate for the Gautam Budh Nagar district is estimated as 113.8 mm/hr.

3.4.7 : Bulandshahar District:

Wide variation in the infiltration rate has been observed in the entire district. The initial infiltration rate in Bulandshahr district varies between 60 mm/hr to 690 mm/hr and the final infiltration rate varies between 3 mm/hr to 94 mm/hr. The average initial and final infiltration rate for the district is found to be 253.9 mm/hr and 18.7 mm/hr respectively. The average infiltration rate for the Bulandshahr district is estimated as 136.3 mm/hr. The higher infiltration rates are observed at sites Baral, Sikandarabad, Badnaura, Gangraul, Salimpur, Pahargarhi, Bhaipur, Naw Nagla, Danwar, Dharampur and Jargwan indicating sandy nature of local soils.



Classification of Infiltration Rate

Rate of infiltration (mm/hour)	Class	Remark
<2.5	Very Slow	Soil in this group has very high percentage of clay.
2.5 – 12.5	Low	Most of these soils are shallow, high in clay and low in organic matter contents.
12.5 – 25.0	Medium	Soils in this group are loams and silts
>25	High	These soils are deep sands, deep well aggregated silt loams and some tropical soils with porosity.

Figure: 3.4 Soil Infiltration Rate in NCR, Uttar Pradesh

3.5 Hydrology and Drainage

The area is drained by the rivers Ganga, Yamuna, Hindon, Kali, Krishni and their tributaries. Besides, there are a number of drains such as Daula, Budhera, Tera, Kandhal etc. and small nalas have also developed at places, draining into these rivers. Major river and drainage system in the area have been shown above in the geomorphic Map (Figure: 3.1). The Ganga river system consists of the master river Ganga and a large number of its tributaries. This system drains a very large area comprising the middle part of the Himalayas in the north, the northern part of the Indian Plateau in the south and the Ganga Plain in-between. The total area of the Ganga basin in India is 861,404 sq km which accounts for 26.3 per cent of the geographical area of the country.

3.5.1 Ganga River

The total length of the Ganga River from its source to its mouth (measured along the Hugli) is 2525 km, of which 310 km in Uttaranchal, 1,140 km in Uttar Pradesh, 445 km in Bihar and 520 km in West Bengal. The remaining 110 km stretch of the Ganga forms the boundary between Uttar Pradesh and Bihar. The river flows majestically from Gangotri to Bay of Bengal with an average gradient of 9.5 cm per km. Ganga river forms eastern boundary of the district has well developed wide flood plain. The flow direction is from North to southeast. The elevation difference between upland and khadar varies from 5 to 7 metres. Along140 km stretch of the river entry point in the north is Hastinapur block, Meerut district and where it leaves Debai block, Bulandshahar district in the southeast.

3.5.2 Yamuna River

River Yamuna enters in Chhaprauli block, Baghpat District and leaves from G.B. Nagar district in the south, flowing almost parallel to River Ganga, i.e N-S. Forming the western boundary of the area, it flows in a wide sandy bed and has the tendency to change course from year to year. The river is perennial and effluent throughout the length of the area. Numerous islands occur along its course. The bank of the river is alternatively slopping and steep.

3.5.3 Kali Nadi

Dividing the area into two almost equal halves, Kali Nadi flows in a defined valley of its own, with narrow and well defined flood plains as also mentioned in the preceding section on geomorphology. It is an ephemeral river and is presently fed heavily by effluents of industrial waste. It flows in N-S direction and NW-SE direction in Bulandshahar district of the area.

3.5.4 Hindon Nadi

The river Hindon enters southeast of village Tavelagarhi in Binauli block and forms eastern boundary of the Baghpat and Meerut districts. It has well developed flood plains.

The banks are steep with ravines. In its lower reaches it almost flows through the flood plains of river Yamuna.

3.5.5 Krishni Nadi

It flows in a valley defined of its own with a tortuous course and narrow well defined flood plains.The river enters the area from northern side near village Asrara (Baghpat district) and after flowing for a short distance in the northeastern part, joins the Hindon river near village Lakha Mandap. It is an ephemeral river and like Kali, is also fed by effluents from industrial units.

CHAPTER-4

HYDROGEOLOGICAL FRAMEWORK

The study area is mainly occupied by thick alluvial deposit between river Ganga and Yamuna of different grades of sand, silt and clay. The ground water is the main source for irrigation, domestic and industrial purposes. Occurence of ground water is dependent on aquifer characheteristics and it lithological behaviour.

4.1 Geological Sequence

The area lies in the Ganga-Yamuna doab, which is a part of Central Ganga Plain on the eastern side (Ganga-Hindon Doab) and part of Marginal Alluvial Plain on the western side (Yamuna-Hindon Doab). The area is underlain by alluvial deposits of Quaternary age, deposited over Precambrian basement. Thickness of alluvium increases from west to east i.e from Yamuna River side towards Ganga River. General geological sequence based on various earlier studies by exploratory drilling by CGWB and other available literature is given in Table 4.1.

Table4.1: General Geological Succession in the NCR, UP.

Age (ma)	Formation		Lithology
Recent - 0.01 m.a.	Younger Alluvium	Neogene Sediments	Sand , clay
Holocene (0.01-1.0 m.a.)	Older Alluvium		Sand, clay, gravel &kankar
	-------Disconformity--------		
Pleistocene (1 m.a.)	Upper Siwalik		Conglomerate, sand stone & shale
Pliocene to Middle Miocene	Middle & Lower Siwalik		Shale & sand stone
	--------Unconformity------		
Precambrian Basement			

The geological map has been prepared on the basis of interpretation of georeferenced Resourcesat-2 and Cartosat-1 satellite imageries having 5.6m and 2.5m spatial resolution respectively, with value addition through limited field checks. The same is presented in Fig. 4.1.

Broadly, two distinct geological units can be seen in the map – **a)** Older Alluvium or Varanasi Alluvium underlying Younger Alluvial Plain or upland area, and **b)** Younger Alluvium underlying Younger Alluvial Plain, i.e the flood plains of rivers.

4.1.1 Older Alluvium

The older alluvium occupies the entire upland and inter fluvial area occurring between the major drainage ways i.e. Yamuna-Hindon and Hindon & Ganga. Soils are sandy, silty and clayey in varying proportions depending upon the local drainage characteristics. Two broad units are -

i. Sandy ridges and Sand Dunes: These occur close to drainage ways and correspond to Bhur (Local Usage). Isolated sandy ridges and sand dunes are indicative of changing drainage pattern.

ii. Central upland/interfluvial area (Older Alluvial Plain): Major unit of the area is dissected by drainage ways. Top sediments being clayey with minor sand and silt. Occurrence of alkaline soils is restricted to this unit only.

4.1.2 Younger Alluvium

Occurring close to drainage and corresponding to Bhur (Local Usage), the area is marked with presence of isolated sandy ridges and sand dunes, indicating changing drainage pattern. Younger alluvium exists along Ganga, Yamuna and Hindon rivers flood plain. Abandoned channels and sand dunes can also be seen in the flood plain of these rivers.

Flood plains can be further divided into two district units.

a. Active flood plain

b. Older flood plain

a. Active Flood Plain:

River channel and adjacent terraces (May be T0 & T1) subjected to periodic flooding consisting of sand, silt and silty and with clay pockets constitutes the active flood plain.

b. Older Flood Plain:

Flood plain and Ganga and Yamuna also locally known as Khadar constitutes older floods plains. This characterized by presence of fluvial land forms such as mender scares, cut and meanders and palaeo channels. The sediments are fine to medium grained sand silt with thin clay horizons. The zone is separated by from uplands/older alluvium by the occurrence of sharp break at places, discontinues natural levees, occurrence of sand dunes and abrupt change in slope.

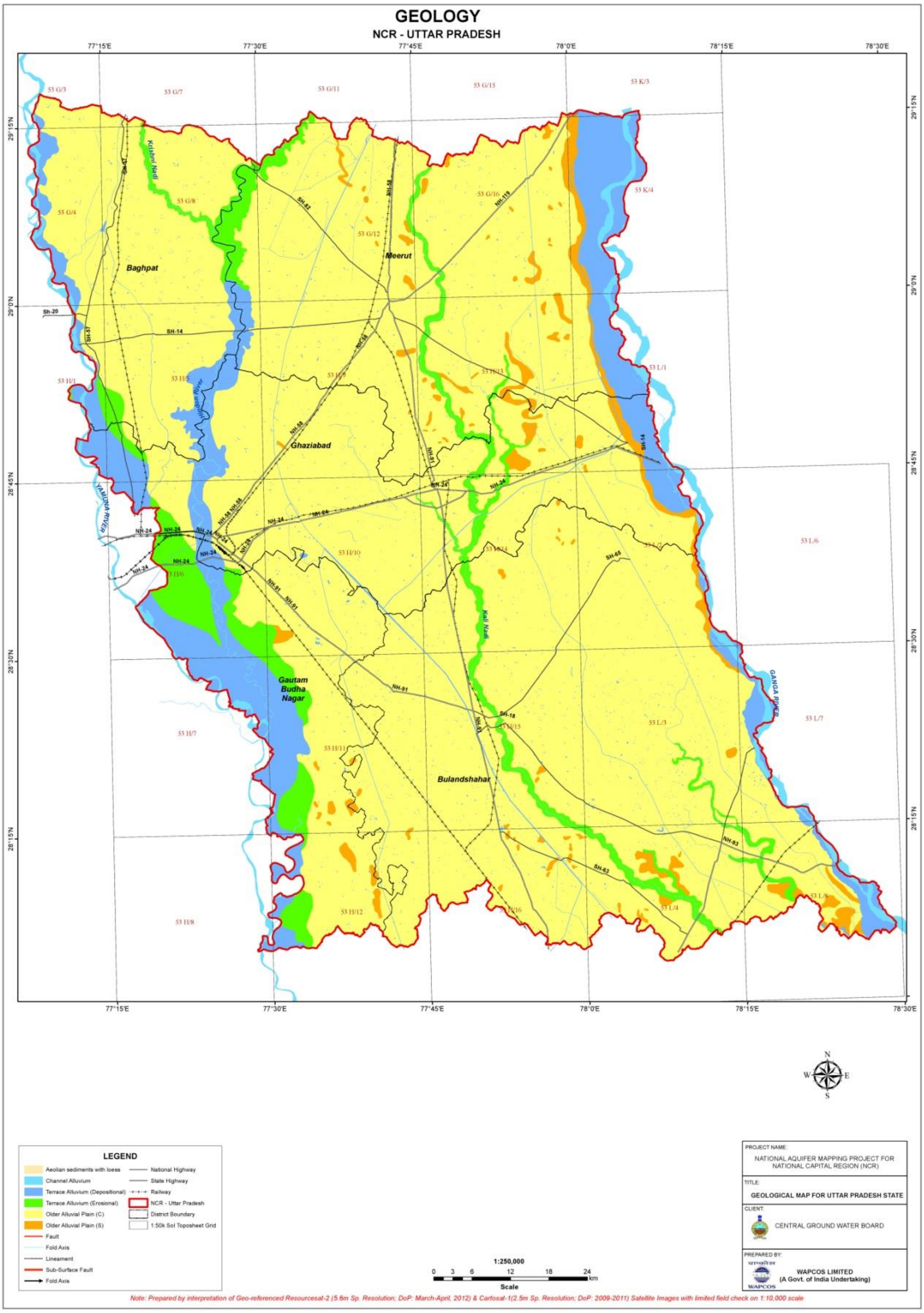


Figure 4.1: Geological Map of study Area NCR, UP

4.2 Hydrogeology

Under exploratory drilling programme, Central Ground Water Board has constructed 37 explratory wells in the five districts of NCR in shallow and deep aquifers in the past years. The exploratory drilling was done by CGWB down to maximum depth of 742 m. Under Hydrogeological Data Generation 40 Exploratory well, 39 Observation wells and 15 Slim Holes down to 450 mgl have been constructed/ drilled in the area. In general 3-tier aquifer system exists in the area where aquifer-IV is also encountered at some places. The granular zones in Aquifer Group–I are generally thick-bedded, very extensive and are consisting of comparatively coarser material than the deeper Aquifer Group – II, and III where these are thinly bedded sometimes lensoid in nature consisting of finer sediments with the domination of silty and clayey material. Quaternary alluvium attains significant thickness ranging up to 742 mbgl and more as per available data (Ganganagar Pz, Meerut district) and its interpretation. In the Hindon Yamuna doab, the thickness of quaternary alluvium/unconsolidated sediments varies from 306m (Tila Moth in north) to 115m (Brij Bihar in central and western part). Bed rock composed of Delhi quartzite has been encountered at different depths in Yamuna-Ganga doab at Pilkhua (530 mbgl), Chanchali (345 mbgl), Firojpur (399 mbgl), Halpura (398 mbgl), Laitfpur Tibra (398 mbgl) Sadhopur (310 mbgl), Shalimar Graden(320 mbgl), Ramprasth (106.53 mbgl), Panchariya (172 mgl), Radhakunj (202.50 mbgl), Loni (118.00 mbgl) In some instances quality of water has been found to be brackish to saline in deeper aquifers in the western parts revealed by the electrical log data. Sediments are more argillaceous below 50 m to 60 m.

4.2.1 Ground Water Exploration for Aquifer Mapping

Since a few of the Exploratory tube wells constructed in the area tapped multiple aquifer system, their aquifer parameters could not be utilized fruitfully for the purpose of aquifer mapping. However under the National Aquifer Mapping & Management Programme (NAQUIM) aquifer wise tube wells were constructed. The exploratory boreholes were drilled down to 450 mbgl or depth to basement and tube wells construction depth was as per aquifer group tapped. District-wise and aquifer wise numbers of Exploratory wells, Observation wells, Slim Holes drilled for data generation are in Table 4.2& Figure 4.2.

Table 4.2: Number of Exploratory wells, Piezometer for Aquifer Mapping in NCR, UP

District	Existing(CGWB)			Data Generation(WAPCOS)		
	EW	Pz	SH	EW	OW	SH
Baghapt	7	1	-	6	5	3
Meerut	12	7	-	8	8	4
Ghaziabad	12	12	-	6	6	3
Bulandsahar	6	3	-	17	17	1
G.B. Nagar	0	5	3	3	3	4
Total	**37**	**28**	**3**	**40**	**39**	**15**

The details of exploratory wells constructed during project period in study are by are given in Annexure-4.1 & Annexure 4.2 (Vol. -II)

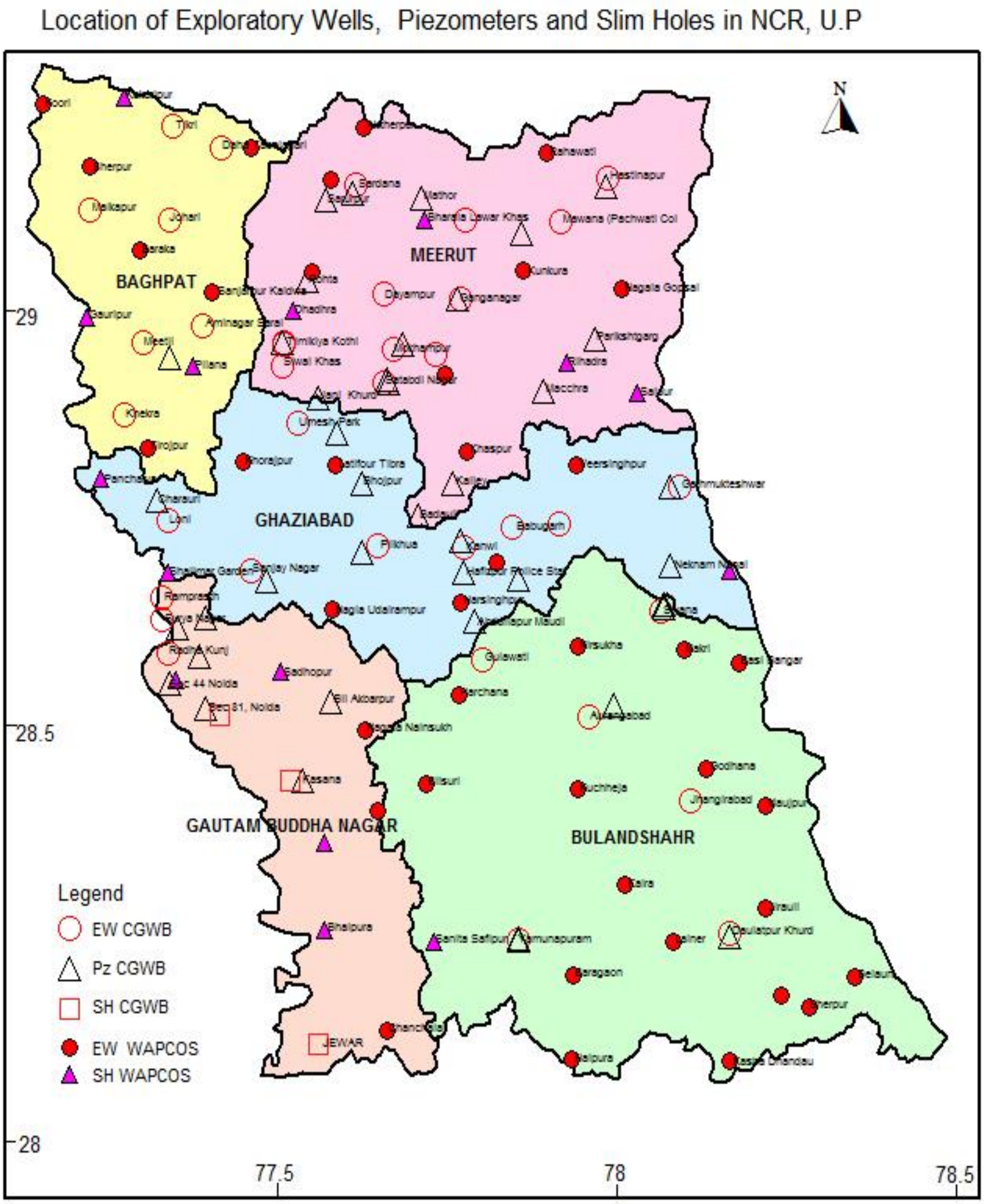


Figure 4.2: Location Map of Exploratory Drilling for Aquifer Mapping, NCR, UP

4.3 Geophysical Investigations (VES and Borehole Logging)

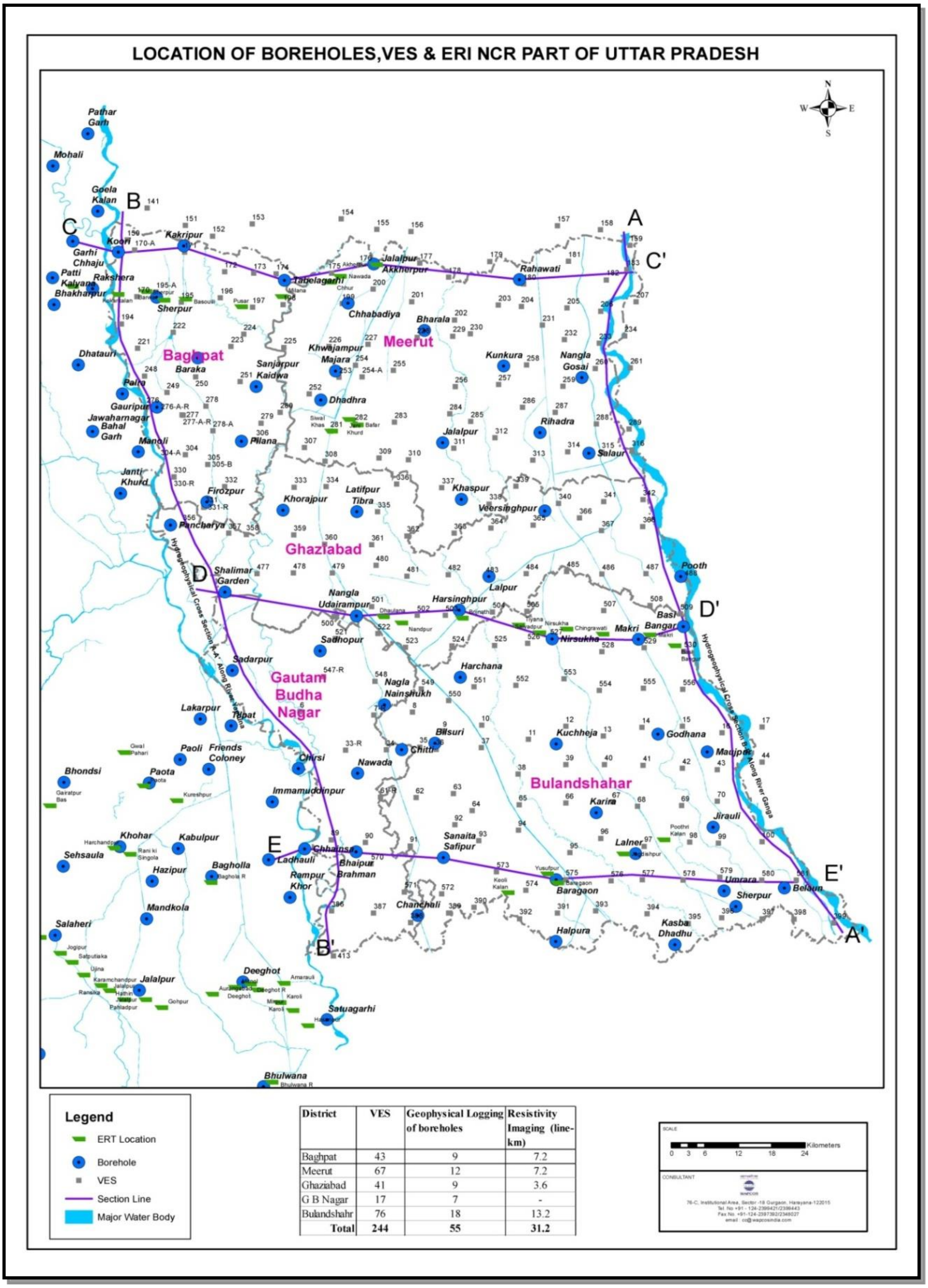
All the Exploratory wells and Slim Holes were geophysical logged for identification of aquifer and clay horizons. Exploratory drilling with geophysical logging amply aided and supplemented by Vertical Electrical Soundings (VES)/ Resistivity Imaging has provided insight into subsurface disposition of aquifer zones and their characteristics. The district wise VES and 2-D Imaging carried in NCR,U.P is shown in Table-4.3.

Table 4.3: District wise VES and 2-D Imaging carried out in NCR, U.P

District	**VES**	**Resistivity Imaging (Line Km)**
Baghapt	43	8.2
Meerut	67	8.2
Ghaziabad	41	3.6
Bulandsahar	17	-
G.B. Nagar	76	13.2
Total	**244**	**31.2**

In addition to the data generation, processing, interpretation and hydrogeological transformation of the data was carried out for preparing aquifer maps and related utility maps. In this endeavour, existing secondary data obtained from CGWB has also been utilized wherever required.

The borehole geophysical log validated interpreted layer parameters obtained from deep VES have been quite useful in deciphering subsurface hydrogeological conditions and mapping the aquifer dispositions up to a maximum depth of 300 m. The state-of-the-art resistivity imaging technique applied selectively has unravelled the subsurface hydrogeological complexities and the lateral continuity of aquifers up to a depth of 240 m. The aquifer maps prepared on the basis of assessments carried out on 7 km x 7 km grid and the results of boreholes present a generalized picture of the sub-surface required for conceptualization and aquifer development and management plans.However, getting on exact information would require point-specific measurements. Location of Boreholes, VES & ERI in NCR, UP is shown in Fig-4.3



District	VES	Geophysical Logging of boreholes	Resistivity Imaging (line-km)
Baghpat	43	9	7.2
Meerut	67	12	7.2
Ghaziabad	41	9	3.6
G B Nagar	17	7	-
Bulandshahr	76	18	13.2
Total	244	55	31.2

Figure 4.3: VES and Borehole Locations, NCR, UP

a) Qualitative Analysis of Resistivity Data from VES

In order to have preliminary idea of depth-wise variation in granularity in terms of resistivity values, maps have been prepared through the interpreted results of VES. Since the inferences drawn from VES for depths beyond 250 m is qualitative, these maps have been prepared only upto 250 m depth (Fig. 4.4a, b, c, d & e). A significant outcome of these maps is the revelation of general spatial distribution of aquifer in different depth ranges. A striking feature is the signature of an east-west trending high resistivity zone at depths beyond 150m (Fig. 4.4d & e) in the central part, falling mostly within Ghaziabad district. This east-west trending high resistivity zone can be interpreted as a sand predominating zone, interestingly collinear with the trend of the 'Moradabad fault'.

A total of 244 nos Vertical Electrical Soundings (VES) on a 7 km x 7 km grid were conducted. In addition to already existing 35 wells, 40 Nos of EW/OW and 15 nos of Slim Holes down to 450 meter depth were constructed in the area. A total of 13.2 Line km Resistivity Imaging (ERI) was also carried out. The work was aimed at demarcating aquifer geometry of different aquifer systems existing in the area in a detailed manner and ascertaining their properties. and shown in Fig. 4.2b (Borehole locations) and 4.4 (Boreholes &VES).

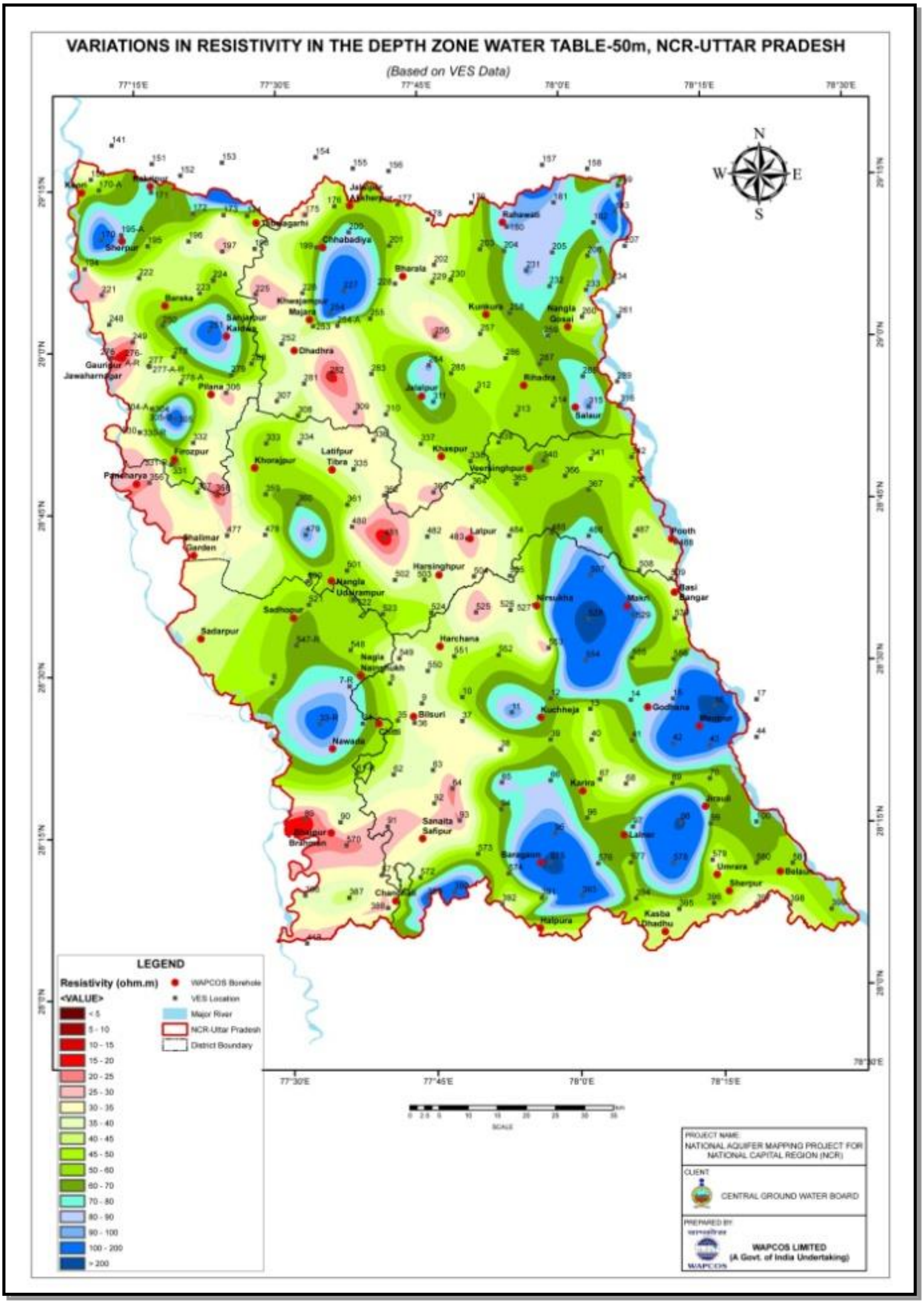


Figure 4.4a: Resistivity Variation in the Depth Zone **WT-50**

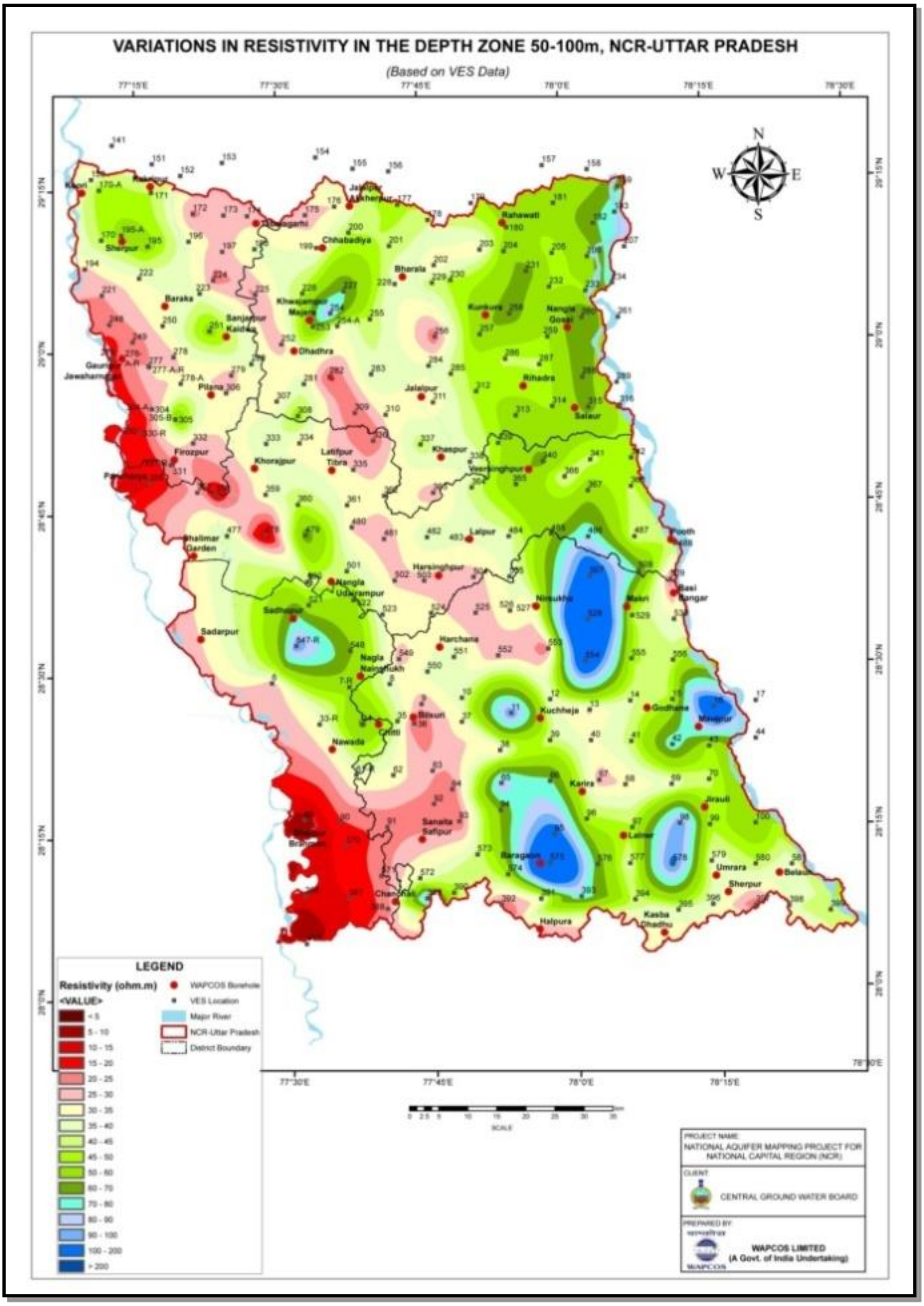


Figure 4.4b: Resistivity Variation in the Depth Zone **100-150**

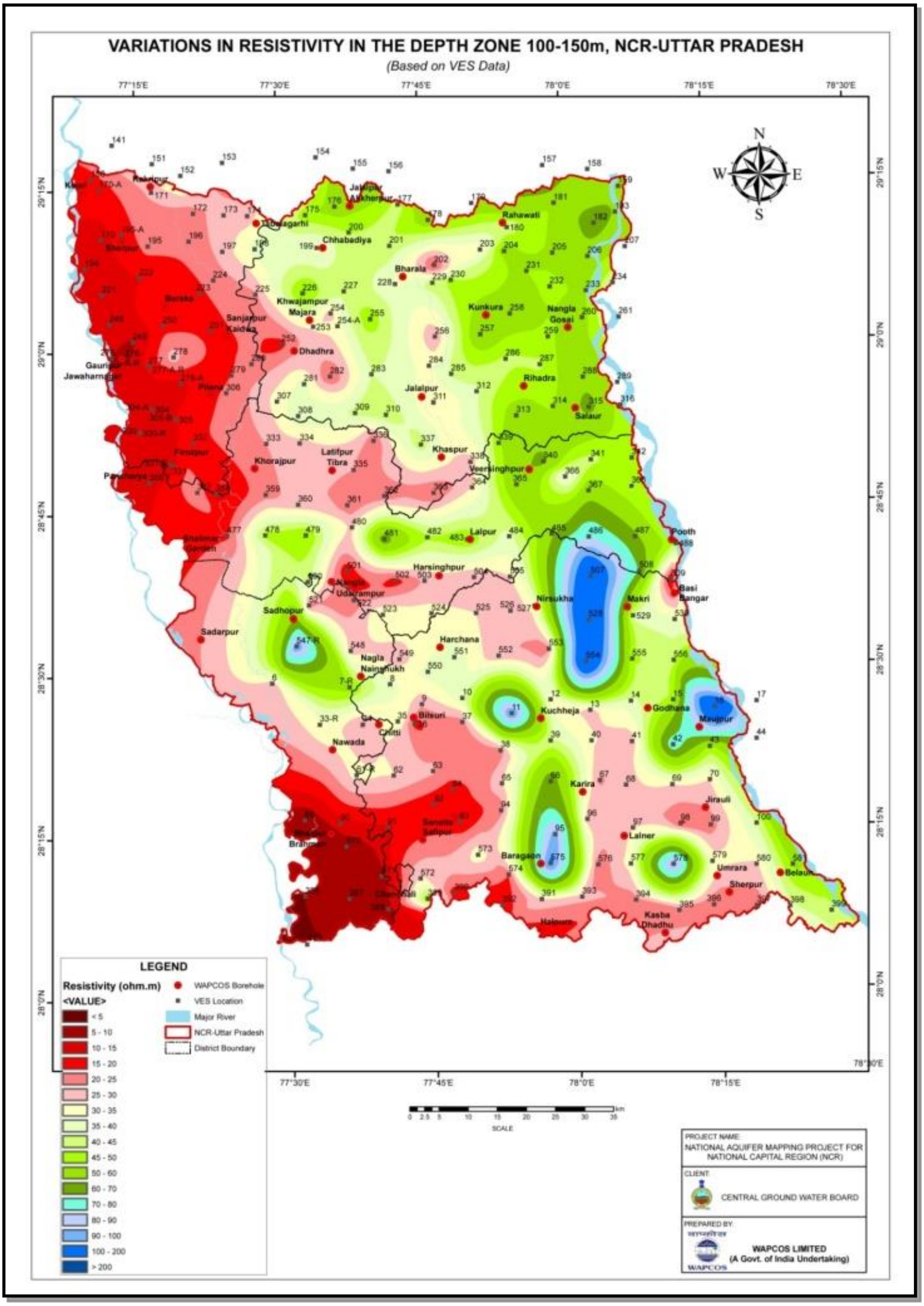


Figure 4.4c: Resistivity Variation in the Depth Zone **50-100**

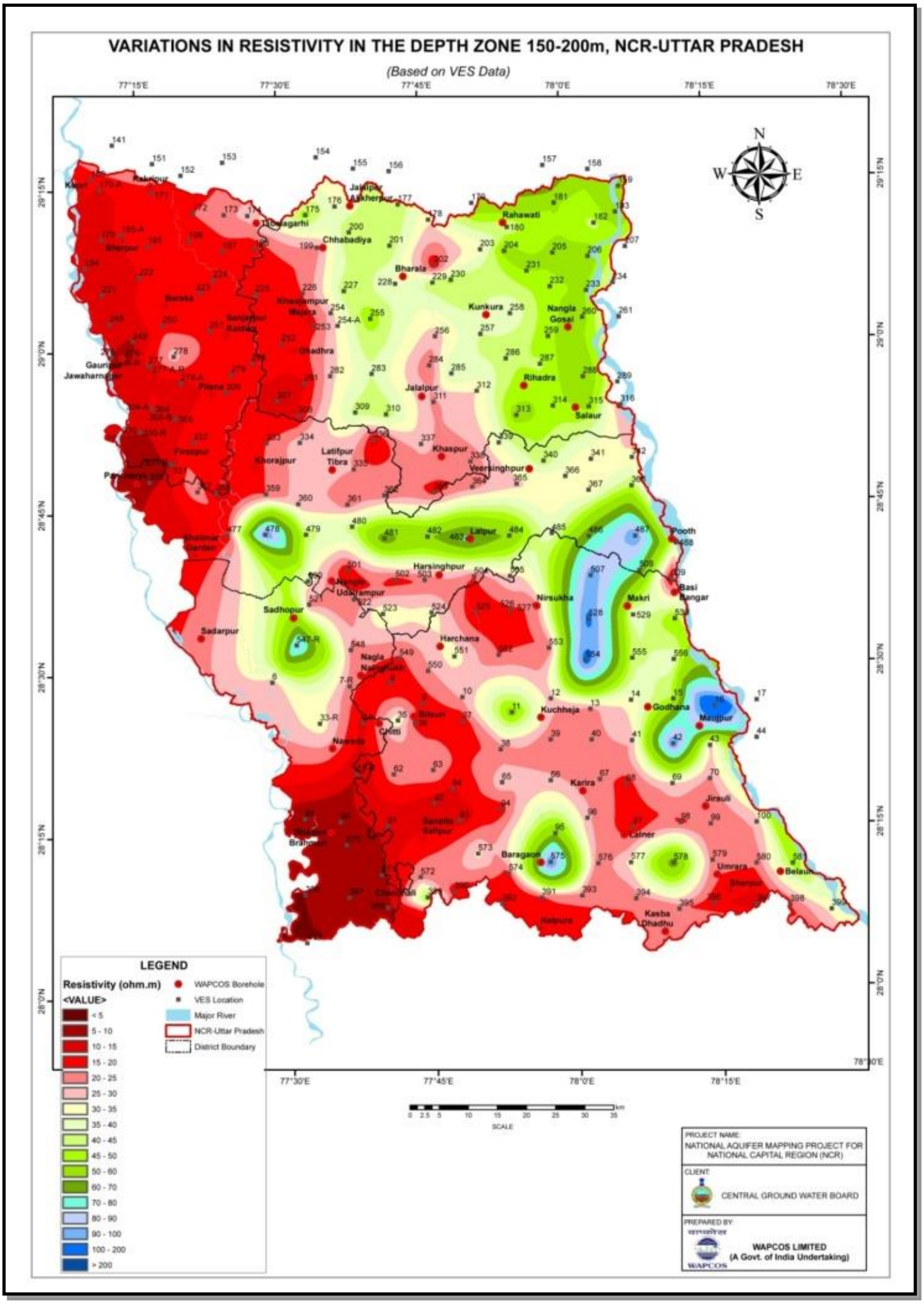


Figure 4.4d: Resistivity Variation in the Depth Zone 150-200; Note the presence of High Resistivity band in central part

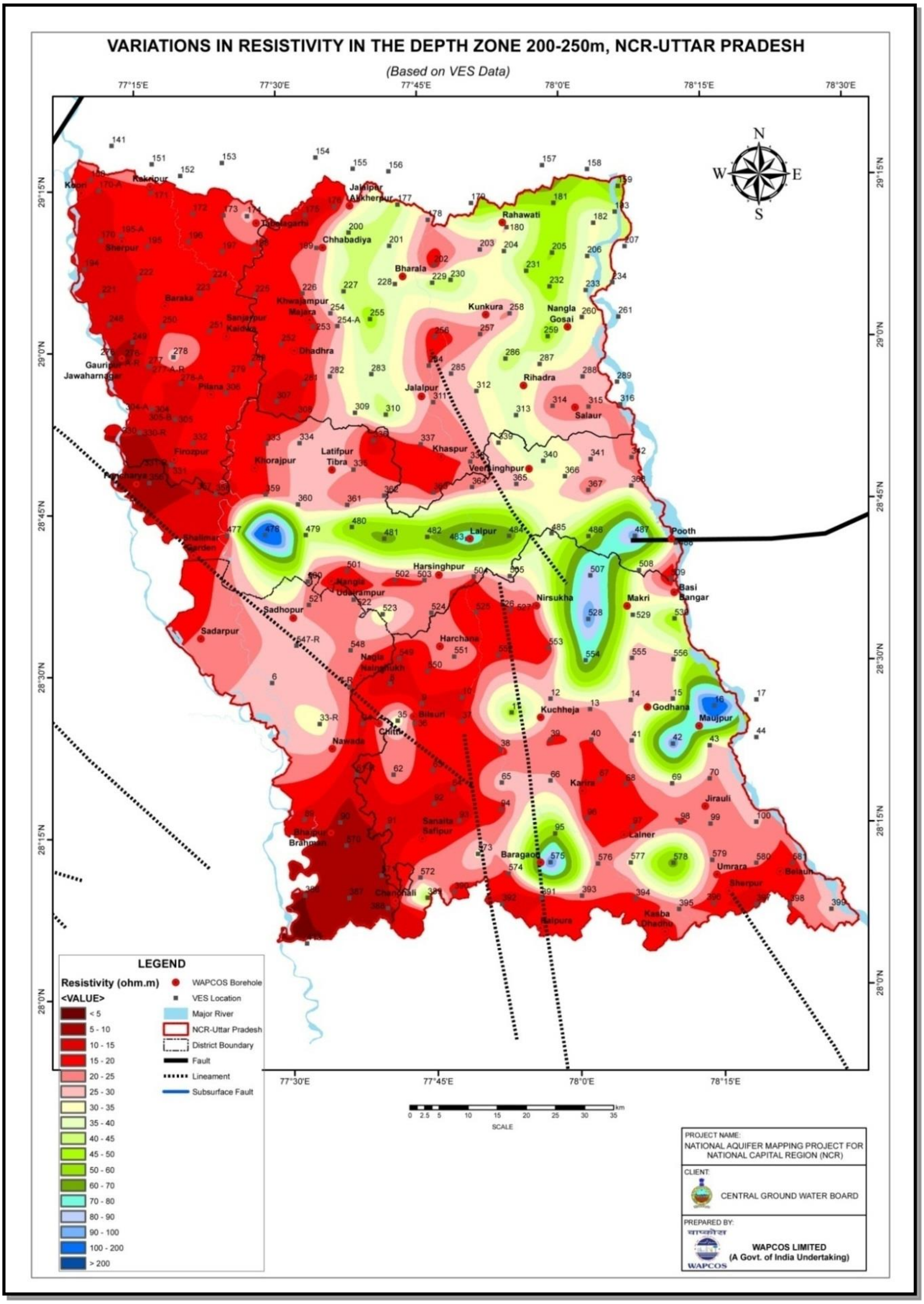


Figure 4.4f: Resistivity Variation in the Depth Zone **200-250**; Note the presence of High Resistivity band in central part

b) Generalized Lithological Cross Sections & 3-D Schematic Presentation of Layers

Resistivity Variation Combining the VES results and borehole information, generalised lithological cross-sections have been prepared along section lines shown in Fig. 4.3.The two N-S along the courses of rivers Ganga (A-A')and Yamuna (B-B') reveal the flood plain aquifers and constitute the flood plain aquifer mapping (Fig. 4.5).

The eastern most N-S cross-section along river Ganga reveals thick column of sand predominating layers in the upper part. The resistivity of the sand column ranging from 34-73 ohm-m, averaging around 50ohm-m indicates predominance of medium- to coarse-grained sands.This sand zone continues upto an average depth of around 200m, with gradual increase in thickness towards north. At most of the places, the sand column is capped by a 10 to 50 m thick layer associated with still higher resistivity values of the order of 100 to 300 ohm.m. This near-surface highly resistive layer holds medium to coarser sands and forms the unsaturated zone or, at some places, partially saturated. Beyond 200m depth exists thick layer having average resistivity of around 25 ohm.m. The layer is formed of relatively finer sand, which may possibly be inter-bedded with thin clay layers as indicated by resistivity values ranging from16 to 30Ohm.m. The lower limit of the range indicates predominance of finer sediments and presence of clays. That is, this layer also holds aquifers but not as prominent as in the upper 200m.

Compared to the cross-section (A-A'), the other N-S cross-section (B-B') in the western-most part along river Yamuna appears more intricate with large lateral variations in litho-facies, possibly due to structural/ tectonic control. Also, there is a general reduction in resistivity along this cross-section. The resistivity of the sand column varies from 23 to 50 ohm.m and the average value is around 30 ohm.m, indicating presence of fine sands with more frequently interspersed clay layers. The thickness of this sand column is about 100 m. In this part again, the fine- grained sand column is capped by a layer with higher resistivity's at places and in general underlain by a thick layer with resistivity values less than 20 ohm.m. It reduces to 4-9 ohm.m in the southern part indicating deterioration in water quality. This entire column of alluvium rests over the quartzite bed rock, which could be delineated at several VES points as high resistivity bottom-most layer. The characteristics features of cross section (B-B') are the undulating bed rock topography and at places absence of bed rock within the depth investigated. Besides, thickening of the sediments towards north is also observed. Interestingly, deterioration in water quality, as well as occurrence of bed rock at shallower depths is abrupt and coincide with each other.
The E-W cross-sections C-C', D-D' and E-E' (Fig. 4.6 a, b & c) reveal gradual increase in clay or finer content from east to west. Thus, towards Ganga, there is predominance of coarse or medium-grained sand, whereas towards Yamuna, the sediments become clay predominant.

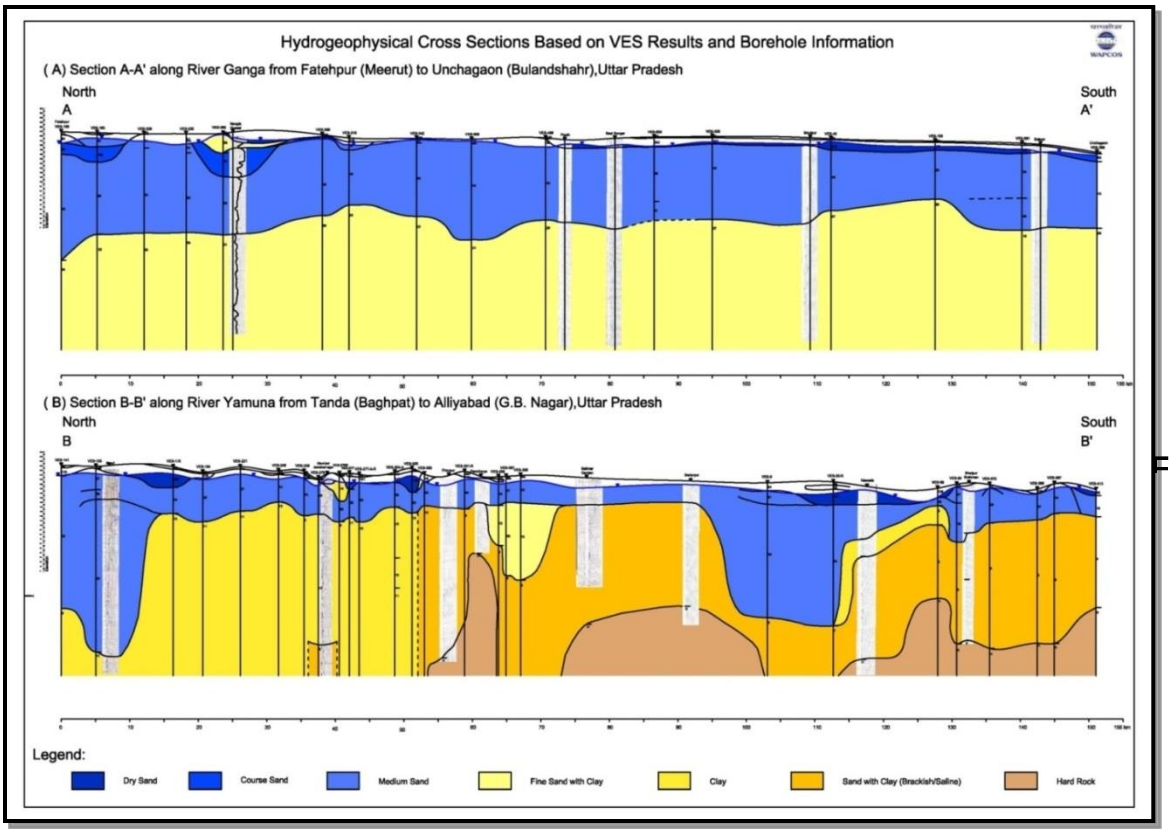


Figure 4.5: Lithological sections along river Ganga and Yamuna based on VES and borehole logs

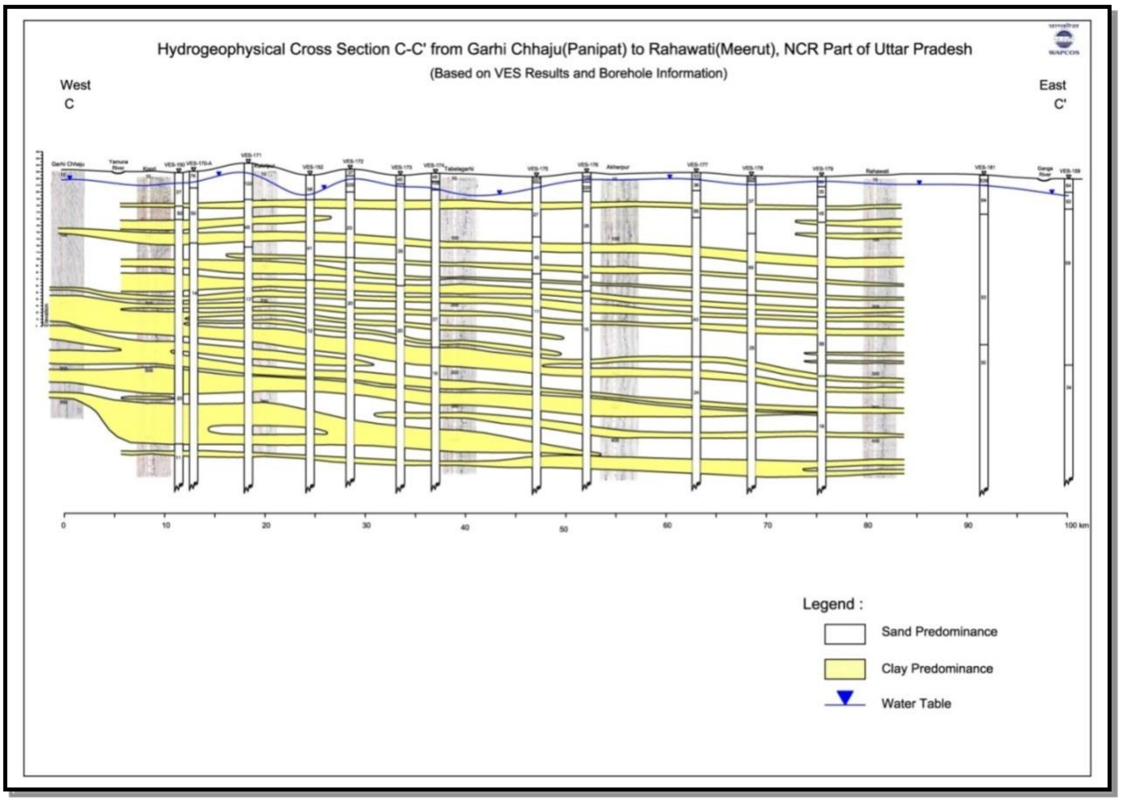


Figure 4.6a: Lithological sections C-C' based on VES and borehole logs

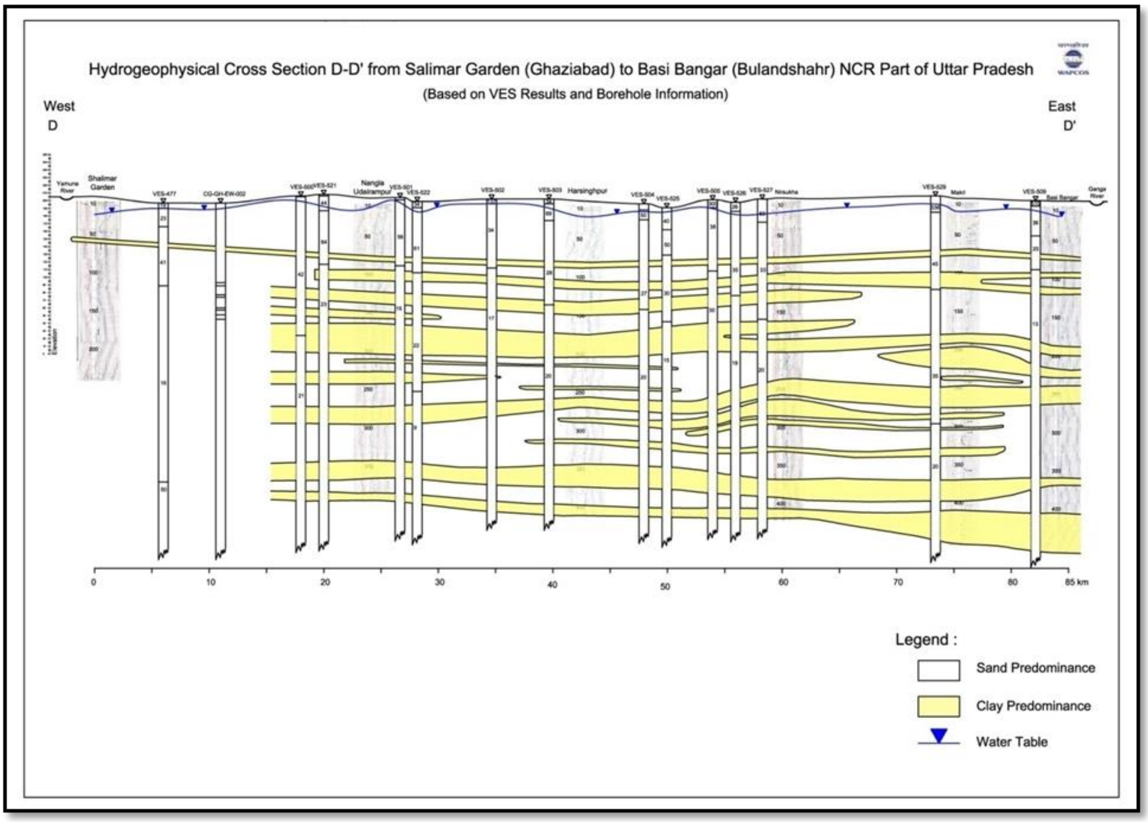


Figure 4.6b: Lithological sections D-D' based on VES and borehole logs

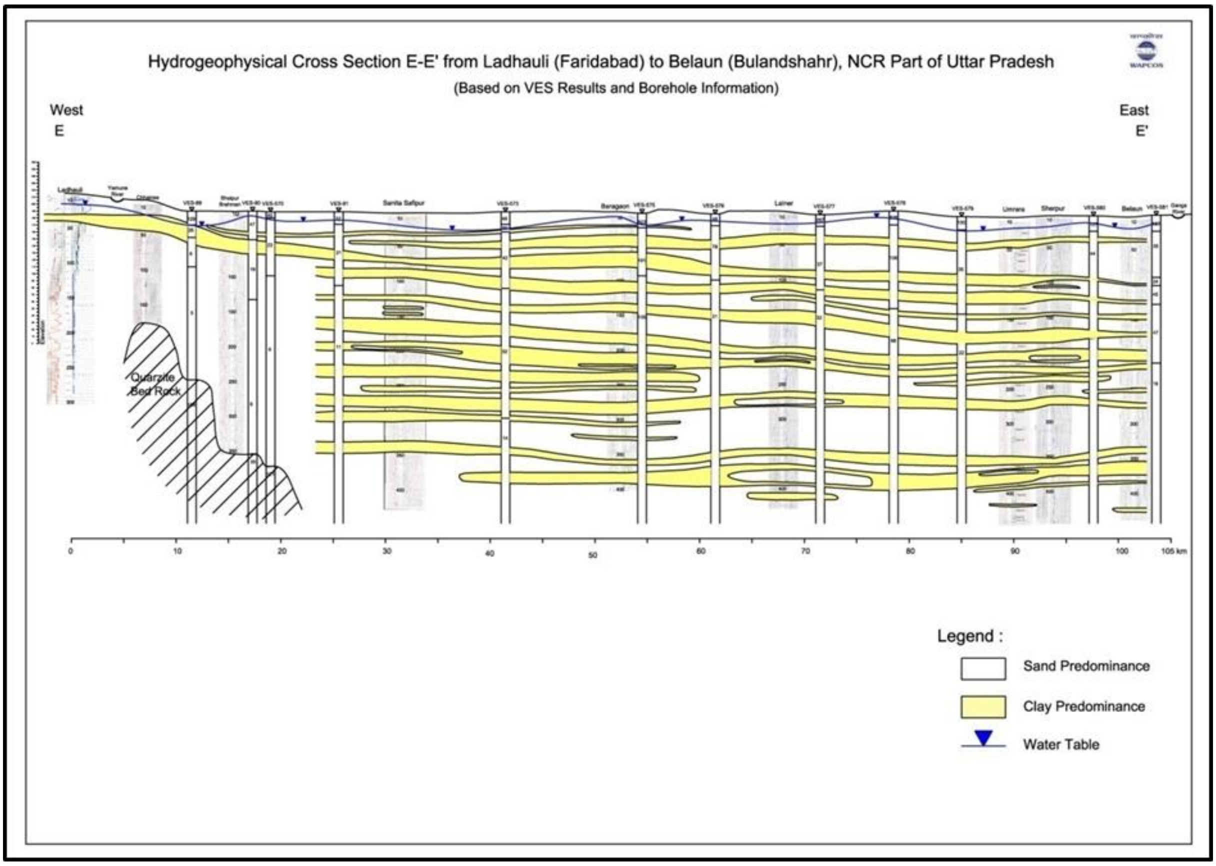


Figure 4.6c: Lithological sections E-E' based on VES and borehole logs

A 3-D schematic presentation of layers having different resistivity values, interpreted in terms of sand, clay and saline water has also been prepared on the basis of bore hole logging results (Fig. 4.6 d). The diagram provides a broad synoptic view of subsurface disposition of various layers.

4.4 Ground water Dynamics-

In order to decipher the ground water regime, the water level data of a total of 40 National Hydrograph Stations of CGWB has been utilized. These structures tap the phreatic aquifer up to 50 m. bgl depth range under unconfined condition. However the deeper aquifers occur under semiconfined to confined conditions. Water table elevation map has been prepared using the pre monsoon depth to water level data with respect to the reduced level of G.L. This map indicates that the general flow of ground water is southerly.

4.4.1 Depth to water Level

In order to decipher the occurrence and variation of water level in shallow aquifer, depth to water level map for the pre- monsoon period of 2013 has been prepared Fig 4.7 (a). The pre-monsoon depth to water level as depicted in the map is highly variable over the NCR area. The surface water irrigation network has great influence over the depth to water level in the area. Along the Ganga canal in the area and in whole of the Bulandshahar district shallow depth to water levels between 5 and 10 mbgl is observed. Along Ganga River in the area in the northern part, depth to water level ranges from 10-20 mbgl and 5-10 mbgl in the southern part (Bulandshahar district). All along Yamuna river in the area deeper depth to water levels between greater than 20 m bgl in northern part (Baghpat district) and 10 and 20 mbgl is observed in southern part of the area and in remaining part of the area viz. north-central part (Meerut district) depth to water level ranges from 10-20 mbgl. Depth to water less than 5 mbgl is observed in a few localized patches in Ghaziabad district. A perusal of the water level record reveals that that the minimum and the maximum water level during the pre-monsoon season is observed from Dhaulana Pz, district Ghaziabad at 3.73 mbgl and 26.75 m bgl from Pilana Pz, Baghpat district. (Annexure 4.3- Vol-II).

The post-monsoon depth to water level as depicted in the map Fig: 4.7(b) shows that in middle part of the NCR area, predominantly shallow depth to water levels between 5 and 10 mbgl are observed excluding the northern area in southern part of Meerut district where deeper depth to water levels between 10 and 20 mbgl is observed. Along Ganga River in the area in the northern part, depth to water level ranges from 10-20 mbgl and 5-10 mbgl in the southern part of the area remaining the same as that in pre monsoon period. All along Yamuna river in the area deeper depth to water levels between greater than 20 m bgl in northern part (Baghpat district) and 10 and 20 mbgl is observed in southern part of the area Depth to water between 2-5 mbgl& less than 2 mbgl is observed in a few localised patches in Ghaziabad & Bulandshahar district. Depth to water level during the post-monsoon period varies from 1.65 at Dhaulana Pz, district Ghaziabad to 25.30 mbgl at Pilana Pz, Baghpat district. (Annexure 4.3- Vol-II)

4.4.2 Water Level Fluctuation:

The depth to water fluctuates in response to rainfall, recharge, discharge and formation characteristic. In the NCR area water level fluctuation between pre and post monsoon period in the year 2013 ranges from -1.27m (Sector 62 Pz, Gataum Budha Nagar district) to 2.04 m (Azad Nagar Pz, Ghaziabad district). The perusal of the water level fluctuation data shows that almost whole of the area shows positive water level fluctuation ranging from 0.0 to 2.0 m Table 4.4 (a)

The Existing data in Baghpat district shows water level fluctuation 1.45 m. In Gautam Budha Nagar district water level fluctuation ranges from -1.27 m to 1.95 m. In Bulandshahar district water level fluctuation ranges from 0.10 m to 1.66 m. In Ghaziabad district water level fluctuation ranges from 0.30 m to 2.04 m. In Meerut district water level fluctuation ranges from 0.04 m to 1.77 m (Annexure 4.3-Vol-II)

4.4.3 Depth to Water Level (Decadal)

The mean of depth to water level from 2004 to 2013 and its fluctuation with respect to 2013, pre monsoon depth to water level has been presented in **Table- 4.4 (c).**The data shows that in almost all the district of the area water level fluctuation is towards the negative side with respect to mean water level. This indicates the cumulative effect of increase in draft and decrease in rainfall recharge on ground water regime of the area(Annexure 4.4-Vol-II).

4.4.4 Hydrograph Analysis:

As per water level trend of period (2004-2013) shows declining trend in most of the area. In Baghpat district Pilana Pizometer shows pre-monsoon decline of 1.4 m/year whereas in post monsoon period is 0.57m/year. In Bulandshahar district Pre-monsoon period decline varies from 0.08 to 0.41 m/year whereas in post-monsoon period from 0.05 to 0.46m/year. In Ghaziabad district Pre-monsoon period decline varies from 0.03 to 0.62 m/year whereas in post-monsoon period from 0.02 to 0.58 m/year. In Meerut district Pre-monsoon period decline varies from 0.21 to 0.70 m/year whereas in post-monsoon period from 0.01 to 0.83 m/year. In Gataum Budha Nagar district Pre-monsoon period decline varies from 0.22 to 1.50 m/year. District wise graphic representation of Hydograph Analysis and water level trend have been represented in (Annexure 4.6-Vol-II)**.**

4.4.5 Ground Water Flow:

The water Table elevation map, Fig.4.7(c) for phreatic aquifer has been prepared keeping the contour interval 10meter. The water table elevation in the area varies from 230 mamsl to 150 mamsl. The perusal of the map shows that the water table elevation follows the topography of the area and ground water flow direction is from NW to SE and broadly following major drainage lines. Steep gentle water table is observedin Baghpat district and western part of Meerut district. Ground water gradient is gentle in Southern part in Ghazaibad, Bulandshahar and Gautam Budha Nagar district.

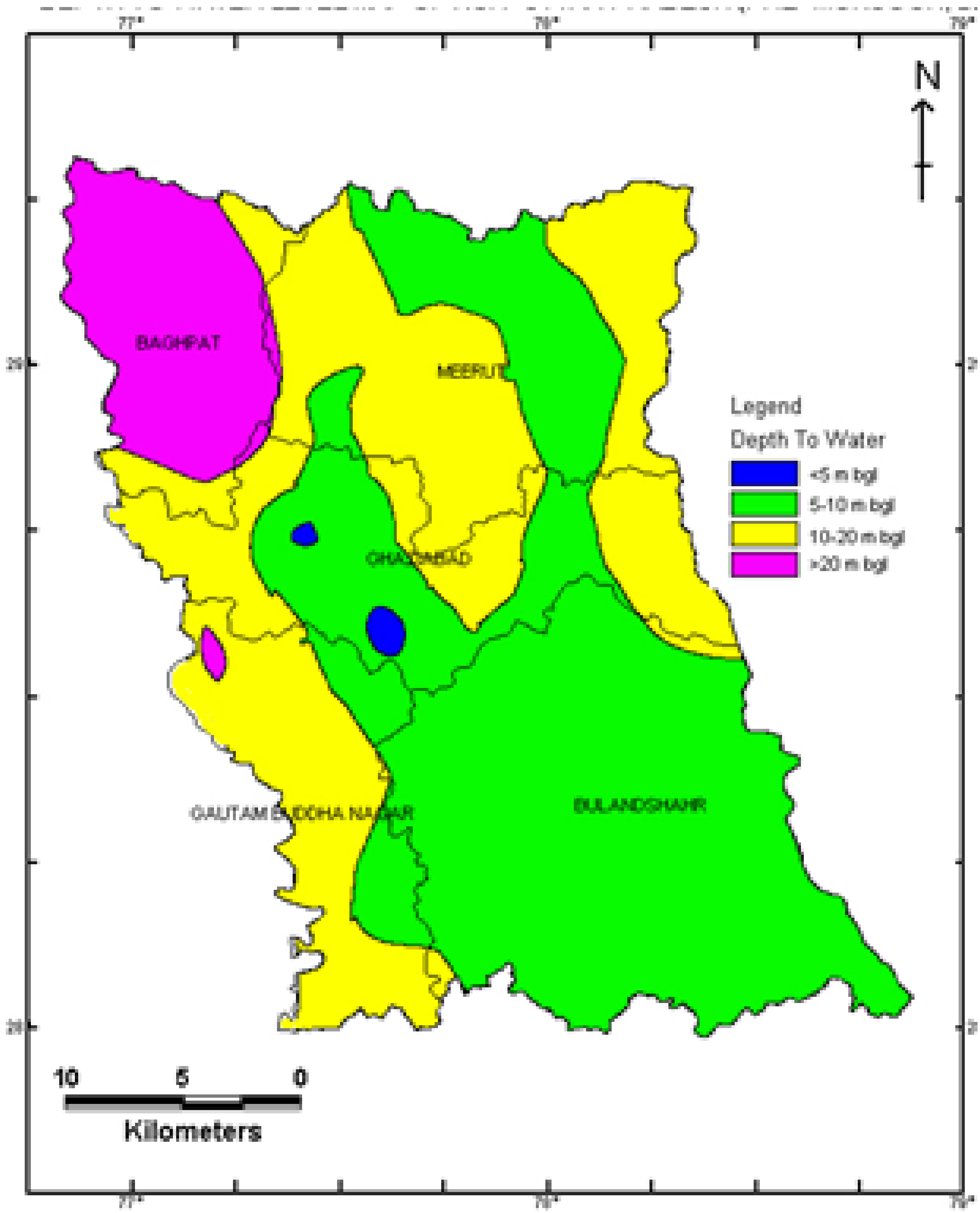


Figure: 4.7 (a): Depth to water level map of pre-monsoon (2013)

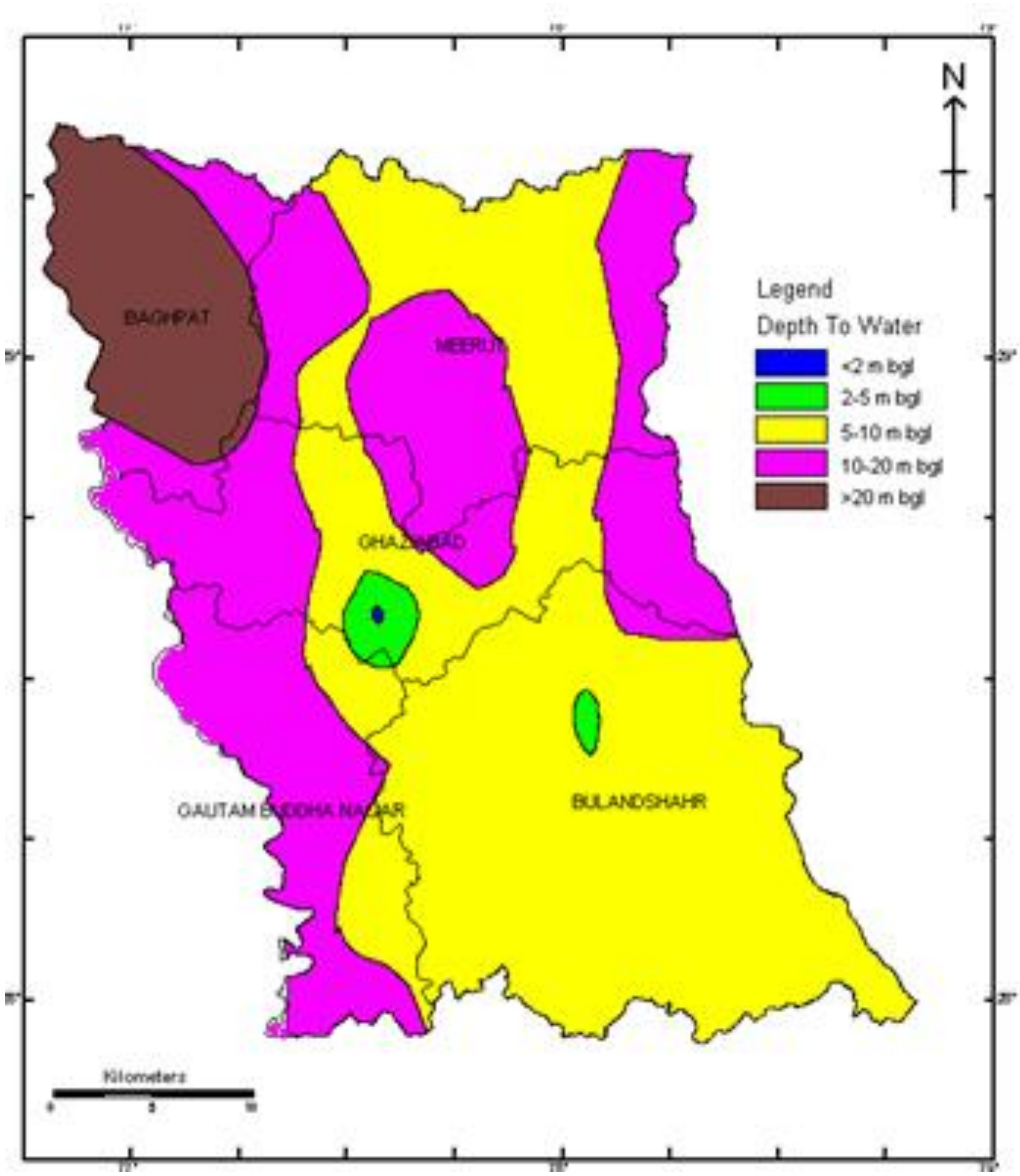


Figure: 4.7 (b): Depth to water level map of post-monsoon (2013)

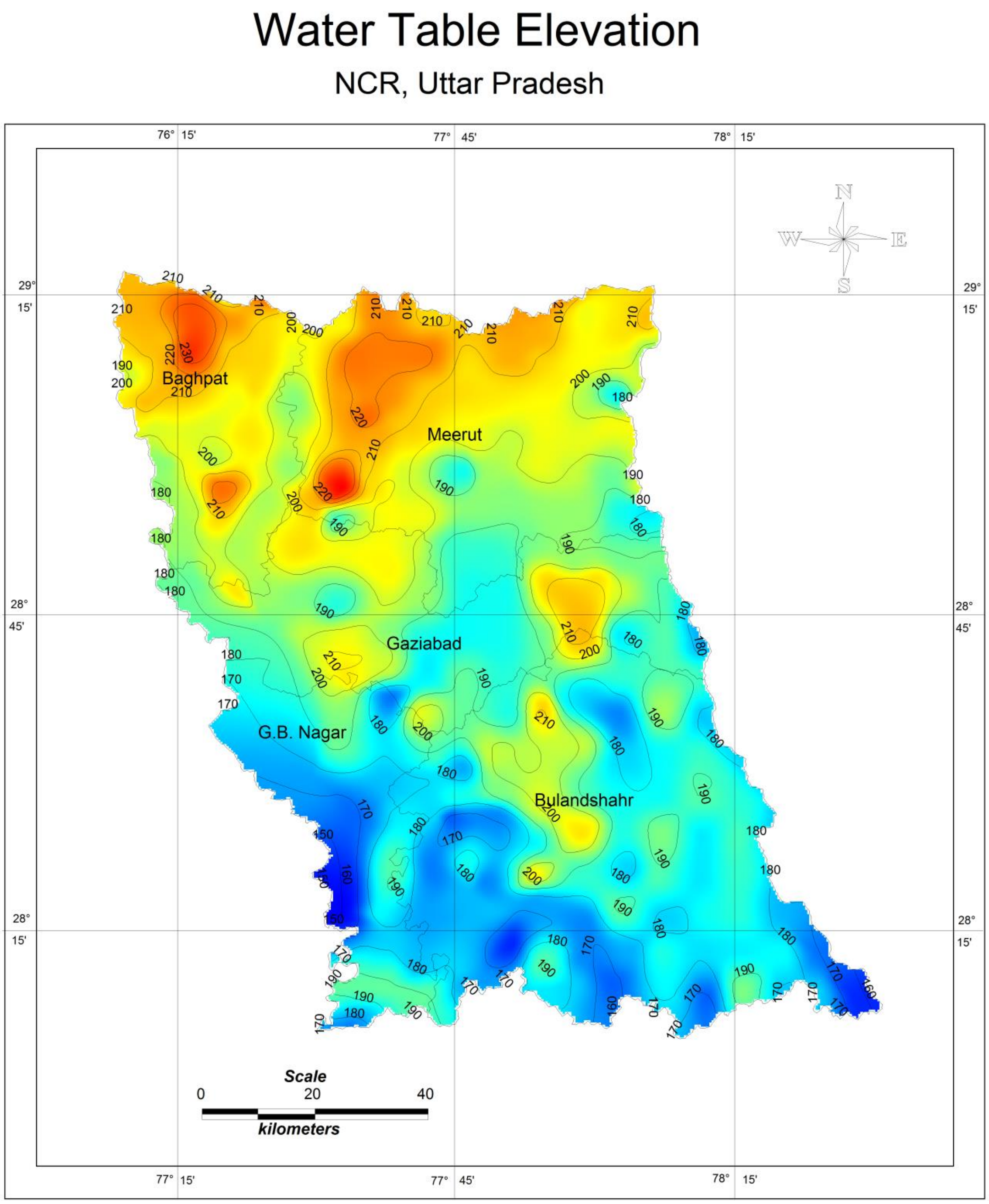


Figure: 4.7 (C) Water Table Elevation Map study area (Pre_monsoon 2013)

CHAPTER-5
WATER QUALITY

Chemical composition of ground water is one of the prime factors on which the suitability of the water for domestic, industrial and agriculture depends. In this chapter, an attempt has been made to interpret the chemical analysis data generated by WAPCOS and data of C.G.W.B.during 2013-14 in Aquifer Mapping Programme, NCR, Uttar Pradesh.

5.1 Basic and Heavy Metal Analysis

Summary of Chemical analysis data of ground water samples collected from study area for basic and heavy metal analysis is given in Table 5.1and Table 5.2 and discussed below-

5.1.1 Baghpat district

A perusal of Table-5.1 shows that concentration of Total Hardness in most ground water samples was found to be within the permissible limit of 600 mg/l as per BIS, 2012. However, its concentration was found to be more than the acceptable limit of 200 mg/l as per BIS, 2012 but less than 600mg/l in 73% of the samples and ranges from 209mg/l to 592 mg/l.

Fluoride concentration was found to be high (above the permissible Limit of 1.5 mg/l as per BIS, 2012) in 13% samples. Maximum concentration of Fluoride was found to be 4.35 mg/l at Saidbhar sampling site. Nitrate concentration was found to be high (above the permissible Limit of 45 mg/l as per BIS, 2012) only at Daha (58.6mg/l) and Baghpat rural (170.9mg/l) sampling sites.

Heavy metal analysis results revealed that Iron concentration above the permissible limit of 300 µg/l as per BIS 2012 has been found in 84% of the samples with a maximum value of 3656.8 µg/l at TilwaraSakoon sampling site. Manganese concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in 4% samples with a maximium value of 678.3 µg/l. Chromium concentration was found to be more than 50 µg/l at Palra and Khekra (rural) sampling sites. Arsenic concentration was found to be within the permissible limit (50 µg/l) as per BIS-2012.

5.1.2 Meerut district

A perusal of Table 5.1 shows that concentration of Total Hardness in most ground water samples was found to be within the permissible limit of 600 mg/l as per BIS, 2012. However, its concentration was found to be more than the acceptable limit of 200 mg/l as per BIS, 2012 but less than 600mg/l in 84% of the samples and ranges from 201mg/l to 598 mg/l.

Fluoride concentration was found to be high (above the permissible Limit of 1.5 mg/l as per BIS, 2012) in nearly 2% samples. Maximum concentration of Fluoride was found to be 3.92 mg/l. Nitrate concentration was found to be high (above the permissible Limit of 45 mg/l as per BIS, 2012) in nearly 22% samples.

Heavy metal analysis results revealed that Iron concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in 94% of the samples. Manganese concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in nearly 8% samples. Arsenic and Chromium concentration was found to be within the permissible limit as per BIS-2012.(table 5.1(b))

5.1.3 Bulandshahar

A perusal of Table 5.1 shows that concentration of Total Hardness in most ground water samples was found to be within the permissible limit of 600 mg/l as per BIS, 2012. However, its concentration was found to be more than the acceptable limit of 200 mg/l as per BIS, 2012 but less than 600mg/l in 52% of the samples and ranges from 201mg/l to 595 mg/l.

Fluoride concentration was found to be high (above the permissible Limit of 1.5 mg/l as per BIS, 2012) in nearly 6% samples and it ranges from 1.51 mg/l to 3.49 mg/l. Nitrate concentration was found to be high (above the permissible Limit of 45 mg/l as per BIS, 2012) in 10% samples.

Heavy metal analysis results revealed that Iron concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in 66% of the samples. Manganese concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in nearly 2% samples. Chromium concentration was found to be above the permissible limit as per BIS-2012 in nearly 5% samples.. Arsenic concentration was found to be within the permissible limit as per BIS-2012.

5.1.4 Ghaziabad

Total Hardness in most ground water samples was found to be within the permissible limit of 600 mg/l as per BIS, 2012. However, its concentration was found to be more than the acceptable limit of 200 mg/l as per BIS, 2012 but less than 600mg/l in 44% of the samples and ranges from 203mg/l to 595 mg/l. Only at Wajheelpur sampling site, its concentration was found to be more than 600 mg/l.

Fluoride concentration was found to be high (above the permissible Limit of 1.5 mg/l as per BIS, 2012) in nearly 7% samples and it ranges from 1.55 mg/l to 3.06 mg/l. Nitrate concentration was found to be high (above the permissible Limit of 45 mg/l as per BIS, 2012) in nearly 8% samples.

Heavy metal analysis results revealed that Iron concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in 52% of the samples. Manganese concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found only at Gadawali and Wajheelpur sampling sites. Chromium concentration was found to be within the permissible limit as per BIS-2012. Arsenic concentration was found to be more than the permissible limit as per BIS-2012 at Rampur Nyamatpur sampling site and its value was found to be 75.09 µg/l.

5.1.5 G. B. Nagar

Total Hardness in most ground water samples was found to be within the permissible limit of 600 mg/l as per BIS, 2012. However, its concentration was found to be more than the acceptable limit of 200 mg/l as per BIS, 2012 but less than 600mg/l in 57% of the samples and ranges from 207mg/l to 596 mg/l.

Fluoride concentration was found to be high (above the permissible Limit of 1.5 mg/l as per BIS, 2012) in nearly12% samples and it ranges from 1.54 mg/l to 6.64 mg/l. Nitrate concentration was found to be high (above the permissible Limit of 45 mg/l as per BIS, 2012) in nearly 9% samples.

Heavy metal analysis results revealed that Iron concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in 86% of the samples. Manganese concentration above the permissible limit of 300 µg/l as per BIS, 2012 has been found in 6% of the samples.. Chromium concentration was found to be within the permissible limit as per BIS-2012. Arsenic concentration was found to be more than the permissible limit as per BIS-2012 at Munjkhera sampling site and its value was found to be 55. 83 µg/l.

Table 5.1 : Summary of Chemical Analysis results for basic parameters (Data Source-WAPCOS Report, 2014)

Districts	No. of Samples	Electrical Conductivity			Total Hardness			Fluoride			Nitrate		
		Range µSiemens/cm at 25°C	No. of samples above 3000 µSiemens/cm at 25°C	Range above 3000 µSiemens/cm at 25°C	RRange (mg/l)	No. of samples above 600 mg/l	Range above 600 mg/l	Range (mg/l)	No. of samples above 1.5 mg/l	Range above 1.5 mg/l	Range (mg/l)	No. of samples above 45 mg/l	Range above 45 mg/l
Bulandshahar	299	210-2950	nil	nil	92-749	3	615-749	0.0-3.49	17	1.51-3.49	0.0-316.6	30	45.9-316.6
Meerut	164	209-2536	nil	nil	73-1266	10	603-1266	0.03-3.92	4	1.61-3.92	0.1-68	37	45.2-68
Ghaziabad	126	229-2446	nil	nil	43-603	\1	603	0.01-3.06	9	1.55-3.06	0.02-78.72	10	45.58-78.72
Baghpat	105	426-3278	1	3278	86-1064	8	605-1064	0.17-4.35	14	1.51-4.35	0.1-170.9	2	58.6-170.9
G.B.Nagar	67	250-6360	3	3110-6360	62-1076	5	667-1076	0.02-6.64	8	1.54-6.64	0.00-246.6	6	45.1-246.6

Permissible Limit : F-1.5 mg/l ,NO_3-45 mg/l,Total Hardness-600mg/l (BIS 2012)

Table 5.2 : Summary of Chemical Analysis results for Heavy Metals/As (Data Source-WAPCOS Report, 2014)

Districts	No. of Samples	Iron			Manganese			Chromium			Arsenic		
		Range (µg/l)	**No. of samples above 300 µg/l**	**Range above 300 µg/l**	**Range (µg/l)**	**No. of samples above300 µg/l**	**Range above 300 µg/l**	**Range (µg/l)**	**No. of samples above 50 µg/l**	**Range above 50 µg/l**	**Range (µg/l)**	**No. of samples above 50 µg/l**	**Range above 50µg/l**
Bulandshahar	299	38.1-2429	196	301.4-2429	0.2-815.5	5	302.1-815.5	0-110.66	14	50.04-110.66	0.09-12.82	nil	nil
Meerut	164	156.1-1261.7	155	305.8-1261.7	0.3-1173.9	14	313-1173.9	0.02-34.7	nil	nil	0.1-16.53	nil	nil
Ghaziabad	126	58.8-1003.7	65	301.3-1003.7	0.2-708.4	2	624.3-708.4	0.02-34.81	nil	nil	0.03-75.09	1	75.09
Baghpat	105	94.1-3656.8	88	306.9-3656.8	0.3-678.3	4	335.8-678.3	0.02-89.33	2	55.78-89.33	0.06-4.31	nil	nil
G.B.Nagar	67	109.6-3012.5	58	304.7-3012.5	4.7-1231.5	6	309-1231.5	0.06-12.13	nil	nil	0.15-55.83	1	55.83

Max.Permissible Limit : Fe-300µg/l, Mn-300 µg/l, Cr-50 µg/l, As-50 µg/l. (BIS 2012)

5.2 Total Dissolved Solids (TDS)

TDS is numerical sum of all mineral constituents dissolved in water and is expressed in mg/l.It has been made to interpret the chemical analysis data of Total Dissolved Solids (TDS). An attempt has also been made to interpret the TDS of ground water based on the Electrical Conductivity data of the samples of Study area.

The values of Total Dissolved Solid (TDS) in Baghpat district exceeded IS-10500 (2012) desirable drinking water limit (500 mg/l) in 82% of the total samples. However, it is well below the maximum permissible limit of 2000 mg/l, except in one groundwater sample at Sarikod sampling site (2163mg/l).In 66% of the samples of Meerut district, it exceeded the desirable limit (500 mg/l) of IS-10500 (2012) in whereas it is below the maximum permissible level in all the analysed groundwater samples of the district. The maximum value of TDS is reported as 1674mg/l. In Ghaziabad district 66% of the samples exceeds the drinking water desirable level (500 mg/l) of IS-10500 (2012) , while it is below the maximum permissible level (2000 mg/l) in all the 126 analysed groundwater samples of the district. In G.B Nagar 72% of the samples exceed the desirable limit and above the permissible level (2000 mg/l) in three groundwater samples at Mursudpur (4563 mg/l), Thora (2128 mg/l) and ChhatangaKhurd (2695 mg/l).In Bulandshahar district 52 % sample exceed the desirable limit and below the maximum permissible in all the analysed samples. The maximum value of TDS was reported as 1947 mg/l.

The TDS of the most of analyzed water samples of study area fall in the category of fresh water 20% samples in Baghpat district, 7% samples at Meerut district, 7% samples at Ghaziabad district and 7% samples at Bulandshahar district whereas 22% samples at G. B. Nagar district fall in brackish water category that is TDS was found to be greater than 1000 mg/l. The maximum value of TDS was 4563 mg/l at Mursudpur in G.B.Nagar district. None of the sample falls in the saline water category with TDS >10,000.

5.3 Bacteriological Quality of Drinking Water

The presence of coliform bacteria in water is an indicator of contamination by human or from animal excrement. The presence of faecal coliform in groundwater indicates a potential public health problem. The groundwater contamination from faecal coliform bacteria is generally caused by water percolation into the aquifer from a contamination source like domestic sewage, drains and septic tanks etc. Inadequate maintenance of wells and unhygienic condition around the water sources may be the major cause for bacteriological contamination. Shallow wells are particularly susceptible for such contamination. Immediate investigative action shall be taken if either E. Coli or total coliform bacteria are detected as per IS 10500:2012.

In Baghpat district out of twelve groundwater samples presence of total coliform in four groundwater samples from Dharaura Tikri, Dharaura Silver Nagar, Noorpur Muzbida ,Baghpat Rural (shall not be detectable in any 100 ml sample as per IS 10500: 2012) and absence of faecal coliform in all the analysed samples. The results are presented in (Annexure: 5.1- Vol-II).The bacteriological test carried out in twenty groundwater samples of Meerut district shows presence of total coliform in six groundwater samples and faecal coliform in three samples. The results are presented in Annexure 5.2- Vol-II. In Ghaziabad district presence of total coliform in four groundwater samples and faecal coliform in two samples. The results are presented in Annexure 5.3- Vol-II..In Gautam Budh Nagar district shows presence of total coliform in three groundwater samples and faecal coliform in two samples. The results are presented in Annexure 5.4(vol-II) .Out of seventeen groundwater samples of Bulandshahr district shows presence of total coliform in three groundwater samples and faecal coliform in one samples collected from Kuversi village Hand Pumps (HP). The results are presented in Annexure 5.5 (Vol -II).

5.4 Pesticide Residues Analysis

The groundwater samples were analysed for organo-chlorinated pesticides like α-HCH, β-HCH, δ-HCH, γ-HCH (Lindane), DDT (o,p-DDE, p,p-DDE, o,p-DDD, p,p-DDD, o,p-DDT and p,p-DDT), Dieldrine, α-endosulfan, β- endosulfan as well as organo-phosphorous pesticides like Methyl Parathion, Malathion, and Chlorpyriphos. The results of pesticides analysis of groundwater samples of study area are discussed below-

5.4.1 Baghpat District

The results of pesticide residues analysis of five groundwater samples of Baghpat district are presented in Annexure 5.6 (Vol-II).

In general, the organo phosphorous pesticide contaminations in groundwater samples have been found absent or below the permissible levels. TheconcentrationsofMethyl Parathion and Chloropyriphosrange from 0.07 µg/l to 0.09 µg/l and 0.38 µg/l to 12.4 µg/lrespectively. The observed values are found much below the permissible levels for drinking water. Malathion concentration is negligible in the analysed samples. The short life of organo-phosphorous pesticides and its easy degradability along with limited application of these pesticides may be the factors for absence of these pesticides in the groundwater of the study are (Annexure 5.6- Vol-II).

5.4.2 Meerut District

The results of pesticide residues analysis of twelve groundwater samples of Meerut district are presented in Annexure 5.7- Vol-II.

The presence of organo chlorinated pesticides have been observed in all the analysed samples. Concentration of γ-HCH (Lindane) is ranging from 2.82 to 4.34 µg/l and exceeded the permissible level of 2.0 µg/l in all the analysed samples of Meerut district. It is also observed that all the isomers of DDT are present in the samples except o,p-DDE.The total DDT is found below the permissible limit (1.0 µg/l) in the analysed groundwater samples except one sample of Nimka Viran. The α-Endosulfan is predominant over the β-Endosulfan in the study area. The concentration of total Endosulfan residue in the analysed samples ranges between 1.49 µg/l and 2.42 µg/l and it exceeded the permissible limit of 0.4 µg/l. The concentration of Dieldrin ranges from 2.59 µg/l to 14.96 µg/l and found abnormally higher than the permissible limit (0.03 µg/l) at all the monitored sites of Meerut district.

Groundwater of the Meerut district is also contaminated with organo-phosphorous pesticides like Methyl Parathion, Malathion and Chlorpyriphos**.** The concentration of Malathion are found within the prescribed limit, while Methyl Parathion concentration marginally exceeds the prescribed limit (0.30 µg/l) in three groundwater samples. Chloropyriphos concentration ranges from 25.48 µg/l to 41.50 µg/l in the analysed twelve groundwater sample of the area and it exceeds the IS-10500 (2012) drinking water permissible limit (30 µg/l) in six groundwater samples.

5.4.3 Ghaziabad District

The results of pesticide residues analysis of eight groundwater samples of Ghaziabad district are presented in Annexure 5.8- Vol-II.

Presence of organo chlorinated pesticides has been observed in all the analysed samples. The concentration level of isomers of HCH (α-HCH, β-HCH and δ-HCH) is ranging from 0.06 to 0.10 µg/l and found higher than the permissible level of 0.04 µg/l. Concentration of γ-HCH (Lindane) is ranging from 0.78 to 3.31 µg/l and it exceeded the permissible level of 2.0 µg/l in four out of eight analysed samples of Ghaziabad district. Except o,p-DDE, all the other isomers of DDT are present in the groundwater samples of the area. The contamination level of p,p-DDE is relatively higher than the other isomers. Total DDT concentration ranged from 0.75 to 0.92 µg/l and is found below the permissible limit (1.0 µg/l) in the analysed groundwater samples. The α-Endosulfan is predominant over the β-Endosulfan in the study area. Concentration of total Endosulfan residue in the analysed samples ranges between 0.78 µg/l and 1.76 µg/l and it exceeded the permissible limit of 0.4 µg/l in all the analysed samples. The concentration of Dieldrin ranges from 2.05 µg/lto 13.53 µg/l and found abnormally higher than the permissible limit (0.03 µg/l) at all the monitored sites of Ghaziabad district.

Groundwater of the Ghaziabad district is also contaminated with organo-phosphorous pesticides like Methyl Parathion, Malathion and Chlorpyriphos**.** Concentration of Malathion (0.41 – 4.45 µg/l) is found within the prescribed limit of 190 µg/l. Methyl Parathion concentration ranged from 0.11 to 0.78 µg/l and it exceeds the prescribed limit (0.30 µg/l) in five groundwater samples. Chloropyriphos concentration ranged from 25.65 µg/l to 34.09 µg/l in the analysed eight groundwater sample of the area. Chloropyriphos concentration slightly exceeded the IS-10500 (2012) drinking water permissible limit (30 µg/l)in six groundwater samples. (Annexure 5.8 -Vol-II).

5.4.4 G. B. Nagar District

The results of pesticide residues analysis of eight groundwater samples of GautamBudh Nagar district are presented in Annexure 5.9- Vol-II.

The presence of organ chlorinated pesticides has been observed in all the analysed samples. The concentration level of isomers of HCH (α-HCH, β-HCH and δ-HCH) is ranging from 0.04 µg/l to 0.10 µg/l and found higher than the permissible limits. Concentration of γ-HCH (Lindane) is ranging from 2.00 to 3.91 µg/l and exceeded the permissible level of 2.0 µg/l in almost all the analysed samples of GautamBudh Nagar district. It is also observed that all the isomers of DDT are present in the samples except o,p-DDE.The contamination level of p,p-DDE is relatively higher than the other isomers. The total DDT is found below the permissible limit (1.0 µg/l) in the analysed samples. The α-Endosulfan is predominant over the β-Endosulfan in the study area. The concentration total Endosulfan residue in the analysed samples ranges between 0.93 µg/l and 2.08 µg/l and it exceeded the permissible limit of 0.4 µg/l. The concentration of Dieldrin ranges from 5.2 µg/l to 12.25 µg/l and found higher than the permissible limit (0.03 µg/l) at all the monitored sites of GautamBudh Nagar district.

Groundwater of the GautamBudhNagar district is also contaminated with organo-phosphorous pesticides like Methyl Parathion, Malathion and Chlorpyriphos**.** TheconcentratiosofMethyl Parathion ranges from 0.10 µg/l to 0.33 µg/l and Malathion from 0.23 µg/l to 0.63 µg/l. Malathion and Methyl Parathion concentrations are found within the prescribed limits. Chloropyriphos concentration varies from 14.81 µg/l to 32.67 µg/l in the analysed ten groundwater samples of the area and it marginally exceeds the IS-10500 (2012) drinking water permissible limit (30 µg/l) in two samples.

5.4.5 Bulandshahar District

The results of pesticide residues analysis of fourteen groundwater samples of Bulandshahardistrict are presented in Annexure 5.10.

The presence of organ chlorinated pesticides have been observed in all the analysed samples except o,p-DDE. The concentration level of isomers of HCH (α-HCH, β-HCH and δ-HCH) is found slightly higher than the permissible limits. Concentrations of γ-HCH (Lindane) are ranging from 0.18 to 2.79 µg/l. The concentration of total DDT ranged between 0.66 and 0.80 µg/l, well below the permissible level of 1.0 µg/l. Concentration of α-Endosulfan ranges from 0.0 to 1.21 µg/l, while the β-Endosulfanranges from 0.02 µg/l to 0.41 µg/l. The concentration of Total Endosulfan residue in the analysed samples ranges between 0.06 µg/l and 1.37 µg/l and it exceeded the permissible limit of 0.4 µg/l in five analysed groundwater samples of the area. The concentration of Dieldrin ranges from

0.89 µg/l to 11.98 µg/l and is found much higher than permissible limit (0.03 µg/l) in the monitored sites of Bulandshahr district.

The concentration of Malathion are found within the prescribed limit, while Methyl Parathion concentration exceeds the prescribed limit (0.30 µg/l) in almost all analysed groundwater samples. Chloropyriphos concentration ranges from 22 µg/l to 32.24 µg/l in the analysed fourteen groundwater sample of the area and it slightly exceeds the IS-10500 (2012) drinking water permissible limit (30 µg/l) in eight groundwater samples.

5.5 Quality Criteria for irrigation use

Several different parameters are used to classify the suitability of water for irrigation. The most important characteristics of irrigation water in determining its quality are-

Alkali and Salinity Hazard (SAR)

The total concentration of soluble salts in irrigation water can be expressed as low (EC = <250 µS cm-1), medium (250-750 µS cm-1), high (750-2250 µS cm-1) and very high (2250-5000 µS cm-1) salinity zone. While a high salt concentration (high EC) in water leads to formation of saline soil, a high sodium concentration leads to development of an alkaline soil. Excessive solutes in irrigation water are a common problem in semiarid areas where water loss through evaporation is maximal. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is adsorbed by the soils. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure due to dispersion of the clay particles.

5.5.1 Baghpat district

Alkalinity & Salinity Hazards

The frequency distribution of the E.C of water samples of Baghpat district with respect to four classes (As per U.S.Salinity Laboratory Diagram) has been determined on the basis of number of water samples (Table 5.3)

Table 5.3 : Water Category as per SAR & EC in Baghpat District, U.P.

SAR	*Water Category*	*% Sample*	*EC µS cm^{-1}*	*Water Category*	*% Sample*
0 – 10	Excellent (S-1)	100%	<250	Low (C-1	Nil
10 – 18	Good (S-2)	0%	250 – 750	Medium (C-2)	16%
18 – 26	Fair (S-3)	0%	750 - 2250	High (C-3)	80%
>26	Poor (S-4)	0%	>2250	Very High (C-4)	4%

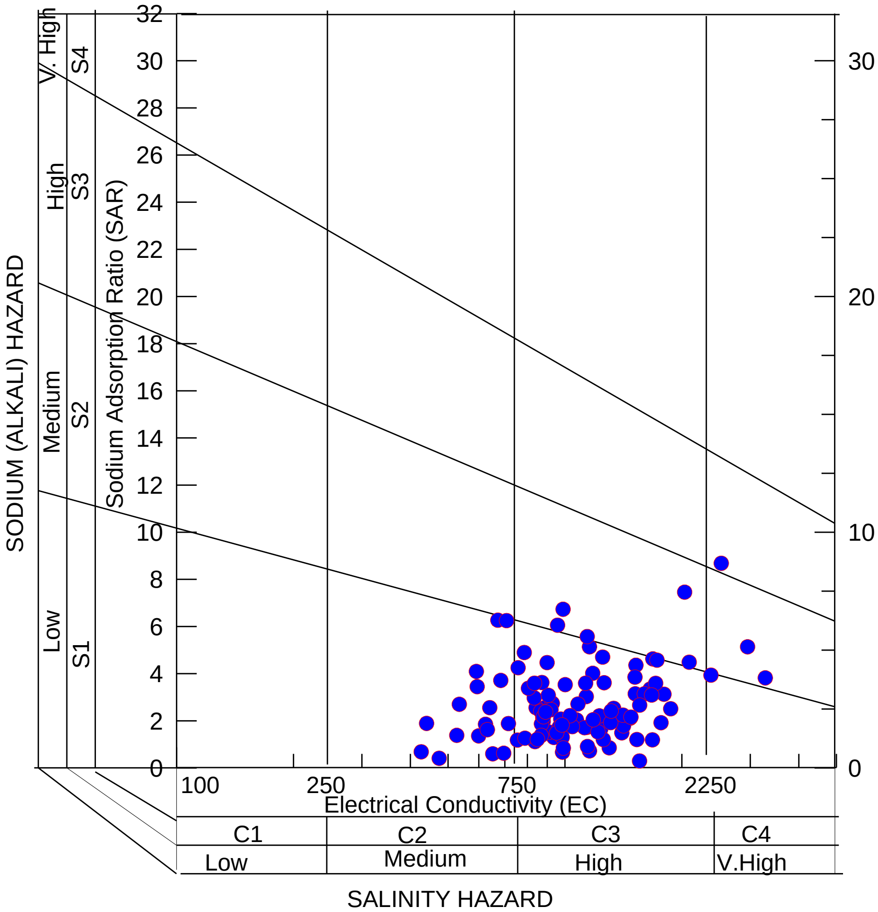


Figure-5.1: Salinity diagram for classification of irrigation water In Baghpat District (U.P.)

The calculated value of SAR in the study area ranged from 0.30 – 8.69. The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that most of the water samples fall in the category C3S1, C2S1 and C3S2, indicating medium to high salinity and low medium alkali water. This water can be used for plants with good salt tolerance (**Figure-5.1**).

5.5.2 Meerut district

Alkalinity & Salinity Hazards:

The Irrigation waters classified into four categories on the basis of sodium adsorption ratio (SAR) and EC: The frequency distribution of the E.C of water samples of Meerut district with respect to four classes (As per U.S.Salinity Laboratory Diagram) has been determined on the basis of number of analysed water samples(Table 5.4).

Table 5.4 : Water Category as per SAR & EC in Meerut District, U.P.

SAR	***Water Category***	***% Sample***	***EC µS cm*** $^{-1}$	***Water Category***	***% Sample***
0 – 10	Excellent (S-1)	100%	<250	Low (C-1	1.2%
10 – 18	Good (S-2)	Nil	250-750	Medium (C-2)	28.7%
18 – 26	Fair (S-3)	Nil	750-2250	High (C-3)	68.7%
>26	Poor (S-4)	Nil	>2250	Very High (C-4)	2.4%

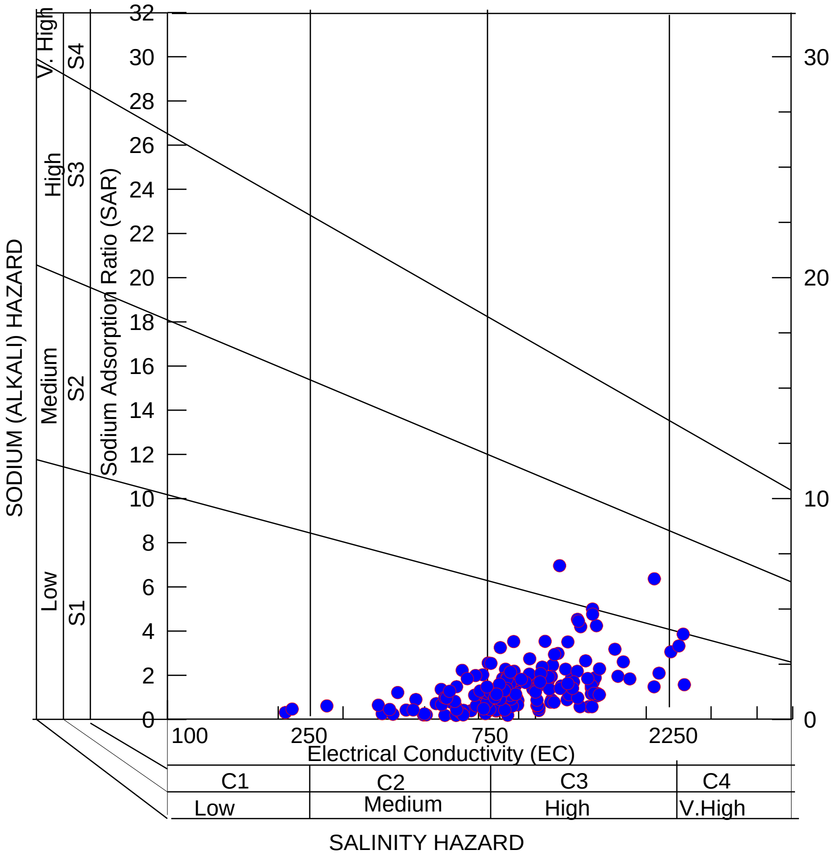


Figure-5.2: US Salinity diagram for classification of irrigation waters Meerut District (U.P.)

The calculated value of SAR in Meerut District ranged from 0.19 – 6.98. The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that most of the water samples fall in the category C2S1 and C3S1, indicating medium to high salinity and low alkali water. This water can be used for plants with good salt tolerance (**Figure-5.2**).

5.5.2 Ghaziabad district

Alkali and Salinity Hazard (SAR)

The frequency distribution of the E.C of water samples of Ghaziabad district with respect to four classes (As per U.S. Salinity Laboratory Diagram) has been determined on the basis of number of water samples (Table 5.5).

Table 5.5 : Water Category as per SAR & EC in Ghaziabad District, U.P.

SAR	*Water Category*	*% Sample*	*EC μS cm^{-1}*	*Water Category*	*% Sample*
0 – 10	Excellent (S-1)	98.4%	<250	Low (C-1	2.4%
10 – 18	Good (S-2)	1.6%	250-750	Medium (C-2)	38.1%
18 – 26	Fair (S-3)	Nil	750-2250	High (C-3)	58.7%
>26	Poor (S-4)	Nil	>2250	Very High (C-4)	0.8%

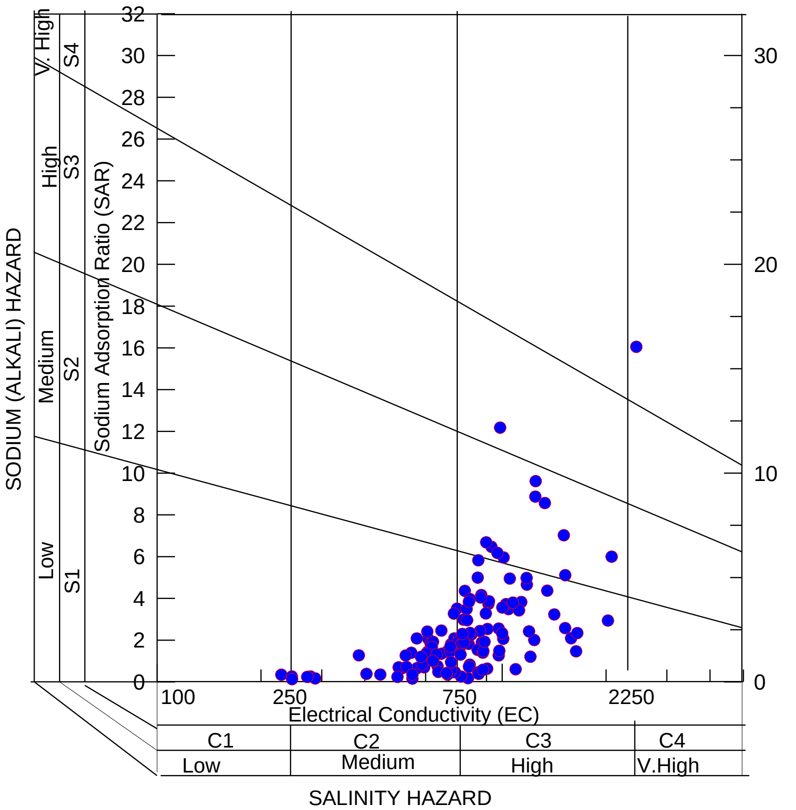


Figure-5.3: US Salinity diagram for classification of irrigation waters (Ghaziabad)

The calculated value of SAR in the study area ranged from 0.14 – 16.05. The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows hat most of the water samples fall in the category C2S1, C3S1 and C3S2, indicating medium to high salinity and low to medium alkali water. This water can be used for plants with good salt tolerance (**Figure-5.3**).

High saline water cannot be used on soils with restricted drainage and requires special management for salinity control. Plants with good salt tolerance should be selected for such areas. Very high saline water is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and salt tolerance crops/plants should be selected.

5.5.3 G.B. Nagar district

Alkalinity & Salinity Hazards

The frequency distribution of the E.C of water samples of G.B.Nagar district with respect to four classes (As per U.S.Salinity Laboratory Diagram) has been determined on the basis of number of water samples (Table 5.6).

Table 5.6 : Water Category as per SAR & EC in G.B.Nagar District, U.P.

SAR	*Water Category*	*% Sample*	*EC* µS cm^{-1}	*Water Category*	*% Sample*
0 – 10	Excellent (S-1)	95.9%	<250	Low (C-1	1.4%
10 – 18	Good (S-2)	4.1	250-750	Medium (C-2)	28.0%
18 – 26	Fair (S-3)	Nil	750-2250	High (C-3)	64.8%
>26	Poor (S-4)	Nil	>2250	Very High (C-4)	6.8 %

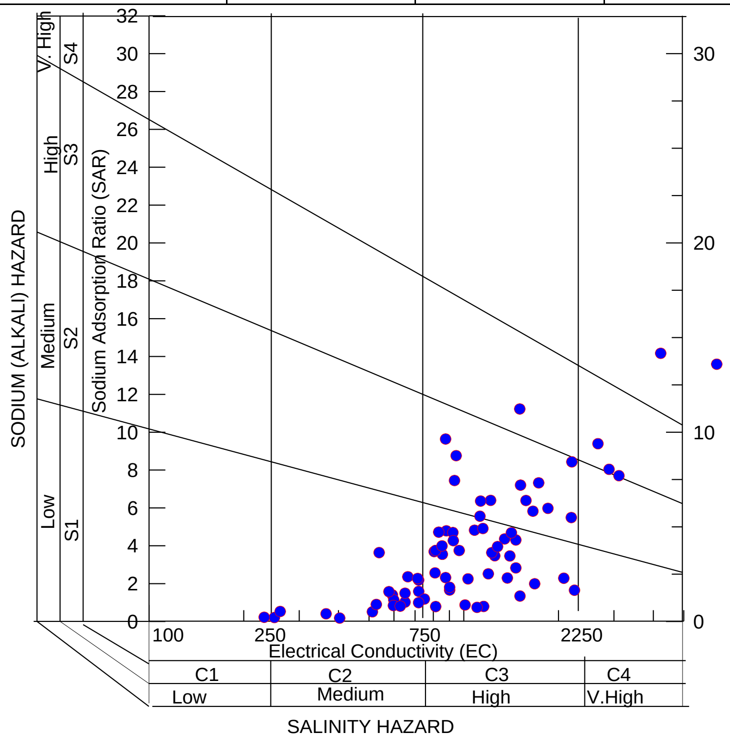


Figure-5.4 : .**Salinity diagram for classification of irrigation waters G.B.Nagar District (U.P.)**

The calculated value of SAR in the study area ranged from 0.19 – 14.2. The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that most of the water samples fall in the category C2S1, C3S1, C3S2 and C4S3, indicating medium to high salinity and low and medium alkali water (Figure 5.4). This water can be used for plants with good salt tolerance.

5.5.4 Bulandshahar district

Alkalinity & Salinity Hazards

The frequency distribution of the E.C of water samples of Bulandshahar district with respect to four classes (As per U. S. Salinity Laboratory Diagram) has been determined on the basis of number of water sample (Table 5.7)

Table 5.7: Water Category as per SAR & EC in Bulandshahar District, U.P.

SAR	*Water Category*	*% Sample*	*EC µS cm^{-1}*	*Water Category*	*% Sample*
0 – 10	Excellent (S-1)	99.70%	<250	Low (C-1	1.0%
10 – 18	Good (S-2)	0.3%	250-750	Medium (C-2)	46.6%
18 – 26	Fair (S-3)	Nil	750-2250	High (C-3)	51.4%
>26	Poor (S-4)	Nil	>2250	Very High (C-4)	1.0%

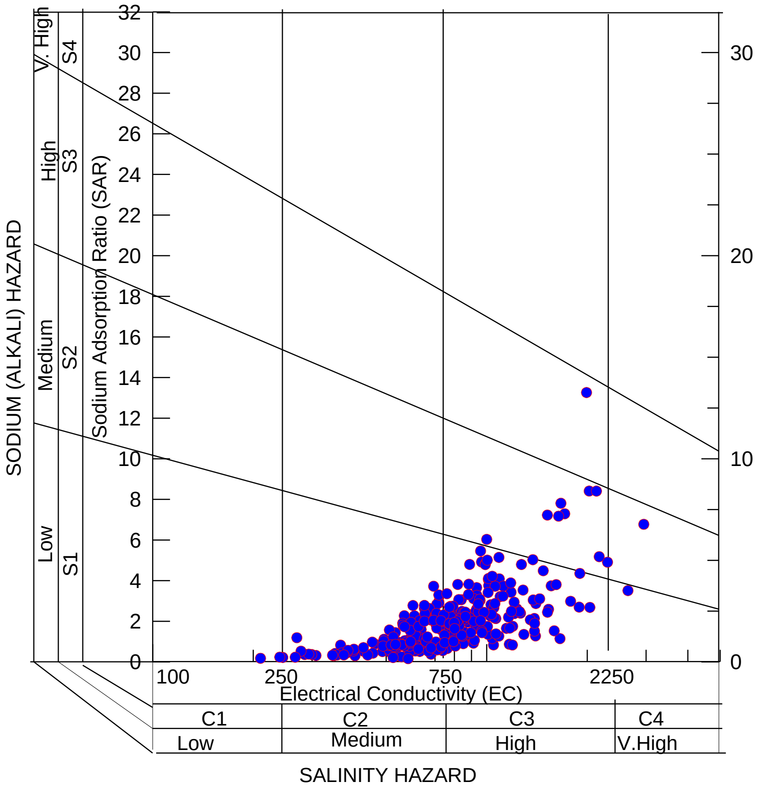


Figure-5.5: US Salinity diagram for classification of irrigation waters Bulandshahar District (U.P.)

The calculated value of SAR in Bulandshar district area ranged from 0.16 – 13.26. The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that most of the water samples fall in the category C2S1, C3S1 and C3S2 indicating medium to high salinity and low and medium alkali water (**Figure-5.5**). This water can be used for plants with good salt tolerance.

5.6 Chemical Quality of Ground Water (Deep Tube Wells)

Attempt has been made to interpret the chemical analysis data of deep tube constructed during 2013-14. Ground water samples collected from deep tube wells, NCR, U.P have been divided into four Aquifer Groups-I (11 samples), Group-II (8 samples), Group-III (12 samples) and Group-IV(7 samples).One sample from Aquifer Group (I&III) and one sample from Aquifer Group (I,II,III&IV). Chemical analysis data for Electrical Conductivity, Fluoride and Nitrate parameters is summarized as per the Aquifer Group I, II, III & IV and discussed below.

The chemical analysis data revealed that value of E.C of the ground water samples collected fromIst Aquifer Group in Bulandshahar (7 samples), Ghaziabad (1 sample), Baghpat(1sample) and G.B.Nagar (2samples) districts ranges from 508microSiemens/cm at 25^{0}C at Kirana sampling site in Bulandshahar district to 972 microSiemens/cm at 25^{0}Cin Umrara sampling site in Bulandshahar district.Its value in IVthAquifer Group was varied from a minimum of 301microSiemens/cm at 25^{0}C at Badaka sampling site at Baghpat districtto a maximum of 1168microSiemens/cm at 25^{0}C at Harchana sampling site in Bulandshahar district. No samples were found to have E.C more than 3000microSiemens/cm at 25^{0}C in all the samples collected from four Aquifer Groups.

The concentration of fluoride in the ground water samples collected from Ist Aquifer Group in Bulandshahar, Ghaziabad, Baghpat and G.B.Nagar districts of U.P varied from a minimum of 0.06 mg/l at Kirana sampling site in Bulandshahar district to a maximum of 0.74 mg/l at Umrara sampling site in Bulandshahar district.Its value from IVth Aquifer Group varied from a minimum of 0.05mg/latBadaka sampling site at Baghpat district to a maximum of 0.96 mg/l at Maujpur sampling site in Bulandshahar district. However, it could be inferred that the concentration of fluoride inground water samples collected from I, II, III & IV Aquifer Groups was found to be within the permissible limit of 1.5 mg/l as per BIS, 2012.

The concentration of Nitrate in the samples collected fromall the four Aquifer Groups in Bulandshahar, Ghaziabad, Baghpat, Meerut and G.B.Nagar districts of U.P is well within the permissible limit of 45 mg/l as per BIS, 2012.

The chemical analysis results of ground water sample of deep tube wells for different aquifer groups of districts Baghpat, Meerut, Ghaziabad, G. B. Nagar and Bulandshahar are presented in table 5.8 to 5.12.

Table 5.8: Chemical analysis results of I[st] aquifer group

Chemical Analysis data of Deep Tube Wells NCR, U.P. (WAPCOS data)

Sl. No.	District	Location	Aquifer Group	pH	EC µSiemens/cm at 25^{0}C	F^- (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
1	Baghpat	FEROZPUR	I	7.31	802	0.69	36	387	56.8	14.23	45.27	24.76	68.3	4.92
2	Bulandsahar	BADAGAON	I	7.08	568	0.28	15	332	34.1	0.18	41.9	27.13	35.7	7.62
3	Bulandsahar	HALPURA	I	8.02	736	0.49	18	455	12.4	4.55	31.7	25.97	90.9	6.96
4	Bulandsahar	JIRAULI	I	8.1	686	0.23	4.5	361	34.1	0.44	9.3	4.4	125.3	2.37
5	Bulandsahar	KIRARA	I	8.16	508	0.06	10	351	5.8	1.6	33.18	31.04	37.8	6.92
6	Bulandsahar	KASBADHADU	I	7.62	694	0.49	8	447	13.3	0.19	45.08	27.82	62.7	7.86
7	Bulandsahar	LALNER	I	7.27	519	0.51	13	325	4.8	3.1	36.9	17.96	43.3	5.37
8	Bulandsahar	UMRARA	I	8.23	972	0.74	30	418	87.5	0.08	22.02	9.25	186.4	5.04
9	Ghaziabad	KHORAJPUR	I	7.77	597	0.48	12	406	15.4	5.66	37.26	24.24	74.4	5.66
10	G.B.Nagar	CHANCHALI	I	8.28	876	0.52	107	165	138.1	0.13	24.16	2.17	153.3	2.74
11	G.B.Nagar	NAGLA NAIANSUKH	I	7.35	893	0.37	15.3	500	27.8	4.92	54.9	26.2	98.4	7.53

Table 5.9: Chemical analysis results of II[nd] aquifer group

Chemical Analysis data of Deep Tube Wells NCR, U.P. (WAPCOS data)

Sl. No.	District	Location	Aquifer Group	pH	EC µSiemens/cm at 25^{0}C	F^- (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
1	Baghpat	KOORDI	II	8.88	715	0.31	30	136	172.7	1.1	10.13	8.21	119.8	2.03
2	Baghpat	SHERPUR	II	8.41	811	0.12	40	240	147.2	0.12	8.19	2.74	151.3	1.55
3	Meerut	JALALPUR	II	8.9	413	0.31	8	277	12.7	0.02	3.25	1.7	89.9	0.72
4	Bulandsahar	BILSURI	II	8.52	894	0.59	94	236	58.7	0.43	16.65	5.74	155.2	1.24
5	Bulandsahar	GODHANA	II	8.21	450	0.31	11	171	54.1	0.18	3.76	0.68	90.1	0.76
6	Bulandsahar	SHERPUR	II	8.05	880	0.87	23	510	34.5	0.16	14.32	7.69	182.1	4.68
7	Ghaziabad	VEERSINGHPUR	II	8.59	508	0.63	33	214	43.7	0.25	4.32	1.9	110.2	1.57
8	Ghaziabad	NANGLA UDAI RAMPUR	II	8.42	799	0.67	57	186	157.6	0.02	10.31	1.8	158.7	2.07

Table 5.10: Chemical analysis results of III[rd] aquifer group

Chemical Analysis data of Deep Tube Wells NCR, U.P. (WAPCOS data)

Sl. No.	District	Location	Aquifer Group	pH	EC µSiemens/cm at 25^{0}C	F^- (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
1	Baghpat	TABELAGARHI	III	8.89	498	0.32	20	211	58.7	0.02	2.75	1.04	100.6	0.9
2	Meerut	KHWAJAMPUR MAJARA	III	8.91	365	0.51	10	199	4.9	0.34	2.8	0.95	77.9	0.77
3	Meerut	KUNKURA	III	7.8	396	0.11	6	255	1.9	0.33	27.4	7.67	46.7	5.7
4	Meerut	RAHAWATI	III	7.88	415	0.26	10	282	2.9	1.34	38.77	19.08	29.6	4.96
5	Bulandsahar	BELON	III	8.58	424	0.45	23	180	34.1	0.76	7.69	3.38	86.3	1.32
6	Bulandsahar	KUCHHEJA	III	8.55	434	0.57	26	221	36.8	0.03	3.42	0.42	101.3	1.3
7	Bulandsahar	MAKARI	III	8.35	490	0.19	7.3	224	60.7	0.25	3.67	0.44	97.6	0.74
8	Bulandsahar	NIRSUKHA	III	8.52	347	0.44	12	203	30.9	0.28	4.8	1.1	90.7	1.17
9	Ghaziabad	HARSINGHPUR	III	8.85	444	0.41	22	176	46.9	0.15	4.82	1.9	95.6	1.17
10	Ghaziabad	LATIFPUR TIBRA	III	8.17	390	0.8	14	215	30.4	0.13	2.03	1.3	99.4	0.85
11	Ghaziabad	LALPUR	III	8.04	1576	0.58	180	128	395	0.26	72.65	13.32	249.5	3.57
12	G.B.Nagar	CHITI	III	7.46	1226	1.14	48	476	74.7	0.36	51.2	10.2	179.2	2.44

Table 5.11: Chemical analysis results of IVth aquifer group

Chemical Analysis data of Deep Tube Wells NCR, U.P. (WAPCOS data)															
Sl. No.	District	Location	Aquifer Group	pH	EC µSiemens/cm at 25^{0}C	F^- (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
1	Baghpat	BADAKA	IV	8.41	301	0.05	16	148	41	0.02	2.35	0.33	82.6	0.71
2	Baghpat	SANJARPUR KAIDWA	IV	8.91	538	0.81	40	206	42.9	0.2	2.79	1.6	106.2	0.71
3	Meerut	CHHABARIYA	IV	8.53	685	0.5	68	165	99.4	0.87	15.05	1.74	137.8	2.38
4	Meerut	KHASPUR	IV	8.86	434	0.44	25	176	41.5	0.21	4.35	1.07	96.6	1.34
5	Bulandsahar	BASI BANGAR	IV	8.12	561	0.41	8.9	242	34.1	0.09	16.4	9.9	76.3	1.64
6	Bulandsahar	HARCHANA	IV	7.97	1168	0.5	155	247	140.5	0.11	36.63	5.1	200.4	3.15
7	Bulandsahar	MAUJPUR	IV	8.58	521	0.96	13.3	249	32.3	0.79	13.3	6.4	92.7	0.73

Table 5.12: Chemical analysis results of mixed aquifer group

Chemical Analysis data of Deep Tube Wells NCR, U.P. (WAPCOS data)														
Sl. No.	District	Location	Aquifer Group	pH	EC µSiemens/cm at 25^{0}C	F^- (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
1	Meerut	JALALPUR - AKKERPUR	II & III	8.2	504	0.49	14	315	13.7	10.3	30.6	25.41	40.5	6.36
2	Meerut	NANGLA GOSAIN	I,II,III,IV	7.45	445	0.26	16	250	39.5	0.22	22.21	10.1	73	3.58

The chemical analysis results of EC, Nitrate, Fluoride, Arsenic and Sodium percentage of shallow ground water for the entire area have been used to prepare maps to depict spatial distribution and presented in Figure. 5.6 to 5.10.

Figure 5.6: Spatial distribution of EC in Shallow groundwater in study area

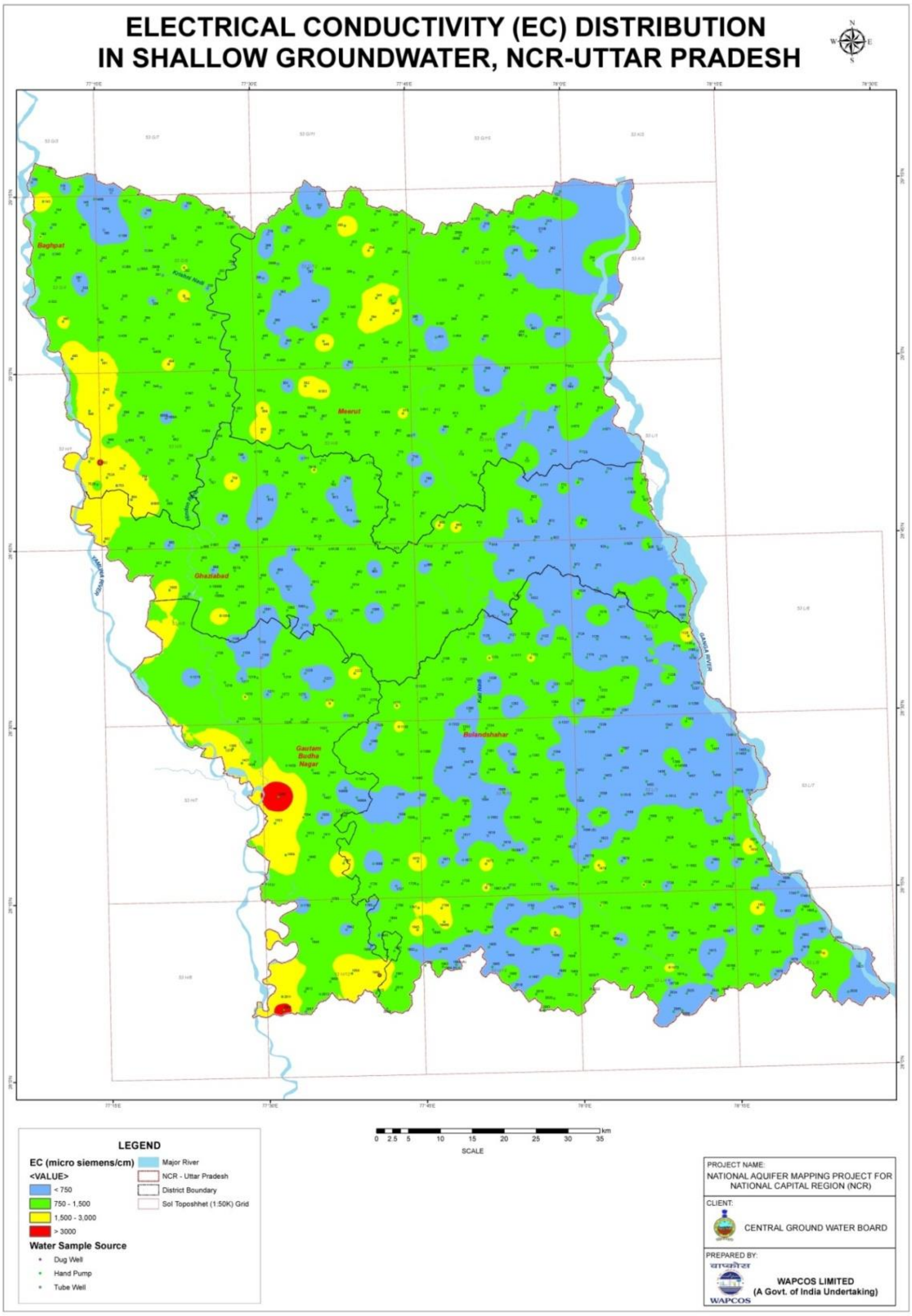


Figure 5.7: Spatial distribution of Nitrate in Shallow groundwater in Study area

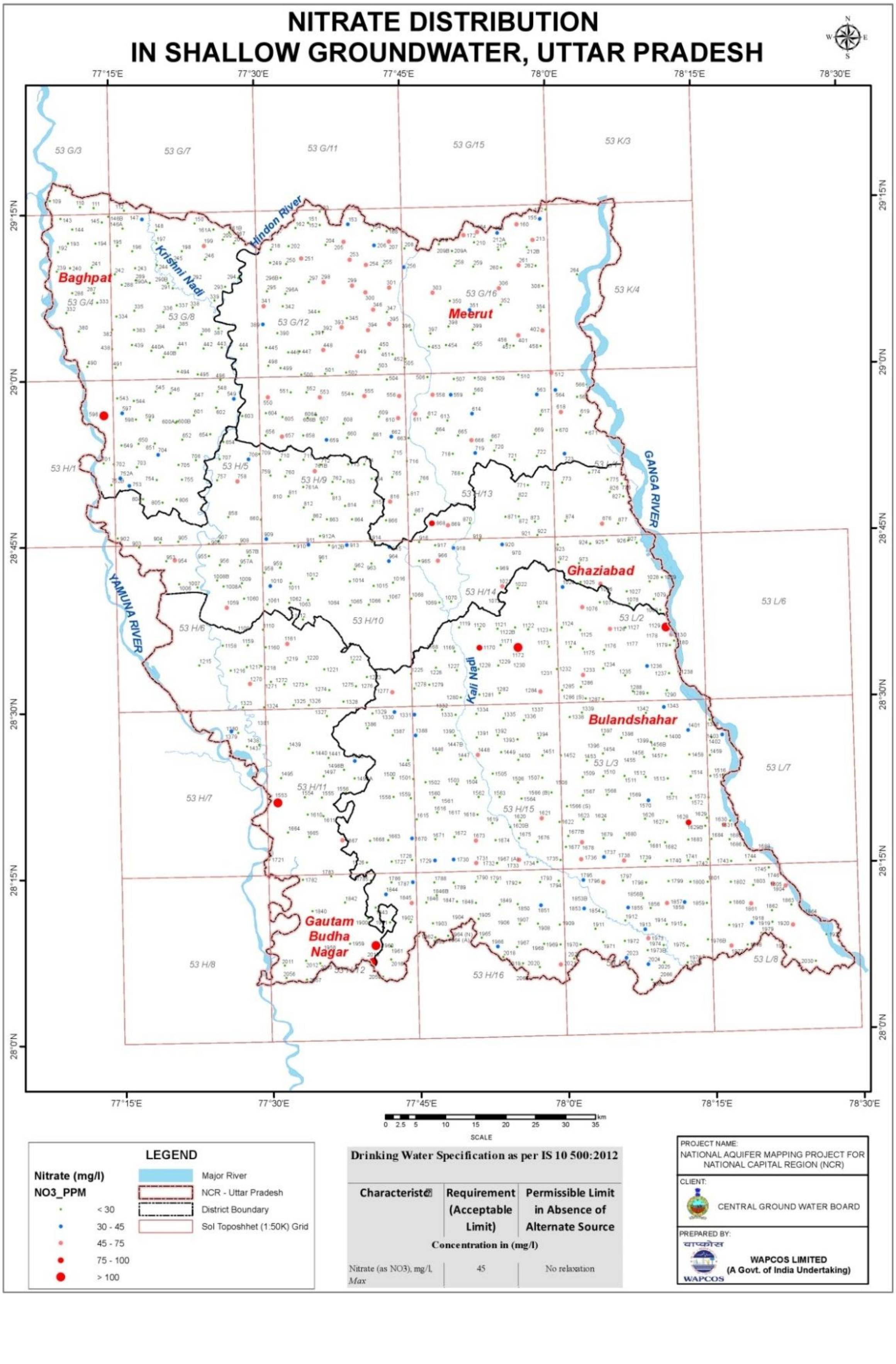


Figure 5.8: Spatial distribution of Fluoride in Shallow groundwater

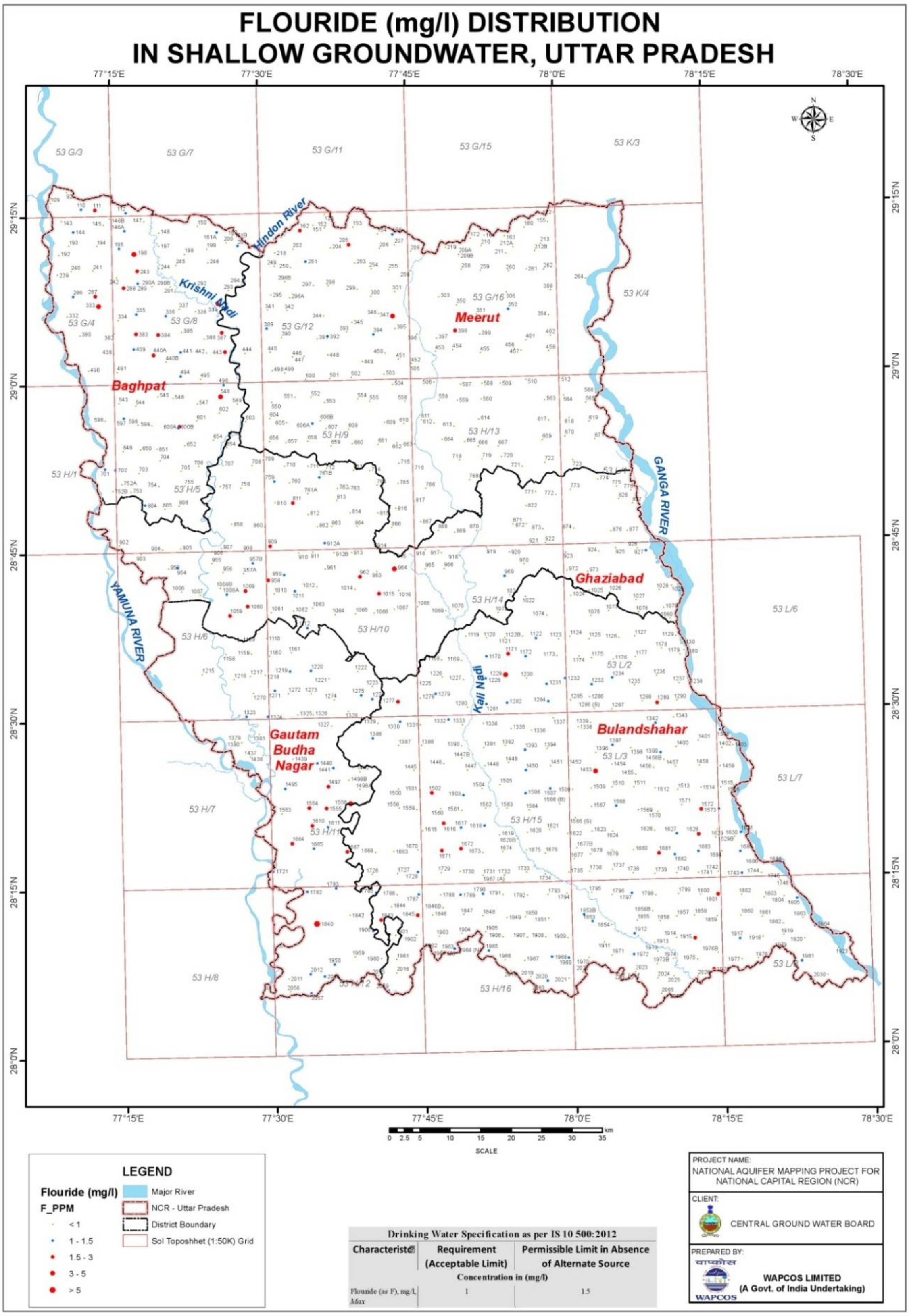


Figure 5.9: Spatial distribution of Arsenic in Shallow groundwater in study area

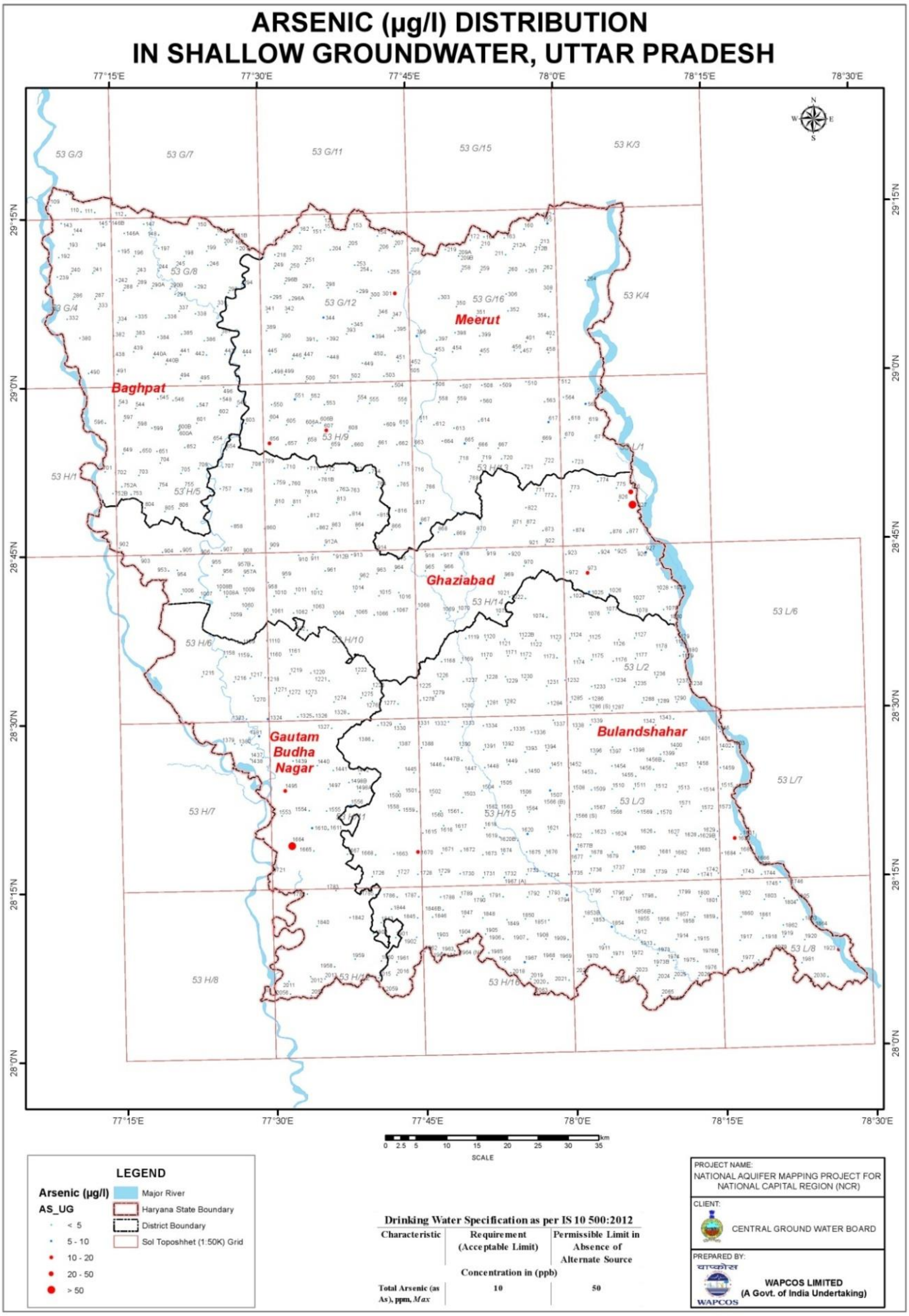
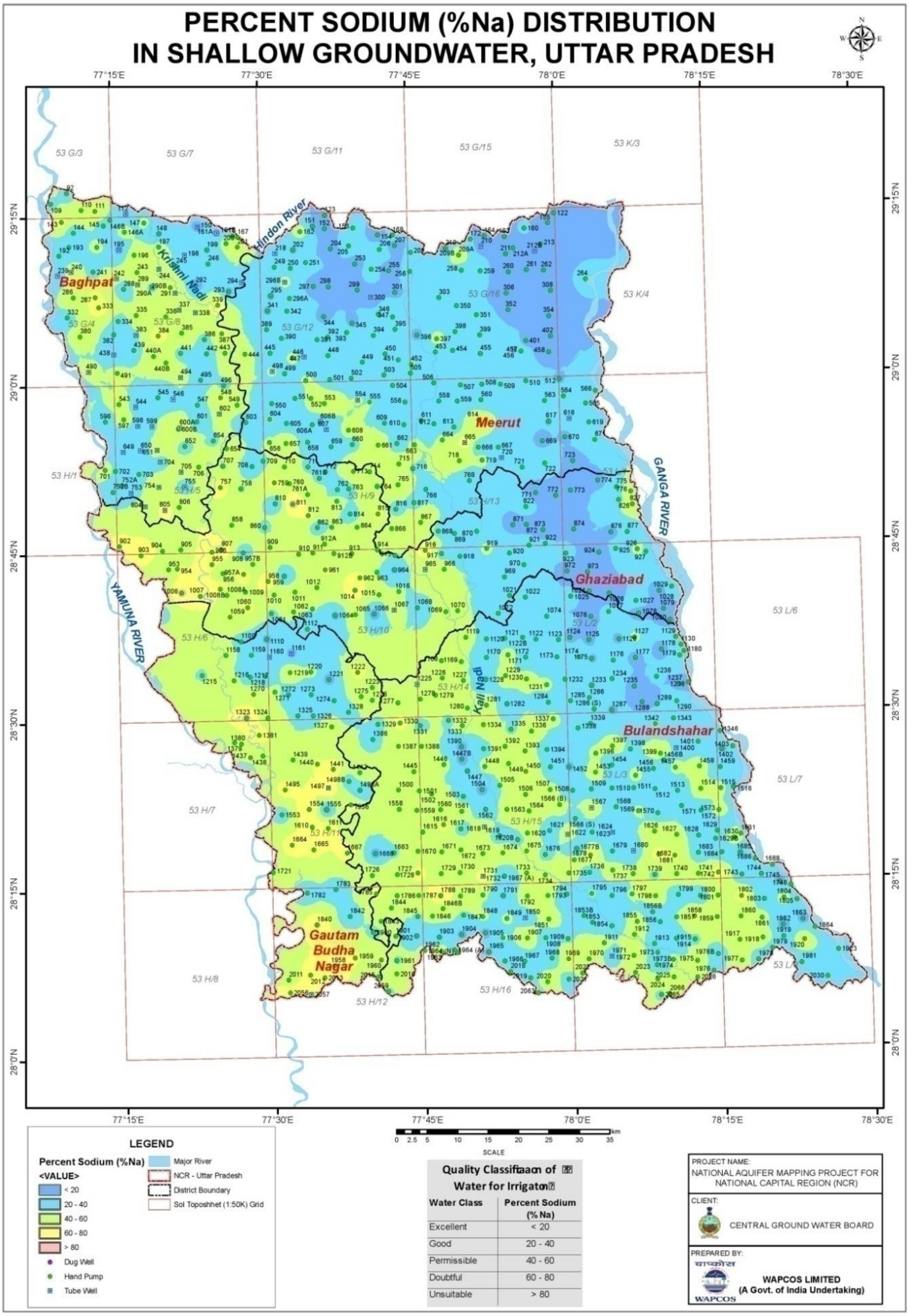


Figure 5.10: Spatial distribution of percent Sodium in Shallow groundwater studyarea



CHAPTER 6

AQUIFER MAP AND AQUIFER CHARACTERISTICS

The aquifers in the study area were mapped through lithology (exploratory drilling) geophysical investigations (VES, ERT and Borehole logging) and aquifer characteristics. The methods and techniques adopted for aquifer mapping are as under:

- Exploratory drilling
  - Litholog
  - Pumping test
  - Slug test
- Surface Geophysical Method
  - Vertical Electrical Sounding (VES) technique
  - 2D Electrical Resistivity Imaging (ERI) technique
- Sub-Surface Geophysical (Borehole Logging) Method
  - Self Potential (SP) and Electrical Resistivity
- Natural Gamma Radioactivity

6.1 Aquifer Disposition

One of the objectives of the study is to know the aquifer disposition of the area through exploration and various geophysical methods. The aquifer disposition map have been prepared based on the lithological and geophysical log information obtained through existing exploratory well data of CGWB in conjunction with the tube wells constructed for Hydrogeological Data Generation.

The granular zones (the aquifers) with varied resistivity's were picked up from the combined interpretations of electrical resistivity (64 inches Normal) and gamma radioactivity logs of the boreholes drilled in the area. The development of Self Potential (SP) was not consistent and therefore it was not considered in the interpretation. Depth wise down to 450 m bgl, the aquifers have been grouped as Aquifer Group-I, Aquifer Group-II, Aquifer Group-III and Aquifer Group-IV. These aquifer groups are separated by confining clay layers of thickness more than 10 m. Also these groups consist of several thin aquifers separated by clays and silts. The resistivity of these aquifer groups in general decreases with depth. While the Aquifer Group-I is characterized by the highest order of resistivity around 35 to 40 ohm. m with a local lowering (16 to 22 ohm.m) in the central part, the underlying aquifers have resistivity's as low as 15 ohm .m. It indicates a general decrease in granularity with depth as well as mixing of silts and clays. The Aquifer Group-II is characterized by a resistivity range of 15 to 25 ohm. m, while Aquifer Groups-III and IV are characterized by a resistivity range of 15-20 ohm .m. It is also manifested that the lateral resistivity variations or granularity of Aquifer Group-I is much higher as compared to the underlying aquifers. The variations in aquifer thicknesses and the trend in their occurrences are indicative of variations in the depositional palaeo-environment and the influences of structural controls at different geological times. Aquifer disposition of the area is described through various panel diagrams and fence diagram, prepared in different orientation.

6.1.1 Aquifer Group Thickness & Demarcation

For demarcation of aquifer Group in the study area existing exploration data of CGWB and data generation though total of 244 VES, 31.2 line-km ERI and 55 borehole logging were conducted in the area(by the WAPCOS). The results of exploratory drilling, aquifer parameters, geophysical investigations and chemical analysis results in the study are utilized for demarcating aquifer groups. The summary of data generated for exploration in the area is given in Table 6.1.

Table 6.1(a) : Aquifer wise Exploratory wells constructed for data Generation in NCR, UP

District	**EW**	**Aquifer Group-wise Break-up of numbers (EW)**				
		I	**II**	**III**	**IV**	**Mixed**
Baghapt	6	1	2	1	2	-
Meerut	8	0	2	2	3	1
Ghaziabad	6	1	2	3	0	-
Bulandsahar	17	6	3	5	3	-
G.B. Nagar	3	2	1	0	0	-
Total	**40**	**10**	**10**	**11**	**8**	**1**

As per the information from the boreholes drilled it is about 300 m thick in the western part and thickens beyond 450m in the eastern part. The alluvium comprises very fine to coarse grained sands, sandy clay, silt, clay and kankar (calcareous concretion). The sand horizons form the aquifers. In the western part, alluvium is predominated by clay inter-beds whereas in the eastern part thick sand beds are encountered. The water level data reveal that water table is, in general, 20-30 m deep in the western part and less than 10 m in the eastern part.

Demarcation of different aquifer groups has been done on the basis of Vertical Electrical Soundings and their properties such as lithological character, hydraulic properties and quality ascertained though exploratory drilling, geophysical logging and pumping tests. As per results of exploratory drilling, four aquifer groups exist in the area. Conventionally, upto the drilled depth around 450-460 m, from ground surface downward, these aquifers separated by prominent and regionally extensive thick clay beds, have been grouped as Aquifer Group 1 (A1), Group 2 (A2), Group 3 (A3) and Group 4 (A4). The details of exploratory wells are given in Annexure-6(Vol-II)

The first aquifer occurs down to 176 mbgl. It is further divided in IA and IB. Aquifer Group II starts from 76 mbgl and extends down to 316 mbgl. The third aquifer starts from 180 mbgl and extends down to 417 mbgl. The fourth aquifer starts from 300 mbgl& continues down to drilled depth of 450 mbgl. However, in Ghaziabad IV Aquifer Group at Shalimar Garden starts from 176mbgl. The aquifer wise exploratory wells constructed in the area are given in Fig. 6.1(a) and locations of exploratory wells, slim holes and piezometers are given in Fig. 6.1(b). District-wise generalised aquifer disposition in NCR area as interpreted from generated data is enumerated in Table 6.1 (b)

Table 6.1 (b): District-wise Depth Range of Different Aquifer Groups

District	**Depth Range of Different Aquifer Groups(mbgl)**			
	Aquifer I	**Aquifer II**	**Aquifer III**	**Aquifer IV**
Baghpat	59 -166	84-301	295-414	316-450 & Conti.
Meerut	60-170	76-301	224-406	341-450 Conti.
Ghaziabad	72-150	92-298	135-410	176-450 Conti.
Bulandshahar	66-174	76-316	180-417	300-450 Conti.
G.B.Nagar	82-132	95 -213	238-376	375-450 Conti.

As observed in preceding sections, the grain size variation across the area, both vertically and laterally, is quite large. Besides, aquifer percentage within individual aquifer groups varies considerably.

The aquifer disposition in Baghpat district is presented in table 6.1 (c). The first aquifer in the district ranges from ground level to 59 -166 mbgl. The second aquifer ranges down to 68 -309 mbgl. The third aquifer ranges from 215-404 mbgl. The fourth aquifer Group ranges from 316 - 450 mbgl. The basement was encountered at 399 m.bgl at Firojpur.

The aquifer disposition in Meerut district is presented in table 6.1 (d). The first aquifer in Meerut district ranges from ground level to 60-170 mbgl. The second aquifer extends down to 76-301 mbgl. The third aquifer ranges from to 224-406 mbgl. The fourth aquifer Group ranges from 341-450 mbgl.

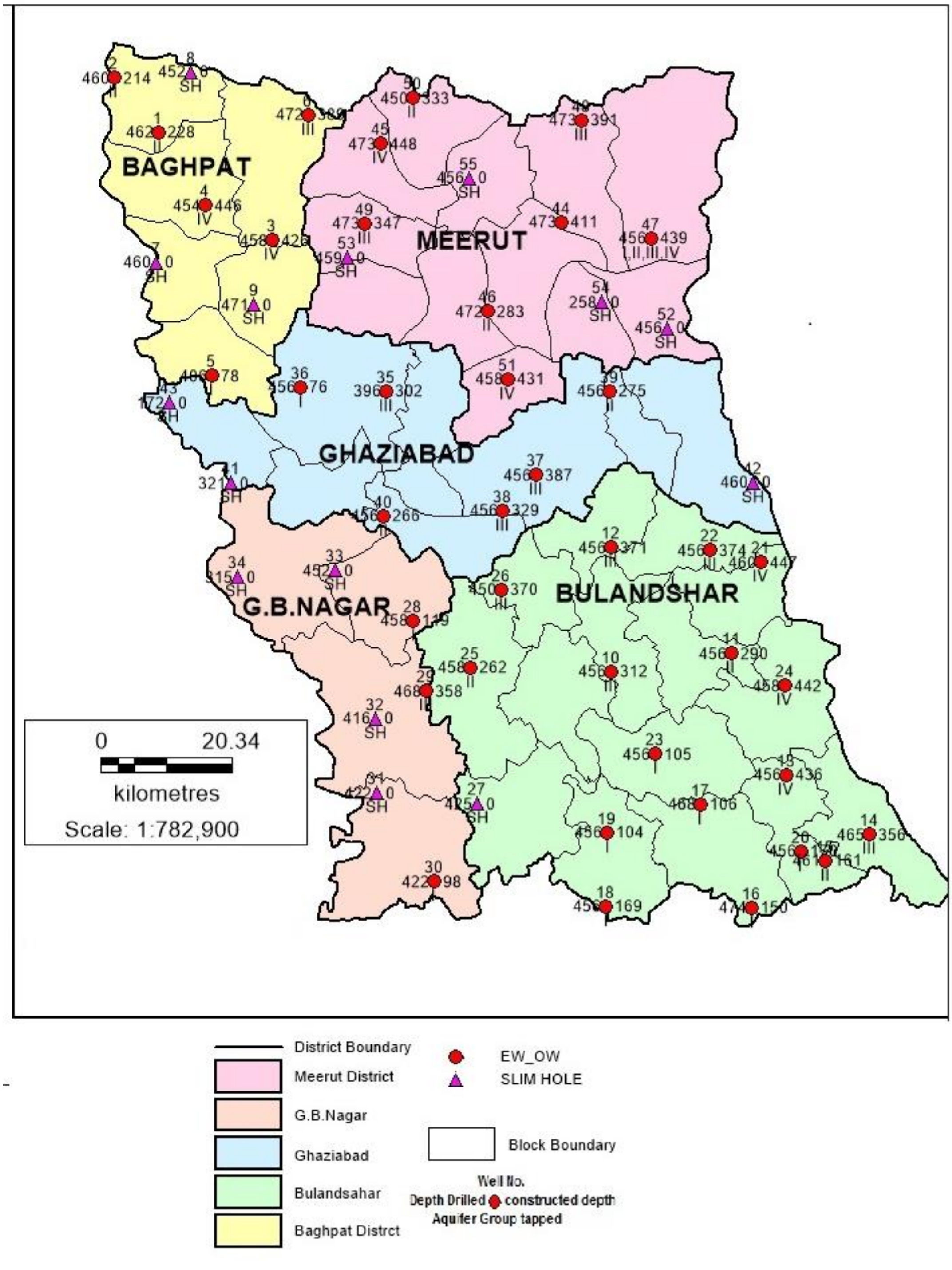


Figure:6.1 (a) Aquifer wise exploratory wells constructed for Data Generation in NCR, U.P

Table 6.1 (c): Aquifer disposition in Baghpat district

Location	**Bot_Aq-1**	**Top_Aq-2**	**Bo_Aq-2**	**Top_Aq-3**	**Bot_Aq_3**	**Top IV Aq**	**Bot_Aq IV**
Koordi	91	109	252	306	358	401	450 &Cont
Tabelagarhi	166	184	260	282	383	316	450
Sanjarpurkaidwa	95	120	189	215	278	325	425 &continued
Firojpur	88	100	192	230	230	316	399
Sherpur	84	94	206	226	314	422	
Baraka	102	136	204	232	312	352	442 &conti
Guripur	115	132	213	232	282	338	&conti
Kakripur	92	142	309	326	394	407	&conti
Pilana	101	116	239	288	404	421	&conti
Tikri	119	133	207	237	252	370	
Aminagar Sarai	126	195	250	-	-	-	
Kekhra	130	215	250	265	350		
Mitili	70	80	168	230	265	281	
Baraut	74	88	183	266	364	393	
Beleni	59	68	142	279	380	391	

(values in mbgl)

Table 6.1 (d): Aquifer disposition in Meerut district

Location	Bot_Aq-1	Top_Aq-2	Bo_Aq-2	Top_Aq-3	Bot_Aq_3	**Top IV Aq**	**Bot_Aq IV**
Kunkura	133	143	301	311	406	422	452
Chabaria	126	136	214	225	313	343	450
Jalalpur	152	152	278	288	341	360	450
NaglaGosain	76	84	237	243	375	389	450
Rehawati	66	76	200	224	385	434	450
Khawjampur Majara	121	167	266	287	348	374	450
Akkherpur	136	148	216	228	338	370	450
Khaspur	120	143	208	226	303	341	450
Salaur	60	76	238	254	372	384	450
Rihadra	130	151	261	278	346	394	450

Bharala	132	142	243	255	395	358	450
Mohkampur	140	160	201	222	260	290	
Kazipur	142	159	278	323	381		
Hastinapur	170	190	245	255	296	305	390
Shiwalkhas	103	137	221	272	345	355	445

(values in mbgl)

The aquifer disposition in Ghaziabad district is presented in table 6.1 (e) The first aquifer in Ghaziabad district ranges from ground level to 72 - 150 mbgl. The second aquifer extends down to 92-288 mbgl. The third aquifer ranges from to 135-410 mbgl. The fourth aquifer Group ranges from 176-450 mbgl. The basement is encountered at 117 mbgl at Loni, 172 mbgl at Panchariya 320 mbgl at Shalimar Graden and at 396 mbgl in Latifpur Tibra.

Table 6.1 (e) Aquifer dispositions in Ghaziabad district

Location	**Bot_Aq-1**	**Top_Aq-2**	**Bo_Aq-2**	**Top_Aq-3**	**Bot_Aq_3**	**Top IV Aq**	**Bot_Aq IV**
LatifpurTibra	93	110	162	198	324		
Khorajpur	114	137	244	290	410	434	456
Lalpur	78	92	186	217	380	434	456
Harsinghpur	114	172	203	339	359	359	450
Veersinghpur	121	134	288	324	425	441	450
NaglaUdairampur	150	194	270	292	341	363	450
Shalimar Garden	76.5	98	125	135	164	176	321
Pooth	84	94	202	226	376	434	450
Panchayra	90	164	-	-	-		
Garh Mukteswar	151	172	200	210	286	325	356
Simbhwali	125	135	234	255	310	320	355
Sanjaynagar	112	134	213	282	330	360	449
Plakhua	121	145	193	207	312	342	520
Loni	72	76	114				

(values in mbgl)

The aquifer disposition in Bulandshahar district is presented in table 6.1 (f). The first aquifer in Bulandshahar district ranges from ground level to 66- 174 mbgl. The second aquifer extends down to 76-316 mbgl. The third aquifer ranges from to 180- 447 mbgl.

The fourth aquifer Group ranges from 300 - 450 mbgl. The basement is encountered at 398 mbgl at Halpura.

Table 6.1 (f) Aquifer disposition in Bulandshahar district

Location	**Bot_Aq-1**	**Top_Aq-2**	**Bo_Aq-2**	**Top_Aq-3**	**Bot_Aq_3**	**Top _ Aq _4**	**Bot_ Aq IV**
Kuchheja	156	176	234	270	320	358	452
Godhana	131	152	286	302	360	404	456
Nirsukha	99	108	232	252	364	390	450
Jirauli	112	134	208	234	304	325	444
Belaun	119	124	200	239	352		
Sherpur	84	94	206	226	314	330	440
KasbaDhandu	145	170	258	285	380		
Lalner	104	116	170	180	283	300	392
Halpura	174	194	265	284	-		
Baragaon	123	152	219	243	371	386	450
Umrara	164	179	316	352	447		
Basibagnar	105	115	185	197	353	367	452
Makari	66	76	246	270	368	392	456
Karira	99	124	212	235	376	396	434
Maujpur	152	162	237	253	330	378	450
Bilsuri	168	190	262	274	382	410	450
Harchana	123	141	222	246	366	390	450
SanitaSafipur	78	110	218	233	327	370	450
Aurangabad	90	105	176	194	282	300	440
Yamunapuram	105	125	230	240	288	312	430

The aquifer disposition in Gautam Budha Nagar is presented in table 6.1 (g) The first aquifer in GataumBudha Nagar district ranges from ground level to 82-132 mbgl. The second aquifer extends down to 95 -293 mbgl. The third aquifer ranges from to 238- 376 mbgl. The fourth aquifer Group ranges from 375 - 450 mbgl. The basement is encountered at 419 mbgl at Chanchali, 345 mbgl at Bhaipura, 416 mbgl at Nawada, 444 at sadhopur and 310 mbgl at Sadarpur.

Table 6.1 (g): Aquifer disposition in Gautam Buddha Nagar district

Location	Bot_Aq-1	Top_Aq-2	Bo_Aq-2	Top_Aq-3	Bot_Aq_3	Top_Aq_4	ot_Aq IV
Nagala Nainsukh	116	132	176	268	340	407	450
Chiti	131	152	228	244	366	424	450
Chanchali	93	125	293	324	-	-	-
Bhaipura	92	110	188	238	255	-	-
Nawada	132	154	215	242	288	375	385
Sadhopur	108	127	238	256	376	406	436
Sadarpur	82	125	182	262	-	-	
Jewar	85	95	150				
Kasna	130						
Suryanagar	83						

(values in mbgl)

The aquifer disposition As mentioned before, boreholes were drilled down to 450 mbgl and existing CGWB wells were drilled down to 742 mbgl or depth to basement, whichever was shallower. Bed rock composed of quartzite belonging to Delhi Supergroup was encountered in some of the boreholes drilled between Hindon and Yamuna at progressively shallower depths when moving towards Yamuna river. Depth to bed rock is shown through contours in Figure 6.1 (b)

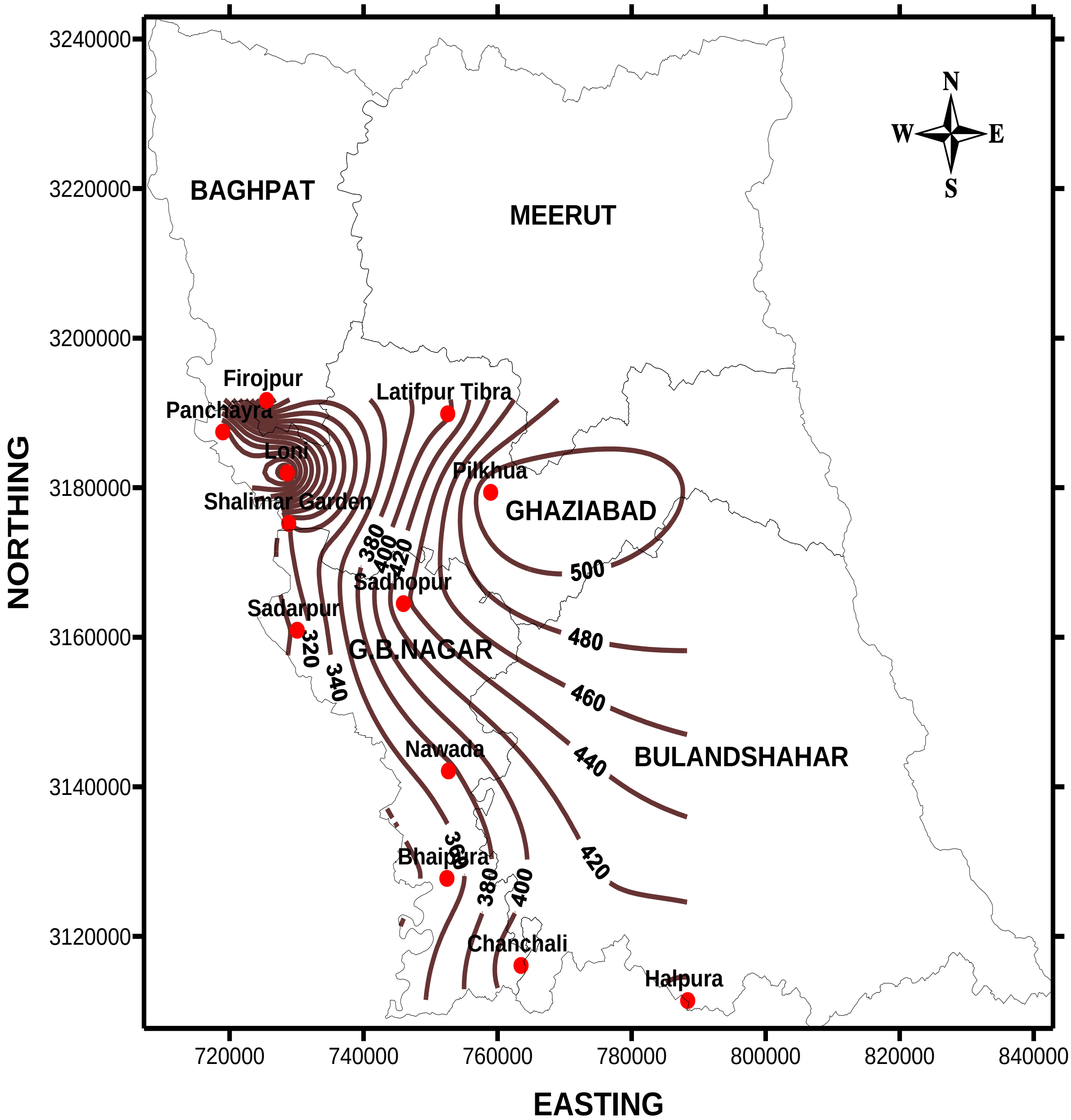


Figure 6.1(b): Depth to Bed Rock Encountered in Boreholes, NCR, UP

6.1.2 Litholog, Aquifer Disposition & 3-D Fence

To obtain a three-dimensional generalized view of the aquifer dispositions and lithological dispositions, 3-D multi-logs and fence diagrams (aquifer group and lithological) have been prepared on the basis of integrated litholog and geophysical log (E-Log and Gamma log), presented in Fig. 6.2 (a & b) and 6.3 (a &b) respectively.

The 3-D multi-logs (aquifer group and lithological logs) depicting lithological variation at individual locations has been prepared using Rockworks software. These logs reveal the presence of a thick pile of alluvial sediments with alternation of various grades of sand, clay and silt. Fence diagrams are showing detailed aquifer geometry on regional scale established in the study area. Principal aquifers in the area have been delineated by grouping the fine to medium sand, coarse sand and gravelly sand as aquifers. Litho-stratigraphic fence diagram prepared joining different wells shows four group of aquifer along with three distinct clay horizons. There is variation in thickness of aquifer group but in regional scale they are making different groups on the basis of aquifer characteristics grade of sand and clay. The fence and panels diagrams reveal the presence of a thick pile of alluvial sediments with alternation of various grades of sand with clay and silt. The area is characterized by occurrence of fairly thick sands of various grades forming prolific aquifers.

The Location map of the exploratory wells and 3-D stratigraphic model is presented in Fig. 6.1.2 (a) and 6.1.2 (b) respectively.

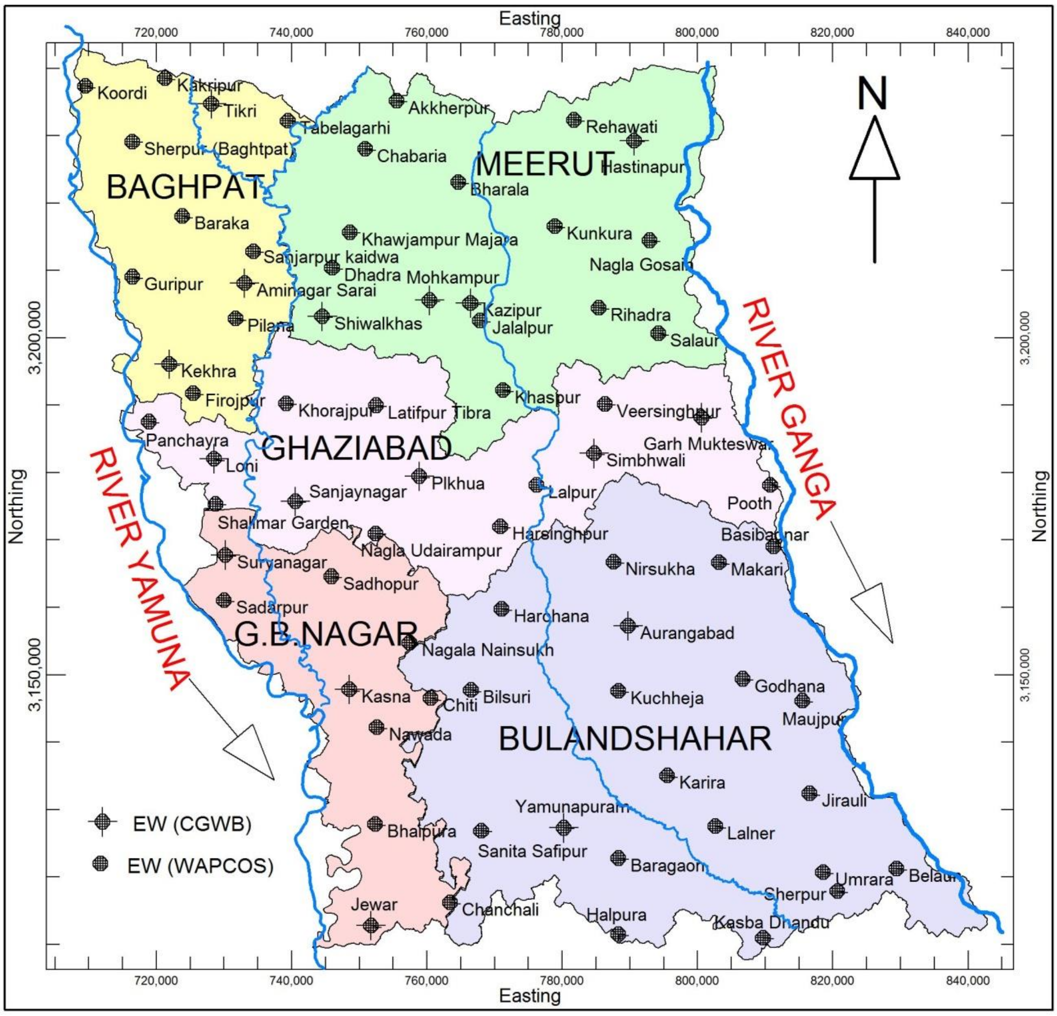


Figure 6.2 (a): Location of exploratory wells considered for preparation of Fence and Section(NCR,U.P).

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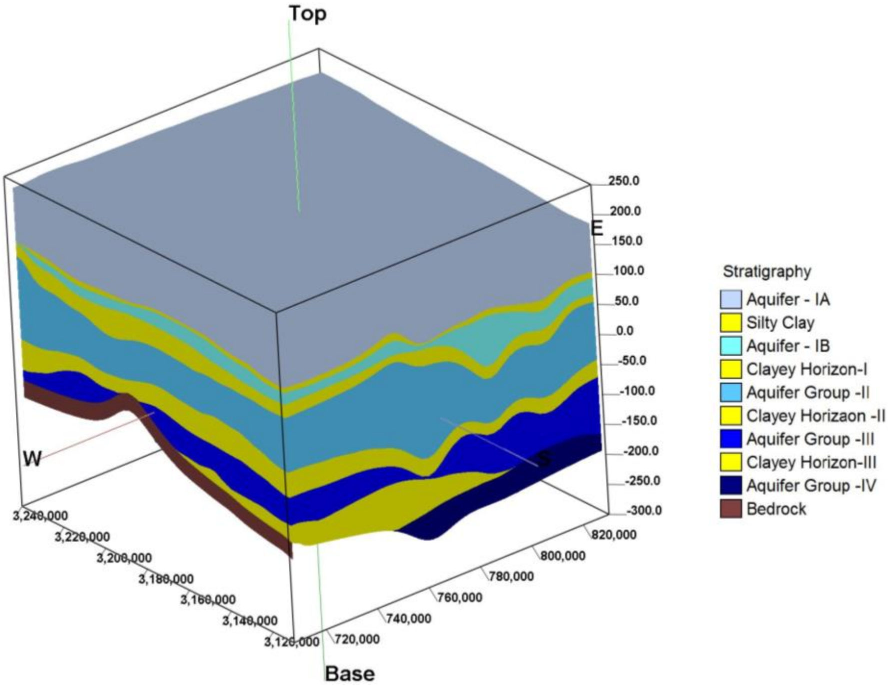


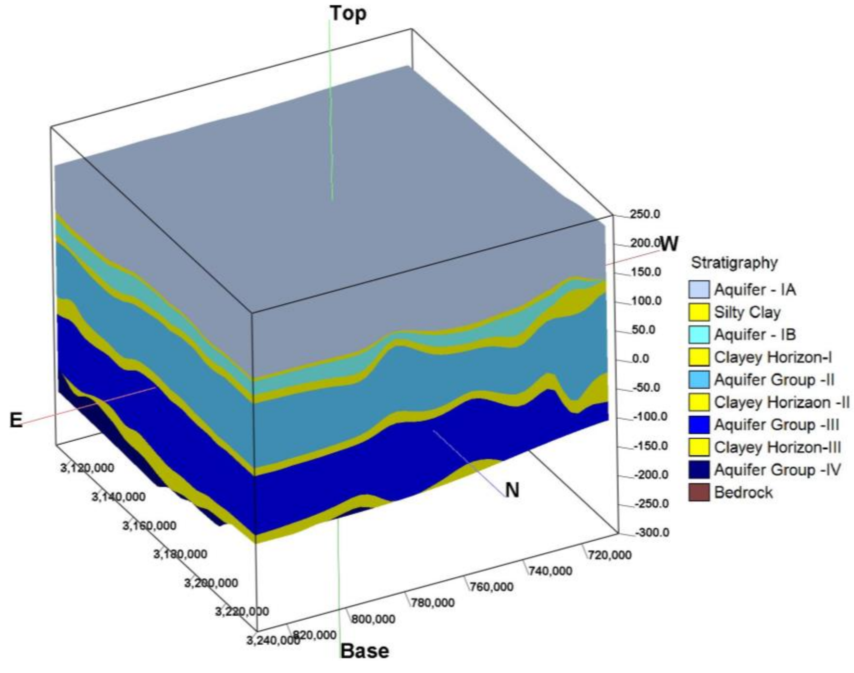


Figure 6.**2(b)**:3-D stratigraphic model showing the individual aquifer dispositionin NCR(U.P. Part)

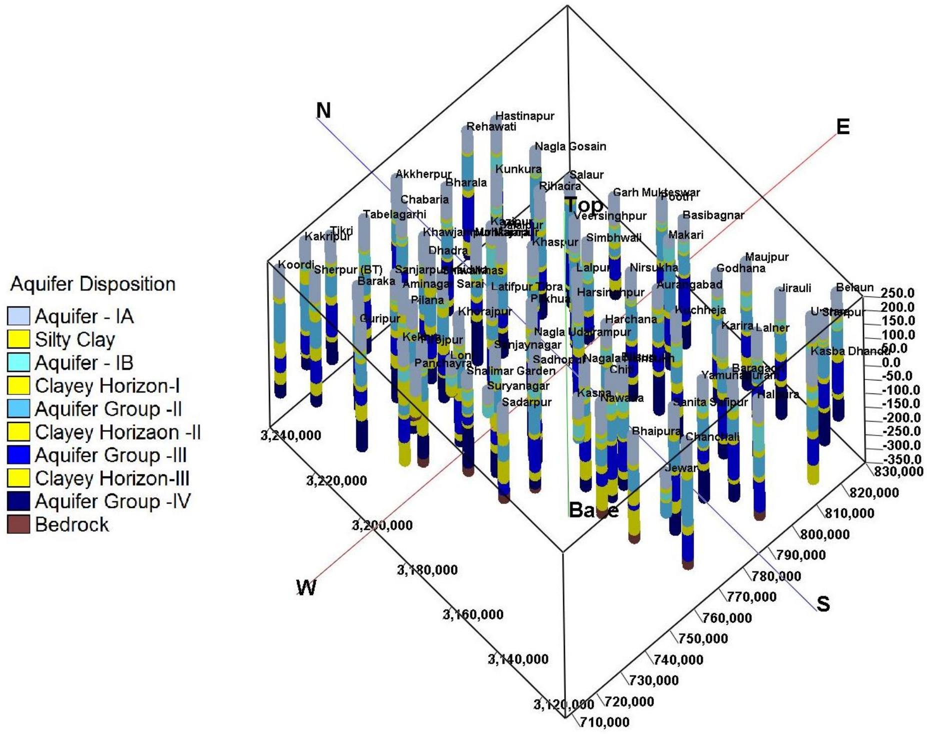


Figure 6.2.1 (a):3-D multi-log showing the individual aquifer disposition

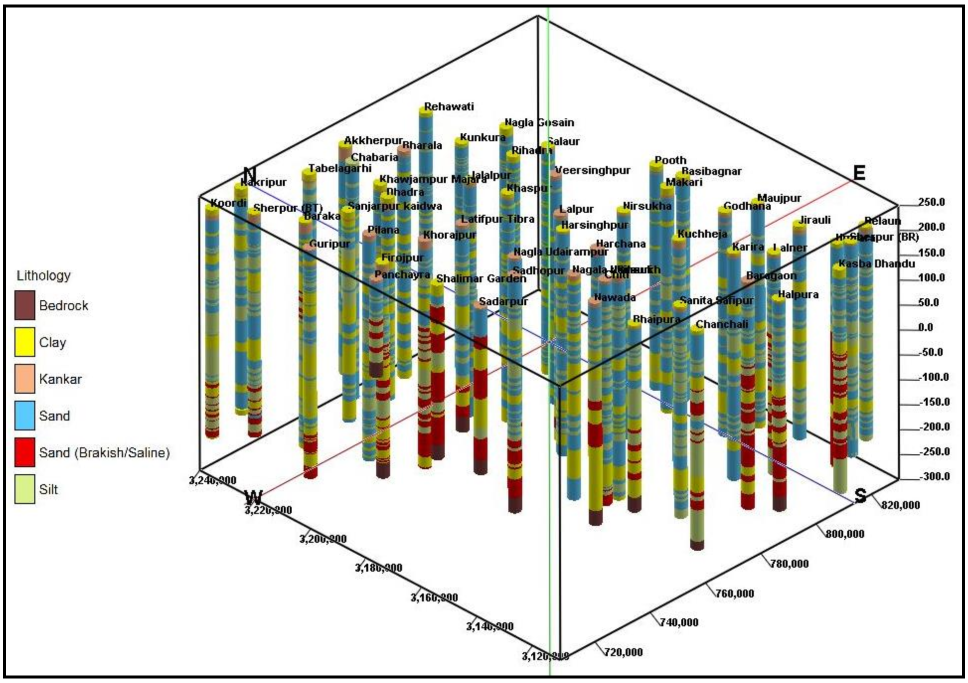


Figure 6.2.1 (b):3-D multi-log showing the individual lithological dispositionin NCR,(U.P.)

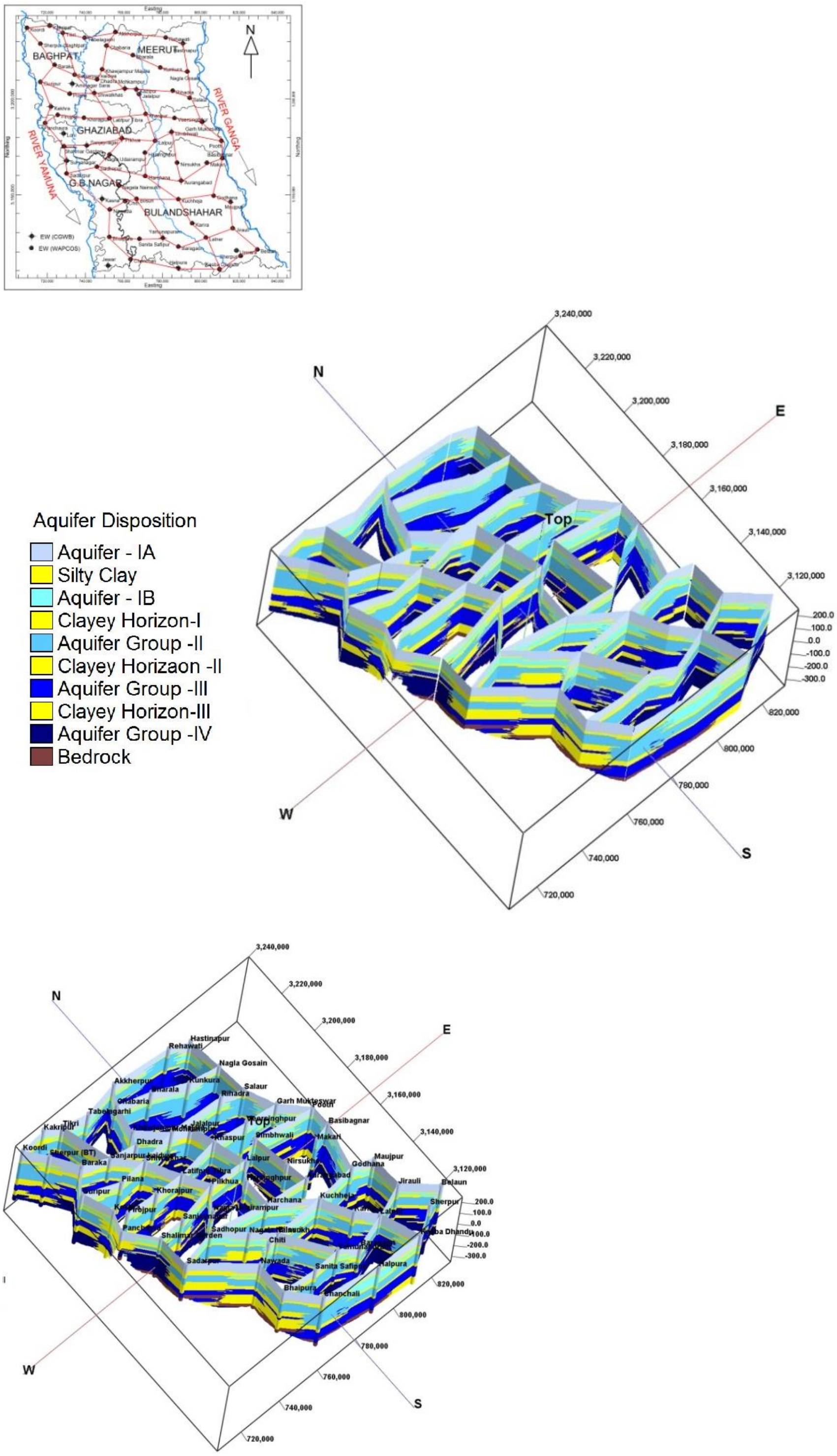


Figure 6.3 (a):3-D view showing the aquifer disposition of the area in NCR, (U.P.)

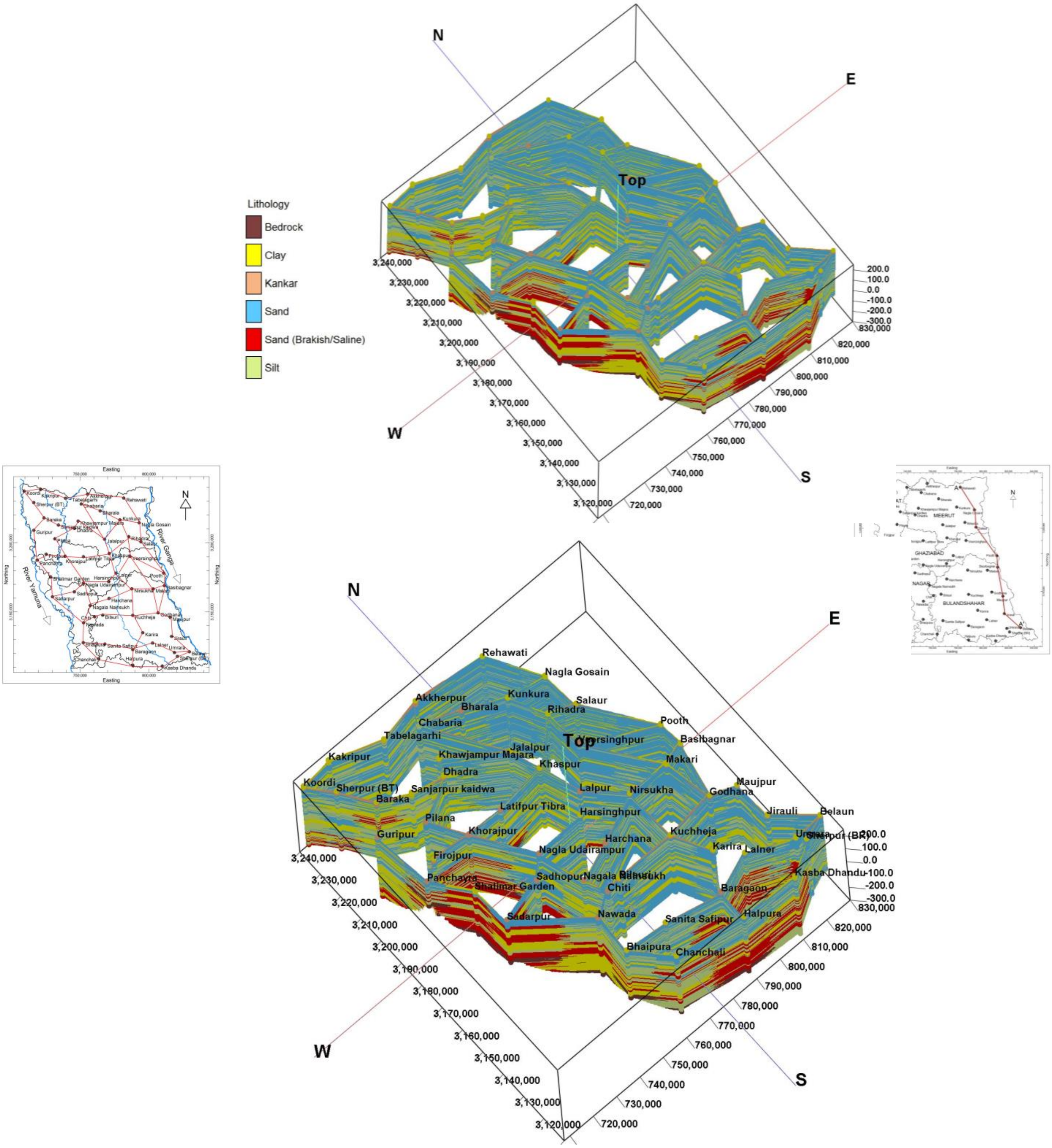


Figure 6.3 (b):3-D view showing the lithological disposition of the area, NCR,(U.P.)

Fig. 6.3 (a & b) clearly indicates that the alluvial deposit is more towards river Ganga. It is indicate that thickening of aquifer towards river Ganga i.e. west to east. The thickness of sand layer is more towards northeast and south east whereas thickness of clay deposit is more in the northwest and southwest of the area.

It is also observed that the quality of groundwater is poor (Brackish/Saline) in spatially varied from NWW to SSE in study area. The bedrock is shallower in west of the Ghaziabad district.

6.1.2(a) Aquifer Disposition along Ganga River, eastern boundary of the area in N-S direction (3-D Panel Diagram)

A panel diagram is prepared to show the aquifer dispositionalong N-S direction along the eastern boundary of the area i.e. along Ganga River, with help of lithologs and geophysical logs at Rehawati- Nagala Gosai- Salaur- Pooth- Nirsukha- Maujpur-Belaun. The section oriented along N-S stretches over a length of 125 km and depicts the aquifer disposition upto a depth of 450 m (Fig 6.4).

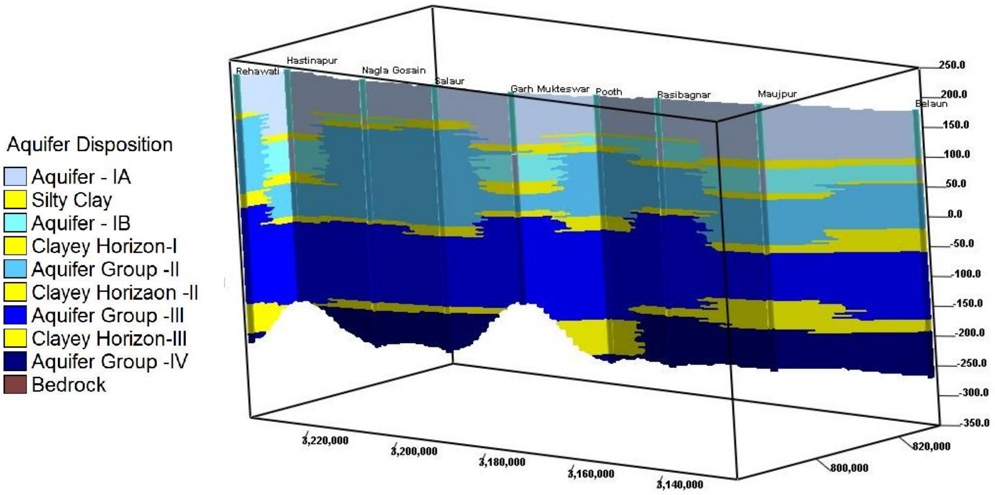


Figure 6.4: Panel diagram (3-D)showing the aquifer disposition along river Ganga

This section reveals the presence of four principal aquifers lying below the top soil layer. The thickness of the first aquifer layer varies from 60m in the Northern part to 150 m in the southern part. Thickness of first aquifer increases southwards. The highly mixed nature of the aquitard layer and presence of occasional sand sequences at places even from the ground level makes the underlying 1st principal aquifer amenable to vertical recharge. The aquitard layer sustains dug wells and shallow hand pumps.

The second aquifer is separated by the overlying Ist aquifer by 10 to 20 m thick intervening clay layer. Second aquifer thickness ranges from 75 m to 125 m. The thickness of second aquifer increase northwards. At Salaur and Nagla Gosai second aquifer starts at 76 and 84 mbgl respectively.

The third aquifer is separated by the overlying second aquifer by 15 to 40 m thick intervening clay layer. Third aquifer thickness ranges from 70 m to 160 m. The thickness of third aquifer increase northwards.

The fourth aquifer is separated by the overlying third aquifer by 12 to 60 m thick intervening clay layer. Forth aquifer thickness varies from70 m to 160 m. The fourth aquifer extends beyond 450 mbgl.

6.1.2 (b) Aquifer Disposition along Yamuna River, western boundary of the area in N-S direction (3-D Panel Diagram)

A panel diagram is prepared to show the aquifer dispositionalong N-S direction along the western boundary of the area i.e. along Yamuna River, using litholog and geophysical logs at Koordi– Baraka- Gauripur- Kekra—Panchariya- Shalimar Garden- Sadarpur-Nawada- Chanchali. The section oriented along N-S stretches over a length of 110 km and depicts the aquifer disposition upto a depth of 450 m (Fig 6.5).

This section reveals the presence of four principal aquifers lying below the top soil layer. The thickness of the first aquifer layer varies from 75 m in the Southern part to 120 m in the Northern part. Thickness of first aquifer increases towards north. The highly mixed nature of the aquitard layer and presence of occasional sand sequences at places even from the ground level makes the underlying 1st principal aquifer amenable to vertical recharge. The aquitard layer sustains dug wells and shallow hand pumps.

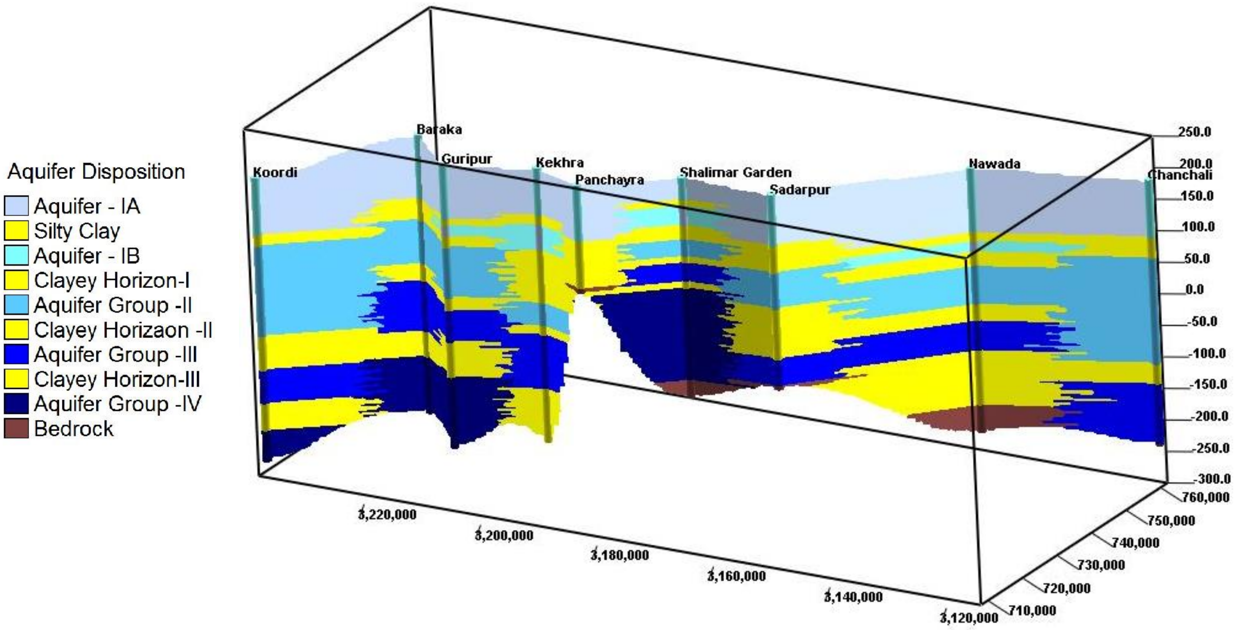


Figure 6.5: Panel diagram (3-D) showing the aquifer disposition along river Yamuna

The second aquifer is separated by the overlying Ist aquifer by 20 to 45 m thick intervening clay layer. Second aquifer thickness ranges from 35 m to 140 m. The thickness of second aquifer is minimum at Shalimar Garden (Ghaziabad district) . Thickness increases towards north and south direction towards KoordiandChanchali respectively.

The third aquifer is separated by the overlying second aquifer by 10 to 50 m thick intervening clay layer. Third aquifer thickness ranges from 70 m to 140 m. The thickness of third aquifer increase northwards north and south direction from Shalimar Garden (Ghaziabad district).

The fourth aquifer is separated by the overlying third aquifer by 12 to 60 m thick intervening clay layer. The fourth aquifer extends beyond 450 mbgl (Drilled depth). The basement encountered in Panchariya, Sadarpur, Nawada. The fourth aquifer does not exist at these locations.

6.1.2 (c) Aquifer Disposition along northern boundary of the study area in E-W direction(3-D Panel Diagram)

To show the aquifer disposition along northern boundary of the study area the litholog and geophysical logs of Koordi – Kakripur- Tikri- Tabelagarhi—Akeharerpur-Rehawati-Hastinapurare used to prepare the panel diagram in E-W direction i.e. river Yamuna to river Ganga.

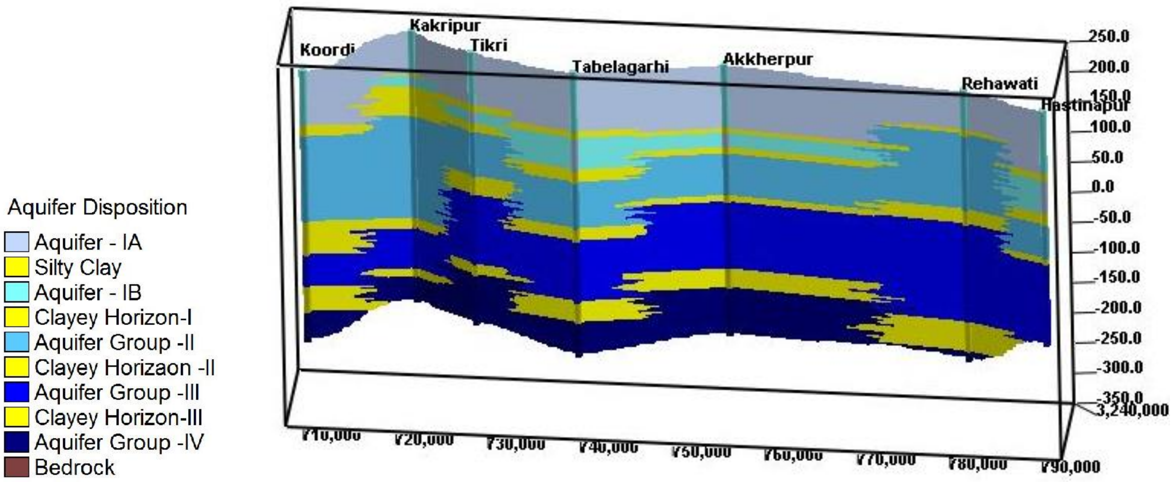


Figure 6.6: Panel diagram (3-D) showing the aquifer disposition along northern boundary of the area

The section oriented along E-W stretches over a length of 100 km and depicts the aquifer disposition up to a depth of 450 m (Fig. 6.6). This section reveals the presence of four principal aquifers lying below the top soil layer. The thickness of the first aquifer layer varies from 75 m in the eastern part to 160 m in middle part in Tabelagarhi and again decease towards waster part at koordi i.e. 90 m. The highly mixed nature of the aquitard layer and presence of occasional sand sequences at places even from the ground level makes the underlying 1st principal aquifer amenable to vertical recharge. The aquitard layer sustains dug wells and shallow hand pumps.

The second aquifer is separated by the overlying Ist aquifer by 10 to 50 m thick intervening clay layer. Second aquifer thickness ranges from 80 to 150 m. The thickness of second aquifer is more towards Ganga river catchment as compare to Yamuna river catchment.

The third aquifer is separated by the overlying second aquifer by 15 to 50 m thick intervening clay layer. The clay thickness increases from east to west and aquifer thickness increases toward eastern direction.

The fourth aquifer is separated by the overlying third aquifer by 30 to 40 m thick intervening clay layer. The fourth aquifer extends beyond 450 mbgl(Drilled depth). The thickness of the clay layer increases towards Yamuna catchment area.

6.1.3. Lithological variation of the Aquifer groups

For the sake of clarity, various panel diagrams are prepared in different orientations in terms of lithology as well as nature of quality of the aquifers. The fine sand, fine to medium sand, coarse sand and gravelly sand are assigned as sand in preparation of lithological panel diagram. The sand indicates the groundwater quality is good whereas sand (brackish/saline) indicates the quality of ground water is poor.

6.1.3 (a) Lithological variation along Ganga river, eastern boundary of the area in N-S direction (3-D Panel Diagram)

The lithological panel diagram prepared along the river Ganga in N-S direction shows sand dominant lithological facies down to 450 m depth. As moving from north to south sand grade is decreases and clay content increases from Meerut to Bulandshahar (Fig 6.7).

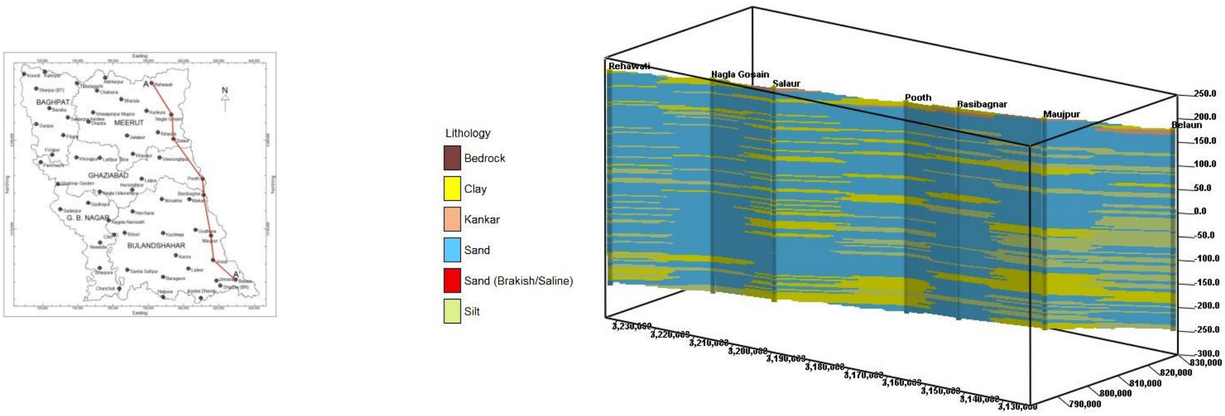


Figure 6.7: Panel diagram (3-D) showing the lithological variation along river Ganga

6.1.3(b) Lithological variation along Yamuna river, western boundary of the area in N-S direction (3-D Panel Diagram)

Perusal of the Litholgical section prepared along the river Yammuna shows clay dominant facies down to 450 m depth. In this area moving from north to south sand grade decreases and clay content increases from Baghpat to Gautam Budha Nagar District. (Fig 6.8). There is water quality (salinity) problem in this belt adjoining Yammua catchment area. Going from north to south saline zones are at shallow depth.

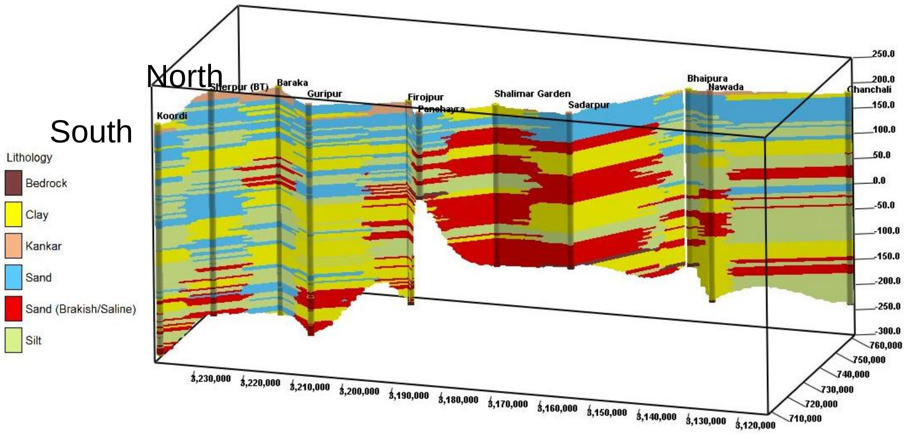


Figure 6.8: Panel diagram (3-D) showing the lithological variation along river Yamuna

6.1.3 (c) Variation in Aquifer Disposition & Lithology in N-S direction from eastern to western boundary

Three parallel panel diagrams are prepared in N-S direction from eastern to western boundary for the clarity of the aquifer disposition as well as lithological variation. As per aquifer disposition and lithological information from north to south along Yamuna, mid Yamuna & Ganga and along Ganga river shows variation in clay facies. As moving from Ganga to Yamuna catchment area, clay dominance in aquifer disposition increases (Fig 6.9 a & b). There sharp change while moving from Bulandshahar to Gautam Budha Nagar & from Baghpat to G. B. Nagar. As compared this aquifer group with formation water quality, shows salinity problem in Yamuna catchment area and in southern part of Bulandshahar district adjoining Aligarh district.

6.1.3 (d) Variation in Lithology in E-W direction from northern to southern boundary

Seven lithology panel diagrams are prepared in E-W direction from northern to southern boundary of the area (Fig. 6.10). Total seven panel’s shows mount variation in lithology of the area. It shows decrease in sand grade and increase in clay content from north to south and east to west. Only in Meerut district there is no problem regarding formation water quality (Salinity). The western part of Baghpat, Ghaziabad, G.B Nagar and Sothern part of Bulandshahar district is salinity affected.

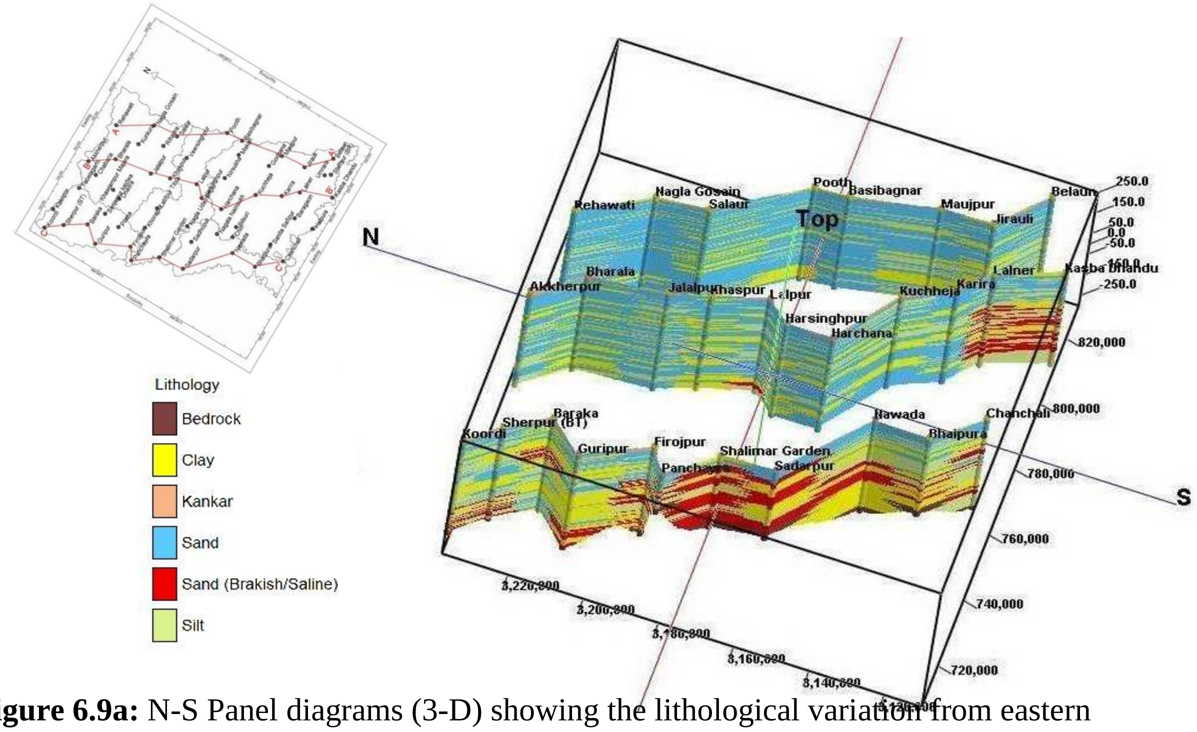


Figure 6.9a: N-S Panel diagrams (3-D) showing the lithological variation from eastern boundary to western boundary

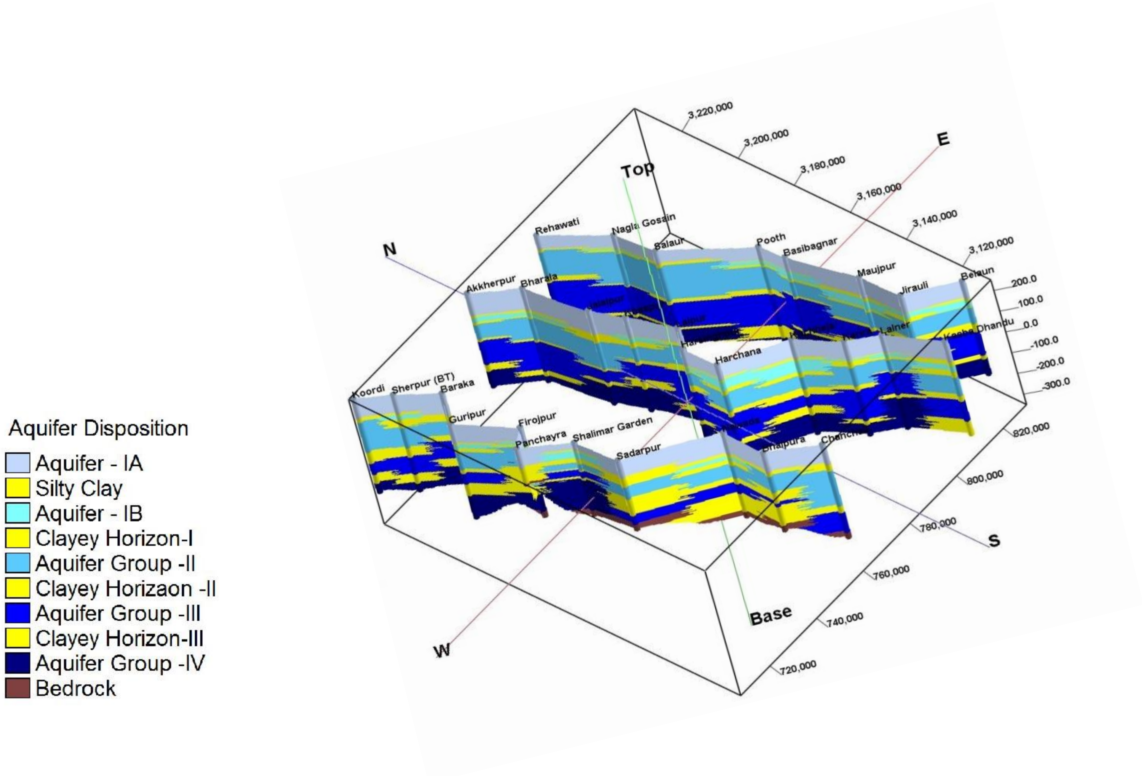


Figure 6.9b: N-SPanel diagrams (3-D) showing aquifer disposition from eastern Boundary to western boundary

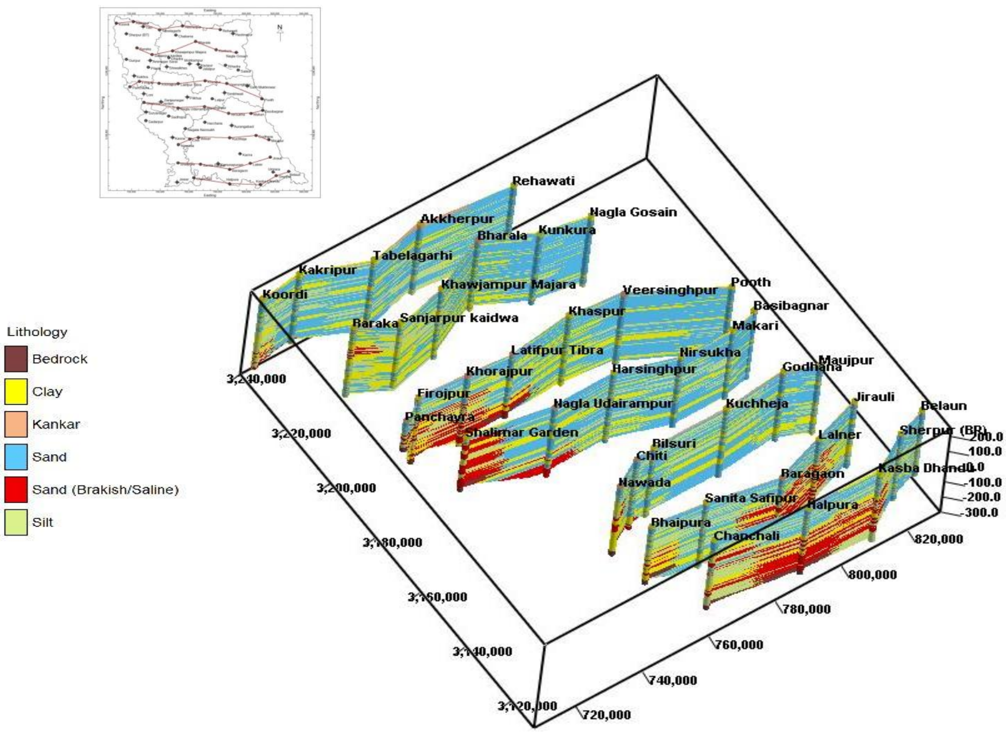


Figure 6.10: E-W Panel diagrams (3-D) showing lithological variation from eastern boundary to western boundary

6.1.4 District-wise Aquifer Map

For the clarity of the aquifer disposition and lithological variation, district-wise 3-D multi- logs of aquifer disposition, lithological disposition and fence diagrams are prepared and presented.

6.1.4 (a) Baghpat District (3-D Multi-logs and Fence Diagram)

To know the aquifer disposition and lithological variation of Baghpat district, 3-D multi-log and fence diagram are prepared (Fig. 6.11 & 6.12). Fig. 6.11 & 6.12 indicates that the quality of aquifers is poor as well as aquifers present is clay dominant in northwest and southwest of the district. In North western part (Koordi, Sherpur & Gauripur) Fresh water zone occurs down to 350 mbgl. In this part ground water is Brackish below 350 mbgl (Aquifer-IV). In southern (Firojpur)ground water is Brackish to saline below 140 mbgl.In this part only first aquifer is fresh, In middle part of the district (Baraka) brackish zone occurs in depth range 139 to 198 mbgl (Aquifer-II) and other aquifers are fresh. In north and eastern part (Kakripur, Tabelagarhi, Sajarpur Kaidwa and Pilana) water is fresh in all aquifers.

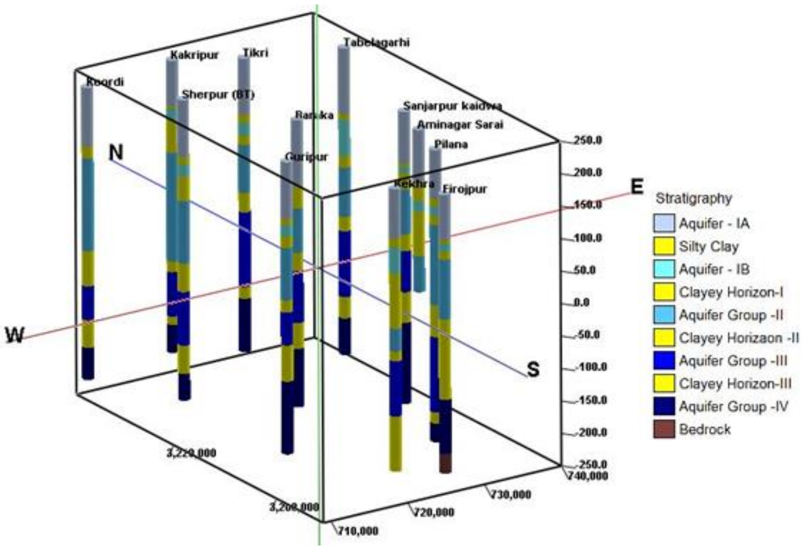
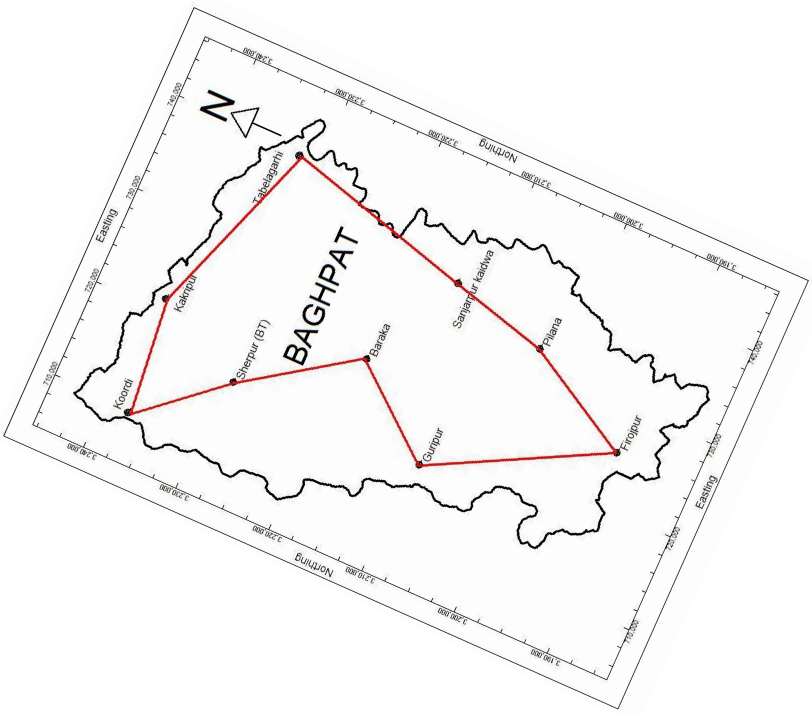


Figure 6.11: 3-D Multi-log of aquifer disposition and lithological variation of Baghpat district



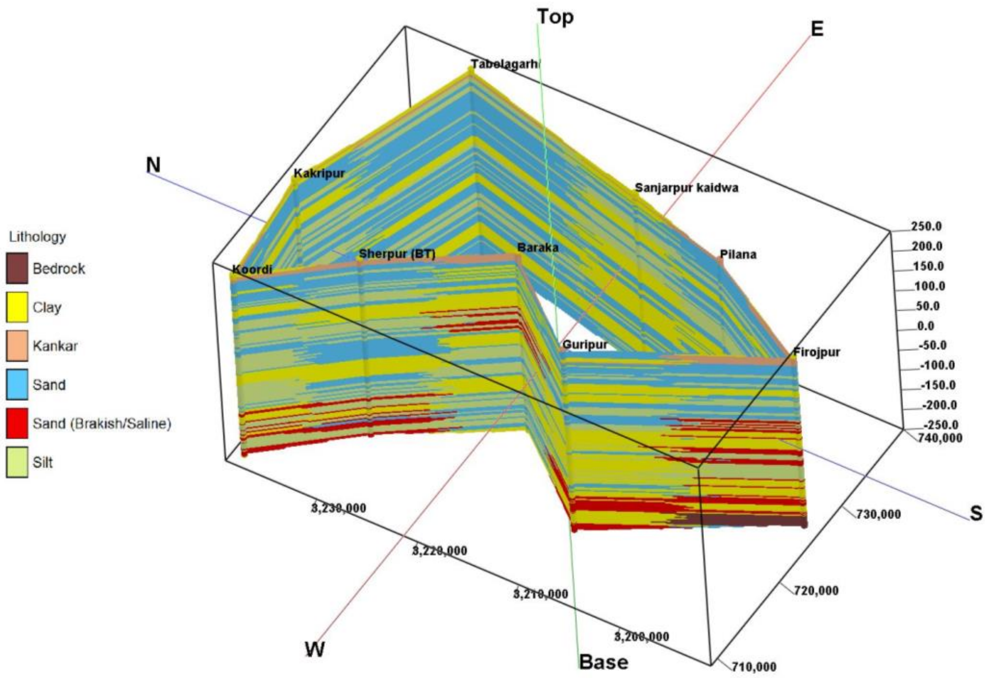


Figure 6.12: Fence diagram showing lithological variation of Baghpat district

6.1.4(b) Meerut District (3-D Multi-logs and Fence Diagram)

3-D multi-log and fence diagram are prepared to know the aquifer disposition and lithological variation of Meerut district (Fig. 6.13 & 6.14). The maps illustrating that the quality of aquifers is good as well as aquifers present is sand dominant in northeast and southeast of the district. The depth of boreholes ranges from 450 to 471 m. The geophysical logs of the boreholes drilled in the district indicate the presence of fresh water aquifer throughout the depth drilled.

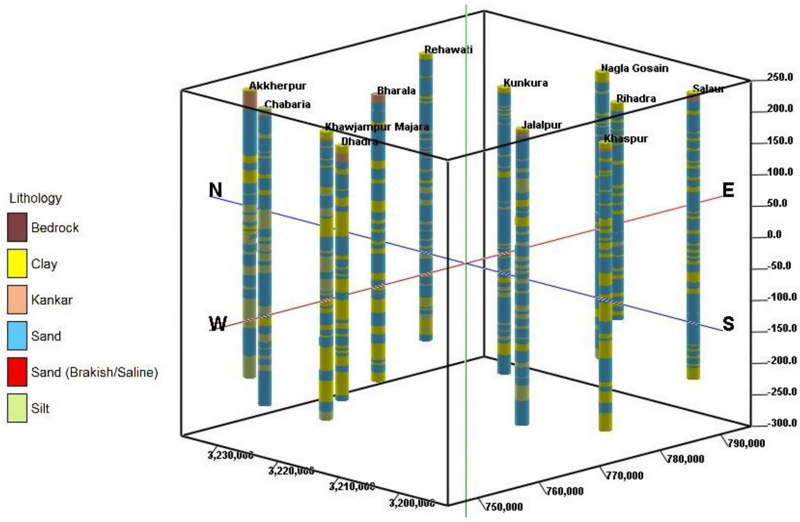


Figure 6.13: 3-D Multi-log of aquifer disposition and lithological variation of Meerut

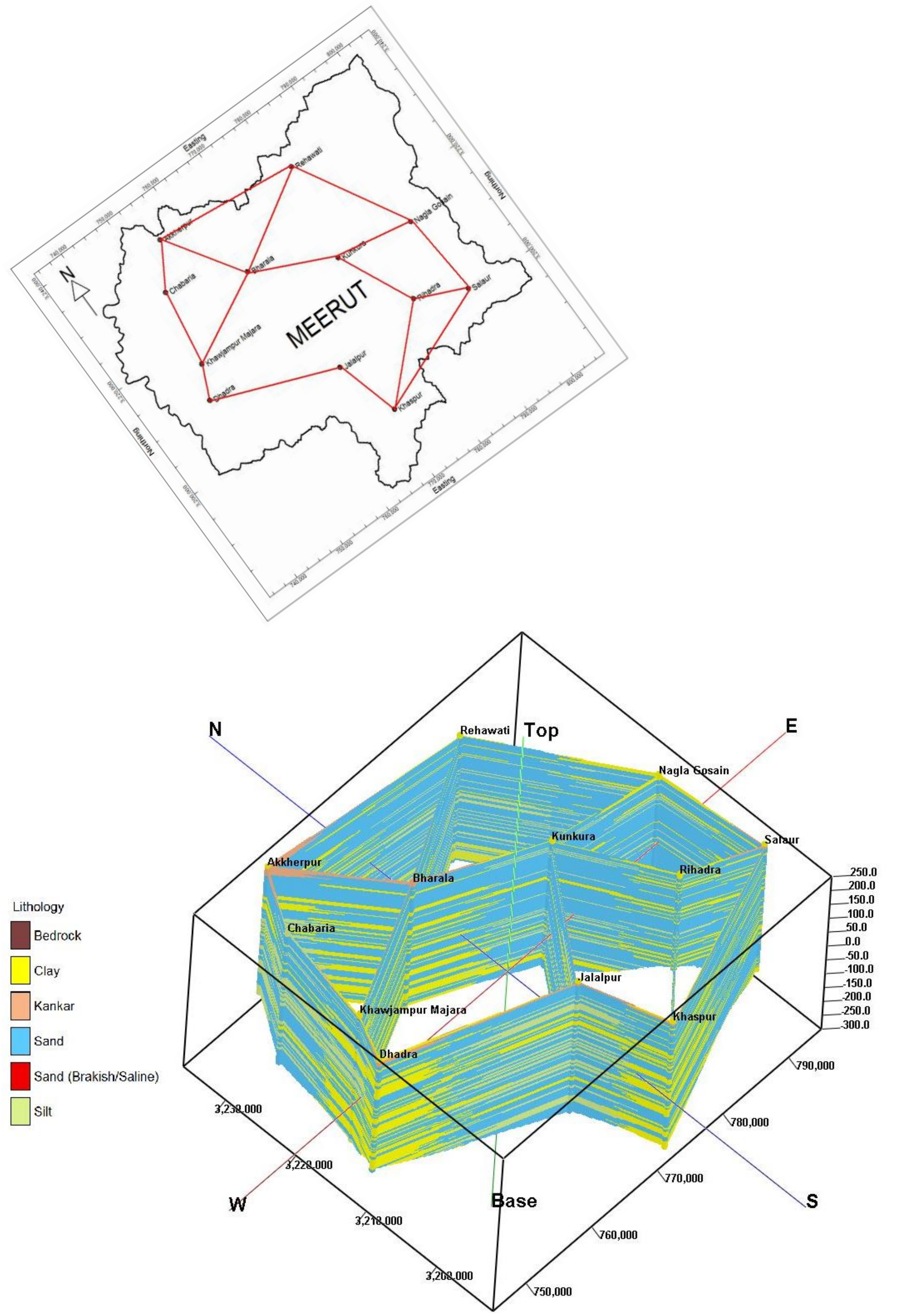


Figure 6.14: Fence diagram showing lithological variation of Meerut district

6.1.4 (c) Ghaziabad District (3-D Multi-logs and Fence Diagram)

Fence diagram and 3-D multi-log are prepared to know the aquifer disposition and lithological variation of Ghaziabad district (Fig. 6.15 & 6.16). The 3-D multi-log and fence diagram clearly indicates that the quality of aquifers is good in eastern and poor in western part of the district. The alluvial formation in Ghaziabad district holds prominent aquifers within 100m depth. This near surface aquifer is extensive, present almost throughout the district with varied thickness. As moved deeper the sand layers forming the aquifers become thin with prominent interbeds of clay and finer sediments The shallow occurrences of brackish/saline groundwater is in the western most part in the area between the rivers Yamuna and Hindon, as observed in the boreholes at Pancharya and Shalimar Garden where the depth to brackish/saline groundwater is 74 and 58 m respectively. The salinity occurrs below Aquifer-II at eastern side at Khorajpur. In latifpur Tibra,Lalpur and Nagla Udairampur fourth aquifer is saline. The boreholes at Harsinghpur and Pooth have indicated moderate resistivity throughout the depth drilled and hold fresh water. The bed rock was encountered in western part boreholes, viz.,Loni, Pancharya, Shalimar Garden and Latifpur Tibra at 118, 168, 320 and 395m m depth respectively.

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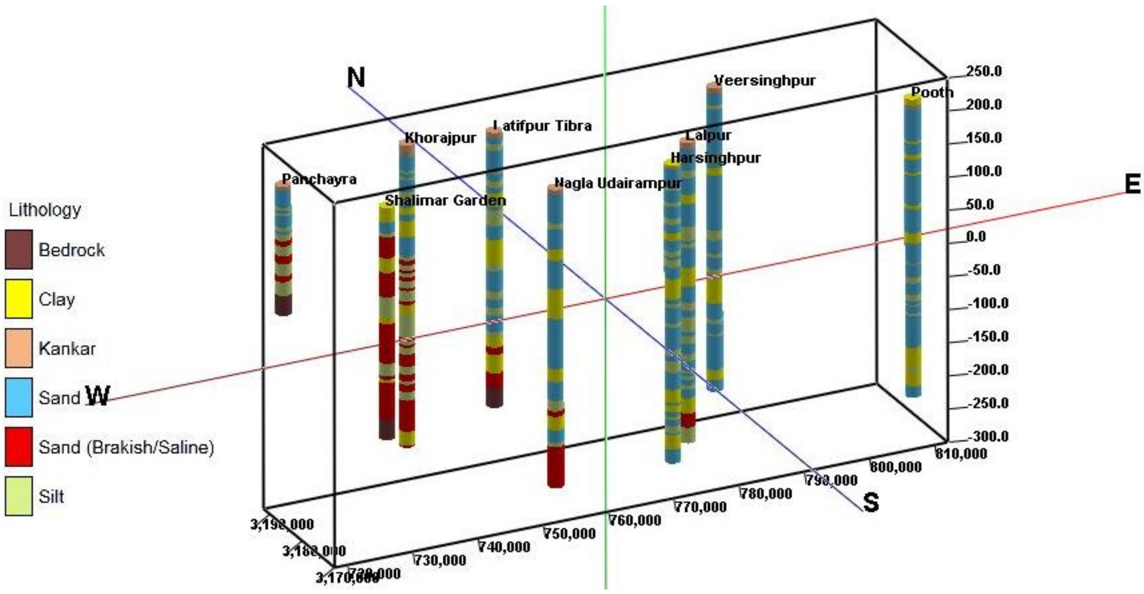


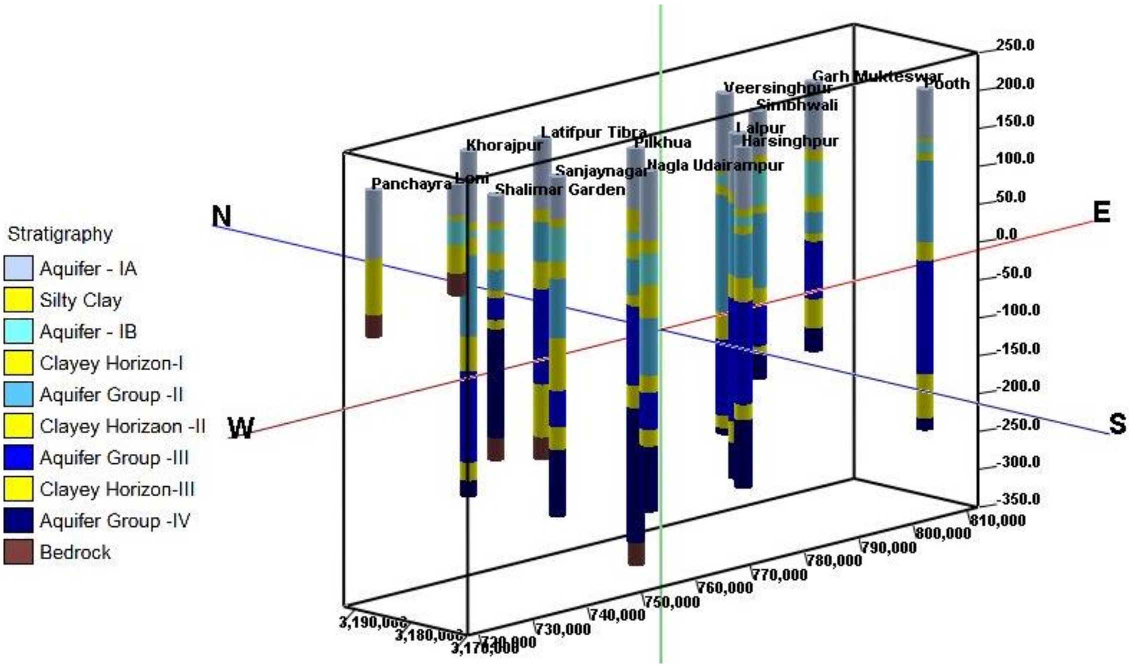
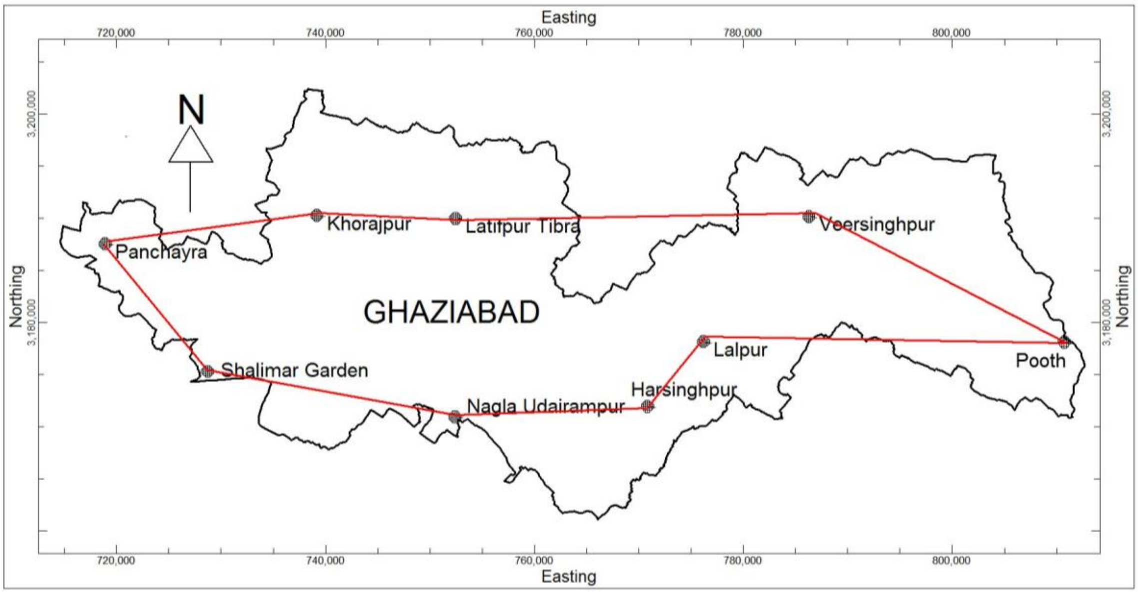


Figure 6.15: 3-D Multi-log of aquifer disposition and lithological variation of Ghaziabad district



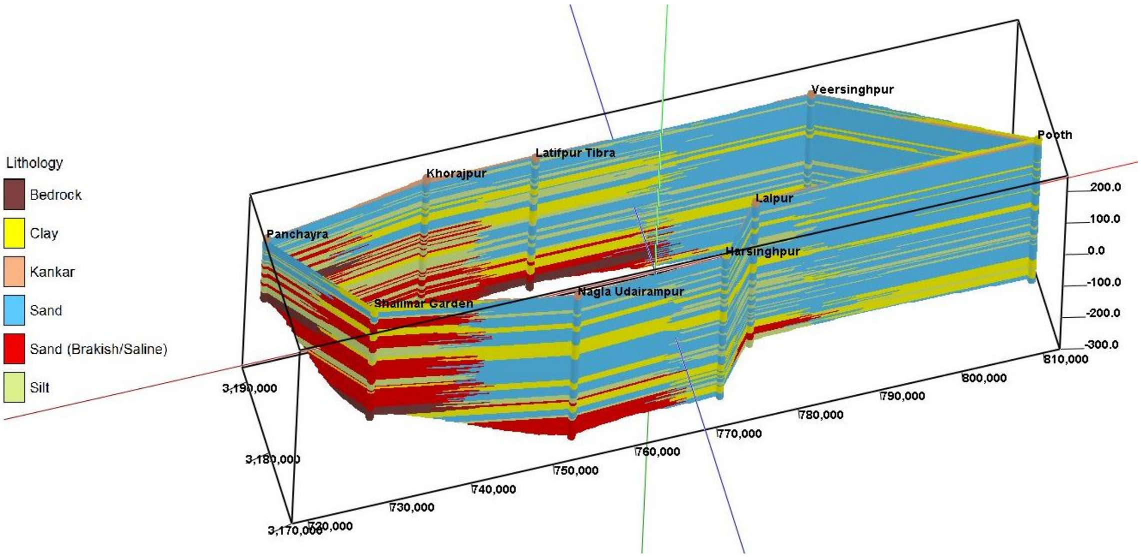
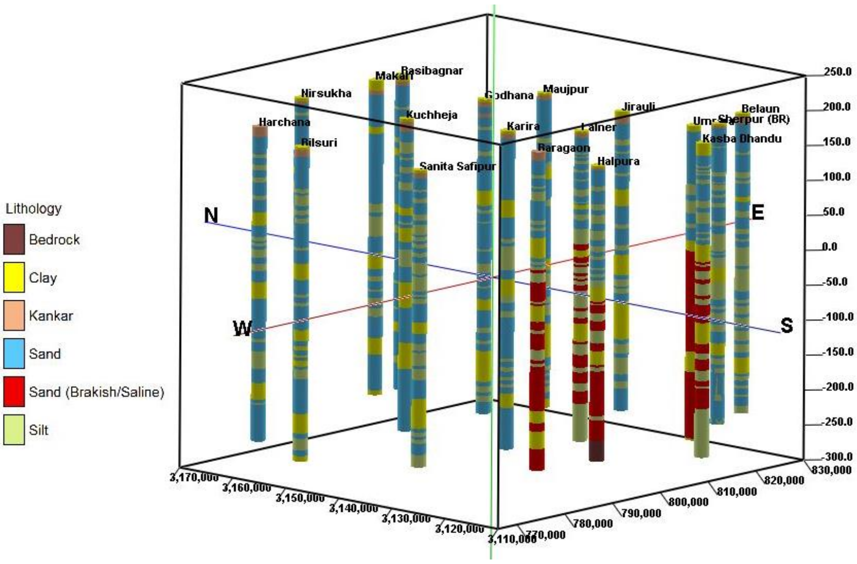


Figure 6.16: Fence diagram showing lithological variation of Ghaziabad district

6.1.4(d) Bulandshahar District (3-D Multi-logs and Fence Diagram)

Aquifer disposition and lithological variation of Bulandshahar is demonstrated by fence diagram and 3-D multi-log (Fig. 6.17 & 6.18). The 3-D multi-log and fence shows that the quality of aquifers is good in northern and poor in southern of the district. At Baragaon, Halpura, Kasba Dhadu, Umrara and Lalner only first aquifer is fresh. The formation water is Brakish/saline below first aquifer in southern part adjoining Aligarh district.



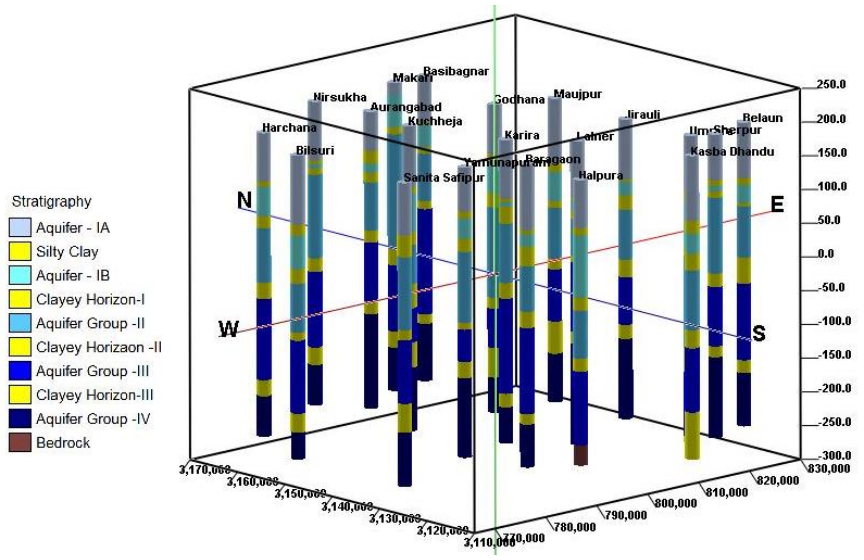
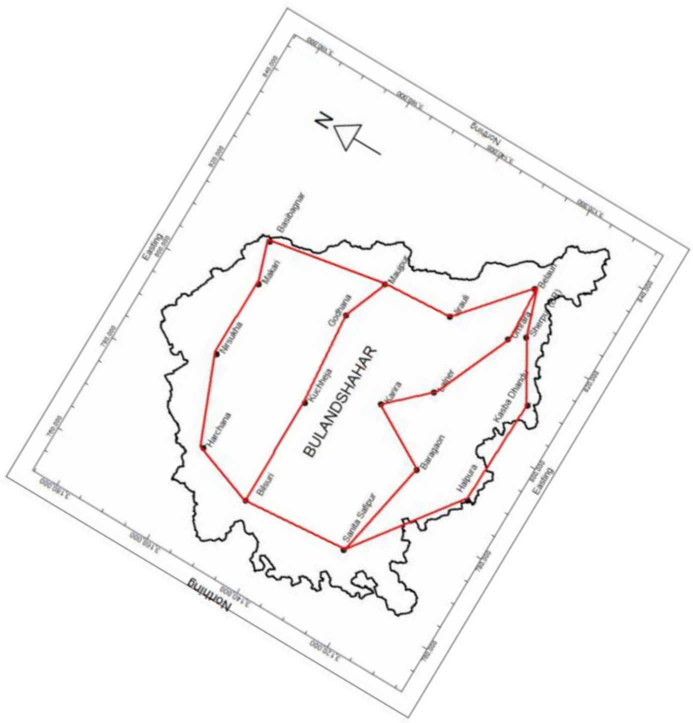


Figure 6.17: 3-D Multi-log of aquifer disposition and lithological variation of Bulandshahar district



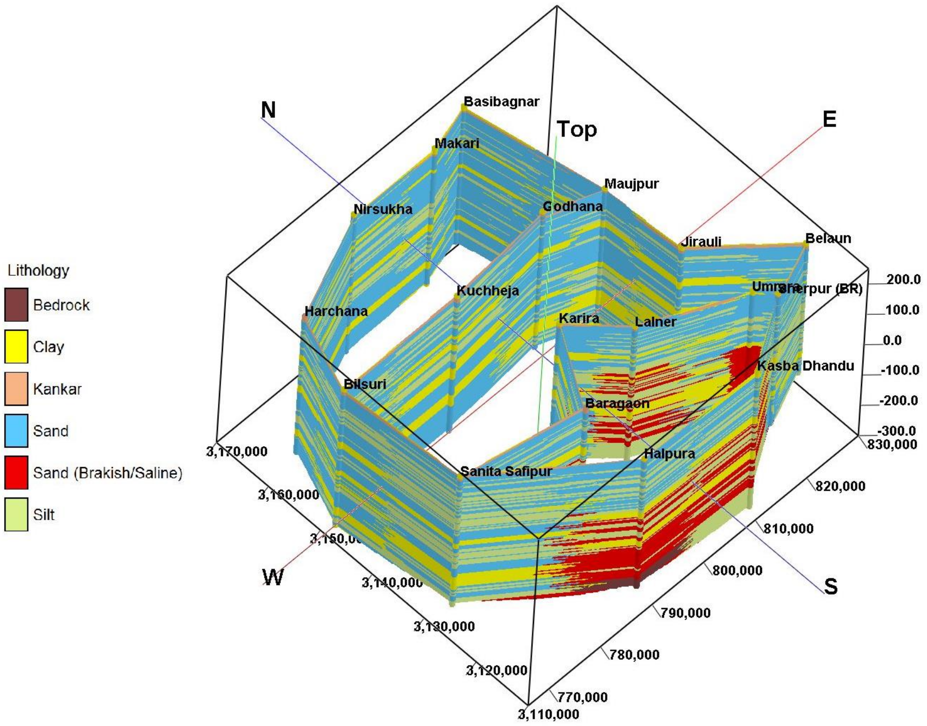
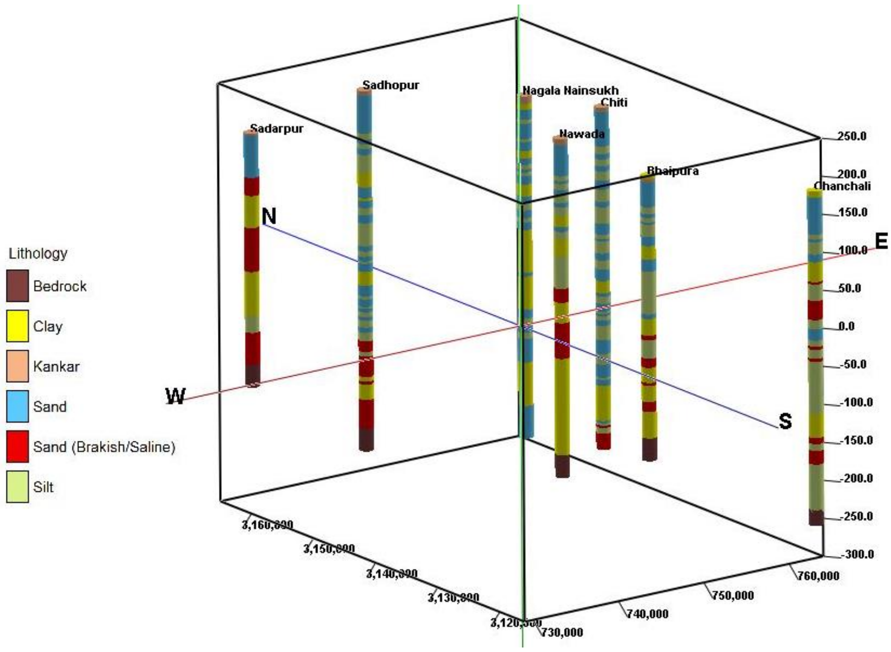


Figure 6.18: Fence diagram showing lithological variation of Bulandshahar district

6.1.4(e) Gautam Buddh Nagar District (3-D Multi-logs and Fence Diagram)

Lithological variation and aquifer disposition of Gautam Buddh Nagar is presented by fence diagram and 3-D multi-log (Fig. 6.19 & 6.20). The 3-D multi-log and fence indicates that the quality of aquifers is poor in all the bore wells in the district except at one place at Nagla Nainshukh, the quality is found good in northeastern part of the district. In northern western part at Sadarpur saline zone starts in first aquifer at 58 mbgl whereas in north eastern part at Sadhopur it occurs in third aquifer at 329 mbgl. In eastern part at Chiti saline zone occurs in IV th Aquifer i.e. 416 mbgl. In Nawada saline zone starts at 197 mbgl(i.e. Aquifer-II). In Sothern part at Bhaipura & Chanchali saline zone starts from Aquifer-II and continues down to drilled depth. The Bed rock encountered at 310 mbgl at Sadarpur,419 mbgl at Chanchali,416 mbgl at Nawada and at 444 mbgl at Sadhaopur. At chiti and Nagala Nainsukh down to 450 m Bed Rock not encountered.



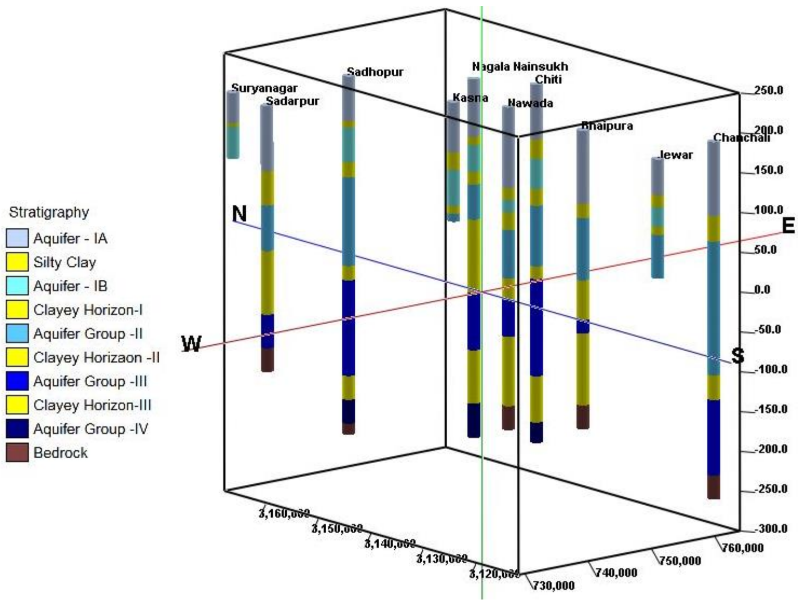


Figure 6.19: 3-D Multi-log of aquifer disposition and lithological variation of G. B. Nagar district

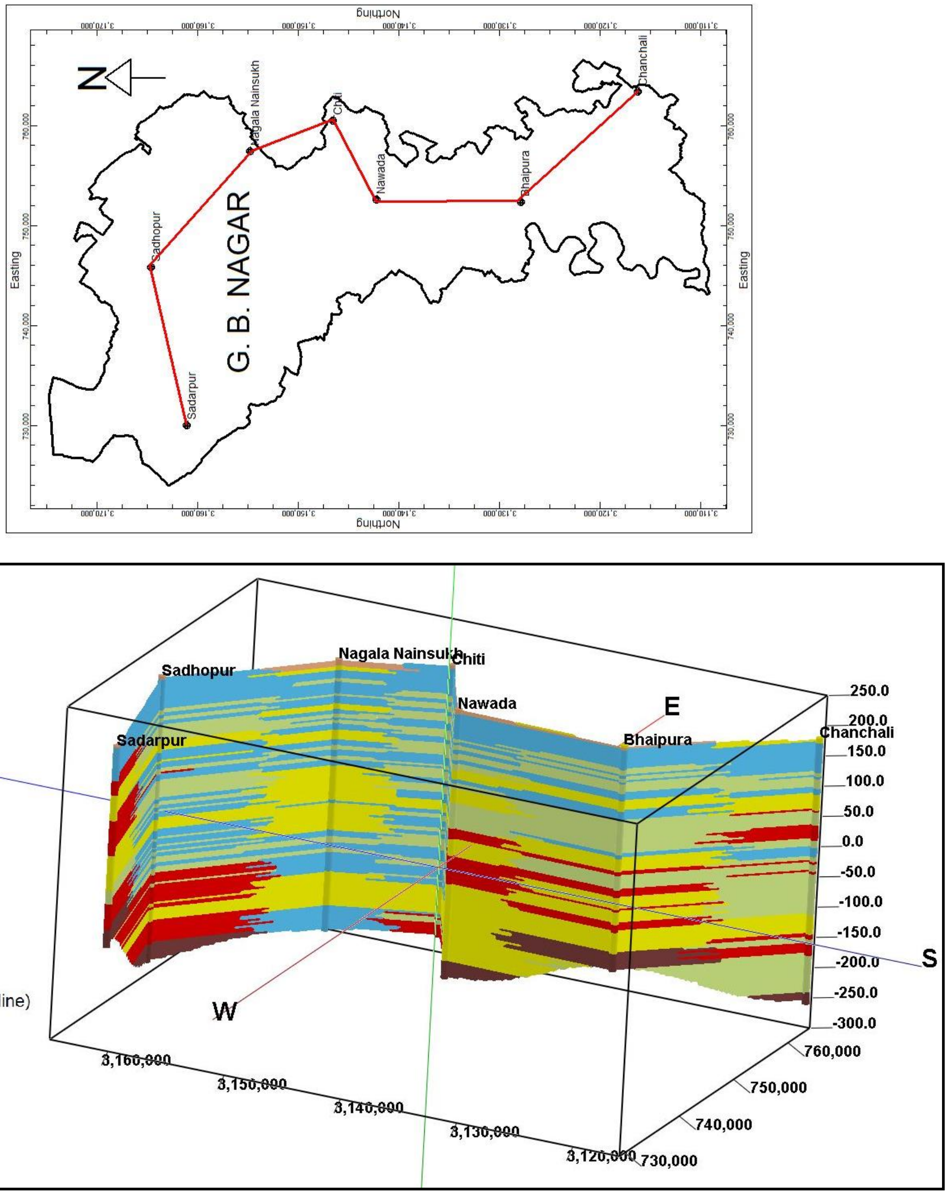


Figure 6.20: Fence diagram showing lithological variation of G. B. Nagar district

6.1.5 Spatial variation of Aquifer thickness (Sand Deposition)

Based on the lithological and geophysical logs results of boreholes drilled in the area cumulative sand layer or aquifer thickness was calculated for the depth ranges: water table-100 m, 100-200 m, 200-300 m and 300-400 m and presented as 2-D maps (Fig. 6.21, 6.22, 6.23 and 6.24). The significant outcome of these maps is an insight into the regional distribution and trend of the aquifers in different depth ranges.

These maps reveal that sand percentage decreases westwards from river Ganga to Yamuna in the area. The granular zone thickness down to shows 100 m depth shows a lesser cumulative thickness in the western part and a general increase towards east of river Hindon. For the depth range 100-200 m, sand percentage is less than 40% covers almost half of the entire area (Fig. 6.22). Sand percentage is maximum in northeast of the Meerut district. Fig. 6.23 shows that the sand percentage decreases towards west and south of the entire area. The granular zone thickness in the depth range 300-400 m indicates that almost 75% of the area is less than 40% sand percentage (Fig. 6.24). The NNE-SSE trending linear moderately thick sand zone parallel to the course of river Ganga is indicative of palaeo-channel. For the deeper ranges the cumulative aquifer thickness increases towards northeast of area near river Ganga.

6.1.5 (a) Isopach Map of Aquifer Group Thickness

Isopach map of the individual aquifer groups have been prepared to know the clear impression of aquifer group thickness in the entire area (Fig. 6.25, 6.26 & 6.27). There is variation in thickness of aquifer group but in regional scale they are making different groups on the basis of aquifer characteristics and grade of sand and clay.

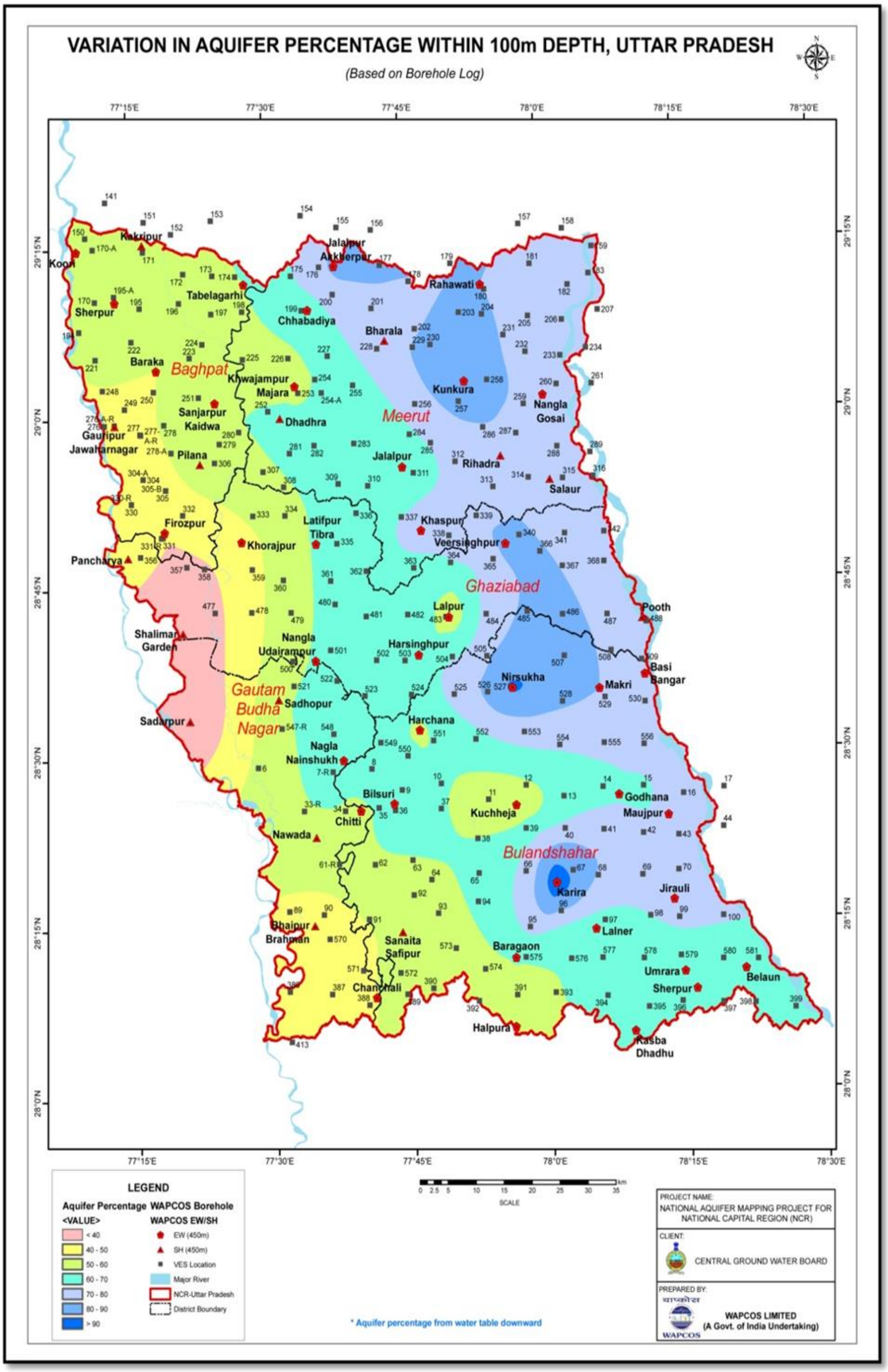


Figure 6.21: Variation in aquifer percentage (based on sand layer thickness) within 100 m depth

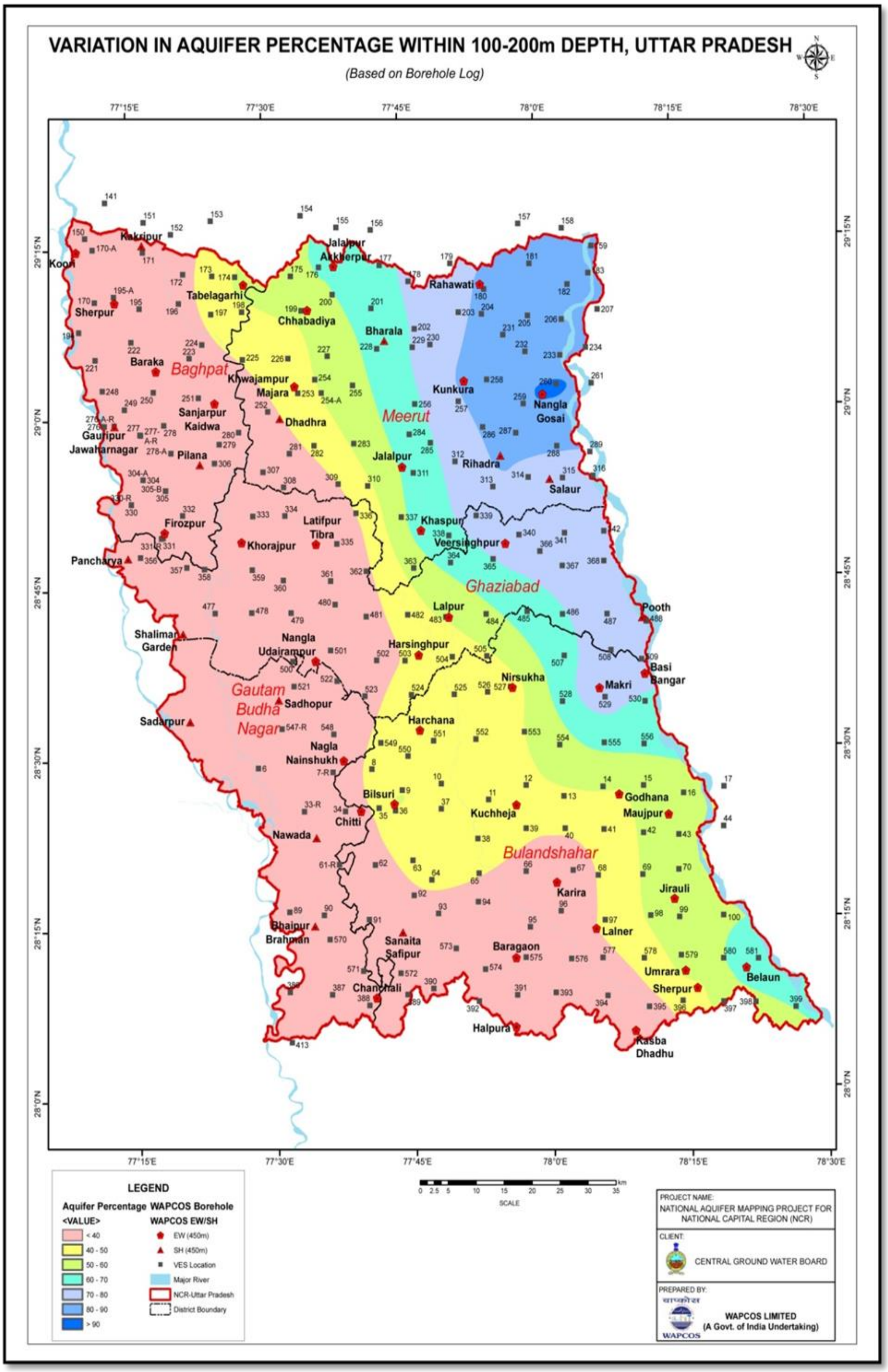


Figure 6.22: Variation in aquifer percentage (based on sand layer thickness) within 100-200 m depth

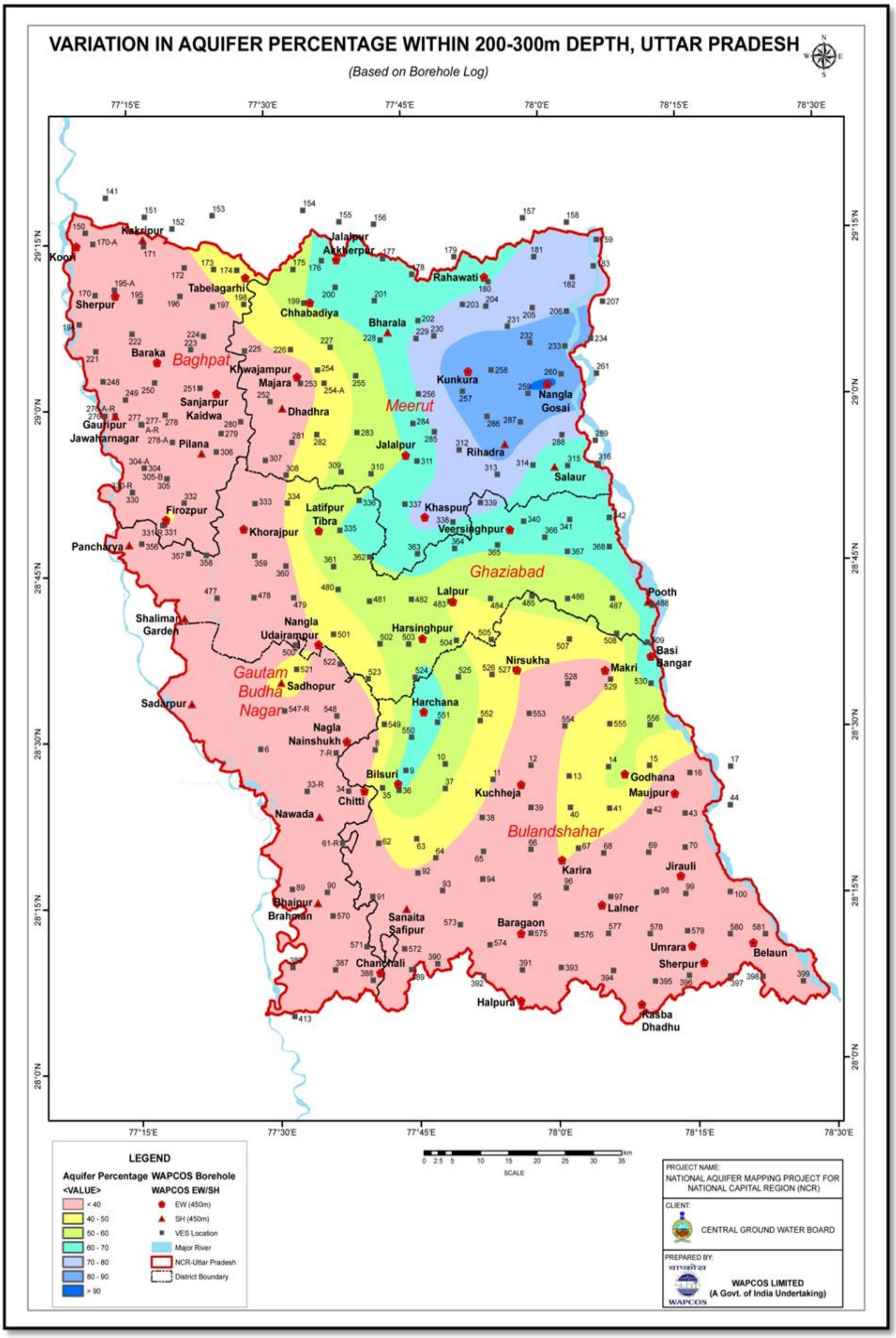


Figure 6.23: Variation in aquifer percentage (based on sand layer thickness) within 200-300 m depth

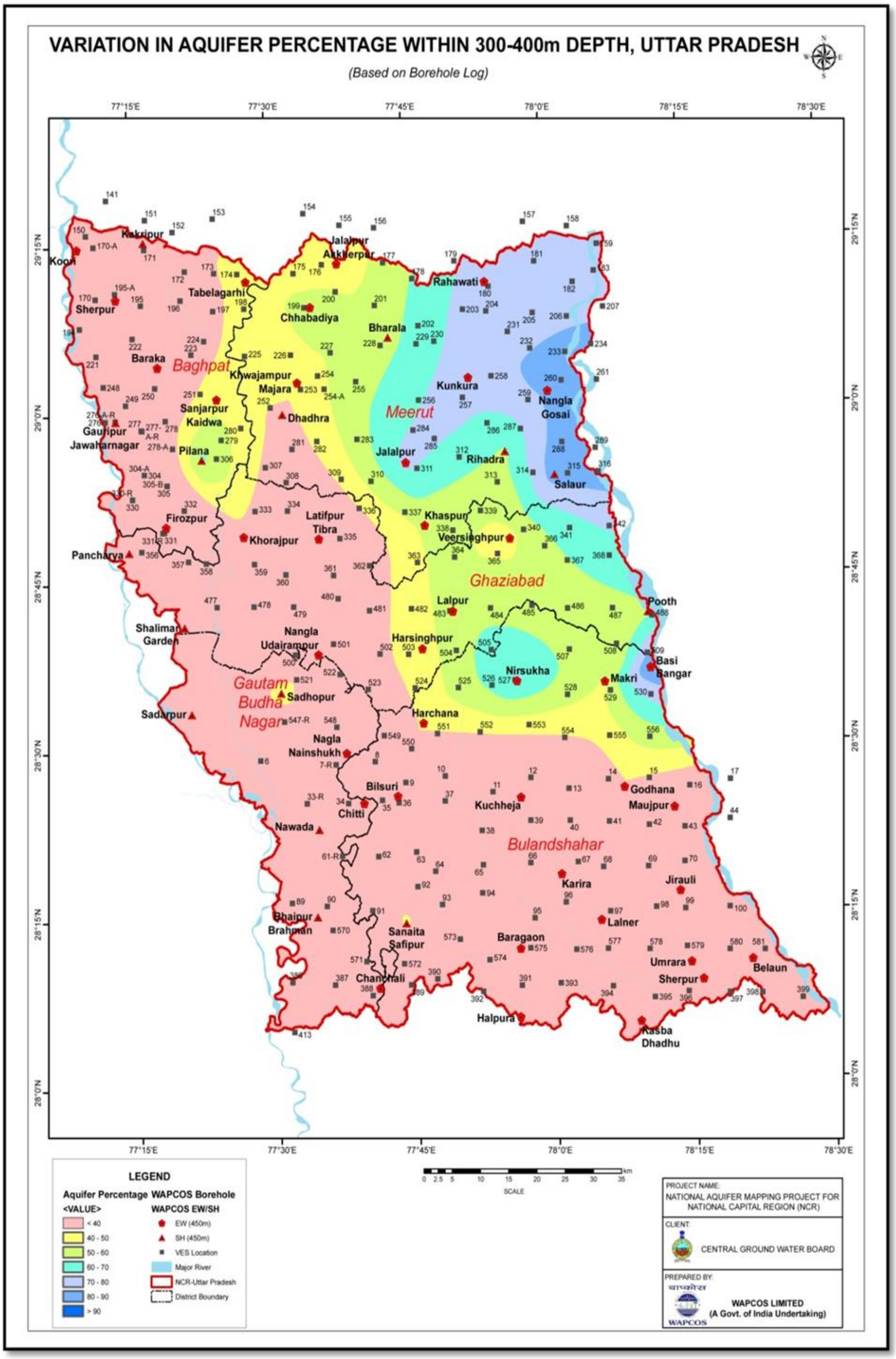


Figure 6.24: Variation in aquifer percentage (based on sand layer thickness) within 300-400 m depth

Fig. 6.25 reveals that the thickness of 1st aquifer is minimum in Baghpat, Meerut and Bulandshahar at some places. The aquifer group thickness range from 50 to 75m covers major part of Baghpat, Gahzabad, G.B. Nagar and in small patches in part of Bulandshahar and southwestern of Meerut district. The aquifer thickness is more than 75 m in Meerut, Ghaziabad and Bulandshahar district and small patches in Baghpat and G.B. Nagar district.

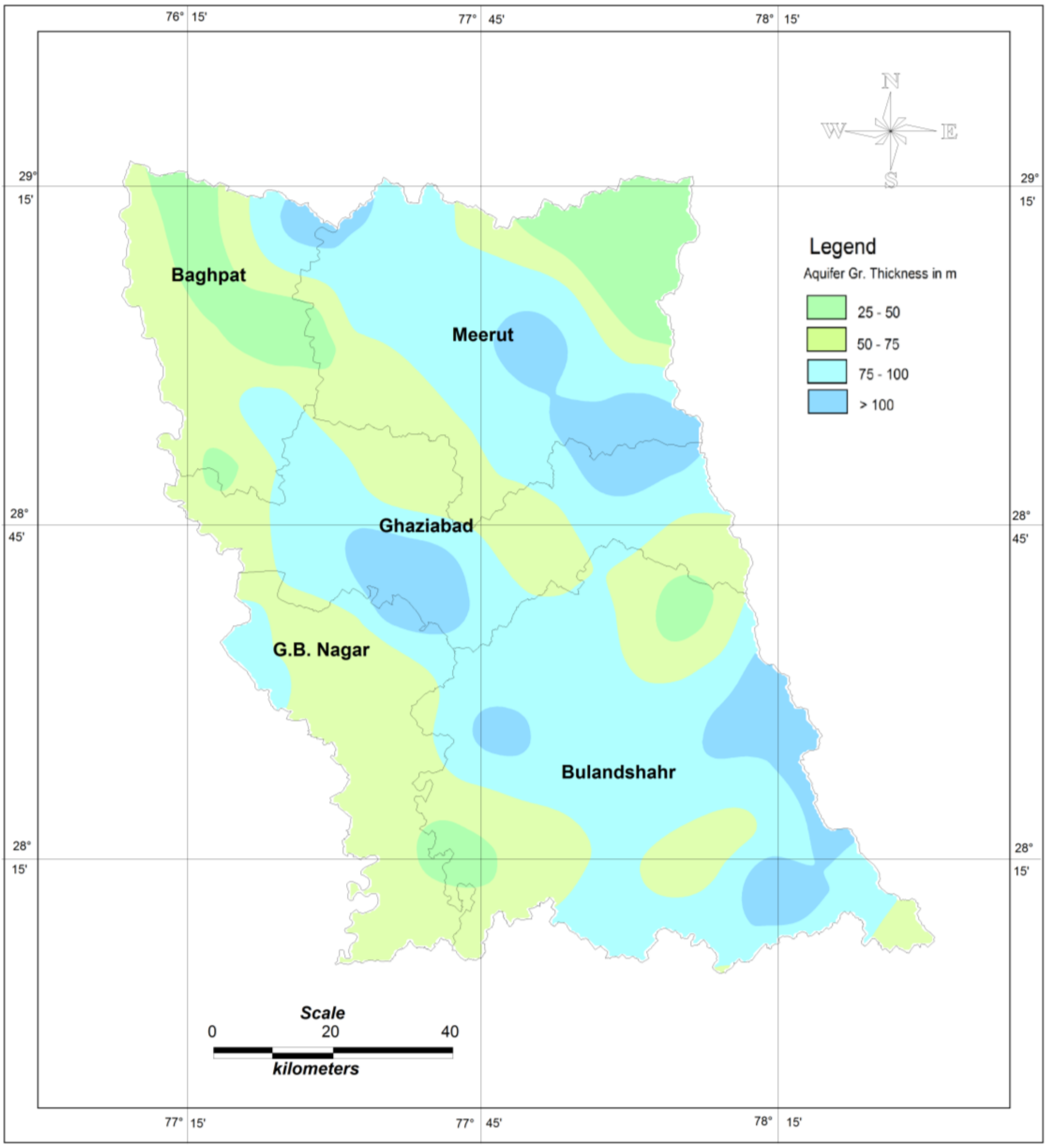


Figure 6.25: Isopach Map of 1st aquifer group in the area in NCR, U.P.

The thickness of 2nd principal aquifer is comparatively much thicker than the 1st principal aquifer group. Fig. 6.26 reveals that the thickness of the 2nd principal aquifer is maximum in northeastern part of Meerut district, east of the Ghaziabad district and in some part of the Bulandshahar district. The second aquifer thickness is decrease from east to west and also in southern direction.

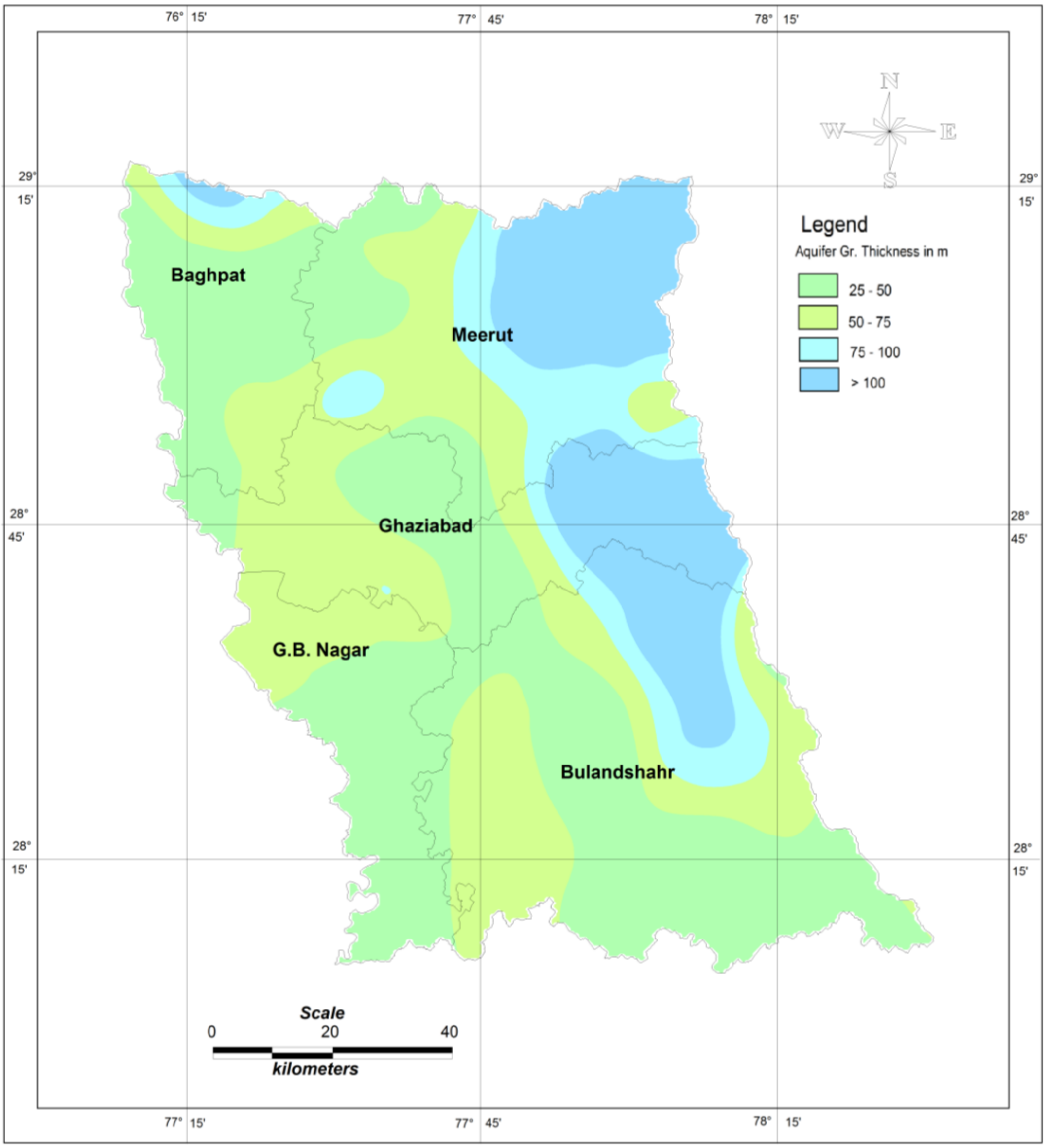


Figure 6.26: Isopach map of 2nd aquifer group in NCR,U.P.

The third principal aquifer group is comparatively much less thickness as compare to second aquifer reveals that the thickness decreases from northeast to southwest direction in general. The thickness between 75-100 meters patch is in northeastern of Meerut district and some parts of Ghaziabad and Bulandshahar districts.

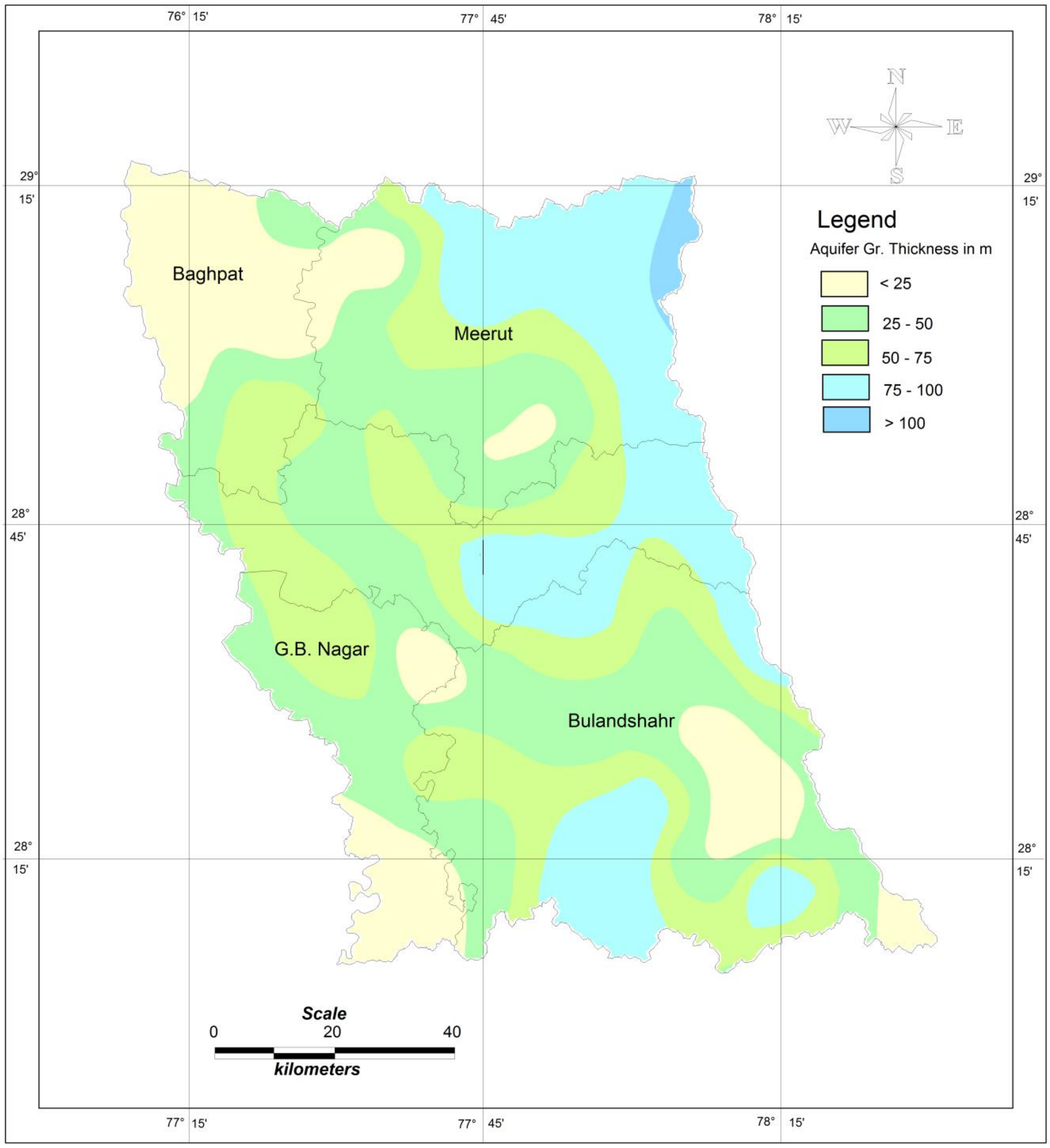


Figure 6.27: Isopach Map of 3rd aquifer group in NCR, U.P.

Aquifer material in percentage Aquifer Group wise plotted for aquifer I and Aquifer II shown in Figure 6.28 & 6.29. There is wide variation in aquifer material % in the area. The granular zone percent in Aquifer Ist is between 60 to 80 percent major part of Ghaziabad, Meerut and Bulandshahar districts and some parts of G.B. Nagar district. It is even more than 80 % in some parts of Ghaziabad and Bulandshahar district.

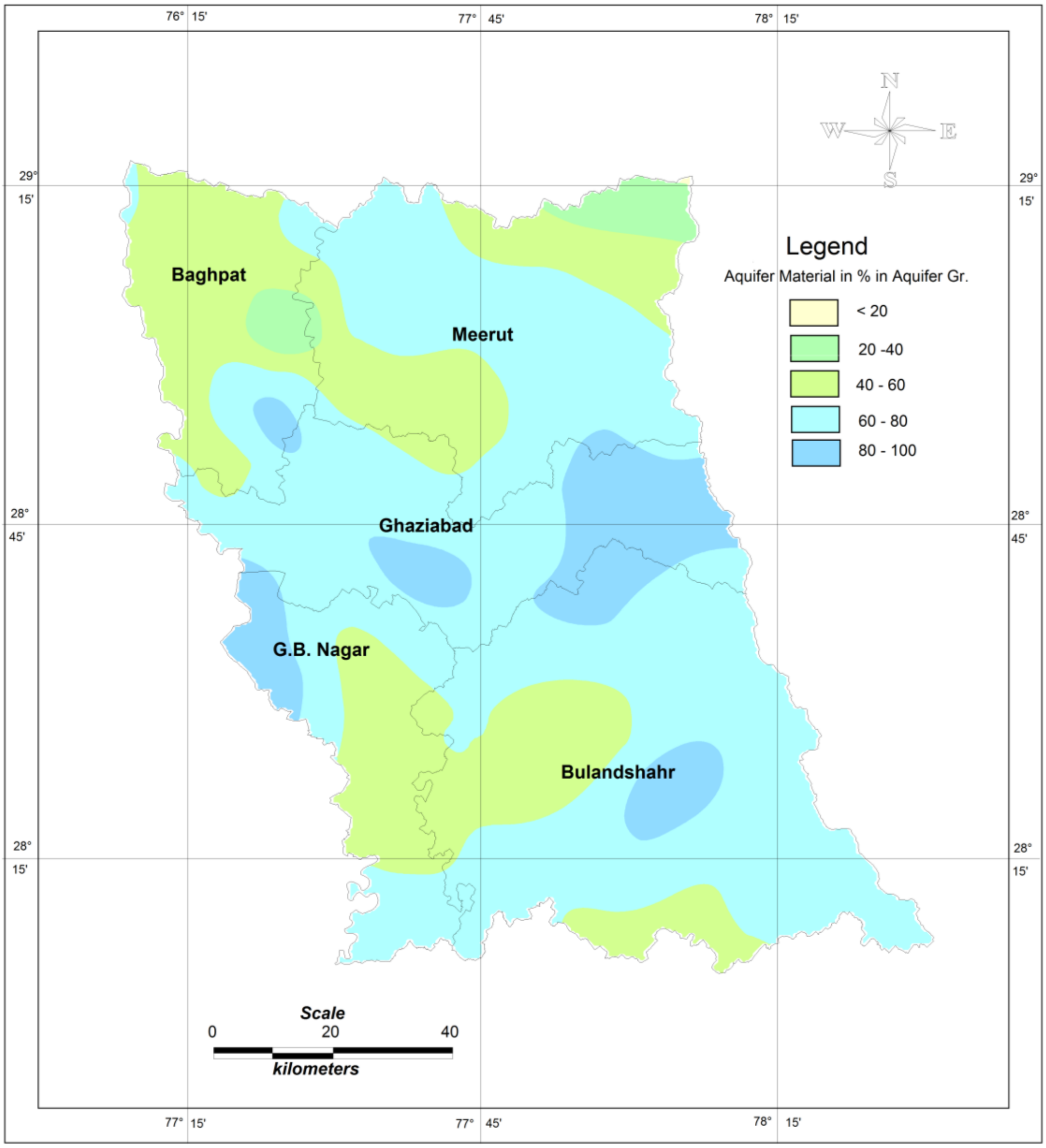


Figure 6.28 Aquifer material percent in 1st Aquifer in NCR, U.P.

For Aquifer-II Group aquifer material percent is more than 80% in major part of Meerut, Ghaziabad and some part of Bulandshahar district adjoin to River Ganga. As moving from east to west aquifer material percent decrease.

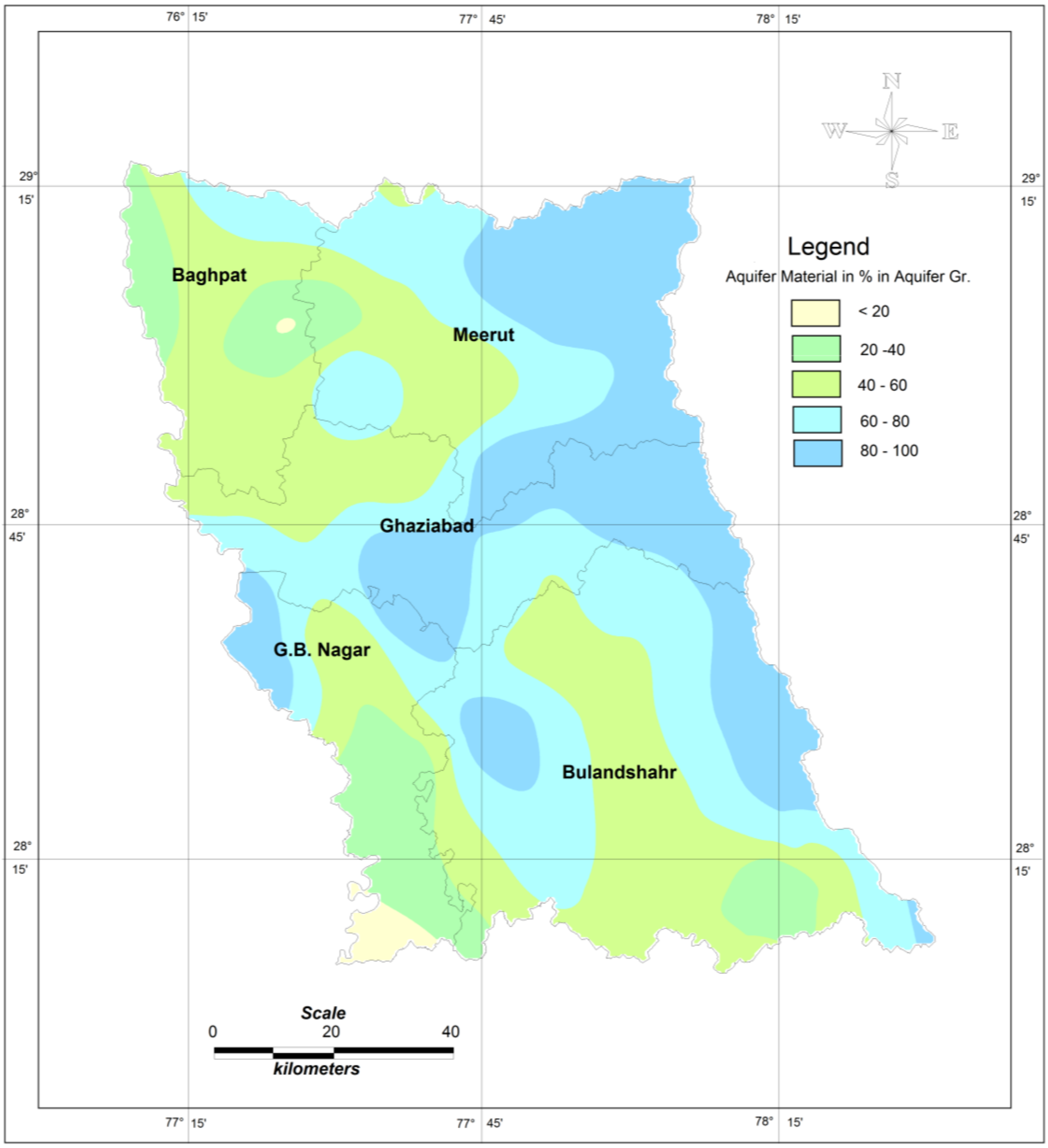


Figure 6.29: Aquifer material percent in II Aquifer in Study area

6.2 Aquifer Parameters

To know the aquifer parameters pumping tests were conducted and transmissivity and storativity values were computed for four aquifer groups in the area. The hydraulic conductivity values were derived by dividing transmissivity with thickness of aquifer Group tapped in respective wells. Hydraulic conductivity of phreatic aquifer determined using slug test conducted in Hand Pumps.

6.2.1 Transmissivity

The value of transmissivity varies in first aquifer derived from time average saturated varies from 1568 to 5314 m^2/day. In second aquifer it varies from 627 to 2783 m^2/day. The transmissivity range of third aquifer varies from 690 to 2783 m^2/day whereas in fourth aquifer it varies from 301 to 2760 m^2/day. The values of transmissivity details are given in (Table-6.2). The analyzed transmissivity values for Upper Yammuna Project are given in Table-6.3.

6.2.2 Hydraulic Conductivity

The hydraulic conductivity varies in first aquifer from 18 to 64 m/day. In second aquifer it varies from 4 to 34 m/day. The hydraulic conductivity range of third aquifer varies from 6 to 31 m/day whereas in fourth aquifer it varies from 4 to 38 m/day. The variation in hydraulic conductivity in the area given in Table-6.2.

6.2.3 Storage Parameter:

In absence of field observations specific yield of unconfined aquifer has been taken from finding of Upper Yammua project as well as from GEC.

Table 6.2(a): Aquifer Parameters as per data Generation in study area

Aquifer Group	Parameters	Range		Average
		From	To	
I	T (m^2/d)	1568	5314	2750
	K(m/d)	18	64	30
II	T (m^2/d)	690	2783	1800
	K(m/d)	4	34	20
	S	$1.26*10^{-3}$	$3.5*10^{-5}$	
III	T (m^2/d)	690	2783	1500
	K(m/d)	6	31	14
	S	$1.85*10^{-3}$	$2.87*10^{-5}$	
IV	T	301	2760	1500
	K	8	34	17
	S	$1.4*10^{-4}$	$8.15*10^{-5}$	

Aquifer Group	Parameter	Range From	To	Average
I	T (m^2/d)	800	5200	2200
	K (m/d)	8.75	47	24
	Sy	2.1	24	12
II	T (m^2/d)	305	1050	700
	K(m/d)	3.95	10.7	8.2
	S	$5.6*10^{-4}$	$2.7*10^{-3}$	$1.5*10^{-3}$
III	T (m^2/d)	345	830	525
	K(m/d)	3.5	10.7	8.1
	S	$6.6*10^{-4}$	$2.4*10^{-4}$	$4.5*10^{-4}$

Table 6.3(b): Aquifer Parameters as per Upper Yamuna Project

6.2.4 Storativity

The storativity values were also determined by conducting aquifer performance test in exploratory wells. The storativity values of 2nd, 3rd and 4th aquifer groups are presented in Fig. 6.30. In second aquifer storativity varies from $1.3x10^{-3}$ to $8.7x10^{-8.}$ The storativity range of third aquifer varies from $1.6x10^{-3}$ to $4.3x10^{-6}$ whereas in fourth aquifer it varies from $1.7x10^{-3}$ to $1.1x10^{-5}$. The details are given in Table 6.2.

6.2.5 Slug Test

Slug and pumping tests are the common hydrological tests that are usually used to determine in-situ properties of water-bearing formations (aquifer) and define the overall hydrogeological regime. Such tests can determine transmissivity (T), hydraulic conductivity (K), storativity (S), yield, connection between saturated zones, identification of boundary conditions, and the cone of influence of a pumping well in a extraction system.

A slug test is a particular type of aquifer test where water is quickly added or removed from a groundwater well, and the change in hydraulic head is monitored through time to determine the near-well aquifer characteristics. Hydraulic conductivity values determined using slug test have been shown in Fig. 6.30. The brief description of results obtained using slug test is discussed district wise.

Table-6.3 Summary of Slug Test Conducted in NCR, U.P.

S. No.	District	No. of Slug Test
1.	Baghpat	11
2.	Meerut	21
3.	Ghaziabad	15

4.	GautamBudh Nagar	9
5.	Bulandshahar	30
Total Uttar Pradesh		86

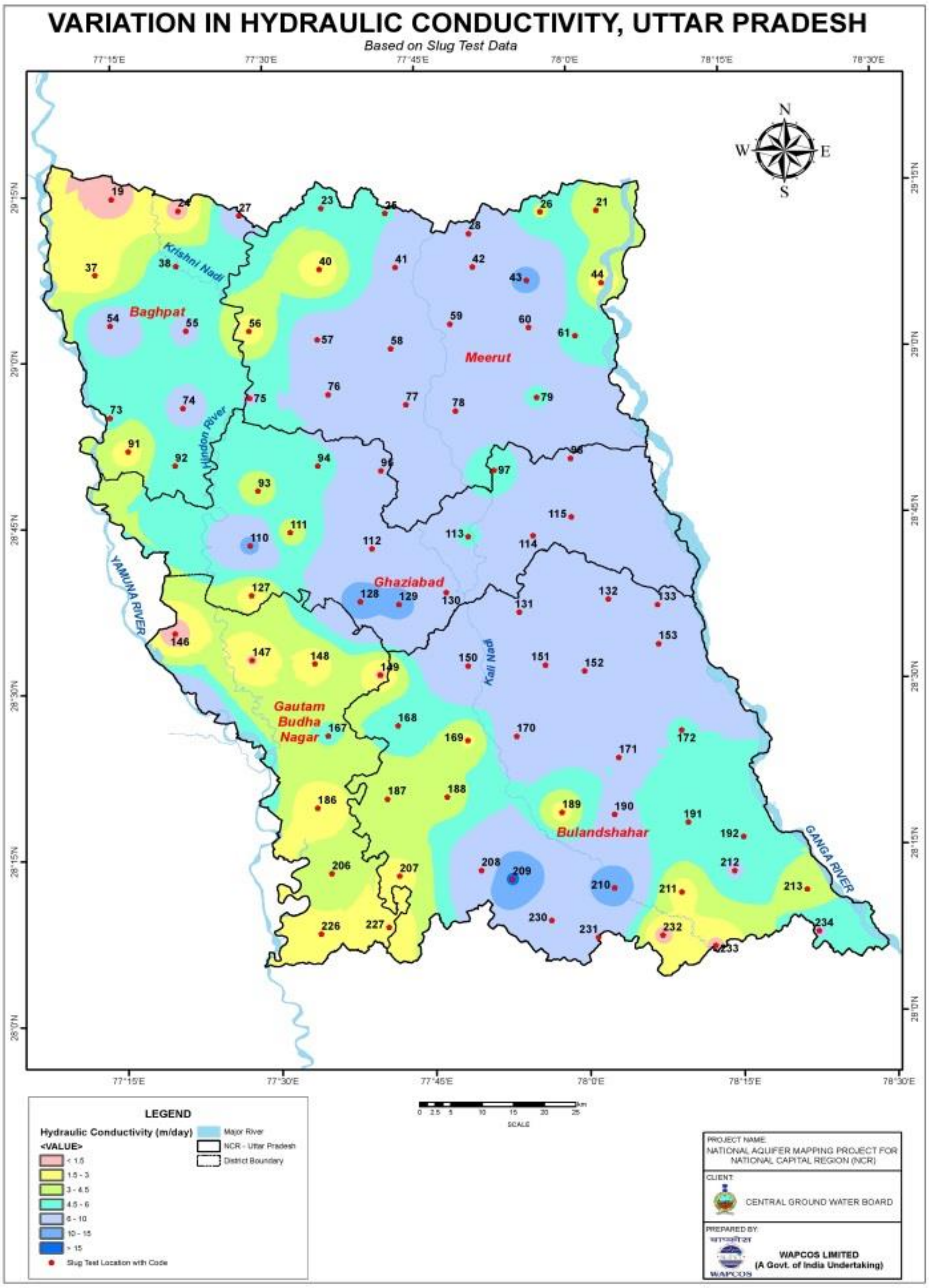


Figure 6.30: Map showing the variation in hydraulic conductivity based on slug test

(a) Baghpat District

The hydraulic conductivity (K) value estimated by Hvorslev method varies from a minimum of 0.83 m/day to 9.26 m/day with an average K value of 5.25 m/day. The hydraulic conductivity value estimated by Bouwer & Rice Method varies from 0.63 to 8.10 m/day (Avg. 4.02 m/day). The average hydraulic conductivity estimated by these two methods is found to be varies from a minimum of 0.73 m/day to maximum of 8.18 m/day with an average of 4.63 m/day. Relatively higher hydraulic conductivity (K) values were obtained at sites Tyodhi (8.18 m/day), DhanuraTikri (8.72 m/day), Rasulpur, Shankarputhi (6.64 m/day) and low K value at Kirthal (0.73 m/day), and Tikri (1.11 m/day).

(b) Meerut District

Hydraulic conductivity (K) value estimated by Hvorslev method varies from 1.77 m/day to 12.90 m/day (Avg. 8.05 m/day). The estimated hydraulic conductivity (K) value by Bouwer& Rice method varies from 1.36 to 9.92 m/day (Avg. 5.40 m/day). The Hvorslev K values are slightly higher as compared to the values computed by Bouwer & Rice Method. The average hydraulic conductivity estimated by these two methods is found to be varies from a minimum value of 1.57 m/day to maximum 11.41 m/day. Relatively higher hydraulic conductivity (K) values were obtained at sites NeemkaVeeran (Avg. 11.41), Zahidpur (Avg. 9.44), Meerut Corporation (Avg. 9.55) and low K value at Julheda (Avg. 1.57) Kanauni (2.02), Dudli Khadar (Avg. 2.20).

(c) Ghaziabad District

Hydraulic conductivity (K) value estimated by Hvorslev method varies from 2.48 m/day to 13.80 m/day (Avg. 8.99 m/day). The estimated hydraulic conductivity (K) value by Bouwer & Rice method varies from 2.03 to 10.60 m/day (Avg. 6.15 m/day). The Hvorslev K values are slightly higher as compared to the values computed by Bouwer & Rice Method. The average hydraulic conductivity estimated by these two methods is found to be varies from a minimum value of 2.26 m/day to maximum 12.20 m/day.

(d) GautamBudh Nagar District

Hydraulic conductivity (K) value estimated by Hvorslev method varies from 0.83 m/day to 5.31 m/day (Avg. 2.63 m/day). The estimated hydraulic conductivity (K) value by Bouwer& Rice method varies from 0.65 to 4.06 m/day (Avg. 2.03 m/day). The Hvorslev K values are slightly higher as compared to the values computed by Bouwer & Rice Method. The average hydraulic conductivity estimated by these two methods is found to be varies from a minimum value of 0.74 m/day to maximum 4.69 m/day.

(e) Bulandsahar District

Hydraulic conductivity (K) value estimated by Hvorslev method varies from 1.12 m/day to 18.7 m/day (Avg. 8.0 m/day). The estimated hydraulic conductivity (K) value by Bouwer & Rice method varies from 0.86 to 13.60 m/day (Avg. 5.37 m/day). The Hvorslev K values are slightly higher as compared to the values computed by Bouwer& Rice Method. The average hydraulic conductivity estimated by these two methods is found to be varies from a minimum value of 0.99 m/day to maximum 15.65 m/day.

Relatively higher hydraulic conductivity (K) values were obtained at sites NaglaSheku (Avg. 15.65), Aterna (Avg. 13.80), Kushalpur (Avg. 9.36) and low K value at Ban (Avg. 0.99), Viraura (1.25), Bhikrampur (Avg. 2.14).

6.3 Recharge

6.3.1 Rainfall recharge

In the NCR area recharge from rainfall during monsoon period is 192736.7 ham whereas recharge from rainfall during non-monsoon period is 20370.6 ham.

6.3.2 Recharge from other sources

Recharge from other sources includes recharge from canal irrigation, canal seepage and return flow from ground water irrigation. The recharge from other source during monsoon period is 2795.88 ham whereas in non- monsoon period it increase to 10938.65 ham. The total annual ground water recharge is 469889.1 ham. The district wise details are given in table 6.4.

Table 6.4: Recharge Estimate for NCR area, U.P (Ham)

S.No.	District	Recharge from Rainfall during Monsoon Season	Recharge from other source during Monsoon	Recharge from rainfall during non monsoon	Recharge from other sources during non monsoon	Total annual ground water recharge
1	Baghapat	29823.43	6354.85	0	12871.64	49049.92
2	Bulandshahar	61151.07	35716.8	7470.67	62992.74	167331.3
3	Meerut	47579.83	27421.56	5742.46	45769.4	126513.3
4	Hapur	21638.97	7009.42	2631.19	13209.41	44488.99
5	Ghaziabad	13444.24	5483.54	1730.4	10938.65	31595.83
6	G.B.Nagar	19100.18	8499.69	2795.88	20515.08	50910.83
	Total	192736.7	90485.86	20370.6	166295.9	469889.1

(Source- Dynamic GW Resource estimation- 2011)

6.4 Discharge

In the study area, irrigation practices include private tube wells, government tube wells and borings. The draft for irrigation in the area is 33585.08 ham and draft for domestic & industrial uses is 24084.02 ham. The natural discharge in the area is 41619.85 ham. The district wise details are given in Table 6.5.

Table 6.5: Discharge estimate for NCR area, U.P (Ham)

S.No.	District	Draft for Irrigation	Draft for Industrial, Domestic water use	Gross draft for all uses	Natural Discharge
1	Baghapat	42400.54	2199.02	44599.56	3681.329
2	Bulandshahar	118442.95	5952.7	124395.65	15465.51
3	Meerut	77432.66	3381.33	80813.99	11353.34

4	Hapur	32979.45	2669.64	35649.09	4448.799
5	Ghaziabad	24458.2	7109.39	31566.59	1579.792
6	G.B.Nagar	39872.28	2771.94	42644.22	5091.083
	Total	335585.08	24084.02	359669.1	41619.853

(Source- Dynamic GW Resource estimation- 2011)

6.5 Aquifer Vulnerability Map (Delineating area requires intervention):

Two maps prepared shows category of blocks and De saturated thikness of aquifer below 3 mbgl to ground water level (Figure No. 6.31& Figure No. 6.32) indicates major part of study area requires water conservation measures including Artficial Recharge to augument the ground water resource.

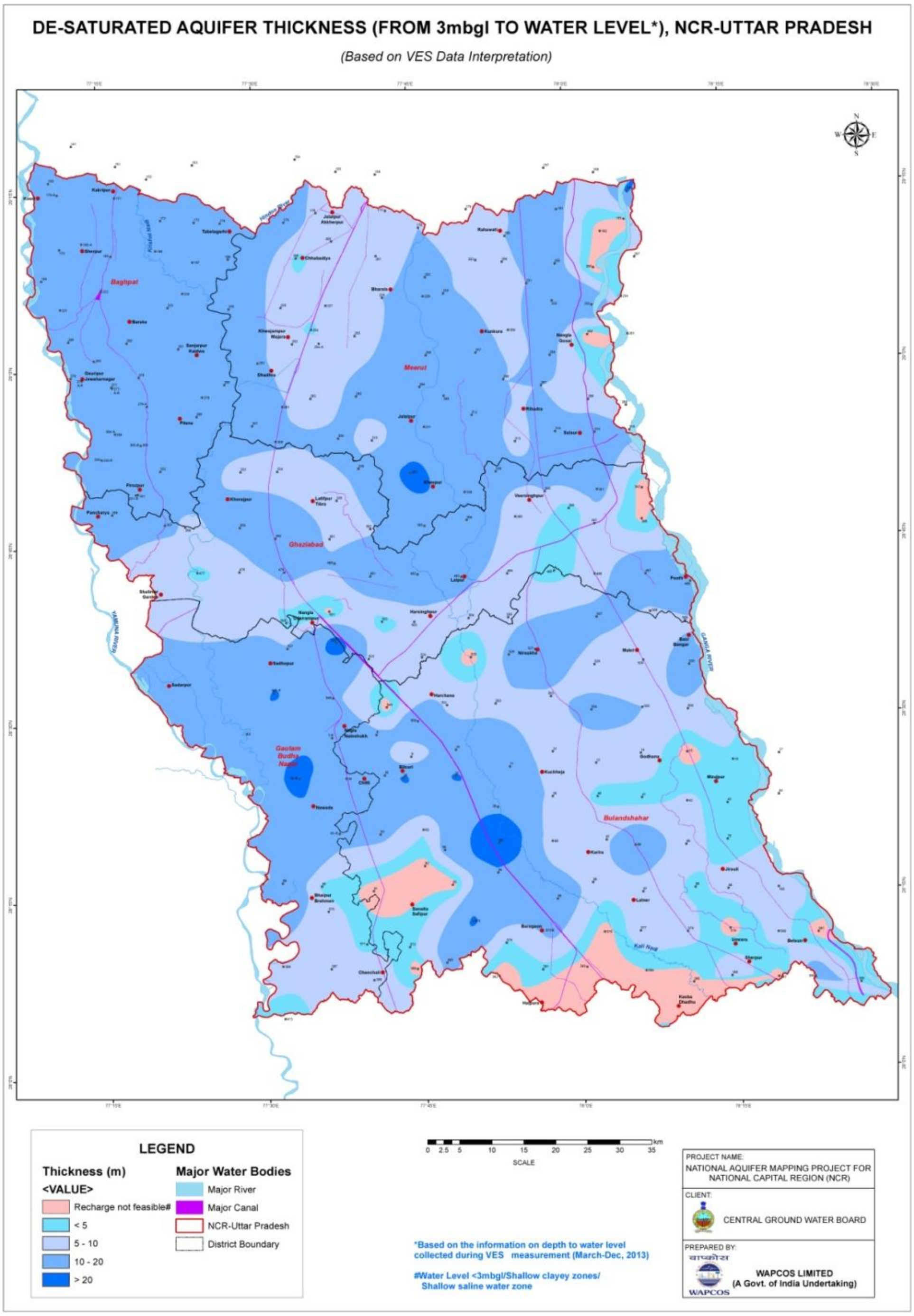


Figure 6.31: De-saturated Thickness of Aquifer from 3mbgl to water level in study area

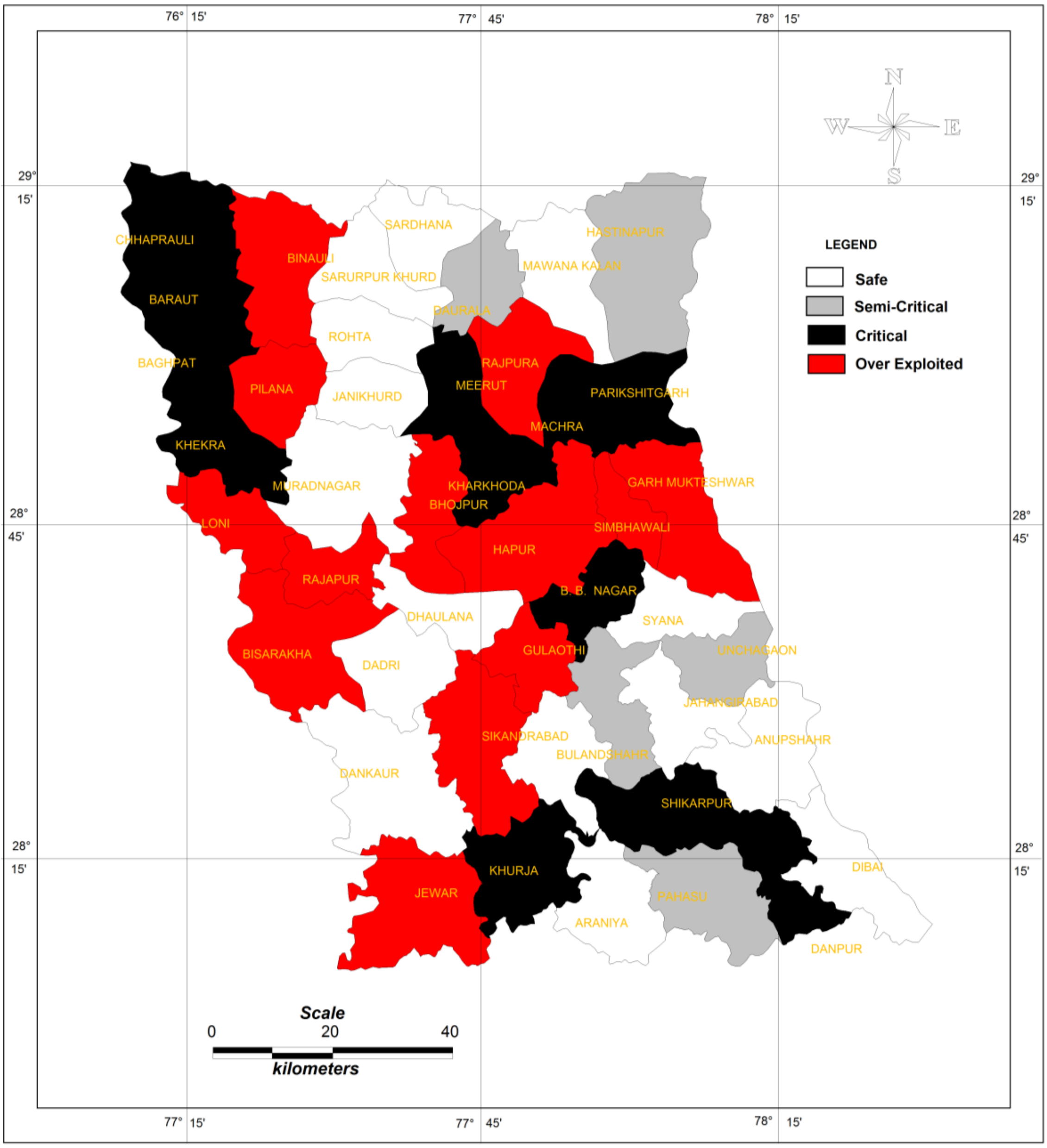


Figure 6.32:: Category of Blocks in Study area (as per resource _2011)

CHAPTER-7

STATUS OF GROUND WATER DEVELOPMENT

There are Five districts and 46 administrative blocks in NCR, U.P. (**Table 1, Fig. 2**). CGWB (2011) has done detailed assessment of the dynamic ground water resources of these blocks. The norms defined by the Ground Water Estimation Committee (GEC 1997) (GOI, 2009) have been adopted while making estimates under different heads for ground water recharges and discharges.

The primary source of recharge in the area is the rainfall, and the other sources are from seepages from canals, tanks and ponds and return flows from the agricultural fields after applied irrigation. These recharges have been estimated for both monsoon and non-monsoon seasons (**Table** 7.2). The primary source of ground water discharge (draft) is agricultural abstractions, apart from usages due to domestic and industrial needs. The district-wise summary of these estimates are given in (**Table** 7.2). Block-wise details on recharges and discharges are in (***Annexure7.1 (a) and (b))***.

The net annual ground water recharge after all natural discharges in the NCR is estimated at 428269.2 ham (100 ham = 1 MCM), while the total ground water discharges/draft is estimated at 359669.1 ham out of which 335585.08 ham (93%) is due ground water abstraction by irrigation wells and 24084 ham (7%) is the existing ground water usage for domestic and industrial needs(**Table** 7.3). On the basis of the current usages, provision has been made for an amount of 35872.38 ham for the ground water usages for domestic and industrial needs in 2035. When this figure is deducted from the net ground water availability along with the existing gross ground water draft for irrigation, a positive figure, i.e., (+) 72181.75 ham(**Table** 7.2) .

A perusal of Table 32 indicates that out of the 46 blocks in the NCR, U.P. 13 blocks are already over-exploited, 12 blocks are under critical condition, and 5 blocks are under semi-critical condition while 15 blocks fall under safe category (CGWB, 2011) .Fig. 6.32 shows the different categories of these blocks. The summarized results are given in (Table 7.1)

In Baghpat district 4 blocks are in Critical and two in Over Exploited Category. In G.B. Nagar two blocks & Ghaziabad district three blocks are in Over Exploited Category. In Meerut district one and Bulandshar district two blocks are in Over exploited Category. The distribution of Critical and Over Exploited blocks shows distribution along Yamuna a Catchment area and urban growth centres i.e. Hapur, Ghaziabad, Noida & Merrut etc. whereas safe are in Ganga Catchment area having intensive canal Irrigation. Hence Eastern part of NCR Meerut & Bulandsahar district have 11 safe blocks out of total 15 safe blocks. The block wise categories(2009 & 20011) and level of development (2011) are given in Table 7.4

Table 7.1 District wise category of Blocks in NCR, U.P.

	Over-Exploited	Critical	Semi Critical	Safe	Total Blocks
Baghpat	2	4	0	0	6
G.B.Nagar	2	0	0	2	4
Ghaziabad	3	0	0	1	4
Meerut	1	4	2	5	12
Bulandsahar	2	4	4	6	16
Hapur	3	0	0	1	4
Total	13	12	6	15	46

Table 7.2: District-wise Ground Water Rcharges from different sources in NCR, U.P. (2011) (units are in hectare metre: ham).

District	**Recharge from rainfall during monsoon season**	**Recharge from other sources during monsoon season**	**Recharge from rainfall during non-monsoon season**	**Recharge from other sources during non-monsoon season**	**Total Annual Ground Water Recharge [(2)+(3)+(4)+(5)]**	**Provision for Natural Discharges**	**Net Annual Ground Water Availability [(6)-(7)]**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
BAGHAPAT	29823.43	6354.85	0	12871.64	49049.92	3681.329	45368.59
BULANDSHAHAR	61151.07	35716.8	7470.67	62992.74	167331.3	15465.51	151865.8
MEERUT	47579.83	27421.56	5742.46	45769.4	126513.3	11353.34	115159.9
HAPUR	21637.97	7009.42	2631.19	13209.41	44487.99	4448.799	40039.19
GHAZIABAD	13444.24	5483.54	1730.4	10937.65	31595.83	1579.792	30016.04
G.B.NAGAR	19100.18	8499.69	2795.88	20515.08	50910.83	5091.083	45819.75
Total NCR	**192736.7**	**90485.86**	**20370.6**	**166295.9**	**469889.1**	**41619.85**	**428269.2**

Table 7.3: District-wise ground water discharges and net availability in NCR, U.P. (AS ON 2011) (units are in hectare meter: ham).

District	Net Annual Ground Water Availability	Existing Gross Ground Water Draft for irrigation	Existing Gross Ground Water Draft for domestic and industrial water supply	Existing Gross Ground Water Draft for all uses (3+4)	Provision for domestic, and industrial requirement supply to 2033	Net Ground Water Availability for future irrigation development (2-3-6)*	Stage of Ground Water Development in per cent. {(6/3) * 100} (%)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
BAGHAPAT	45368.59	42400.54	2199.02	44599.56	3598.37	933.53	98.30
BULANDSHAHAR	151865.77	118442.95	5952.70	124395.65	8403.00	26314.41	81.91
MEERUT	115159.91	77432.66	3381.33	80813.99	4636.12	33560.45	70.18
HAPUR	40039.19	32979.45	2669.64	35649.09	3645.10	5045.44	89.04
GHAZIABAD	30016.04	24457.20	7109.39	31566.59	12455.64	2383.83	105.17
G.B.NAGAR	45819.75	39872.28	2771.94	42644.22	3134.15	3944.09	93.07
TOTAL NCR	**428269.2**	**335585.08**	**24084.02**	**359669.1**	**35872.38**	**72181.75**	

- * (Taking negative value of respective blocks as zero)

Table 7.4.: Block-wise status of Ground Water Development in NCR, U.P. in 2009 and 2011.

Sl No.	District	Block	Stage of Development (%) (2011)	Category of Block (2011)	Category of Block in (2009)
1	Baghpat	Baghpat	91.6	CRITICAL	OVER EXPLOITED
2	Baghpat	Baraut	90.9	CRITICAL	SEMI-CRITICAL
3	Baghpat	Binauli	107.7	OVER-EXPLOITED	OVER EXPLOITED
4	Baghpat	Chaprauli	94.1	CRITICAL	OVER EXPLOITED
5	Baghpat	Khekra	91.5	CRITICAL	OVER EXPLOITED
6	Baghpat	Pilana	118.0	OVER-EXPLOITED	OVER EXPLOITED
7	G.B.Nagar	Bisrakh	117.6	OVER-EXPLOITED	SEMI-CRITICAL
8	G.B.Nagar	Dadri	80.6	SAFE	SAFE
9	G.B.Nagar	Dankaur	85.0	SAFE	SEMI-CRITICAL
10	G.B.Nagar	Jewar	100.8	OVER-EXPLOITED	OVER EXPLOITED
11	Ghaziabad	Bhojpur	111.1	OVER-EXPLOITED	CRITICAL
12	Ghaziabad	Loni	**147.0**	OVER-EXPLOITED	OVER EXPLOITED
13	Ghaziabad	Muradnagar	75.4	SAFE	SAFE
14	Ghaziabad	Razapur	**152.2**	OVER-EXPLOITED	SAFE
15	Meerut	Daurala	70.1	SEMI-CRITICAL	SEMI-CRITICAL
16	Meerut	Hastinapur	77.5	SEMI-CRITICAL	SEMI-CRITICAL
17	Meerut	Janikhurd	34.3	SAFE	SAFE
18	Meerut	Kharkhoda	99.6	CRITICAL	OVER EXPLOITED
19	Meerut	Machhra	90.6	CRITICAL	SAFE
20	Meerut	Mawana	76.9	SAFE	SEMI-CRITICAL
21	Meerut	Meerut	92.1	CRITICAL	SAFE
22	Meerut	Parichhat Garh	93.4	CRITICAL	SAFE
23	Meerut	Rajpura	106.9	OVER-EXPLOITED	OVER EXPLOITED
24	Meerut	Rohta	56.9	SAFE	SAFE
25	Meerut	Sardhana	50.3	SAFE	SAFE
26	Meerut	Saroorpur	46.4	SAFE	SAFE
27	Hapur	Dholana	50.6	SAFE	SAFE
28	Hapur	Garh	101.4	OVER-EXPLOITED	SAFE
29	Hapur	Hapur	105.9	OVER-EXPLOITED	SEMICRITICAL
30	Hapur	Simbholi	102.0	OVER-EXPLOITED	SEMICRITICAL
31	Bulandsahar	Agauta	87.4	SEMI-CRITICAL	SEMI-CRITICAL

32	Bulandsahar	Anup Shahar	64.9	SAFE	SAFE
33	Bulandsahar	Arnia Khurd	75.6	SAFE	SAFE
34	Bulandsahar	B.B.Nagar	99.1	CRITICAL	SEMI-CRITICAL
35	Bulandsahar	Bulandshahar	89.3	SAFE	SAFE
36	Bulandsahar	Danpur	91.2	CRITICAL	SAFE
37	Bulandsahar	Debai	**28.3**	SAFE	SAFE
38	Bulandsahar	Gulauthi	100.4	OVER-EXPLOITED	CRITICAL
39	Bulandsahar	Jahangirabad	81.7	SAFE	SAFE
40	Bulandsahar	Khurja	98.4	CRITICAL	CRITICAL
41	Bulandsahar	Lakhaoti	97.8	SEMI-CRITICAL	SAFE
42	Bulandsahar	Pahasu	96.4	SEMI-CRITICAL	SEMI-CRITICAL
43	Bulandsahar	Shikarpur	93.5	CRITICAL	SAFE
44	Bulandsahar	Sikandrabad	104.5	OVER-EXPLOITED	SEMI-CRITICAL
45	Bulandsahar	Siyana	63.1	SAFE	SAFE
46	Bulandsahar	Unchagaon	82.9	SEMI-CRITICAL	SAFE

CHAPTER-8

AQUIFER RESPONSE MODEL AND AQUIFER MANAGEMENT PLAN

8.1 Aquifer Response Model

8.1.1 Numerical Modelling

Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer, the contaminant transport mechanisms and chemical reactions. Because of the simplifying assumptions embedded in the mathematical equations and the many uncertainties in the values of data required by the model, a model must be viewed as an approximation and not an exact duplication of field conditions. Groundwater models, however, even as approximation, are a useful investigation tool for a number of applications.

Mathematical models provide a quantitative framework for analyzing data from monitoring and assess quantitatively responses of the groundwater systems subjected to external stresses. Over the last four decades there has been a continuous improvement in the development of numerical groundwater models (Mohan, 2001). Numerical modelling employs approximate methods to solve the partial differential equation (PDE), which describe the flow in porous medium. The emphasis is not given on obtaining an exact solution rather a reasonable approximate solution is preferred. A computer programme or code solves a set of algebraic equations generated by approximating the partial differential equations that forms the mathematical models. The hydraulic head is obtained from the solution of three dimensional groundwater flow equation through MODFLOW software (McDonald and Harbaugh, 1988). Anisotropic and heterogeneous three-dimensional flow of groundwater, assumed to have constant density, may be described by the partial-differential equation.

$$\frac{d}{dx}\left[K_{xx}\frac{dh}{dx}\right]+\frac{d}{dy}\left[K_{yy}\frac{dh}{dy}\right]+\frac{d}{dz}\left[K_{zz}\frac{dh}{dz}\right]-W=S_s\frac{dh}{dt}$$

Where,

Kxx, Kyy, Kzz are components of the hydraulic conductivity tensor, h is potentiometric head, W is source or sink term, S s is specific storage, and t is time.

8.1.2 Scope and Objective

The need of the aquifer response model in the present study is to evaluate the effects of the present and projected groundwater withdrawals on the prevailing water levels regime in the alluvial aquifer underneath the National Capital Region (NCR) area covering Baghpat, Meerut, Ghaziabad, G. B. Nagar and Bulandshahar districts of Uttar Pradesh state.

This report describes the model design, calibration procedures, and results of simulations and the response of the aquifer under different conditions.

8.1.3 Conceptual Model

The purpose of building a conceptual model is to simplify the field problem and organize the associated field data so that the system can be analyzed more readily. The conceptualization includes synthesis and framing up of data pertaining to geology, hydrogeology, hydrology and meteorology. A conceptual model is a simplified representation of the ground water flow system depicting the hydrostratigraphic unit of interest along with the system boundaries (ERD, 1998). Developing a modelling concept is the initial and most important part of every modelling effort and requires a thorough understanding of hydrogeology, hydrology and dynamics of ground water flow in and around the area of interest. The basic components of a conceptual model are the sources and sinks of water to and from the region, the physical boundaries, their nature and the spatial distribution of hydrogeological properties within the region.

Formation of a conceptual model is an essential prerequisite to the successful execution of the more quantitative representation of groundwater flow model such as a numerical model. Further, it also helpsto identify the knowledge or data gaps that must be filled before attempting a quantitative model. To begin with, it is always better to start with a simpler model as it facilitates model refutability and transparency (Hill, 2006). A model is considered as refutable if the assumptions upon which the model is constructed can be tested whereas transparency refers to the degree to which the model dynamics are understandable (Orskes, 2000).

In the present study, conceptual model of the area was developed on the basis of different hydrogeological information collected from studies done by the previous workers, Exploration activity done by the CGWB and WAPCOS in five districts of NCR part of Uttar Pradesh covering about 10,000 sq. km.This model is four layered model consisting of two aquifer system separated by aquitards. First aquifer system is unconfined in nature and is under stress, whereas second aquifer is confined to semi confined in nature and is not under any kind of stress.

8.1.4. DEVELOPMENT OF NUMERICAL Model

The steps in Numerical Model Design includes design of the grid, setting boundary and initial condition, preliminary selection of values for the aquifer parameters and hydrologic stresses. The finite-difference computer code Visual MODFLOW (McDonald and Harbaugh, 1988) numerically approximates this equation, and were used to simulate the groundwater flow in the study area.Visual MODFLOW was used to simulate the ground water flow of NCR part of U.P. MODFLOW is a versatile code to simulate groundwater flow in multilayered porous aquifer. The model simulates flow in three dimensions using a block centred finite difference approach. The groundwater flow in the aquifer may be simulated as confined/unconfined or the combination of both. MODFLOW consists of a major program and a number of sub-routines called modules. These modules are grouped in various packages viz. basic, river, recharge, block centred flow, evapo-transpiration, wells, general heads boundaries, drain. MODFLOW is a computer program that numerically solves the three dimensional ground-water flow equation for a porous medium by using a finite difference method (Waterloo Hydrogeologic Inc. 2005). In the finite difference method (FDM), a continuous medium is replaced by a discrete set of points called nodes and various hydrogeological parameters are assigned to each of these nodes.

8.1.5 Grid Design

Based on the data availability and objective of the model area has been divided into 34 columns and 34 rows with a uniform grid size of 4000m X 4000m, further along the river Ganga and Yamuna has been divided where each grid has been divided to a grid size of 2500 x 2500m.

Spatial and vertical variations in hydrologic characteristics in the aquifer framework were represented by discrete values in each of the model cells. Model cells extend vertically into the aquifer and divide the aquifer into discrete volumes of aquifer material that are assumed to have uniform hydrologic characteristics. The model grids showing the active and inactive cells are shown in Fig 8.1

The ground elevation data available for 80 stations within the study area have been assigned and these were interpolated for other locations through natural neighbourhood technique. In similar manner the elevation for other layers were also assigned for known locations and were interpolated.

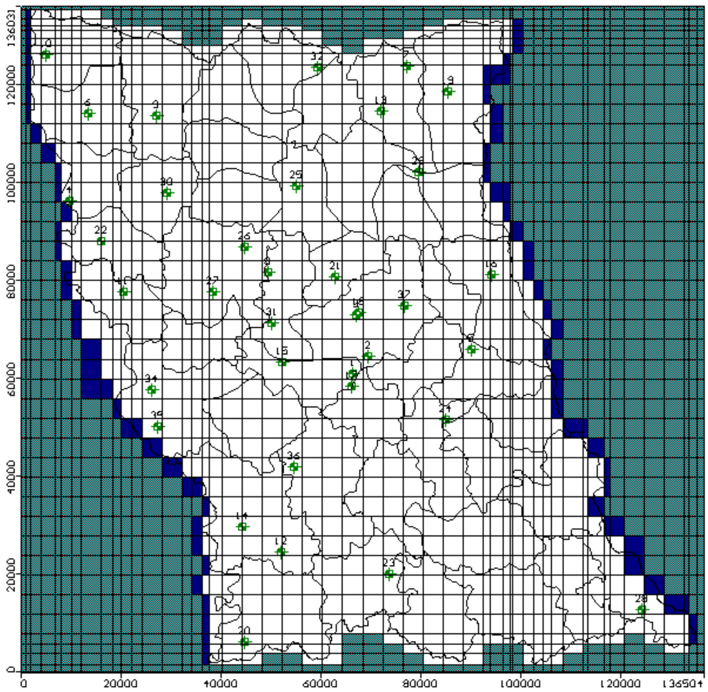


Fig 8.1. Grid Design

8.1.6 Aquifer Geometry and Boundary Conditions

8.1.6a Aquifer Geometry

Geologic information including geologic maps, cross sections and well logs are combined with information on hydrogeological properties to define hydrostratigraphic units for the conceptual model. The Lithological data, VES data and Logging data of boreholes from the study area were utilized for sketching horizontal and vertical disposition of aquifers and aquitards in the study area to a depth of 300 m bgl (Fig. 8.2a & b).

Top and bottom of the Layer

The model consists of 4 layers with layer 1 & 2 being the aquifer I and aquifer II, whereas layer 2 and 4 represent the aquitard (Clay). The elevation of layer 1 ranges from 182 to 235 msl, layer 3 ranges from -134 to 49 msl. Average thickness of layer 2 and layer 4 is 40 and 55 m respectively. The model layer is represented in Fig 8.2a and 8.2b.

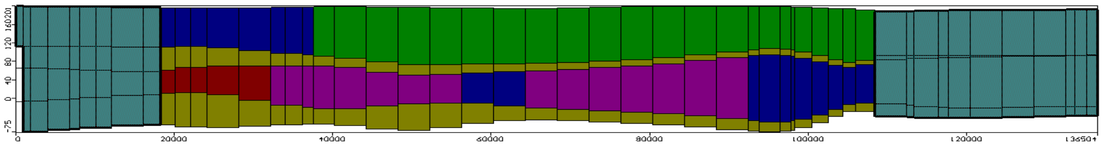


Fig.8.2a Hydrogeological cross section along row 18 showing four layers system.

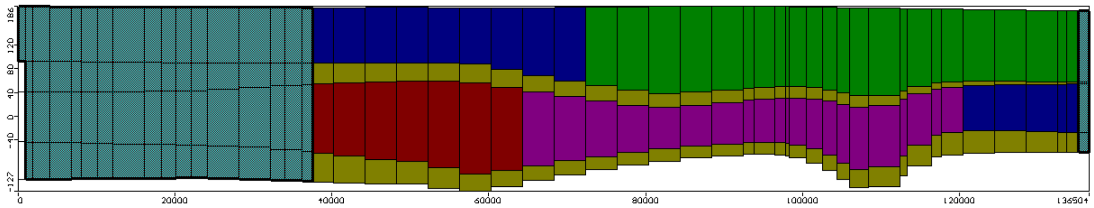


Fig.8.2b Hydrogeological cross section along row 25 showing four layers system**.**

8.1.6b Boundary Conditions

Boundary conditions are defined along the edges of the simulation domain including the top and the bottom. Model boundaries are either Physical (real) and hydraulic (artificial). While the physical boundaries are well defined geologic and hydrologic features that permanently influence the pattern of groundwater flow, hydraulic boundaries are artificial and are derived from groundwater flow nets (Kresic, 1997). Mathematically, they are necessary for arriving at a unique solution of a differential equation. Conceptually, they can be visualized as the influence of the hydraulic conditions occurring across the boundary of the domain, of the solution. Thus, to obtain a unique solution of the differential equation, it is necessary to define boundary conditions all along domain boundary. The boundary condition may either be a known head (head assigned) or a known flow rate (flow assigned) across the boundary. A no-flow boundary is a special case of specified flow boundary and a constant head boundary is a special case of specified head boundary. Out of the two types of boundary conditions, the head assigned boundaries are more suitable for forecasting since the water elevations in the hydraulically connected water bodies may generally not be significantly influenced by the pumping/recharge pattern in the aquifer. With head assigned boundaries the known prevalent water elevations may be assumed to hold good under the projected conditions (i.e., the pumping/recharge rates different from the prevalent ones) as such the same has been used in the present study. On the other hand, the lateral inflows across the boundary are very sensitive to any change in pumping/recharge. Thus, the inflow rates under the projected conditions may vary significantly from the prevailing ones. In other words the known prevalent inflow rates may not provide the necessary boundary conditions.

The model area is bounded by river Ganga and river Yamuna along the eastern and western sides. Both the rivers are perennial in nature and influent throughout the year. The eastern and western boundary of the model area are along the course of the river Ganga and Yamuna respectively and have been assigned as River Boundary. River Ganga and river Yamuna within this segment are effluent in nature. For the period under the projected scenario, the mean half yearly stage of River Ganga and Yamuna for the pre-monsoon and post-monsoon period has been assigned.

River Ganga and river Yamuna constituting the eastern and western boundary of the study area for Layer I has been assigned river boumdary for different time steps. As the river is perennial in nature and has significant base-flow during the lean season, river boundary is well justified.

The northern and southern boundary has been taken as flux boundary. For layer 1 and 3, the northern and southern boundaries has been taken as flow boundary and flux has been assigned along the boundaries. The flux to the layers has been estimated using the *TIL* equation for different segments in layer 1 (Aquifer 1) and Layer 3 (Aquifer 2). The estimated flux has been assigned by adding recharge wells along the boundary.

8.1.7 Range of Conductivity/ Transmissivity and Storage Parameters The exploratory wells drilled by CGWB and WABCOS reveal significant potentiality of the aquifer of the area as the transmissivity values for layer 1 ranges between 1568 and 5314 m2/day with mean value of 2756 m2/day. The mean hydraulic conductivity (K) has been found as 30.4 m/day corresponding to medium grained to fined grained sand

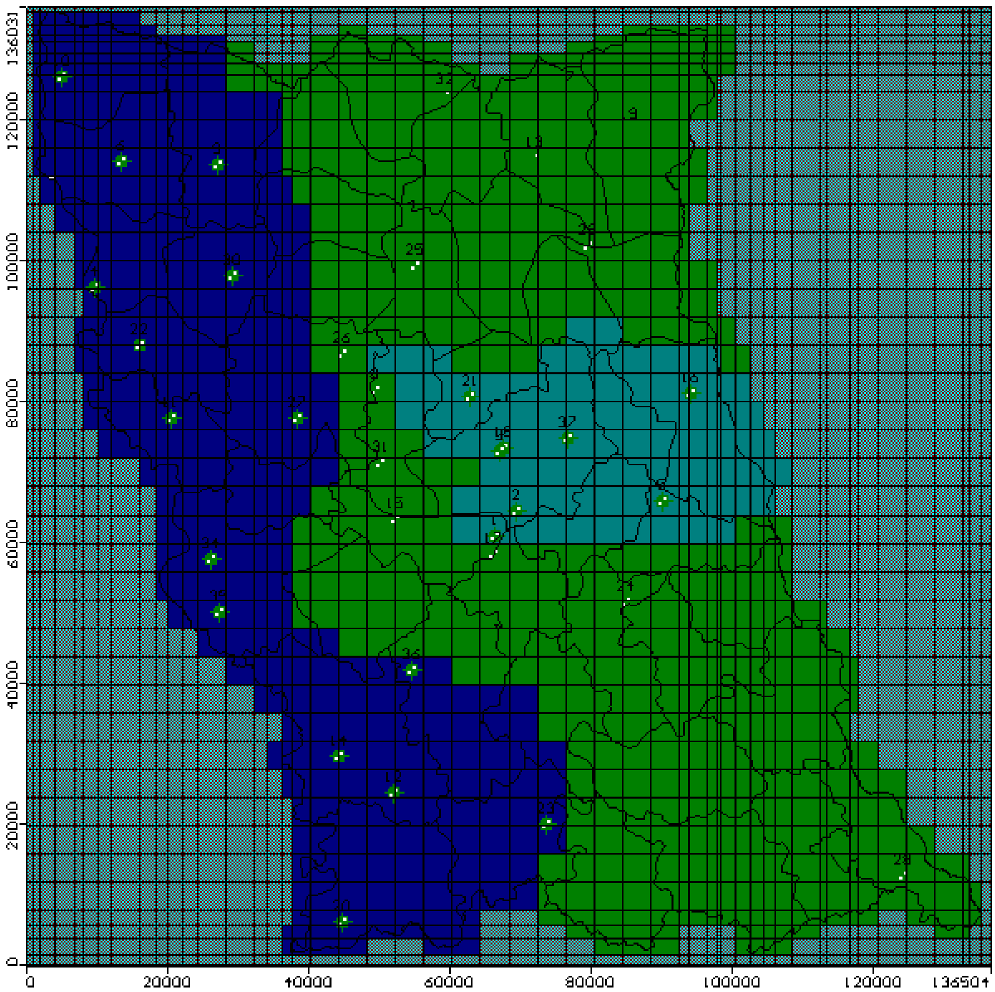


Fig.8.3: Zone wise distribution of hydraulic conductivity in the study area (for Layer1)

For the purpose of assigning conductivity value to different zones in layer 1 map of percentage aquifer material was used, which guided the zonation and their values.
Hydraulic conductivity values for Aquitards have been taken to be one 100^{th} of conductivity values of layer Layer 3 (Aquifer 2) shows perceptible decline in the hydraulic conductivity value on account of fining of the aquifer material. Conductivity values ranges from 4 to 34 m/day with the average value 19 m/day.Vertical conductivity in both the layer has been taken 10% of the horizontal conductivity values of the respective layers.

8.1.8 Distribution of Storage Parameters

The values of specific storage have been computed by dividing the field determined Storativity values with the thickness of the aquifer. As the number of Storativity values determined through pumping test is imited in the study area, an attempt has been made to estimate the Specific Storage based on the lithology and past experience of the project studies conducted by CGWB.

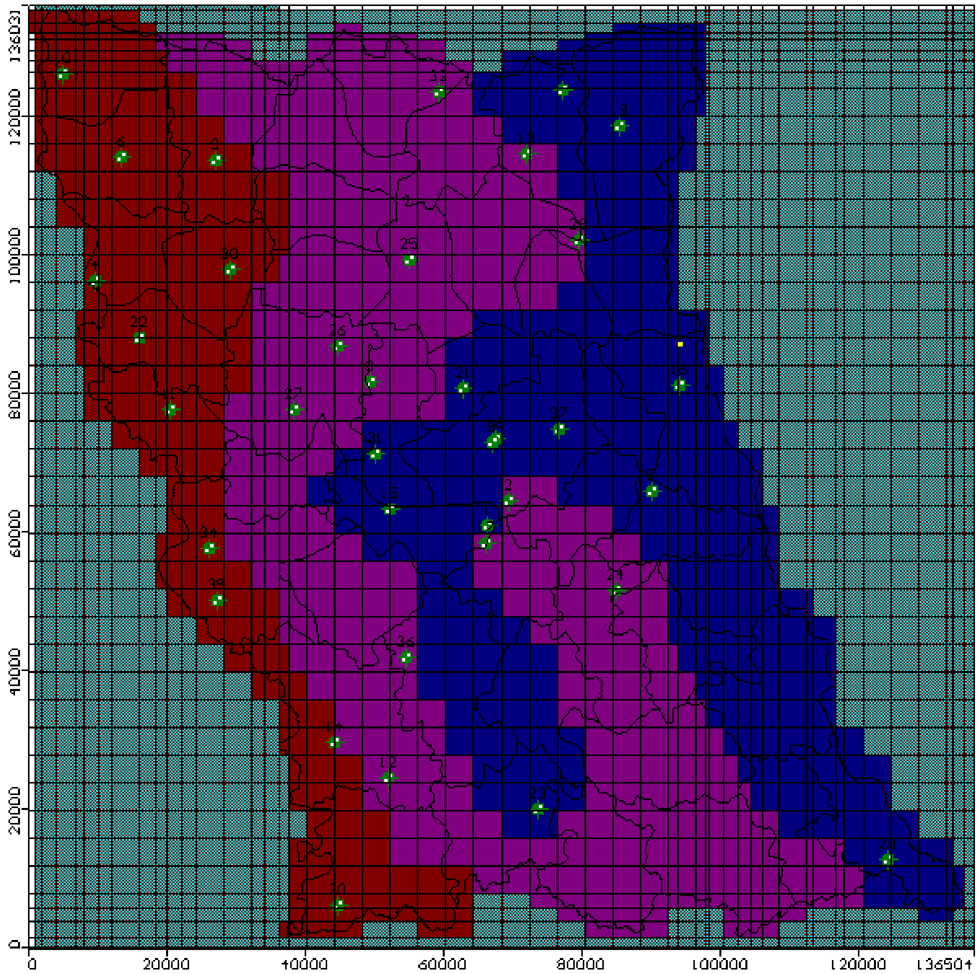


Fig 8.4 Zone Wise Distribution of Storage

Where the predominant lithology is fine-to-medium sand, the Ss has been considered as 1.6 X 10^{-3} while for the predominant lithology of medium to coarse sand and fine gravels, Ss has been considered as 1.05 X 10^{-6} (Younger 1993). The specific storage has been found varying over 3 orders of magnitude in the study domain between 10^{-3} and 10^{-6}.

8.1.9 Recharge

This package is used to simulate surfacial distributed recharge to the groundwater system. Annual precipitation within the study area averages about 690 mm, part of which seeps through the fine-grained material overlying the aquifer to the water table. Areal recharge to the aquifer is equal to precipitation minus (1) runoff into streams, (2) evaporation, and (3) evapotranspiration from plants in the soil zone. Infiltration of precipitation probably accounts for the largest amount of recharge. Recharge estimates are a function of vertical hydraulic conductivity which is a function of geology. Hence, surface geologic units are likely to represent a reasonable initial distribution of recharge.

For the purpose of calculation recharge from the other sources e.g. canal irrigation and return flow from ground water irrigation has also been taken into account.

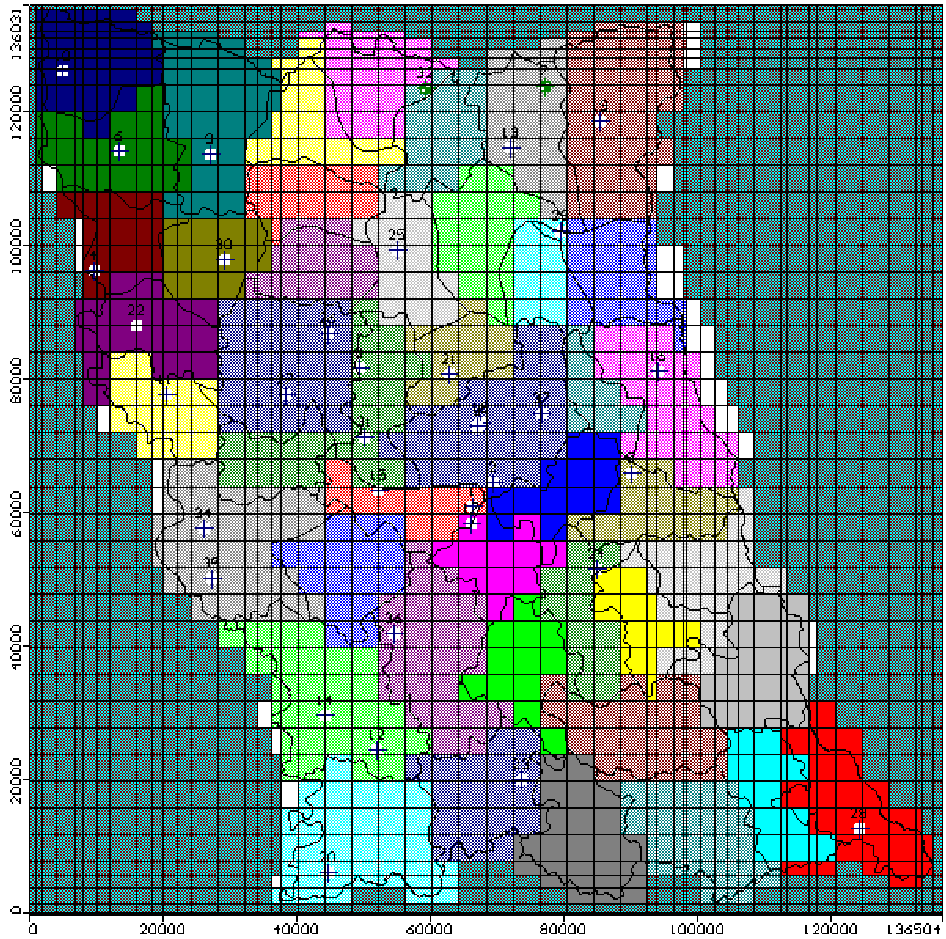


Fig 8.5 : Blockwise Recharge map of the Study area

In order to simulate realistic picture of the recharge in the area water table fluctuation data have been used to calculate recharge. Recharge estimation have been made for each block separately. On this basis whole area was divided into 46 recharge zones.

8.1.10 Discharge Data Within the study domain the main discharge input is the groundwater pumping from the area. The time variant groundwater draft has been assigned to each grid. The abstraction for each block has been worked out using the unit area groundwater draft from the study area. Data from the previous studies like resource assessment and available records of pumping from the municipal corporation have been used to arrive at the pumping estimate for a grid area of 16 sq km from the aquifer has been assigned in the model.

8.2 Model Calibration

An important part of any groundwater modelling exercise is the model calibration process. In order for a groundwater model to be used in any type of predictive role, it must be demonstrated that the model can successfully simulate observed aquifer behaviour. Calibration is a process wherein certain parameters of the model such as recharge and hydraulic conductivity are altered in a systematic fashion and the model is repeatedly run until the computed solution matches field-observed values within an acceptable level of accuracy. The purpose of model calibration is to establish that the model can reproduce field measured heads and flows. Calibration is carried out by trial and error adjustment of parameters or by using an automated parameter estimation code. In this study, trial and error adjustment has been used.

8.2.1 Steady State Calibration

Steady state conditions are usually taken to be historic conditions that existed in the aquifer before significant development has occurred (i.e., inflow are equal to outflows and there is no change in aquifer storage). In this model, quasi-steady state calibration comprised the matching of observed heads in the aquifer with hydraulic heads simulated by MODFLOW during a period of unusually high recharge. Steady state simulation of the model was carried out using the specified hydraulic heads of pre-monsoon 2008. Calibration involved making minor adjustments to the hydraulic conductivity field of the different layers and the river bed hydraulic conductivity levels until the steady state model was calibrated to a reasonable satisfaction. The preset calibration targets in the present study included (a). a root mean square error between measured and simulated heads of less than 2 m. and (b). a good visual match between the measured and the simulated potentiometric surfaces of Aquifer I and Aquifer II. (c). Quantitatively correct flow directions and flow gradients. River stage and river bed bottom for post-monsoon 2008 given as input in the model. In present study steady state model was calibrated for the hydraulic conductivity values to achieve the observed heads. The calibration was made using 37 observation wells monitored during November 2008. Figure-8.6.a show observed and computed heads of November 2008. The computed water table almost synchronises with the observed water table. The computed water level accuracy was judged by comparing the mean error with mean absolute and Root Mean Squared (RMS) error (Anderson and Woessner, 1992). Mean error is -3.241 m. RMS error is the square root of the sum of the square of the differences between calculated and observed heads, divided by the number of observation wells, which in the present simulation is 8.01 m (Figure-8.6b). The absolute residual mean is 5.481 m.

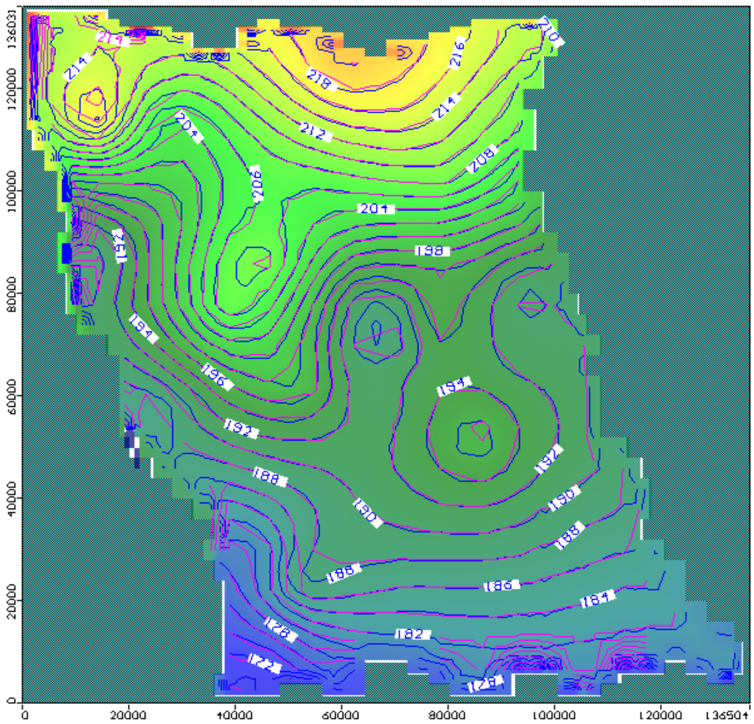


Fig. 8.6a:Computed heads (Brown colour) and Water Table Elevation (Blue colour) for November 2008.

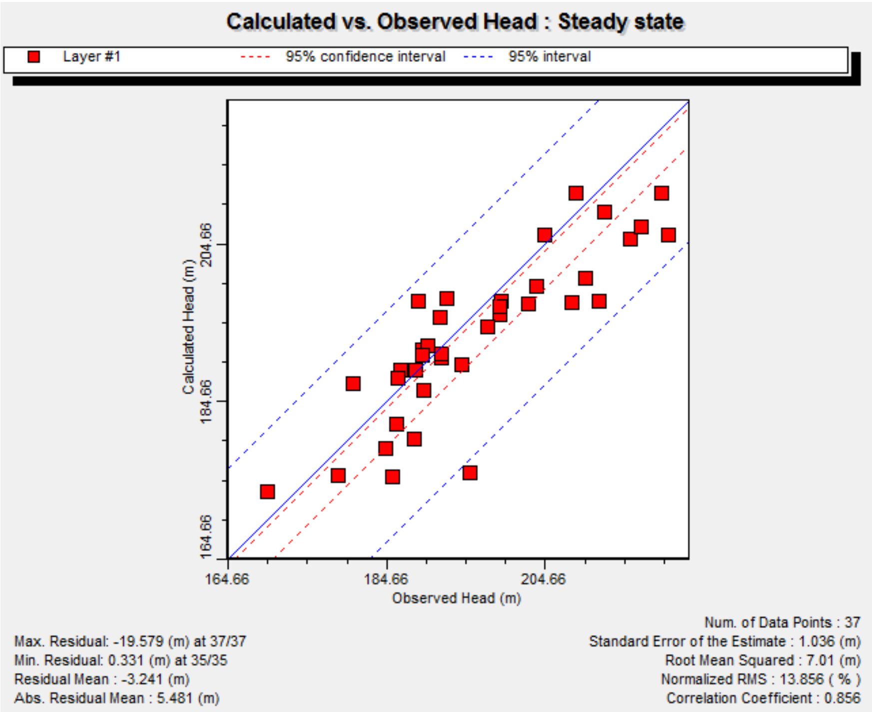


Fig. 8.6b: Calculated versus observed heads of aquifer-1 (November 2008)

8.2.2 Transient State

In Transient state, head change with time. Transient state are also called time dependent, unsteady, non-equilibrium, or non-steady state problem. The output of the steady state was taken as input for transient state model run from 2008 to 2013.

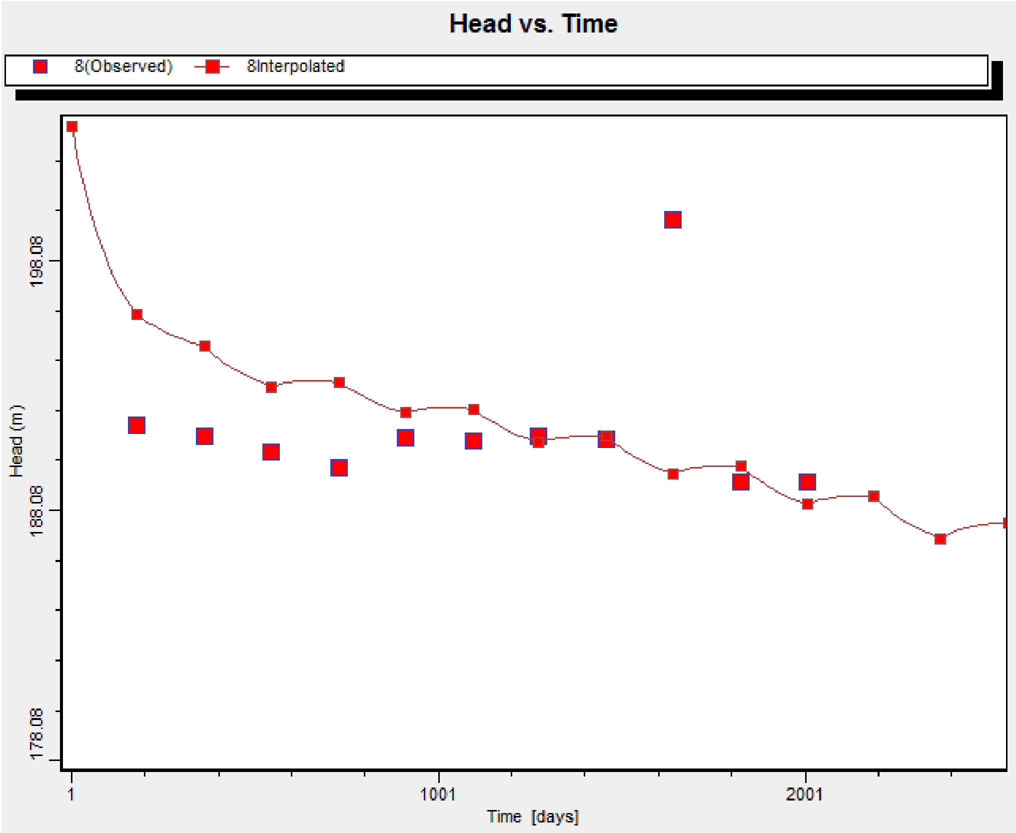
8.2.2a Transient State Calibration

The model was calibrated under transient state from November 2008 to November 2013 and validated for the period under transient state from November 2013 to May 2015. Visual MODFLOW uses boundary conditions imposed by the user to determine the length of each stress period. After a number of trial runs, the input/output stresses were varied, till the computed water levels matched fairly reasonably to observed values.

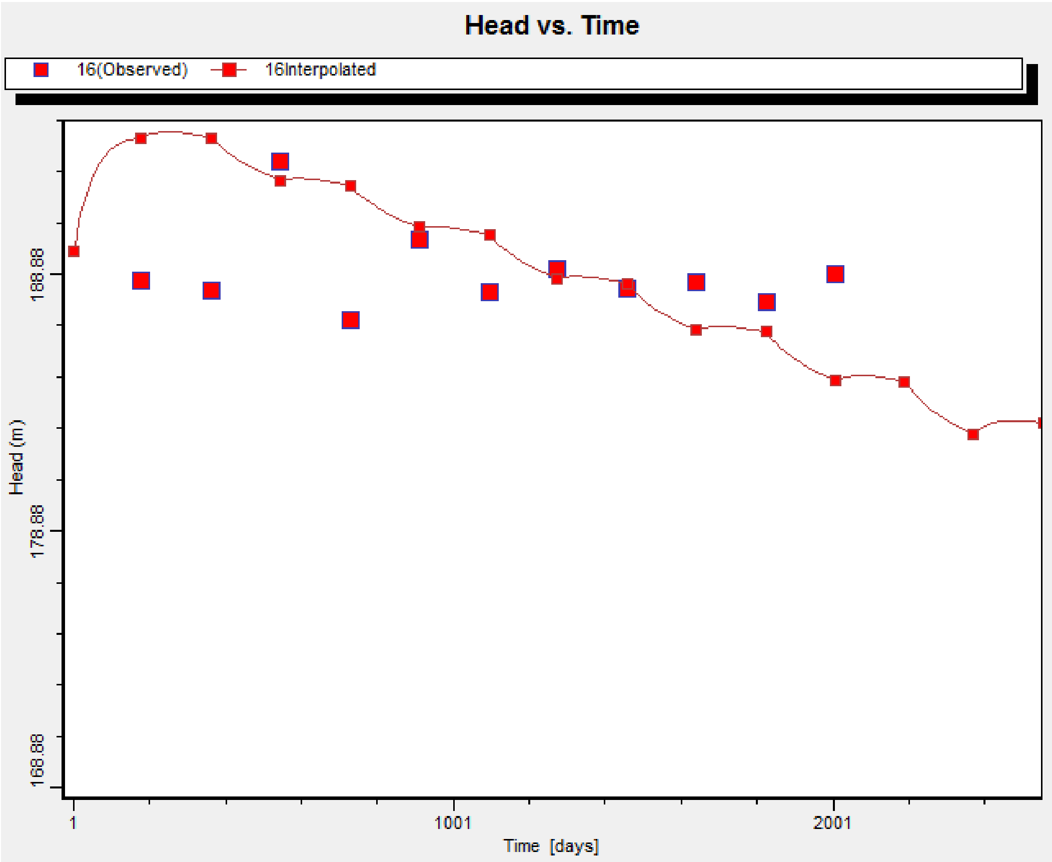
8.2.3 Model validation/Verification A calibrated model uses selected values of hydrogeologic parameters, sources and sinks and boundary conditions to match field conditions for selected calibration time periods (either steady-state or transient). However, the choice of the parameter values and boundary conditions used in the calibrated model is not unique, and other combinations of parameter values and boundary conditions may give very similar model results. History matching uses the calibrated model to reproduce a set of historic field conditions. This process is also referred to as "model verification". To evaluate the validity of the updated flow model, the altitude of water levels simulated by the updated flow model were compared to observed water-level altitudes. The altitude of water-level observations for the period of November 2008- May 2015 has been used for validating the model. The hydrograph of selected stations for the period under transient calibration and validation are given in figure 8.7a to 8.8.j

8.2.3a Model Limitations:

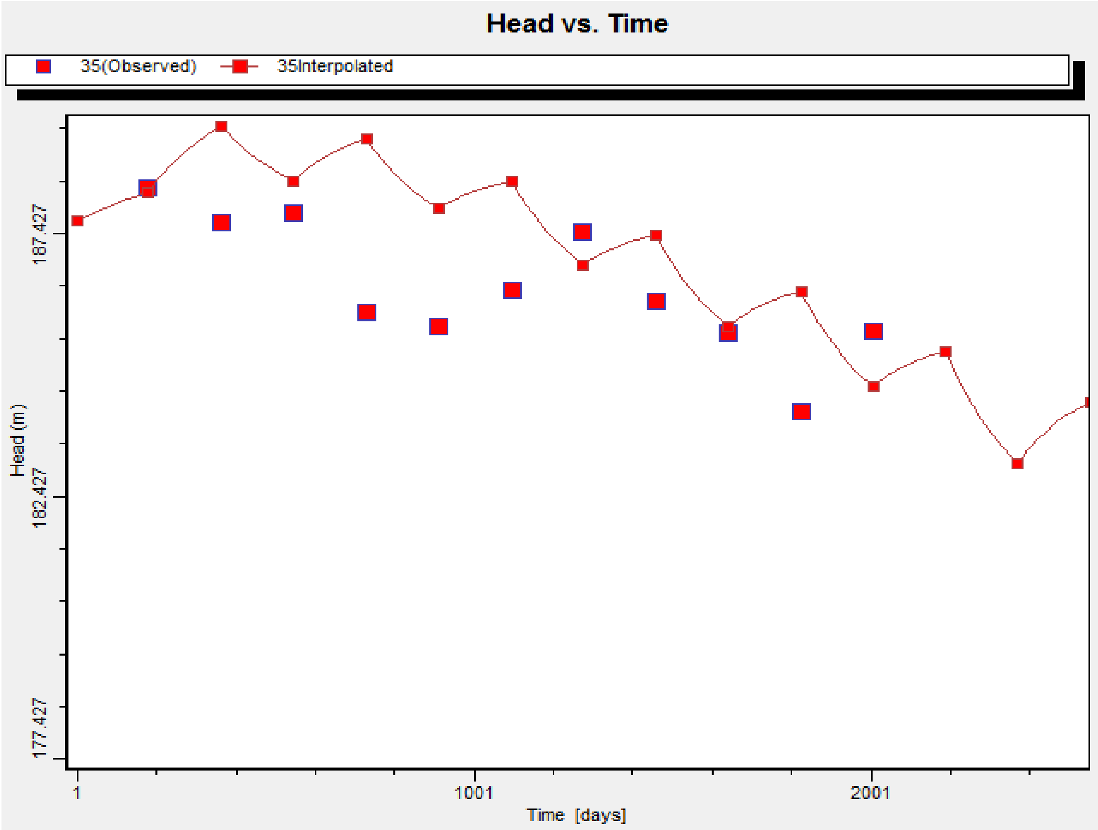
Though the model was successfully calibrated, in few places there exists difference between computed and observed water levels by 1 - 2 m . Further data is required for further refinement of model in places where mismatch exists between the computed and the observed groundwater level.



Head vs. Time
8(Observed)
8Interpolated
Head (m)
198.08
188.08
178.08
1
1001
2001
Time [days]



Head vs. Time
16(Observed)
16Interpolated
Head (m)
188.88
178.88
168.88
1
1001
2001
Time [days]



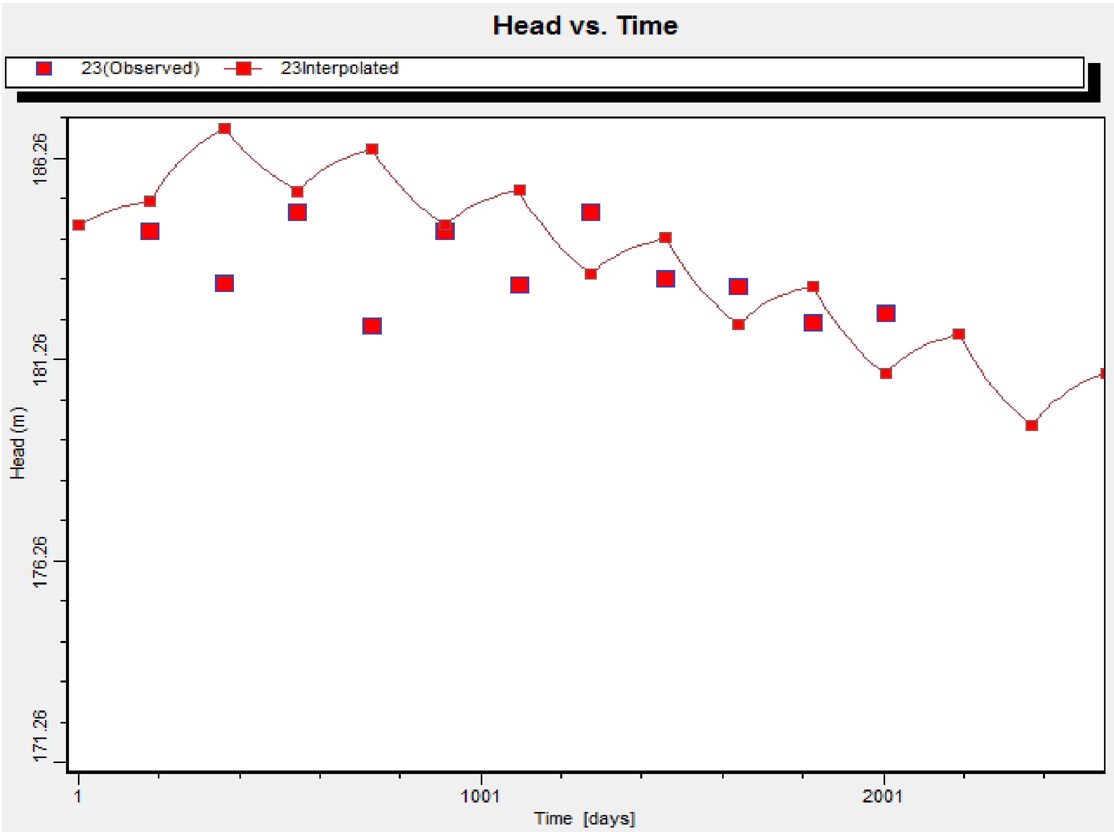
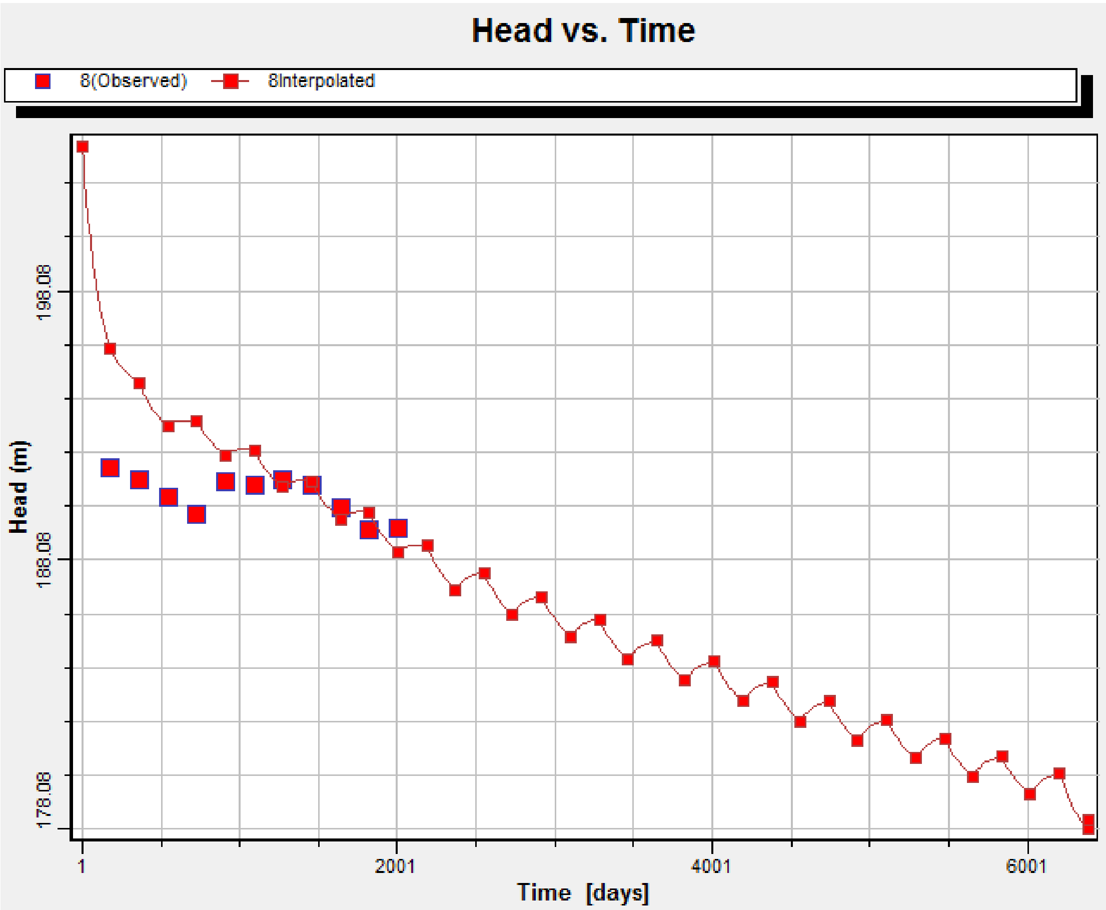


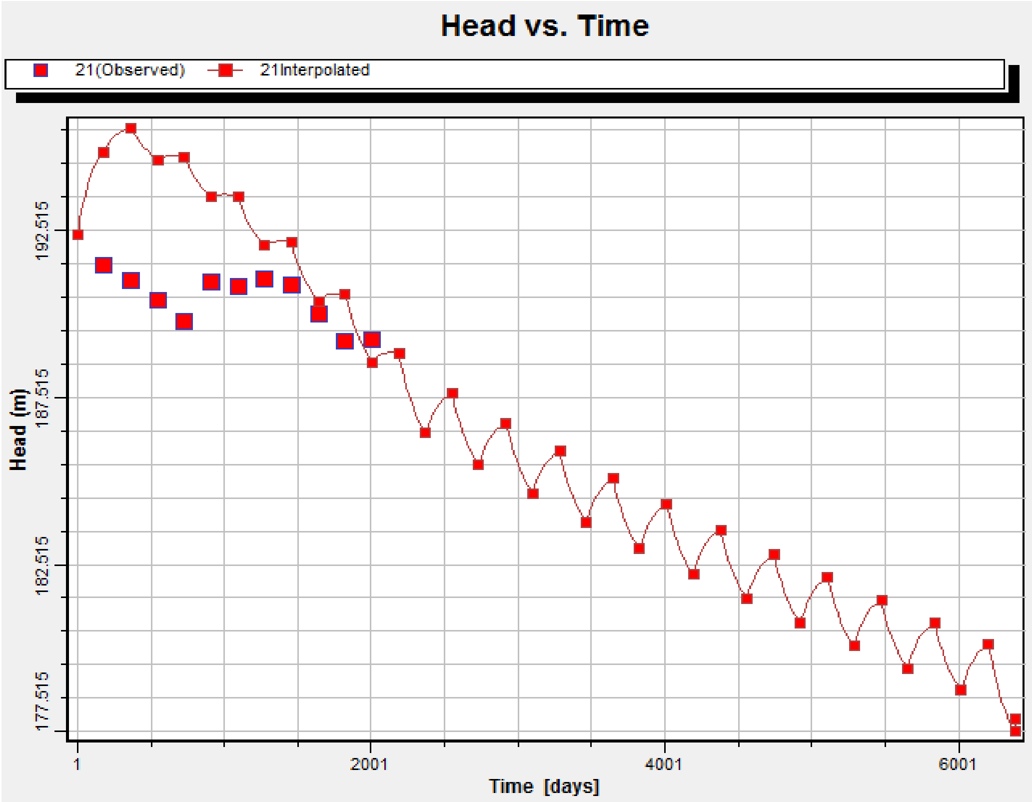
Fig 8.7 a to d. Comparison between observed and computed heads

8.3 Aquifer Management plan

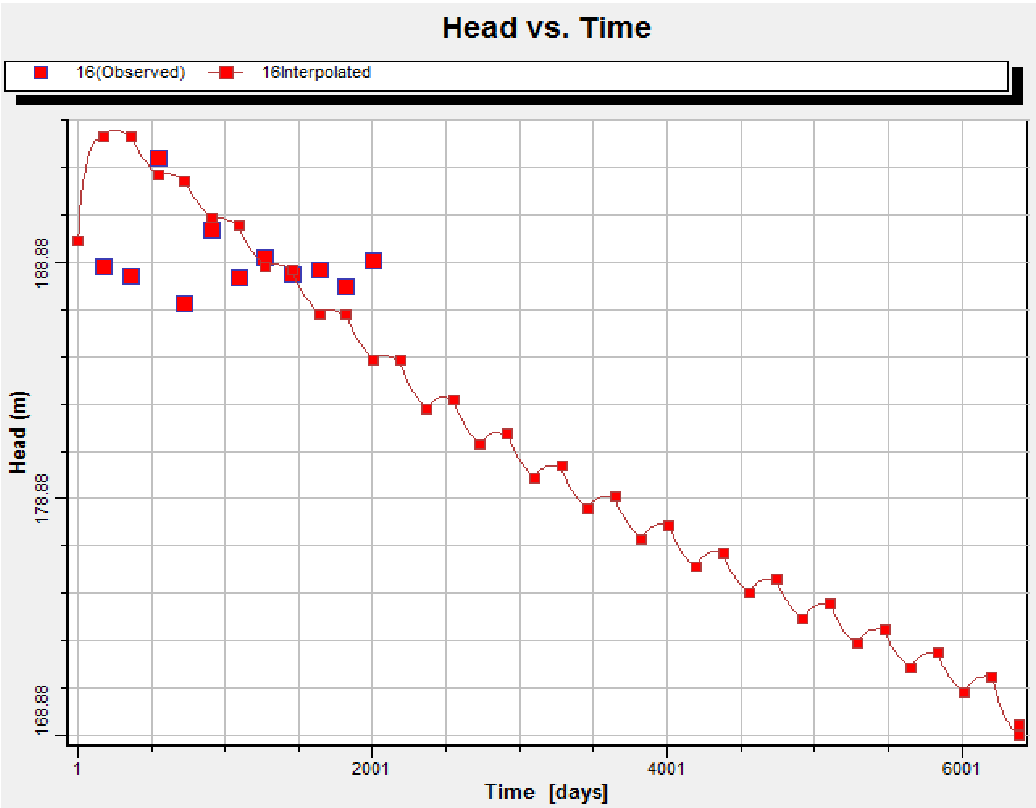
In order to understand the response of the aquifer to various stress conditions the model was run upto days by varying the recharge and discharge according to the future scenarios.

Scenario1: The model area is under intensive irrigated agriculture since decades. Almost all the tube wells are tapping ground water from aquifer I, which is highly prolific aquifer. In order to bring out the response of Aquifer I with the current rate of pumping (2015), the model was run up to 2025 by keeping the recharge rate same. The model predicted the declining trend of the ground water level continued in most Pumping for all purposes from Aquifer II is insignificant hence the piezometeric head of aquifer II remains the same throughout the model run. The declining trend of the ground water level of the piezometer are in the range of 0.2 m to 0.3m annually. The hydrograph of selected stations for prediction scenario - 1 are given in figure 8.8a to 8.8.j

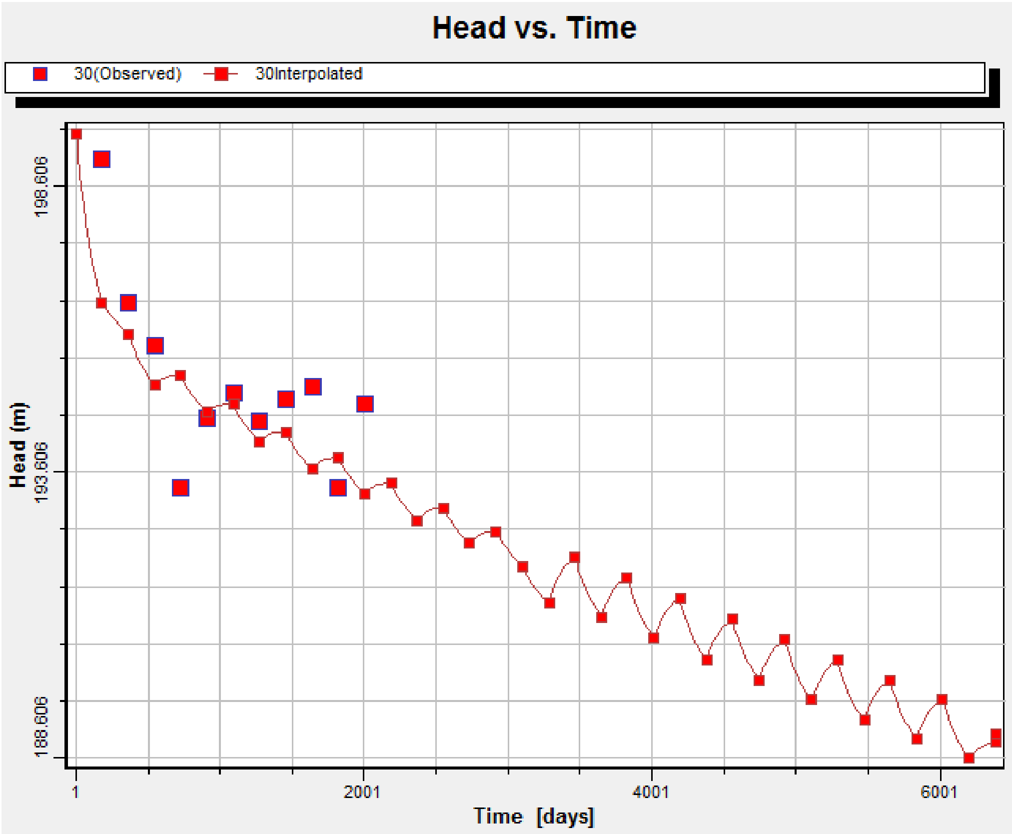


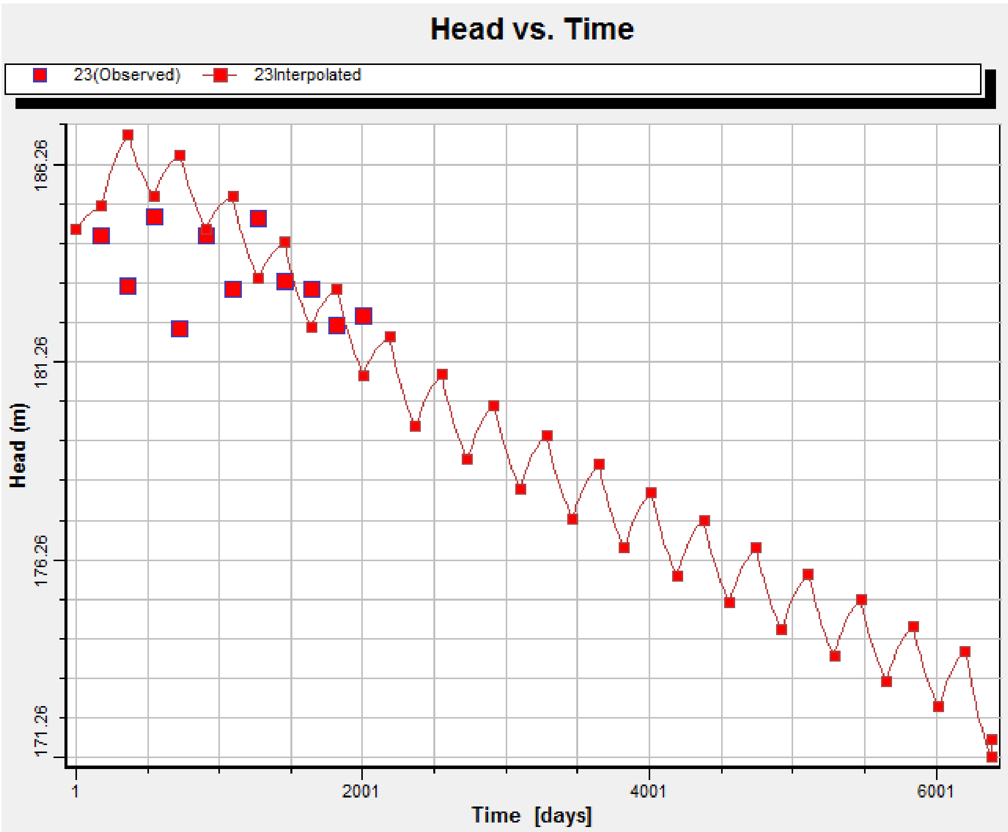


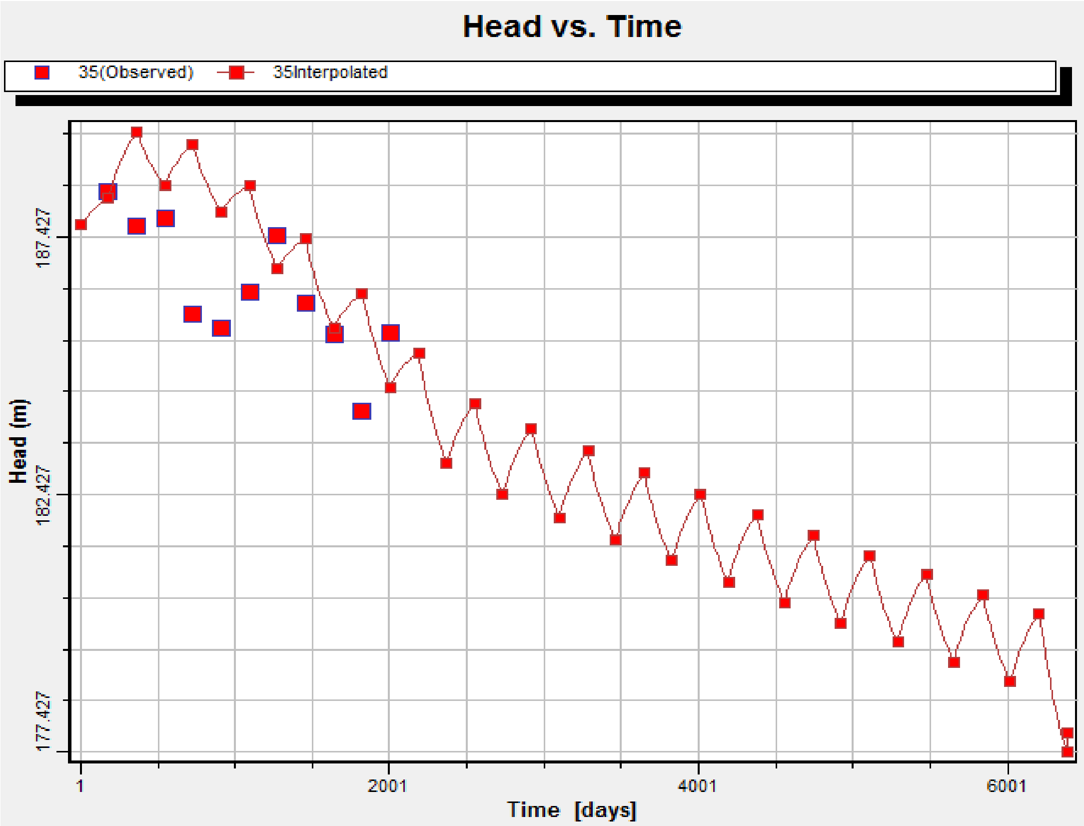
Head vs. Time
21(Observed)
21Interpolated
Head (m)
192.515
187.515
182.515
177.515
1
2001
4001
6001
Time [days]



Head vs. Time
16(Observed)
16Interpolated
Head (m)
188.88
178.88
168.88
1
2001
4001
6001
Time [days]


Head vs. Time
30(Observed)
30Interpolated
Head (m)
198.606
193.606
188.606
1
2001
4001
6001
Time [days]


Head vs. Time
23(Observed)
23Interpolated
Head (m)
186.26
181.26
176.26
171.26
1
2001
4001
6001
Time [days]



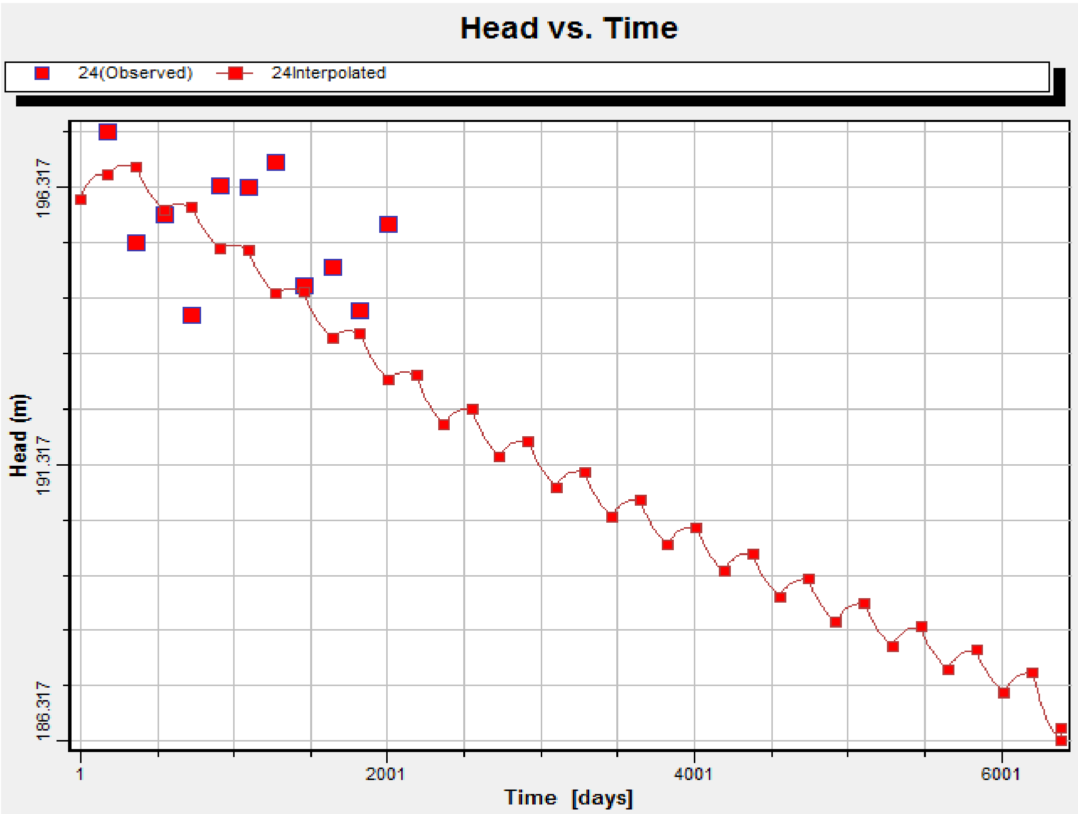
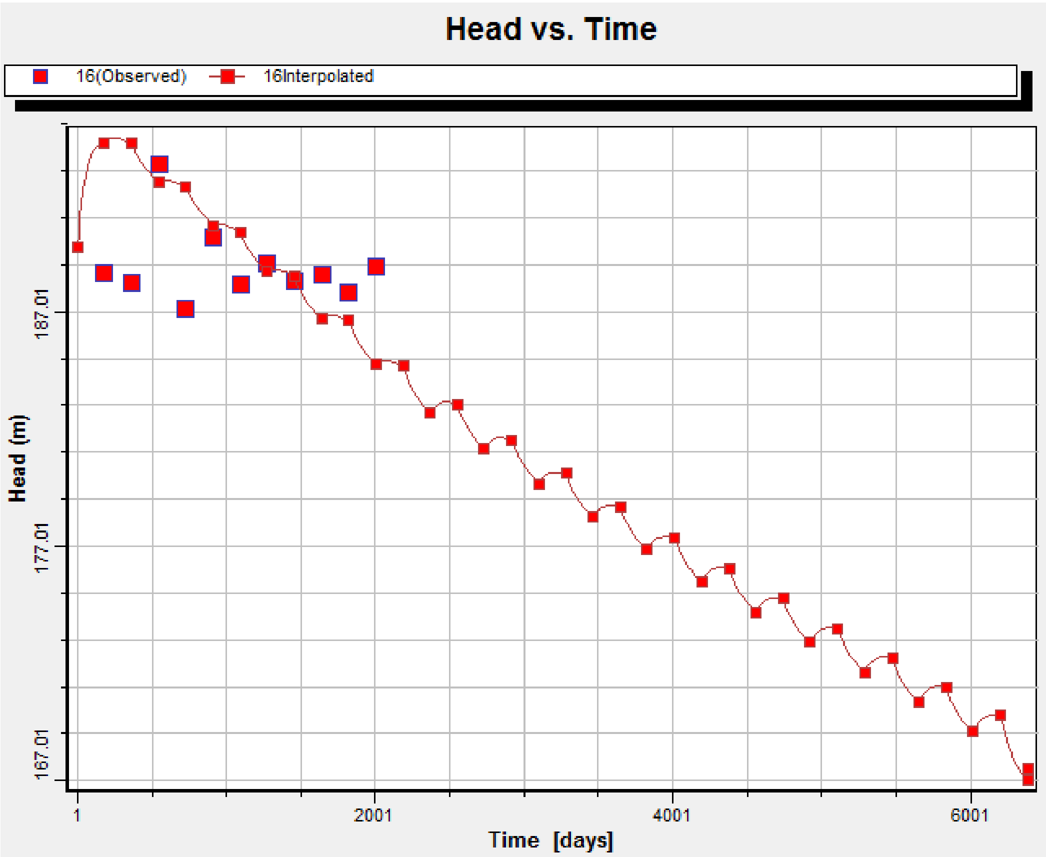
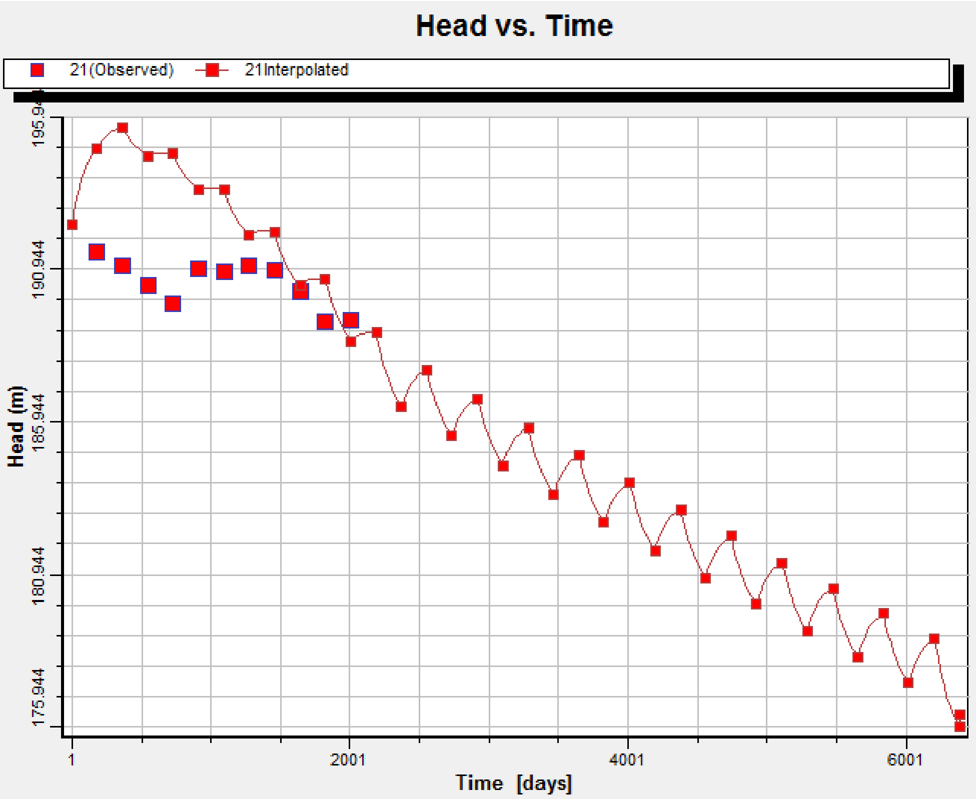


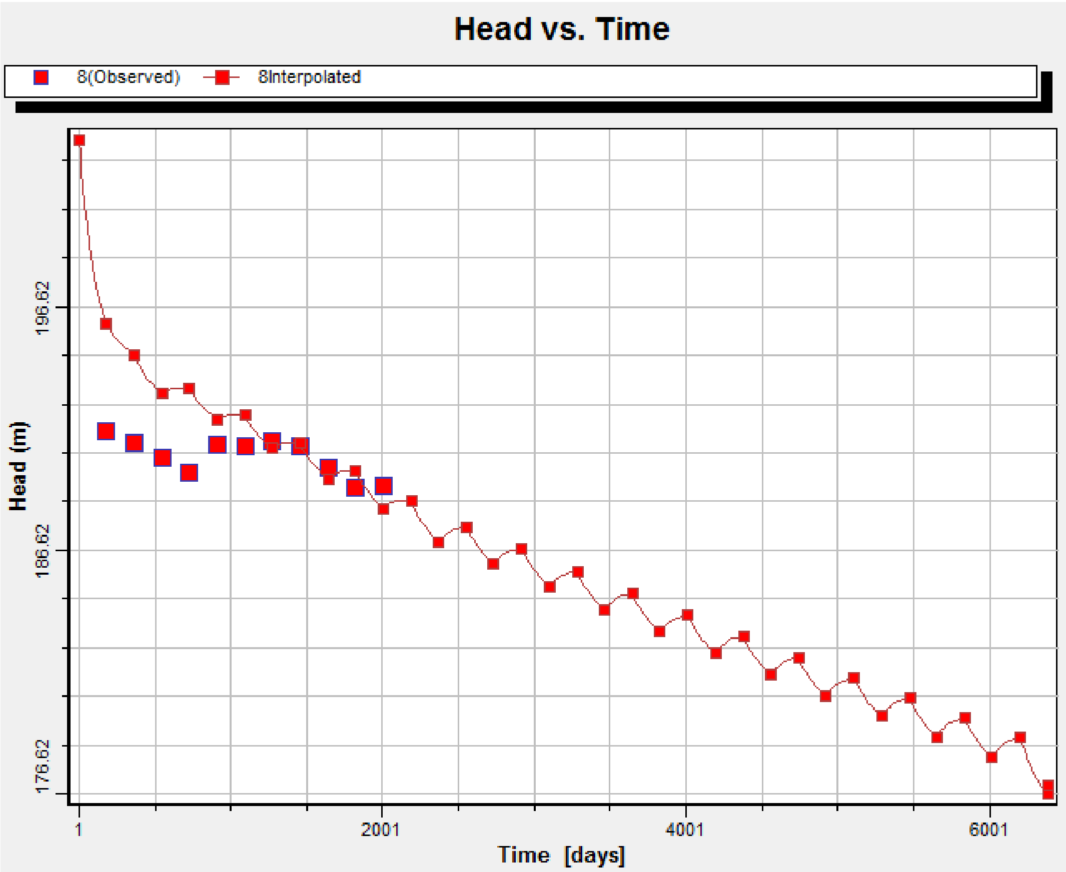
Fig 8.8 a to g. Hydrographs of the well during prediction scenario 1

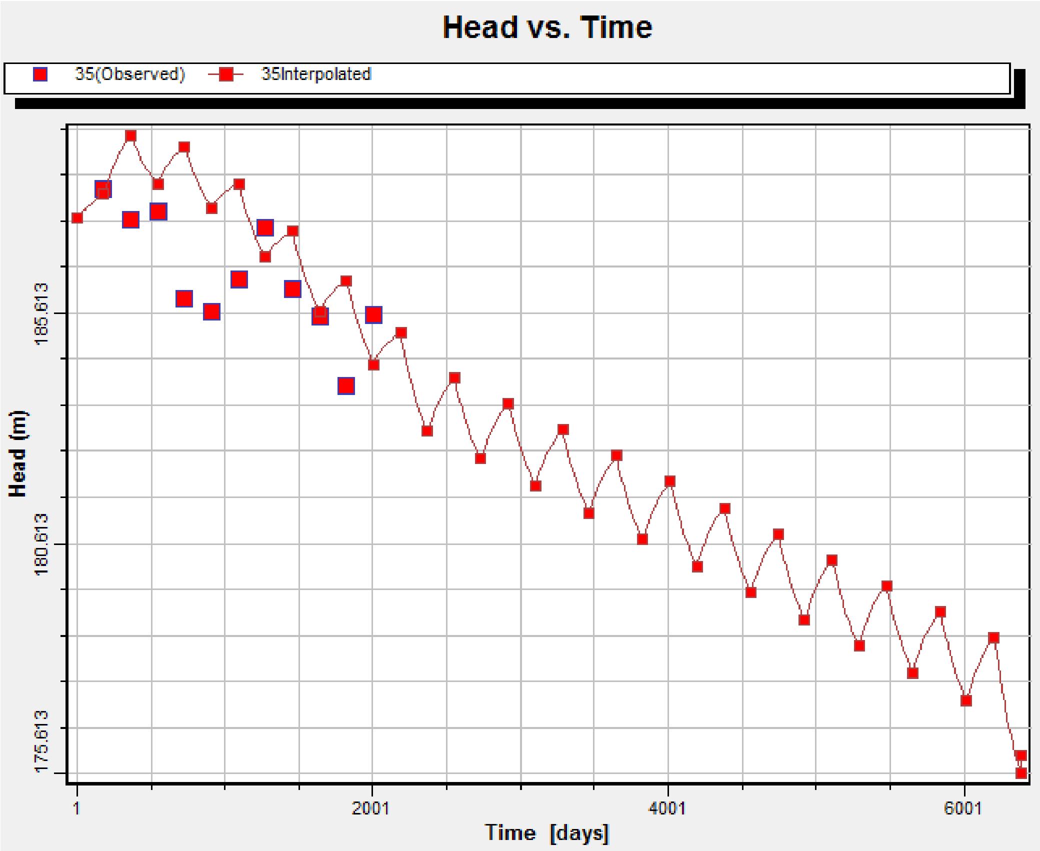
Scenario2: As National Capital Region part of Uttar Pradesh is an intensively irrigated agricultural region by ground water the demand for withdrawing ground water increases annually. By considering the increase in pumping by 1% annually from the current pumping, the model was run upto 2025. The model results has shown that the ground water level in Aquifer I decreased by 0.2 to 0.**4** m annually.

If the declining trend of the ground water level in aquifer I is linearly extrapolated for next 20 years i.e. 2045, the saturated thickness of the aquifer I will be reduce to 50 to 60% of the total aquifer thickness, which is fit to be considered alarming. The hydrograph of selected stations for prediction scenario - 2 are given in figure 8.9a to 8.9.j

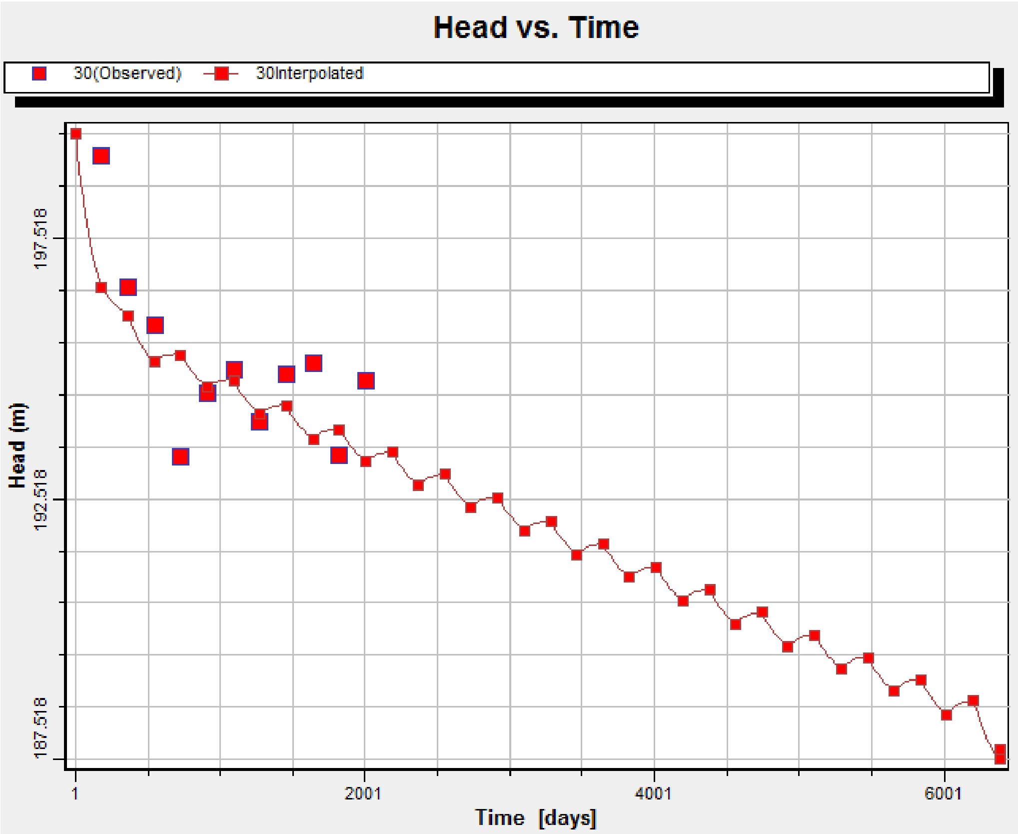



Head vs. Time
21(Observed)
21Interpolated
Head (m)
195.944
190.944
185.944
180.944
175.944
1
2001
4001
6001
Time [days]

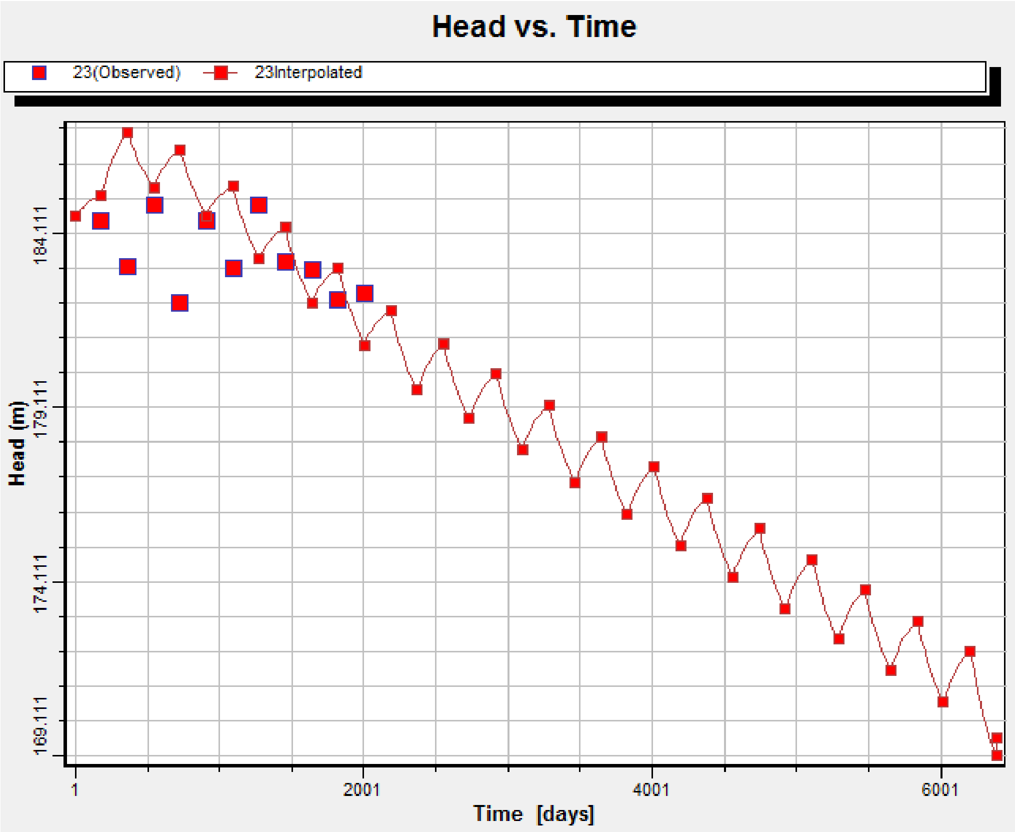

Head vs. Time
8(Observed)
8Interpolated
Head (m)
196.62
186.62
176.62
1
2001
4001
6001
Time [days]



Head vs. Time
35(Observed)
35Interpolated
Head (m)
185.613
180.613
175.613
1
2001
4001
6001
Time [days]



Head vs. Time
30(Observed)
30Interpolated
Head (m)
197.518
192.518
187.518
1
2001
4001
6001
Time [days]



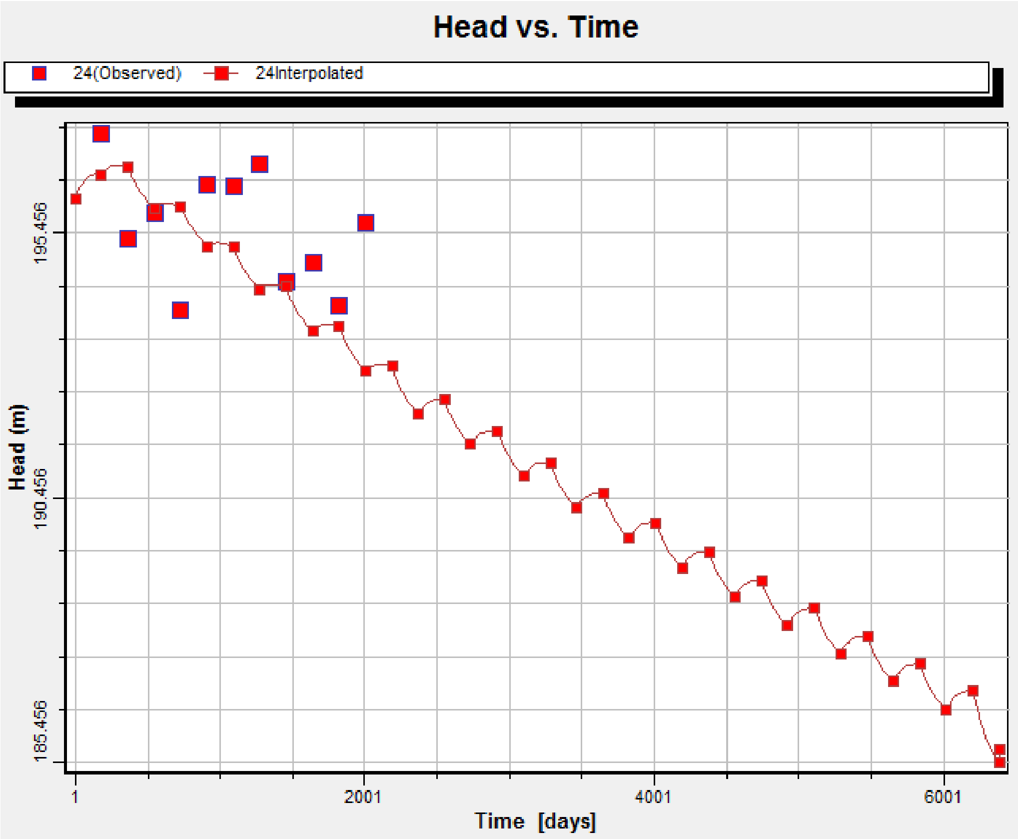


Fig 8.9 a to g. Hydrographs of the well during prediction scenario 2

Scenario3: Within the model area many urban centre exists, the demand for ground water within this urban centre increases day by day. It is to mention that the agricultural land is being converted into urban area at the rapid pace. By considering increase in pumping rate by 5% annually for the next 10 years and keeping the recharge rate same the model was run upto 2025. Model prediction has shown that at Loni and Bisrikh, Ground water level lowered by 0.2 m at Loni and 0.80 at Bisrikh. The lowering of water level by 0.2 to 0.8 m in 10 years is insignificant by considering the total saturated thickness of the aquifer I.

If in future the demand for ground water for domestic and industrial purposes increases in these urban centre in much more larger areas than the impact on the ground water shall be alarming.

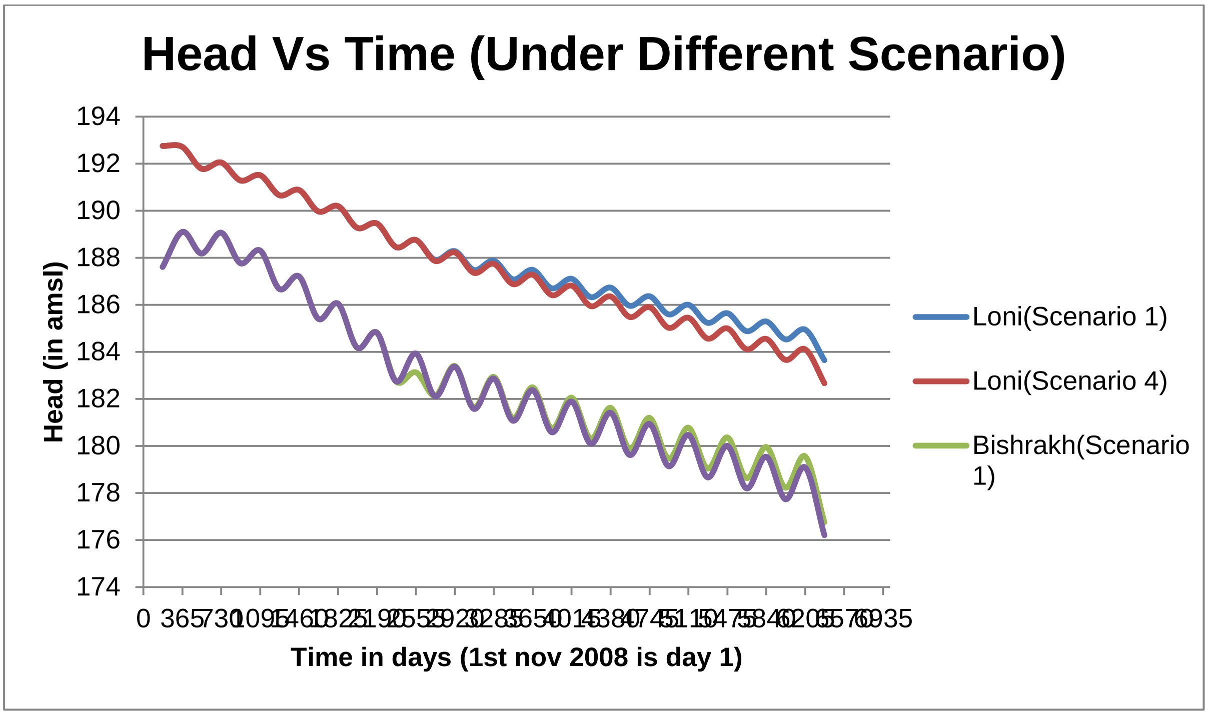
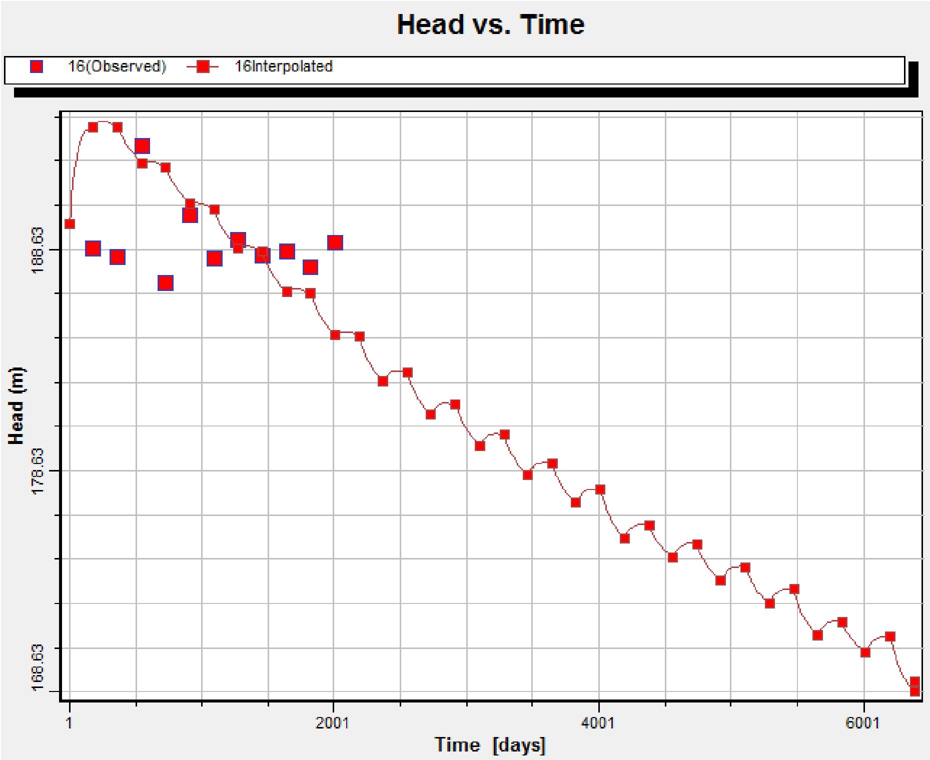
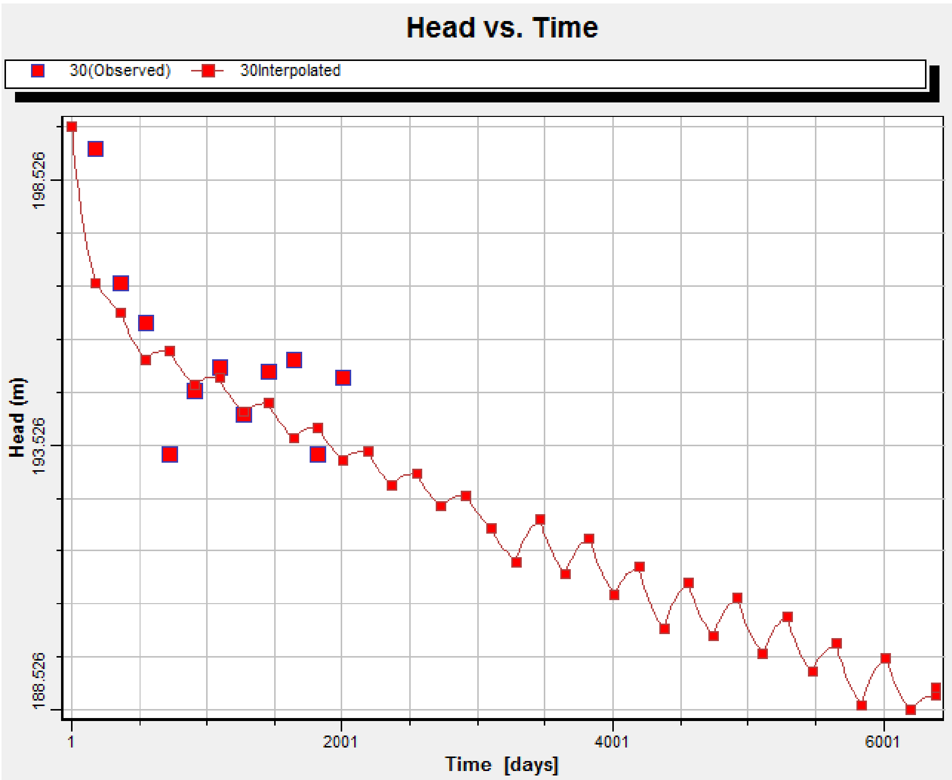
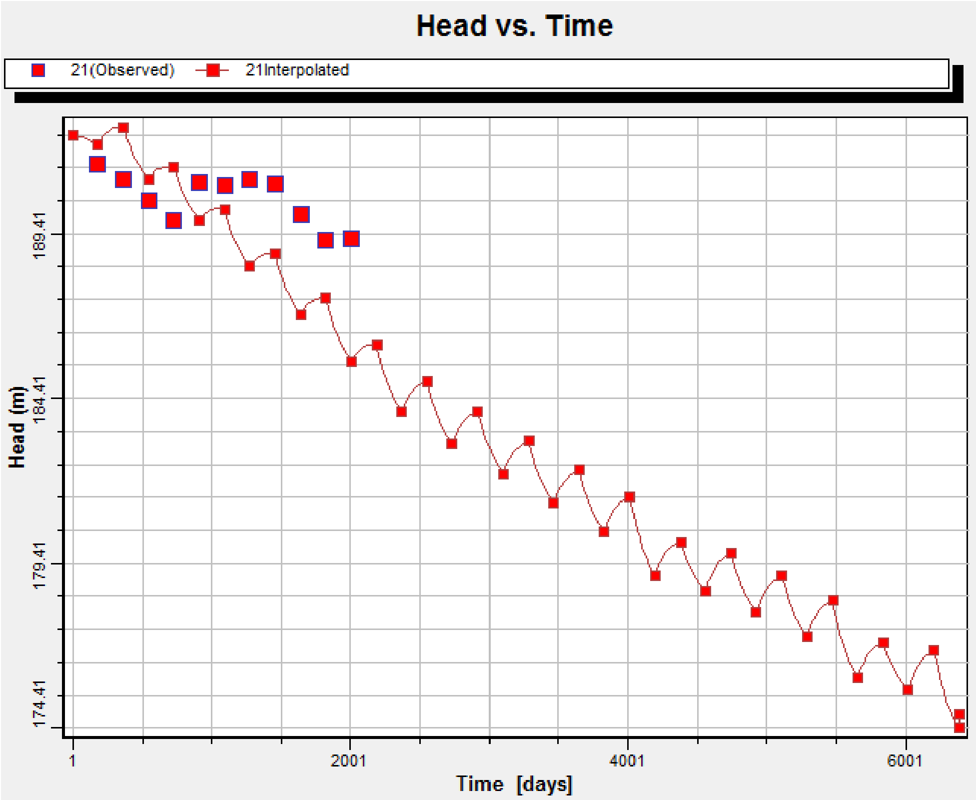


Fig 8.10: Head vs. Time under scenario 1 and 3 for urban area of Loni Block (Ghaziabad) and Bisrikh Block (G.B.Nagar).

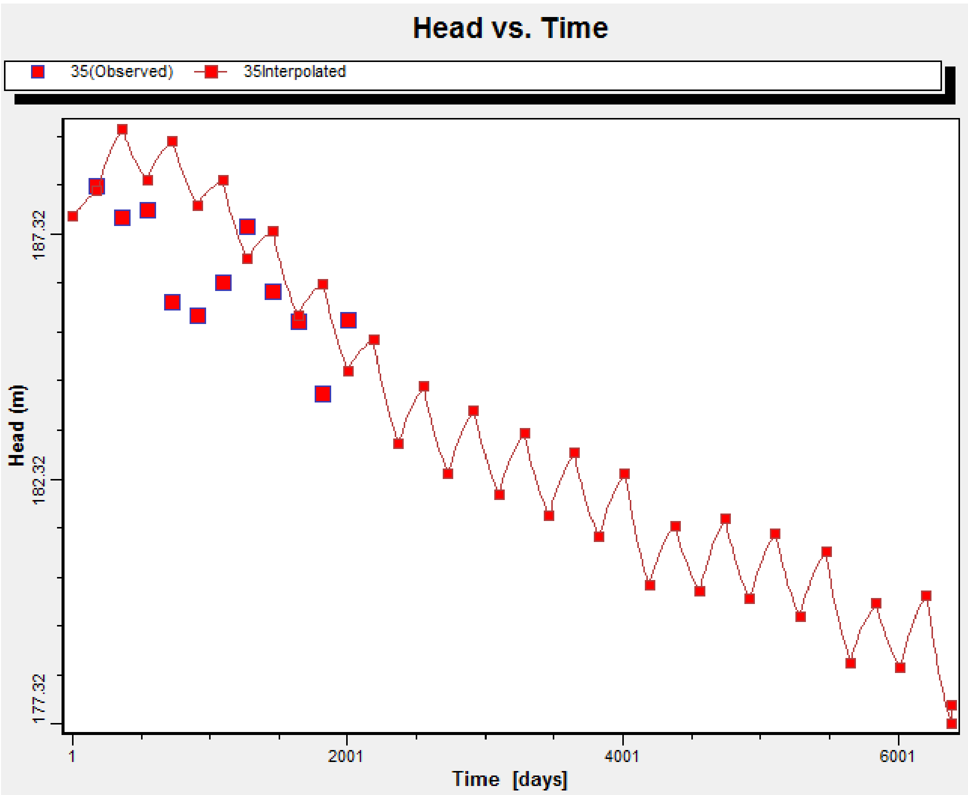
Scenario4: The average annual rainfall of the model area is 690 mm. The model area receives erratic rainfall with max being 900 and minimum being 400mm. Drought analysis has revealed most systematic occurrence of drought however the model was run by considering the occurrence of drought once in four years. The recharge rate was almost kept the same since recharge to the model area is by rainfall during monsoon and non-monsoon, recharge by unlined canals in command areas and more amount of recharge by irrigation return flow. However, the pumping rate was increased by 6% for the drought year from the current level of pumping. The model predicted that the ground water level lowered by just 0.2m, which again is insignificant. However consecutive drought shall create larger impact in the model area. The hydrograph of selected stations for prediction scenario - 4 are given in figure 8.11a to 8.11.h


Head vs. Time
16(Observed)
16Interpolated
Head (m)
188.63
178.63
168.63
1
2001
4001
6001
Time [days]


Head vs. Time
30(Observed)
30Interpolated
Head (m)
198.526
193.526
188.526
1
2001
4001
6001
Time [days]



Head vs. Time
21(Observed)
21Interpolated
Head (m)
189.41
184.41
179.41
174.41
1
2001
4001
6001
Time [days]



Head vs. Time
35(Observed)
35Interpolated
Head (m)
187.32
182.32
177.32
1
2001
4001
6001
Time [days]

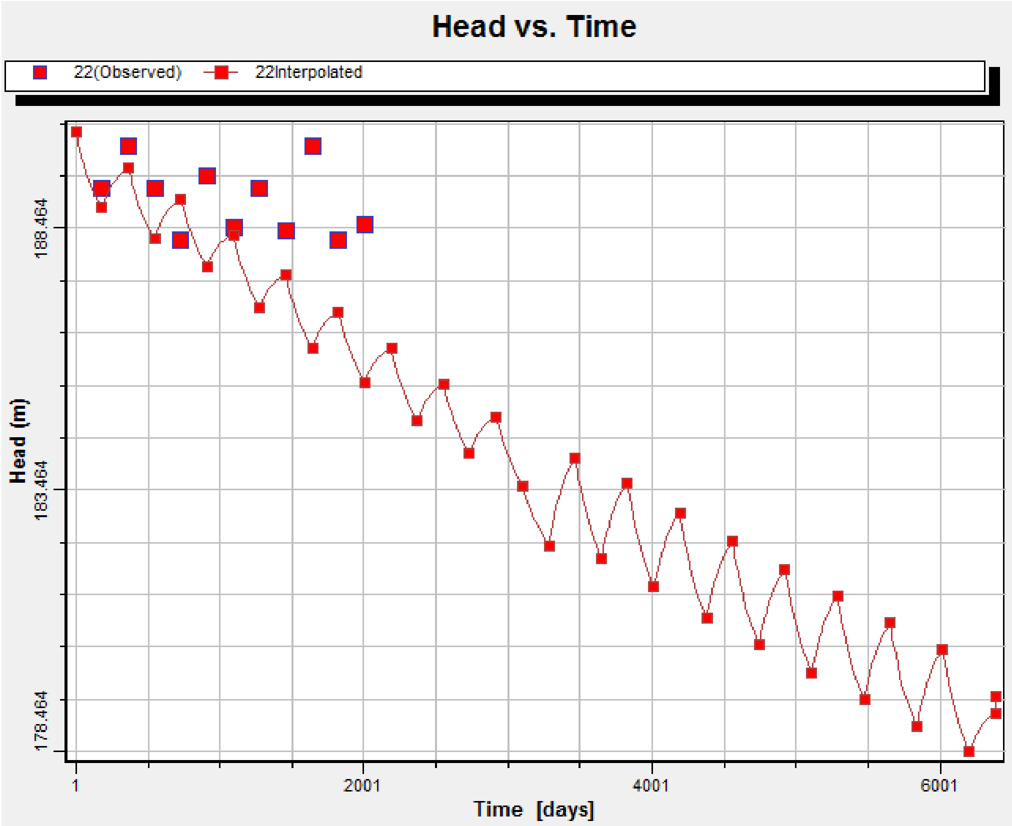


Fig 8.11 a to h. Hydrographs of the well during prediction scenario 4

8.4 Desirable Management Interventions

The study area in basically under intensive irrigated agriculture by groundwater and by canals. Paddy and sugarcane are the important crops cultivated by farmers in the region apart from wheat, barley and maize. In major part of the area farmers depend only on groundwater for cultivation of these crops during all seasons. Any reduction in the yield of the tube wells due to decline in groundwater shall adversely impact the production of the food grain. Though the study area has multilayer aquifer system, the aquifer I is highly potential in nature and holds fresh water. Aquifer I cater to the need of drinking water supply, agriculture and industries. The urban agglomeration also depends on aquifer I for their requirement. A model result has shown the ground water decline in most of the area under irrigation as well as in the urban areas. Therefore there is need for efficient management of the aquifer system for sustenance of the tube wells tapping aquifer I. Aquifer Management plan for the NCR part of UP is brought out keeping in view of the above field conditions (Fig 8.12).

For the purpose of management the entire NCR part of UP is categorized as Zone A, Zone B, Zone C and Zone D. The Zone A region comprises of Urban centres, Zone B Comprises of Agricultural area, Zone C is Urban area under groundwater stress and Zone D is Agricultural area under stress.

The ground water level in zone A and in Zone B though show continuous decline in ground water level however trend are not alarming. The present rate of pumping can be continued in future also. However, during drought period increase in pumping in these zones shall add stress to aquifer I.

Region under Zone C is urban area under groundwater stress due to annual increase in the demand of the ground water. Model study have shown even with 10% of increase from the present pumping rate in next 10 years, the ground water levels decline by 0.80m in addition to the annual declining trend of the ground water. Further these area are categorized as Over-Exploited blocks with ground water development more than 100%. Therefore artificial recharge schemes through dug-wells, percolation pond and recharge shafts are recommended in these zone depending on the availability of source water. As industries are located within these urban agglomeration due care must be taken to avoid pollution of aquifers in planning any artificial recharge structure.

Region under Zone D is agricultural area with aquifer under stress. They are Over-Exploited blocks with ground water development more than 100%. Though the ground water levels declines at the rate of 0.2 to 0.3 m per year annually in most of the areas, as this is primarily an agricultural area where farmers tap aquifer-I for irrigation, the groundwater that is being withdrawn for irrigation may not be reduced as it shall effect their livelihood and lead to decrease in crop production, however crops that utilise less ground water may be encouraged.

Table 8.1: Response of Aquifer to different Hydrologic Stress Conditions for NCR Part of Uttar Pradesh:

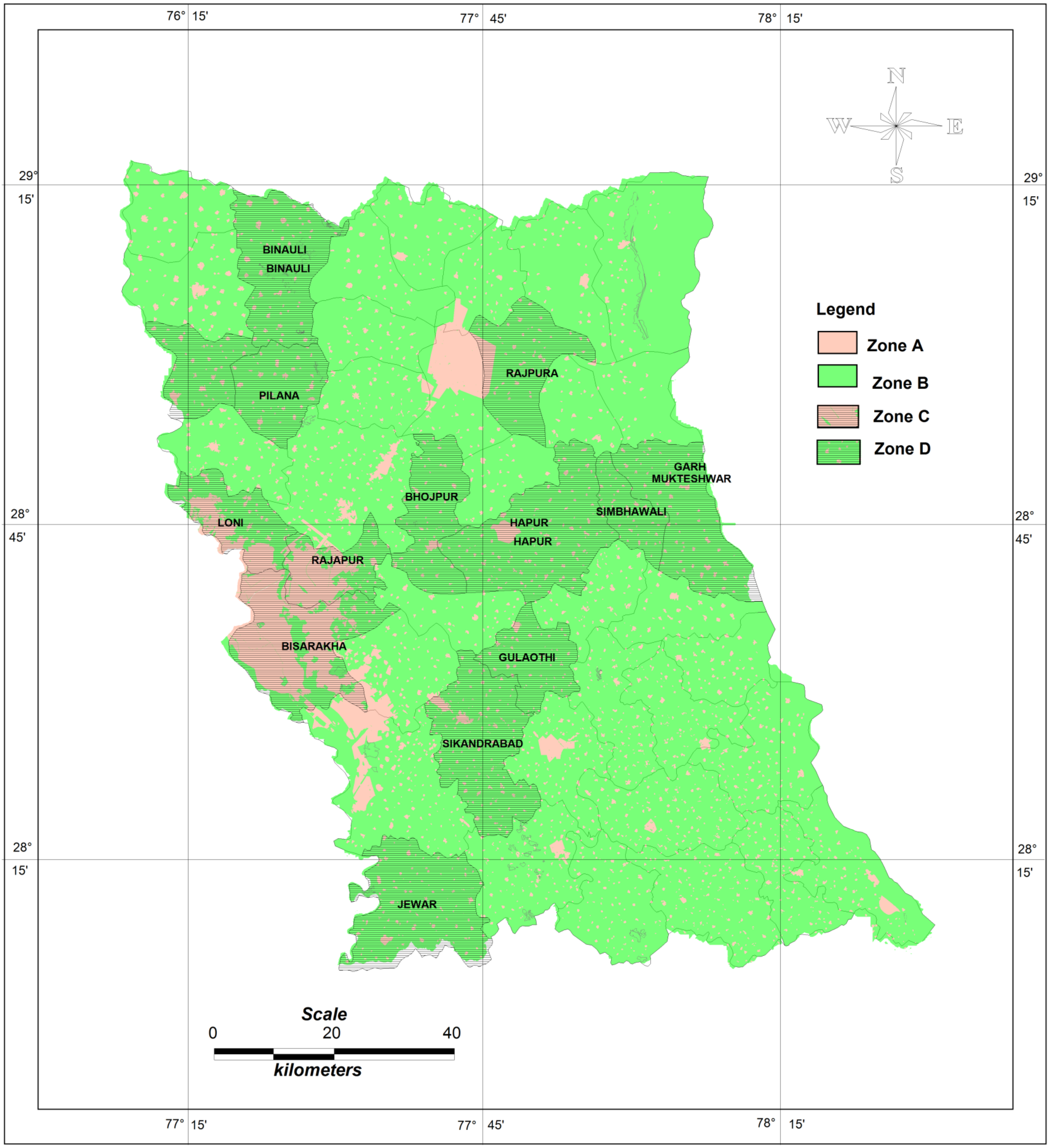
S.No.	Scenario	Aquifer -I	Aquifer -II	Remarks
1.	Scenario 1: To know the effect on the aquifer with the current rate of pumping.	Declining Trend. Water Levels decline at 0.2 to 0.4 m annually.	Insignificant/ No impact	▪ The Aquifer I is the most prolific aquifer with fresh ground water and ground water abstraction for irrigation, domestic and industrial need is met from this aquifer. ▪ The aquifer II is yet to be tapped. Aquifer II is a potential aquifer under confined conditions. Few regions within the aquifer II have brackish/ poor quality water. ▪ By extrapolating the decline of the ground water level in aquifer I for next 30 years i.e. 2045, the saturated aquifer thickness of aquifer I will be reduced to 50 to 60% of the total aquifer thickness, which can be considered alarming.
2.	Scenario 2: Draft is increased to 10% in next decade. (Based on the demand of ground water Draft for irrigation)	Declining Trend. Water Levels decline at 0.2 to 0.3 m annually.	Insignificant/ No impact	
3.	Scenario 3: Draft is increased from present level to 50% at the rate of 5% annually within the urban agglomeration. (Based on the demand of ground water for domestic and Industrial requirement.)	Declining Trend. Water Levels decline at 0.2 to 0.8 m annually.	Insignificant/ No impact	
4.	Scenario 4: Drought occurs once in four year and pumping is increased 6% in pre and post monsoon period. (Based on the long term rainfall analysis.)	Water Level decline insignificant.	Insignificant/ No impact	

Table 8.2: Aquifer Management Plan for NCR Part of Uttar Pradesh:

S.No.	Management Plan	Aquifer -I	Aquifer -II	Vulnerability to Hydrologic Stress	
1.	Zone A Urban Agglomeration	Decline in ground water level but not alarming. The current pumping rate may be continued.	Insignificant/ No impact	No	No
Management Plan		The current pumping rate may be continued.	Reserve for future development.		
2.	Zone B Intensive Agricultural Area	Decline in ground water level but not alarming. The current pumping rate may be continued.	Insignificant/ No impact	No	No
Management Plan		The current pumping rate may be continued.	Reserve for future development.		
3.	Zone C Urban Agglomeration under ground water stress.	Decline in ground water Level greater than the normal declining trend at the rate of 1.0 to 1.5 m per year or 10 to 12 m in 10 years.	Insignificant/ No impact	Yes	No
Management Plan		All the blocks of zones C come under Over-Exploited Category. Current Pumping rate may be continued and no more	Reserve for future development except regions with brackish water.		

S.No.	Management Plan	Aquifer -I	Aquifer -II	Vulnerability to Hydrologic Stress	
		furtherground water development. schemes like Rooftop rainwater harvesting and Artificial Recharge may be taken up depending on availability of source water.			
4.	Zone D Intensive Agricultural Area under ground water stress.	Decline in ground water Level greater than the normal declining trend at the rate of 0.8 to 1.0 m per year or 8 to 10 m in 10 years. All the blocks of zones D except Baghpat come under Over-Exploited Category.	Insignificant/ No impact	Yes	No
Management Plan		Current Pumping rate may be continued and no more further ground water development recommended. Crops that utilised less ground water may be encouraged. Along with water conservation method emphasis be made on attaining higher water use efficiency.	Reserve for future development.		

Fig 8.12: Desirable Management Intervention in the Study area



8.5 Zone Budget

Zone Budget: Zone Budget of the NCR Part of Uttar Pradesh have been taken out as output from the model and has been given below :

Table 8.1: Zone budget of the model area

Item	2009	2015
Aquifer Group I, Input (MCM)		
Storage	6855.97	678.91
Recharge	5079.90	3226.49
River Leakage	1081.02	655.32
Zone 2 to 1	40846.50	46409.75
Zone 3 to 1	38.71	60.48
Zone 4 to 1	33.35	66.57
Total	53936.55	51096.35
Aquifer Group I ,Output (MCM)		
Storage	3914.87	1242.75
Wells	45395.80	47880.70
River Leakage	2855.51	1205.88
Zone 1 to 2	1603.51	521.84
Zone 1 to 3	59.28	142.25
Zone 1 to 4	0.27	0.95
Total	53822.95	50994.15
Aquifer Group II, Input (MCM)		
Storage	290.89	148.86
Zone 1 to 3	59.28	142.25
Zone 2 to 3	635.17	368.21
Zone 4 to 3	2794.96	15290.95
Total	3780.41	15949.04
Aquifer Group II, Output (MCM)		
Storage	18.93	0.18
Wells	28.51	28.48
River Leakage	0.07	60.48
Zone 3 to 1	38.71	60.48
Zone 3 to 2	3209.89	15748.66
Zone 3 to 4	486.11	111.31
Total	3780.39	15949.04

Based on the model output it can be inferred that there exists vertical leakage between aquifer I and Aquifer II and Aquifer II and Aquifer I,. The total volume of the ground water stored in aquifer I approximately 53936.55 MCM and . The Layer 3 and 4 in the model which represents the aquitard i.e. Clay also has vertical leakage as ground water from these aquitards leaks into the aquifer system.

Though the Aquifer I and Aquifer II functions as individual aquifer units as they have different hydraulic heads, Due to the vertical leakance it can be inferred that the Aquifer I and Aquifer II are vertico-laterally connected.

The change in the aquifer storage varies with time. During monsoon period the total volume of ground water in aquifer I is 31042.80 MCM and during non monsoon it reduces to 22893.75 MCM i.e. reduction to 73.74%.

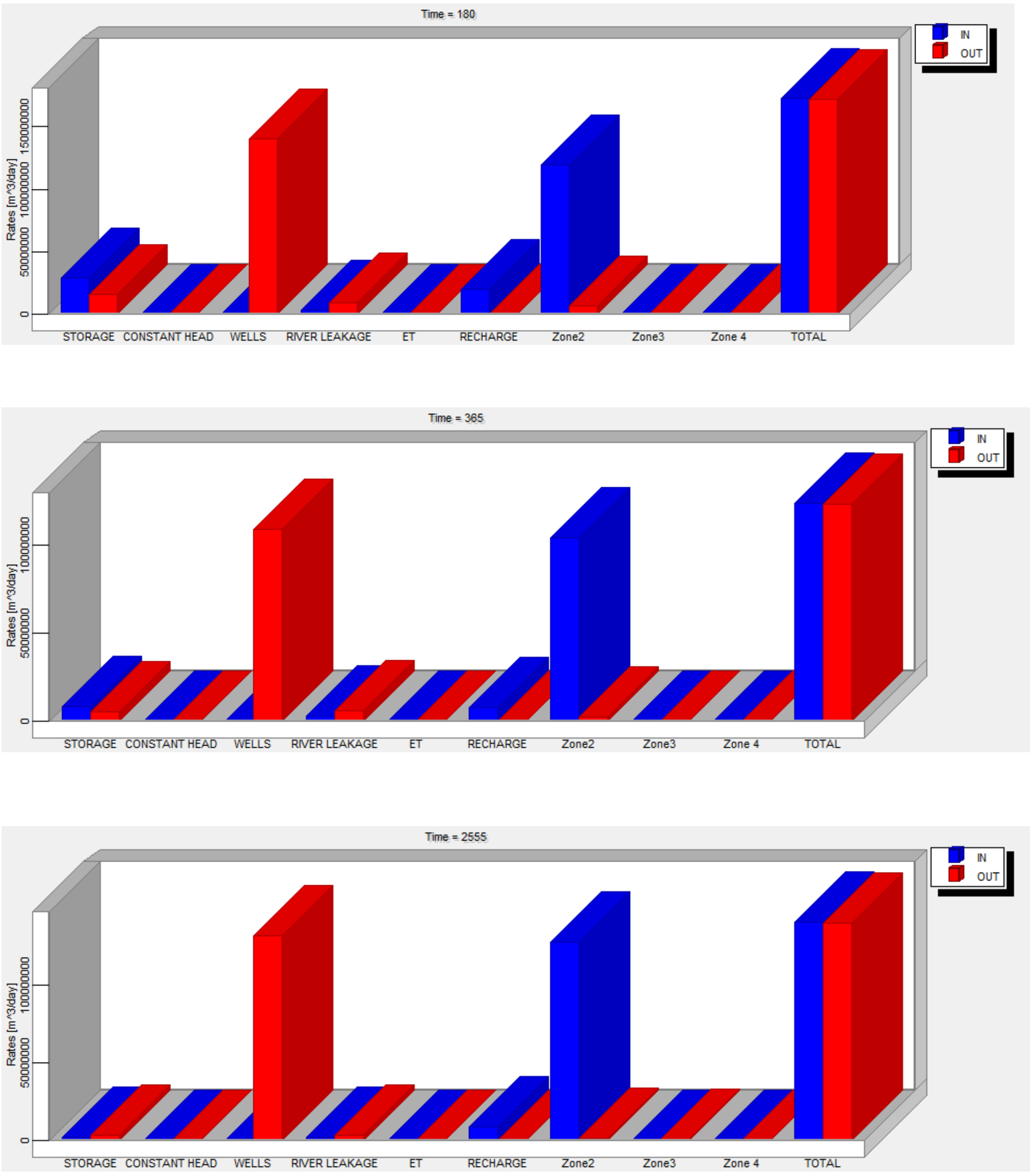


Fig 8.13 : Zone Budget for Zone 1, 180 and 365 days

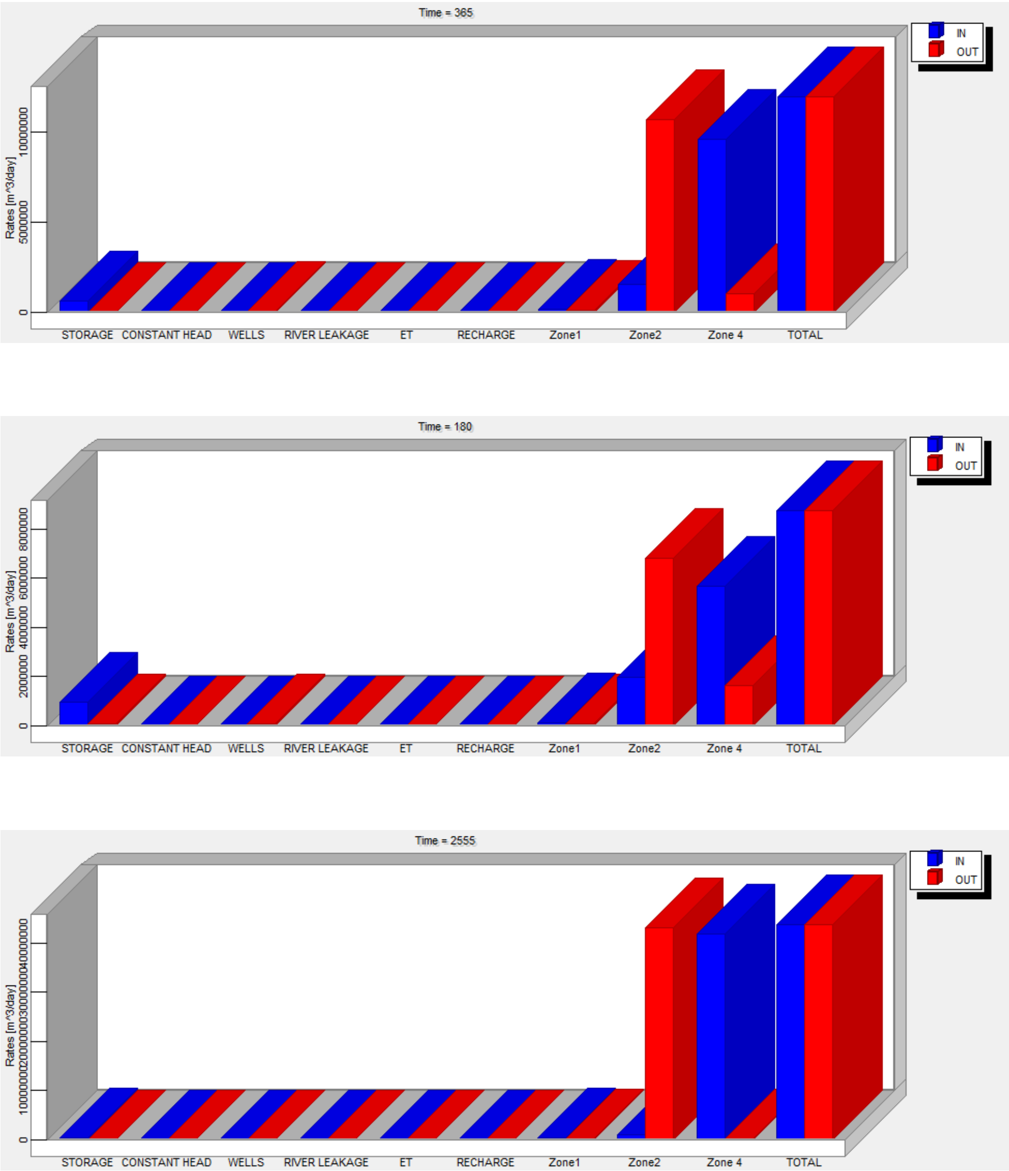


Fig 8.14 : Zone Budget for Zone3, 180 and 365, 2555 days

CHAPTER-9

Summary & Recommendation

The broad objective of the study is to establish the geometry of underlying aquifer system in horizontal and vertical domain and characterize them so as to work out the development potential and prepare aquifer wise management plan using ground water simulation model. National Capital Region (NCR), Uttar Pradesh comprises of five districts, namely, Baghpat, Bulandshahar, G.B. Nagar, Meerut and Ghaziabad districts (including the recently carved out Hapur from Ghaziabad districts) with total of forty six administrative blocks covering an area of 11275 sq km approx. (including urban and rural area with population of,45,61,224persons.

The three dimensional generalized view of the aquifer from the boreholes drilled has been inferred is about 300 m thick in the western part and thickens beyond 450m in the eastern part. The alluvium comprises very fine to coarse grained sands, sandy clay, silt, clay and kankar (calcareous concretion). The sand horizons form the aquifers. In the western part, alluvium is predominated by clay interbeds whereas in the eastern part thick sand beds are encountered. These aquifers separated by prominent and regionally extensive thick clay beds, have been grouped as Aquifer Group 1 (A1), Group 2 (A2), Group 3 (A3) and Group 4 (A4). The first aquifer occurs down to 176 mbgl with thickness varies from 60 to 166 m. It is further divided in IA and IB. Aquifer Group II starts from 76 mbgl and extends down to 316 mbgl with thickness varies from 27 to 153 m. The third aquifer starts from 180 mbgl and extends down to 417 mbgl. With thickness varies from 35 to 167 m. The fourth aquifer starts from 300 m.bgl & continues down to drilled depth of 450 mbgl which continued further.

The formation water quality is brakish to saline in deep aquifer in Western part of Baghpat and Shallow depth in G.B.Nagar district. In southern part of Bulandsahar district brackish zone starts below Aquifer Ist. .The isopach maps of different aquifer Groups shows thickness of Aquifer Groups are thick in Meerut, Ghziabad and Parts of Bulandsahar district and in Small parts of G.B.Nagar district.

The level of ground water development varies from 28% to 152%. The stress on ground water is more in western part i.e. Yamuna catchment area.It is also shown in category of Blocks. Out of 13 Over Exploited blocks 10 blocks are in Baghpat, Ghaziabad, Hapur and G.B.Nagar districts.

As per category, 13 blocks are in Over Exploited category, 12 blocks are in Critical category, 6 blocks are in Semi Critical Category and 15 blocks are in Safe category.

Recommendations:

Though the NCR, Uttar Pradesh as a whole has sufficient ground water for further development, the symptoms of stress on ground water resource are surfacing at places, particularly in urban and rural areas. For Aquifer management plan area is divided in four zones.

Zone A: Urban Agglomeration:

Area lies in Town area and urban area with medium growth of population like Meerut, Bulandhashar, Baghpat district. Here stress is in Aquifer I^{st} and decline in water level is not in alarming condition. Here along with Aquifer I^{st} Aquifer II^{nd} should also be utilized for future water supply. There is large scope for development of Aquifer II^{nd} in this area.

Zone B: Intensive Agriculture area:

The area is mostly in Ganga Catchment area in Bulandshahar, Meerut and parts of G.B.Nagar & Ghaziabad districts. Here decline in water level is not alarming. Present rate of pumping may be continued and Government tube wells may be constructed in II^{nd} Aquifer as there is ample scope of this aquifer.

Zone C: Urban Agglomeration under ground water stress:

This is the area around Ghaziabad, Meerut and G.B.Nagar district decline in ground water Level greater than the normal declining trend at the rate of 1.0 to 1.5 m per year or 10 to 12 m in 10 years.. In this area All the blocks of zones come under Over-Exploited Category. Current Pumping rate may be continued and no more further ground water development. Artificial Recharge & Rooftop rainwater harvesting scheme and may be taken up in the area depending on availability of source water. Water use efficiency may be improved by reducing leakage loss and recycling of water. IInd Aquifer may be utilized for water supply & Brakish water in parts of Bisrakh block and Loni Block can be utilized for industry.

Zone D: Intensive Agricultural Area under ground water is in stress condition :

This is the area all blocks are in Over- exploited category except Baghpat which is in critical category. Decline in ground water level greater than the normal declining trend at the rate of 0.8 to 1.0 m per year or 8 to 10 m in 10 years. For Aquifer Ist current rate of pumping may be continued and no more ground water development is recommended. Cropping pattern may be changed for less water utilizing crops. Water use efficiency may be improved for saving water. Artificial recharge & water conservation structure like Check Dam, On Farm water harvesting, restoration of old ponds and construction of New Ponds may be encouraged for enhancing the ground water recharge. All new Government Tube wells may be constructed in Aquifer IInd for future ground water development..

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